The Filmmaker's Guide to Visual Effects

The Art and Techniques of VFX for Directors, Producers, Editors, and Cinematographers

Eran Dinur

A **Focal Press** Book

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The Filmmaker's Guide to Visual Effects

The Filmmaker's Guide to Visual Effects offers a practical, detailed guide to visual effects for non-VFX specialists working in film and television. In contemporary filmmaking and television production, visual effects are used extensively in a wide variety of genres and formats to contribute to visual storytelling, help deal with production limitations, and reduce budget costs. Yet for many directors, producers, editors, and cinematographers, visual effects remain an often-misunderstood aspect of media production. In this book, award-winning VFX supervisor and instructor Eran Dinur introduces readers to visual effects from the filmmaker's perspective, providing a comprehensive guide to conceiving, designing, budgeting, planning, shooting, and reviewing VFX, from pre-production through post-production.

The book will help readers:

- Learn what it takes for editors, cinematographers, directors, producers, gaffers, and other filmmakers to work more effectively with the visual effects team during pre-production, on the set and in post, use visual effects as a narrative aid, reduce production costs, and solve problems on location;
- Achieve a deeper understanding of 3D, 2D, and 2.5D workflows; the various VFX crafts from matchmove to compositing; essential concepts like photorealism, parallax, roto, and extraction; become familiar with the most common types of VFX, their role in filmmaking, and learn how to plan effectively for the cost and complexity of VFX shots;
- See visual effects concepts brought to life in practical, highly illustrated examples drawn from the real-world experiences of industry professionals, and discover how to better integrate visual effects into your own projects.

Eran Dinur is an Emmy and VES award-winning VFX supervisor, artist, and instructor. His work at ILM Singapore includes films such as *Iron Man*, *Star Trek*, *Transformers: Revenge of the Fallen*, *Indiana Jones and the Kingdom of the Crystal Skull*, and *Terminator Salvation*. Since 2011 Eran has served as the VFX supervisor of NYC-based company Brainstorm Digital on numerous film and TV projects, including *The Wolf of Wall Street*, *Boardwalk Empire*, *The Lost City of Z*, *Café Society*, *Nerve*, *Delivery Man*, *The Heat*, *The Men Who Built America*, and *The Immigrant*. Eran won a Primetime Emmy Award as well as two Visual Effects Society Awards for his work on *Boardwalk Empire*. Eran teaches VFX production skills at the School of Visual Arts, has created popular online courses at fxphd, has written numerous articles for *3D World Magazine*, and has presented at various international conferences including SIGGRAPH, NAB, and Mundos Digitales.

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The Art and Techniques of VFX for Directors, Producers, Editors, and Cinematographers

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To Karin, Yotam, and Ayala

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Introduction

The days when visual effects belonged to the exclusive domain of big budget sci-fi and superhero movies are long gone. VFX are now used extensively in almost any type of film and TV program in a wide variety of genres—not only to create spectacular visuals but also to support storytelling, overcome production limitations and reduce costs. Yet despite their widespread use as a filmmaking tool, visual effects remain a somewhat bewildering and often misunderstood part of the filmmaking process.

Most film schools, for example, offer courses in scriptwriting, cinematography, editing and sound, but few include visual effects on their curriculum. The vast majority of books, courses, and online tutorials are geared toward VFX artists, not the filmmakers who use their services. As such, most information sources are highly technical, software-oriented and focus on a narrow specific craft rather than the process as a whole.

This book fills in the gap by providing a comprehensive approach to visual effects **from the filmmaker's perspective**. It is a detailed, practical guide to conceiving, designing, budgeting, planning, shooting, and reviewing VFX from the early stages of pre-production to the last bit of tweaking in post-production. The book also illuminates and clarifies the different underlying concepts that have a direct effect on the complexity and cost of VFX shots, and discusses the various tasks and workflows that are involved in the process.

As the visual effects supervisor of Brainstorm Digital, an NY-based VFX company, I have had a chance to work on a wide variety of film and TV projects, and collaborate with an equally wide variety of directors, producers, editors, and crew members. Each of these projects was a unique journey. Some journeys were smooth-sailing, others a bumpy ride, but they all provided me with plenty of opportunities to experience first-hand the issues that filmmakers face when working with visual effects. "How can VFX help me solve this problem?", "Why is this shot costing so much more than the other?", "Will this camera move work for VFX?", "Should we shoot a real element or use CG?", "Roto or green screen?", "Shoot with smoke or shoot clean?", "Wide or long lens?", "With or without tracking markers?", "Why doesn't the shot look real enough?", "Why is the color different from dailies?"—these are just a few examples of the many questions that come up during production, questions that I hope will find answers in this book, both on a theoretical and practical level. In that sense, real-world examples are often the best way to explain a

specific issue or aspect. And while there is of course a tremendous amount of fantastic VFX all around to refer to, there is a certain extra value, I think, in discussing examples from a personal, intimate point of view. So wherever I could, I tried to bring something "from the trenches"—to discuss a relevant case from one of the film or TV projects I was involved with.

Who is this Book For?

Throughout the book, I use the term "filmmaker" in its broadest sense because I believe there is a wide range of film professionals (and aspiring filmmakers) who can benefit from it

Directors, first and foremost, must be versed in VFX to fully unlock their potential. It is not only about knowing how to harness the power of visual effects to realize the creative vision and support the narrative, it is also about understanding how to do so within the constraints of time and budget.

Producers need to have a solid understanding of the various factors that affect cost and schedule when budgeting for visual effects and handling bids, and a firm grasp of the entire process, from pre-production to post-production.

Editors, by nature of their work, are intimately familiar with every shot in the cut, and are often the ones who review the VFX work and provide feedback to the VFX team.

Assistant editors and VFX editors are responsible for the communication and daily back-and-forth between the VFX team and editorial.

On the set, **cinematographers** and **gaffers** clearly benefit from understanding the needs of VFX when lighting green screens, shooting VFX elements or setting up for crowd tiling, set extension, and other types of VFX shots.

First and second ADs are the ones who run the show on set. The first AD is usually the one responsible for planning the shoot and is the one who gets into the details of setting up VFX shots and coordinating with various departments.

Production and location managers can benefit from a deeper understanding of the needs and limitations of VFX when choosing appropriate locations and arranging for the necessary resources.

Film students must be familiar with the basics of visual effects if they want to succeed in contemporary filmmaking—understanding the process and language of VFX is as important today as being well versed in cinematography, scriptwriting, sound design, and editing.

Finally, this book will benefit any person involved in filmmaking, or anyone with an interest in cinema and the world of visual effects. While the book does require a basic familiarity with filmmaking and cinematography terms, there is no need for any previous knowledge of visual effects.

Visual Effects on a Shoestring

Every aspect of filmmaking costs money, and visual effects are no exception. This book would be rather incomplete without addressing cost factors every step of the way. After all, any experienced filmmaker knows the importance of successful budget management.

Visual effects as seen in the high-budget tentpole blockbusters involve hundreds of artists working in multiple large facilities, and usually cost millions of dollars. The VFX budget alone on many of those movies can easily top the entire production budget of a typical indie film. Can VFX be done on a small budget without sacrificing quality? Yes, definitely—with careful planning backed by a solid understanding of the medium. I see it as a primary goal in this book to discuss VFX from the low-cost point of view. Throughout the book, whenever possible, I try to suggest alternative methods for expensive processes or ways to avoid them altogether, and offer tips that can help the filmmaker take the most economical decision.

About This Book

This book is divided into three parts: Part 1 covers the fundamental aspects of VFX; Part 2 provides an in-depth discussion of the various crafts and workflows of VFX; and Part 3 is a practical guide to working with VFX in production. While you can certainly jump, say, straight to the third part, I really recommend reading the chapters in order, as the "how" depends a lot on the "why", and many concepts and workflows are explained in detail in the first two parts. Here is a quick overview of the book's ten chapters.

Chapter 1: Core Concepts
A brief discussion of key VFX concepts such as CGI, realism, photorealism, 2D, and 3D.

Chapter 2: VFX as a Filmmaking Tool
An overview of the benefits of using VFX in production, and a discussion of the most common types of visual effects, from fix-it shots to set extensions.

Chapter 3: From 2D to 3D
This chapter provides a study of camera movement, parallax and perspective shift, and explains 2D, 3D, and 2.5D workflows by analyzing the methodology of a specific matte painting shot.

Chapter 4: Separation
Separation is a vital process in VFX, and its success affects not only the end result but also time and cost. This chapter provides a close look at the two methods of separation: roto and green screen, with a focus on extraction challenges.

Chapter 5: The VFX Workflow
This chapter, the book's longest, takes the reader inside the VFX facility, and explores every VFX craft, from previs and layout, modeling and shading to dynamic simulations, matte painting, and comp.

Chapter 6: Workflow Case Studies
By analyzing the methodologies of four different shots, we see how the various VFX crafts discussed in the previous chapter are combined into different workflows, and how these workflows affect schedule and budget.

Chapter 7: Pre-production
Planning, budgeting and scheduling visual effects are vital steps during pre-production. This chapter offers advice on choosing a VFX supervisor and producer, creating breakdowns, budgeting, the importance of tech scouts, VFX meetings, and more.

Chapter 8: On Set
This chapter covers essential practical on-set procedures and provides tips for successfully shooting VFX elements, setting up green screens, acquiring on-set data and reference, crowd tiling, and working with special effects.

Chapter 9: Post-production
The bulk of the VFX work happens in post, and here we'll explore post-production and color workflows, the vital connection between the editorial and VFX teams, review and feedback procedures, formats and color spaces, communication, and more.

Chapter 10: The Future
What's on the horizon? In this concluding chapter, we look at some emerging technologies and trends that may affect the way we work with visual effects, like lightfield cameras, super-black materials, Virtual Reality, and real-time rendering.

PART 1

VFX FUNDAMENTALS

Chapter 1

Core Concepts

Special Effects or Visual Effects?

The terms "special effects" and "visual effects" are often used interchangeably in the media and even by some professionals. Historically it made sense. In the pre-digital days and before visual effects were primarily computerized, most effects work was done in-camera and on location, using miniatures, practical techniques, and various camera and optical tricks. There really wasn't a clear line of separation between special and visual effects. But things are different today, and these two terms are used to describe two distinct and very different crafts. Special effects (SFX) are practical, real-life effects performed on the set and captured by the camera. Visual effects (VFX) are digital manipulations and enhancements of the footage, and happen primarily during post-production. The knowledge, techniques, and skillsets used in each craft are widely different. Creating a practical explosion on set requires experience in explosives and pyrotechnics, while creating the VFX equivalent of that explosion calls for a mastery of computer graphics

Special effects are often shot as element plates for visual effects. In this example from *Boardwalk Empire*, a burning tree stump is used to augment a World War 1 shot.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

and photoreal rendering. Despite those differences there's still an important relationship between SFX and VFX. The two crafts often complement (and sometime contradict) each other. This relationship, and how it translates into practical decisions on set, will be discussed in Chapter 8.

What Does CGI Really Mean?

CGI stands for **Computer Generated Imagery**. People (and the media) use the term "CGI" to talk about visual effects in general ("The CGI in that movie was really awesome!" or "Movies today have too much CGI"), but in professional VFX discourse CGI (often just CG) has a much more specific meaning. It is used to make a clear distinction between VFX elements that were created "artificially" in the computer and real-world elements that were shot with a camera. For example, "a CG ship" refers to a virtual ship that was built, lit, and rendered using computer software, and then composited into the footage digitally. On the other hand, a ship (real or miniature) that was shot with a camera as an element for visual effects is not CG. A group of cheering spectators shot on green screen to be used for crowd tiling in a shot is not CG, but a group of animated digital characters is. Despite the popular use of the term, not all visual effects are CGI. In fact, many types of VFX shots do not need any CG at all, and are done solely by manipulating the footage or combining it with additional footage or still photos. The distinction is therefore important because CG indicates a different (usually more complex and expensive) process than working with photographed elements. The decision on whether to use footage or CG depends on a variety of factors, and stands at the very foundation of VFX production. It will therefore be discussed throughout the book—and in more than one context.

An example for a mixed use of photographic and CG elements in one shot. First an element of a rowboat with soldiers is shot in a lake. This is of course real footage.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Ocean and sky plates (real footage) are used to extend the lake, and different takes of the same rowboat are added to create multiple instances.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Now the large warships are added. These are CG models—built and textured from scratch.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

The final shot, with additional practical, non-CG elements like the soldiers on the ships (shot on green screen) and the seagulls (from a video I shot at the beach).

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

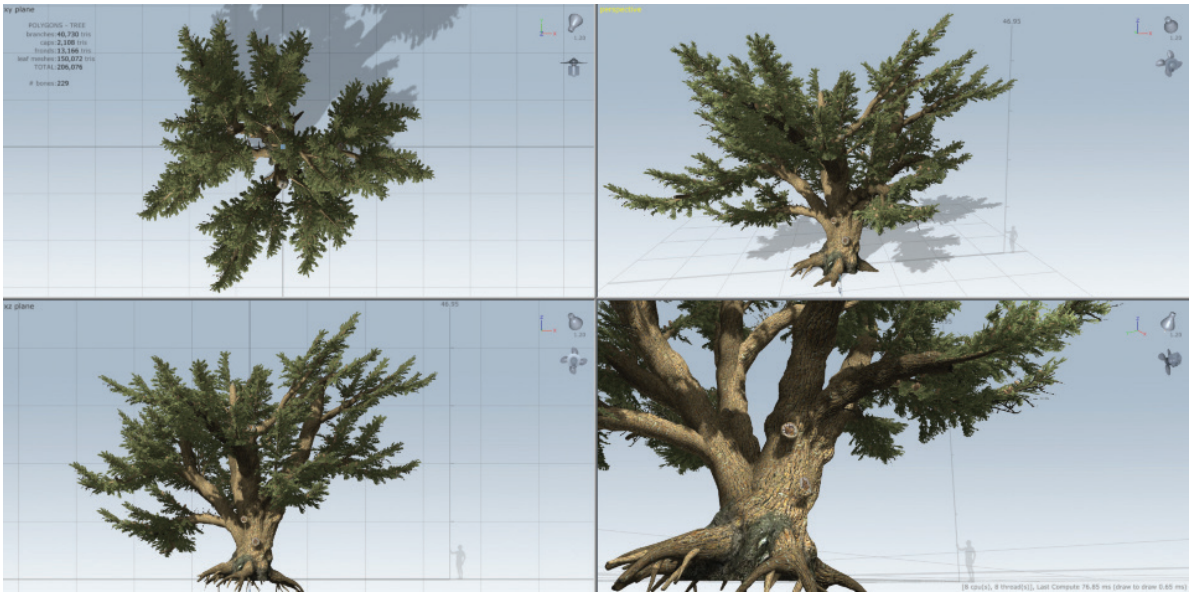
Now, at the risk of stating the obvious, I should point out that "computer generated" does not mean "created by the computer." It is true that visual effects depend on highly sophisticated computer software. There is certainly a lot of number crunching under the hood, probably more than in any other film-related craft. But all this technology is useless without the creative, resourceful, and highly skilled craftspeople who possess the knowledge and expertise to drive it. Looking from the outside, there's something enigmatic, even baffling, about these people who sit silently in dark rooms staring intensely at their monitors—but in essence, CG artists do pretty much what their colleagues do on set: they build, they paint, they construct, they light, they operate the camera, they shoot.

2D, 3D, and Stereoscopic 3D

Movies are shot in a three-dimensional world. The environment, the actors, the set, and the props are all three-dimensional entities that have depth and are spatially positioned at varying distances from the camera. But the moment the action is captured by the camera, this three-dimensional world is flattened into a two-dimensional image. This is a point of no return. From now on and forever after the movie will be in 2D. The depth dimension is gone—you can't reach with your hand through the footage to grab distant objects or measure how far they are. All visual effects are essentially performed on a two-dimensional source. This is a fundamental notion that is so easily overlooked—there really is no depth to work with, as the footage is always two-dimensional.

When visual effects are done by means of manipulating the footage or by adding elements that are either still photos or different footage, they are essentially done in 2D. This is similar to Photoshop work, but on "moving pictures" that change over time. Although a sizable portion of all VFX work is done in 2D, it is a limited workflow. It is very hard to realistically convey changes in perspective and distance solely in 2D. Much of the work we see in movies would not have been possible without the ability to create and animate three-dimensional CG elements within a virtual three-dimensional space. The 3D workflow is in fact a synthetic "imitation" of the way a movie is shot—once the 3D environment, set, and props are "filmed" with a virtual camera (the process we call rendering), they become a series of two-dimensional images. So when we talk about 3D, we really talk about the process—the end result is still two-dimensional. The differences between the 2D and 3D workflows, and the pluses and minuses of each will discussed in Chapter 3 along with an in-depth analysis of camera movement and how it affects the choice of workflow.

There is however a certain confusion between 3D as discussed earlier (and throughout the book), and the popular (though not really accurate) use of the term "3D" to describe something quite different, more accurately called **stereoscopic 3D**, or stereoscopy. This process creates an **illusion** of depth by sending slightly different images to each eye (picked up separately with the help of special glasses). Stereoscopic imagery has been around, in one form or another, since the mid-19th century. Contemporary stereoscopic films are either shot with a stereoscopic camera rig, or converted to stereo in post. The latter (obviously inferior) option requires an entire army of roto artists (see Chapter 4) that painstakingly separate foreground, mid-ground, and background elements.



Four views showing different angles of a 3D cedar tree model.

Model courtesy of Speedtree.

So, to clarify, the 3D workflow itself has nothing to do with whether the movie is screened "in 3D" or not. Whenever 3D is mentioned in this book, it refers to the process of creating and animating CG elements in a virtual 3D space and rendering them as 2D images that are composited into the footage. This should not to be confused with stereoscopy.

Realism and Photorealism

Visual effects are constantly being judged by how "real" they look. This is a vital part of the discourse surrounding VFX, and for a good reason—few filmmakers will be content with VFX that damage the believability and credibility of their movie. Yet there is something paradoxical in talking about the "realism" of VFX when in fact nothing in a movie is real. The actors pretend to be someone else, the set is just painted panels of plywood and Styrofoam, and if you turn the camera away from the action you'll probably capture a bunch of trucks and trailers, lots of cables and boxes, and some crew members happily munching at crafts service. The word "real" is therefore somewhat problematic. Yet there is indeed something that distinguishes VFX in this context. That something needs a more accurate word. That word is **photorealism**.

Let's borrow the iconic scene of the sick Triceratops from *Jurassic Park* as an example. In that scene, the dinosaur is lying on the ground, sick, and breathing heavily. The filmmakers have two choices: they can use an animatronic Triceratops (a mechanized, motorized puppet), or they can shoot the scene "empty" (or with a temp dummy), and have the VFX team add a CG Triceratops in post. Now, both the animatronic and the CG Triceratops are just fake props that pretend to be the real thing. They are both lies at the service of truth, to use Haneke's famous expression. Yet there is a key difference: the animatronic Triceratops is physically present on location along with the rest of the set, the props, the actors, and the lights. The camera captures the animatronic as an integral part of the environment, complete with all the intricate interaction between surfaces, lights, atmosphere, reflections and refractions, dust and smoke. This makes our animatronic, by definition, **photoreal**. The fact that it is just a fake puppet does not matter in this regard. At the moment the picture was taken, it was there, in front of the lens. The CG dinosaur, on the other hand, will never be captured by the camera. It will not be part of that physical interaction of light, matter, and optics. It will be rendered separately and synthetically, outside the context of the physical location environment, and then transplanted into the footage in a sort of a "visual surgery."

Movies are fake, but at least they are "real" in the eyes of the camera. In other words, anything captured by the camera is, by default, photoreal. Visual effects are not. This is why VFX artists constantly strive to make their work as photoreal as possible. Integration is a paramount concept in VFX. It's so much about integration—making the work as seamless as it can be, as if every VFX element that's been added to the footage was actually there, on location, captured by the camera. Photorealism, therefore, is not so much about making things "look real" as it is about making them "sit" realistically in the footage.

Now, if we go beyond the aspect of photorealism and integration, there isn't much of a difference between our animatronic and CG dinosaurs. The believability of both fake props depends on the choice of correct materials, accurate detail, and—most of all—realistic movement. Live action movies are

The Triceratops was captured in camera, along with the surrounding environment and the interactions with the actors. It is therefore 100% photoreal. But the overall realism is fully achieved thanks to the meticulous construction and texturing of the animatronic.

Jurassic Park © Universal Pictures, Amblin Entertainment.

much less forgiving in terms of movement than animation features. There is very little room for stylized animation in an environment that has real-life actors, which accounts for the prevailing use of motion capture in visual effects (see Chapter 5).

To sum it up, we can say that realism in VFX is three-leveled. On the first level, elements need to be built and surfaced with the right amount of accurate detail, just like any set piece or prop. On the second level, they need to move in a plausible fashion. On the third level, they need to look photoreal—integrated into the footage as if they were physically captured by the camera. The success of these three levels of realism depends on the work of artists who handle a wide variety of tasks—from modeling and texturing through animation to lighting and compositing. In Chapter 5 we will take a close, detailed look at each one of these tasks (or crafts, as I prefer to call them), and see how they contribute to the overall process of visual effects.

The Danger of Over-indulgence

The believability of visual effects does not depend just on the quality of animation, detail, and integration. There is another facet to it, which has less to do with the work of the VFX team and more

to do with the filmmaker: Visual effects are not bound by any physical limitation. They are, in a sense, limitless—a magic playground filled with fascinating toys for the filmmaker to play with. And herein lies the danger. When visual effects are used judiciously and with respect to real-world physics and optics (and to the aesthetic conventions of filmmaking), they become an integral and coherent part of the movie and its story. But when the temptation to use every available VFX toy crosses the fragile border of artistic sensibility, when VFX are tossed in just "because it's possible," they are likely to become an irritating excess that throws the film off its balance and the viewers off the story.

We once worked with a director who wanted almost every VFX shot to have a "dramatic sky." We struggled to explain that throwing in a sky that does not match the lighting of the original footage or the surrounding shots will not help the movie. Rather, we argued, it will cause the VFX shots to pop out in the context of the sequence, creating a dissonance that screams: "Attention everyone, this is a VFX shot!" Visual effects are like magic tricks—the magic only works when the trick is hidden. It is of course the responsibility of the VFX team to create the perfect magic, but it is also the responsibility of the filmmaker not to over-indulge in the use of this magic.

Animation, Games, and Visual Effects

It is customary to warp these three crafts into a single entity, and it's true that they share similar tools and techniques. But there are some key differences between animation, games, and VFX, and it's important to discuss them here. First, to clarify, animation is of course an integral part of the processes of visual effects and games production. But in the context of this discussion, "animation" refers to the specific genre of

This frame from *Brave* shows Pixar's signature attention to lighting, texture, and detail. Yet the overall look is stylized, and the focus is on expression, mood, and aesthetics rather than realism.

Brave © Walt Disney Pictures, Pixar Animation Studios.

With every year that passes, games look and feel increasingly realistic, as in this example from *Fallout 4*. But the limitations of real-time playability still require compromises—noticeable here in the foreground rocks, the broken windshield, and the plants.

Fallout 4 © ZeniMax Media Inc., Bethesda Game Studios.

fully animated feature films (or shorts), such as the ones that come out of Pixar, Disney, or Dreamworks for example. The convention in this genre is that everything is CG, from the characters to their surroundings, and no live footage is used. This allows for a certain unity and coherence of the entire environment, since everything is created on the computer and rendered together. Take, for example, a Pixar classic like *Finding Nemo*: the animation is stylized (well, it's about a talking fish) and the environment is not quite photoreal—yet the result feels immersive, detailed, and extremely convincing. Now take Nemo and his surroundings, and drop them into real underwater footage, and they will look and feel noticeably artificial. In this respect, visual effects differ significantly from animation. As previously mentioned, adding CG elements to live action footage dictates a strict adherence to photorealism and realistic movement. This shifts much of the focus from the design of enticing CG characters and environments and the use of stylized movement, to the integration of CG elements with live action footage and the heavy use of motion capture for realistic movement.

Video games are similar to animation in the sense that they are a complete virtual creation rather than a mix of live footage and CG. But the process of creating a game presents two additional challenges.

First, in most cases the game's protagonists need to be able to move around freely, which means that everything around them must be designed and built as a fully three-dimensional environment. VFX on the other hand are often created solely "for the camera": since the footage already dictates what we see and

don't see, there's really no need to spend time and resources working on parts that are hidden or outside the frame.

The second challenge for games is that they must be rendered in real time, and while the capabilities of graphics cards are constantly on the rise and the level of realism in games is improving tremendously, game creators still face strict limitations on the amount of detail they can put in. Visual effects do not abide by this rule. With no real-time rendering limitations, shots can be extremely complex and detailed, which of course facilitates much higher levels of photorealism and visual quality than games (in Chapter 10, I look at the not-so-distant prospect of real-time rendering at full VFX quality).

VFX and the Digital Revolution

Some might argue that "digital revolution" is an overstatement, I embrace this term fully. Digital technology truly affected almost every aspect of our lives, for good or for worst. As far as visual effects are concerned, it's more than a revolution—it's a founding event. VFX as we know today could not have been possible without the ability to convert images into a series of numbers, and the development of computers that could handle and manipulate these numbers and spit out virtual imagery. Before digital technologies took center stage, visual effects were achieved through a combination of on-set and in-camera practical work, animatronics, stop-motion, painted glass panels, optical tricks, and chemical film manipulations. Some of the most beautiful and creative visual effects in the history of film have been done with such non-digital means, from Georges Méliès' 1902 *Le Voyage Dans la Lune* to George Lucas's 1977 *Star Wars*. Yet the dinosaurs that roamed Jurassic Park could not have been created, animated, and rendered without the emerging digital technologies and 3D applications (and, of course, the brave and talented team at ILM). These technologies did not only open up almost endless new possibilities for visual effects, they revolutionized their use in the industry—from unique events in a handful of movies to a widespread filmmaking tool that's used extensively in every genre and on any budget.

Digital vs. Film

Not so long ago, video cameras were practically a taboo in cinema, and were used almost exclusively in the TV domain. But the past few years have seen giant leaps in the development of digital cameras, which lead to a massive shift toward digital cinematography. Not only do digital cameras like Arri Alexa and Red Epic provide similar results to film cameras in terms of color depth, light sensitivity, and resolution, but today's filmmakers also have a wide choice of small portable video cameras that offer an astounding image quality for their size and price. Subsequently, the use of film media has seen a very sharp decline. There are still some cinematographers and directors who will only shoot film, but they are facing an increasingly challenging situation, as many film stocks are becoming hard to find and fewer labs are now equipped to process film. There is indeed a certain quality and feel to film that is hard to replicate with even the best digital cameras. Yet I should point out that from the visual effects standpoint,

digital media (if shot well, of course) is in fact preferable to film. Since visual effects are done digitally, the film stock must first be converted to digital. This is done by scanning the film—a delicate process that, if performed incorrectly or with badly calibrated scanners, may produce wobbly, inconsistent imagery. We've had some nightmarish experiences in the past with badly scanned film that was so jittery we had to resort to some tricky spline-warping to get the VFX elements to "stick" to the footage. The fact that fewer labs now have the right equipment or experienced personnel to handle film scanning makes this issue even more problematic. So, if you want to shoot film and plan to use VFX, do make sure that the scanning and processing is done by a trustable lab and experienced technicians. Otherwise, shooting with high quality digital cameras ensures a smoother VFX process down the line.

Film vs. Television

Film and television used to be miles apart in terms of visual quality. VHS was simply not comparable to film, and since the media was inherently limited (as was the budget), fewer resources were spent on the visual side of TV productions. Consequently, visual effects in TV programs were used sparsely, and their quality was considerably lower than VFX created for film.

Those days are gone. Television is now on par with movies in terms of quality of content (some say even better, at least in the USA). And as far as visual quality goes, the gap between TV and film has narrowed down considerably. Most home TVs are now HD resolution (or higher), and the same digital cameras are now used to shoot TV and cinema. The level of complexity and the quantity of visual effects in TV programs has increased significantly, with TV series such as HBO's *Game of Thrones* pushing the quality bar ever higher. When we worked on *Boardwalk Empire*, we were treating it as a feature film, applying the same high standards to the VFX work as if we were working on a movie (and interestingly, *Boardwalk Empire* was actually shot on film).

There are differences however. Budgets for TV productions are still much lower, on average, than film, and the schedule is usually much tighter. This forces VFX teams to come up with creative and technical solutions to compensate for the limited resources and time. This is not necessarily a bad thing—the experience gained on TV productions can be used for low budget features as well. But besides the budget and schedule differences, working with VFX on film and television today is very much the same. Therefore, everything in this book applies equally to film and TV, and although I use the words "film" and "movie" for convenience, they can always be substituted with "TV program" or "series."

Commercials and music videos also make extensive use of CG and visual effects. These are much shorter formats than feature film or TV series, and as such have a much shorter turnaround time. They also differ in their approach: often the focus in commercials is to make the product (or the advertised concept) visually enticing and attractive, sometimes at the expense of photorealism, while the style of many music videos lies on the fringe between photoreal CG and stylized motion graphics. Yet despite these differences, commercials and music videos share the same VFX concepts and workflows as film and TV, and much of this book applies to these fields as well.

Visual effects in service of a TV docudrama: A quarry in West Virginia is getting a VFX makeover to look like the Panama Canal under construction, in the History Channel mini-series *The Men Who Built America*.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

Chapter 2

VFX as a Filmmaking Tool

When we published the reel that showcased our VFX work on director Martin Scorsese's *The Wolf of Wall Street* we anticipated a fair number of viewings, considering the relative buzz around the movie. But nothing prepared us for the massive response the reel received the moment it went online. The counter topped one million views in less than two weeks, and the clip became a subject for numerous articles on websites like *Gizmodo*, *The Verge*, and France's *Le Figaro*. We were truly taken by surprise. We were proud of our work, of course, but never thought it was particularly spectacular or groundbreaking. Only after reading through the comments did we realize that the reel had become so popular because it revealed visual effects in a movie where no one expected to see them, and in shots that no one suspected were VFX shots.

What we did on that movie was mostly environment work—"extracting" the action from one location and "placing" it in a totally different location. A wedding shot in New York was transformed into a Caribbean beach; a Brooklyn tennis court was converted into a desert prison; and actors shot on a green screen stage were transported to a pier in Italy. The visual effects were hidden, never trying to grab attention for themselves. They were merely used as a tool to achieve a simple goal: to save production a considerable amount of money by shooting everything in New York. It was a clever decision by Scorsese and production VFX supervisor Robert Legato to harness the power of visual effects, not for creating the extraordinary but for helping out with the ordinary.

If you look at visual effects simply as a filmmaking tool, they can be used in a wide range of scenarios to help the filmmaking process. Budget is one area where VFX can make a big impact. The ability to change, modify, or enhance locations in post helps reduce costs, time, and bureaucratic complications. The ability to extend practical sets with VFX means that less time and less money are spent on constructing large sets. And crowd-tiling techniques make it possible to populate big scenes with just a limited number of extras. Sure, visual effects cost money too. Sometimes a lot. But careful planning and a good understanding of the medium can keep VFX costs considerably lower compared to real-world practical solutions. Removing an unwanted street sign on location, for instance, can easily cost several thousand dollars for labor and municipal permits, while the VFX removal may be much cheaper, and without the legal and bureaucratic hassle.

In *The Wolf of Wall Street*, shooting a wedding scene in New York and using VFX to transform it into a Caribbean beach saved the costs and hassle of moving the entire production abroad. Instead, only a small second unit was required to shoot the background plates, which we used with some additional matte painting to achieve this "location switch."

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

But cost saving is certainly not the only reason to use VFX. Some ideas are simply not possible to achieve practically, no matter how big the budget is. A massive tsunami destroying Manhattan, a dinosaur stampede or an alien invasion—these are ubiquitous examples of how VFX are used in big-budget blockbusters to create the impossible and astound the audience with mega disasters and incredible stunts. But there are also more mundane instances of production cul-de-sacs that can be elegantly solved with VFX.

In one scene of the movie *Delivery Man*, Vince Vaughn's character goes to Madison Square Garden to watch his son play basketball as a NY Knicks player. To have an actor participate as a team member in a real NBA game is something that no amount of money can facilitate. So to make this possible, production shot an actual Knicks game at Madison Square Garden, and we later replaced the face and hair of one of the Knicks players (Steve Novak) with a CG animated face replica of the actor (we also changed his Jersey number from 16 to 13). Not a spectacular wow-inducing effect, but a crucial step in keeping the storyline and making the impossible happen.

Face replacement is used to solve an otherwise impossible scenario.

Delivery Man © Touchstone Pictures, DreamWorks SKG, Reliance Entertainment. Visual effects by Brainstorm Digital.

Cost saving, storytelling, practical problem solving—all these are reasons important enough to use visual effects in almost any project. But one cannot (and should not) ignore the essence of VFX as cinematic magic. Visual effects are, after all, a tool that can lift certain moments in the movie up high. Even in a low-budget film or TV program, a few instances of VFX enchantment might be all that's needed to create an impact and push the narrative forward. Sometimes, a single, well thought-of touch of visual effects can be more effective than sequence after sequence of VFX shots—a cinematic icing on the cake that can make a strong impact without draining the budget.

Common Types of VFX Shots

Trying to categorize VFX shots is of course a tricky proposition. There are as many types of visual effects as there are movies, directors, and visually creative minds. Yet there are certain types of "bread and butter" VFX shots that seem to recur in almost every project, big or small. Whether it's a sci-fi movie, action flick, a TV drama or a comedy, at least some (and sometimes all) of the VFX work is bound to fall within one of the categories that follow.

Fix-it Shots

Even if you have no intention to use visual effects in your film, there's a big chance you'll end up needing some VFX to fix things in post. Let's face it, things happen on set, no matter how carefully planned and professionally executed a movie is. A boom accidentally crossed into frame, a crew member was caught

on camera, somebody from the art department made a spelling mistake on a sign and no one noticed it on time, the camera was shaking, a logo on a laptop must be removed for legal clearance . . . this category essentially includes all the VFX shots that were never planned, and are usually spotted and added to the list only during the editing stage.

In the old days, when visual effects were too limited or too expensive, solutions usually involved switching to a different take, or cutting around mistakes or problematic shots. But today there's no reason to ditch that single take with the most amazing performance just because a crew member was caught in frame or because the camera is reflected in a mirror. The techniques of VFX allow for seamless removal, cleanup or modification of elements in the footage, and when done well, the removal is invisible, leaves no traces, and does not affect the rest of the shot. Common fix-it work includes:

- Removing unwanted elements (boom, gear, crew, unwanted background elements, reflections)
- Modifying or fixing mistakes in set elements or props (a misspelled sign, for example)
- Split-screens (stitching together two halves from different takes for best performances)
- Enhancing prosthetics, makeup or practical effects (and removing unsuccessful ones)
- Beauty/aging enhancements (it is no secret that visual effects are used extensively to remove blemishes, clean up wrinkles and fix unflattering lighting on actors)
- Stabilizing camera shake
- Fixing strobing lights, TV screens or monitors
- Retiming action (for example, an actor who reacts too late to a gunshot).

There are of course many other fix-it scenarios. A random selection of fixes we did in the past includes dealing with an extra who was staring at the camera (changing his eyes), removing a hair from an actor's face, adding a flow of concrete coming out of a cement mixer (because it malfunctioned), and stabilizing a dead man's chest (because you could see the actor breathing).

In this shot from *Extremely Loud & Incredibly Close*, the director wanted us to clean up the background by "inserting" a door behind the actor.

Extremely Loud & Incredibly Close © Warner Bros., Scott Rudin Productions, Paramount Pictures. Visual effects by Brainstorm Digital.

In this shot from Woody Allen's *Café Society,* we added cement flowing down the chute to fix a malfunction in the cement truck.
Café Society © FilmNation Entertainment, Gravier Productions, Perdido Productions.

While many standard fix-it shots fall within the easy category, not all are simple by definition. Removal of elements is commonly referred to as **paint out** ("Can you paint out the car in the background?"), but it's important to remember that nothing can be erased from the footage without replacing it with something else—there is no blank canvas and you obviously can't leave a black hole. The most common removal method is creating a seamless patch that covers the area of removal and is tightly tracked to it. That patch is made to look just like the original background, only without the element that needs to be removed (this process is often called **clean-plating**). In other words, VFX are always about **adding** something to the footage, even when the purpose is to remove something else. Such work can be simple and straightforward, or complicated and time-consuming. As you read through the next chapters you'll get a better idea of the various factors that may affect the difficulty level of any given shot. Here's a quick example. . .

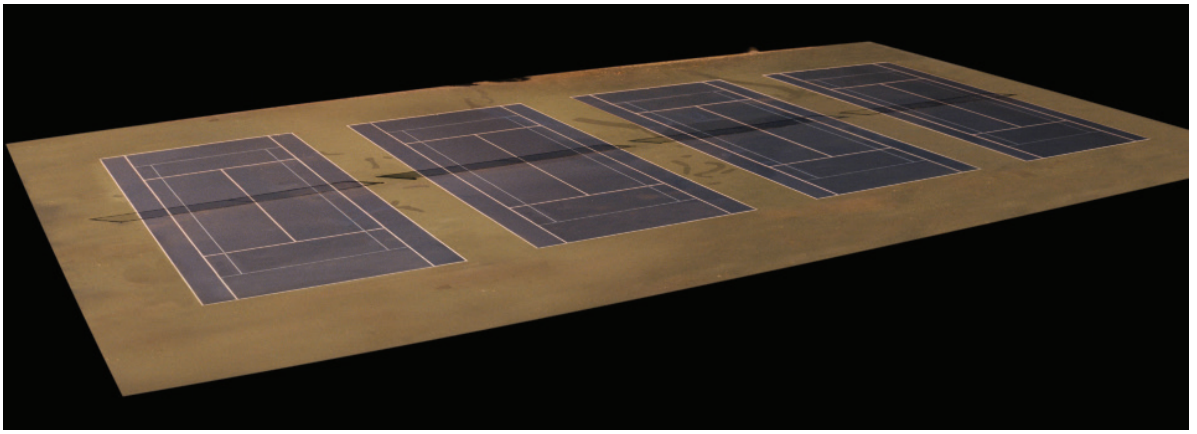
In *Fading Gigolo*, we had to fix a shot where the two actors were riding wooden horses on an old merry-go-round. The actors were having a long conversation (the shot was a very long one-take) as the carousel was spinning (the camera was mounted on the carousel). Unfortunately, the boom was visible just above the actors throughout the entire shot. Boom removals are usually fairly simple cleanup VFX, but in this case the background was constantly spinning and changing, so in order to remove the boom and add back the missing background behind it, we had to recreate and track-in long patches of background that seamlessly tie in to the footage. The work on this shot took around two weeks to complete, an unusually long time for a boom removal shot.

But perhaps the most complicated fix-it scenario I ever had to deal with was the prison shot in *The Wolf of Wall Street*. The first half of the shot was a big crane pull back move, starting from Leonardo DiCaprio picking up a tennis ball and then revealing the tennis court and players. Originally, we were supposed to extend that move further back and up to reveal the prison surroundings around the tennis court

The original crane pull-back footage was shot in a small park in Brooklyn.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

(which we created as a CG/matte painting set extension). But at some point during post, director Martin Scorsese wanted to shorten the first "real" half of the shot by speeding up the original camera move. Retiming the footage was not, of course, a viable solution, as it would also affect the action. To speed up the camera move without affecting the action, we had to roto out each actor (roto is discussed in Chapter 4) and re-project on cards in 3D space (see Chapter 3), then do the same for the actual environment.

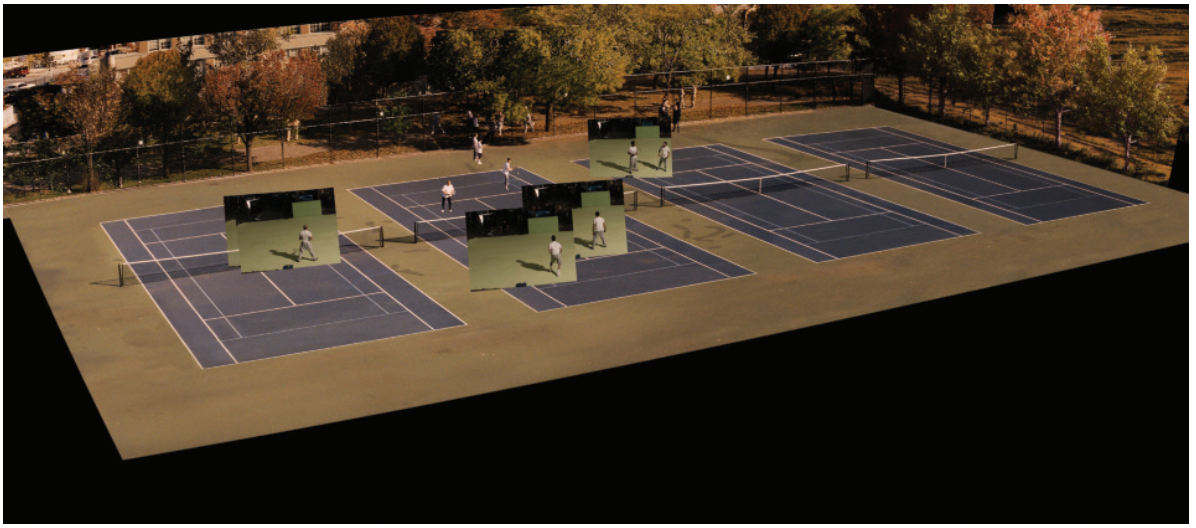


This scene had to be cut out into separate pieces and then rebuilt. This example shows the cleaned-up tennis court.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

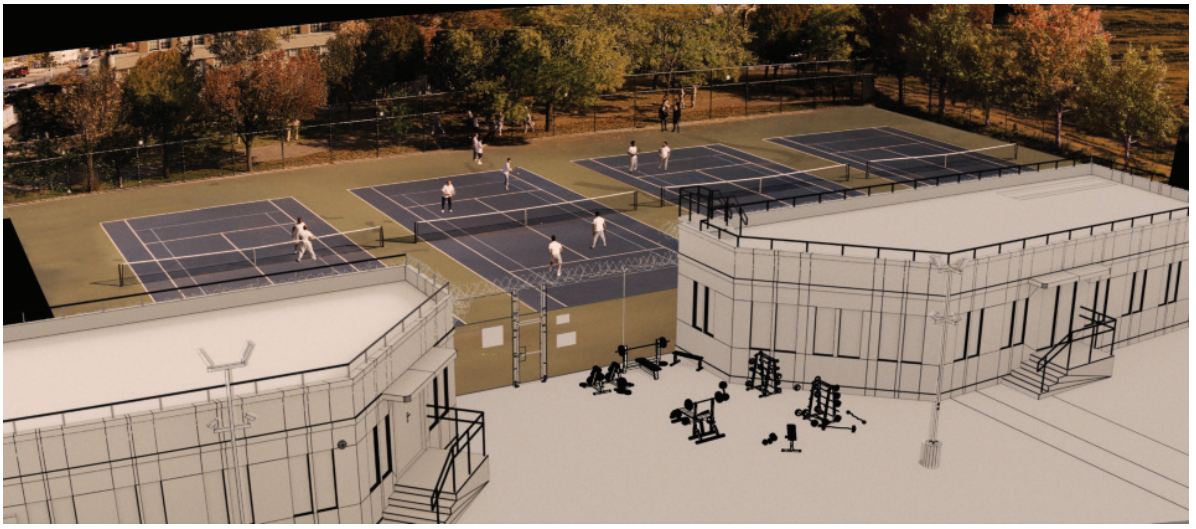
The nets and the background were added back.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.



Additional tennis players were shot separately on green screen and projected on cards.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.



The CG prison was added to the footage to extend the environment.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

The final shot—with the textured CG prison, and with additional green screen elements of guards and inmates.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

Because some of the tennis players came into frame as the crane pulled back, they could not be used with the faster virtual camera, so production had to separately shoot new tennis players on green that we then projected on cards in the scene. This was a very difficult undertaking, all for the sake of speeding up a camera move, and although it does not represent your average fix-it shot, it does give an idea of the vast potential of VFX as a post-production fixing tool.

Screen Inserts

We are surrounded by screens in our everyday life—phones, tablets, computer monitors, TVs—and it is hard to find a contemporary movie or TV show that does not involve at least some of those. Many films rely heavily on visual information that appears on a screen to tell their story, from text messages to the ubiquitous "copying file" progress bar. Graphics and text that appear on various screens can be done practically on set by feeding the specific video signal to the TV/monitor/phone screen. This of course provides the most realistic results (for example, light and reflection interactions with the actors and environment)—but there are quite a few disadvantages when going the practical way.

- It is hard to precisely time the video signal to the actors' action.
- It requires additional hardware and video technicians on set.
- All the text and graphic design need to be locked and prepared ahead of the shooting period.
- The screen material is "baked" into the footage—the only way to swap it later is by removing and replacing it in VFX.

- It is hard to control unwanted reflections on the screen.
- You need to account for issues like refresh rate and scanning frequency mismatches to avoid strobing and flickering.

On one movie, we shot a scene that took place in a control room that had an entire wall of monitors. The original production plan was to do it all practically, and the monitors were connected to an elaborate video feed system. But the timing of the feed could not be properly synced to the action, and after several unsuccessful takes the director decided to go the VFX route. The feed was switched to uniform green, and we later added all the screen material in post. An initial decision to do it as VFX rather than practical would have no doubt saved the cost of setting up and operating an expensive video feed system.

