Simulation FX: Cinema and the R&D Complex

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Abstract

Simulation FX: Cinema and the R&D Complex

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This study looks at the ongoing development of tools and practices used to animate nonlinear physical phenomena, such as the crash of ocean waves or the movement of human hair, in the visual effect and animation industries. These tools and practices are developed in a nexus between public funding, research universities, the film industry, and various other sectors, such as aerospace and meteorology. This study investigates how technological development became integrated with film production, and in turn how epistemic paradigms were shared between the film industry, scientific research institutions and other industries.

At the heart of these animation tools and practices, and the networks of institutions that developed them, is a way of thinking that seeks to make use of unpredictable nonlinear complexity by shaping it toward specific applications. I observe this in the way animation and visual effect studios seek the realistic appearance of nonlinear natural movement through simulation, while also implementing technologies and practices to *direct* the *look* of these simulations. I also observe this in a variety of related examples, from the way the concept of research and development unites science and application, to the way management science promotes *hands off* approaches that preserve the unpredictable nature of creative work. My methods consist of charting the circulation of ideas, technologies, moving images and people through contact zones such as the computer science special interest group ACM SIGGRAPH, using archival research of trade communications, scholarly publications and conference proceedings, as well as interviews with industry workers.

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Introduction: Defining Simulation FX

Animators have long been interested in the unique, complex quality of natural movement. Disney animators Sandy Strother and Ugo D'Orsi were dedicated to this subject on projects such as *Fantasia* (1940) and *Pinocchio* (1940), where they specialized in animating water. The splashing and flow of water in their animation was naturalistic, less abstract than previous examples. Yet they were not exactly seeking photorealism. They were seeking to bring water to life, to animate it. The water had a certain look, a certain style. Seventy-seven years later, Walt Disney Animation Studios is still interested in brining natural movement to life. In a recent case like Disney's digital animated feature *Moana* (2016) the ocean is imbued with its own personality, as though it were a character. Artists are able to make the water behave a certain way, sculpting a living, moving thing. This contemporary approach to animating natural movement entails a very different way of making moving images than the work of Strother and D'Orsi though. The kinds of tools used to animate water in *Moana* illustrate a great deal about the evolving relationship between scientific research, technological development and the film industry. They also illustrate a way of seeing and managing the world that has developed within the nexus of these three domains.

Images such as the water sequences in *Moana* are not animated directly by hand. Their motion is not deterministically set through a manual process like drawing on a cel or manipulating a 3D object with a digital cursor. Instead, the movement of the water is animated through an extensive process that starts with scientists doing basic physical and mathematical research, continues with engineers and technical directors building specialized simulation software, and concludes with simulation artists or FX artists manipulating parameters in that software in order to achieve a specific desired look. Thus, the process of animating water requires research and development (R&D) as well as creative control. This same approach is used to animate the complex movement of things like, hair, fur, cloth, earth, destructible objects, smoke and groups of creatures in the VFX and animation industries. Throughout this thesis I will be using the term *simulation FX* to describe this form of animation.

The earliest forms of simulation FX were developed for the Hollywood VFX and animation industries starting in 1981. In the past few years simulation FX have become more ubiquitous, proliferating in global film industries and other media forms like video games. They have also gone from being spectacular *hero* effects in films to being more mundane and ubiquitous background effects. While simulation FX still play a relatively minor role in most productions, today every full-service animation or VFX studio has a department dedicated to simulation-based animation.

This thesis will use simulation FX and the scientific paradigms that underpin them to investigate the entanglement between technological development, scientific research and film production during the past four decades. At the heart of simulation FX is a way of thinking that seeks to make use of unpredictable nonlinear complexity by shaping it toward specific applications. This applies both to the way animation and VFX studios build tools to *direct* the *look* of simulated images and also to the way they use *hands-off* management techniques that seek to direct unpredictable labour tasks involving R&D and creativity. This thesis will investigate how this way of seeing and managing the world is imbricated with the development of similar approaches in a number of other industries and research disciplines, from climate science to sociology to finance. Understanding simulation FX entails understanding a broader archaeological layer of knowledge, which includes various institutions and forms of organization and management. This research will offer original contributions to theoretical debates about the technological transformations cinema has undergone in the past few decades and the historical significance of those transformations as they relate to things like labour management and economics.