The advantages of VFX screen inserts are clear: there is much more flexibility; timing can be fully controlled; focus, reflections, color, and luminosity can be tweaked and refined. It is therefore no wonder that many films rely heavily on VFX for all the screen inserts, and this is indeed one of the most ubiquitous types of VFX work. Screen inserts are generally not a complicated type of visual effect, especially since screens have no depth and do not usually require 3D camera tracking. It is also important to note that unlike the old TV sets of yore, which typically cast a strong light and glow on the surrounding and had a distinctive curved glass screen, modern TVs, computer monitors and phone screens are flat and produce much less ambient light and glow. They are thus easier to integrate. The difficulty of screen inserts is usually determined by the number of reflective surfaces around them (because that requires adding the reflections for proper integration), and the complexity of separating the elements that go in front of the screen (see Chapter 4 for extraction and roto basics). As to what goes on the screen during shooting (black/green/tracking markers?)—this will be covered in Chapter 8.

Rig Removal and Period Cleanup

This category is in fact similar to fix-it removal and cleanup, but the (important) difference is that shots in this category are well planned in advance and are part of the original VFX breakdown and budget. Unlike fix-it scenarios, the elements that need to be removed can (and should) be identified and discussed on location during pre-production with the relevant department heads (camera, art, grips, lighting, stunts). That way, proper measures can be taken to minimize the extent and difficulty of the removal. For example, period movies and TV series usually require the removal or modification of non-period elements such as satellite dishes, AC units, modern signs, lights, and cars (to name just a few). The complexity (and cost) of the VFX removal can be reduced by practically dressing at least some parts (usually the areas that have the most interaction with the actors, like the ground and immediate surroundings).

Wires and rigs are used for safety on a variety of stunts, and obviously need to be cleaned up in post. The amount and complexity of such VFX work depends on how the rigs are set up. As always, careful pre-production planning and tight cooperation between the VFX supervisor and other heads of departments can help reduce costs on VFX removal dramatically (this will be discussed in detail in Chapters 7 and 8).

In this classic example of period cleanup from *The Immigrant*, production took care of the ground level by practically covering or removing non-period objects. We took care of the upper levels, where we removed AC units, satellite dishes, modern lights, and graffiti (circled in red), while also enhancing the period look with additional fire escapes and hanging laundry.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

Set Extensions

This category covers everything from adding a small distant element in the background to completely replacing the entire surroundings. Set extensions go an incredible way in helping the filmmakers achieve their dreams and visual aspirations without draining their budget. They are therefore used extensively—from low budget TV programs to tentpole blockbusters.

The same street scene as above is getting a set extension where we replaced everything behind the green screen with a matte painting to complete the 1920s Lower East Side look.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

This shot from *The Wolf of Wall Street* is another example of a set extension, but here, essentially everything was replaced except the strip of "pavement" that the actors are walking on.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

Constructing practical sets is costly and time-consuming, so it makes sense to construct a limited set that covers the main action area (and thus provides real interaction between the actors and their surroundings), and let the VFX team extend it further and into the distance. Likewise, shooting on a real location limits the filmmakers to what's already there (and to the local laws and regulations), and while the art department can add features and dress existing elements practically, tearing down complete buildings or constructing additional ones is usually not an option. Set extensions are created using matte paintings techniques (see Chapter 5) or built in 3D, but, either way, they truly open vast opportunities for the filmmaker. Successful set extensions and CG environments are most effective when they are well integrated with the real footage. Even the most spectacular or out of this world matte painting will feel like a cheap backdrop if it is not seamlessly tied to the foreground elements. VFX artists use the original footage as their guide—looking for cues about time of day, lighting, and atmosphere.

Crowd Tiling/Crowd Simulation

Scenes with hundreds of people are tough on the budget. The more extras you have on set, the more people you need to pay, feed, transport, dress, and manage. There are two main VFX techniques to populate a shot with additional people: the crowd tiling technique involves shooting the main plate first with all the available extras, and then shooting additional plates with the same extras (shuffling their position to avoid a duplicate look). The CG technique on the other hand uses a large number of virtual CG characters, which are often animated and controlled with the help of special crowd simulation software (see Chapter 5). This technique is by far more expensive and involving, but it offers much more freedom in terms of camera movement and a lot more flexibility in designing the action (and of course does not require additional shooting time or a second unit). As you read through the next chapters, you'll see the advantages and disadvantages of 2D and 3D, and these crowd tiling/extension techniques can serve as a good example. The first (non-CG) option is more commonly used on medium and low budget films as it requires much less resources, but its success depends on careful planning and on-set practices, which will be discussed (alongside some examples), in Chapter 8.

A rather empty beach springs to life with crowd tiling. In this shot from *Boardwalk Empire* the camera panned from the beach to the boardwalk, where we also added people.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

This shot from *World War Z*, as well as many others in that movie, could not have been done without extensive use of CG crowd simulations.

World War Z © Paramount Pictures, Plan B Entertainment, Skydance Productions.

Action Elements

Gun shooting, explosions, bullet hits, debris, blood, gore—all can be done practically on set as special effects (and have been done this way since the early days of cinema). But filmmakers often choose to rely on visual effects for some or even all of the action elements. Practical effects may be hampered by safety regulations, cost, and practical limitations. Some SFX (destruction effects for example) can only be done once, confining the filmmakers to a single "take it or leave it" version. Others require a long time to reset, time that is not always available on tight shooting schedules.

Sometimes visual effects are used to replace a malfunctioning practical effect or to augment one. Muzzle flashes, for example, are so quick that they often happen in between frames, just when the shutter is closed. Blood squibs sometimes fail, or are obstructed by quick movement. Action scenes in general are quick and messy, and it's hard to predict and control every element while shooting them, so VFX come in handy even when most effects are done practically on set.

In the action/heist movie *Triple 9*, for example, most of the action elements were done practically, but we still had to do additional VFX work on over 100 shots to add, augment, or replace muzzle flashes, bullet hits and holes, explosion debris, and other action elements. Since a lot of this type of VFX is directly

related to (and affected by) the work done on set by the SFX and makeup departments, it is beneficial to decide in advance which department is doing what (more on this in Chapter 8).

Advanced VFX

Once we move beyond these common basic categories, a vast ocean of possibilities is revealed. Advanced visual effects usually call for the creation and integration of CG elements—which can be anything from a small CG creature in the background to an entire army of charging Orcs, a little water splash or an epic flood, a helicopter crashing or an entire city being destroyed by an earthquake. Almost all of the more advanced VFX shots also include work from one or more of the categories listed earlier. They become a compound and multi-faceted process that usually requires the work and expertise of several VFX artists.

Beyond the basic work already described, there are so many different types of shots, so many options, and so many levels of complexity—it is practically impossible to list them here in some kind of orderly fashion, or to tuck them neatly into predefined categories. But the following chapters will provide insight and examples that will help deepen your understanding of the VFX process. This should enable you to consider every idea, every option and every type of potential VFX shot with a clear and practical understanding of what it takes to achieve it and how.

Chapter 3

From 2D to 3D

The Quest for the Lost Dimension

Movies are a flat, two-dimensional representation of a three-dimensional world. That third dimension—depth—is lost the moment the image is captured. It is therefore logical to assume that VFX work itself should be done in 2D, just like Photoshop image manipulation (but on a series of sequenced images rather than a single still). This assumption is correct to a certain extent. Many VFX shots are worked on and completed fully within the 2D realm. On any given movie, you can expect a substantial chunk of 2D-only shots. And there's a good reason for this: the 2D workflow is generally simpler and faster (and cheaper) than the 3D workflow, as I will explain.

Yet visual effects can, and often must be created in a virtual three-dimensional world. The seemingly depth-less footage can in fact be "opened inside out." The lost depth, the missing third dimension can be reevaluated and restored. How exactly can this be done? And why only on certain shots and not all of them?

Understanding the differences between the 2D and 3D workflows is crucial for filmmakers not only because the choice of methodology has a direct effect on the cost of the shot and the time it will take to complete, but also because it affects the look and "feel" of the final result. The decision whether to use a 2D or 3D approach (or some combination thereof) is influenced by many factors. Clearly, any animated object or character that moves around in the shot needs to be three-dimensional, unless it is small and far in the distance. The cartoonish 2D look of traditional animation does not pair well with live footage. But at the most fundamental level, the choice between 2D and 3D is, first and foremost, dictated by the camera movement. To better understand this relationship, we need to examine camera movement from the VFX point of view.

Camera Movement and VFX

A director or a DP thinks of a camera move first and foremost from the narrative standpoint: How well does the move tell the story? How does it fit in the dramatic flow? What is its emotional effect on the viewer? Next come the practical decisions about how to physically move the camera in space: should the camera be mounted on dolly tracks or on a crane? Hand held or on a Steadicam rig?

From the filmmaker's standpoint, optical or physical effects are the resulting by-products of the desired move. But from the VFX point of view it is exactly these factors that matter the most because they define

the way the shot should be approached. The goal, after all, is to make the added VFX elements feel like they are native to the footage. They should move in frame exactly like the elements in the original footage. That relative movement and spatial relationship between objects in the footage can be narrowed down to two key factors: **parallax** and **perspective shift**.

Parallax

Let's take the classic example of parallax: looking out through a train window. As the train is traveling, nearby objects appear to move across the window faster than objects further away. The trees right next to the tracks whoosh by quickly while the mountains in the background move very slowly. This complex overlapping "motion" is known as parallax. It is so embedded in our perception of movement and depth that we hardly pay attention to it in real life, but the lack of parallax is immediately apparent to even the most uninitiated eye. A movement without parallax feels like there's no depth, as if all the objects are on the same exact plane.

If the train window is a camera lens, then the train movement is essentially a track move. Any type of horizontal or vertical move (track, dolly in/out, and crane up/down) generates parallax. One thing to note here is that the effect of parallax diminishes with distance. Two trees standing 3 and 20 feet away from a moving lens will parallax strongly, but if those two trees were standing half a mile away, with the same 17-foot distance between them, they would move practically in unison, with no noticeable parallax between them. This is a key point for VFX, as will soon become clear.

So far we have looked at track, dolly, and crane camera moves. But what about pan and tilt? Do rotational moves also generate parallax? To be precise, only a perfect **nodal pan** is totally parallax-free. If you rotate the lens around its exact nodal point, objects will not shift in relation to each other, no matter how close or far they are. This is because there is zero travel on any axis, only a prefect rotation. Specialized nodal heads do exist, but they are mostly used for shooting panoramas and spherical images

The effect of parallax in a short sideways track camera move: notice the extreme shift of the foreground plant, the much smaller shift between the mid-ground lamppost and the trees behind it, and the almost complete lack of movement in the distant background.

A left to right pan. Notice the minimal shift in the foreground, and the complete lack of parallax shift in the mid-ground and background. If the camera were mounted on a nodal head, even the foreground would be parallax free.

with still cameras. The rotation axis on most film and video camera rigs is usually around the center of the camera body, farther away from the nodal point, so in most cases a tilt or pan are not truly nodal, and some minor parallax does happen. But as I mentioned before, parallax is reduced with distance, so that minor parallax on a pan or tilt is really only noticeable on objects that are very close to the lens. In most cases, tilts and pans can be considered parallax-free.

Perspective Shift

In VFX terminology, a perspective shift means that the camera reveals different parts or areas of an object as the camera moves. If we crane up in front of a house, we'll first see its façade, but as the

As the camera moves to the right, the perspective shifts and reveals the side of the car, which was completely invisible at the starting position.

camera moves higher up we'll start seeing the roof from above. Just like parallax, perspective shift is more pronounced in the foreground than the background. A camera that travels along a street will reveal the sides of nearby buildings as it travels, but distant buildings will still show only their front facades.

2D Workflow

Now that we have defined some key factors of camera movement, let's pick a real shot we have worked on for *Sons of Liberty* as a case study that will enable us to explore both the 2D and 3D workflows. It is an establishing shot of Hancock Manor (John Hancock's lavish house in Boston, which unfortunately no longer exists) that shows two guards opening the exterior gate as one of the characters walks up the stairs toward the entrance door. Building a full set of the iconic Hancock Manor and the garden surrounding it was not a possibility, due to location and budget limitations. It became clear that this would be a VFX set extension, but to avoid using a green screen and to retain the physical interaction between the actors and the environment, it was decided that production would build a practical set that included only the gate, the walkway and stairs, and the front door and portico. All the rest would be added as a VFX set extension.

Let's first take camera movement out of the equation, and assume that the shot is captured with a locked-off, static camera. In this case, there is absolutely no reason to do anything in 3D, and we can very easily work the shot completely in 2D. We can "build" the extended set using various photographs that are combined to create the house and its environment (incidentally, we found a full-scale replica of the house in Ticonderoga, NY, which served as a good source of reference and textures). As long as we make sure that the elements we combine match the foreground set and actors in terms of angle, perspective, and lighting, things should work out well. This background doesn't need to be totally still. We can, for example, introduce some movement in the trees, or some distant flying birds, simply by shooting relevant elements. One of the major advantages of the 2D workflow is that you can use real photographs and footage without having to create everything from scratch. This ensures that the elements that are being added to the original footage already have a photoreal quality "built in." After all, nothing looks more photoreal than real photos. The feeling of depth, distance, and dimension in the 2D workflow is achieved in the same way as in traditional painting—by using perspective, size, and color. Objects become smaller with distance, far away objects have less contrast and saturation and take on a slight bluish tint, and proper perspective is achieved by adhering to plotted converging lines—all tried-and-tested art techniques that have been honed and perfected through centuries. We can effectively trick the eye into seeing distance and dimension without ever creating a single element in 3D. So far so good.

The original footage for the Hancock Manor shot, showing the gate, walkway, stairs, and entrance set pieces.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

With a locked camera, the entire set extension could be done completely in 2D, without any need to build or render elements in 3D.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

The Missing Dimension

The real shot, of course, was not locked off; it had a wide crane-up camera move, starting low and ending up high, a move that adds drive and drama to an otherwise potentially dull establishing shot. Now, let's see how such a move affects our 2D set extension. If we simply slide our background the opposite way to "fake" that movement, the set and actors will parallax against the background, but there will be no parallax at all within the background itself. Our brain will instinctively interpret the lack of parallax as lack of depth, so the entire background, from the foreground wall to the distant houses and trees, will feel as if it's on the same plane, like one of those sliding theater backdrops in a children's play. To realistically convey depth and motion, every single object in the image, every leaf on every tree, and every blade of grass, needs to move separately, based on its distance from the camera. But how can we do that? If our background is a single photo, it's very clear that we can't simply cut out different parts of the image and move them around to create parallax, because we will reveal the "nothingness" behind them. However, if our background is made of separate layers of photographic elements, we can possibly move them across each other. But how can we tell how far from the camera an object in the footage really is, and how do we know how much it needs to move in relation to other objects and the actors? Clearly this can't be guesswork.

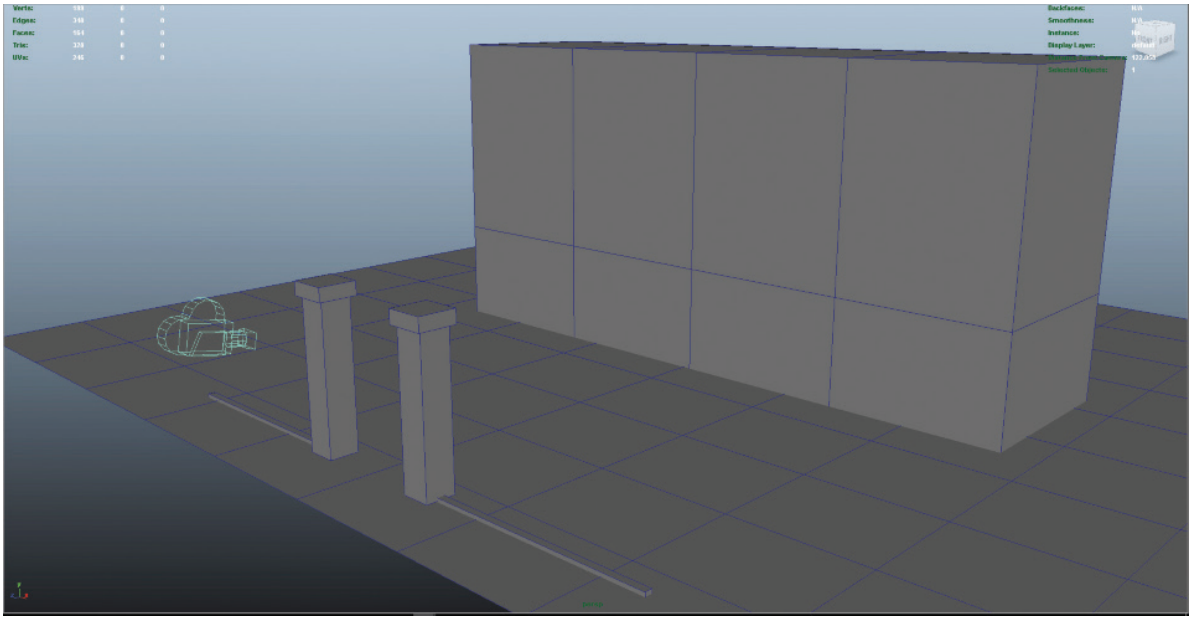
And there is yet another problem: the wide crane-up move does not only generate parallax, it also causes a very noticeable perspective shift. How will our 2D elements withstand perspective shift? The fact that they have no depth, no additional sides or a "top," will reveal their cut-out nature—the theatrical equivalent of the child going on stage after the show and realizing that the backdrops are just paintings on flat panels. Our 2D solution, which worked so well when the camera was static, is now turning out to be a dead end. It becomes evident that we must switch to a 3D solution, but where do we start?

The start and end frames of the crane up move. Notice the extensive parallax between foreground and mid-ground, as well as the perspective shift in the foreground.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Recreating the Camera

We start with the camera. To accurately represent the correct parallax and perspective shift generated by a camera move, we must first recreate this move with absolute precision. In other words, we need to generate a virtual camera that duplicates exactly not only the position, angle, and movement of the original camera but also its lens type and distortion characteristics. Without the ability to track the camera, visual effects would be truly limited, and the range of possibilities severely diminished. Recreating the camera is the first and most fundamental step in the 3D workflow because it "opens up" the two-dimensional footage back into a three-dimensional world. Camera tracking (also called matchmove—see Chapter 5 for detailed explanation of the tracking process) not only provides us with a virtual camera duplicate, but also with a virtual space. It gives us an accurate indication of where objects in the footage actually are, as well as their relative distance from the camera and from other objects in the scene. For instance, in our Hancock Mansion shot, a camera track will give us the relative position of the front gate, the stairs and the back door. This in turn will help us figure out the spatial relationship between objects in the footage and the virtual VFX elements—where the front wall and trees should be, the exact position of the house and how far the background elements need to be in this virtual space.



A tracked camera replicates the move in a 3D environment and provides indication for the position of key elements in the footage.

3D Workflow

Once we have a virtual camera that perfectly mimics the movement of the real one, we simply need to place our CG models where we want them in 3D space to achieve accurate parallax. Working in 3D also solves the problem of perspective shift—objects are built as truly three-dimensional elements and therefore can be viewed from any angle. Moreover, unlike the photos and footage used in the 2D workflow, 3D elements can be lit from any direction and in any fashion. And of course, animated objects and characters can move and behave in a truly three-dimensional fashion, inside a three-dimensional world. It is virtually impossible to imagine today's visual effects without the ability to track cameras and create and animate three-dimensional environments, objects, and characters that can be seamlessly integrated into live action footage that was shot with various camera moves.

3D vs. 2D

There's no fire without smoke. The 3D workflow is indeed tremendously powerful and flexible—but it comes with a price, literally. Just like in the real world, every 3D object needs to be built and textured, and then the entire scene needs to be lit and rendered. It only takes a good photo to make a tree in 2D, but recreating the complex structure of branches, twigs, and leaves in 3D is a whole different thing.

In Chapter 5 we will take a closer look at modeling, texturing, shading, rigging, animating, and rendering, but in a nutshell, the 3D workflow requires more artists per shot, more processing power, and more time than 2D. Building a car from scratch is much harder than taking a photo of one. Achieving a photoreal look with 3D is also a considerable challenge. All the fine detail and lighting nuances that you get "for free" with photographic material need to be meticulously recreated, because the dreaded synthetic "CGI look" is always lurking around the corner.

The table that follows shows a quick summary of the pros and cons of 2D and 3D workflows.

	2D	3D
Creation method	Photographic elements	Modeling, texturing, shading
Lighting	Baked in the image, cannot be changed	Completely flexible
Animation	2D animation only	Full 3D animation
Camera	Works with Lock offs, pans/tilts, or on specific areas that can be tracked in 2D	Works with any camera move, but requires 3D camera tracking
# of artists per shot	1–2 artists (compositing, matte painting)	Usually 2–5 artists (modeling, texturing, shading/lighting, rigging, animation, compositing) but can be much higher on complex shots
Photorealism	Photoreal quality already exists in the images, but it's harder to match the lighting to the original footage, or integrate elements from various sources	Lighting can be matched more accurately to original footage and is coherent for all the elements, but photoreal quality depends on adding a lot of modeling and texturing detail

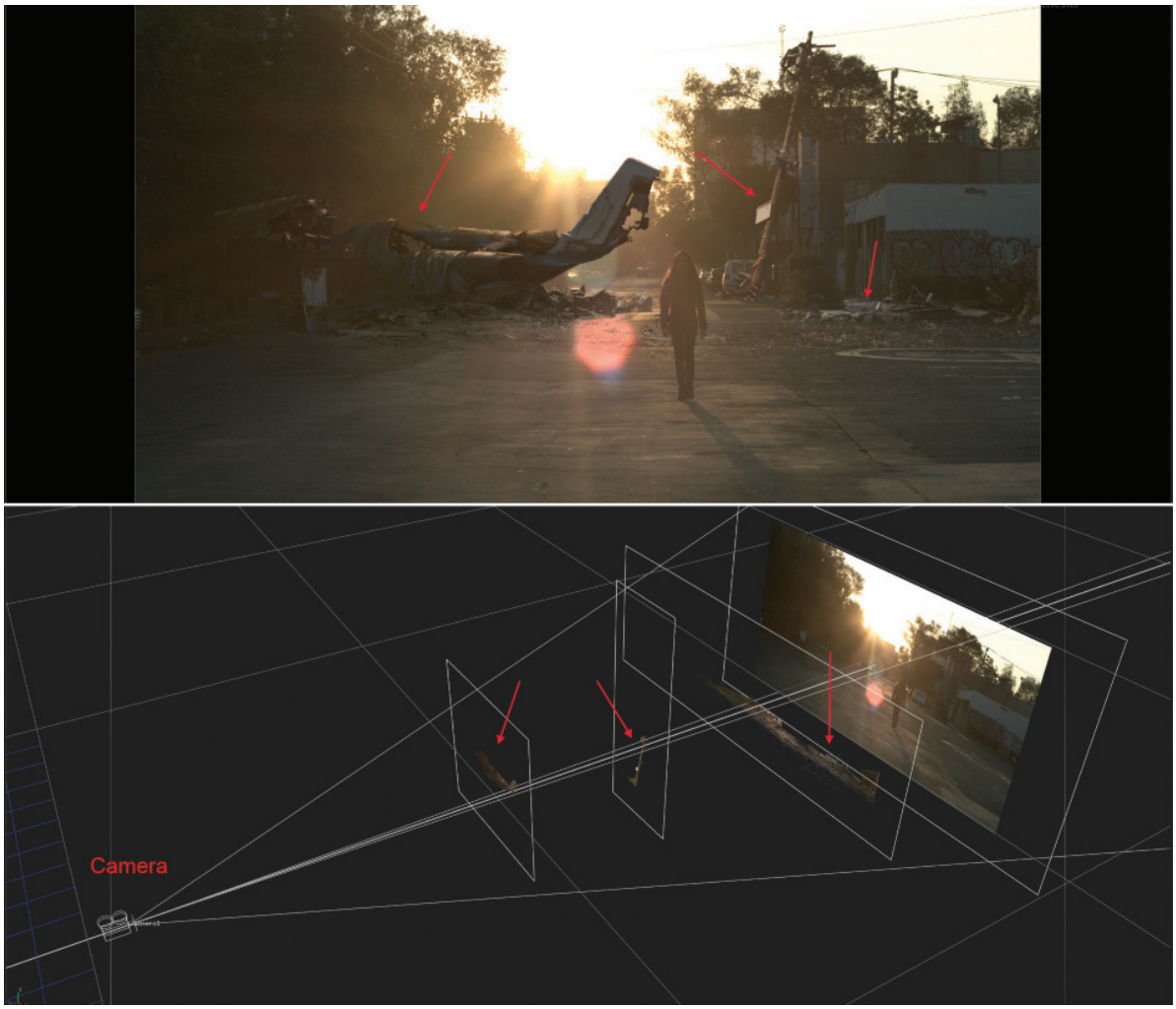
	2D	3D
Rendering	Faster	Slower
Main advantages	Faster, less complex, cheaper, photographic material has photoreal qualities "built in"	No limitation in terms of camera movement, object animation and lighting; elements can be reused in different shots; easy to achieve proper parallax and perspective shift, easier to match lighting to footage and achieve coherent look
Main disadvantages	Limited in terms of camera movement, object animation and lighting; elements need to be created per-shot unless shots are very similar in terms of camera angle; hard to match lighting to footage and achieve a coherent look	Much more complex, and expensive, requires more artists; harder to create photoreal quality; rendering 3D scenes can very time-consuming

As this table shows, there is a huge advantage in the flexible and virtually unlimited 3D workflow, but the 2D solution offers a more modest and less resource-intensive solution. Now, wouldn't it be great if we could rip the benefits of both workflows? Enters the 2.5D solution.

2.5D: The Hybrid Solution

Let's revisit our example shot. We have already concluded that because of the camera movement it cannot be done in 2D, so we must construct it in 3D. If we want to mimic reality as close as possible, we need to create every tree leaf and every blade of grass as separate 3D entities. When you think of the lawn extending around and behind the house or the trees in the far background, it is obvious that there is no way this can be done—such a scene, with billions of objects, is totally impractical to model and render. It is also a gigantic overkill—we cannot really see that much detail in the distance anyway. In fact, even creating separate trees in the distance is an overkill—as I've mentioned earlier, there would hardly be any noticeable parallax and perspective shift between those trees because of their relative distance from the camera. So is there really a need to build the entire scene in 3D? What if there was a way to use the 2D workflow within a 3D scene?

Such a technique is called 2.5D, or camera projection. Of course, there's no such thing as 2.5D, but this moniker appropriately describes this technique—essentially a compromise between 2D and 3D, a smart and efficient way to get the best of each workflow. The idea is simple: the elements are created in 2D but are separated into several layers according to distance. Then each layer is projected on a flat card (or a very simple model) that is placed in three-dimensional space, at the correct distance from the camera. When the scene is rendered through the virtual camera, there will be accurate parallax between the different layers since they are in fact placed at different distances from the lens.



This example of a matte painting in progress shows how different elements added to the footage are projected on separate cards. Notice that the cards are not yet arranged in the correct order—the debris element should be just in front of the plane, and the electricity pole should go in the back.

Courtesy of fxphd/Eduardo Abon.

Obviously, this technique is not suitable for animated characters or foreground objects, especially if there is a strong perspective shift. But it works wonderfully well for backgrounds and distant objects, and even foreground elements that do not have much depth in them (a wall, for example). Rendering is extremely fast because there are no detailed 3D objects and no CG lighting, only images on cards (or simple geometry), and you get the benefit of being able to use real footage or photos, and avoid having to build and light everything from scratch.

Technically, the reason why the 2D elements are **projected** on cards (or simple geometry) is easy to understand if you examine the real-world difference between painting something on a screen or projecting onto it. If you paint on the screen, the image is "stuck" to it. Move the screen away from the camera, and the image will become smaller. Bring it closer and the image will grow bigger. Move it sideways and the image moves too. But if you use a projector to project an image on the screen, the image will not change at all as you move the screen around (basically, the screen will move "through" the image). The projection method therefore allows the artists to create a 2D matte painting in a 2D software such as Photoshop, and then transfer it to a 3D environment. The artist can move around the projection geometry without affecting the projected imagery, which enables proper set up of the scene for accurate parallax and depth without destroying the original look of the 2D matte painting.

The 2.5D workflow is widely used in visual effects, especially for environments. Matte painters (see Chapter 5) harness this technique to create extremely detailed and believable surroundings that have depth and realistic parallax without ever getting into any 3D work. The results can often be more convincing than a full 3D build, because what is lost in terms of fully accurate parallax and perspective shift is gained by the use of photographic material (incidentally, this technique is also prevalent in video games. Take any car race game, for example—you'll easily notice that most of the background objects are not 3D, but rather 2.5D cards).

Putting It All Together

The reality of VFX work is that many shots are done as a combination of 2D, 3D, and 2.5D. There is no reason to stick rigidly to one workflow when in fact a combination can give the best results with the least amount of resources and time. So let's return to our example shot once again, but this time, rather than look at it from a strictly 2D/3D standpoint, we'll come up with a smarter plan that combines all options, starting from the foreground and moving towards the background. . .

Foreground: The strong perspective shift necessitates 3D in the foreground, so the front wall and fence are built in 3D. However, this does not mean that the models need to be very elaborate, because a lot of detail can be achieved with proper textures (see Chapter 5 for further discussion of texturing and shading). It also makes sense to create the big foreground tree as a full 3D element, because this will generate some fine parallax between tree branches and leaves, which will boost the believability of the shot. In an ideal world, the grass on the lawn (or at least the foreground part of it) would be created in 3D, but this will require a very dense model. We can get away with a 2.5D projection of a lawn image on the ground plane, because the human eye is more forgiving with very small detail and will probably not pick up the lack of internal parallax and perspective shift in that area.

Mid-ground: The main element in the mid-ground is the house itself. Most of the detail on the façade can be 2D; the only areas that need to be depicted in 3D are those that are either protruding from the façade or recessed from it, like the balcony and windows. Other elements such as bushes and nearby structures can be done as 2.5D projections on cards.

The foreground fence is built as a 3D element to achieve correct perspective shift.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

The model of the house is very simple. Most of the detail will come from the textures. The importance here is to build the protruding parts (like the balcony) and the sunken areas (like the windows) in 3D, because this is where parallax and perspective shift will be most noticeable.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

The base wall texture is added to the house.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

More texture detail is added to the house while the adjacent structure is also built with simple geometry.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Background: All the distant elements can be simple 2.5D projections. There is really no need to add any 3D detail, as long as the projections cards are placed at the correct distance from the camera based on the camera tracking information.

Lawn grass, bushes, distance trees and other elements are added as 2.5D projections on cards.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Finally, the large foreground tree is added as a full 3D model. This allowed us to achieve subtle but necessary parallax within the tree itself, and to add some breeze animation to the leaves.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

This analysis of a specific shot and the plan that ensues are typical procedures within the VFX workflow. They are absolutely necessary in order to ensure proper usage of resources, time, and money. In an ideal world, doing everything in 3D could be great (assuming all the 3D work, from modeling to lighting, is top notch, of course). But in the realities of filmmaking, a pragmatic approach that takes into consideration practical limitations often leads to better end results.

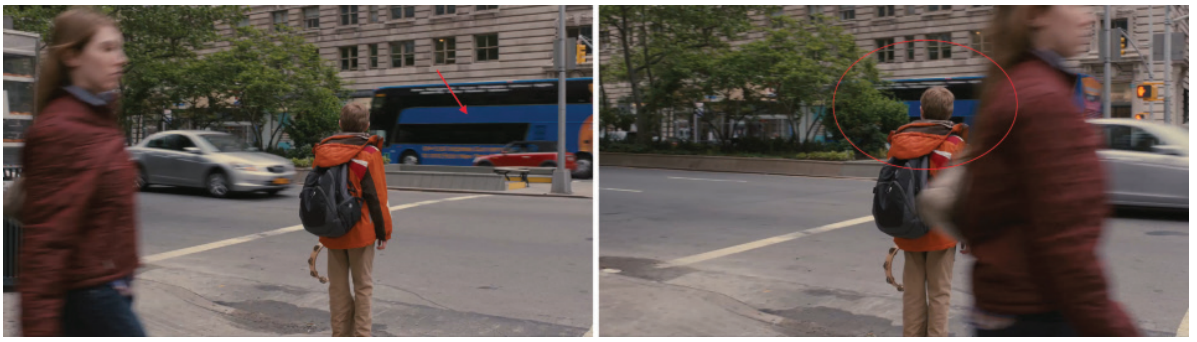
Chapter 4

Separation

Roto, Green Screens, and the Challenges of Extraction

When a VFX element is added to the footage, it needs to be placed at the proper distance from the lens. This means that the element most likely needs to be inserted **behind** some parts of the footage (unless the element is in front of everything else). For example, adding a sign to a storefront at the opposite side of a busy street means that all the people and cars that pass in front of the sign need to be separated and then put back on top of the newly added sign. This is a constant challenge, because, as discussed in the previous chapter, the footage itself is two-dimensional and there is no way to separate objects within it based on their distance from the camera (3D camera tracking can solve the relative position of objects, but cannot accurately trace their outline).

Separation is not just required for depth sorting. In many instances, a specific area in the footage needs to be treated or modified. This area needs to be isolated, and any parts in the footage that stand or cross in front of it need to be separated too, otherwise they will become affected by the treatment. For instance, if you want to change the color of a car that passes behind some trees, you need to isolate the



A simple cleanup of a sign on the bus requires separating the elements that are in front of the bus: the kid, the woman and the tree.

Extremely Loud & Incredibly Close © Warner Bros., Scott Rudin Productions, Paramount Pictures. Visual effects by Brainstorm Digital.

car in order to change its color without affecting the background, but at the same time you also need to isolate the trees in front of it—otherwise the color change on the car will affect them too.

As you can tell, the task of separation is an essential and fundamental process in VFX. It may therefore come as a surprise that there really are only two methods of doing it: rotoscoping (roto); and green screen. Both methods, to be perfectly honest, are not quite hi-tech elegance, and both require a considerable amount of work on the part of the VFX team (and in the case of green screens, also on the part of the film crew).

Rotoscoping

Rotoscoping existed long before computers. In the 1959 Disney animation film *Sleeping Beauty*, for example, real actors were filmed first, then the animators traced their contour and applied these resulting moving shapes to the animated characters as a sort of pre-digital motion capture technique (see Chapter 5). Technically speaking, modern rotoscoping (roto) is very similar: the artist articulates the contours of the subject with a line (roto spline) that is defined by numerous dots (roto points). It is essentially the same as drawing a line around the subject with a pencil, but the difference is that the dots can be animated over time, and thus the roto shape can accurately follow the movements and deformations of the subject.

Partial roto for the kid. Notice that a separate roto shape is used for the head and the upper torso. Roto for complex subjects like people is usually broken down into many pieces, which helps the process of animating the roto and makes it more efficient.

Extremely Loud & Incredibly Close © Warner Bros., Scott Rudin Productions, Paramount Pictures. Visual effects by Brainstorm Digital.

In most cases, and especially when rotoing people, animals and other organic forms, the complex movement and ever-changing silhouette means that the roto points need to be animated frame by frame, and the more complex the shape is, the more points will be needed to precisely articulate it.

Evidently, roto is a laborious and time-consuming process: long shots that require lots of roto can take days or weeks to finish, even with several roto artists working in tandem. But in the absence of a green screen, or when a green screen is not practically possible, roto is the only option for separating a subject from the background. In small amounts, roto is an indispensable part of the basic compositing workflow. But shots that require massive amounts of roto can become expensive and time-consuming, and should be avoided unless a green screen option is absolutely not feasible.

Roto works well for subjects with hard, well-defined edges, but is not as successful for thin wispy parts like hair and fur, or when edges are very fuzzy (for example, when the subject is out of focus or when it has motion blur). At the very beginning of *The Wolf of Wall Street* there's an eighties-style TV commercial with several shots of a lion calmly walking through a busy office. The lion was real (held on a leash by a trainer), and so were the office workers. For obvious reasons, they were shot separately: the lion in the empty office and then the same office full of people (but without the lion). A green screen was not practical in this setting, so we had to roto out the lion in order to put the office workers behind it and remove the trainer and the leash. The body of the lion could be easily roto-ed. But the lion's mane was a totally different story. It is quite impossible to roto out thin, semi-transparent strands of hair. There's simply no way of separating such fine detail from the background using roto.

The lion from *The Wolf of Wall Street* had to be cut out so that the office workers could be inserted behind it. The outer parts of the mane were recreated, because this type of detail is too thin and wispy to be extracted with roto.

The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

What we did instead was to roto the mane closer to the roots, where it's solid enough, and leave out the wispy parts. We then recreated those wispy parts as static single-frame elements, and tracked them to the lion's movement. Basically, we created an artificial mane that looked close enough to the original one, but did not require a frame-by-frame roto. A green screen (see later) enables a much better separation of fine, semi-transparent detail, and provides a consistent (rather than busy) background. It is therefore important to consider the type of subject before deciding on whether to place a green screen or resort to roto. A head covered with a hat will be much easier to roto out than one with long frizzy hair.

At this point you might wonder why, with all that cutting-edge technology invested in visual effects, people are still painstakingly moving points frame by frame to trace the shape of an actor. Couldn't there be some smart algorithm that enables the computer to distinguish between an actor and the background? The answer is 'No'—at least, not yet. While any toddler can easily tell where a person's head ends and the background starts, the level of artificial intelligence that a computer needs to figure this out is still well out of reach. Unlike those clunky face recognition algorithms found in many consumer cameras, VFX separation requires extremely accurate tracing of the outline of the subject. We distinguish between objects by recognition and association. The computer can only make a distinction based on numerical values.

Color, for example, is something that the computer can evaluate much more accurately than humans. But in any regular setting, the actors and the background behind them have too many similar colors to allow a computer-assisted, color-based separation—unless, of course, the background is made of one consistent color that does not appear in the foreground. And this, in fact, leads us to the second separation method. . .

Green Screen

Arguably no other subject in visual effects is discussed ad nauseam like green screens. Sometimes it seems as if green screens are the symbol, the essence and the raison d'être of visual effects rather than a mere tool for separation. We talk about "green screen movies" and "green screen actors." But green screens are not a fashion, nor a style; they are simply a means to allow cleaner and faster separation of subjects. That said, they are indeed a vital tool that merits detailed discussion because it is one of those areas in VFX that relies equally on the successful performance of the film crew and the VFX team. It is also an area where it's crucial for the filmmaker to understand the techniques and challenges of green screen extraction and compositing. Many of those problems can be minimized, or avoided altogether, by properly setting up and lighting the screen and the subject on set. The practical issues of physically setting up the green screen (color consistency, coverage, shadows, spill, tracking markers, lighting, etc.) will be discussed in Chapter 8. Here, I would like to offer some insight into common issues of green screen extraction—problems that seem to prevail in post even when the screen was perfectly placed and lit on set. These problems may affect the final look of the shot, potentially causing it to feel "comped" and unnatural, though it's often hard for the filmmaker to pinpoint the exact cause.

First, if you were wondering, let me explain why I haven't mentioned blue screens so far. The use of blue screens has declined in recent years. There are several reasons for this, these being the main ones.

- Digital camera sensors are inherently more sensitive to green than blue.
- The blue channel is much grainier than the green channel.
- Under similar lighting conditions, green comes off brighter than blue, making it easier to light a green screen.

A blue screen is obviously still needed when green color is present in the scene (vegetation, for example), and is still sometimes preferable to green in low-light scenarios because it bounces less light back. Generally, though, green screens work better as they are easier to light and easier to extract. Still, the discussion of green screens in this chapter and in Chapter 8 applies equally to blue screens—the principles are the same.

The Challenges of Extraction

The idea of a green screen is simple: since the computer can analyze color with great precision, placing a background of a consistent color (assuming that color does not appear anywhere on the subject) makes it easy for the computer to distinguish between the subject and the background, and provides a fast way to separate the subject without rotoscoping. Highly saturated green is far removed from human skin tones and does not frequently appear on clothes and most objects, so it is a good choice as a background color.

It all sounds straightforward enough, but unfortunately it rarely works as smoothly as you'd expect, for a number of reasons which I will detail. The green screen extraction process, as it's usually called (some still like to refer to it as "pulling a key" or "keying"), is therefore far from being a push-button affair, and requires considerable work and a fair amount of expertise from the compositor. A perfectly uniform and well-lit green screen is obviously important for achieving a clean extraction, but is not a guarantee for a successful shot. Let's look at some of the challenges and issues that affect green screen extractions. . .

Background Matching

The number one reason for unsuccessful green screen compositing is not the quality of the green screen, the difficulties of extraction, or the skills of the compositor; it is the choice of background that replaces the green screen.

Many filmmakers assume that a green screen gives them the freedom to place any kind of background behind their subject, but this assumption is wrong. It is very difficult to marry successfully a background and a foreground that are very different in terms of lighting, perspective, luminance values, or hues. It

does not matter how clean and well-lit the green screen is, or how skilled the compositor is at extracting fine detail, there is nothing that contributes more to that infamous "green screen comp look" than a total mismatch between foreground and background. It is therefore necessary to think in advance about the background and the environment that the subject will eventually be in, and light both the subject and green screen with that environment in mind. For example, if you plan to put a dark and ominous sky behind the subject, don't shoot the subject in bright outdoor light. Shoot indoors instead, or use black overhead screens to reduce the intensity of the natural sky light. Likewise, if you plan to place the subject in a bright, sunny environment and you must shoot on a stage or under a cloudy sky, light the subject with a strong warm key and bluish fill. Once the shot has been captured, it is equally imperative not to try to force a mismatched background behind the subject, because it is very hard, often impossible, to change the lighting on 2D footage.

A green screen shot from a short movie that I used for my compositing course at fxphd.
Courtesy of fxphd/Eduardo Abon.

The green screen is replaced by the background—but the shot is still not working. There is too much of a difference in contrast, brightness, and hue between the bright, hazy, and warm foreground and the rather dark and cool background. Notice also how the background feels too sharp and in-focus compared to the foreground.

Courtesy of fxphd/Eduardo Abon.

Some color and focus adjustments improve the shot quite a bit, making everything feel more integrated and natural.

Courtesy of fxphd/Eduardo Abon.

In Chapter 8 I will describe the on-set process of shooting a complex sequence of a nighttime crane dare over NYC for the movie *Nerve*. In post, we had to deal with shots captured by two different cameras: one was a GoPro-style action cam attached to the head of the stunt as he precariously walked on the crane; the other was an Alexa on a technocrane that showed actor Dave Franco from the POV of a drone camera. Both types of shots were done in a fairly bright, consistent ambient lighting environment because of the extensive use of green screens (in essence a day-for-night scenario). When we composited the shots, we darkened and graded the foreground footage. This worked very well with the GoPro first-person POV footage, because we could really take down the brightness and saturation of the crane to match it to the NYC nighttime background. But it was much harder to make it work with the drone POV shots—here the reduced brightness caused the actor's face to go too dark. Brightening the actor would make him feel detached from the environment, brightening just his face would make him look weird, and brightening the environment instead would create a mismatch with the first person POV shots in the sequence. We ended up doing a bit of everything to make the foreground and background work together, but it was certainly a difficult balancing act, not unlike walking on a crane at night. . .

Hanging from a crane over a NYC street.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

Spill

Green spill (or blue, in case of a blue screen) is an unavoidable side effect, although it can certainly be minimized on set by following a few simple rules (see Chapter 8). Compositors have some excellent spill-suppression tools at their disposal, and these are used to kill areas of unwanted green hue on the subject without changing the overall color balance. But if you are reviewing a VFX shot and the subject still feels a bit odd and unnatural, it might be that spill is still present (look especially around shiny skin areas like the forehead, bright clothing, and wispy hair and fur). Conversely, sometimes a heavy-handed spill suppression affects too much of the original color—overly red or magenta skin tones are usually a sign of excessive spill suppression.

The actress in front of the green screen before extraction.

Courtesy of fxphd/Eduardo Abon.

After extraction and with background added. Notice the green spill around the wispy edges of her hair, as well as on her white shirt.

Courtesy of fxphd/Eduardo Abon.

The green spill is suppressed.

Courtesy of fxphd/Eduardo Abon.

Sometimes, spill occurs even where the green screen is not visible. In this frame, the camera is looking at the opposite direction of the green screen, but the green is still reflected in the glass panels. Spill suppression helps bring the color back to a neutral place.

Courtesy of fxphd/Eduardo Abon.

Non-solid Edges

If the green screen is clean, consistent, and well lit, one can assume that the computer can accurately extract the subject. This assumption is right as long as the edges of the subject are sharp and solid. But this is hardly ever the case, as edges are often soft and semi-transparent. This can happen with hair and

fur, as in the lion example earlier, thin wires, garments, smoke, and steam, or simply because an otherwise solid subject like a person is out of focus or motion-blurred (or both). In all these cases, the soft, semi-transparent edges are harder to extract, because they partially contain the green screen. This often results in dark or bright edges, or areas that seem unnaturally sharp and cut-out. Since these issues are often very subtle and hard to spot, the best way to detect them is to compare the VFX version with the original green screen footage—an easy thing to do on the Avid or any other editing tool.

Experienced compositors have a whole arsenal of methods and tricks to extract tough areas like hair, bring back soft motion-blurred edges that get cut off in the extraction process, or even extract wispy smoke or fog. That said, sometimes extractions are overly processed in an attempt to fix bad edges. A good example is light wrap. In real-life photography, very bright areas in the background tend to subtly spill over the edge of the foreground subject, a familiar occurrence when shooting against the sun or when there's a light source right behind the subject. Some compositors tend to overuse light wrap in order to cover or "hide" bad edges. Light wrap is a great way of tying the foreground to the background and improving integration, but only when it's used judiciously.

Green screen shots can and should look natural and convincing. But if a shot feels a little off, look first at the relationship between the subject and the background. Is the lighting similar? Are the colors and luminosity matching? Does the focus make sense? If all this feels good, look at the edges, and compare

This is a tricky extraction, because one actress is fully in focus while the other is completely out of focus.
Courtesy of fxphd/Eduardo Abon.

When the subjects are extracted and comped over the background, two problems surface: first, the soft defocused edges of the distant actress carry too much of the original green screen in them; second, there are areas in the background that are much darker than the original green screen, which causes edges to pop out unnaturally. This is especially apparent on the screen left shoulder of the distant actress, as well as all around the hair of the closer one.

Courtesy of fxphd/Eduardo Abon.

Additional compositing work was done to alleviate the issues of soft edges and mismatched luminosity, and the integration between foreground and background now feels less disjointed.

Courtesy of fxphd/Eduardo Abon.

to the original footage. Is an out-of-focus object too sharp at the edges? Does a fast moving arm lack the motion blur trail? Are there any unnaturally dark or bright edges along the subject?

Both green screen and roto are essential for separation but are far from ideal solutions. Eventually they will be replaced by better, more efficient technologies (see Chapter 10: The Future), but until then, roto and green screen remain a fundamental aspect of visual effects and require attention and diligence—when planning the shots, on set and during post.

PART 2

THE INSIDE LOOK

Chapter 5

The VFX Workflow

An In-depth Look at the Various Crafts of Visual Effects

Take a stroll around a movie set and observe the crew at work. The set builders are busy constructing, the camera crew is practicing the next move, the wardrobe people are sorting through the costumes, the gaffers are putting up a lighting rig, the hair and makeup people are adding the last touches on the actors, the stunts are fixing the safety rig . . . even if you've never been on a set before, it shouldn't be too hard to figure out what each crew member does, and to distinguish between the different crafts. But step into a VFX facility, and pretty much everyone you see is sitting in front of a computer screen. With everyone using just a mouse and a keyboard, it is hard to tell what each artist is doing, and in what way the work of one artist is different from that of the artist sitting right next to them. Behind the seemingly uniform façade of computer monitors, the activities that take place in a VFX facility are as diverse and distinct as those that happen on set. In fact, as I mentioned in Chapter 1, there are many points of similarity: there are CG builders and painters, camera operators, lighters, riggers, and even hairdressers. This chapter will take you on a guided tour through a typical VFX facility, presenting and explaining each craft and its contribution to the overall process. For the filmmaker, being familiar with the different crafts of VFX is beneficial every step of the way—from initial breakdowns and bidding, through the shooting stage, and into post-production.

Previous chapters have already made clear that the number of artists working on a single shot may vary substantially. While many VFX shots need only one compositor to complete, highly elaborate shots may require ten or even more artists performing a variety of tasks, from camera tracking and roto through animation and lighting to dynamic simulations and matte painting. The internal flow of work in a VFX facility, and the way a single shot may pass from one artist to another in a certain order is usually referred to as **pipeline**. Admittedly, the term has a bit of an industrial tinge to it, but this is far from a conveyor belt scenario. Rather, it is a team collaboration, where different artists contribute to the final result by working in their own area of expertise, or craft.

VFX artists tend to specialize in a specific craft because of the steep learning curve and vast technical knowledge that's required to master the specific tools. The work of an animator is very different from that of a matte painter and requires a completely different skillset. The software tools they use are also different. As it is, all-round players in VFX are rare, but supervisors and lead artists, by nature of their job, usually have a broader understanding of the different crafts.

Pre-production Crafts

The bulk of the VFX work happens in post-production, after the movie has been shot and a rough cut assembled. Previsualization (previs) and concept art take place long before that, often at the early stages of pre-production. They are unique to other VFX crafts in the sense that they precede all other work, and are used as planning and development tools rather than building blocks of the finished shots.

Previs

Previsualization allows the filmmaker to design shots both in terms of camera movement and the actual action. It is a way of blocking out how various players interact and how they are framed. More often than not, the live actors and elements are depicted as well (usually represented by animated dummies). You can look at previs as animated 3D storyboarding, and the advantage is clear—the filmmakers can really play around with the camera as well as the position and movement of various players in 3D space.

A previs for *Boardwalk Empire*. Notice the rather rough look of the elements and the use of a piece of old photograph. As crude as it was, it helped visualize the boardwalk long before any VFX were actually done.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

There's a tremendous benefit from being able to preview and design shots virtually, so there's no wonder that previs has become indispensable for many directors and cinematographers. In fact, some directors go to the extreme and previs their entire movie from start to finish.

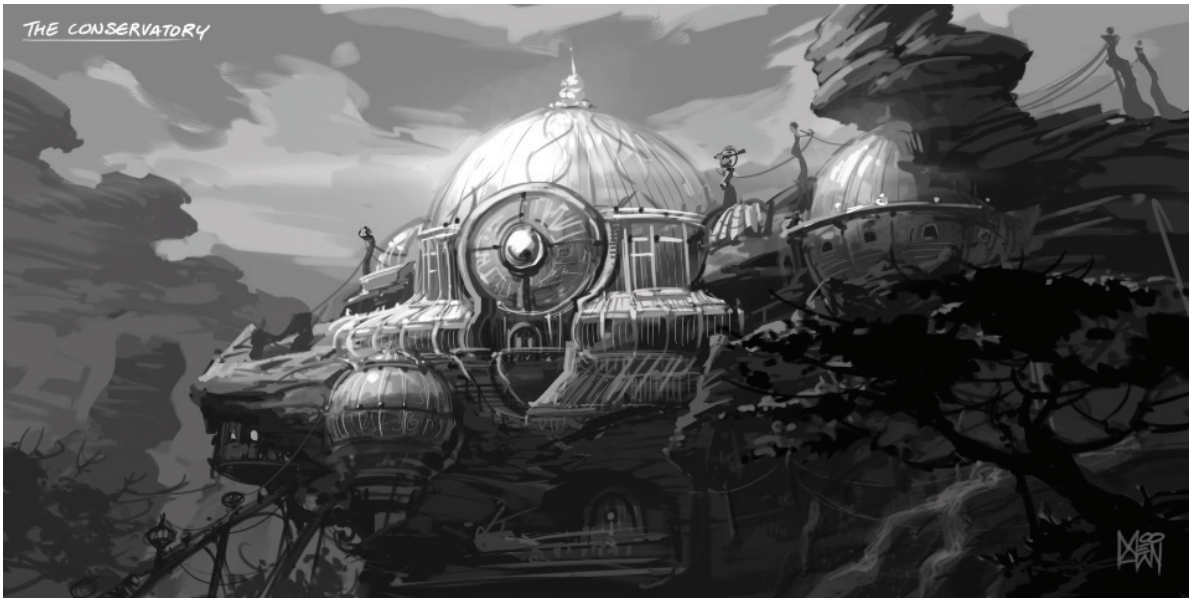
That said, previs on this scale is a luxury reserved for high-budget productions. Although previs artists use basic models and rough out the animation to show only the important aspects, previs is still a delicate and time-consuming process that requires skilled artists with a keen sense of camera movement and timing. Also, investing in previsualization only makes sense if the filmmakers adhere strictly to the design of the shots. Going out on set and shooting something completely different from the previs is a total waste of money. On small budget films, it is wise to previs only those shots or sequences for which precise planning of layout and camera move is crucial, or shots that rely heavily on CG. Sometimes a previs is not intended to lock in the position and camera move, but just to provide the filmmakers with a rough virtual environment where they can "play" with different cameras and get a sense of how it will eventually look. This is helpful to visually "fill in the blanks," because shooting a CG-heavy scene means that much of it does not exist on set and will only be added later.

Concept Art

While the previs process focuses on position and timing, concept art is all about the look. Although the vast majority of more "mundane" VFX shots do not require any concept work at all, it is a critical part of the visual design and development of CG assets, from fantastic creatures to futuristic vehicles and environments. If, for example, your film features some sort of CG character in a prominent role, you will need to start the concept art process early enough in pre-production to allow ample time for look development. Later on, when the CG artists start modeling, texturing, and shading the character, they will need to have clear and detailed concept art references as guides to the look that was established and decided upon by the filmmakers and VFX team. It is certainly not a good idea to start making drastic changes at the CG stage, because of the technical difficulties of modifying models, rigs, textures, and UVs. It is much faster, and much more efficient, to play and experiment with the look and design during the concept stage, since the concept artist can quickly draw or paint new versions.

Concept artists are usually exceptionally versatile and have a strong traditional art technique, though many work digitally, in Photoshop or even using 3D software. Concept art styles vary widely, from blocky sketches and mood boards to ultra-realistic detailed designs. But the principle is the same: developing and refining the look of CG elements and providing the CG team with effective reference material.

The decision on whether to hire production concept artists (or use VFX company's in-house concept artists) depends largely on the type of VFX shots in the film and the nature of the CG elements. A present-day action movie that requires mostly CG replicas of present-day vehicles, weapons, or environments, for example, can probably do just fine without spending on concept art—after all, these are known objects and reference material is abundant. A period film where historical accuracy is important might benefit more from archival photos or paintings as reference sources. But concept art is crucial for imaginary and fantastic elements that need to be conceived from scratch, and is therefore prevalent in sci-fi, fantasy, and superhero genres.



In this example of black and white concept art by Jerome Moo, the focus is on the overall design and impact rather than specific detail.

Camera Tracking

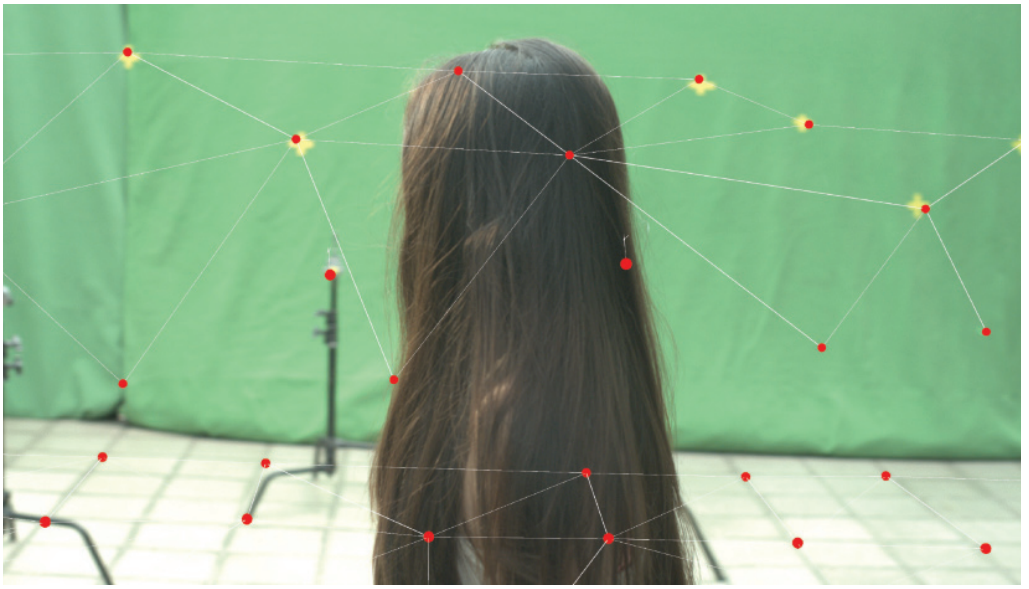
As discussed in the previous chapter, camera tracking (also called **matchmove** or **3D tracking**) is a crucial step in the VFX chain. Whether the shot is 3D-heavy or uses 2.5D projections only, an accurate track is the very foundation upon which everything else is built. No matter how good the VFX work on a shot is, a sloppy camera track will cause objects to slide and float in relation to the footage, which is an instant shot-killer. In addition to "locking" VFX elements into the footage, a tracked camera is a vital tool throughout the work on the shot. It allows the artists to perform their crafts in a virtual three-dimensional "set" that matches the real-life environment captured in the shot, giving them an accurate indication of position and depth. Moreover, since VFX is generally done "for the camera," having a virtual camera gives the artists a clear idea of what is actually seen through the lens. This way, work is efficiently done only on the necessary areas.

Camera tracking is essentially a reverse-engineering process. By tracking the movement of a large number of points in the footage, the matchmove software analyzes the parallax in order to "solve" the motion of the camera. Lens distortion (a natural occurrence, especially with wider lenses) needs to be accounted for as well. Usually the footage is analyzed for distortion, and then undistorted for the tracking process. Most of the CG work is done on the undistorted version, and then re-distorted in comp to bring everything back to the original look.

3D tracking is a precision job, and the time it takes to complete depends on the length of the shot and its level of difficulty (for example, shots that have many moving objects or people in the frame are harder

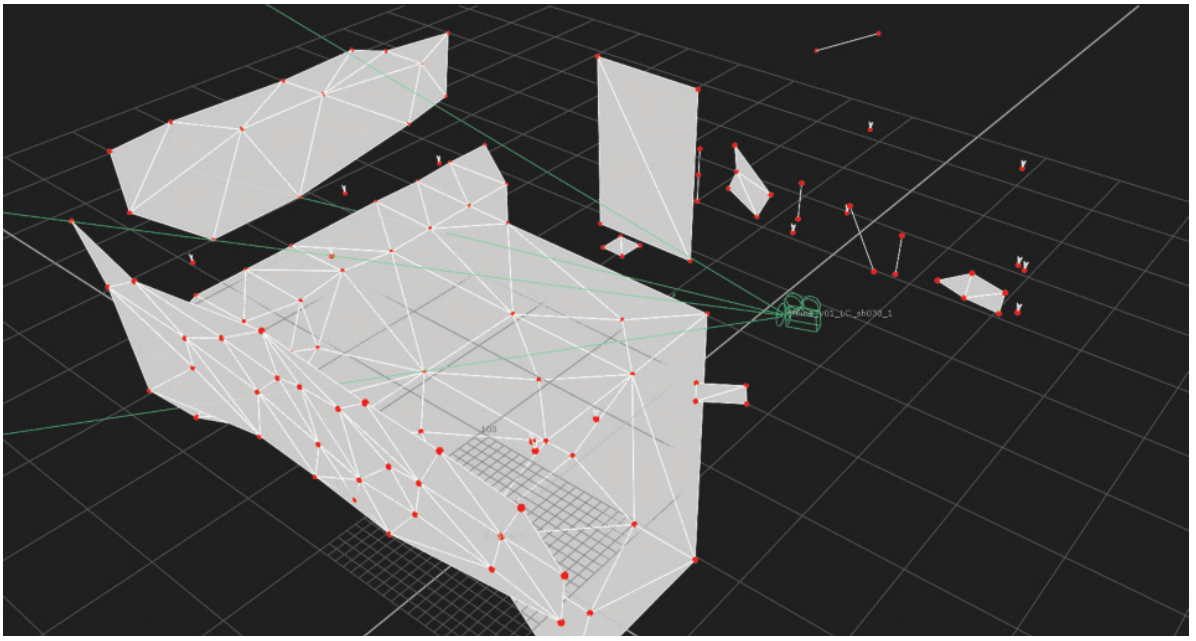
Camera tracking in progress. Each tracker shows its motion path for that frame. The red ones are automatically discarded as "bad trackers," and you can clearly see how their paths deviate from the rest. The roto around the actress is used to mask her out of the tracking process. For obvious reasons, only static objects can be used to track the camera move.

Courtesy of fxphd/Eduardo Abon.



When the camera movement is solved, a basic mesh can be created by connecting the main tracking points.

Courtesy of fxphd/Eduardo Abon.



The 3D scene shows the tracked camera and the mesh, which in this case indicates the position of the green screens, the ground, and parts of the back wall.

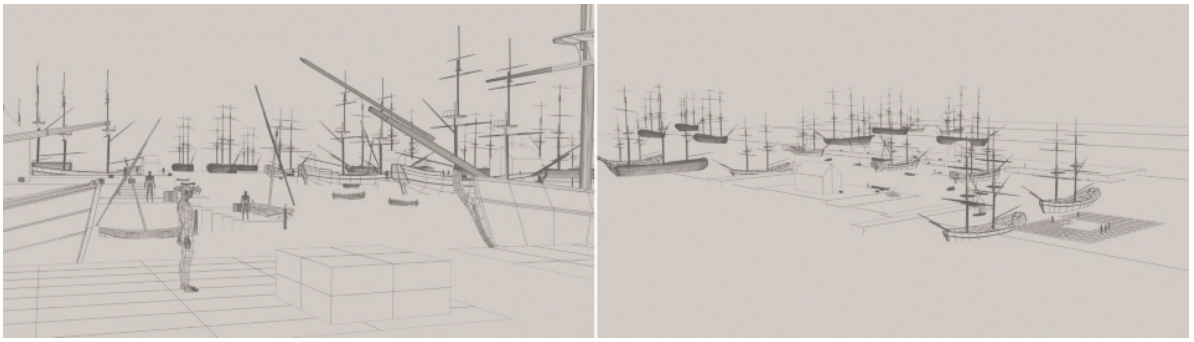
Courtesy of fxphd/Eduardo Abon.

to track because only static points or areas can be used to solve the camera). This is purely technical work, and requires virtually no creative input from the filmmakers. But while there's very little that the filmmaker can do to make a shot easier to track once it's been filmed, there are certainly some steps that can be taken and some things to be avoided before and during shooting to help the matchmove process down the line (see Chapter 8).

Layout

Think of the layout stage as the virtual equivalent of blocking out a shot on set—figuring out the placement of actors and extras, rehearsing the camera move, timing the action. It is similar to previs, but is usually done at a later stage, after the footage has already been shot and a rough cut established. When a VFX shot consists mostly of modifications to the plate or extensions to an existing set, a layout stage is not necessary. However, when the shot relies heavily on CG elements and animation or when a shot is created fully in CG, layout is crucial. It is an important initial stage where the director's feedback is needed in order for the VFX team to move forward on the shot and successfully achieve the director's vision.

For example, in a fully CG shot of a battle between two 18th-century battleships, a layout helps visualize and determine the camera move and lens type, the position and movement of each ship, and the timing



A layout shows the design and position of key elements for the Boston harbor CG/matte painting environment in *Sons of Liberty*.

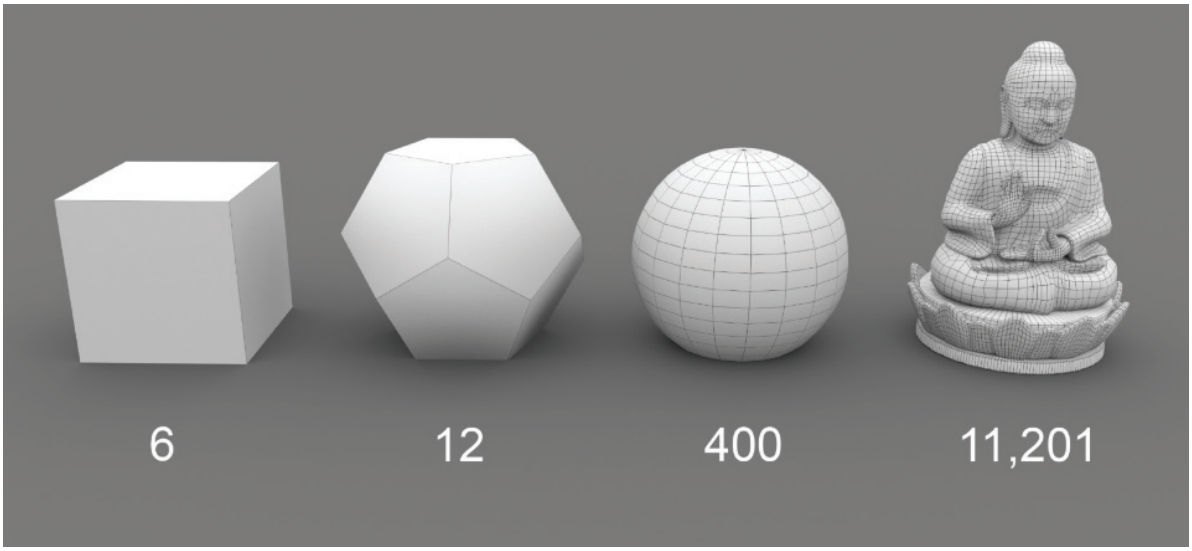
Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

and direction of the firing canons. These basic decisions on timing and position have a decisive effect on additional work like destruction, fire, and smoke simulations, as well as water interaction (all described later in this chapter). This example shows why it is important for the filmmaker to approve and lock the basic moves earlier on, and conversely, why it is not wise to change the layout decisions at a later stage. Such changes inevitably cause a "chain reaction" of modifications and further changes down the line, resulting in schedule delays and additional costs.

Modeling

All 3D models are made of the same basic elements: points (vertices) connected by straight lines (edges) which form a small closed flat surface called polygon. Combine enough polys (short for polygons) and you can create any surface imaginable. A wireframe view of a model shows this underlying structure, and provides a clear indication of how complex, or "polygon-heavy," it is. Naturally, smooth surfaces need more polys (a cube is just 6 polys, but a sphere requires at least 200 to be smooth), and the more detailed and complex an object is, the more polys it requires. As I mentioned in Chapter 1, unlike computer games, where real-time performance mandates a constant awareness of poly counts (and lots of trickery to keep it low), in visual effects the modeler has much more leeway with the amount of detail and complexity, because the rendering is never done in real time. That said, keeping poly counts reasonably low is still a consideration, as it makes scenes more manageable and faster to render.

The two main categories of modeling are **technical modeling** and **organic modeling**—roughly the equivalents of construction and sculpting in real life.



Polygon counts for each of the four objects. This clearly shows how the number of polygons grows exponentially with more detail.

Technical Modeling

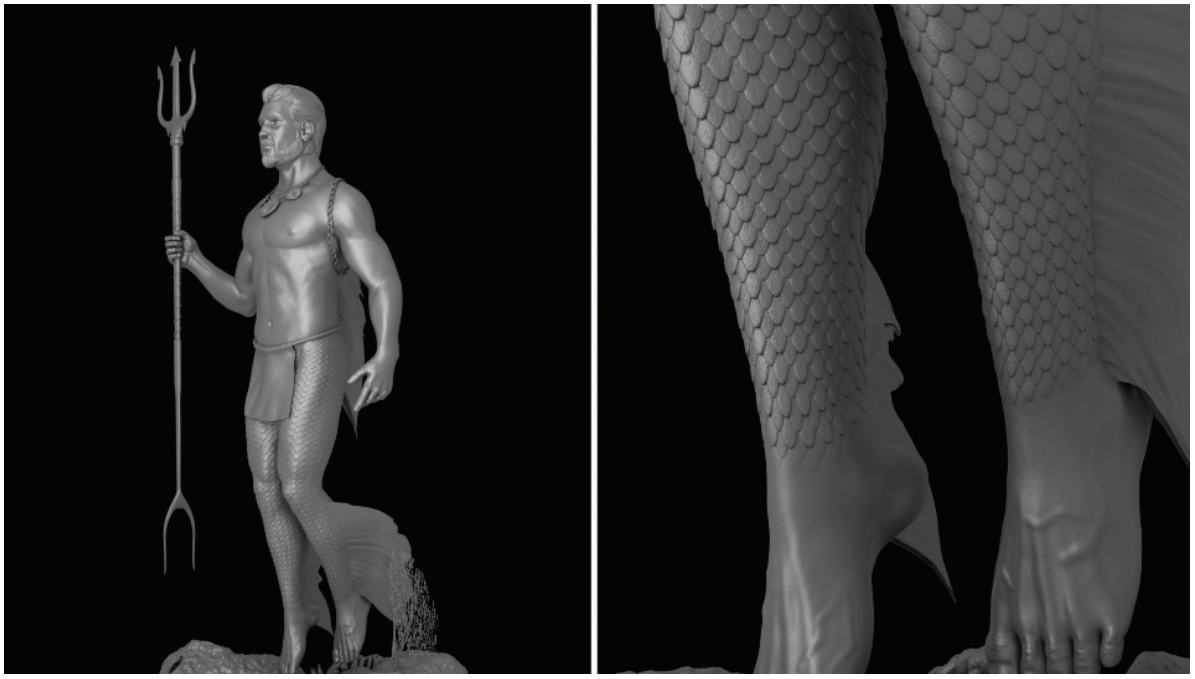
Technical models include cars, airplanes, ships, buildings, spaceships, furniture, robots, machines, weapons, and basically anything man-made (or alien-made) that requires precision construction techniques. Technical modeling (often referred to as hard-surface modeling) is commonly based on blueprints, diagrams, or reference photos, and the model is usually constructed with many smaller parts, just like in real life. (The exception, of course, is that only parts that will actually be visible to the camera are built. There's no reason to model a car's engine if the camera never goes under the hood).

Organic Modeling

Organic modeling is very similar to sculpting, and is therefore better suited for continuous-surface models of humans, animals, and creatures of all kind. It is less about technical precision and more about a thorough knowledge of anatomy and physical proportions. The best organic modelers often have traditional sculpting skills, and must also have a good understanding of how characters move in order to create muscles and joints that will bend and bulge realistically when rigged and animated.

An example of technical modeling: part of a crane model we built for the movie *Nerve*.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.



A highly detailed organic model by David Eschrich. Such level of detail does not come cheap in terms of polygons—this model contains over 5 million of them. But there are ways (like displacement, see elsewhere) to reduce the polygon count and still retain much of the small detail.

© David Eschrich.

Cost-saving Alternatives

LICENSED MODELS There are quite a few online stores (for example, Turbosquid: www.turbosquid.com) that sell licensed models of cars, helicopters, ships, buildings, landmarks, and even generic people. If you just need some standard cars in the background or some humans in the far distance, pre-made consumer models are a good alternative. Evidently, the higher-quality models are usually the most expensive, but even those could cost much less than paying a modeler to build a model from scratch. You should however always consult with the VFX team—purchased models might have faulty topology or bad UV maps which may require a substantial amount of cleanup and repair work.

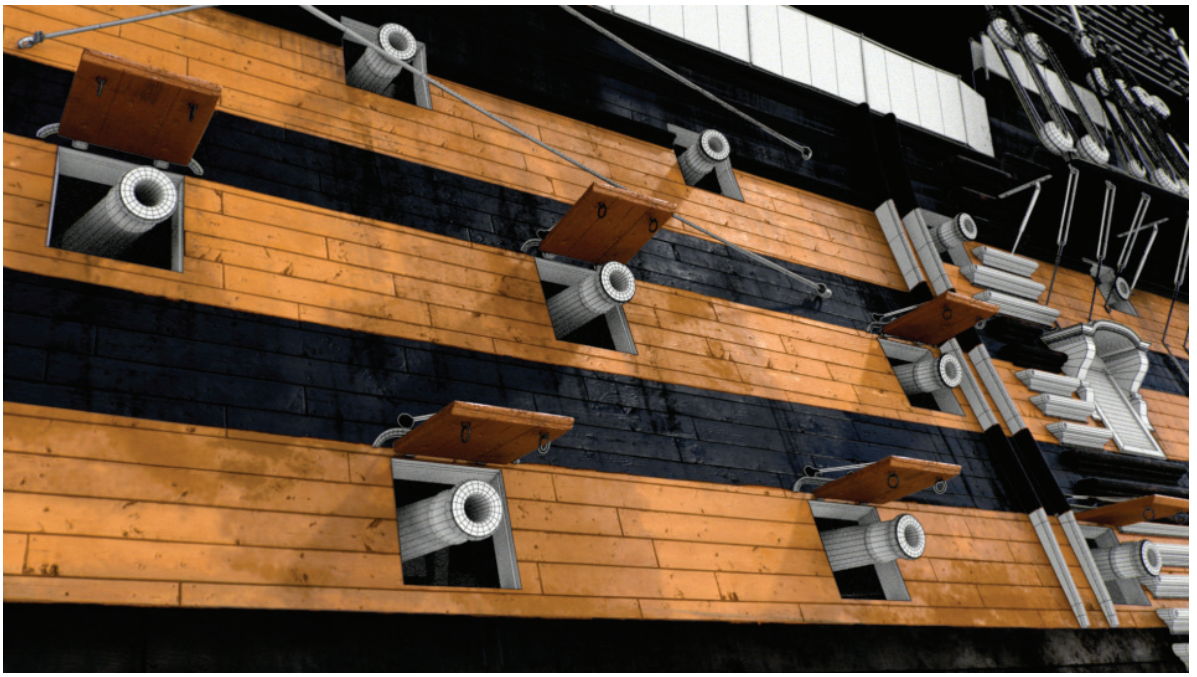
When working on the mini-series *Sons of Liberty* we had to create several different 18th-century ships. The largest and most complex was a British warship based on the HMS *Victory* (which is now a tourist attraction in Portsmouth, UK). Since this ship is well known and well documented, there are quite a few decent licensed CG models of it, and we found a good one at Turbosquid. Although it still needed a substantial amount of texturing and some modeling refinements, using a pre-built model saved us days of modeling work, and allowed us to spend more time building other ship models from scratch.

3D SCANNING A full-on 3D Lidar scan is not necessarily cheap, and requires the appropriate gear and operators. Yet for some modeling tasks it can be indispensable. For example, if there's a need to model a digital double of an actor, a 3D head scan can go a long way in helping the modelers create an accurate replica. It's important to note that the actual mesh generated by the scanner is usually too dense and disorganized for practical purposes, so it is often used as a guide for creating a more manageable model (more on Lidar scanning in Chapter 8)

PHOTOGRAMMETRY This "poor man's 3D scanning" method is a wonderfully simple way to acquire 3D models from existing objects. It calls for nothing more than a decent stills camera, and is based on multiple photographs of the subject, taken from different angles. A special software then analyzes these photos and creates a 3D model replica of the original object. Since the photos include all the surface detail and colors, the 3D model comes fully textured. While photogrammetry is not sufficiently accurate to produce animation-ready models, it is very efficient for generating virtual props to populate a scene or a matte painting, and is especially useful on set for "stealing" 3D versions of real props created by the art department (see Chapter 8).

Texturing and Shading

Modeling a 3D object is half the work. Shading and texturing that model is the other half. A simple sphere with no texture could potentially be a hundred different things. It could be a basketball, an eyeball, a bubble, a cannonball, or a giant planet, to name just a few possibilities. There's really no way of telling what the sphere is without seeing the surface detail and getting a sense of what it's made of. Shaders are virtual materials. A shader describes the general properties of the material, or more specifically, how it reacts to light. Is it shiny or dull? Transparent or opaque? Matte or reflective? Textures add the surface and color detail. Together, textures and shaders generate all the visual cues that turn the model into a believable real-world object. Meticulous texturing and shading is a crucial step in avoiding a cold and sterile "CG look."



Texturing in progress: parts of the ship have not been surfaced yet but the main hull has a basic texture applied. Notice the small detail, dents and imperfections.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Shaders

Think of a shader as a master container for a single material. It defines all the properties of that material, and contains all the textures that are used to control and vary those properties.

The most common shader properties are:

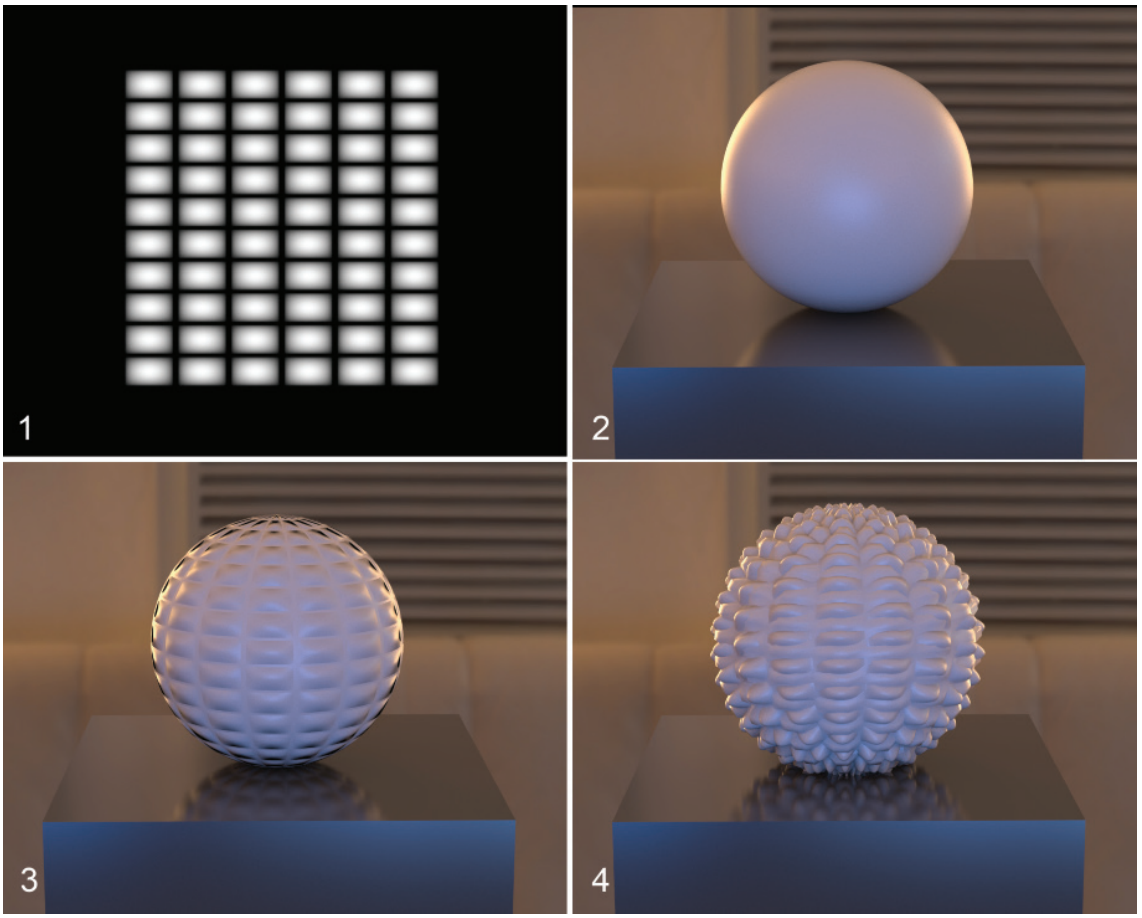
- **Diffuse** (base color)
- **Specular** (shininess)
- **Reflection** (usually tied to specularity, but sometimes defined separately)
- **Refraction** (the way transparent materials like water or glass bend light rays)
- **Transparency**.

Two additional shader properties are **bump mapping** and **displacement**. Bump maps are used to add a sense of "roughness" to a surface (like the pores and wrinkles on an elephant skin or the rivets on a ship's hull). Bumps are not really three-dimensional; they basically "cheat" the light to give an illusion of roughness—and are therefore more appropriate for small detail. Displacement on the other hand actually changes the geometry of the model, and is a very effective way to add small detail without the need to physically model it.

The most accurate type of displacement is achieved with the use of **normal maps**. Unlike regular bump maps, which use black and white values to describe height, normal maps use red, green, and blue to describe all three axes, essentially enabling three-dimensional features and concave displacement. Normal maps are good, for example, for creating realistic ocean surfaces or rock features. They are used extensively in computer games to add detail to low-poly models.

Some materials require additional (though less common) properties such as:

- **Translucency** (back light showing through thin objects like paper or leaves)
- **Subsurface scattering** (the characteristic short-distance light scattering that happens in materials like marble, jade, wax, and human skin)
- **Emission** (for light-emitting objects like neon tubes, TV screens and, of course, light sabers).



A simple black and white texture (1) is applied to a sphere (2), first as a bump map (3), and then as a displacement map (4). Clearly, the bump map version, which is just a shading trick-of-the-eye, fails around the edge, which looks totally smooth. On the other hand, displacement generates a much more realistic look since it actually changes the shape of the model.

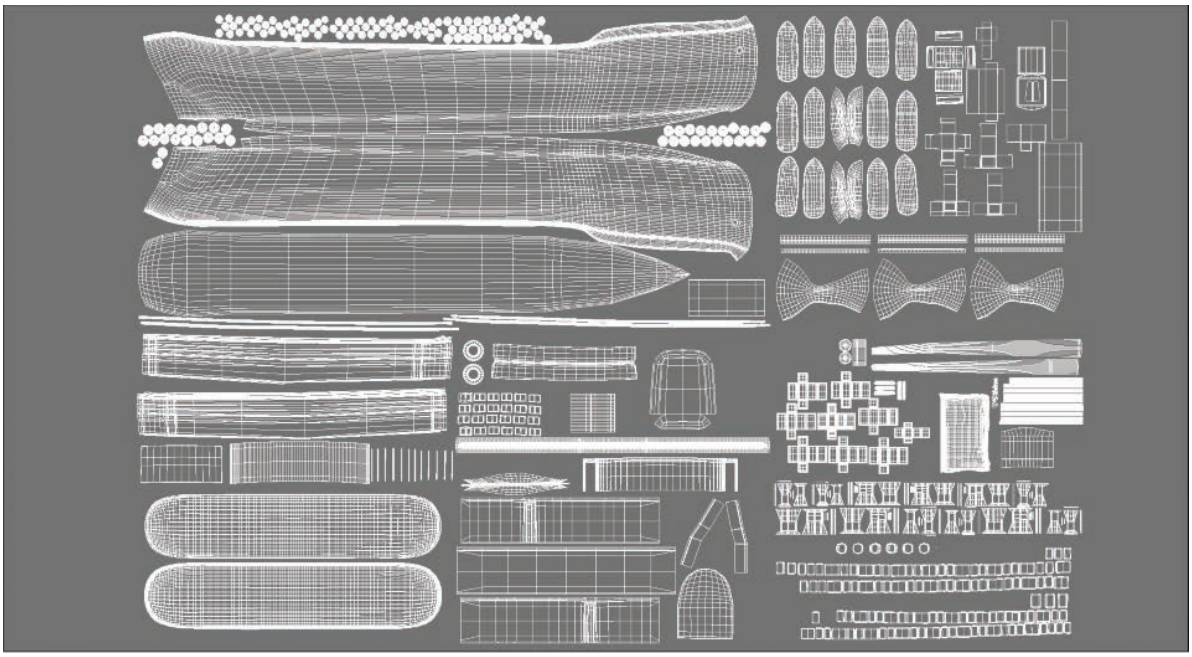
Shading experts can write complex custom shaders that can mimic very intricate surfaces, and even 3D detail that is not possible to achieve through modeling or displacement, such as wool, fur, and hair. Shaders can also be used to create volumetric effects like smoke or fog, and even large-scale animated surfaces like a field of wind-blown grass.

By changing just a few shader parameters like diffuse, specular, refraction and subsurface scattering, a wide variety of base materials can be created, such as iron (1), gold (2), chrome (3) plastic (4), jade (5), glossy paint (6), wax (7), glass (8), and tinted glass (9). These basic attributes can then be further enhanced with textures to add detail and break up uniformity.

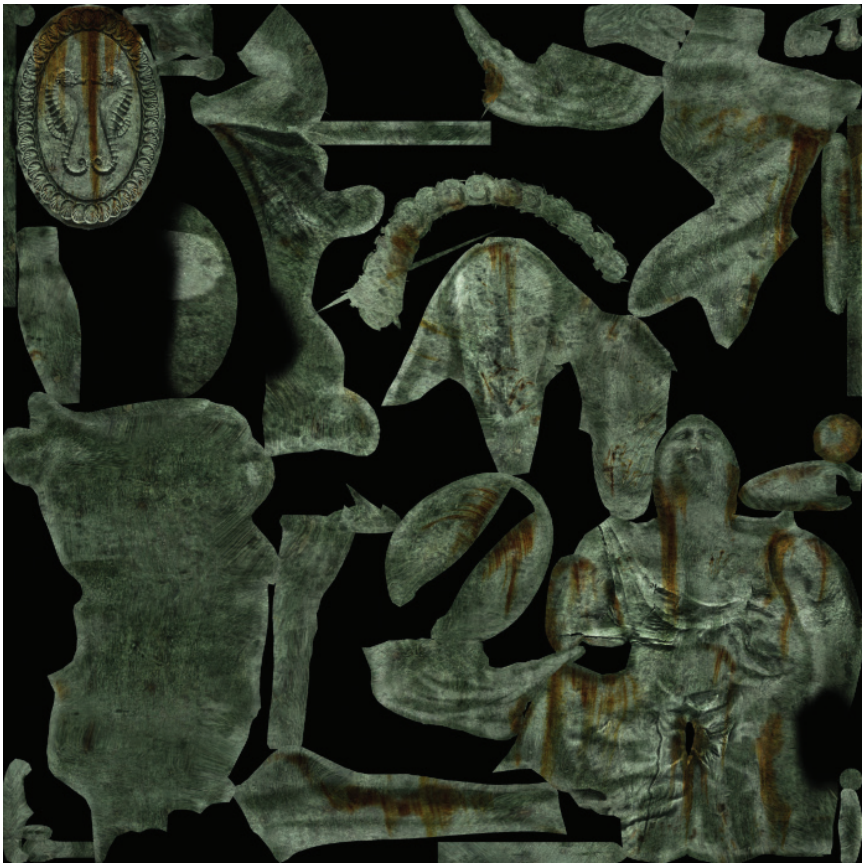
Textures

Perfectly uniform surfaces are rare. Even a shiny chrome ball has some spots of dust, smudges, or other small imperfections on the surface. Textures are therefore used not only for color detail, but also to control and vary other properties of the material such as shininess or transparency (and of course bumps and displacement). Texturing is an intricate art, and great texture artists know how to create surfaces that feel naturally imperfect. A brick wall, for example, is essentially a tiled, repetitious surface. But look closer and you'll see an infinite amount of small variations in the bricks and the mortar, as well as color and shininess variations due to weathering and aging. Those subtle inconsistencies go a long way toward making a model feel believable and not synthetic, and texture artists achieve them by layering different images and hand-painting additional detail to create a rich, naturally detailed surface.

UV MAPPING In order to wrap a two-dimensional texture onto a three-dimensional model (think of gift-wrapping a ball, for example), the model needs to be unwrapped (flattened out) first. This process is called UV mapping, and although it is an essential part of any modeling/texturing work, it is usually completely transparent to the filmmaker. However, it is a step in the process that needs to be accounted for in terms of schedule and budget. UV mapping a complex model can take several days, as the model needs to be broken down and flattened into many small pieces, then those pieces laid out and organized.



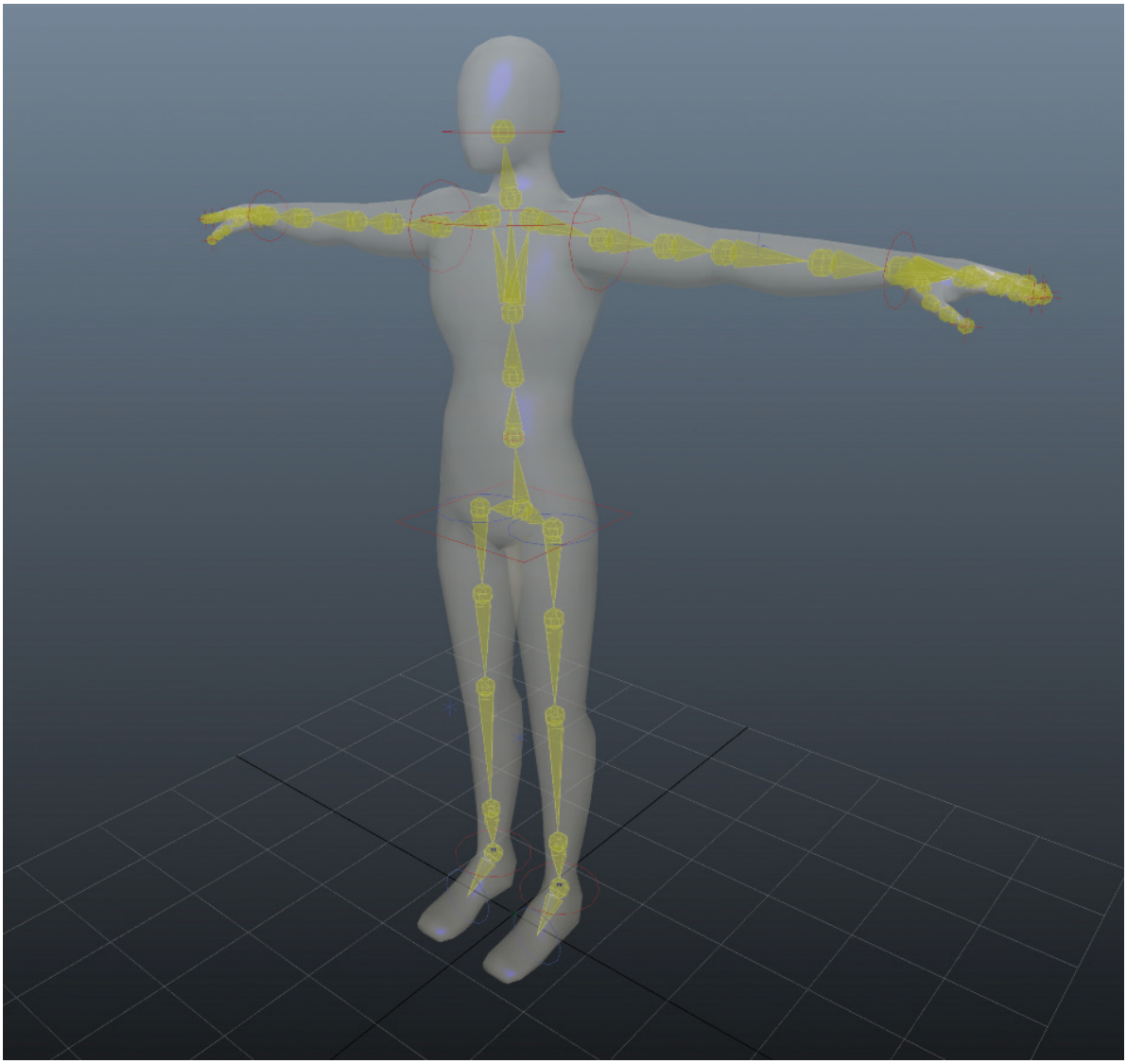
A full UV layout of a ship model. Every surface needs to be flattened out and organized in this layout to be accurately textured.