I will accomplish these objectives by charting the circulation of ideas, technologies, moving images and people through contact zones such as the Association for Computing Machinery's Special Interest Group on Computer Graphics and Interactive Techniques (ACM SIGGRAPH), using archival research of trade communications, scholarly publications and conference proceedings, as well as interviews with industry workers. Some of these industry sources have a habit of exaggerating or over-hyping the innovative and transformative qualities of the new technologies they develop. Thus there is good reason to approach this connection between film production and scientific research with a sceptical eye. To get to the truth, I will seek to identify discourses in trade and promotional communications while balancing these sources with more objective information on the history of technologies and institutions.

Before getting into a layout of the following chapters, it is necessary to establish first a more detailed explanation of what simulation FX is and what we can learn from studying it.

While the term simulation FX is not commonly used in VFX or animation industries, the people in these industries widely accept the grouping of special simulation-oriented tasks into one ontological unit. Often this type of work is grouped into a special department of a VFX or animation studio. Simulation FX tools and techniques also tend to have their own section in industry training material. More common terms used to describe simulation FX are physical simulation, dynamic simulation, technical animation, or simply *FX*. I do not use any of these terms because each only captures one or two significant conceptual aspects of simulation FX, and I want to encompass all of these aspects in a single term. As a way of introducing simulation FX, I will go through each of these more common industry terms and explain what is significant about each of them in the following three sections.

Physical and Nonlinear Simulation

I will engage the subject of simulation in greater depth in chapter 1, but it is important to establish some basic nomenclature as early as possible. Many computer graphics researchers working on simulation make the distinction between visual simulation and physical simulation.[1] To visually simulate something is to imitate its appearance. This is the way observers often describe computer generated VFX and animation, as an artificial approximation of how something appears on camera or to the human eye. A good example of this is Stephen Prince‘s influential concept of “perceptual realism.” Perceptual realism refers to the way filmmakers can make anything look realistic through the use of perceptual cues like reflection, shadow and perspective.[2] Physical simulation, by contrast, refers to the imitation of an underlying mechanism. For example, to simulate a bouncing ball one would have to model the coefficient of gravity and the mass and elasticity of the ball. With these factors one could build an algorithm to compute the way the ball would bounce. A physical simulation may not necessarily be visually realistic. Indeed it may not be visual at all. One could calculate the movement of the bouncing ball numerically without visualizing it. But physical simulation is realistic in the sense that it

[1] See for example D. Terzopoulos et al., “Physically-Based Modeling: Past, Present, and Future,” in *ACM SIGGRAPH 89 Panel Proceedings*, SIGGRAPH ‘89 (New York: ACM, 1989), 191–209.

[2] Stephen Prince, “True Lies: Perceptual Realism, Digital Images, and Film Theory,” *Film Quarterly* 49, no. 3 (April 1996): 29–33.

attempts to imitate the rules that govern reality. This is a principle that is at the heart of all scientific simulation, and it is also at the heart of simulation FX.

Simulation FX applies to only one particular category of physical simulation: nonlinear physical simulation. The simplest way to differential different kinds of physical simulation is to break them into kinematic and nonlinear forms. Manuals on animation algorithms tend to organize their chapters around these categories.[3] A kinematic simulation has simple, linear, deterministic causality. In other words, you can calculate the outcome based on the initial conditions. By contrast, the outcome of nonlinear simulations cannot be determined based on starting conditions. Nonlinear simulations are unpredictable; they have a mind of their own, so to speak. Certain things are conventionally animated with either kinematic or nonlinear simulation. For example, the rigging of a character model (the design of a character‘s bones, joints and range of motion) is typically modeled with kinematic simulation. This makes the job of animating a character very direct and predictable. The animation of a stormy ocean, by contrast, with its chaotic, unpredictable waves and splashes, requires a nonlinear simulation. A linear animation of an ocean would look far too uniform, and attempting to manually animate every undulation would require monumental amounts of labour. This is a prime example of simulation FX. With these two concepts of physical and nonlinear simulation, I will build a picture of a form of animation and VFX that is far more than visually or perceptually realistic. These concepts have deep epistemic importance that merits investigation.

Game Studies scholars have, up to this point, generally been the only media scholars to discuss at length the conceptual importance of simulation. As Espen Aarseth writes in the introduction to the first issue of the online academic journal *Game Studies*, the concept of simulation is vital to understanding some games. Most games are not neutral spaces or linear narratives, they are ―complex systems based on logical rules.”[4] Aarseth is famous for advocating for game studies as ―ludology” rather than ―narratology.” In order to understand games, he

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[3] A good example of this is Rick Parent‘s popular book on animation algorithms, although he uses the term ―dynamic” in place of ―nonlinear.” Dynamic and nonlinear are often used interchangeably. In chapter 1 I will delve into the subtle differences between these two terms. Rick Parent, *Computer Animation: Algorithms and Techniques* (Burlington, MA: Morgan Kauffman, 2008).