A diffuse color texture map for a masthead figure. Notice the fine detail such as rust marks and discolorations.

Rigging

The movement of a CG character such as a human or animal is complex. A simple human walk cycle, for example, involves the transformation and rotation of numerous joints, from the toes through the hips and spine to the arms and head. Since most organic models are built from a single continuous mesh, an underlying structure needs to be built in order to push and pull the muscles and skin. That structure is very similar to a skeleton (in fact, the joints that make up the rig are often called "bones"), and is designed in a way that restricts the rotation freedom of each joint to its real-world equivalent. For example, the knee joint on a human can only rotate on one axis, about 70–80 degrees backwards from a straight leg to a folded position. These restrictions are essential because limbs like legs and arms are rigged in a way that enables the animator to move the whole chain from the end point (for example, move the entire leg from the heel or the arm from the hand), rather than rotate each joint separately. (This is called **IK**, short for Inverse Kinematics.) Without the proper restrictions, the joints will bend awkwardly in all directions, like a simple wire puppet. A properly constructed rig is a key to successful animation, and expert riggers create truly elaborate rigs that give the animator a lot of subtle control over



A simple humanoid rig. The yellow joints are the "bones"; the red and blue shapes are the controllers for the animator.

every moving part. When the rig is completed, it is attached to the model in a process called **skinning**. During this process, the rigger weighs each bone to adjust how much it pushes or pulls the vertices around it. Riggers often skin characters in a way that simulates bulging muscles as joints are flexed.

Hard-surface technical rigging does not require an underlying bone structure or skinning process, but complex machines can have hundreds of moving parts, and the rigger must set up all the joints and restrictions in a way that allows the animator to control the object with efficiency. Mathematical formulas are often used to automate secondary motions (for example, to spin the wheels of a car according to its

movement). The Robots in the *Transformers* franchise are a great example for highly elaborate hard-surface rigs that allow not only mind-boggling mechanical trickery but also humanoid motion.

Like UV mapping, rigging is largely invisible to the filmmaker. It goes under the hood, is never rendered, and has no effect on the visuals. But it is nonetheless a crucial step in the animation process and directly affects the success of a shot.

Animation

Of all the different crafts of VFX, animation is arguably the one most people are familiar with. We all know what animation is; it has been with us for more than a hundred years in the forms of traditional cell animation, stop motion animation, and, more recently, 3D animation. Most VFX crafts are newcomers, evolving over the past thirty years or so. But animation, like filmmaking itself, is backed by a vast and venerable tradition of time-tested techniques and artistic conventions. It is true that animating a CG character in 3D space is different in many ways from animating a hand-drawn 2D character. But the underlying essentials are exactly the same: timing, weight, anticipation, follow through, secondary and overlapping motion, expression, intent . . . it is not surprising that many of the best CG animators come from a traditional animation background. But, as I noted in Chapter 1, there is a fundamental difference in the animation style between a fully animated movie such as *Toy Story* or *Frozen* and a live-action film. The marriage of real actors and CG characters necessitates a very strict adherence to realistic motion and the laws of physics, and leaves very little room for stylized movement.

If we look at the bigger picture for a moment, animation in VFX is not only about characters. In fact, anything that changes over time, anything that interpolates between one keyframe and another, is animated. Points on a roto shape, the changing position of an element in comp, the intensity of a light, the flicker of a flare, a color shift, a rack focus—these are all examples of prevalent low-level animations that are part of every VFX artist's day-to-day work. Dynamic simulations and particle systems are examples of higher-level animations—complex, interactive events that happen over time, usually built around action rules and parameters. But the highest level of animation is indeed character animation. Breathing life into a human, animal or any creature (and doing it successfully within the restrictive limits of live action realism) requires highly developed animation skills, and a deep understanding of anatomy, timing, emotion, and physical expression. Successful character animations start with good modeling and rigging—the animator will usually work with the rigger to adjust and improve the rig by testing various motions and scenarios. Prominent characters in a movie usually undergo a preparation period in which the animator/s develops the character's movement style and "identity," not unlike the way an actor prepares for a certain role by adopting specific physical and facial characteristics.

Motion Capture

The need for realistic, non-stylized character motion in live action VFX inevitably led to developing ways to record the movements of real-life actors and transfer them to CG characters. Simple motion capture

(mocap) techniques have been around for many years—Eadweard Muybridge studied galloping horse motion using a series of images back in 1872, and (as mentioned in Chapter 3), Disney animators traced real actors with roto to duplicate their movements in 2D animations. Modern mocap techniques were only developed in the nineties though, and the 2001 film *Final Fantasy: The Spirits Within* is generally considered a mocap milestone. However, it is the character of Gollum in *The Lord of the Rings: The Two Towers* that really pushed mocap forward as a mainstay cinematic technique and made actor Andy Serkis the first mocap star ever. Serkis' performance in the *LOTR* franchise, as well as in subsequent movies like *King Kong* and *Planet of the Apes*, changed not only how mocap is used in movies but also how mocap actors are regarded—no longer anonymous stunt people but fully credited talents, much like voice actors on animation films.

There are several different techniques for motion capture, but the most common nowadays is the optical method: An array of special cameras is placed around the capture area. The mocap actor wears a dark tight suit (like a diving suit), and multiple bright (or self-illuminated) markers are attached to it at specific

Eight frames from a motion-captured cartwheel animation.

locations. Often facial expressions are captured as well, in which case additional smaller markers are placed on the actor's face. As the actor moves, the camera array calculates the relative position of every single marker in 3D space. The resulting mocap information is a very accurate depiction of the actor's movement, down to minute detail. That information is then transferred to a fully rigged CG character. Originally, mocap had to be performed on a special stage, away from the set and the actual action, but today mocap is often done on location, which allows full interaction between the mocap actor, the environment, and the other actors in the scene.

Yet despite the obvious advantages of mocap for VFX animation, traditional keyframing is still very much in use and is certainly not going away—first, because mocap info is very rarely used as-is. In most cases, the action needs to be cleaned up, and animators often fix and enhance the motion with traditional keyframing. In addition, mocap can only be performed by human actors, which limits its use to humanoid and bipedal characters. There is hardly any point in using mocap to animate, say, an elephant, a spider, or a fish. That said, actor Benedict Cumberbatch, who voiced the dragon Smaug in *The Hobbit* trilogy, did provide mocap data in addition to his voice—most of it, probably, for enhancing facial expressions and for giving the animators performance reference.

Sneaky Little Hobbitses . . . with an emotional range of a Shakespearian actor, the wide-eyed, passive-aggressive Gollum is one of the best CG characters ever—thanks not only to Serkis' great mocap performance but also to Weta's talented animators.

The Lord of the Rings: The Two Towers © New Line Cinema, WingNut Films, The Saul Zaentz Company.

Lighting and Rendering

CG lighting sounds like a cinematographer's heaven: lights can be placed absolutely anywhere—no need for stands, rigs, clamps, or ladders. Light color and intensity can be changed on the fly—no gels or filters required. Shadows intensity can be tweaked at will (or even turned off completely) and you can even choose which light affects which object in the scene. If only you could do that in real life . . .

But this total freedom from all physical constraints is exactly what makes 3D lighting so challenging. Like everything else in CG, lighting can easily look and feel too perfect, too clean, too mechanical. Achieving natural light is a goal that requires not only a thorough understanding of the physical behavior of natural light but also a good knowledge of film and stage lighting techniques.

The integration of CG elements into the footage depends a lot on the work of the lighting artist (often called Lighting Technical Director, or **Lighting TD**). It involves not only placing and adjusting lights but also tweaking the shaders applied to objects in the scene to get the desired reaction to the light on different materials. Lighting is also tightly linked to compositing, because it is generally easier and faster to fine-tune color, brightness, and contrast in comp. A lighting TD usually creates initial comps (called **pre-comps**) to establish the look, or works in tandem with the compositor.

CG Lighting Essentials

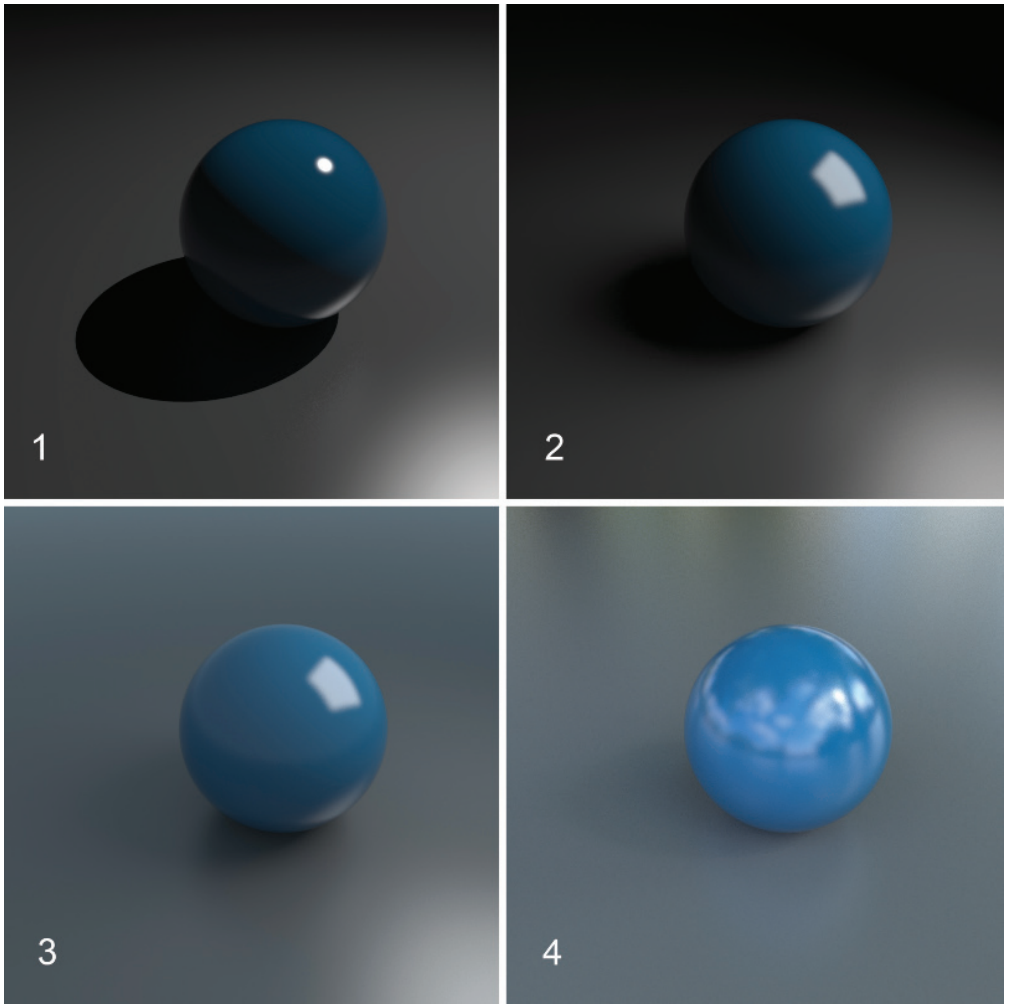
CG lighting is an intricate craft, yet the basic principles are identical to real-world lighting, and should be familiar to gaffers, cinematographers, directors, and anyone with some on-set lighting experience. The main difference is that those physical side effects that are taken for granted in real-life lighting (like indirect light reflection, color bleeding or soft shadows) are the hardest to simulate in CG, and require longer rendering time. There's always a tradeoff here—softer, richer, more natural light comes at the expense of slower rendering.

KEY AND FILL LIGHTS The simplest types of lights in CG are **point lights** (omnidirectional) and **spot lights**. The problem with both is that the light emanates from a singular, infinitely small point. In the real world, light is always generated from a surface that has size and shape (a filament, a neon tube, a softbox, etc.). Single-point CG light sources therefore produce a perfectly sharp shadow with no falloff or diffused edge, and perfectly clean, circular highlights on shiny and reflective surfaces. This rather harsh lighting look is characteristic of renders from the early days of CG, before area lights and global illumination entered the scene.

Area lights give much more natural results, at the expense of longer render times. An area light can be any size and shape. A sphere can simulate a light bulb, a cylinder can be used for a neon tube, and a plane produces a similar result to a softbox. Because the light rays are generated from a surface rather than a singular point, the shadows are naturally soft and diffused, and the highlights on shiny surfaces appear as distinct, varied shapes rather than the old-style uniform circles.

Finally, a **directional light** is often used to simulate sunlight. Unlike the other light types, it shoots parallel rays, so shadows uniformly face the same direction (technically the sun is a spherical area light, but because of its distance from earth its light rays are nearly, if not absolutely, parallel).

SKY LIGHT AND IMAGE-BASED LIGHTING A sky light (also called skydome or spherical light) is a large hemisphere that surrounds the entire CG scene and lights it from all directions, just like our real sky. A sky light is a vital component for providing soft ambient light in outdoor scenes. The color of the sky light usually varies between light blue and gray, to simulate clear or overcast skies.

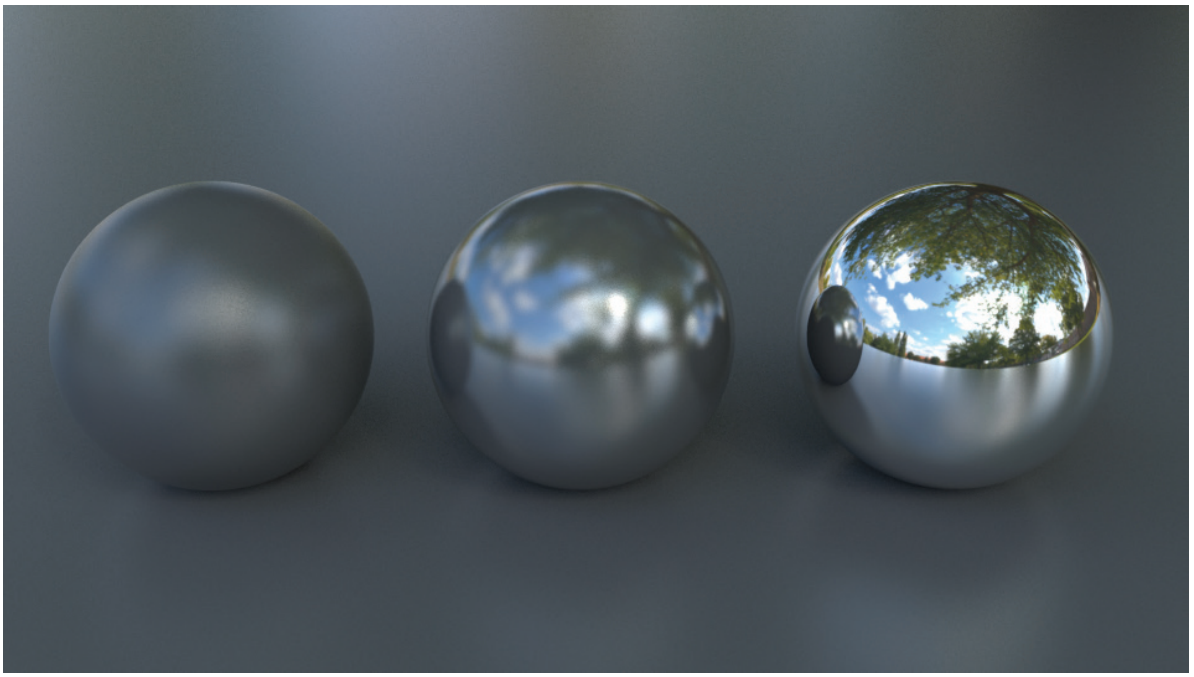


CG lighting evolution: 1) A simple point light creates a harshly sharp shadow and a perfectly round, unnatural highlight. 2) A rectangular area light generates a more natural soft shadow and highlight. 3) A light dome adds some much needed ambient fill, which reduces the shadow and creates a more pleasing overall light. 4) The area light is removed and an HDR image is used for the light dome—this produces a more complex light and specular pattern.

Image-based lighting (IBL) is a technique of mapping a 360-degree spherical image to the sky dome. The image can be a generic sky or environment (outdoor as well as indoor), but IBL becomes truly useful when that spherical image is actually taken on location during shooting, and thus contains all the environment and lighting information of the original shot. Because a **High Dynamic Range** (HDR) image format is used, the lights in the image retain their full luminosity values and act as true light sources when IBL is used in the CG scene. In addition, because the image surrounds the entire scene, it is effectively reflected in shiny surfaces, which further helps in terms of matching the CG renders to the actual plate. HDR spherical images are therefore extremely valuable for VFX lighting, and in Chapter 8 I will discuss shooting spherical HDRs in the context of on-set data acquisition.

GLOBAL ILLUMINATION (INDIRECT LIGHT) When light rays hit a surface, some of their energy is absorbed, and some of it bounces back off and contributes additional reflected light to the surroundings (the amount of light bounce depends on the material and its color, as well as the intensity of the lights). If you take two identical rooms, one painted white and the other one black, and put the same light bulb in both,

Three shots with a fish eye lens at 120-degree slices are stitched to create a fully 360-degree spherical HDR. The increased dynamic detail (in the sky, for example) is generated by combining several exposures. The goal here is not to make a "pretty HDR photo," but merely to maximize the dynamic range for lighting purposes.



An HDR spherical image used as an environment map, as seen in three spheres with varying degrees of reflectivity.

the white room will fill up with more light because white reflects more light energy while black absorbs it. Consequently, objects with strong bright colors will bounce some of their color on nearby surfaces, creating a subtle color bleed effect. Indirect light is a delicate and intricate effect that contributes tremendously to the realism of CG scenes. It is the glue that pieces together the different objects into a coherent environment. It is also, unfortunately, a strong contributor to longer render times, as the computer needs to trace each ray of light as it bounces around numerous times until all or most of its energy is gone.

OUTDOOR LIGHTING VS. INDOOR LIGHTING Generally speaking, all you need to simulate outdoor light is a key light for the sun (usually a directional light) and a sky light. If the sky is cloudy and the light is predominantly ambient, a sky light may suffice. It's important to note here that CG lighting does not need to adhere to natural laws. DPs and gaffers often use additional lights, reflectors, or screens to enhance outdoor light or compensate for strong shadows or contrast, and the same techniques are often used in CG lighting (albeit without the hassle of physically moving fixtures and rigs around).

Indoor lighting can be trickier, because enclosed spaces usually have multiple light sources with varying characteristics and color temperatures, and they also rely more heavily on bounced light. That said, CG indoor lighting techniques are quite similar to real-world lighting. For example, to simulate daytime light seeping through a window, a large flat area light is placed outside the window, just as it would be done on a set. Since the main goal of the lighting TD is to closely match the lighting in the footage, image-based lighting is often used, because it mimics more accurately all the intricacies of the lighting on location.

AMBIENT OCCLUSION When objects are lit by a sky light, the rays hit them equally from all directions. Naturally, areas that are more exposed to the lighting dome receive more light, while objects that are partially hidden, or occluded (hence the meaning of the term) are darker. Ambient occlusion occurs naturally as part of any lighting scenario, but I am mentioning it here because in its generic bare-bones version it is usually used for presenting un-textured and un-shaded models and 3D scenes. Ambient occlusion (AO) renders are faster—there are no lights except for the dome, no shading qualities like reflection or refraction, no indirect light and color bleed. AO renders show the objects in an unbiased gray-shaded lighting scenario, perfect for testing and reviewing modeling details without being distracted by color or highlights.

Rendering

When the scene is all set up—the models textured and shaded, the animation tweaked and perfected, lights positioned and adjusted—it is handed over to the computer for the number crunching. Rendering is the process in which the computer meticulously traces the complex journey of every ray of light that hits the virtual camera's lens. Which light source in the scene generated it? Which surfaces are hit by it, and how much of it is bounced back? How does each shader in the scene affect that light ray? The entire scene, including all objects, shaders, animations, and light sources, is evaluated and calculated, until a final image is generated—an image that (hopefully) produces similar results to the light-speed events that happen in the fraction of a second when the camera shutter opens up. Then this whole process starts anew for the next frame, and so on.

As you can imagine, ray-tracing is an extremely complex computational process. CG artists do their best to model, shade, and light in ways that speed up rendering, but heavy CG scenes, especially those that have lots of transparent, reflective, and refractive surfaces, and scenes that use volumetric, fur, and hair shaders, can indeed take a very long time to render. Rendering speed depends on multiple factors, and a single frame at 2K resolution can take anywhere from a half a minute to several hours to render. You need exactly 3 seconds to shoot 3 seconds of footage, but it may take hours (even days) to render out 3 seconds of a complex CG scene.

You may logically assume that rendering today is so much faster than it used to be twenty years ago. After all, those pioneer 3D artists used workstations with processing capabilities similar to your average cellphone. But as computers quickly evolved, so did advanced lighting and surfacing technologies like global illumination, area lights, and volumetric shaders. These technologies allow for much more complex and realistic renders—but of course take their toll on rendering times. So in a way, the huge stride in computing power is somewhat counterbalanced by the ever more complex scenes to be rendered and the higher expectations of the filmmakers. To speed up rendering, most VFX facilities own a **render farm**, essentially a network of dedicated computers that enables parallel rendering of multiple frames simultaneously. While large facilities obviously have bigger and faster render farms, they also typically handle heavier CG loads than smaller facilities.

Cloud rendering is a relatively new option to in-house render farms, and has become more popular as internet speeds allow faster transfer of files. It's essentially an outsourced render farm. Instead of investing in expensive processors, maintenance, and space, the facility simply sends the scene files to an

external dedicated online render farm, and gets back the fully rendered images. The downside in this arrangement is the times it takes to upload the material and download the results, as well as the fact that costs can quickly add up when rendering many iterations. Many VFX companies use a hybrid approach: they do all the low-res test renders in-house, and only render the final, full-res images on the cloud.

But no matter how you approach it, rendering is a time-consuming VFX production process that needs to be taken into consideration. As far as the filmmaker is concerned, any changes to a CG scene (such as changes to animation, modeling, layout or surface properties) usually require a full re-render of the shot. On the other hand, changes that can be made in the compositing stage (see later), can be achieved much faster, as 2D rendering only takes a fraction of the time of CG rendering (because there is no light tracing involved). It is often a good approach to ask the VFX team whether a certain change necessitates a full CG re-render or can be done in comp, especially during crunch time. Also, reviewing playblasts or low quality rough renders is always an efficient way to avoid too many rendering iterations (see Chapter 9).

Compositing

If I had to choose a single VFX craft as the ultimate be-all and end-all, it would most certainly be compositing. First, because no matter how simple or complex the VFX pipeline is on any given shot, and no matter how many crafts are being used along the way, compositing is always needed at the end of the chain. Second, because compositing is often the one and only craft used for completing a wide range of shots. It is, essentially, the workhorse tool of VFX, the "Photoshop of moving picture." And third, because compositing is a crucial last step where the "last look" of the shot is tweaked, polished, and finalized.

At its most basic level, compositing is used to put together all the elements created by the various artists working on the shot and integrating them with the footage by adjusting color, focus atmosphere, lens effects and grain. In this respect, it is very similar to sound mixing. But this is only part of the craft. Compositing is where green and blue screen extractions take place, where roto is created and adjusted, and where a plethora of 2D and 3D elements such as lens flares, smoke, fire, explosions, debris, and dust are added and refined. It is where the final (and sometimes most crucial) steps toward photorealism and integration are performed through careful adjustment of color, contrast, light, and depth. Compositing software today is not limited to 2D only. Extensive 3D tools provide the ability to import cameras and 3D models and create 2.5D projections (and even change CG lighting to a certain extent).

When lighting TDs render out a CG scene or element, they often output additional layers (called **render passes** or AOVs) that represent only certain aspects of the lighting (for example, specular or indirect light), as well as a whole slew of utility layers like mattes for certain parts, depth pass or atmosphere passes and technical passes that allow further manipulation of the CG renders. These are invaluable for the compositor. They allow very detailed fine-tuning in 2D without going back to the much slower 3D rendering process.

While most other VFX artists concentrate on their own respective area of expertise, compositors need to look at the whole picture—in many pipeline configurations, compositing is the converging point of all other crafts. Compositors therefore have a wider understanding of the various crafts, and must have a

sharp, critical eye. It is not surprising that many VFX supervisors come from a compositing background (myself included). For me, the compositing software is the go-to tool for any type of look development and experimentation. It is not only the finalizing platform—it is also the sketchpad and drafting board of visual effects. To paraphrase the "Who would you take with you to a deserted island?" I'd say, if you ever find yourself in a situation where you can afford only one VFX artist, take a compositor.

Sometimes, all it takes to get the comp right is some defocus, as is evident in this example from *Boardwalk Empire*.
Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

The version on the top is a "slap comp"—the elements are all in place, but there is a lot yet to be done: the ships are too saturated, too uniformly sharp front to back, there's not enough sense of depth, the interaction with the water looks odd, there are no shadows and contact shadows, the sky feels too saturated and uniform, there is no sense of light reflected in the lens. The version at the bottom shows how this type of attention to small detail in compositing can really make a shot come alive and feel coherent and integrated.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Matte Painting

I think of matte painters as the nobility of VFX artists (and I do apologize to any other contenders to the title). I believe there is no other VFX craft that embodies the essence of visual effects and requires such a noble mixture of technical and artistic skills, creativity, and attention to detail. Matte painters create backgrounds. These include, of course, those iconic (shall I say clichéd?) matte paintings of vast futuristic

In this establishing shot of NYC from Woody Allen's *Café Society*, we had to transform the current Manhattan skyline into its 1930s' equivalent, making sure it was historically accurate. Notice how the sky, lighting, and mood of the original shot are preserved in the matte painting.

Café Society © FilmNation Entertainment, Gravier Productions, Perdido Productions.

cities à la *Blade Runner* and sprawling jungles with ancient Mayan pyramids, but the work of the matte painter often involve more mundane set extensions. Mundane, maybe, but difficult nonetheless, because unlike concept artists, matte painters must create environments that feel absolutely photoreal and are tightly and seamlessly integrated into the footage.

The term "matte painting" originates from the pre-digital days, when background elements were painted on glass panels, and positioned on set at varying distances from the camera. This generated some parallax when the camera was moving, adding a sense of depth and allowing for richer, more believable backgrounds. As you can tell, this is essentially the non-digital forerunner of the 2.5D projection technique discussed in Chapter 3, which is widely used by matte painters today as a way of adding depth to environments created with 2D elements.

So while the term "matte painting" remained, there is very little "painting" in matte painting today. By using computers, matte painters rely mainly on photographic material—sourcing, cutting, manipulating, and assembling multiple pieces of imagery to create the desired environment or set extension. Photographic material is inherently detailed and photoreal, but putting together a coherent environment using images from widely varying sources is an immense challenge, and it is here where the combination of technical and artistic skills comes into play. The hybrid environment used as example in Chapter 3 is a typical depiction of a matte painting process, and of the way matte painters use a combination of 2D and 3D elements. This type of work requires not only a strong background in traditional art and Photoshop but also skills in 3D modeling, texturing, lighting, and compositing.

Matte painting, step by step: First, the original footage.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

The flat ground is enhanced with low hills to add some more depth.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

More drill towers and other structures are added to create a busier scene.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

Oil pipes are laid down (the smoke and additional people are added by the compositor).

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

The rather empty foreground gets a treatment with a pipe running right through it.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

Finally, some foreground elements are added on the left to create a more balanced composition.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

Dynamic Simulations

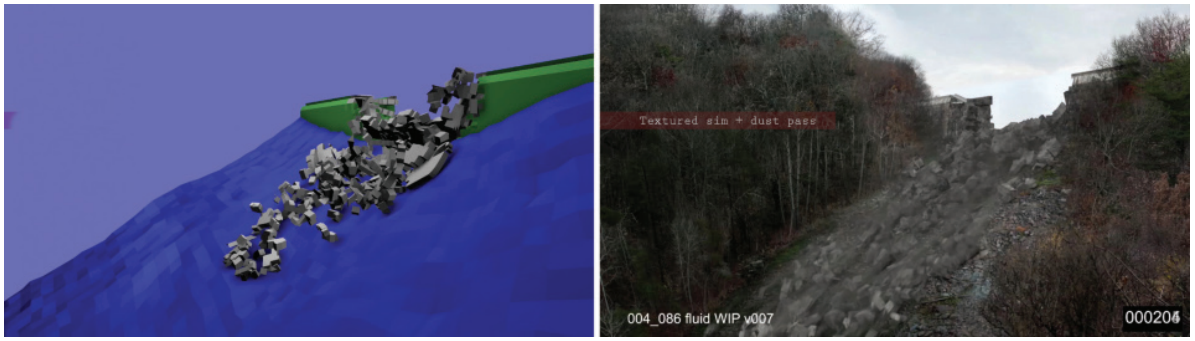
We're now entering big ticket territory: giant tsunamis, buildings collapsing into clouds of dust, swirling flocks of birds, destructive tornadoes, liquid metal robots—the most spectacular and impressive effects usually involve complex particle systems or physical simulations. Indeed, these crafts take advantage of some of the most remarkable (and fascinating) technical achievements in CGI, and it's easy to get excited about the possibilities that such technologies open up for the filmmaker (and not just in the realm of superhero, sci-fi, and disaster genres). But there is, of course, a high price tag attached. Of all the VFX crafts, simulations require the largest resources of raw computational power, and take the longest time to generate and finesse. Attempting to create a believable CG flood scene, for example, without sufficient resources, an expert team, and a realistic schedule and budget, is a recipe for failure. This doesn't necessarily mean that dynamic simulations and elaborate particle effects are reserved for big-budget productions only, but rather that a good understanding of these procedures and what they involve can help keep both the budget and the expectations within reasonable limits.

The different types of dynamic simulations described later all share the same basic concepts: a physical environment with predefined gravity (and often additional forces like wind or turbulence), and objects with predefined physical characteristics such as mass and friction. The objects are placed in a starting position, the parameters are tweaked, and when the button is pressed the computer begins to figure out what exactly happens to the objects as they are affected by the global forces while interacting with each other. When the simulation process is done, the artist can view it in real time, adjust the

parameters, and kick in a new simulation. This is repeated until the desired effect is achieved. Unlike rendering, the artist cannot test an arbitrary single frame. The calculation must start each time on the first frame and move forward linearly, frame by frame. This is therefore a very time-consuming process. Fast, powerful processing power is certainly a must, but what really helps speed things up is a highly experienced simulation artist who knows which parameters to tweak in order to get the desired result, and thus cut down considerably on the number of simulation iterations. It is important to remember that simulations mimic the utterly complex interactions of real-world objects and physical forces, and hence are inherently quite unpredictable. If you spill a glass of water on the table, you cannot possibly foresee the exact manner in which the water will behave. Dynamic simulations are therefore much harder to direct than regular animation. Good sim artists have skills and tools for guiding the simulation toward the desired result, but the filmmaker should not attempt to micro-direct every wisp of dust and every drop of water. After all, it's exactly their real-world chaotic nature that makes physical simulations so powerful.

Rigid-body Simulations

This is the most straightforward type of dynamic simulation, because the objects either keep their shape, or just break into smaller rigid pieces. There are usually less physical properties to be defined: objects typically have some weight and therefore tend to fall down; collisions usually result in objects either pushing each other, bouncing around, or breaking apart. There is no calculation of geometry deformations as in cloth, fluids, or water. Rigid-body simulations are most frequently used for destruction effects, usually in combination with fluid sims (for dust/smoke) or particle systems (for small debris). On a smaller scale (say, an object smashing through a window), a rigid-body simulation can be a pretty quick and effective VFX solution, certainly within the budget of any movie. However, large-scale destruction effects like collapsing skyscrapers and similar mayhem must have sufficient detail and thousands (even millions) of interacting pieces to look convincing. These mega-sized simulations can only be achieved with sufficient resources typical of large facilities.



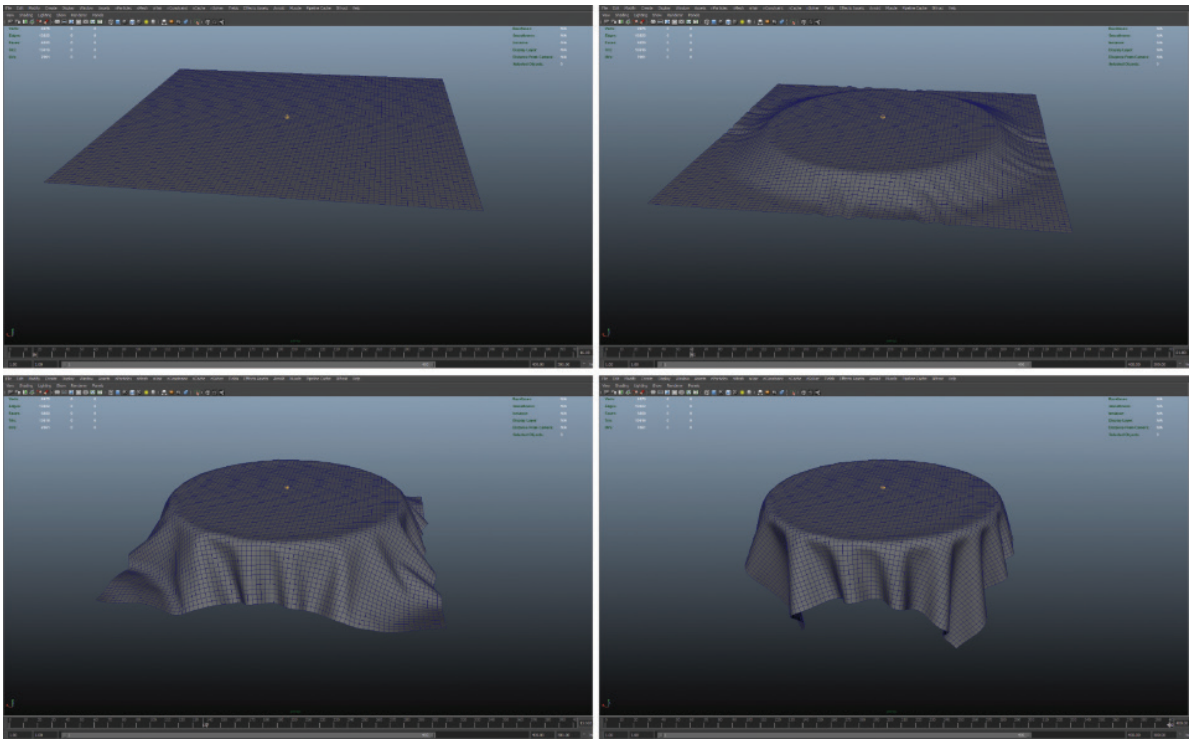
Preliminary rigid-body and dust simulation tests for *The Men Who Built America*.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

COST-SAVING ALTERNATIVES There's a wide variety of destruction effects that can be created by the special effects team on set. It is always a good idea to have at least some parts of the shot done practically (using special effects techniques like hidden charges to generate some on-set destruction) and use VFX to augment it and cover the missing parts. You can also shoot some generic elements of debris, dust, shattering, and breaking to substitute for dynamic sims or at least augment them with some extra detail and realism. There are also quite a few commercial libraries that offer useful footage of destruction and debris; most VFX facilities have access to at least some of those libraries.

Cloth Simulations

Cloth behaves differently from rigid objects, so additional parameters like stretchiness, bend resistance, and springiness need to be set. Cloth simulations let you pin the cloth to an object at specific points (like the way a skirt is held only around the waist, or a flag attached to a pole), and even stitch together several flat pieces of "garment" to tailor a clothing item to a CG character. Simulating a wind-blown flag is a ubiquitous quick-and-easy cloth sim, but simulating a dress on an animated character is more complex, because there's interaction between the cloth and the moving body, as well as in the cloth



Four stages of a simple tablecloth simulation.

The sails, as well as the ropes, were rigged and simulated using real footage as reference.

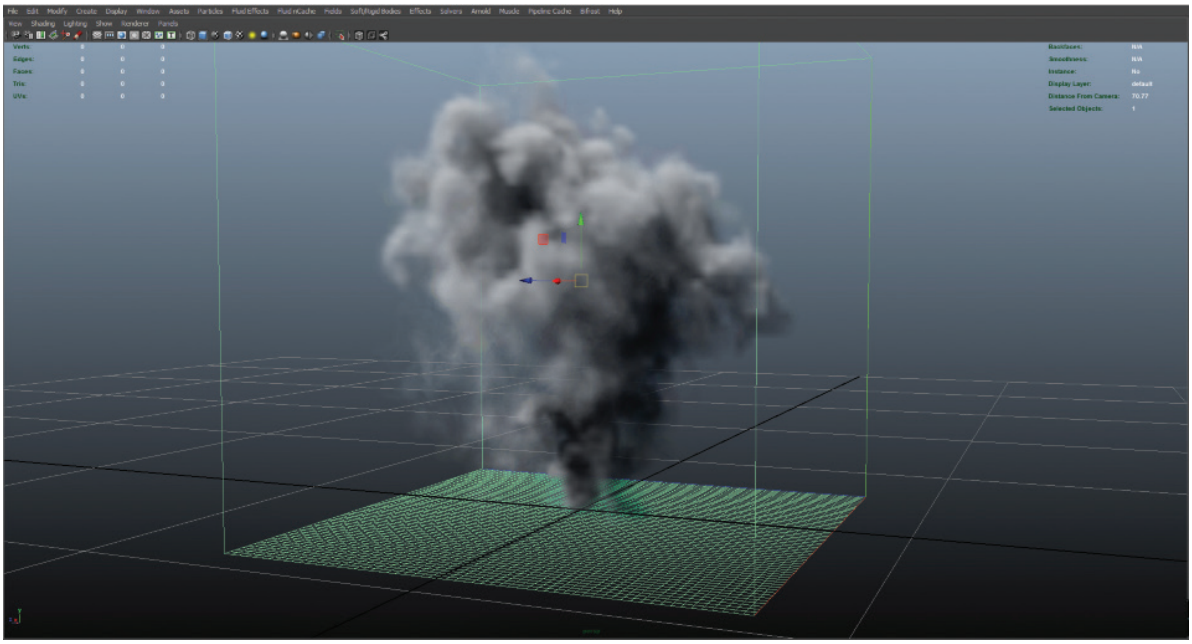
Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

itself. These types of cloth simulations are obviously dependent on the primary animation, and need to be re-simmed if the animation changes.

Ship sails are a good example of a tricky cloth simulation. On the History Channel mini-series *Sons of Liberty*, we had to create several shots of 18th-century gunships crossing the ocean. Unlike flags, sails are connected to a rather complex rig of beams and ropes, and are also generally much larger and made form a heavier material (canvas). In order to accurately simulate the way sails react to wind we had to recreate at least some of this rig, including ropes that were an active part of the simulation. This required some trial an error until the right balance of material characteristics and rig tension gave us the desired subtle but realistic results.

Fluid Simulations

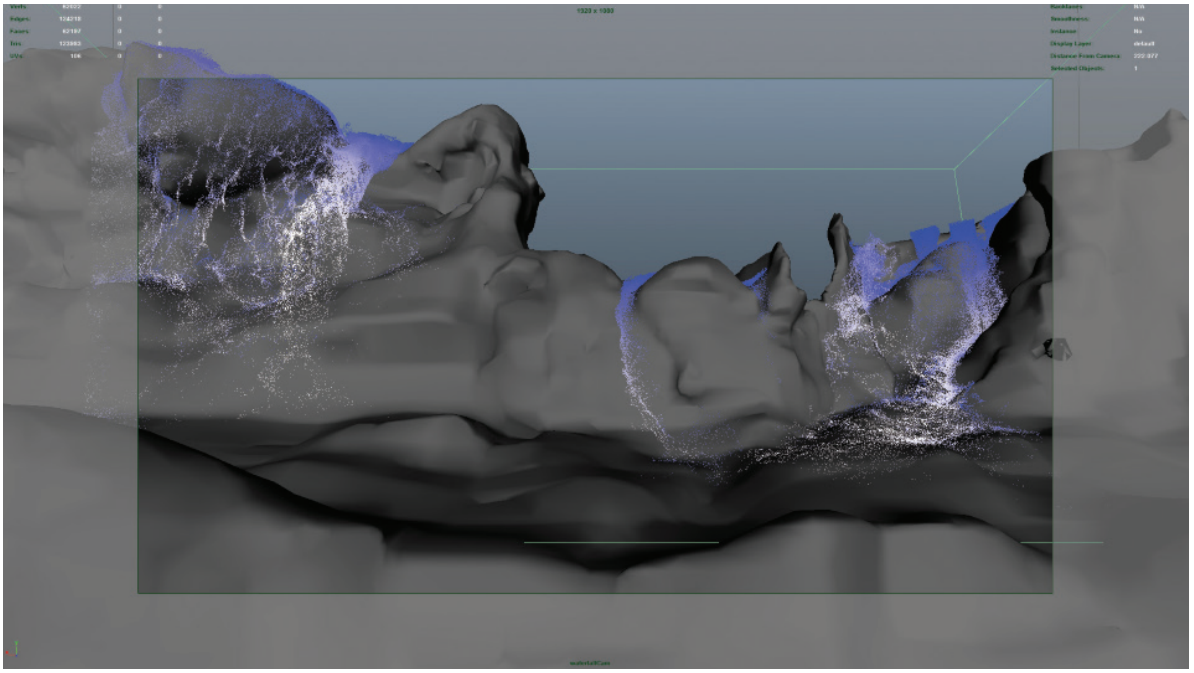
GASSES Fluid sims can be roughly divided into gas and heat effects (smoke, steam, fog, fire, explosions) and liquids. Gasses behave very differently from solids, and require a different set of physical attributes with properties like temperature, viscosity, and density. They are also much harder and slower to simulate. Because gasses tend to spread out, they cannot be simulated in infinite 3D space. Rather, the simulation is contained within a predefined domain, which is subdivided into small cells called **voxels**. Higher voxel



Simulating smoke in Maya. The green box is the domain that contains the fluid, and the subdivided grid indicates the density of the voxels.

subdivisions mean a more refined look and behavior, but also longer simulation times. When it comes to rendering, gasses use special **volumetric** shaders that accurately mimic the way light hits and travels through amorphous non-solid entities like smoke and steam. Volumetric shaders are inherently slower to render than standard solid shaders.

LIQUIDS Arguably the toughest of the simulation types, liquid simulations have somewhat become the obligatory VFX showpieces for blockbusters, with each doomsday wave bigger and meaner than the previous one. But the technology for simulating liquids is indeed fascinating and powerful, and constantly pushes the boundaries of visual effects. The behavior of water and the way it interacts with objects is extremely complex. There are currents, turbulences, waves, wakes, splashes, foam, droplets, spray . . . To accurately simulate a body of water, a dense particle cloud is used to calculate the behavior of the liquid and its interaction with static and dynamic objects, and the result is "meshed" into a continuous surface that can be shaded and rendered as liquid. This process is understandably slow and intensive. In the past, only those few VFX facilities that had developed their own in-house tools were able to handle liquid simulations, but now there are several excellent applications on the market that enable any facility of any size to simulate liquid. That said, special expertise and adequate hardware resources are still needed, and sufficient time and budget should be allocated for liquid simulation effects, especially large scale ones. It is relatively faster to create one of those ubiquitous water/soda splashes we see in commercials, than it is to create a giant flood or tsunami. The larger the scale, the more detail is needed.



Waterfall simulation in progress. This example shows the particle stage, before meshing. The color indicates velocity—brighter particles are moving faster.

COST-SAVING ALTERNATIVES If the camera move does not preclude the use of 2D elements and there is no need for specific interaction with CG elements, then real footage of smoke, steam, dust, and fire elements, as well as water effects such as splashes and wakes, are all excellent options. Scheduling a day with special effects to shoot some elements is always a good idea, and if possible, it's best to shoot them on the same location and with similar lighting and camera angle(s). Most facilities have a library of photoreal elements that were acquired over time, either as part of a previous production or purchased from a stock library.

To go back to those 18th-century *Sons of Liberty* ships mentioned earlier—we knew that we would need to model and texture some high-detail, historically accurate tall ships, and that we'd need to allocate resources for cloth simulations for the wind-blown sails. But the use of liquid simulations for the ocean surface and the interaction between the ships and the water was beyond the budget and schedule of that production. Instead, we spent a day shooting a real (and fully operational) sail ship in open sea off Cornwall, UK. After selecting several takes, we proceeded by replacing that ship with our CG period-accurate warships, but kept the ocean surface and the actual wakes and splashes generated by the original ship. We also extracted those wakes and splashes and used them as separate elements that we could add to additional ships in the shot. This 2D method gave us photorealism at a fraction of the cost of a full water simulation. The caveat was that we had to use the original footage as a base—we did not have the freedom to design the shot from scratch and move the camera at will—which would of course necessitate a full CG solution and full water sim.

The ocean surface, as well as all the water interaction, wakes, and splashes in this shot are real—taken from footage we shot of a sail ship in Cornwall, UK.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Particle Systems

Particle systems allow you to control the animation of a very large number of objects that behave and interact according to a set of predefined rules. Effects such as rain or snow can be easily created with the most rudimentary particle systems: The particles are simple points or stripes, generated from a single large plane that's kept well overhead. A gravity force pulls the particles down, a wind force adds some directional push, turbulence causes snowflakes to swirl, and additional noise contributes to a more irregular, non-repetitive behavior.

But particles can be more than just points. They can be fully textured models, complete with their own animation. To create a flock of birds, for example, a pre-animated bird model (usually with a repeating cycle of movement) is used as the particle instance. This way, hundreds of wing-flapping birds can be controlled by a single particle system, instead of being animated individually. Variations on the model and the cycle animation at the particle level, combined with speed and trajectory variations in the particle system contribute to a more irregular and realistic flow that does not feel too mechanical or duplicated.

At the high end, particle systems can be very elaborate. In such systems, the particles interact with objects, other particle systems or even between themselves, and each interaction can result in a specific

action—particles can disappear, slow down, bounce off, change direction or split up into more particles. Such systems are necessary to create a complex behavior of large groups of animated entities or destruction debris. We used such a system to create a multitude of bats for one shot. The system mixed a number of bat wing-flapping cycles, and allowed us to design some elaborate flocking patterns, as well as trajectory changes around obstacles and some individualized and randomized behavior.

Crowd Simulation

A combination of particle systems, physical simulation, and artificial intelligence, these fascinating systems allow animators to procedurally control the behavior of a very large number of CG characters. The spectacular battles in *The Lord of the Rings* or the hordes of zombies frantically scrambling up a wall in *World War Z* are good examples of VFX work that relies on crowd sims. The process starts by creating a library of rigged characters, along with a library of animated actions and reactions. Then a set of procedural rules (often quite complex) is set up. These rules control which action is triggered depending on the surrounding actions, and how the characters react and interact with their surroundings. Additional dynamic simulations are factored in for cloth and physical interaction, and some advanced crowd simulation systems even incorporate a sort of artificial intelligence that allows each character in the crowd to "choose" an action based on a variety of factors. It sounds exciting and it really is—but like any high-end simulation, this process is lengthy and expensive, and requires extensive team work, from modelers and texture artists to riggers, animators, and crowd sim programmers. The amount of work and the cost depends a lot on the scenario. For example, a crowd of cheering spectators in a football stadium might require much less work than a medieval battle scene. The first needs only a limited number of actions (sitting, standing up, waving arms, cheering, etc.) and almost no interaction between crowd members, while the second asks for a much larger library of complex actions and a very intricate set of interaction rules.

As mentioned in Chapter 2, crowd tiling is often used as a much less expensive alternative to CG crowd simulation. There is a clear advantage in using a crowd of real actors and extras instead of CG dummies, in terms of the action as well as the photorealism. However, like most 2D solutions, there are limitations when going this route, which will be discussed in Chapter 8.

Chapter 6

Workflow Case Studies

Now that we've gone through the various crafts of VFX, it's time to look at how they are combined in different scenarios, and how the various combinations affect budget and schedule. The cost of a shot is predominantly dictated by man-hours—the time spent to complete it as well as the number of artists working on it during that time. Thus, two shots that were completed in the same amount of time could potentially vary widely in price, depending on how many artists were involved. Additional costs take only a fraction of the final price in VFX. Come to think of it, there are no materials or special parts to be ordered, no transportation costs or municipal permits. Companies generally charge a certain amount for overhead expenses such as systems maintenance, hardware and software, rent and management. But this is usually a fixed amount and is not affected by a specific shot's complexity. It's mostly down to man-hours, and in this regard, it's also important to note that there's very little room in VFX for untrained low-pay employment. The majority of the work requires a high level of expertise and well-honed skills. In order to break down various pipeline combinations, I will analyze the VFX process on four different shots (three of them are actual shots we've worked on), each posing different challenges that require a different combination of artists and workflow. Even though each of these shots is no more than a few seconds in length, they vary immensely in VFX production time (from a few days to several months) and number of artists (from one to over a dozen).

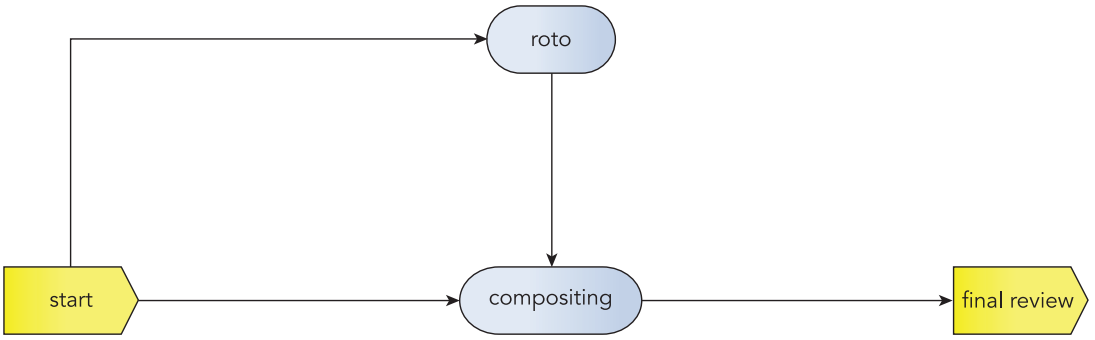
Shot 1: Background Cleanup

This is a classic fix-it shot from the film *Extremely Loud & Incredibly Close*. A big truck crossed the frame just behind the actors, and a passerby inadvertently stepped into the frame on the left. Both needed to be removed. Since the camera in this shot was locked off, there was no need for camera tracking. Removing the truck and passerby meant that the original background had to be put back in. In this specific shot, no matte painter was required because an unobstructed view of the background was available at the start of the shot just before the truck and passerby entered frame. When working on the shot, the compositor was able to use a still frame of that clean background (a "clean plate") to replace the removed elements. This part of the work was fairly easy, and took a day or so for a single compositor

to finish. However, the real challenge of the shot was the separation. Like most fix-it shots, this was never planned as a visual effects shot, and subsequently there was no green screen to help with the separation. The body of the actors and the objects around them were fairly easy to roto, but both actors' hair was not, especially since the truck was moving right "through" it. As discussed in Chapter 4, this type of difficult roto takes time, several days at least, so to speed up the process, a roto artist joined in to work just on the difficult sections while the compositor handled the rest. Still, if you compare the original footage to the comp you can see that some very wispy clumps of hair could not be fully resorted. This is sometimes a "necessary evil" when only roto is used to extract wispy elements from a busy background. Overall, with two artists working in tandem, this shot took four days to complete—putting it in the mid-range of fix-it shots in terms of time and cost.

Removing the truck and passerby.

Extremely Loud & Incredibly Close © Warner Bros., Scott Rudin Productions, Paramount Pictures. Visual effects by Brainstorm Digital.



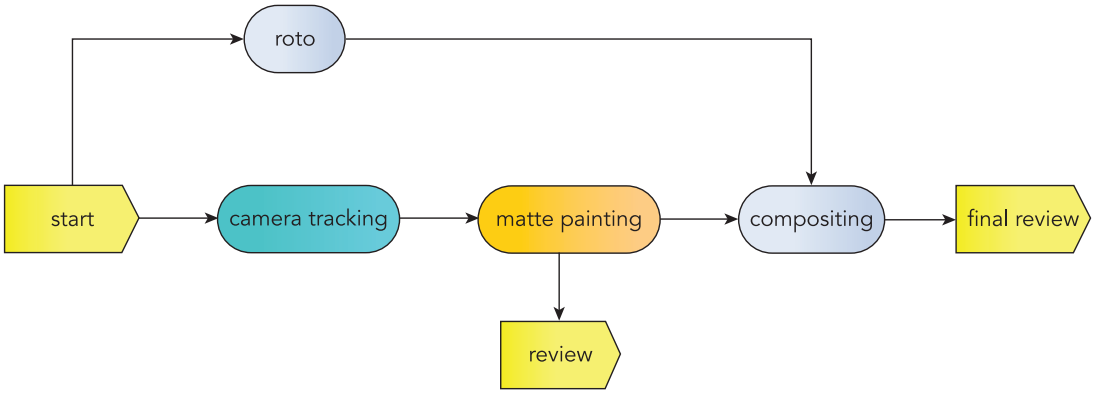
Shot 1: flow chart.

Shot 2: The Homestead Strike

This was an establishing shot from a scene depicting the unfolding of the Homestead Strike in *The Men Who Built America*. The camera craned up and pushed in to show a crowd of hundreds of protesters behind the barricade. The shot needed extensive crowd tiling as well as matte painting to change the modern background into a period accurate industrial environment. The technocrane move required a 3D camera track, since this type of vertical/forward motion produces parallax and perspective shift that affect the matte painting as well as the crowd. The additional crowd tiles were shot on green screen, but the actual shot with the foreground group of people was not (because a green screen would cover most of the background) so some hefty roto work was also required. Four artists worked on this shot:

The original footage and the finished comp with crowd tiling and matte painting.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.



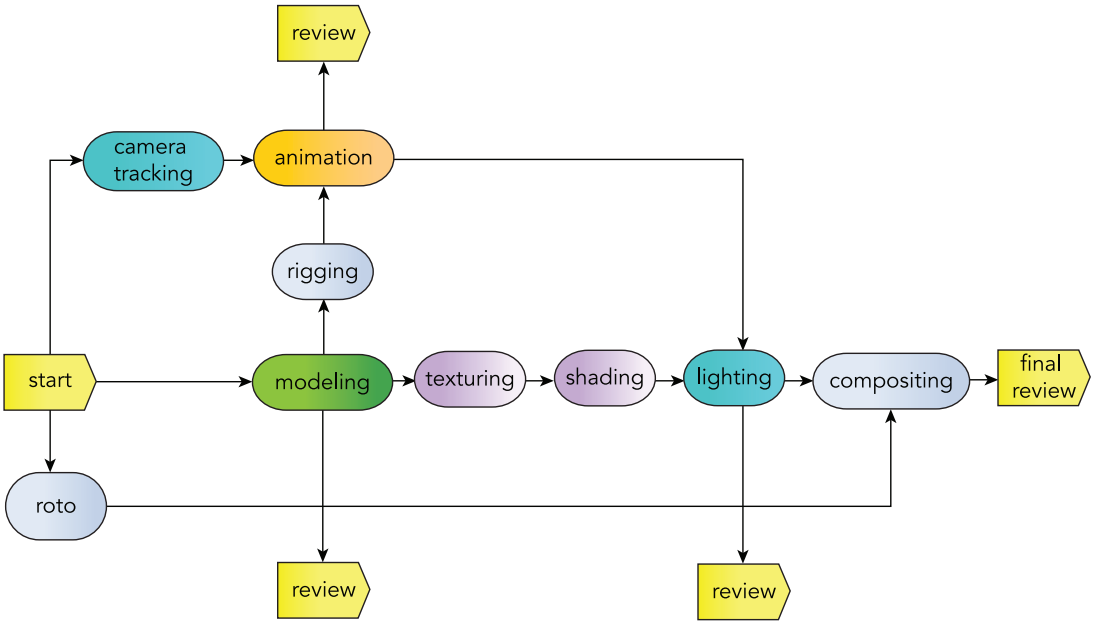
Shot 2: flow chart.

a matchmove artist for the camera tracking; a matte painter for modifying the background; a roto artist; and a compositor to extract the tiling plates and put everything together. Roto work started immediately while the matchmove artist was tracking the shot. Once the track was ready, the matte painter started working on the environment. The compositor joined in as well, updating the comp as the roto and matte painting work was progressing. Camera tracking took a day to complete, and the environment matte painting took about five days. Such a matte painting also requires feedback from the filmmakers—it is a prominent visual element in the shot—so we sent a single style frame for review and feedback even before the roto and comp were completed. It took about a week and a half of compositing to extract all the tiles, lay them down to create the crowd, work on integration and fine-tune the small details. With four artists and some of the work overlapping, the shot took a little less than two weeks to complete.

Shot 3: Piranha Attack

In this shot, two people get entangled in a fishing net underwater and are struggling to get free while being attacked by Piranhas. The actors were shot in a diving pool by an underwater camera operator. Green screen was never an option for this underwater shot—first, because it would be almost impossible to get a good extraction in a murky underwater environment, and second, because it would ruin the lighting (which was carefully set up to create an illusion of a natural river, and to hide the pool walls). Subsequently, extensive roto was required not only to separate the actors, but also the fishing net around them (to enable placing fish behind the net, in front of the actors and behind them). However, the main difference between this shot and the preceding two examples is the fact that it involves animated CG animals. This puts it squarely in an altogether higher category of complexity—which obviously reflects on both schedule and cost.

Concept art was not needed here, because the Red-Bellied Piranha is a real animal. But proper reference material was crucial—and we gathered still images and videos by shooting real Piranhas at the NY Aquarium and collecting additional reference from the web. This reference was used to study the look



Shot 3: flow chart.

and movement of the fish, and served a vital role in the process of creating and animating realistic Piranhas. The CG work required a modeler, a rigger, a texture artist, a lighting TD, and, of course, an animator. It also required a matchmove artist (since the camera was hand held), two roto artists, and a compositor. In all, nine artists worked on the shot at one point or another.

Some of the toughest challenges were replicating the erratic movements of Piranhas in feeding frenzy and integrating the fish into the murky backlit underwater environment. Overall, the work took several months to complete, from gathering reference material through preliminary animation tests to the final comp. But as I will explain, much of that time was spent on developing and testing the CG asset for the entire sequence—which meant that subsequent similar shots took considerably less time to complete.

Asset Work vs. Shot Work

When dealing with CG elements we can split the work into two categories: **asset work** and **shot-specific** work. An asset is usually a CG model or character that will feature in several shots or sequences. Therefore, the work spent on creating the asset does not need to be repeated for each shot. Asset work includes modeling, texturing, shading, and rigging. Shot-specific work includes tracking, animation, simulation, lighting, and compositing—tasks that depend on factors that differ from one shot to the other. Theoretically, the asset work can start even before the film has been shot. The designs and concept art serve as reference for the modeling work, after which the process moves into UV mapping,

texturing, shading, rigging, and simulation setups like cloth, hair, and fur. While some work can happen simultaneously, the process is fairly linear—for example, the model should be finalized before moving on to texturing, as changes in the model often require re-doing the UV mapping. On the other hand, shot specific work must be performed individually for each shot, even when re-using the same asset. The camera movement and lighting vary between shots, and the animation is obviously shot-specific.

Shot 4: Tsunami Mayhem

This shot is a wide overhead view of several city blocks getting hit by a tsunami wave. Hundreds of people frantically run away as the wave sweeps away cars, trees, and various objects; large glass windows explode and pieces of buildings fall into the water in big splashes. This is an example of a typical large-scale visual effects tour de force. Although we are looking at a massive amount of work here—from modeling and rigging to dynamic simulations of water and destruction—shots like this are quite common in most action/disaster/superhero movies, provided of course the budget can support the extensive work of a large VFX team. In this case I am not using an actual shot that we've worked on at Brainstorm. The

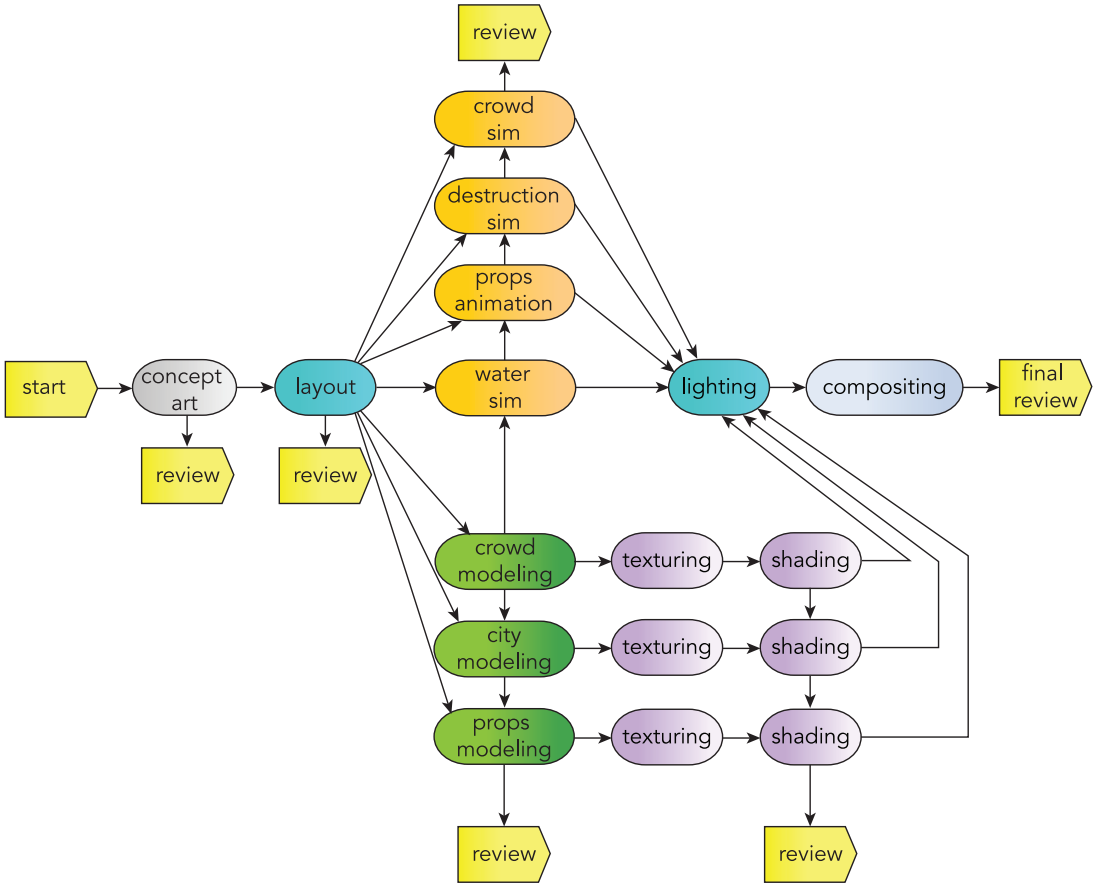
Although not quite the tsunami scenario described here, this shot from *San Andreas* represents a similar combination of massive water and destruction simulations, as well as all the related tasks like modeling, texturing, lighting, and compositing.

San Andreas © Village Roadshow Pictures, New Line Cinema, RatPac-Dune Entertainment, FPC, Warner Bros.

reason is simple: shots like this are barely within the capabilities of small or mid-sized companies, and are usually handled by large VFX facilities that have the necessary human and tech resources. I am not saying it's impossible for a small VFX team to handle such a shot, but the long time it will take to complete with limited resources makes it quite impractical within the parameters of a typical production schedule.

For this scenario, I am assuming that the director wants the entire city to be CG in order to be able to freely adjust the camera move (as opposed, say, to a helicopter shot of a real city, where the camera move is baked in). This requires building from scratch a substantial chunk of a city—a massive model when you think of all the detail that needs to go into it, the numerous additional vehicles and other props, and of course the various human models for the crowd. All these assets need to be designed, modeled, textured, and shaded, and any asset that will be animated needs to be rigged. The city model (or a low-poly version of it) can serve as a base for the layout artist to design the camera move, a critical step in a fully CG shot. The camera animation will dictate a lot of the action, so once the camera move is approved, simulation and animation work can start. Because of the complexity and scale of the dynamic simulations, several teams will be working in tandem, one on the water, one on the crowd, another one on destruction and debris. The tricky part is getting all these to work together, since there's obviously a strong dependency between the elements and the way that various events unfold. The water will most likely be the leading factor here, driving the destruction and the actions of the simulated crowd. The tweaking and refinement of the simulations is a slow and time-consuming process, and so is the final rendering of such a heavy scene. It's hard to predict the exact number of artists that will be contributing to such a shot at one point or another, but it would not be an exaggeration to estimate around ten or fifteen people, or even more. Successful completion of such a shot also requires adequate hardware like fast workstations and a powerful render farm, as well as tech support and system administrators to make sure that simulations and rendering all run smoothly.

Work on a shot like this, from concepts to final version, can stretch over a substantial period of time. During that time the filmmakers need to review the progress at different stages, from concepts and layout to specific models, look development, animation, and comp. Budget and schedule must be carefully (and realistically) calculated. Any attempt to squeeze such a shot into an unrealistic budget and timeframe is a sure recipe for failure. Moviegoers nowadays are accustomed to seeing these types of massive VFX shots, and, consequently, are much less lenient toward half-baked ones. Careful planning and a consistent and timely feedback loop are a must. The filmmakers need to be tuned into the process from start to finish—asking for major revisions or changing concept mid-way through or toward the end should be avoided. Reviewing and approving the work in progress at different steps through the process ensure that the final results are completed in time and on budget.



Shot 4: flow chart.

PART 3

VFX IN PRODUCTION

Chapter 7

Pre-production

A successful journey starts with a good plan—you wouldn't go on an Everest expedition without adequate preparation. Filmmakers know this, of course. They know that making a movie, while not exactly a mountaineering adventure, can be as challenging as crossing the Khumbu glacier. They know that the best way to successfully overcome the challenge is to carefully plot a path around obstacles and crevasses in advance. That's why filmmakers spend months, sometimes even years, planning, going over every shot and camera angle, designing the set and props and costumes, scouting for locations, refining the script, budgeting, casting, rehearsing . . . yet in too many films, all too often, the visual effects are pushed to the back end of the pre-production process. Maybe it is the fact that the bulk of the VFX work happens during the post-production period. "They'll fix it in post," "VFX are just the icing on the cake," "we've got more urgent matters to tackle right now," "the VFX guys can do anything"—these notions, while understandable, may eventually backfire on the filmmakers. Visual effects need every bit of attention and careful planning at the early stages as any other aspect of filmmaking.

If you've read through this book you are already aware of the many factors that affect the complexity and price of any given VFX shot. Many of these factors are directly related to the way the shot was filmed on set, and it is therefore crucial to plan these shots in advance, especially since so many things can go unexpectedly wrong. The pre-production period is a time to discuss all the VFX ideas, creative whims and wishes in context of practical and budgetary constraints, and come up with a solid game plan and specific solutions. It is a thrilling time where creative ideas start taking shape as storyboards, concept art, and previsualizations. It is also a time where the realities of VFX costs and various other limitations surface and must be confronted. The VFX post-production period can be generally broken up into these steps:

- Rough breakdown of potential VFX shots based on the script
- Preliminary bids and initial cost estimates
- Choosing the VFX supervisor, VFX producer, and VFX team/s
- Starting the conceptual and visual development of CG characters and environments
- Creating detailed plans and coming up with practical solutions through storyboards, VFX meetings, location scouts, and previs
- Finalizing the VFX budget and on-set plans.

Preliminary VFX Breakdown

The purpose of this very first step is to figure out, in very wide brush strokes, which scenes and shots might require visual effects, and to get an initial estimate of the scope of the VFX work for the specific project. With probably nothing more than the script at this stage, the director and producer go through it bit by bit and pencil in all the potential visual effect, with a short description of what is required. There's really no need to get too specific or figure out detailed solutions at this point, as this will happen later with the help of the VFX supervisor and VFX producer. Some things will inevitably change as pre-production kicks into high gear: the script will most likely go through additional revisions, and VFX shots will be added and dropped for practical or budgetary reasons. But at this stage, the preliminary VFX breakdown is used as a base for getting initial rough estimates and for sourcing a suitable VFX team (or several).

Since your VFX breakdown will be used for initial bidding, make sure that it has scene numbers that correspond to the script. At this early stage, there is usually no specific shot listing, so noting down an estimated number of shots per scene or per visual effect is acceptable—for example, "matte painting of distant ocean & ships, crowd tiling. 4 shots." It is totally fine to leave in question marks wherever ideas are still in flux or when you are unsure about the correct solution. Things will get clarified once the VFX supervisor and producer join in and the planning process starts. It's important to list **everything** at this point—even ideas you're not sure about or effects that you feel are beyond the scope or the budget. Things will naturally get filtered out as the process evolves.

The VFX Supervisor and VFX Producer

These two key roles can be roughly equated to a director and producer: the VFX supervisor is responsible for the creative, artistic, and technical side of the visual effects, while the VFX producer takes care of bidding, budgeting, and scheduling. Together they are responsible for the planning, design, and execution of the visual effects, and will work closely with the director, producer, and DP, as well as the production team, on-set crew, and VFX team/s from the early pre-production phase all the way to the final stages of post-production. VFX supervisors may come from different backgrounds: some started out as VFX artists, others come from cinematography or second unit directing. But whatever their roots, they need to serve as a bridge between the filmmakers and the VFX artists, and thus must have a very strong knowledge of both the on-set filmmaking side and the in-house VFX work. They should be able to successfully carry on the VFX production through the challenges of pre-production, on-set, and post-production, and be equally at ease talking to a director or a CG lead, DP or lighting TD, editor, or animator. When on set, the VFX supervisor should be able to look at a shot not only through the filmmaker's eyes, but also through the eyes of a compositor or matchmove artist. Likewise, when working with the VFX artists, he/she should keep a broader view of the film as a whole, while also looking at the specific technical and artistic details.

VFX producers, by nature of their role, do not necessarily need to know every nut and bolt in the VFX machine, but they certainly must have a deep understanding of the process. They should also be familiar

9	1.24	118_010	2	EXT. HUTCHINSON'S MANSION - NIGHT A large mansion…	Set extension. Assumes nodal camera move
10	1.37	130_010	1	EXT. BOSTON STREETS - DAY Commander Preston MARCHES DOWN the street…	Composite 2.5D Matte painting for top of set extension Assumes nodal camera move
11	1.43	136_010	1	EXT. HANCOCK'S MANSION - DAY The most MAGNIFICENT private residence in Boston	Set extension. Assumes nodal camera move
12	1.75	156_010	1	EXT. BOSTON HARBOR - DAY The Liberty. Pull out to reveal the SMALL SHIP	Composite 2.5D Matte Painting Boston Harbor Extension. Populate with distant CG boats, GS people plates and 2D water extension plates. Assume practical boat, dock and FG practical interactive water. Assumes nodal camera move
13	1.75	156_020	1	EXT. BOSTON HARBOR - DAY A Soldier WHACKS a Sailor across the face, BLOOD GUSHING	Blood spray enhancement to (possible makeup reveal for wound)
14	1.A55	146_010	1	EXT LONDON - DAY Wide and impressive shot of the PALACE OF WESTMINSTER	Matte painting, water plate. Assumes no people, carriages.
15	1.63	163_010	1	EXT. LONDON WHARF - DAY BRITISH REDCOATS on	**TO BE DISCUSSED FURTHER**

A page from a preliminary VFX shot breakdown for *Sons of Liberty*.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Courtesy of Brainstorm Digital.

with general film production processes. Choosing a VFX supervisor and producer is a vital step. The right people can make a huge difference, and directors naturally prefer to partner with VFX supervisors and producers they've worked with in the past. If you're looking for a new partnership, try to find a supervisor that is not only highly proficient and experienced but one that you feel at ease with. Sometimes good communication and mutual understanding are more important than credits and accolades. Think collaborators—these people are there to help you realize your creative goals, and this can only be achieved through intimate and honest interaction.

Traditionally, the VFX supervisor and producer are hired as part of the film's production team, and are not affiliated with the VFX facilities that will eventually do the VFX work. This is necessary on a VFX-heavy film, and especially in a multi-vendor scenario (when more than one VFX company works on the film). But for reasons I'll detail below, this arrangement is sometimes an overkill for low-budget films with a limited scope of VFX work. In such cases, it might be more economical to use the VFX company's in-house supervisor and producer. Let's examine these two models. . .

Model 1: Dedicated Production VFX Supervisor and Producer

By hiring a VFX supervisor and producer early on as part of the production crew you ensure that they are dedicated to the film and work closely with the director and producer from the early stages. As full-time members of the crew they are free of external liabilities and can attend every production meeting, and take part in every creative and budgetary decision along the way. Their familiarity with all aspects of production will become an important asset when several VFX companies are hired. It will enable the VFX supervisor and producer to handle both the creative and financial sides much more efficiently. There's also an obvious loyalty to the interests of the production that cannot be matched when the VFX supervisor and producer are being paid by the VFX company (the vendor in this case). As mentioned earlier, this model is absolutely crucial in VFX-heavy productions and when multiple companies are used. The mechanism of a multi-vendor scenario is very complex. The film's production VFX supervisor will be dealing with each company's in-house supervisors on a daily basis, while the production VFX producer will need to continually make sure everyone is operating on budget and on schedule. This heavy workload and complex management requires the full-time presence of production-hired VFX supervisor and producer.

While the advantages of this model are clear, there is a significant disadvantage: cost. Hiring a VFX supervisor and producer from the early stages of pre-production all the way to the very end of post-production means paying two full-time salaries over many months, and possibly a year (or even longer). Except for the director and producers, very few crew members are hired for such a length of time—most on-set crew is hired only for the shooting stage, while the editorial team only comes in for post-production, for example. When the extent of visual effects and the resources are limited, this money can be well spent somewhere else. Merging the roles of the VFX supervisor and producer into one is usually not a good solution. There are very few people who possess the skills and knowledge to do both successfully and handle the creative and budgetary aspects simultaneously. Instead, model 2 can be a more economical solution:

Model 2: Company In-house VFX Supervisor and Producer

Tapping into a specific VFX company at the early stages means that you can work with that company's in-house supervisor and producer. In that case, their daily salary is paid by the company, while production only needs to pay for on-set supervision when it's needed (most VFX companies will not charge extras for attending pre- or post-production meetings). This can be further minimized by planning in advance on which days the VFX supervisor actually needs to be on set, assuming that many shooting days might not involve VFX at all. Another advantage in this model is the fact that the VFX supervisor is intimately familiar with the capabilities of the VFX team, and can communicate directly with the artists. Likewise, the VFX producer has more flexibility in shuffling resources around to get the job done. While this model is much more economical, it works best when a single company does the majority of the VFX work on the movie. It also requires, for obvious reasons, a bigger involvement on the part of the filmmakers.

Preliminary Bidding

It's important to get an initial estimated cost for your film's VFX as soon as possible. Also, if you're not set on a specific VFX company to do the work at this point, sending the VFX breakdown to several companies and getting back a number of bids is a good way to get a sense of each company's suggested methodologies and overall approach, and of course shop for a good price. At this stage, it is usually mutually agreed that the pricing is a very rough estimate, and that many things will most likely change along the way.

There are several points to consider when sending out bids and reviewing them.

- Provide the bidder with all the information that you currently have. This includes the most up to date version of the script, your preliminary VFX breakdown and any specific notes or visual material (location photos, reference clips) you think might be useful.
- Be ready to answer questions and give clarifications, or better yet, walk the bidder first through your breakdown on the phone or in person. That way you can give a clearer idea of your vision and thoughts. You want the bidder to have the best possible understanding of what you're after so you can get back an accurate estimate.
- Ask for a detailed bid. Some companies do not specify the different tasks that each shot will require, according to their estimate. Instead, they only put down the total price, assuming the filmmakers are not interested in the methodology. You want a clear tasks list per shot/effect, such as: "Stormy ocean surface: Camera tracking, liquid simulation, lighting, compositing," or "Crowd tiling: 2D tracking, roto, compositing." This not only gives you a more detailed price breakdown, it also offers an indication of how the company is planning to solve and execute the specific effect or shot. If you've read the book thus far, you already know how important the methodology is, and how it can affect both the price and the final look.

Item #	EP.Sc	Asset #	# of Assets	Description	VFX Notes	Asset Cost	Extended	(ASSET +COMPS)
1	Misc	101	1	MATTE PAINTING - BOSTON STREETS **(DAY)**	2D Matte painting/set extension for anything above practical 2-story build. Various angles	$ [redacted]	$ [redacted]	$ [redacted]
2	Misc	102	1	MATTE PAINTING - BOSTON STREETS **(NIGHT)**	2D Matte painting/set extension for anything above practical 2-story build. Various angles	$ [redacted]	$ [redacted]	$ [redacted]
3	Misc	103	1	BOSTON HARBOR **(DAY)**	2.5D Matte painting. CG Ships. Water plates.	$ [redacted]	$ [redacted]	$ [redacted]
4	Misc	104	1	BOSTON HARBOR **(NIGHT)**	2.5D Matte painting. CG Ships. Water plates.	$ [redacted]	$ [redacted]	$ [redacted]
5	Misc	105	1	LIBERTY SHIP	3D CG /extension for masts above practical build	$ [redacted]	$ [redacted]	Part of "Harbor" comps above
6	1.24	106	1	EXT. HUTCHINSON'S MANSION	Matte painting / set extension for Hutchinson's mansion	$ [redacted]	$ [redacted]	$ [redacted]
7	1.43	107	1	EXT. HANCOCK'S MANSION	Matte painting for Hancock's mansion and surrounding environment	$ [redacted]	$ [redacted]	$ [redacted]
8	1.54	108		WESTMINSTER PALACE	Matte paintng, water plate	$ [redacted]	$ -	
9	1.85	109	1	HMS ROMNEY	3D CG Warship	$ [redacted]	$ [redacted]	$ [redacted]
Assets - Night 2								TOTAL COST (ASSET +COMPS)
Item #	EP.Sc	Asset #	# of Assets	Description	VFX Notes	Asset Cost	Extended	
10	Misc	201	1	CG WARSHIPS	3D CG Warships. 3 models to be modified for multiple uses	$ [redacted]	$ [redacted]	$ [redacted]
11	Misc	202	1	CG MERCHANT SHIPS	3D CG Merchant Ships. 1 model to be modified	$ [redacted]	$ [redacted]	$ [redacted]
12	2.38	202.5		EXT. HANCOCK'S MANSION	Matte painting for Hancock's mansion FROM GAGE'S POV and surrounding environment	$ [redacted]	$ -	
13	2.43	203		PHILADELPHIA	2.5D Matte painting of section of Philadelphia next to river (boats) **Assumes plates shot for people, horses, carriage movement**	$ [redacted]	$ -	
14	2.A43	204	1	PENNSYLVANIA STATE HOUSE	3D Bell Tower of State House and set extension of practical location(formerly a 2D matte painting)	$ [redacted]	$ [redacted]	$ [redacted]
15	2.A58	206	1	PHILADELPHIA STREETS	2D Matte painting/set extension	$ [redacted]	$ [redacted]	$ [redacted]

A page from Brainstorm Digital's *Sons of Liberty* budget. This page is taken from the first section where all the asset prices are listed. Each asset will be used in at least one shot; most will serve several, or an entire sequence. These assets include both CG elements like sail ships and matte painting assets like the Hancock Manor (I have redacted the prices for obvious reasons).

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Courtesy of Brainstorm Digital.

Inside the Bidding Process

To better evaluate a bid, you need to understand the underlying cost factors from the VFX company's point of view. Visual effects companies rarely charge by the hour or by work days. The reason is that most film studios and producers will never agree to such an arrangement. The creative, ever-changing nature of filmmaking means that work times on any given shot can extend substantially beyond the original budgeted estimate, and additional revisions, creative changes, new ideas, and re-cuts can easily lead to uncontrollable, detrimental VFX budget overruns if the VFX company is charging strictly by the hour. Most bids, therefore, consist of a fixed price per shot, based on the shot's complexity and

estimated total number of work days. This bidding system protects the production to a certain extent, but does put the VFX company in a somewhat precarious situation. Indeed, if the work on a shot extends significantly past the original estimate, the artists still need to be paid for the added days but the price remains the same—a loss for the company. Change orders are one acceptable way to overcome this. But they usually apply only when additional work is required, beyond the original bid. For example, if a shot was originally budgeted for adding a building in the background, and later on the filmmakers decide they want to add two more buildings, a change order that covers the additional work days will be issued. However, if the design and look of that single building goes through numerous revisions and changes, the shot can easily become a problem: there's no viable cause for a change order, but the work on the shot extends way past the original budget. The VFX industry is highly competitive, and companies opting to win a bid will rarely pad their prices heavily just to keep on the safe side. However, from a filmmaker's point of view, you should understand that realistic shot prices (rather than drop-dead minimums) are actually beneficial not only for the VFX company but also for your movie. Productions often shoot themselves in the foot by opting for the lowest bid or forcing the vendor to cut down prices to unrealistic minimums. At the end this leads to more money spent (not to mention frustration and loss of time) when the VFX team can't keep up the pace or preserve a certain quality of work because of lack of resources.

When shopping for a VFX company, do consider lower bids but be wary of sharply underpriced ones. Carefully examine the bid and compare to the others. The low pricing might be due to misinterpretation of the requested VFX, but you should be careful of over-optimistic pricing. Visual effects need the time and resources to be done properly, and you do want to base your decisions on a realistic estimate. Never hesitate to call back the bidder and ask for clarifications, or discuss anything that seems problematic. Bidding is far from an exact science, and the creative nature of filmmaking and VFX leaves a lot to interpretation. Mistakes can be made on either side, especially at the early stage—communication is the best way to ensure both you and the VFX company are given a fair chance to price the estimated body of work.

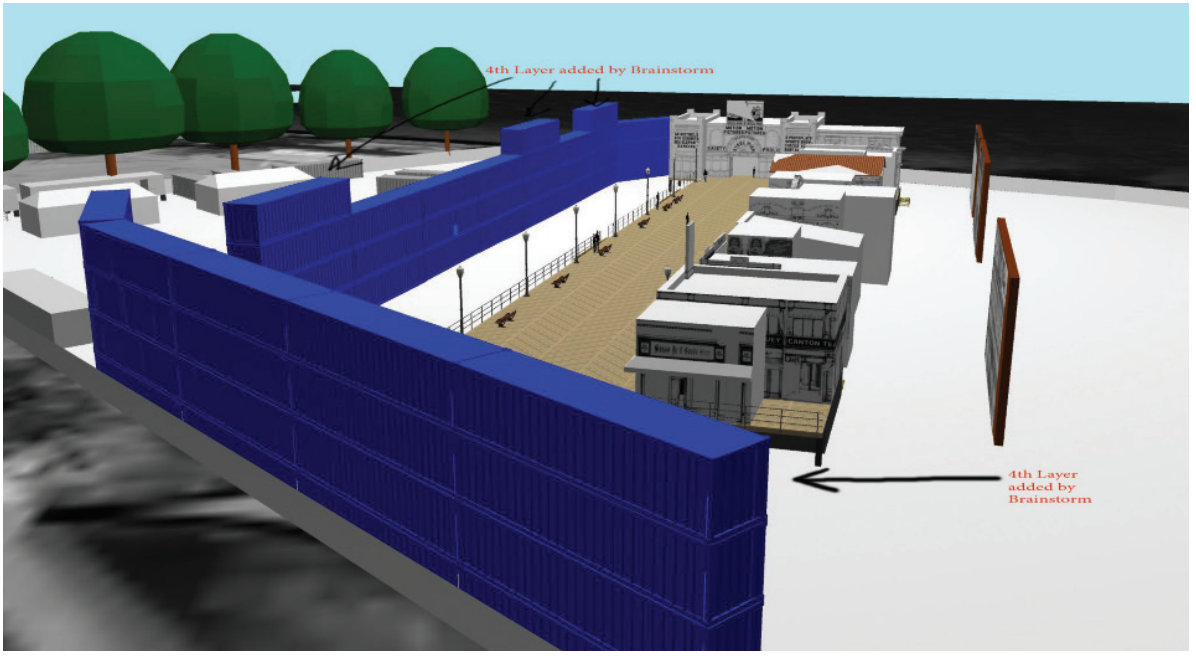
Storyboarding

As the director, DP, and first AD go through the shots one by one and plan the scene and camera angles and moves, they are often joined by a storyboard artist. I cannot stress enough how important storyboards are for the VFX team. They are tremendously helpful in figuring out the correct methodologies for every shot, as they not only show the action and framing but also the lens type (wide lens, long lens) and camera movement. Needless to say, storyboards also provide the on-set crew (and the director) with a framework and visual reference that helps plan the shooting day in advance. Storyboards are also very useful for the bidding and budgeting process as they provide the VFX team with a clear visual reference to the ideas of the director, so it is well worth it to hire a good storyboard artist early enough in pre-production. If the budget is limited, the storyboard artist should focus primarily on VFX shots, and those shots that are visually or logistically complicated.

Previs and Concept Art

In Chapter 5 I gave a short overview of these two pre-production VFX crafts. Whether previs is used in a certain project depends a lot on the filmmakers. Some directors tap into the possibilities of previs even for non-VFX films, simply because it allows them to preview and design the framing and camera movement in advance. Evidently, CG-heavy, complex shots benefit enormously from preliminary previsualization. The previs serves as a guide to the cinematographer, as well as other key crew members, and provides visual cues for those "imaginary" elements and characters that are not present on set but will be added later in post. But previs is not necessary for every type of VFX work, and often storyboards do the job just as well. If you choose to use previs, however, the decision should be taken early enough to allow sufficient time for the modeling and animation work. When the shots depend on a specific physical location, it is important to create an accurate depiction of that location in 3D. On *Boardwalk Empire*, for example, a Lidar scan of the Boardwalk set provided a base for our previs.

Concept art is invaluable for designing and developing CG elements. The more a movie relies on VFX for its environments and characters, the more concept art becomes a necessity. Ample time should be allocated for the process of revising the look and updating the concepts. Ideally, the filmmakers want to reach the shooting phase with a fairly established look, because once that shooting starts there will be hardly any time for concept development. That said, and as I mentioned in Chapter 5, CG work that is based mainly



A previs from *Boardwalk Empire*, showing the layout of the actual set, with the containers that were used to hold the giant blue screens.

Boardwalk Empire © Home Box Office (HBO).

on existing elements and relies on easily obtainable reference does not require concept work, and the same applies to productions where most of the VFX fall within the basic categories listed in Chapter 2.

VFX Production Meetings

Throughout the pre-production stage, it is important to have VFX meetings to iron out the details for the more complicated VFX shots and come up with a plan for setting them up on set. These meetings allow a face to face dialogue where creative and technical ideas and solutions are thrown in and discussed in a relatively relaxed environment—once the shooting phase starts things tend to get much more hectic and stressful. The meetings usually involve the supervisor and producer form the VFX side, and the director, line producer, and first AD from the production side. Additional department heads such as the DP, production designer, gaffer, stunt coordinator, and special effects supervisor may also join, depending on the type of shots discussed. The planning and design of VFX shots often requires a tight cooperation between the various departments, in particular camera, lighting, set design, and special effects. From the filmmaker's side, it is important to clearly lay out the creative vision while also being attentive to the issues brought forward by the VFX team and other departments. Unless the filmmakers enjoy an unlimited budget and schedule, a certain amount of pragmatism is usually needed at this phase to help the vision become reality. It is a collaborative problem-solving effort, and works best when the people involved are open to ideas and are not entrenched in their respective points of view. It is helpful to bring into the meetings all the material available at that point, such as production design sketches, set design blueprints, location photos, storyboards, reference material, concept art, and previs clips.

Tech Scouts

Also called crew location scouts (or "recce" in the UK), these tours allow the heads of departments to visit and study the various filming locations in person. For the VFX supervisor, this is an excellent opportunity to spot potential problems and limitations in terms of VFX-related needs such as green screen placement and rigging, and to discuss solutions with relevant heads of departments like lighting and grips. I have been in tech scouts that proved to be extremely useful not only for figuring out the planned VFX shots but also for discussing previously unplanned shots. Very often, HODs on the tech scouts discover an issue that is impossible (or too expensive) to tackle practically, and the filmmakers turn to the VFX supervisor and producer to check if a VFX solution is feasible instead. For example, during a scout of an open field location, it becomes clear that a bunch of unwanted cattle fences will be too complicated to remove practically. Being part of the discussion, the VFX supervisor and producer can get some needed information from the DP regarding planned camera angles and moves, and from the first AD regarding the action and position of actors and extras, and can roughly figure out the extent of 3D tracking and roto needed for removing those fences in post. They can then provide a cost estimate, thereby helping the filmmakers to come up with a decision on the spot. If the VFX people cannot attend the scout, or no scout is scheduled, it's a good idea to at least send a PA over to the location to take some stills that can be used to discuss a location in one of the VFX meetings.

Tech scout: walking toward the location.
Photo by Eran Dinur.

Detailed Budget and Schedule

As pre-production progresses, meetings are held, storyboards drawn, concepts and ideas narrowed down, previs produced, script tightened, and locations sorted out, the VFX shots and their methodologies become clearer and more defined. Consequently, the budget needs to be updated, since the original bid was only a preliminary estimate. By now, there is a lot more accurate information to work with, and many decisions have been made that allow for a more precise VFX budget. It is imperative at this stage, and before the shooting starts, to produce a comprehensive VFX budget along with a detailed schedule. Everything needs to be accounted for in the budget at this point, and the schedule must have times allocated for shooting the necessary VFX elements or tiling plates. The filmmakers and the VFX team need to have a clear idea of the scope of the visual effects and work together within these guidelines and constraints on set. The reality of filmmaking means that not everything will work out exactly as planned, which makes it even more important to have detailed budget to lean on and refer to during the on-set stage, and a well-planned schedule to adhere to.