[4] Espen Aarseth, ―Computer Game Studies, Year One,” *Game Studies*, July 1, 2001, http://www.gamestudies.org/0101/editorial.html.

argues, we must understand the logic and rules of their underlying structure. That is the most important way games make meaning. Simulation is thus a vital concept for game studies, because the underlying mechanisms of games often simulate (very abstractly) mechanisms in the real world. Consider for example how the classic board game Monopoly simulates the real estate industry. It is not exactly accurate, but it approximates the mechanisms that structure the industry, a simulation to be sure.

Although I am brining the study of simulation to cinema with this project, I will not be employing games studies methods. Game simulation and simulation FX are simply too different. Games consist of sets of relatively static rules that a user interacts with, while simulation FX are of course non-interactive. The viewer does not sense the underlying structure of simulation FX, they are far too complex and nonlinear to be parsed. Furthermore, simulation FX do not construct a virtual interactive world like a game, they model some sort of discreet physical phenomenon. In recent years there have been more and more cases of simplified simulation FX technologies being used in games to animate physical phenomena like water and smoke. This is a relatively recent development, because historically simulation FX have been far too complex to be animated in real time, even on state-of-the-art workstations. But the fact that we can identify simulation FX as a kind of special effect within a video game points to its particularity. In the following chapters I will occasionally note points of overlap between games and cinema such as these. I will also note the instances where researchers or technologies are exchanged between the film and games industries. Yet the focus of this project is positioned squarely on VFX and animation.

Aside from game studies, there is one other facet of media studies where the term simulation is used, and that is discussions of postmodernity. Jean Baudrillard‘s monograph *Simulation and Simulacra* likely springs to the readers mind first and foremost. Baudrillard argues that in postmodernity we treat a simulation of reality as reality itself. He theorizes that we have made a map of our world, so extensive and totalizing, that we have replaced reality. Baudrillard writes, ―It is the generation by models of a real without origin or reality: a hyperreal.”[5] Hyperrealism, an artificial realism so complete and detailed it exceeds reality, was, and in some cases is, a popular term for describing Hollywood VFX and animation. During the

[5] Jean Baudrillard and Sheila Faria Glaser, *Simulacra and Simulation* (Ann Arbor: University of Michigan Press, 1994), 1.

peak of theorization about postmodernity, one could not help but look at the overwhelmingly convincing unreality of blockbusters like *Jurassic Park* (1993) or the convincingly falsified historical footage in *Forest Gump* (1994) and see signs of the times. VFX and digital animation were a prime example of the dematerializing effects of both late capitalism and information technology.

This gloss on simulation has dominated the way media and cultural studies have understood the term for the past four decades. The term hyperrealism has been used in describing digital VFX and animation by countless theorists, from Dudley Andrew to Lev Manovich.[6] I will be offering a different interpretation in this thesis. While I am definitely seeking to historicize simulation FX and the institutions and epistemology connected to it, I do not find that it is a synthetic symptom of a disappearing reality. To define it in these terms is to neglect the significant ways simulation has shaped how we make sense of the world and how we control it. As I will demonstrate, simulation FX are intimately connected to the way we make sense of nonlinear, dynamic, unpredictable things such as weather and financial markets. Simulation does not represent the waning of access to reality; it represents a historically specific episteme that is imbricated in a variety of aspects of society. Furthermore, I do not see simulation FX as the by-product of political and economic conditions. Instead I see deep transactional connections between simulation and society, with power and knowledge feeding into each other. I will demonstrate this in terms of how the paradigm of nonlinear simulation permeates different examples, but I will also trace very specific institutional connections between VFX, animation, scientific research, and varied public and industrial applications of simulation.