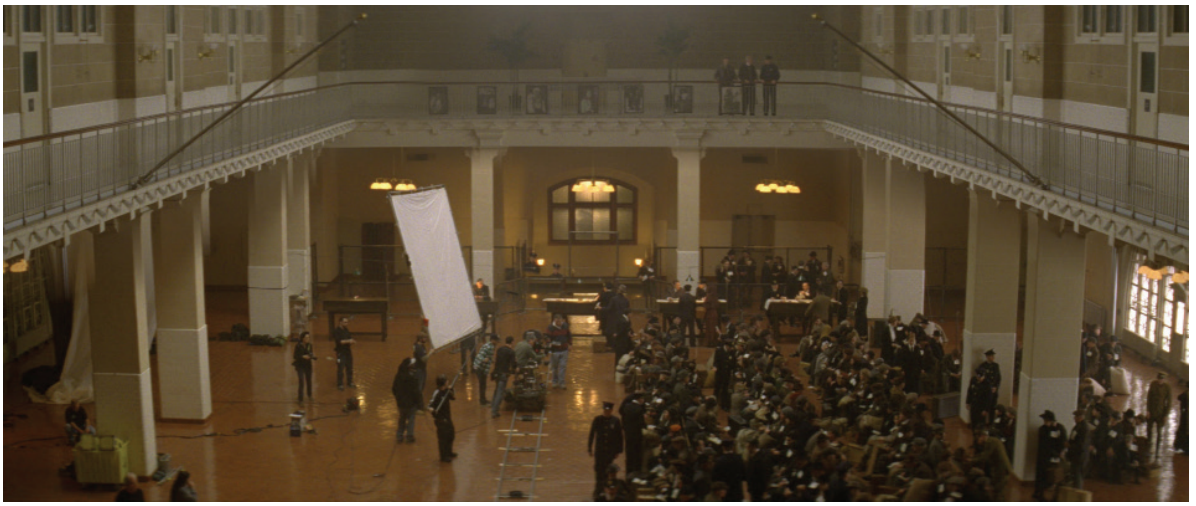
Case Study: Ellis Island

This is a good example to show the process of planning a VFX shot as part of a discourse between the various departments (locations, lighting, camera, AD). 1920 Ellis Island was a prominent location in *The Immigrant*, and a substantial part of the film takes place there. Director James Gray wanted an establishing daytime interior shot of the main hall, with a pan down that started on the upper balcony and ended with an overhead view of the main floor where hundreds of immigrants were being inspected by immigration officers. Several issues and limitations were brought up by various departments:

- Ellis Island is a museum, and allows shooting indoors only at night, after closing
- Shooting overnight required lighting outside the windows for a daytime effect; the lighting department said that due to several restrictions they could only set up exterior lighting for one of either sides of the hall, not both at the same time
- In addition, flooding the interior space with "daylight" could only be done by using large balloon lights, because the museum did not allow heavy rigging inside; such floating lights would of course block most of the upper floor
- The budget could only allow for enough extras to fill in about half the floor.

With these restrictions in mind, it was necessary to find a VFX solution that would allow shooting in the actual Ellis Island location and preserve the authenticity of this iconic place. After discussing with the director, first AD, line producer, and DP, we came up with a game plan: we would divide the frame into four quadrants, and shoot each quarter separately with a programmable repeat head to replicate the camera move precisely in each take. This is how it went.

1. Lights outside the windows were set up on one side of the building, and the balloon lights were lifted to the second tier, floating above the main floor. The crowd of extras playing the immigrants and immigration officers were placed on one half of the room, with careful attention not to have anyone crossing the exact centerline.
2. After a good take was shot, the extras were shuffled around within the same area, different actions were assigned, and we shot another take.
3. The next step was to clear the floor of the extras and remove the balloon lights. A few extras were moved over to the second-tier balcony. We then shot a few more takes.
4. During post-production, and after editorial selected two takes for the bottom half and two for the upper half, we mirrored and stitched each pair, then stitched both halves to create one seamless shot. Of course, it wasn't as easy as it sounds, as the anamorphic lens distortion and very slight shifts between the takes did require some work, and areas around the center stitches needed some additional matte painting work to tie them seamlessly, but the plan worked well and the shot was successful.



The interior Ellis Island shot. This is the original footage, with extras occupying half of the floor, and the windows lit on one side only (notice that the flags have been removed to allow more control in post).

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

The same frame, after mirroring and stitching the two takes, and adding CG flags.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

The balloon lights at the top tier.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

The upper tier after mirroring and stitching two clean takes.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

Chapter 8

On Set

All the writing and re-writing, planning, budgeting, scouting, designing, building, casting, rehearsing—all these months (or even years) of pre-production work culminate in the shooting period. The long preparations for the Everest expedition are complete; it's time for the actual climb—and it will likely be a condensed, exhilarating, adrenaline-charged experience, not without bumps and obstacles, of course, but hopefully a successful journey from which a movie will be born.

From the VFX standpoint, the complexity and price of the work is determined, to a great extent, by the way the shots are captured on set and the attention they receive. Proper planning during pre-production, as discussed in the previous chapter, plays a crucial role here. But no matter how well planned the shots are, there's bound to be unexpected obstacles along the way. After all, there are so many factors that can affect any shooting day, from bad weather and transportation issues to technical malfunctions and miscommunications. It is therefore important to have a VFX supervisor on the set. When the director, first AD, DP, and script supervisor are all busy and under stress, small issues that can save a lot of time and money later in post-production are easily overlooked. The VFX supervisor focuses on those issues, and can communicate directly with other department heads to solve them on the spot.

The VFX supervisor is often accompanied by a data wrangler, who is responsible for acquiring visual and technical information that is necessary for executing the VFX shots (more on this later in this chapter). Usually the VFX producer will also be present on set, to make sure everything is kept within the budget and to work alongside the line producer. There are times, however, when no VFX person is present on set. This can happen, for example, when a shot that was not originally planned for visual effects suddenly requires VFX because of an unexpected limitation, or when the director comes up with a new idea that requires VFX on the spot. Regardless of whether there is a VFX team on set or not, directors, assistant directors, cinematographers, SFX crew, script supervisors, gaffers, grips, set designers, and other crew members can all benefit from a better understanding of the requirements of a visual effects shot.

Shooting VFX Elements

Shooting VFX elements is an important, often crucial, part of the process. It doesn't take more than small mistake, a detail that goes unnoticed, or disregard to a seemingly unimportant factor to turn a much needed element into a completely unusable piece of footage. Often, a quick adjustment or an extra half hour to set things properly is all that's needed. But the reality is that VFX elements shoots are often

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Boardwalk Empire – Ep 101 VFX Plate Shoot

Day Of Shoot (if possible)

#	SCENE	SEQUENCE	PLATE/ELEMENT	VFX NOTES	NOTES
1	1, 2, 47, 75	Atlantic Ocean, Gardner's dock	Fog	Fog against black or the night with side light	
2	1	Atlantic Ocean	Bootlegger Boats		
3	10, 22, 34, 36, 43, 65, 67-69, 84	Boardwalk	Crowd Replication	**Day and Night lighting.** Various actions for use throughout. Especially for costuming, set and prop interactions (i.e. rolling chairs, store entrances)	
4	1, 2,10, 34, 43, 48	Boardwalk, Gardner's Basin	Horizon Ref	**Over exposure or Speed change to give vfx horizon line reference**	
5	11, 73	Sewell Avenue	Building replication	Need Elements for extending the bungalows in both directions and oposite side of street	
6	23	Margaret Beaten	Window reflection plate	To be filmed without glass in window	
7	25, 33	Fish Haul	Fish	For posibble fish replication	
8	35	Movie Theater	Crowd tiling		
9	42	Boxing Arena	Crowd tiling		
10	44, 50	Eddie Cantor	Crowd tiling		
11	44, 50	Eddie Cantor	Foot lights	Shoot against green for more control	

A page from a VFX plates list, *Boardwalk Empire*.

Boardwalk Empire © Home Box Office (HBO), courtesy of Brainstorm Digital.

pushed to the back end of the day's schedule, and when the clock is ticking and the crew is tired, things tend to get rushed. Understandably, getting the actual shots and the lead performances is always first priority. But it is important to remember that those VFX elements ARE a part of the shot, sometimes an indispensable part. The guidelines and suggestions that follow are meant to help you get both the main action and the VFX elements on schedule, and ensure that the elements are shot in an optimal way.

To be clear, a VFX element can be anything that is captured separately and used in another shot (the element often needs to be separated from the background via roto or green screen). Elements can be a single person or a group, crowds, objects, specials effects such as explosions, smoke or blood squibs, backgrounds, environments, skies, etc. Regardless of what the element is, the importance is to know where and how the element will be used. VFX elements can be generally divided into two categories: **shot-specific** elements; and **generic** elements. The first category includes elements that will be used in a particular shot, which mandates a strong coherence in lighting, camera angle, and lens type between the original "master" shot and its accompanying VFX element/s. Crowd tiling is a good example (and will be discussed separately later in the chapter). Generic elements on the other hand are intended to be used in any number of different shots (or be part of a library of elements), and therefore must be shot in a way that makes them usable in a variety of scenarios. As I go through the guidelines, I will specify the difference in approaches for each category.

Camera Movement

No human can repeat a camera move precisely. Highly skilled camera operators and dolly grips may get a pretty close match, but pretty close is just not enough for VFX. The slightest mismatch, slip or slide in camera movement is immediately noticeable and is an absolute shot killer. VFX elements must be precisely tracked to the shot, and nothing should be floating around loosely. It is therefore absolutely crucial to shoot VFX elements with a **fully locked off** camera, so that they can later be tracked to the master shot by the VFX team. The camera should be mounted on a sturdy base to prevent any vibrations or accidental movement. It is true that footage can be stabilized in post to a certain extent, but the motion blur, perspective shift and parallax that result from a jittery camera cannot be undone. A hand-held camera is therefore not an option for shooting VFX elements. This rule applies equally to generic and shot-specific elements. The only exception is when a **motion-controlled** camera is used. High quality motion control rigs let you program a move and repeat it over and over with full accuracy. They are expensive and take the extra time to set up, but they are indispensable for complex VFX shots that involve wide, sweeping camera moves and require several repeated shooting passes for different elements (like the Ellis Island example in the previous chapter). The more advanced motion control systems can also output exact motion data that saves a lot of time and money on camera tracking. That said, for any other manually controlled camera, the rule for shooting VFX elements is simple: keep the camera static.

Camera Angle and Position

If the elements are **shot-specific**, it's very important to **match the master shot's camera angle** as closely as possible. For example, if the master plate was shot from a high angle and tilted down, the elements will not work in terms of perspective if they are shot from a straight or low angle. For this reason, you should always get the master shot first before shooting elements for it. The distance of the object from the camera is important mainly when using a wide lens, because the perspective distortion on objects that are close to the lens is much stronger than for distant ones (more on this in the next section).

Matching the camera angle for the element is easy if the master shot was a locked-off, and can usually be "eyeballed" by the camera operator simply by looking at a single frame of the master shot. However, if

Replacing the NYC house with a Victorian London house on *The Wolf of Wall Street*. Our VFX work on this shot went very smoothly, mainly because the movie's second unit made sure to match the original camera's lens, position, and angle precisely when they shot the London plate.

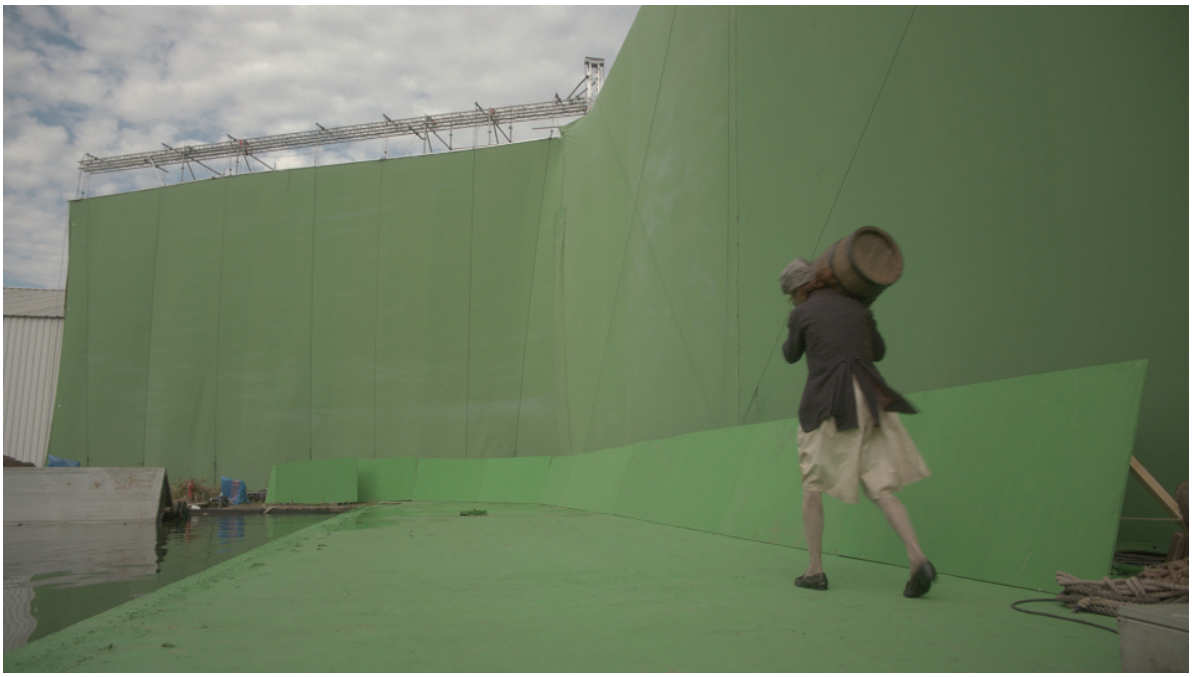
The Wolf of Wall Street © Paramount Pictures, Red Granite Pictures, Appian Way, Sikelia Productions, EMJAG Productions. Visual effects by Brainstorm Digital.

the camera was moving, the camera operator needs to pick one position/angle along the move and lock the camera to that position for the elements shoot. Usually, it's best to choose a **position/angle that's roughly mid-way through the move**, to minimize the amount of stretching on the element when it is projected on a card in 3D space.

Generic elements, on the other hand, should always be shot at a **straight angle**. It is much easier for the VFX team to add some fake perspective skew to a 2D element than try to undo one that is already baked in. Generic elements that are shot from an extreme low or high angle will be of very limited use. As for position, it's best to try to get as close as possible to maximize resolution and the amount of detail, as long as a medium lens is used and the element does not break frame (see below).

Lens Type

Ideally, **shot-specific** elements should be captured with the **same lens** that was used in the master shot. However, this only works when the angle and the distance are also matched. For example, a wide lens will characteristically produce more perspective distortion on objects that are close to the lens, while objects in the distance will be much less distorted. So, if you are generating elements that are intended



For this element, a wide lens and a low angle were needed to match the shot. A setup such as this, however, is not really suitable for generic elements—the wide lens exaggerates perspective and the low angle will not work for most shots.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Courtesy of Brainstorm Digital.

to be composited in the distance, but actually shoot them much closer to the camera, you will be adding unwanted distortion. This will make it hard (or impossible) for the VFX team to get the elements to look right in the shot, since perspective distortion cannot be easily undone. Bottom line: if you can place the objects where they need to be, then go ahead and match the lens to the master shot. But if you can't match the distance (because of physical set limitations or because you want to capture the elements at full resolution), then it is best to use a **medium lens**, which will minimize perspective distortion regardless of the distance.

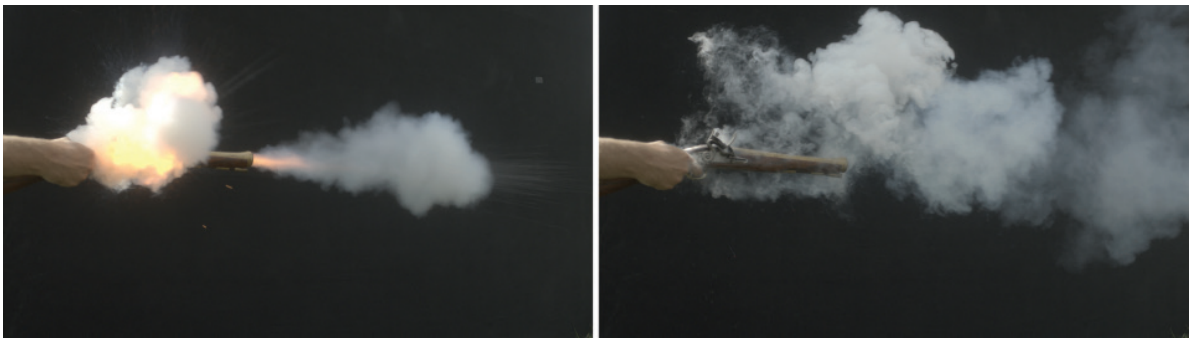
As for **generic elements**, wide angle lenses should be avoided, because the perspective distortion drastically reduces the usability of the elements. As I said before, "faking" perspective distortion is easier than removing it. **35–65mm lenses** are best for generic elements, as they are neither too wide nor too long.

Framing

An element that breaks frame is no longer usable. Even if most of it is in frame, or it's in frame most of the time, the part or the moment when it breaks frame is still unusable. Filmmakers often ignore a little frame-breaking, assuming that having "most" of the element in frame is good enough, and that the VFX team will somehow recreate the missing parts. An element that breaks frame is sharply cut off at the frame edge. Think of it: if the element is an explosion for example, the VFX team will need to use additional elements and seamlessly blend them in to extend the missing pieces, or even trash the element footage and go for a full-on CG simulation. Imagine what it will take to extend or recreate an actor who goes, partially or fully out of frame. Whether it needs to be extended in 2D or 3D, the outcome is similar: an element that was originally shot to save time and money will now cost a lot more just to be "fixed," when in fact this could have been prevented by simply moving the camera back a bit or instructing the actor not to step beyond a certain boundary.

For **generic elements**, it is of course crucial to **keep everything in frame**. This is easy when the element is a defined entity such as a person or an object, and a bit more challenging with amorphous and unpredictable elements like smoke, splashes, charges, or debris. Large explosions are especially hard to frame because they are usually a one-off event that can't be rehearsed. When in doubt, remember that it's usually preferable to have the element smaller but within frame than larger but breaking frame.

When trying to keep an element in frame, it is preferable by far to **move the camera back** rather than switch to a wider lens. (As already discussed, you really want to avoid the perspective distortion of wide lenses.) Shot-specific elements are somewhat different—it makes sense that if the angle, distance, and lens are matched to the master shot, then elements can naturally break frame as they would do in the master shot. Still, I always recommend pulling the camera back slightly to add a bit of a buffer area in frame. The VFX team can always push back in, and having a few more pixels on the edges is always a good safety measure.



This muzzle flash/smoke element looks great on the first frames, but a few frames later the smoke shoots forward and breaks frame right, making it quite unusable as a generic element, except for extreme close-up situations. If on the first take the element breaks frame, the best thing to do is push the camera back. It is usually better to have the element smaller in frame than to have it break frame.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Courtesy of Brainstorm Digital.

Choosing the Right Background

Since in most cases the element will be separated from the background, it's important to make sure that the background allows for successful extraction or roto work. I am often asked on set about the preferred type of background for a specific element. Should it be a green screen? Black screen? Or maybe a plain gray or white background?

Let's first rule out **white**—it's a terrible choice for a background. Having no saturated hue, it cannot work as an extractable color like green, and in addition it will brighten up any edge that's not 100% solid, making it very hard to comp the element over any background but the brightest. In short, do not use a white background.

Gray, like white, is not extractable, but at least will not brighten the edges and will work better over a variety of comped backgrounds. If a green screen is not available and roto is the only option, a solid gray cement wall or a gray panel will at least provide consistent background without too much contrast or saturated colors.

A **green screen** (or blue screen if the element has green in it) should be used for most types of elements. It is the best choice for extraction and will usually turn out to be the most economical choice down the line, provided it is properly set up. (In the next section I will discuss setting up green screens in detail.)

A **black screen** is a preferable background for elements that are extracted using luminance rather than hue. This includes self-illuminated elements like fire, flames, muzzle flashes, lights, flares and sparks, as well as bright white elements such as steam, white smoke, snow, and rain. For all these elements, a black screen provides more contrast between foreground and background than a green screen, and preserves the original color of the element, since no spill or green bleed is present.

There are certain circumstances when **no screen** can be used as a backdrop—for example, when shooting explosions that are too large to be covered by a screen. In such cases, it is always better to shoot against

The explosion element used here was too big to be shot against a green screen. Instead, it was shot against a clear sky, a "poor man's blue screen" of sorts.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

a relatively consistent background. Overcast or uniformly blue sky are preferable to partially cloudy skies. A clean concrete wall is better than a brick wall. Luminous elements like explosions can also be shot against a dark night sky as a natural replacement for a black screen.

Frame Rate

There are advantages in shooting elements at a higher frame rate. Special effects that need to appear much larger than their actual size (a giant water splash or a big explosion) are usually timed slower to feel bigger—this is a venerable well-known trick for miniature work. Shooting an element at 48fps means that the VFX artists can smoothly play it two times slower, without the degrading artifacts of artificial retime. Double, triple, or even quadruple frame rates are quite feasible with digital cameras, so it's becoming common practice to shoot all generic elements at higher frame rates. It's probably worth it—even if the element will not be slowed down, it doesn't hurt to have that option in store. The only difference will be a certain lack of motion blur on fast-moving elements. This is hardly an issue since motion blur can be added back when the slow-motion element is retimed back to actual speed.

When it comes to shot-specific elements though, shooting at a different frame rate than the master shot does not make much sense (unless of course, the idea is to have that element move in a different speed than the rest of the shot, as part of the effect). Normally, you'd want to keep everything looking the same and seamlessly integrated, which means shooting the element at the same frame rate as the master shot.

Green Screens

In Chapter 4 I discussed green screens from the compositing stand point—the challenges of extraction, soft edges and integrating green screen footage with a different background. But the success of a green screen shot undeniably starts on the set. A bad green screen setup can easily transform a relatively

straightforward VFX shot into a nightmare. What was supposed to be a day worth of compositing may turn into a week of struggle. The truth is that it does not take a whole lot of work or expertise to set up a proper green screen shot—often the setup is botched by simple lack of attention or unintentional neglect rather than difficult conditions or lack of resources. In other words, an extra ten minutes of straightening some folds or slightly rotating the screen can save hours, if not days, of VFX work down the line.

Action Coverage

"Keep it away and keep it inside" is the motto here. This refers to the action, not the screen. Actors or other subjects should never stand too close to the green screen. A proximity of less than 5 to 7 feet (depending on the lighting and the size of the screen) puts the actor into the "death zone" of extreme spill and light bounce. As I said in Chapter 4, small or moderate amounts of spill can be corrected in comp, but there's a certain point where excessive spill and light bounce affects the color, contrast, and overall look of the subject in a way that is very hard to correct. Additionally, when a subject is bathed in heavy green spill, it might be altogether impossible to extract, as the extraction algorithm cannot make a clear distinction between the subject and the screen. Because the green screen is bright and saturated, it acts as a strong light reflector, creating an unnatural backlit edge on the subjects, so keep the action a safe distance from the screen.

Consequently, "keep it inside" means that you should always use a screen that is large enough to cover all the action in the designated area. By "designated area" I mean the specific area that will need to be replaced or treated by VFX. For example, if the shot is a wide street view, and only one façade needs to be replaced, only that façade needs to be covered by green. On the other hand, if the entire background needs to be replaced, then the screen must cover the entire action area.

It is not unusual that action goes beyond the edge of the screen. This can happen because the size of the screen was miscalculated, a smaller screen was used due to rigging limitations, or a suitably sized screen was simply not available. It can also happen because the actors are not aware of the perimeter of the safe action area. There's a common assumption that it's good enough to have "most" of the action within the screen, and that a little bit of overflow is negligible. But as I explained in Chapter 4, roto is much more limited than extraction when it comes to wispy or semi-transparent edges like hair, or areas of motion blur or defocus. Because of that, there can be a very noticeable drop in extraction quality between the areas that were on the green screen and those that spilled out.

Green screens come in various sizes, so planning is key here. It's a fine balance between not going overboard (large screens take more time to set up and require more rigging for stability and safety) and making sure the action is fully covered. A minimum distance from the screen should also be factored in. The farther away the screen is from the subject, the larger it needs to be. It's also important to remember that the screen only needs to cover the action and areas we want to keep. Anything else can be simply discarded and replaced. So if, for example, the action area is just a quarter of the frame, and the rest does not require any separation, there's absolutely no need to set up a giant screen to cover the entire frame.

It is always wise to scout the location with the relevant department heads—VFX, camera, grips, and lighting—and discuss the possibilities and limitation in order to come up with a clear plan for the size and position of the screen, the action area and coverage, the camera moves, rigging, and lighting.

Screen Consistency

Since green screen extraction relies on color values, it is important to make sure that the screen is uniform and consistent. Ideally, a green screen should have the same exact hue and luminosity values across its entire surface. In reality though, green screens are never 100% perfect. Lighting and set limitations often mean slight variations in color, and seasoned compositors can usually handle these minor inconsistencies well. However, areas of strong discoloration, dirt, holes, folds, shadows, and unbalanced lighting can seriously hamper the extraction, or even render the screen totally unusable. Fortunately, many of these issues can easily be avoided by proper handling and rigging of the screen:

DIRT AND TEARS Dirt creates areas of discoloration that will not extract properly. Even small spots that seem rather harmless on set may force the compositor into additional paint or roto work. Tears and holes in the screen may be bright or dark, depending on what's behind the screen, but either way they will not extract. Green screens should be properly maintained and cleaned up after extensive use, and again when they are fully rigged and stretched. Holes and tears can be temporarily fixed on set with green tape. An extremely dirty, blotchy or discolored green screen will simply not serve its purpose and is better avoided altogether.

FOLDS Green screens are usually stored folded, and have noticeable fold lines and creases when unfolded. These can be straightened out by tightly stretching the screen on a frame. If the screen is not properly stretched and tightened, even unassuming small folds or bends create areas of varying shadows which can become an extraction problem. Wind can make things even worse, causing those parts of the

Folds and varying levels of brightness on the screen appear as inconsistent areas in the extraction on the right. The more even the screen is, the cleaner the extraction is.

Courtesy of fxphd/Eduardo Abon.

screen that are not tightened to the frame to wave and flap, generating shadows that constantly move and shift. Working with different key grips on different projects, I have seen quite a few different methods for rigging large green screens outdoors. Here's one method, which seems to work very well: The screen is tightly attached to a sturdy aluminum frame, and then mounted on a Genie crane or scissor lift. This provides both a solid base without the need for additional rigging to keep the screen upright and stable, and offers the added bonus of easy mobility and flexibility. Adjustments to the position and orientation of the screen can therefore be done quickly, without the hassle of disconnecting and reconnecting support rigs and cables.

NON-GREEN PARTS It's important to make sure that every part of the screen is indeed green (unless this part is outside the action area). The usual suspects are metal or black frame pieces and rigs. For example, it's quite common to place two green screens side by side to cover a wider area, which means that there could be some exposed metal frames right in the middle of the screen. Often these areas look insignificant on the monitor, but become a real problem in comp. The extra time and cost involved in fixing such areas during post can be easily eliminated by taking a few minutes to wrap up non-green areas with smaller pieces of green material or green gaffer tape.

Cast Shadows

If there is one issue that should be avoided at all costs, it is strong sunlight or key light shadows on the green screen. These shadows are more likely when a green screen is shot outdoors on a sunny day, and can be cast by adjacent structures, set pieces, rigs, another green screen at a different angle, or the actors themselves. The huge drop in luminosity and hue between the lit and shadowed areas practically splits the screen into different extraction zones, which causes a whole slew of problems as subjects move between these zones. The simplest solution is to make sure the green screen is completely in shadow. Knowing the sun trajectory on the given day (there are several mobile apps for that), you can plan the placement and orientation of the screen to avoid potential direct sunlight. When screen placement is limited by terrain or set features, cast shadows can still be eliminated by blocking the sunlight with black screens. If the action area and screen are too wide to be fully protected from direct light, it might be wise to wait for some cloud cover. If the sky is clear and all else fails, some additional light on the shadowed areas can at least somewhat reduce contrast and the intensity of the cast shadow, though this is hardly an ideal solution.

There are circumstances in which cast shadows are simply unavoidable. For example, in *Sons of Liberty*, the main Boston harbor set had a very large L-shaped green screen wall that covered pretty much the entire background. (This was necessary because the set was not built in a port, not even close to a sea or any body of water, but rather in a backlot near Bucharest, Romania.) Because of the size of this green screen it had to be solidly and permanently built into the set, so moving it around was not an option. Unfortunately, the sky was clear and the sun was brightly shining on every single day, which meant that for a substantial part of the day, the shorter side of the L-shaped wall was casting a strong shadow onto the main front part of the screen. Not only did we have to roto the right half of the green screen because it was too dark for a clean extraction, but we also had to carefully treat every person that

This type of strong drop shadow on the screen should be avoided—though in this particular case there was not much to be done, as the screens were not adjustable. Sometimes such large green screen setup is built at an angle that takes into consideration the sun's trajectory during the day. But this of course is not always possible.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

crossed between the sunny and shadowed areas. Needless to say that comp times went much longer than originally budgeted. But in this particular instance, there was no practical solution on set. The best thing a VFX supervisor can do is such a situation is alert the filmmakers to the fact that the complexity of the green screen work may increase, and the best thing a filmmaker can do is take into account that costs and schedule might be affected.

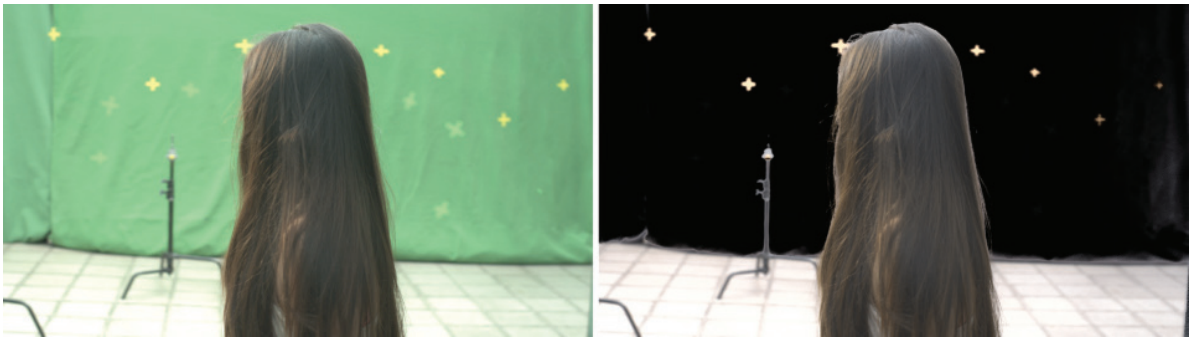
Tracking Markers

As discussed in Chapter 5, successful camera tracking depends on having enough static features in the frame to track to. So, when a green screen blocks most of frame and the camera is moving, tracking markers become a true necessity. (The tracking software needs to track visible features; a green screen is just too uniform and smooth.) Markers are usually small X shapes made with two pieces of tape. There should be enough markers on the screen to cover the camera move and ensure that there will always be at least three or more markers visible in frame at any point through the move. Since standard gaffer tape sticks easily to the screen and comes off as easy, trackers can be quickly placed, removed, and readjusted as necessary as the camera move is rehearsed. Marker size should be kept at minimum—just large

enough to be visible in the monitor. When the screen is heavily defocused, you might need to make the markers larger, but in general it is not so important to see the actual X shape, tracking software can still lock on to a small blurry blob, as long as it is discernible from the background.

The main question about tracking markers on a green screen is: what color? One of the most common assumptions is that the tracking markers need to be of a different color than the screen to "stand out." I have seen yellow, pink, red, white, and even black markers on green screens. All these colors are not only unnecessary, they are totally counter-productive, as they do not extract at all. The compositor will subsequently need to carefully paint out each and every marker, frame by frame. This is an especially delicate process when the markers appear behind hair and other wispy or semi-transparent areas. The only tracking marker color that should be used on a green screen is green. You just need to make sure the marker is of a slightly different shade of green than the screen. On a bright ("Digi") screen, use a darker green tape; on a deeper ("Chroma") screen, use a slightly brighter tape. Check your markers in the monitor—if you can see them, then the tracking software will most definitely see them. And the fact that they are still a shade of green makes them very easy to extract along with the rest of the green screen. So, the rule is simple: green markers on a green screen, blue on a blue screen—same color of the screen, just a slightly different shade.

There's another aspect of tracking green screens that needs attention. As I explained in Chapters 3 and 5, 3D tracking solves the camera movement by calculating the parallax between different tracking points. For this to be successful, the camera tracker needs to be able to track points that are at different distances from the camera. The points on a green screen are on the same plane, and if the screen covers most or all of the frame there's not much else to track to, as anything behind the screen is hidden. If there are no static objects in front of the screen that can be used for tracking, it is recommended to add some markers between the camera and the screen at varying distances. This is usually done by attaching a small card with an X to a standard C-stand and placing a few of those between the subject and the screen. (Obviously, it is not a good idea to place them in front of the subject.) The important thing is to make sure that the stands and the cards are all painted or taped



Yellow and green tracking markers. Notice how the green markers go away with the rest of the screen, but the yellow ones stay, and require frame-by-frame paint-out when they intersect the subject (see the marker that crosses right behind her hair).

Courtesy of fxphd/Eduardo Abon.

green to eliminate any extraction obstacles. The decision whether to add "in-between" markers depends on the camera move (a pan or small move might not even require 3D tracking and can be handled with a simple 2D track), as well as the amount of visible static background and foreground features.

Smoke and Atmospherics

This is where things become a bit tricky. Ideally, green (or blue) screen shots should be kept completely clean. Indeed, it does not make sense to cover the green screen with smoke or fog, as this will make it very hard (or impossible) to extract. Also, all this smoke will be cut out and discarded anyway, so it might seem like a total waste to have it there in the first place. Generally speaking, green screen shots are better off without atmospheric effects like smoke, fog and steam.

There are, however, good reasons to make exceptions to this rule. I have worked, more than once, with DPs who rely heavily on smoke and mist to shape the light, texture, and "feel" of their shots. On such films, and especially if surrounding non-VFX shots all have smoke and fog, a clean shot will feel strangely out of place. While smoke and other atmospheric effects can be added as VFX, it is usually very hard to precisely replicate the look of practical atmospherics. I have found myself more than once in a debate situation with a DP—me, understandably, trying to push toward a clean shoot, while the DP, equally understandably, wanting to preserve the look and feel of the rest of the scene. My reasoning that all the smoke that happens on the green screen will need to be cut out and replaced with CG smoke (and will most likely not be an exact match), is challenged by the DP's reasoning that the smoke on the subjects will still be retained, at least preserving the right look on the main action.

One parameter that can help the decision in such cases is the size and prominence of the green screen in the shot. If the screen covers only a small portion of the frame (for example, if it is placed in the very back for some minor set extension), then it definitely makes sense to leave the smoke or

In this shot from *Boardwalk Empire* we had to replace the background. While the green screen was useful for extracting the subject, we were able to extract only some of the smoke, and had to augment it with generic elements.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

fog on, as most of the atmospheric effect will be retained and only a small portion will have to be replaced. However, if the frame is predominantly green screen, it is much better to shoot it clean, since large chunks of the smoke will go away with the green screen and will need to be recreated by the VFX team anyway.

Reflections

An often overlooked aspect of green screens is their reflections in surrounding surfaces like windows, cars, water, mirrors, metallic or glass objects, or even the actor's sunglasses. It's important to remember that the green color can usually be easily removed through the usual spill suppression methods. However, if the reflection is sharp and you can see the distinct shape of the screen, some measures must be taken to avoid that, as this will require more elaborate (and often unnecessary) paint-out work. Change the actor's angle to eliminate the sunglasses reflection, stick a poster on a background window, or dry out those water puddles on the ground.

In the film *The Immigrant* (which takes place in the 1920s) we had a shot of Joaquin Phoenix and Marion Cotillard walking down a NYC street, in the shadow of the imposing prison known as The Tombs (which no longer exists). During pre-production meetings, we suggested that the best location to shoot the scene would be a place that has a period-accurate cobblestone pavement. The logic behind this was that it would be easier for us to replace and rebuild everything around the actors, but not the ground beneath their feet (because of the interaction and shadows). Bond Street in NYC, which has an old cobblestone surface, was selected as the location, but now the question was how to cover the actors' long walk down the street with a green screen. Instead of building a costly ultra-long green screen along the street, it was decided that a few grips would carry a smaller portable screen and simply move with it behind the actors. It all worked very well during the shoot, except for a certain "force majeure" that went practically unnoticed by all of us: a couple of hours before the shoot it had rained heavily, leaving the cobblestones wet and shiny. We weren't really aware of any problem until we received the scans and started working on the shot. Only then we realized that the wet cobblestones acted as a mirror, clearly reflecting the moving green screen (and the guys carrying it). No spill suppression or any cosmetic fix would do the trick here. We had to replace the entire ground, and recreate every contact shadow and subtle interaction between the actors' feet and the ground. It worked in the end, but, ironically, we had to replace the one surface in the shot that we planned to keep.

The actors, the portable green screen, and the reflection in the cobblestones.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

A happy ending nonetheless, with the offending reflections removed and the actors walking down the matte-painted 1920s' NY street.

The Immigrant © Worldview Entertainment, Keep Your Head, Kingsgate Films, The Weinstein Company. Visual effects by Brainstorm Digital.

Lighting Green Screens

The relationship between the subject and the screen, as well as the exposure, are the key components in lighting a green screen. Naturally, you want to expose for the subject and not the screen. It is the lighting on the subject that really matters at the end, since the screen is discarded. But there's a certain danger here: if the screen is over-lit or over-exposed it will lose its green saturation and will become hard or impossible to extract. An under-lit or under-exposed screen will end up causing similar issues, losing its hue and eventually becoming unusable. The importance is to keep a good balance between the subject and the screen. Such a balance happens naturally on a fully overcast day, for example. Assuming the subject stands far enough from the screen to avoid green spill and light reflection, the ambient nature of a cloudy day should provide that kind of consistent and well balanced lighting, if exposed correctly.

Things get more complicated when shooting indoors, on a soundstage, in low light or under harsh sunlight. In a low light situation, for example, the green screen must be lit artificially to preserve enough brightness and saturation. The light must be consistent across the screen, which means only soft, well-diffused fixtures should be used. Kinoflos are a popular choice, especially for small cramped spaces, because of their compact size and low heat release. Overhead Spacelights are often used on a soundstage as they provide a strong but even coverage. It's important to try to achieve as much separation as possible between the screen and subject lighting, so that each can be adjusted separately without affecting the other. This of course becomes harder in a small space or when the subject is surrounded by green screens on three or four sides.

It is also important to remember, as discussed in Chapter 4, that the subject will eventually be comped over a different background, so the light on it should not be too strongly suggestive. Consistent ambient lighting often works best as a generic setup, rather than a prominent directional key. But this depends on how the shot is conceived and planned. If the nature of the background is already clear to the filmmakers, the DP can light the subject to match that intended background.

Once both green screen and subject lights have been set up, the balance should be optimized. In most cases, you'd want the brightness of the screen to be similar or just slightly lower than the brightness of the subject. Since a green screen is a flat surface and (hopefully) has no highlights or shadows, it's best to judge by the subject's mid-tones. DPs usually use a spectrometer to gauge and adjust the lighting on both the subject and the green screen. In general, if the green screen is tight and clean and no shadows are cast on it, then lighting it to the proper luminance level should not be hard. Compositors can handle green screens even if they are somewhat dark or bright. It is the strong inconsistencies that pose the most difficulties.

Roto or Green Screen?

This question pops up often in pre-production and on set. It is also a hard one to answer definitively as it depends on many factors. Obviously, it would have been much simpler on set if green screens could be avoided altogether. But, as I explained in Chapter 4, roto is not just a matter of additional VFX work and time; some things like hair and fur can never be fully extracted without a proper green screen. On

the other hand, using green screens for every single VFX shot is not only impractical, it is often also counterproductive. The following questions can serve as guidelines to help make the decision between using a green screen and relying on roto.

- How much of the background needs to be replaced and how much will be kept? If most of the background stays than it doesn't make sense to hide it with a large green screen. Use green only in the small portion that needs to be replaced or modified, and if that is not possible then just keep the shot as a roto shot.
- How solid and well-defined are the subjects? Filmmakers are surprised that my first question is: "Will they be wearing hats?" but the truth is that people with hats are much easier to roto than people with long or frizzy hair. Likewise, if objects move really fast or are out of focus, a green screen will allow for a much more natural extraction. Needless to say, elements like smoke, steam, splashes, explosions, fire, and dust hits must have a green or black screen behind them if they need to be extracted. Roto is not an option here. Solid objects can be easily extracted with roto, and if most of the foreground consists of static man-made objects, a green screen is probably not needed.
- How large in frame are the subject(s) that will need to be extracted? Elements that are smaller in frame have less visible detail and work better with roto. A close up on an actress where every strand of hair is clearly visible will make a poor candidate for roto.
- What does it take to set up a green screen for the shot? Sometimes it's extremely hard, or simply impossible to set up a screen in a certain shot. It can be due to physical limitations, location constraints, or other technical difficulties. In such cases, when roto is the only viable option, it is beneficial to at least reduce the difficulties by keeping the foreground subjects in focus and avoiding wispy elements if possible.

Case Study: The Crane Dare

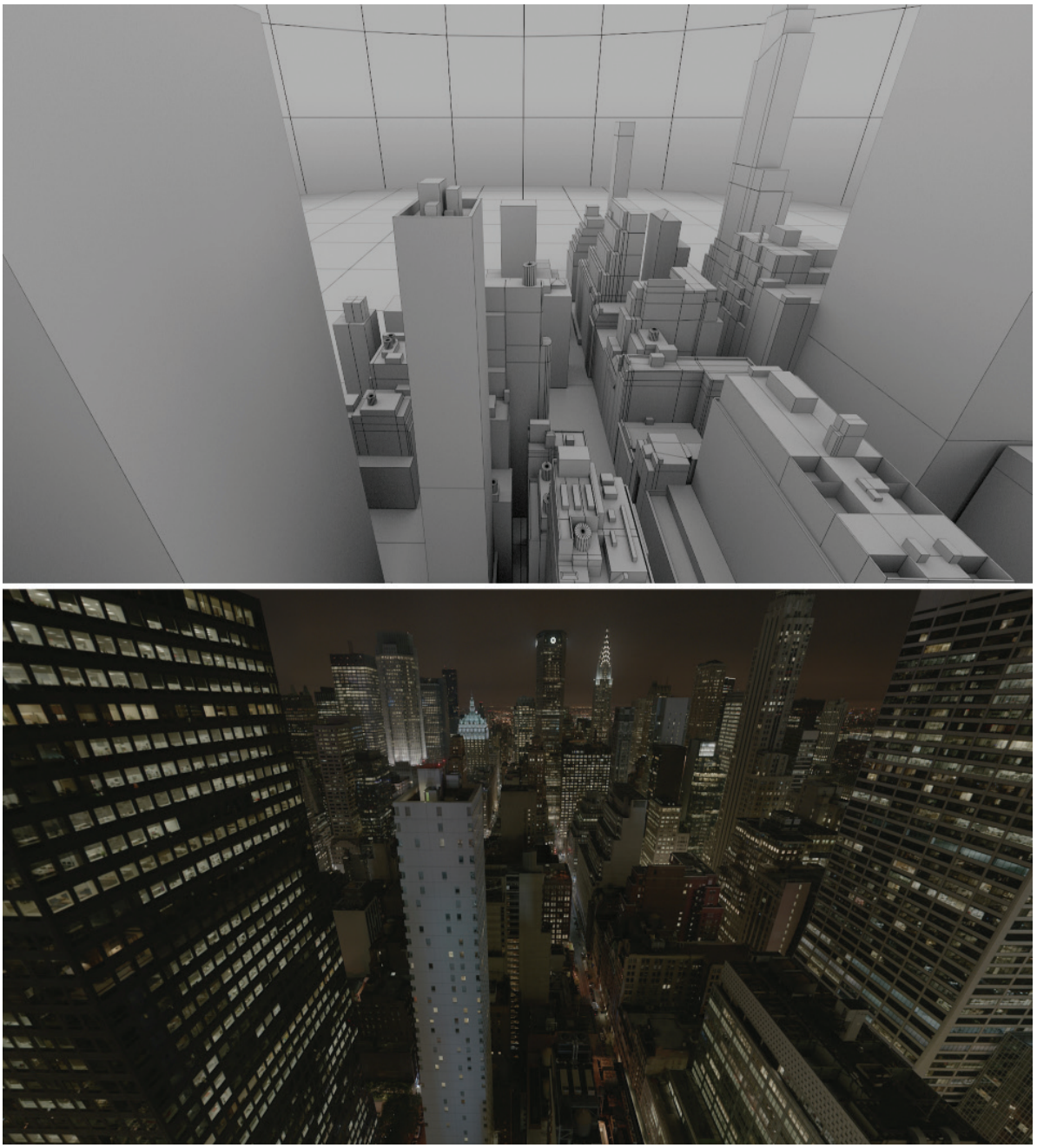
The crane dare scene in the movie *Nerve* was challenging both in terms of physical limitations and budget constraints. It is a good example of the VFX process and how it relies on the work of other production departments—from planning in pre-production through implementation on set to the post-production VFX work. In that scene, Dave Franco's character performs a dangerous nighttime dare by climbing and walking on a construction crane that is perched high on a skyscraper in midtown NY, all while capturing his own POV with a cellphone cam, GoPro style. Safety regulations precluded any possibility of having a stunt actually climb a crane on a skyscraper, so it was clear from the start that the scene would have to be shot on green and then composited into a CG environment of NYC. The first plan was to use a section of a crane placed about 10 to 20 feet above the ground in a parking lot and shoot the scene overnight. But we dropped this idea because it would have been very hard to set up an enormous green screen all around the crane in an exterior set (think of all the rigging and the possibilities of strong wind gusts), and even harder to shoot at night, especially when the crane and the actor need to be kept dark and the green screen sufficiently lit. It was therefore decided to drive a mobile crane into a large soundstage at Grumman Studios in Long Island, and cover the sides as well as floor and ceiling

1) The crane on the stage at Grumman studios. 2) Setting up the stunts rigging. 3) Richard Friedlander (VFX producer) and myself laying down tracking markers. 4) Me looking a little worried. . .

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

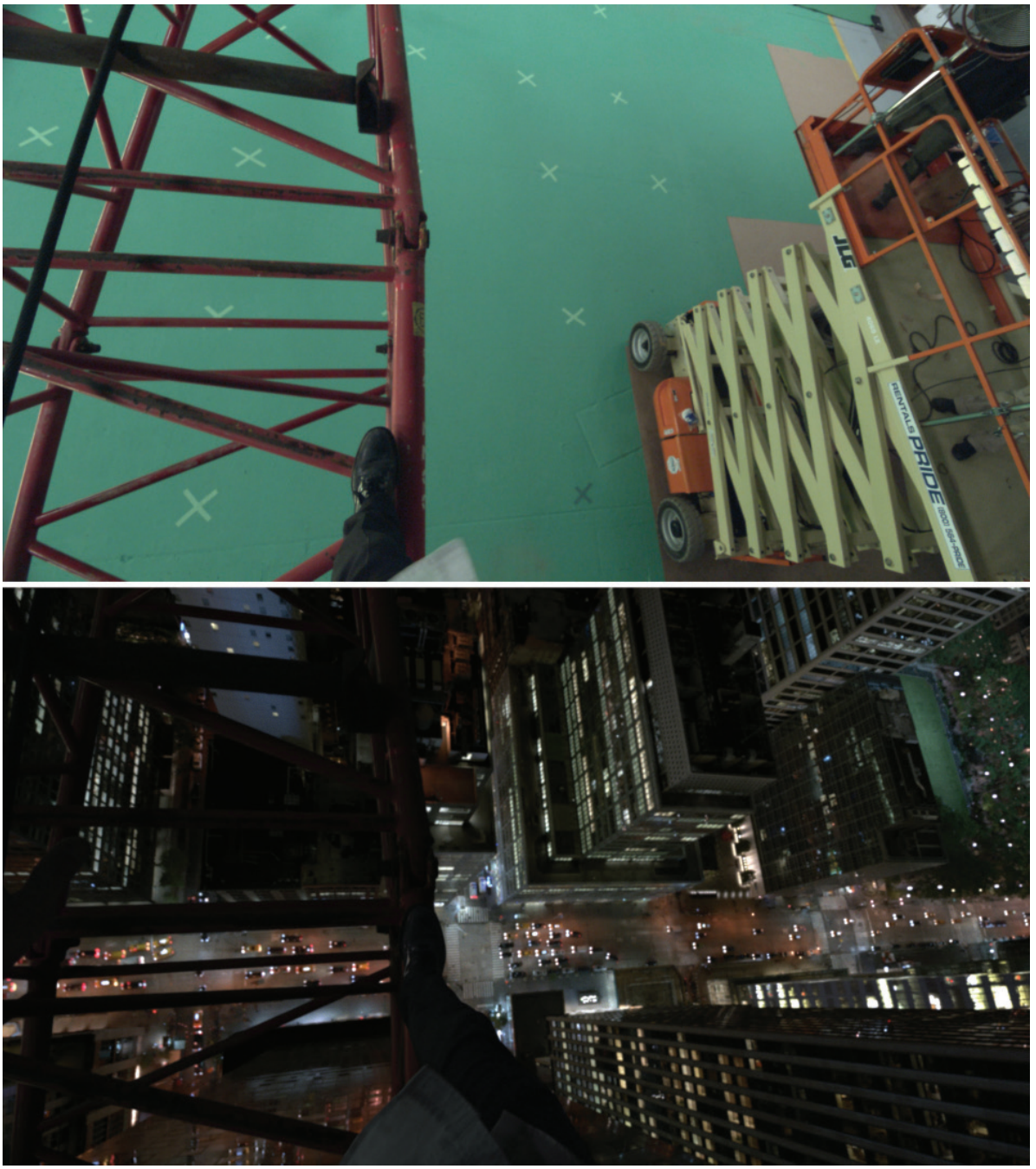
At left, setting up the technocrane on the roof. At right, the crane is ready for action.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.



Top: our CG build for the NYC environment. Notice the simplicity of the models and the fact that they extend only a few blocks out. Bottom: when the texture is applied, an enormous amount of detail is added, and it is impossible to tell where the 3D models end and the simple projection starts—it is now a seamless environment.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.



The original footage and the final comp from one of the shots in the *Nerve* crane scene. In this frame, the stunt looks straight down at his feet. The original footage has been darkened substantially to match the nighttime environment.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

around the crane arm in green. In terms of lighting, we decided to go with a day-for-night solution: keep the overall lighting bright enough to enable 3D tracking and green screen extraction, and later on darken the footage in comp to feel like nighttime.

As far as the VFX challenges, we knew that there would be some intensive camera tracking, lots of safety rig cleanup and obviously a lot of green screen extraction and roto work. But the biggest challenge was building the nighttime NYC environment. Since the action happens high above the streets, the view would be wide and far. Modeling fifty (or more) blocks of Manhattan in 3D, with all the necessary detail (including hundreds of moving cars and pedestrians on the streets below), would be an incredibly massive feat, way beyond what the budget and schedule allowed. Plus, we were concerned that the CG look would just not feel real enough, especially since we're dealing with such an iconic and well-known location. On the other hand, a 2D solution (say, using panoramic footage of NYC) could possibly work for a static or slow-moving camera, but certainly not for a hectic, constantly moving head-mount action camera.

The solution we chose was a mix of 3D and 2D. We scouted several rooftops around Midtown and found one that had a clear view and relatively easy accessibility. Up on the roof, the resourceful second unit crew extended an Alexa out on a technocrane, so that the camera could have a clear and unobstructed view from top to bottom. We then shot numerous tiles with a medium lens, each about half a minute in length (to capture the traffic and pedestrian movement), starting from the street down below and slowly moving out and sideways, tile by tile, until we had a full coverage of about 250 degrees around. Our matte painter then stitched all the tiles into a hemispherical panorama, which was used for the background (where very little parallax and perspective shift happen). The same footage was used for the foreground and mid-ground buildings and streets, but this time cut out into pieces and projected on simple 3D models (there was no need to put much detail into these models, as most of it came from the photoreal textures). This hybrid 2D/3D environment allowed for parallax and perspective shift, and preserved all the realistic detail and street action with relatively minimal modeling and texturing.

On-set Data Acquisition

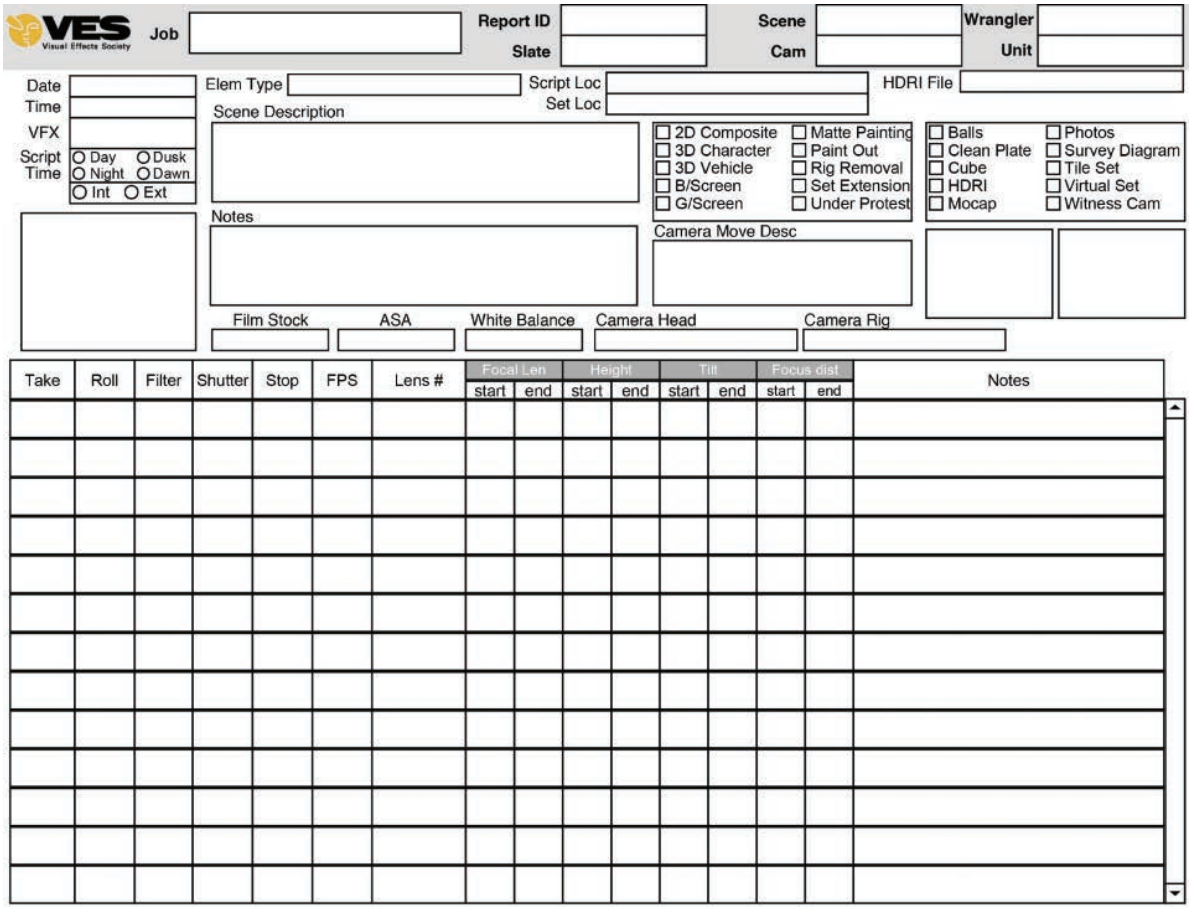
While many VFX shots can be completed simply by working on the existing footage, a great portion requires additional visual, technical, and contextual information. Looking at captured footage is like peering through a porthole—you only see what the lens sees. Much of the information that's crucial for VFX actually exists outside of the frame—the location of the light sources, their intensity, or how the sky looks on the opposite side, for example. This information can be obtained by taking stills and spherical HDRIs around the set. On-set photography can also be used to take close-ups of props, textures, and elements that are either hidden or too small in frame. Camera data is essential for successful camera tracking and needs to be meticulously documented. Set survey models are important for complex 3D work and require accurate measurements. And occasionally, 3D scanning and photogrammetry are used to create digital doubles for actors or props.

On VFX-heavy productions there is usually at least one VFX data-wrangler who is responsible for acquiring all the necessary information and footage while the VFX supervisor is working with the director

and DP. On movies with a limited budget, it is often the VFX supervisor who handles the data acquisition. But when no VFX person is on set, the crew members themselves (often the script supervisor, sometimes with the help of a set PA) need to pitch in and help with data acquisition or set photography. As I go through the various information and visual data that can be obtained on the set, I also highlight the bare minimum necessary data, in case there is no person dedicated for this task.

Camera Information

Camera data is crucial whenever 3D tracking is needed, but it is helpful for any VFX shot, even ones where the camera is locked off. The rule is simple: when it comes to camera data, it's always better to have redundant info than missing info. Professional VFX data wranglers usually document a wide range of



This empty camera report template is from the excellent application by the Visual Effects Society (which can be downloaded here: http://camerareports.org/). It allows the data wrangler to input an extensive array of information using a tablet or phone.

parameters, the most common being lens type, camera model, height, tilt angle, focus range, aperture, exposure, and lens filter (if used). Obtaining all these details requires being around the camera crew most of the time and making frequent inquiries to ensure the camera and lens info is properly updated for each take. Many wranglers prefer using a tablet or phone over pen and paper for inputting and saving data. There are some excellent templates available for download that can be used to organize and store the data. These templates also have the option to quickly insert additional comments and information, along with the slate and camera data. These comments can be very helpful later on to sort out the different takes, especially when multiple plates are shot for VFX.

In the absence of a data wrangler (or even a VFX supervisor) on set, it is usually the script supervisor who notes down the camera details along with the slate info. Understandably, this means getting just the bare minimum. In most cases, a successful camera track can be done with only two basic parameters: the **lens length** in millimeters and the **film back** (or sensor size for digital cameras). The latter is always tied to the specific camera model, so it's usually sufficient to write down the camera make and model. The tracking artist can then research that model and figure out the film back size. I have noticed that script supervisors often document the lens type but not the camera model. In the past, this might not have been a big issue because the same one or two cameras were used throughout production. But today it is very common to use a variety of different cameras on a single project, so documenting the camera model is important.

On-set Reference Photography

Visual reference can provide essential cues to the VFX artists—for any given shot, it reveals what's outside the frame and behind the camera. On set, the DP and the lighting team do everything they can to ensure that no movie lights are visible in frame, but the VFX lighting TD will be thrilled to know what type of lights were used and where exactly they were placed. Matte painters use references of the sky and environment all around for set extension work, and texture artists often use close up stills of various elements on the set as texturing material. Reference photographs are also often used for camera tracking, as they provide a view of the set from multiple angles and help set up the 3D environment.

Experienced VFX data wranglers constantly move around the set, taking stills from different angles and locations, often using bracketed exposure to provide the artists with multiple exposures of each still. But the absence of dedicated VFX professionals on set does not necessarily mean that good reference cannot be obtained. In fact, in many cases, a few simple snapshots around the set can be quite sufficient to give the VFX team a sort of poor-man's panorama survey of the location. Taking still photos is a simple task, and can be done by a set PA with any standard DSLR, pocket camera or even a smartphone. Low quality reference is still better than no reference.

Close-up reference photo references of various set pieces and items on location are indispensable for modeling and texturing.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

Spherical HDRI Light Domes

In Chapter 5 I mentioned the use of HDRI spherical domes in the context of CG lighting. High Dynamic Range spherical images provide an extremely efficient way to light CG elements with the same lighting environment that existed on the practical set. They are also used as a reflection environment, which ensures that reflective CG surfaces realistically reflect the original location surroundings. HDR spherical domes are not really necessary for 2D footage-based work such as simple compositing or matte painting, but they become indispensable whenever CG elements are added to the shot and need to be lit to match the set.

To shoot usable spherical HDRIs you need a DSLR that can store photos in RAW format and bracket exposure in at least three steps, preferably five or even seven. You also need a nodal tripod head and a fish-eye lens with 180-degree coverage. A nodal head is important because, as I mentioned in Chapter 3, regular tripod heads do not rotate around the nodal point of the lens, so they will not work for creating seamless spherical stitches.

The camera is usually mounted on the nodal head flat-on or with a slight tilt up (to get full coverage of the sky). It is set to bracket exposure in several steps, covering a wide exposure range (the lowest exposure should be almost black, and the highest almost fully blown-out). Most nodal heads have built in increments for 90 or 120-degree rotation, so four or three images (respectively) are taken by rotating the camera around the nodal point. Later on, the VFX team uses a special software to blend the various exposures into a single HDR images, and then stitch the three or four angles into a single seamless spherical panorama that is used for the lighting and reflection dome.

VFX data wranglers are very adept at taking spherical HDRIs quickly and efficiently, and they usually take more than one during a shooting day, to cover for changing weather and lighting condition on outdoor locations. But the basic technique is not difficult to master, and the required equipment is not particularly expensive or hard to get. With a little bit of preparation and training, a set PA can certainly perform this task when a professional VFX data wrangler or supervisor are not present. Just like any other type of on-set reference, more is better than less.

Lidar 3D Scanning

For more elaborate CG work, and especially on locations that are used extensively and repeatedly in the movie, a full 3D scan of the environment might be necessary. Such a scan provides the VFX team with an accurate and detailed survey model, which tremendously helps in the camera tracking process as well as 3D, layout, animation and set extension work. A 3D scan is also helpful when you need to create a digital double for an actor, and you need to model an accurate facial replica. Lidar scanners use a laser beam to triangulate a distance from the origin and create a dense point cloud. A Lidar scanner is not really part of the standard film crew equipment, and usually must be brought to the set and operated by a specially hired team. It is therefore best used only when a full-on 3D scan is necessary.

Photogrammetry

In Chapter 5 I mentioned photogrammetry as a simple and cheap way of obtaining 3D models on set. It requires nothing more than a decent camera, and is acquired simply by shooting the object from as many angles as possible, keeping the exposure, aperture, and focus consistent. Photogrammetry will only work well if you can cover the object from different angles, so is not quite suitable for scanning large structures or objects that are difficult to access. It is generally used as a quick way to replicate props and set pieces so that they can be later added as 3D elements to different shots. It is also used as a faster and cheaper way to scan faces of actors for creating digital doubles.

Crowd Tiling

Large crowd scenes are a big production headache. Hiring hundreds of extras, preparing hundreds of costumes, transporting all these people to and from the location and feeding them—all this requires complex logistics and a big chunk of the budget. The idea of crowd tiling is that you shoot several plates of the same small group of extras, and the VFX team composites these plates to create a much larger crowd. It is a very efficient way to cut down on the hassle and the costs of working with large numbers of extras on set—but only if done right. Crowd tiling (as opposed to CG crowd simulations) is a completely 2D/2.5D effect and as such is limited in terms of camera movement and separation. A successful crowd tiling shot needs to be carefully planned, set up, and filmed with those limitations in mind.

Setting Up the Camera

In Chapter 3 I discussed at length the challenges that camera movement represents when working in 2D. Crowd tiling is a perfect example for such a challenge. Every plate of a crowd group is just a flat, two-dimensional image. In order to achieve proper parallax, the plates need to be projected on cards in 3D space (the same technique used for matte painting). While this can work for small, limited camera moves, it will fall apart with wide moves like a big crane up or a wide track or dolly. On such big moves, the lack of perspective shift or internal parallax between the people in the plate itself will become noticeable, and the shot will not work. The only practical way to implement a wide camera move in a crowd tiling shot is by using a motion controlled rig, as mentioned previously. However, if no motion-controlled rig is available it is better to avoid extreme moves, especially ones that produce substantial perspective shift.

LOCKED-OFF CAMERA Just like when shooting VFX elements, it is important to set up the camera for the master plate, and then keep the same exact setup for all subsequent tiling plates. Make sure the camera head is locked, and the tripod firmly stabilized and weighted to prevent any accidental movement that will throw the camera out of alignment (it's a good idea to mark the exact position, height and angle in case such an accident does happen). The same lens and exposure should also be used throughout.

MOVING CAMERA Rehearse the move to make sure that it does not generate a noticeable perspective shift. Shoot the master plate with the full move first, and then lock the camera in a middle position to shoot all the subsequent tiles. For example, if the move is a left to right track, lock the camera roughly halfway through that move. It is crucial to keep the camera fully locked off for all subsequent plates. That way, the VFX team can track the camera of the master plate and apply that move to all the other tiles by projecting them on cards in 3D space.

In Chapter 6 I described the crowd tiling shot from *The Men Who Built America*. Here, moving the virtual camera back over the crowd reveals the many layers of 2D crowd elements that are placed on cards to achieve parallax.

The Men Who Built America © Stephen David Entertainment, History Channel, Lions Gate Films Home Entertainment. Visual effects by Brainstorm Digital.

Setting Up the Crowd

For most scenarios, you'd want to start from the foreground and gradually move backwards. Your master plate will therefore include the action closest to the camera. This is preferable for several reasons.

- It is easier to set the action and reaction of the crowd when the extras are closer to the camera.
- It provides a good indication of what is actually visible behind the foreground action and which areas need to be filled up in subsequent tiles (and can save time shooting unnecessary tiles).
- Since parallax and perspective shift are much stronger closer to the lens, it makes sense to get as much of that "for real" in the master shot, and tile in the back, where parallax and perspective shift are less noticeable.

On some occasions—for example, when the shot is very wide or filmed from the distance—sideways tiling is also necessary. In this case, even the very foreground action needs to be shot as two or more tiles. In such a scenario it is usually best to have the crowd at foreground center in the master shot and then tile toward the sides.

Sometimes you will need to shoot the tiles in reverse. On one such occasion we had to shoot the tiling plates first, before the master shot, because the first unit and the lead actors were busy shooting another scene at a nearby location. The DP and director came first to set up the camera and then left for the other location. We shot the tiles with the second unit, starting from the very back and slowly moving forward. By the time we got close to the main action area, the first unit moved in and shot the master plate in the foreground. It is not an ideal way to do crowd tiling, but it worked because the crowd area was well defined and there was minimal movement of people in the scene.

MOVING AND REARRANGING THE EXTRAS It is very important to clearly mark the boundaries of each tile. For example, when going front to back, the boundary line will be just behind the last extras, and as the group moves back for the next tile, no one should be standing on or in front of that line. This rule must be carefully kept, otherwise unwanted overlap and penetration will happen when the plates are composited. There is no effective way to fix such problems in comp, because resizing or repositioning the tiles can mess up the perspective and believability of the shot. Another important step is to mix up the extras from tile to tile to avoided repeated patterns. Special care should be taken with clothing artifacts or props that are of a unique color or easily identifiable. These should be replaced from tile to tile. For example, if one of the extras is holding a bright red umbrella in the master shot, and that umbrella really sticks out, make sure they don't keep that umbrella in the subsequent tiling takes.

GREEN SCREEN SETUP When the crowd tiles are composited, they need to be placed one behind the other. A green screen is therefore necessary for efficient separation. Roto is a much less desirable method because it is very time-consuming to roto out a large number of people, especially if they are moving a lot (for example, when tiling a group of charging soldiers). Roto makes more sense when tiling relatively static groups like a seated concert crowd. If you are tiling sideways, additional screens need to be placed to cover the side boundaries of the group. In low light or indoor locations, the green screens need to be adequately lit. Placing and repositioning one or more screens adds a considerable time, especially if lighting rigs also need to be moved around. This is yet another reason for carefully planning a tiling shot,

and allocating enough time for moving and rearranging not only the group of extras but also the green screens and lights.

The last scene of the movie *Nerve* takes place in a sort of a Coliseum (shot at Fort Wadsworth in NYC), with three stories of about twenty arched booths each, arranged around the main stage where most of the action takes place. All the booths had to be filled with spectators, and lit with an elaborate setup of changing colors and patterns, a sort of a giant rave party. Filling up the top floor was impossible because of safety regulations and the limited number of extras. Also, it was too expensive to set up the top floor with the same lighting arrangement as the other two floors. Our role was not only to fill the third floor with spectators but also to light it with the same changing colors and patterns to match the other floors, for each shot in the sequence. Many of the shots were filmed by a Steadicam operator who moved around the ground stage, and thus presented a variety of camera angles and distances. We therefore had to shoot crowd elements that would not only cover the entire set of lighting cues, but would also provide us with the enough variety of camera angles. To achieve this, we placed the actors in the second floor, and set up three Alexa cameras—a center one aimed straight and tilted up and two cameras at each side shooting at an angle. We started with all three cameras placed quite close to the structure for the very low angles, and shot the crowd going through all the lighting cues and reactions, one by one. We then moved the three cameras further back for a more straight-on angle, and repeated the entire cycle again.

Originally, we were slated to start shooting the tiling plates around 3 am, which would have given us over two hours of darkness before dawn. But, as it often happens, the main photography went on much

A wide shot from *Nerve* of the Fort Wadsworth set. The upper level is unlit and empty.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

One of the VFX plates is used to fill in the center booths of the top floor. Notice the sky in the VFX plate—it was captured at the very end of the night shoot, when dawn was already breaking.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

Other plates are used to fill in the entire top floor. Notice also the little "fix" to the special effects fire on the right.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

longer than planned, and the plates shoot was delayed by two hours, leaving us a very short window of opportunity. Luckily, I had the help of Doug Torres, an experienced and very resourceful first AD, who managed to move the hundred or so extras around, shout out instructions, cue in the lights, and basically get everything done in half the time.

We ended up with almost an hour of footage. When the cut was locked, we sifted through the footage and picked those parts that best matched every specific shot, both in terms of angle and lighting cues. Even with all this material at hand, we still had to do quite a lot of pushing and pulling on the elements to make each booth fit in terms of perspective. This was crucial because we weren't just tiling people, we were actually replacing the entire booth—from an empty dark one to a populated and lit one. In a way, this was a combination of crowd tiling and matte painting.

Screen Inserts Setup

As mentioned in Chapter 2, the use of VFX to add material to phone screens, computer monitors, and televisions is ubiquitous. Because this type of work is considered easy and rather trivial, mistakes are often made on set that unnecessarily complicate things. On one film, we had a series of close-up and medium shots of people reading text messages on their phones. We were not on set that day, and for some reason all the phone screens were programed to emit bright white light. These were all nighttime shots and the light emanating from the screens was clearly visible on the hands holding the phones (and also emitted a very strong glow). During post, we were asked to replace the screens with white text on black background. With the phone screens now predominantly black, all that light spill and glow looked totally out of place and unjustified, which made the shots look really bad. "Removing" the light was not an option—that would require some very difficult and time-consuming paint work, way beyond the original budget for these supposedly simple shots. We eventually convinced the filmmakers to change the graphics to black text on white background, but this could have been avoided altogether if the phone screens were kept dark in the first place. If you don't yet know what color and brightness the insert will eventually be, it's better to leave the screens black or use green as explained below.

Green is a preferable choice if there are people or objects in front of the TV, computer, or phone screen. This is especially important with hair, smoke, and anything that has lots of fine detail that will be hard or impossible to roto. Green also makes it easier to separate objects that are out of focus or motion blurred. However, the advantage of black is that reflections are stronger. This is helpful when you want to preserve some of the reflections and add them back over the insert material to improve realism. A little bit of moving reflections on a phone screen can go a long way into making the insert feel less "pasted" and more integrated into the shot. So in general, use green if there are people or other elements in front of the screen, otherwise you can keep the screen black or dark gray.

Just like with green screens, tracking markers are needed when the screen covers most of the frame. Markers are also helpful on phone screens (even if they are small in frame) because these are usually hand-held and move around quite a lot. If the screen is green, the markers should be a different shade of green. On a black or gray screen, use markers that are a bit brighter or darker, respectively. As I pointed out in the example above, avoid using white or feeding a very bright video signal to the screens.

Stunts and Visual Effects

Much of the VFX work on stunt scenes includes removing harnesses, wires, platforms, high fall air mattresses, and other rigs. Safety is always the first consideration on set, and consequently the VFX needs become secondary. Still, there are some guidelines that, if followed, can reduce the costs of cleanup and removal without impeding the performance and safety of the stunt team.

- Keep the wires behind the actors/stunts. It is much easier to clean up wires that go behind the person. Removing wires or rigs that are in front of a person requires difficult (sometimes extremely tricky) reconstruction of the actor's body, face, and clothing. Sometimes all it takes to keep the wires behind is a slight change in camera position or a little adjustment to the stunt rig, but the amount of VFX work and costs saved by that can be substantial. If the wire must be in front of the actor, pulling it up or to the side can minimize the overlap and reduce the amount of actor reconstruction work.
- Avoid rig pulls on clothes. This is something that's often overlooked on set, but becomes a major issue in post. As the rig pulls underneath the shirt, for example, it creates an unnatural "hump." That immediately calls attention and suggests a hidden wire. It is quite hard to remove this, especially if the actor moves and turns and the folds in the clothes shift and change. Usually this can be minimized by fairly quick adjustments to the rig and/or the clothes.
- It is really not necessary to have wires and small rig parts painted green, and does not make it easier to paint them out. However, large surfaces like high-fall mattresses and other supporting rigs should be painted or wrapped in green if they cover a wide area behind the actor. This can help separate the actor in order to clean up the rigging in the background.

On one TV series, we had three shots of safety wire removal. Two of them took just one day to complete; the third took almost two weeks. Why such a big difference? Because in two of the shots, the rope was properly held back and away from the actor, covering mostly sky. In the third shot, a tighter medium shot, the rope was hanging loose and swinging over the actor's entire body. Removing it meant reconstructing large parts of the clothing, including the constantly shifting folds in the fabric, and changing light and shadows. Such a complicated (and rather expensive) paint out shot could have been simplified by holding the rope away from the actor to minimize the overlap with the clothes.

Special Effects and Visual Effects

Special effects are done practically on the set and in-camera. Visual effects are done digitally on the footage during post-production. Even though these two crafts are separated by means, methods, skills, and time, there is a strong connection between them—for good and for worse. Some of the issues I have already discussed have to do with this relationship—for example, the question of whether to use ambient smoke in green screen shots. Special effects have the advantage of being photoreal—but setting them up and making them work properly is sometimes a big challenge, a one-off chance, or an expensive operation.

Visual effects are often called in to augment or extend special effects, but they can only be as good as the practical source. For example, on one project we had to extend the practical "rain" because there weren't enough sprinklers to cover the whole frame. This is pretty standard fare. The problem was that the sprinklers were not placed and oriented properly, and as a result the rain was crisscrossing rather than parallel, and simply didn't look right. This put us in a sort of a catch 22: if our rain extension was done correctly, it would not match what was already in there. And if we matched the source, we would make the badly done practical rain look even worse . . . At this point, the director asked us to clean up the practical rain and replace it completely, which ended up costing a lot more. To summarize: if there is no way of getting a good-looking special effect on set, it is better to leave it all for VFX rather than plan on VFX to "fix" it.

On the positive side, VFX are indeed a great way to augment special effects, especially when production allocates some time for VFX to shoot a variety of relevant practical effects for later use. On an action or war movie, for example, there will always be a need for additional explosions, fire, muzzle flashes, smoke, debris, blood, and bullet hits. One session of properly shot plates of various charges and blood squibs provides a priceless library of elements that look and feel just like the ones captured in the shots (because they are done by the same SFX team), and are also shot with the film and actual scenes in mind, as opposed to generic elements. Dynamic simulations can generate a variety of CG pyro, fluid, and destruction effects, but there's still nothing quite like the real thing, and practical elements are often used very successfully to enhance CG simulations.

There are certain occasions when it is wiser not to use special effects at all. In the previous rain example, it might have been better, knowing that the practical rain is not very successful, to just leave it all to VFX rather than have the VFX team painfully remove the practical rain from the footage. In other cases, it is important to decide in advance what is done practically and what is done by VFX. On *Boardwalk Empire*, Richard Harrow's deformed face was done completely as a visual effect—it was shot with just a few small tracking markers. It was not clear from the start that this was the right methodology; early plans called for shooting the actor with a practical prosthetic that would be enhanced by VFX. However, the complexity of re-applying the prosthetic and makeup on a day-to-day basis (and the time it would take), as well as concerns that the end result might not look convincing enough, eventually led to the decision to shoot the actor clean. The important thing in such decisions is to stick to the agreed methodology throughout. That way, assets and techniques can be developed and re-used for all the shots.

The making of the deformed face of Richard Harrow—from the CG mask that was tracked to his face and animated to follow his facial expressions, through the various stages of texturing, lighting and compositing to the final result.

Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

Chapter 9

Post-production

My Everest ascent analogy from the previous two chapters works only partially here: while most of the crew does go home happy (hopefully) at the end of principal photography, for the core group of filmmakers a whole new journey is just about to begin. They are joined by the fresh new post-production crew: the editor, assistant editors, composer, sound designers, colorists—and of course the entire VFX team (or teams). For the dozens (or hundreds) of VFX artists, this *is* the true Everest climb, where the bulk of the VFX work is done. During post-production, the raw takes are assembled into a coherent storyline while the visual and aural aspects are polished and refined. Post-production is driven by the creative process of cutting the film. As the film is edited and a rough cut is established, the filmmakers and the VFX team begin to see an accurate picture of the amount and complexity of the work. Shots that were originally planned may go away, while new shots that were never planned may be added to the list. Fresh creative ideas pop up as the film takes shape in the editing room, along with unforeseen issues that need VFX solutions. The post-production process can easily become overwhelming for the filmmakers, who need to juggle between editing, sound, color, and visual effects. There are so many things that happen simultaneously—back and forth with editorial, I/O with the lab, reviews and feedback, notes from the studio, notes from the legal department, comments, ideas, creative shifts, change orders, budgetary reshuffling, cutting, sound, color . . . it is therefore crucial to maintain a smooth, efficient workflow between the filmmakers, editorial, and the VFX team. This workflow is essential on both the technical and creative levels, because without it the post stage can quickly plummet into time and budget overages. Most of the actual process of creating visual effects has already been discussed in previous chapters. In this chapter, we will look at the most important aspects that contribute to a successful VFX post-production stage:

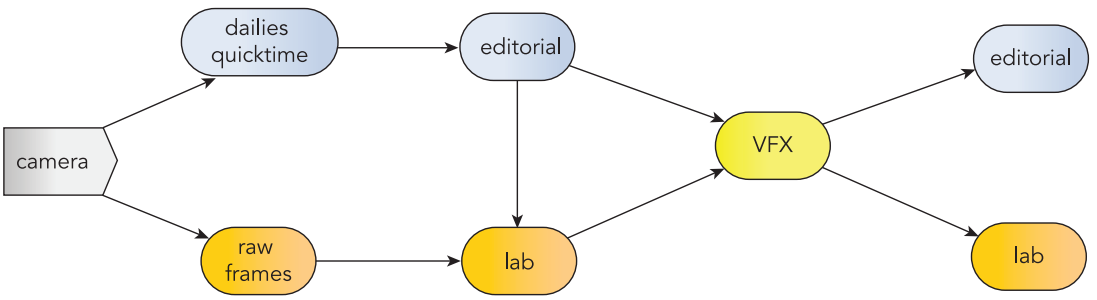
- Technical delivery pipeline between the lab, editorial, and the VFX team
- Color workflow
- Communication between editorial, filmmakers, and the VFX team
- Proper procedures for delivery and redelivery
- Organized review process and feedback loop
- Structured re-bidding and budgetary changes.

The Post-production VFX Workflow

At the end of the day's shooting, the raw footage (film or digital) is sent to the lab for storage, not before it is quickly scanned (film) or converted (digital) into Quicktime videos that can be played in real time without the need for expensive hardware. These are usually called **dailies**, and are used by the filmmakers to review the footage at the end of every shooting day. These Quicktime dailies are also used for offline editing throughout most of the post-production process. The raw footage is only used at the very end of post-production, after the cut is locked. This usually happens in the **DI** (Digital Intermediate) phase, where the raw frames are conformed to the cut, and the final color grading takes place.

It is important to remember that the dailies video clips are compressed, low quality versions of the raw footage. They do not have the full color range or resolution of the original material, so while they are good enough for editing, music, and sound mixing, these Quicktimes are absolutely not suitable for visual effects work. When a shot is delivered to the VFX team, editorial sends a request to the lab with the relevant timecode, and the lab then "pulls" the frames and sends them over to the VFX team. If the raw material is film, the lab scans the desired portion using a high-quality pin-registered scanner to convert the film into digital images. If the footage is digital (as in most productions nowadays), the process usually involves a conversion of the camera raw format to one of the standard image file types (see below).

The VFX team works on the high-resolution full quality frames, and renders out the shot into exactly the same format, resolution, and color space as the received plates. However, when it's time to send a version over to editorial for review, they will not send those hi-res frames (which editorial cannot use in offline editing anyway) but instead will generate a Quicktime that matches the dailies in specs and color. This ensures that editorial can drop the received VFX shot straight into the cut without the need for additional adjustments. The shot is then reviewed by the filmmakers (usually the director and editor), notes are given, a new version is sent, and at some point, after several iterations, a version is "approved pending DI review" by the filmmakers. This means that the shot looks good enough for everyone on the Avid, and the next step is to watch it at full-resolution and quality. At this point the VFX team will send the high-res, full quality version of the shot straight to the lab or DI facility. Once production goes into DI, the director, editor, and VFX supervisor review the approved shots in the DI room. This is an opportunity to examine the shots in their "full glory" and on a big screen, and a chance to look for possible issues or errors that might have not been apparent on the low-res Quicktimes. If all looks good, the VFX shot is approved as "final."

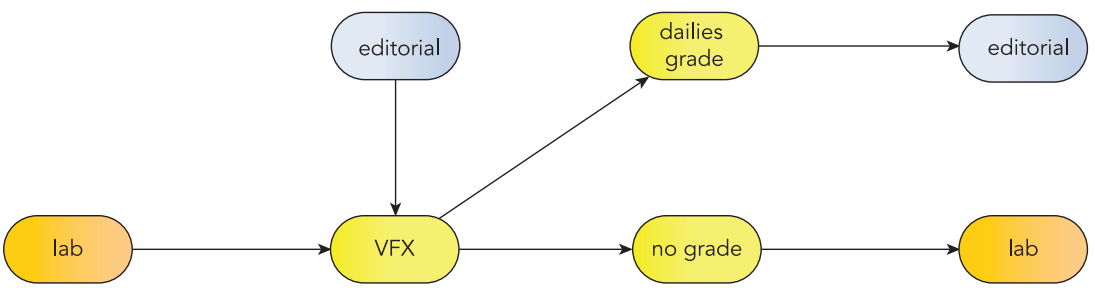


The VFX post-production workflow.

VFX Color Workflow

Raw digital footage and scanned film almost always need some preliminary color correction to look natural, and the color of various shots needs to be balanced to achieve color coherence within a scene or a sequence. When the dailies are generated, a colorist usually grades the raw color before generating the Quicktime files. This is done either by using pre-defined LUTs or by individually color grading each shot (or a sequence of similar shots). A LUT (Look Up Table) is a cross-platform file that accurately describes a specific color adjustment. Production usually decides on a LUT that works well for the specific type of camera and raw footage, and, often, several additional LUTs are created for daytime, nighttime, and interior shots. The advantage of using LUTs is clear—any post-processing facility or VFX company that needs to match the dailies grade can simply apply the relevant LUT file to the raw footage, and a perfect match is guaranteed. This method is indeed used in VFX-heavy productions, especially those that are serviced by multiple VFX vendors, because it ensures a smooth and consistent color pipeline. However, in most film productions the dailies are manually graded by a colorist without the use of predetermined LUTs.

When the VFX team works on the raw footage, they keep the color intact (unless a color change is part of the VFX work, for example, a day-for-night shot). But when they generate Quicktime files for editorial they need to match the dailies, otherwise there will be a noticeable shift in color when the VFX shot is cut back into the movie. Editors are especially sensitive to this color mismatch. If the production is using a LUT-based dailies grade, then it's a simple matter of applying the LUT specified by editorial. But if a traditional grading workflow is used (or individual per-shot adjustments are done on top of the LUT), then someone in the VFX team (usually the supervisor or sequence lead) needs to manually match the grade for each shot, either by eye or by using specific software tools. This is certainly a more time-consuming process (and more prone to mistakes), but many filmmakers still prefer to go this way because it frees them from the restrictions of pre-defined LUTs. When considering this versus using LUTs, you should think of the ratio of VFX shots within the total shot count in the movie. If it is a substantial amount, then LUTs can save a lot of headache—especially in the early stages of post-production and VFX delivery.



The VFX color workflow.

Finally, it is important to remember that all this color matching and dailies grading only applies to the offline stage. In other words, the dailies grade is only a temporary color adjustment. Once post-production moves into the online phase and the raw footage is used, the DI grading process starts anew. It is therefore important that the VFX team delivers the hi-res full quality frames without any color adjustment baked in. This entire process sounds a bit confusing (and it often is!), but establishing a seamless color pipeline early on in pre-production ensures that things go smoothly and prevents a lot of unnecessary back and forth.

Image and Video Formats

In the biblical story of the Tower of Babel, god punishes the people's impudence by forcing them to converse in many different languages. It is not clear what crime we in the digital entertainment industry have committed, but we have certainly been punished with a confusing array of image and video formats. Are all these formats necessary? Not at all. We could do very well with a much smaller selection. But this proliferation of formats is a natural by-product of the constant competition in the market of digital content. It's a true Darwinian evolution out there. Formats come and go; new codecs pop up while old ones go extinct. It is just a bit hard to keep up with all of that. There are many books, articles, and online sources that go into deep technical detail while comparing various formats. I will not do it here. Instead, I will try to simplify, as much as I can, this rather confusing subject.

At the most basic level, the difference between image file types can be narrowed down to two aspects: **bit depth**; and **compression**. Both affect the ratio between quality and file size—higher quality usually means bigger file sizes and slower playability, and vice versa.

Bit Depth

Bit depth corresponds to the number of digits (in binary) that are used to represent the color of every pixel. So an 8-bit file stores color information using 8-digit binary numbers, while a 16-bit file has twice as many digits. If you ever tried to count in binary, you know how quickly the digits accumulate. This does not mean, however, that an 8-bit image looks horribly bad in comparison to a 16-bit one. In fact, you might not even see the difference. But it becomes very evident when you start pushing and pulling the color, especially around the deep darks and brightest highlights. Higher bit depth is especially crucial for visual effects, where elements are often heavily color-corrected for integration. Some formats, like JPG, are limited to 8 bit, while others (see below) can be 10, 12 16, or even 32 bits.

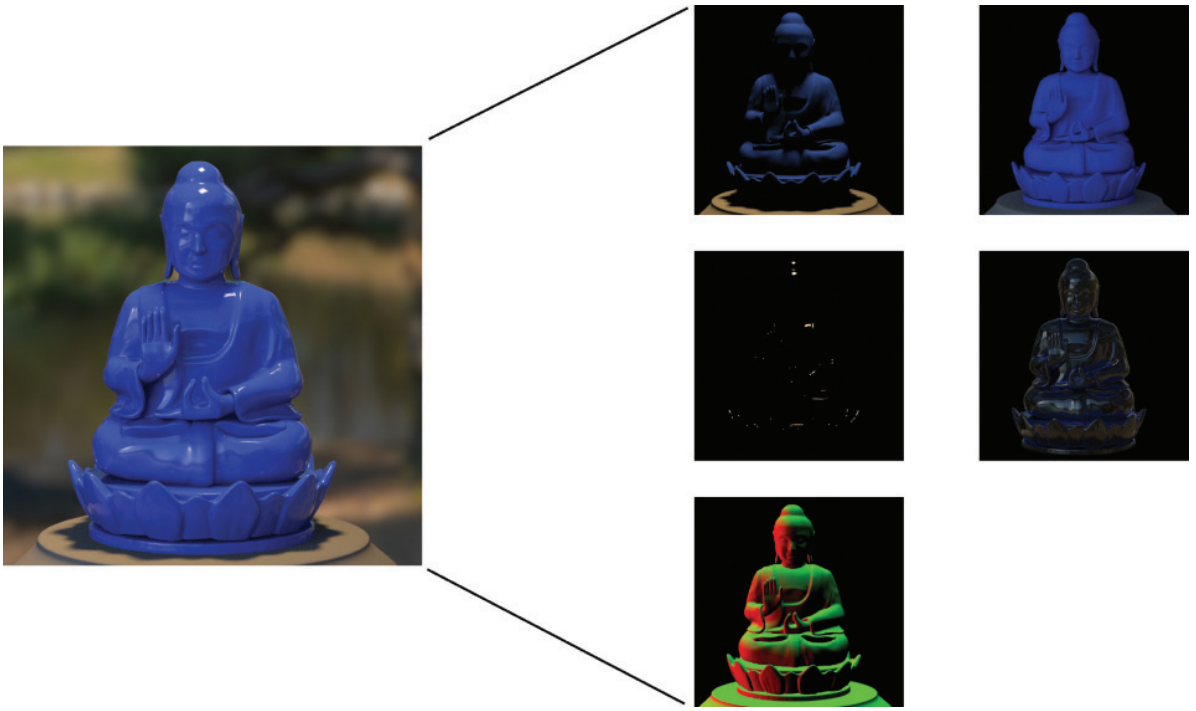
Compression

Raw uncompressed formats have optimal quality, of course, but if you've ever tried to play a sequence of 2K raw DPXs on a regular computer you know they just don't play in real time, and need to be cached into RAM memory first. That's why most digital video formats are 8 bit, and usually also use some form of compression. This includes most Quicktime and AVI formats. Offline editing, for example, is always done with compressed video formats, because the fine quality and color accuracy are less important than the ability to play the cut in real time, and quickly load and manipulate clips. Some compression algorithms (see below) are actually lossless, which means that when the image is played back it looks exactly like it did before the compression was applied—not unlike the way a zipped file goes back to its original state when it is unzipped.

Optimal Quality Formats

These formats are used for VFX work as well as the final color correct in DI. They are always a series of images, each representing a single frame, never a single video clip. Here are the most common ones.

- **DPX:** This venerable format has long been the standard for digital film scans, and remains the most used format, not necessarily because it's the best (EXR is better), but because the workflow of most labs is still centered around this format. DPXs can be 10, 12 or 16 bits. Although the difference between 8-bit and 10-bit is substantial, it becomes less so as you go higher, and in terms of color accuracy, the difference between 10 bits and 16 bits is negligible as far as VFX go.
- **Open EXR:** This powerful format (usually referred to simply as EXR) was originally developed by ILM. It packs so many features and possibilities, that it was quickly adopted by the VFX industry as the image format of choice for rendering and internal work, and is now also used more frequently by labs. The most important feature of the EXR format is that a single image file can store a limitless number of different images. It's like a TV—switch to a different channel, and you get a totally different image. This is a priceless feature for CG rendering, since all the different rendering passes can be stored on a single image file or a single sequence of images. EXRs can also go all the way up to 32-bit depth—and while this is pretty much an overkill as far as representing color, it is much needed for certain technical render passes that use extremely large number ranges (for example, a position pass represents the position of every point in 3D space, so numbers can easily go very high). Finally, EXR has some excellent lossless compression algorithms. This is especially necessary for files that contain many different channels.
- **TIFF:** Another venerable image format and one that is widely used in the print and retouching industry. Tiffs are usually 8, 16 or 32 bit, and can be uncompressed or use lossless compression. They are generally less frequently used in film and TV than DPX or EXR.



This single EXR image of a CG render contains five additional channels with various render passes: Direct diffuse, indirect diffuse (light bounce), direct specular, reflection, and face normal (the facing direction of each polygon).

Lower Quality Formats

JPG: When it comes to single images, JPG is the king. It is universally used and has excellent quality/size ratio. Yes, it should most certainly not be used for raw footage or final imagery, but it is perfectly suitable for sending over style frames, annotated images, and reference photos, because it is lightweight and can be viewed on any platform.

Quicktime: The ubiquitous Apple video format has somewhat pushed aside Windows AVI as the format of choice in the film and TV industry. There are numerous different compression codecs out there. Let's look at the ones that are most frequently used by editorial and VFX.

- H264: This codec is used primarily for the web, as it allows for very small file sizes at a relatively good quality. It's great for general reference (for example, when sending sequences for bidding), but I would not recommend using it for edit refs (see the VFX and editorial sections, which follow), especially if the color needs to be matched by the VFX team. H264 often causes slight gamma shifts and is not the most accurate in terms of color.
- Avid DNxHD: This is one of the most tried-and-tested formats for edit refs, and has excellent color accuracy. It's the native format for Avid Media Composer, which is pretty much the standard

editing software in the film and TV industry. DNxHD Quicktimes are always HD resolution, and come in several compression levels. The most frequently used compression levels are 36, which produces very small and manageable file sizes at the expense of image quality (which is highly compressed), and 115, which is considerably heavier in terms of file size but provides excellent image quality.

- Apple ProRes: The Apple flagship codec comes in many variants such as 422, 4444 and 4444HQ. The latter variant has such high color and dynamic range reproduction level that it is used as an actual capture format in digital cameras, which reduces the cost associated with fast high-volume storage devices required for shooting raw footage. This could be the start of a new wave of very high quality video codecs that will eventually replace the single-frame image sequences and will provide excellent reproduction within a much more manageable format.

Color Space Demystified

If the multitude of formats is confusing, just think of all those color spaces like sRGB, Cineon, LogC, rec709, RedLog, Panalog . . . if you work in the movie industry you are bound to hear these terms thrown around you, and they are as confusing as they sound. Once again, instead of getting into the technical details (which can be easily obtained online), I would like to bring this subject down to its essence. Color spaces, in a nutshell, are color/contrast curves that are applied to raw footage in order to make it look "correct" on various viewing devices such as computer monitors and TV screens. They are (if I may reuse the Tower of Babel analogy) like languages. In that sense, there are no "good" or "bad" color spaces—they are all equally legitimate; it's just that things can sometimes get lost in translation. A linear color space is a true, unbiased representation of light, but because of the way computer monitors function, it looks rather flat and desaturated. Apply a sRGB curve, and the image looks much better. (sRGB is indeed the standard for computer graphics, internet and print.)

Logarithmic color spaces, on the other hand, are better suited to represent light as it is chemically captured on film, and the Cineon logarithmic color space is widely used for film scans. Digital footage usually has a similar log curve applied, and different digital camera makers have their own variations, such as AlexaLogC or RedLog.

The raw footage that is sent to the VFX facility is almost always in a logarithmic color space. The VFX team can reverse, or "remove", the log color curve for the purpose of working in linear color space, and then re-apply the exact same curve on the output. In other words, when the VFX team sends back their work, the images are in the same color space as they came in, and look exactly the same in terms of color. Problems only occur when the translation is wrong, and images are exported with a different color curve.

It is important to note here that in terms of the visual effects work itself, color spaces have little meaning. Processes such as matte painting and compositing involve mixing together many different images and footage from various sources, and these get so heavily processed and color-corrected, that the whole notion of color space becomes quite redundant. The only important thing, really, is that the final output remains in the same color space as the input. What happens in between has no effect.

Color space mismatches may sometimes happen between the editorial and the VFX teams. For example, if the VFX team sends a Quicktime in rec709 (the standard color space for video), and the assistant editor loads it into the Avid as sRGB, the Quicktime will appear too dark. It's always good to establish the color space and adhere to it through the back and forth process (see more on VFX and editorial later).

ACES Color Space

Wouldn't it be great if we had just one single standard color space for all those different digital cameras and other sources? This is already happening, thanks to the Academy of Motion Picture Arts and Sciences. In 2104 they released ACES (Academy Color Encoding System), a color space that can encompass the extremely high dynamic range of contemporary digital cameras, and can accurately represent output from various sources and on various platforms. As is usually the case when a standardized format appears, it takes some time for it to find its way into everyday use, but it looks like the ACES will become the "language" of choice as a unified color space in film and TV productions.

VFX and Editorial

Throughout the post-production period, the editorial and VFX teams work closely together. For every VFX shot, editorial needs to request a pull from the lab and make sure that the VFX team receives the relevant hi-resolution raw frames as well as accompanying edit-ref Quicktimes, instructions, and temps (see later). Additional VFX plates are also pulled, either by request from the VFX team or according to editorial specifications.

When the VFX team delivers a shot back, the editorial team cuts it back in and prepares it for review by the director, editor and/or VFX supervisor. Feedback from the filmmakers needs to be documented, organized, and sent back to the VFX team. As the editing process continues, any change in the cut that affects one or more VFX shots needs to be communicated back to the VFX team as soon as possible, and the relevant frames must be ordered from the lab and delivered to the VFX team.

This is a constant and relentless back and forth process, and it's essential to keep it flowing smoothly and make sure there are no communication hiccups along the way. This part discusses the main factors that contribute to a successful collaboration between the VFX and editorial teams.

The VFX Editor

Having a dedicated VFX editor is truly essential for VFX-heavy shows (and the big-budget ones usually employ several VFX editors). Even modestly budgeted movies greatly benefit from a dedicated VFX editor, or at least a second assistant editor who can double as a VFX editor. The constant daily back and forth with the VFX team is simply too much for the principal or first assistant editors to deal with (as they

need to concentrate on cutting the movie). A VFX editor takes over that burden and acts as a dedicated liaison between VFX and editorial teams, in addition to creating temps and rough comps as needed. It's therefore recommended to look for a person who has some VFX experience (usually After Effects or Nuke compositing skills) on top of their editorial skills.

When to Deliver Shots to the VFX Team

The post-production process rarely goes on with unlimited time. Budget restrictions dictate a certain defined schedule from the first day of cutting to the last day of DI and sound mixing. With that in mind, both the filmmakers and the VFX team are eager to get the VFX process going as soon as possible to maximize the work time within the schedule limits. There is however a risk in handing over shots too soon in the editing stage. The director and editor should ideally have a locked cut of the movie before starting to deliver shots to VFX. It is a total waste of money to have the VFX team work on a shot that will later get cut out of the movie or replaced with a different take (which, in terms of VFX work, is practically a new shot). To be clear, it is quite acceptable that a few shots that were already worked on or even completed by the VFX team end up getting cut out and omitted. This happens on almost any film. But this must always be considered an exception and not the rule. Replacing VFX shots, switching takes, and extending shots in progress can be detrimental if done extensively. To minimize this, editorial should deliver only the shots that are editorially locked, and hold off on those shots that are still undecided or in editing flux. With this in mind, it is often best to cut the VFX-heavy sequences first—this way the VFX team can start work early enough while editorial continues editing the rest of the film.

Handles

Handles are commonly used as an editorial "safety buffer." The shot is delivered to the VFX team with extra frames at the head and tail, which gives the editor some leeway in the cut. Handles are usually 4, 8 or 12 frames on each end (8 is the standard), and the little bit of extra VFX work is usually accepted as a norm and absorbed in the budget for the shot. Longer handles are sometimes used on specific shots where the filmmakers want to keep their editing options wide open. Handles longer than 12 frames usually incur additional costs, especially if 3D is involved.

Edit Refs

When a shot is handed over to the VFX team, a Quicktime is delivered along with the high-resolution frames. This edit ref (editorial reference) is pulled straight out of the Avid and gives the VFX team a clear indication of the shot's cut length and dailies color (for matching the grade). In addition, the edit ref shows any manipulation that the editor might have already done on the shot (like flopping, repositioning, scaling or retiming). If a temp (see below) has been prepared, editorial should send the temp along with

a clean edit ref. It is sometimes important for the VFX team to see the original shot without any temp work, especially when green screens are involved. It is also a good idea to send an additional edit ref of the entire sequence (even if that sequence has many non-VFX shots). This gives the VFX team a better idea of how the shot plays in the context of the scene and what the surrounding shots look like, and often provides crucial clues for lighting and environment.

Editorial Temps

Editorial temps are very rough comps that are usually created by the VFX editor. They have a dual purpose: they are used as temporary placeholders in the cut until the actual VFX work comes in; they also provide the VFX team with a visual and temporal reference to what the director and/or editor have in mind. Green screen shots, for example, are usually first candidates for a temp, because they are such an eyesore in the cut and distract from the flow of the movie. The VFX editor will usually do a quick rough extraction in the Avid and replace the green screen with a temporary background. Even if the background is not the correct one and is not properly tracked or integrated, it is still preferable to an ugly green screen.

For the VFX team, temps can be very helpful on, for example, shots with monitor or TV inserts. In this type of shot, the insert footage is specifically selected and timed by editorial as part of the film's narrative, so having a temp with the insert roughly comped in gives the VFX team a precise indication of selection and timing. Tracking, extraction, and integration are really not important—this is the job of the VFX team—so there is no need for the editorial team to spend time and effort on making the temp look good.

With that in mind, editorial temps can become counter-productive if too much work is invested in them. It's important to remember that no matter how skilled the VFX editor is at creating great-looking temps, they are still done on the dailies Quicktimes and not the high quality raw footage. Color range is limited and the dailies grade is baked in. We have, more than once, been asked to make a shot "look just like the temp." This approach does not give the VFX team a chance to create a shot that is actually better than the temp—and eventually hurts the filmmakers. The right tactic with editorial temps is to treat them for what they are (quick, rough, temporary placeholders), and let the VFX team take the shot to its maximum potential and use their best artistic judgment and technical abilities. However, if there is a certain aspect of the temp that the filmmakers want to retain, they should specify it very clearly to avoid any misunderstanding.

Budgeting and Scheduling

Budget Updates

As the cut progresses and the full scope of the VFX work is revealed, the budget needs to be revised accordingly. While the pre-production budget served as a financial guide and framework for the shooting phase, it cannot accurately represent the work at this stage. It's very likely that some shots that were originally planned will be omitted and new ones added. The VFX producer usually adjusts the budget

several times during the post-production period to reflect those changes as they happen and provide the filmmakers with accurate updates. Hopefully the overall balance is kept more or less within the limits set forth by the initial budget, but when the number of added shots exceeds the number of omitted shots, or when the complexity of shots increases because of unexpected events on set or a change in concept, the bottom line is likely to go up. Since this is quite common, it is always wise to make room in the initial budget for a certain contingency factor. This should hopefully cover for the additional unplanned shots that tend to crop up during the editing process.

Change Orders

Change orders are always a bit hard to swallow. It is only natural to expect that a certain shot will cost as budgeted and not grow in price. Yet, as I mentioned earlier, there is a difference between additional work for polishing a shot or fixing technical issues, and additional work that's the result of a change in concept or new request from the filmmakers. If a shot outgrows its original scope, its budget needs to be reevaluated. This may seem simple enough, but it is often a cause for friction between production and the VFX team. The line is not always clear cut, and is prone to opposing interpretations. Some directors, for example, are just never satisfied with the work, asking for more and more iterations, which may eventually lead the VFX provider to issue a change order as a sort of compensation for all the unplanned extra time put into the shot. From the production side this may seem like an unfair move; after all, no additional work was requested, just improvements. It's easy to see how both sides can feel like they are being taken advantage of. But it shouldn't necessarily be like that. Good and consistent communication between production and the VFX team, and a collaborative attitude is often all that's needed to avoid this type of friction. When both sides are kept in the loop and potentially problematic issues are quickly being communicated and discussed, there's less chance for disagreement.

Scheduling

There is a clear and obvious advantage in fitting the VFX work into a well-defined timeframe. The combination of creative processes and technical challenges can easily lead to uncontrolled time overages. Putting up a concise schedule is in the interest of the filmmakers as well as the VFX team—both sides want to get things done on time. However, this has to be a two-way process: the milestones and deadlines need to be agreed upon with mutual consideration of the challenges that the VFX team is facing and the priorities of the filmmakers and production. As much as it is important to set milestones and deadlines for shots and sequences, it is also important to allow a certain flexibility within the time framework. VFX facilities usually assign work internally based on difficulty level and the availability of the artists. In order to optimize the workflow, often artists that are free start working on shots ahead of the original schedule. Conversely, some shots may take longer to finish because of unforeseen difficulties. As a result, some shots are likely to be delivered behind schedule while others will be completed before their deadlines. From the production standpoint, it usually does not make much sense to demand a strict adherence to the schedule. It is much more important to maintain a constant dialogue with the VFX

provider in order to get a clear picture of the progress. From the VFX team's side, it is equally important to keep production updated, and clearly flag any potential delays.

The Reviewing Process

Visual effects are an iterative process, and the dialogue between the VFX team and the filmmakers constitutes a vital part of it. Some directors insist that they cannot respond properly to a given VFX shot until they see the final result. While this can work for simple fix-it or cleanup shots, it is certainly not a good approach when dealing with complex shots that involve heavy CG and animation work. Requesting major changes after several months of work have already been invested in the shot can be detrimental—as I've already stressed throughout this book, such shots necessitate the active involvement of the filmmakers during several stages of the work. This asks for a certain acquired ability to judge each stage for what it represents while ignoring other aspects—in a way "imagining" the missing pieces while responding to the existing ones.

As the work progresses, the VFX team sends material for review and feedback. This material may be mockups, style frames, playblasts, turntables, layouts, or full shots in progress. With all this different material at various stages of completion, it is often hard for the filmmaker to know which aspects to address and which to ignore. A production VFX supervisor can be very helpful in sorting out the material and presenting it to the filmmakers for review with a clear indication of what needs feedback and what is still in progress. The supervisor can also handle most of the technical feedback and involve the filmmakers only in the more creative aspects. However, if you're communicating directly with the VFX team (as is often the case on lower-budget productions) you don't have the luxury of a middle person. The VFX team may deliver material with some accompanying notes that will help you focus on the areas that need feedback ("Here's a rough version with the castle added. Please let us know if you like its position and scale"), or clarify which areas are yet to be done ("The airplane is still missing some textures, but we're sending it over to get your feedback on the animation"). Unfortunately, this is not always the case, and sometimes notes from the VFX team can be confusing, or missing altogether. Never hesitate to ask for clarifications—it is the VFX team's responsibility to indicate clearly where they are in the progress of the shot and what they still need to address. In any case, and no matter which VFX supervision model you choose, it is important to be familiar with the different types of intermediary formats that will come your way for review. Here are some common types of in-progress outputs. . .

Mockups

A mockup can be a very rough sketch, a basic render or a clip. Unlike concept art or style frames, it does not show a developed, polished look; and, unlike layout clips, it is not intended to get your approval on precise timing and position. It is just a quick and dirty way to show an idea or composition: "Here's a rough mockup of the camp and the surrounding mountains. If you like this composition, we'll start working on the matte painting." Treat it for what it is, and ignore the lack of fine detail and integration.

A rough mockup (top) of this shot from *Boardwalk Empire* was sent to production at an early stage, to lock the scale and position of the ship. The crude temp model was replaced by the fully detailed one in the final shot (bottom).

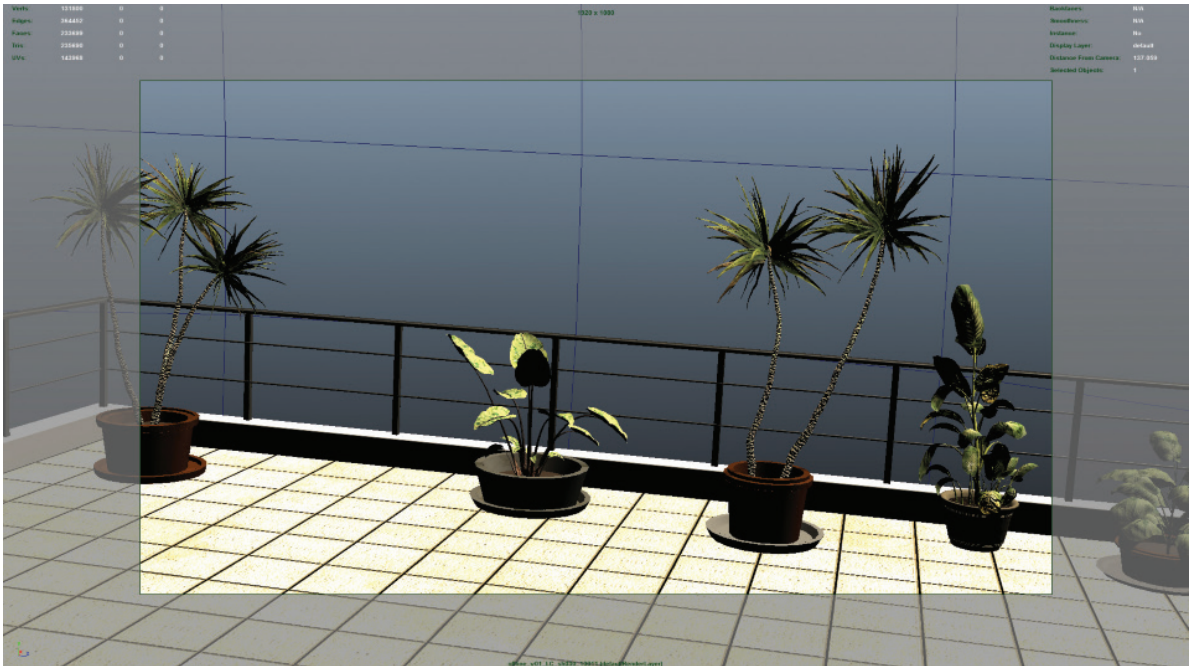
Boardwalk Empire © Home Box Office (HBO). Visual effects by Brainstorm Digital.

Style Frames

A style frame is used to show a fairly developed matte painting or CG build, but as a single still frame rather than the entire shot. While concept art usually happens during pre-production and is therefore not based on the actual footage, style frames are already done on the footage, and represent a more advanced and accurate look development stage. Presenting a style frame to the filmmakers is an efficient way to get them to sign off on a look before the VFX team moves forward with additional work like tracking, extractions, roto, and integration. It is common to send more than one style frame, giving the filmmakers a choice between several variations. For example, if the shot requires a new design element such as a neon sign for a bar, it makes a lot of sense to show a style frame with possibly a few different design options, before moving on to the comp stage and sending the full shot for review.

Playblasts

The term is borrowed from Maya (the ubiquitous 3D software), but is now generally used to describe a sort of a poor-man's render for reviewing animations. Instead of rendering the animation through the



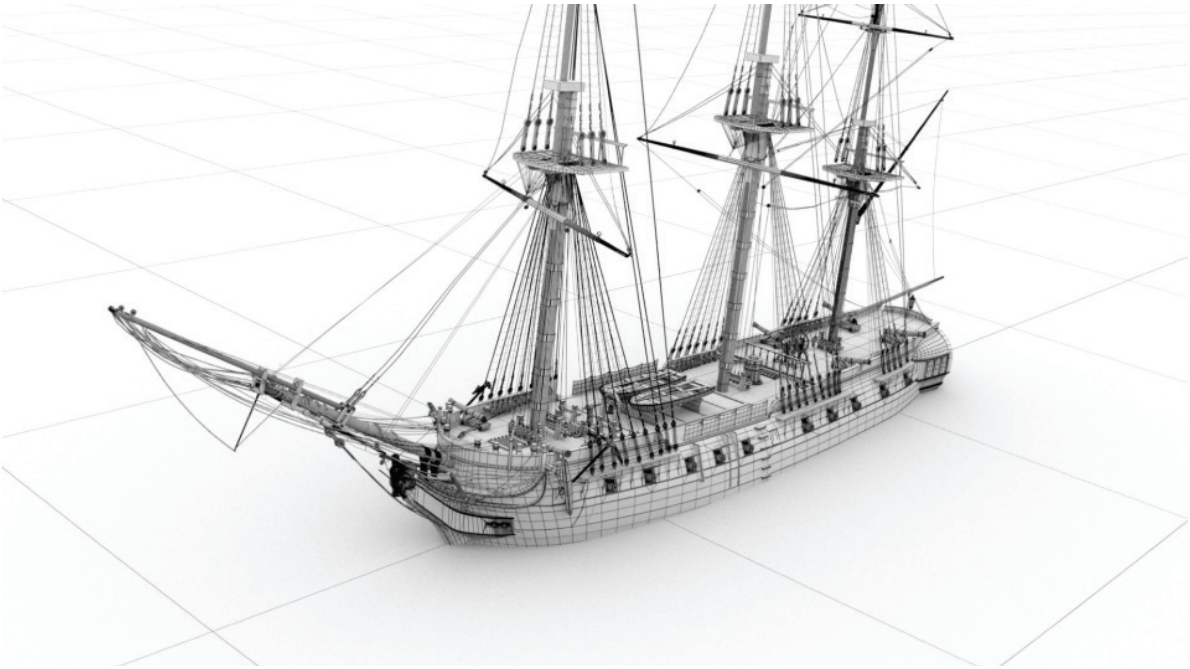
A Maya playblast. Notice the rough representation of texture and lighting. This is basically how the artist sees the scene before it is rendered.

render engine with full lighting and shading (which can be a very lengthy process), the artist simply renders out the on-screen display, in a fraction of the time. Essentially, it's like an animated screen grab—what you see is what the animators see on their monitor as they animate. A playblast therefore has a very basic representation of lighting and textures (if any), and a rather crude, lo-fi look with basic (and often wrong) colors, no motion blur, and no focal depth. When reviewing playblasts, ignore the look and concentrate only on the animation.

Turntables

Examining a CG object as it rotates on a turntable is the preferred way to review models, textures and shaders. Not only does a turntable allow you to see the object from all sides, but shading characteristics like reflection and specularity come alive as the object rotates in a lighting environment. This makes it easier to get a feel of how the object will look when animated, and how the different surfaces react to light.

A modeling turntable is normally rendered without specific lighting, with just a monochrome ambient occlusion shader (usually light gray or white). A texturing/shading turntable however uses a full lighting/reflection environment to show how the materials react to light. Often, spherical HDRs taken on location are used instead of just a generic lighting setup. This makes the turntable even more valuable, because the light matches closely to the environment in which the model will eventually be seen in the film.



A modeling turntable of a CG ship.

Sons of Liberty © Stephen David Entertainment, History Channel, A+E Studios. Visual effects by Brainstorm Digital.

Comp

Compositing is where all the elements are put together and the final look is established. For simple shots, this might be the only stage that is presented for review, while for more complex shots it is the final (and most crucial) step in a long series of development iterations. This is often the hardest stage to comment on and provide feedback, because it's here that the minutest detail can make a big impact for better or for worst. Look for integration of color, depth, motion blur, and focus, extraction edges, integrity of the overall picture, as well as potential small errors like a stray matte or missing roto. It is a good idea to be able to flip back between the comped shot and the original footage. This is usually a great way to identify issues.

Final Approval

Regardless of how many stages of review a shot goes through, every shot needs to be approved or "finaled". This usually happens twice: a first approval during the offline process; and a final approval in DI review. As explained at the beginning of this chapter, reviewing the shots on the Avid first and then in the DI screening room gives the filmmakers a chance to see the shot both in the context of the cut and at full quality on a large screen for final approval.

Nerve/Presto
2K Review 11/24/15

submission ID	submission date	format (QT/DPX)	frames	editorial notes	vendor submission notes	cut in	cut out	2K Notes
065V_015_v02.mov	11.11.15	DPX	111		For final	9		Final
065V_030_v05.mov	11.17.15	DPX	82		Added watchers	9	74	Remove rig on frame right
065V_040_v02.mov	11.11.15	DPX	117		For final	9	109	Final
065V_050_v04.mov	11.11.15	DPX	83		For final	9	75	Final
065V_060_v03.mov	11.17.15	DPX	82		Wire removal, movie light removal	9	74	Final pending. Remove rope
065V_080_v03.mov	11.11.15	DPX	52		For final	9	44	Final pending. Remove rope
065V_090_v08.mov	11.17.15	DPX	81		Wire removal, movie light removal	9	73	See version with light in other window. Send other options of lighting with stills.
065V_110_v02.mov	11.11.15	DPX	67		For final	9	59	Final
065V_120_v03.mov	11.11.15	DPX	98		For final	9	90	Final pending. Remove rope
065V_130_v06.mov	11.17.15	DPX	78		Added watchers	9	70	Final pending. Remove rope
065V_140_v03.mov	11.11.15	DPX	117		For final	9	109	Take a look at the dailies of this shot for a version w/o the crane reflection
065V_150_v06.mov	11.11.15	DPX	76		For final	9	68	Remove enforncement on ladder or re-color it to blend with the ladder. Rope removal at head of shot.
065V_160_v03.mov	11.11.15	DPX	114		For final	9	106	Final
065V_170_v03.mov	11.11.15	DPX	74		For final	9	66	Final pending. Remove rope
065V_180_v03.mov	11.11.15	DPX	61		For final	9	53	Remove plexiglass and rope.
065V_210_v02.mov	11.11.15	DPX	57		For final	9	49	Final pending. Remove rope
065V_220_v02.mov	11.11.15	DPX	105		For final	9	97	Final
065V_240_v02.mov	11.11.15	DPX	76		For final	9	68	Smooth out harness in her shorts. Remove specific line frame left. Remove Rope
065V_250_v03.mov	11.11.15	DPX	96		For final	9	88	Final
065V_260_v04.mov	11.17.15	DPX	80		Added watchers	9	72	Final pending. Remove rope
065V_270_v03.mov	11.17.15	DPX	87		Wire removal	9	79	Put phone screen on. Just a light. Remove rope.
065V_290_v03.mov	11.17.15	DPX	118		Wire removal, movie light removal	9	110	Final
065V_300_v03.mov	11.11.15	DPX	58		For final	9	50	Still need to look at light source. Remove rope.
065V_320_v03.mov	11.11.15	DPX	120		For final	9	112	Final
065V_340_v02.mov	11.11.15	DPX	35		For final	9	27	Final
065V_350_v03.mov	11.19.15	DPX	29		Wire and movie light removal	9	21	Remove rope. Re-examine connection between phone falling
065V_380_v03.mov	11.11.15	DPX	90		For final	9	82	Final
065V_410_v02.mov	11.11.15	DPX	109		For final	9	60	Final
065V_420_v07.mov	11.17.15	DPX	94		Wire removal, movie light removal	9	86	Still need to look at light source. Remove rope.
098V_050_v05.mov	11.19.15	DPX	58		Wire and movie light removal	9	50	Final pending. Remove rope
098V_100_v02.mov	11.17.15	DPX	74		Wire removal	9	69	Final
098V_110_v03.mov	11.19.15	DPX	51		Wire and movie light removal	9	43	Still need to look at light source. Remove rope.
098V_120_v05.mov	11.19.15	DPX	37		For final	9	29	Final
106C_180_v11.mov	08.19.15	DPX	370		New version based on the approved style frame	28	291	Increase the flares; don't have them fade out. Add more red glow at the head of the crane. Add some red glow to bottom of shot.
109_010_v13.mov.	11.11.15	DPX	186		Took out the crane boom	17	170	Final

109_020_v12.mov	11.03.15	DPX	498		Added head extension	17	482	Add highlight to his shoes. Fix glow around the light.
109_030_v08.mov	08.21.15	DPX	642	Currently omitted from cut	New shot			Final
109_045_v09.mov	11.10.15	DPX	75		added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks	17	59	Dynamic zoom within the shot. Remove the hump of the harness on his back. Fix up roto on his right arm.
109_060_v21.mov	11.20.15	DPX	148	Does not have final graphics in phone	Changed the lighting and shading to increase the reflections of the environment on the drone's shiny plastic body. Added red lights of the crane; can be seen in reflection. Increased the red light glow on the propellors (when seen from above)	2	117	Add people in building. Use this look for other drone shots. Fix glow on the red light a little
109_075_v08.mov	11.10.15	DPX	233		added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks	139	217	Decrease the contrast on Dave when the light is on. Add more drone shake as he starts to go down the crane.
109_080_v12.mov	11.03.15	DPX	261		Same as v11 but without the mattes	101	245	Final
109_090_v30.mov	11.19.15	DPX	256		reduced light flaring	95	240	Final
109_220_v13.mov	11.10.15	DPX	290		added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks	93	274	Final?
109_230_v08.mov	11.03.15	DPX	139		Same as v07 but without the mattes	17	123	Check plate for motion blur on Ian's hand.
109_240_v13.mov	11.10.15	DPX	482		added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks	17	164	More traffic on the bottom. Rel still wants to see weight on crane move. Check if we can move up more so his feet aren't lost.
109_242_v06.mov	11.10.15	DPX	189	Currently omitted from cut	added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks			
109_245_v09.mov	11.10.15	DPX	219	Currently omitted from cut	added camera movement effect, subtle light flaring, and some also have additional color/integration tweaks			
109_250_v10_clean.mov	09.02.15	DPX	277	Has avid resize	Just fixed the reflection pass.	51	252	Wants highlights on the shoes and hand. Possibly add more traffic?
109_260_v19.mov	11.11.15	DPX	625		Added camera move etc.	9	495	Pan up to the sky or pan down to the street.
143_090_rotation_test_v 01.mov	10.27.15	DPX	790	Not up for final. Just to be viewed.	We pushed in gradually just enough to keep the plate within the mattes. This solution does not require any additional matte painting extensions and plate reconstruction.	164	716	Add a little wobble to the first drone. Rotation is good.

A DI review summary from *Nerve*, including shots that received notes and those that were approved. Notice that the DI review is called "2K review" here. This is a vestige from the days when most films were scanned to 2K resolution. Nowadays, the resolutions of cameras can be 3K, 4K, or even higher.

Nerve © Lionsgate, Allison Shearmur Productions, Keep Your Head, Supermarché. Visual effects by Brainstorm Digital.

These approval stages might seem a bit restricting—there's an understandable wish to keep things open for as long as possible and to avoid signing off on shots too early—but in truth an ongoing approval process is beneficial for the filmmaker too, as it gradually clears off some of the load and eases the decision-making process. Dragging too many shots all the way to the finish line is not recommended. As you've already seen throughout the book, last minute changes in visual effects are a risky proposition, especially when the changes are major. Maintaining an iterative, coherent, and timely process of review and approval is essential.

Communication

There's no need to explain the importance of good communication in general and specifically in a creative environment. The VFX review process and feedback loop is no exception. A film can be brilliant, the director a genius, the VFX team superb, creative ideas and great intentions abound, yet miscommunication and misunderstandings can easily turn the VFX production process into a nightmare of incorrect decisions, wasted time, and budget overflows (not to mention frustration for the filmmakers and the VFX team). In more than one way, VFX are more susceptible to flawed communication than any other process in the post-production stage.

To explain why, let's compare VFX to other common post-production processes such as editing, sound design, and color grading. In these, the director is usually physically present in the editing room, the mixing stage or the DI Theater. This allows for an immediate, direct communication between the director and the editor, sound designer, and colorist. Moreover, changes can be applied relatively fast, so the director enjoys the benefit of taking part in the tweaking process, and seeing the results almost in real time. It is also worth noting that the editorial, sound, and DI teams are usually rather small, rarely more than a dozen professionals each.

This is hardly ever the case with visual effects. The VFX team is most likely in a different location, and sometimes in a different city or even a different country. There could be dozens, even hundreds, of artists on the team. All this, of course, is multiplied when more than one VFX company is involved. The feedback from the filmmakers often passes through several people (supervisors, leads, production coordinators) before reaching the artists. It is usually given via email, which is rarely written by the director himself—more likely by an assistant editor or a production coordinator. Changes rarely happen in real time or overnight since VFX are technically more complex than editing, mixing, or grading. It can take several days, even weeks, before a note given by the filmmaker materializes as a new version and is available for review. In short, there's very little of that direct, one-on-one interaction and near-real-time feedback loop that exists in the editing, sound, or DI room.

All this means that good communication is critical when it comes to visual effects. There's very little margin for error; vague feedback or a misinterpreted comment can easily send the VFX team down a wrong path. It is the responsibility of both the filmmaker and the VFX team to keep feedback and notes clear and concise, to leave as little as possible to guesswork and assumptions, and to ask for clarification whenever in doubt.

On an individual level, some people are simply better at communicating than others, and this true in the film industry as much as in any other. But regardless of the respective communication skills of the creative and production people involved, there are certainly some basic guidelines that can greatly improve and streamline the back and forth between the filmmakers and the VFX team.

Providing Feedback

Let's examine the four comments that follow (all, by the way, quotes of actual comments we have received at one point or another).

1. "The shot is not working. It doesn't look real. Can you make it better?"
2. "The background and foreground feel very disconnected. Can they speak to each other more fluently?"
3. "The shot looks good overall, but there's still something that feels a bit off in the integration of the foreground. Take a look around frame 220. Can it be the color of the element? Is it too lifted? Not enough contrast?"
4. "Reduce the brightness of the foreground by 25%, add 15% more contrast in the background, move the left building 230 pixels to the right and take out 10% green from the sky."

In all four of these comments, the filmmaker is evidently pointing to a problem in the shot, something that does not quite feel right. We should of course assume that both the filmmaker and the VFX team want to bring the shot to a point where everyone is happy with it. But which of these notes will get them there faster?

In comment number one, the filmmaker expresses a clear dissatisfaction. But besides this, there is really nothing specific in the feedback. "Doesn't look real" is a very vague statement in visual effects. It can mean almost anything. And realism is often in the eye of the beholder. In an attempt to "fix" the shot, the VFX team will probably try to modify whatever they interpret as bothersome to the filmmaker. They might even go ahead and steer the shot to a completely different direction altogether because "the shot is not working" and the filmmaker is clearly not happy. This is all pretty much guesswork. The VFX team might hit the jackpot and get it right this time, or they might end up taking the shot in a totally wrong direction, causing even more frustration on both sides, not to mention wasted time and money. Vague comments such as this are quite unproductive. They also go against the very essence of filmmaking: instead of a team of creatives working together to achieve a common goal (a great movie), they establish a sort of a sterile (and rather unpleasant) client–vendor relationship.

The second comment is already much more specific. The filmmaker is pointing toward the relationship between the foreground and background, but stops short of specifying what the problem might be. "Can they speak to each other more fluently?" is a nice lyrical expression that might make a great line of dialogue in a script, but a rather nebulous comment as far as VFX goes. It is not unacceptable, to be sure. But it still leaves it up to the VFX team to figure out what it is that bothers the filmmaker. Is it color? Design? Tracking? Scale? Perspective? All of the above? Something else altogether?

Comment 3 starts with "The shot looks good overall." This is not a mere "feel good" phrase, and is not given simply out of courtesy. It makes a clear statement: we are on the right track, the work is going in the right direction, but we need to solve a specific issue. The filmmaker then focuses the attention to a certain area in the shot where that issue is most evident: "take a look around frame 220," and goes on to suggest that it might be due to lack of contrast in the foreground. By presenting it this way, the filmmaker is not only pointing to a specific issue, but also allowing the VFX team some room for exploration while still pointing them in a certain direction. It is by far the most productive feedback of the four examples.

Comment 4 goes all the way toward the opposite extremity. It leaves no room for interpretation, and the artist will most likely do exactly as instructed, literally performing the changes by the given numbers. This is a risky way to go. Unless the filmmaker is a seasoned VFX artist and is able to test these values with the relevant software, it is better not to be that explicit. "Take out some green" or "Add a little contrast" is specific enough, yet leaves room for the VFX team to use their best judgment when performing the changes.

With these examples in mind, here are some guidelines for providing feedback to the VFX team:

BE SPECIFIC

- Give your notes as bullet points, not one long rambling paragraph.
- Point to the relevant frame number or frame range ("see around frame 233").
- Point to a certain area in the frame ("Top left of frame, under the wing").
- Even if you are not completely sure, or lack the precise terminology, try to explain the issues that bother you in layman terms. The VFX team can take it further.
- Use specific terms like color, placement, movement, focus, timing, and scale, and avoid associative or vague notions.

USE VISUAL REFERENCE

- Send an annotated frame grab with some arrows or circles to explain your idea.
- Send a photo or a frame from another shot (or movie) as reference.
- Ask the VFX editor to mockup a rough temp to show what you are after.

DISCUSS IN PERSON There is no better way to sort out issues than to talk about them. Emails are limited, prone to misinterpretation and not very interactive. Nothing is more productive than a verbal discussion in a meeting (or, if not possible, then over the phone). There are several useful applications like CineCync that enable both sides to interactively review video clips while talking on the phone or VOIP. This is an opportunity not only to present your feedback but also to listen to ideas or issues from the other end. A weekly (or even daily) conversation with the VFX team is an excellent addition to the continuous flow of back and forth emails.

KEEP A POSITIVE ATTITUDE I have worked on many different films and TV series, and have experienced a wide variety of attitudes and work ethics when collaborating with filmmakers. I can say without a doubt that aggressive, negative, or manipulative patterns never help, and often just make things harder for both

sides. There is no shortage of tension, pressure, and anxiety in the process of filmmaking, and, as I have already mentioned, the lack of immediate interaction when dealing with VFX can certainly be frustrating. But if you keep the VFX team "on your side" by establishing a collaborative and respectful environment, you have much better chances of getting back what you ask for.

Chapter 10

The Future

This is not an attempt to envision visual effects a hundred years from now. I leave this type of prediction to sci-fi writers. Instead, I am simply pointing out technologies and trends that are already happening and are likely to affect the way we create and use visual effects in movies and TV in the near future. Major changes may happen within the next few years. It is fairly safe to bet that computers will continue to grow even faster and more powerful, digital cameras will become smaller and more portable, image quality and resolution will increase, and VFX in general will play an even bigger role in the production of film, TV programs, commercials, and even corporate and home video. But what will be the real game-changers? Will roto and green screen become obsolete? Will CG be rendered in real time? How will VFX be applied in Virtual Reality?

Lightfield Cinematography

Arguably no other technology is bound to have a bigger impact on VFX than lightfield cinematography. Like many other VFX professionals, I have been waiting for a camera that can shoot pixel-accurate depth information for years—and to be honest, did not expect one in the near future. Granted, depth sensors of sorts have been around for a while—in gaming consoles like the Wii for example, but these are very basic, and the depth map they produce is far too crude for any VFX application. Digital camera technology has been advancing at a very fast pace though, and at the time of writing this book there is already a first model of a lightfield camera with pixel-accurate depth mapping. Built by Lytro (www.lytro.com/), a company that has been leading this field for a while, this is a monster of a camera—it's big, bulky, and requires a dedicated server to store the huge amount of data it generates. It is also, evidently, very expensive. But if it really does what Lytro says it does—captures depth and direction for every pixel in the frame, for every frame—then it really is a pioneering precursor of a major change. We can probably assume that, in time, what is now a bulky and expensive prototype that requires specialized storage will become an affordable and portable camera that will find its way into every production. So how exactly will lightfield technology affect visual effects (and cinematography in general)?

Depth-based Separation

If every pixel in the frame has depth information, you can easily separate elements in the footage based on their distance from the camera. You may, for example, keep the foreground elements and delete everything beyond 10 feet. Or keep only parts of the image that are between 8 and 12 feet from the camera. The ability to perform pixel-accurate depth separation will save enormous roto and extraction times and costs, and practically eliminate the need for green screens on set. It will also affect the way films are currently converted into stereoscopic 3D. Instead of a large team of roto artists painstakingly separating elements, most of the work could be automated, or at least reduced to a fraction of the current amount of labor.

Per-frame Dense Point Clouds

With every pixel carrying depth information in addition to color and light, the result is a dense point cloud for every frame—essentially a very accurate 3D scene that represents every element visible in the frame. First and foremost, this greatly simplifies camera tracking, since there is no more need to solve the 3D space based on parallax. It also makes depth based compositing a breeze—for example, adding fog that intensifies with distance, or placing elements in the correct position in 3D space. It also opens up new horizons for cinematography because it allows the DP to freely tweak the focus in post and easily apply depth-based filter effects or color grading. Having both spatial and directional information for each pixel also makes it easy to retime shots and apply very accurate motion blur, or perform 3D stabilization on camera movement.

Big Changes Ahead

It will likely take some time before lightfield cinematography becomes affordable and manageable enough to be used in mid-to-small-sized productions. Roto and green screens will not disappear overnight, but eventually, as lightfield technology becomes widespread, they will. As I said at the beginning of Chapter 4, roto and green screens are rather crude, low-tech solutions for separation (not to mention the hassle of shooting with green screens). The demise of roto and green screen will be, I think, a long overdue and much welcome change. But this change will also drastically affect the VFX industry in ways that are hard to predict. Roto is a laborious process, and is currently being done on a colossal scale for VFX-heavy films and stereo conversions. Because it is a straightforward technical process that does not require creative back and forth, it is being massively outsourced to countries with lower wages like India and China. More and more roto/paint studios are opened in order to satisfy the growing need of the VFX industry. These studios provide work opportunities for thousands of people across the globe. It is hard to predict how the industry will be affected if roto, extraction and tracking work becomes redundant or obsolete, but it will no doubt go through some major changes.

Super-black Materials

Nano-technology companies constantly research and develop new types of materials for a wide variety of industries. For example, Surrey NanoSystems (www.surreynanosystems.com/) developed a coating that absorbs almost all incident light (in fact, it holds the Guinness world record as the darkest man-made substance). Because it reflects no light back, it shows no surface features, shading, highlights or any detail at all. When applied to a three-dimensional object, the material makes the object look like a perfectly flat, perfectly black matte. If such a material is used as a background instead of a green screen, it can allow the compositor to extract the foreground based on luminosity only. That's because everything in the shot, even the deepest blacks, will still have higher luminance values than the background. This can be a much more precise extraction method than hue-based extraction like green or blue screens. In addition, the super-black screen does not generate any light bounce or spill and can be used in any lighting scenario (even direct sunlight). Essentially, it remains pitch black and totally consistent no matter what light is thrown at it or around it. While lightfield cameras will eventually make background screens unnecessary, it will take time until they are used regularly in every production. In the meantime, super-black screens may very well become the successors to green screens and represent a far cleaner and more elegant solution to separation (not to mention their additional benefits for the lighting and camera teams).

Real-time Rendering

As discussed throughout the book, rendering times present a significant bottleneck in the process of VFX creation. Even small changes require a re-render, and the filmmakers must wait for the render to finish. It would have been a tremendous time-saver if changes could be applied in real time (or near-real time) in the presence of the filmmaker, just as with editing, sound mixing or coloring. And of course, let's not forget the advantages this will bring to the CG artists as they adjust the shaders, textures, lighting, and animation.

The gaming industry is constantly advancing real-time rendering closer and closer to the quality needed for film and TV visual effects. And the developers of gaming graphics cards, in particular Nvidia and AMD, keep pushing the envelope at an impressive pace. At the core of such cards are GPUs (Graphics Processing Units), which have a highly parallel structure and are thus faster in processing graphical information than standard computer processors (CPUs). There are currently some GPU-based rendering engines like Furry Ball (http://furryball.aaa-studio.eu) or Octane (https://home.otoy.com/render/octane-render/) that provide very high quality output in near real time on a computer equipped with one or more powerful graphics cards. One can only assume that at this rate of development, the quality gap between real time on non-real time renders will eventually disappear.

True real-time rendering at film quality will not necessarily speed up other CG processes like modeling or animation, but it will certainly affect texturing, shading, lighting, and look development. It will also substantially speed up the creative back and forth process between the VFX artists and the filmmakers, and will no doubt contribute to a more interactive collaboration.

AR, MR, and VR

Virtual Reality (VR), and its siblings AR (Augmented Reality) and MR (Mixed Reality), are all the hype nowadays, and are already affecting everything from video games to advertising and entertainment. Augmented reality is not likely to rely heavily on VFX, since it's more about supplementing a person's view with information like GPS navigation cues, and less about creative visuals. Mixed reality, on the other hand, promises some interesting prospects for visual effects. MR devices like Microsoft's Hololens (www.microsoft.com/microsoft-hololens/en-us/why-hololens) can perform real-time 3D tracking of the viewer's environment, which enables integration of CG elements within the actual surroundings in real time. Such technology can potentially be used on set to provide filmmakers with an interactive way of previewing the VFX in context of the location. For example, the director and DP can adjust the camera as they view not only the actual set, but also the virtual CG extensions. The technology is already here. It just needs to be implemented for these specific purposes.

With VR, the entire environment is replaced by a virtual one. VR systems like Oculus Rift (www.oculus.com/) and others already have (and will continue to have) a profound effect on the gaming industry, training simulators, theme park rides, architectural visualizations, and more. But it is hard to tell how and if VR will take a major role in movies. The very essence of filmmaking is rooted in a linear narrative where the audience is led by the camera—and the ability to freely look around certainly breaks all traditional conventions. Will filmmakers come up with a completely new language that uses VR for enticing storytelling, or will VR remain on the fringe of cinema as a cool but esoteric gimmick? Time will tell. But in any case, the techniques used for visual effects equally apply to VR—only on a much larger scope. As noted in Chapter 1, VFX is traditionally done "for the camera" only, whereas with VR the "camera" essentially encompasses a full 360-degrees view. Consequently, 3D environments need to be built and rendered all around (much like in games), and 2D work must be performed on a flattened spherical panoramic plate. Similarly, when shooting for VR, the set (including green screen coverage) must be built for a 360-degrees view, and the action must happen simultaneously all around the multi-camera rig (and of course, crew members can't just stand behind the camera). The first VR movies are already being made, and VFX are already being harnessed for cinematic VR work; it will be interesting to see what kind of new creative channels VR technology will open up.

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