Technical Animation and R&D

Another term often used to describe simulation FX that captures some important concepts is technical animation. The term technical animation denotes that the labour put into creating simulation FX animations is technical more than it is direct and manual. The term technical animation points to the role algorithms play in this type of animation. Algorithms are instructions for computing, they do some sort of task automatically. They are the basic unit of computer

[6] Lev Manovich, *The Language of New Media* (Cambridge, Mass.: MIT Press, 2002), 191–92; Dudley Andrew, *What Cinema Is!: Bazin's Quest and Its Charge* (Malden, MA: Wiley-Blackwell, 2010).

automation. Algorithms have become an important part of understanding digital media for scholars such as a William Urrichio, Lev Manovich, Alexander Galloway and Eivind Røssaak.[7] Algorithms are noteworthy because they can be used to create automatic processes in a digital environment, approximating the automatic nature of physical media apparatuses like the film camera. All digital animation uses algorithms in the sense that software tools are made of algorithms, but technical animation makes writing algorithms part of the act of making animation. A digital key-frame animator uses software to manually create shapes or draw lines using a mouse or stylus and they manually set the movement of those objects over time. Technical animation, by contrast, means that an artist programs instructions and then the software creates the animation automatically. The artist creates a sort of digital machine, and that machine in turn creates the image. In the most basic of cases, technical animation can be used to make very simple and linear shapes and movements, but in the case of nonlinear simulation, the algorithms produce something unpredictable, something beyond what the artist initially programmed. The study of simulation FX is therefore an important contribution to existing discussions of algorithmic media.

This emphasis on tool-building as a component of image-making has some interesting consequences. For one, it modifies the division between above-the-line creative work and below-the-line technical work, a division studied by production culture scholar Vicki Mayer.[8] This is a subject I will address in chapter 3. The concept of technical animation prompts us to consider how the extensive process of developing new technologies is an integrated part of the image-making process. While the VFX and animation industries generally have a strong emphasis on technological development, the term technical animation demarcates special cases where technology development is particularly demanding.

[7] Alexander R Galloway, *Gaming: Essays on Algorithmic Culture* (Minneapolis: University of Minnesota Press, 2010); Eivind Røssaak, ―Algorithmic Culture: Beyond the Film Photo Divide," in *Between Stillness and Motion: Film, Photography, Algorithms*, ed. Røssaak Røssaak (Amsterdam: Amsterdam University Press, 2011); William Uricchio, ―The Algorithmic Turn: Photosynth, Augmented Reality and the Changing Implications of the Image," *Visual Studies* 26, no. 1 (2011): 25–35; Lev Manovich, *Software Takes Command* (New York: Bloomsbury, 2014).

[8] Vicki Mayer, *Below the Line: Producers and Production Studies in the New Television Economy* (Durham, NC: Duke University Press, 2011).

Building technology for nonlinear simulations often requires the work of research scientists and working university professors, a phenomenon I will study in detail in chapters 2 and 3. In every step of this thesis I will note how a vast network of sustained R&D that reaches into academic computer science, mathematics and physics departments, supports simulation FX. My research uncovers formerly unmarked connections between the film industry and other institutions and industries. These connections underline the epistemic relevance of simulation FX as more than mere hyperrealism. It is through these connections that we can see how the epistemology of simulation FX is connected to other facets of society.

The involvement of public research institutions and funding undermines some popular myths about the Hollywood VFX and animation industries. VFX and digital animation studios are steeped in a mythology of visionary entrepreneurialism. Pixar Studio's history is intertwined with Apple computers, for example. As special effects scholar Julie Turnock notes, special effects studios like Industrial Light and Magic (ILM) have similar mythologies. ILM's official history sees the company as a group of outsiders who disrupted settled ways of doing things in Hollywood. Turnock argues that this is more mythology than history though. ILM was populated by many industry veterans.[9] Economist Mariana Mazzucato's recent work similarly illustrates that Silicon Valley corporations like Apple, which are so keen to promote their disruptive entrepreneurial spirit, actually rely heavily on government-funded research funding and training.[10] My work in this thesis will offer a similar contribution to Mazzucato's and Turnock's. The case of simulation FX demonstrates how heavily integrated these industries are with larger scientific research infrastructures. To do this, I will explore the concept of R&D.

The concept of technical animation points to how deeply integrated R&D and simulation FX are. Indeed, I would argue one cannot understand one without the other. R&D is vital for understanding both the institutional context that made simulation FX possible, and also the logic structuring simulation FX production practices. Beginning as a concept around the turn of the century, but not really achieving total ubiquity in the United States until the Cold War, R&D has in many ways shaped the way we think about science and technology. In chapters 1, 2 and 3, I

[9] Julie A Turnock, *Plastic Reality: Special Effects, Technology, and the Emergence of 1970s Blockbuster Aesthetics* (New York: Columbia University Press, 2015), 64.

[10] Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Myths in Innovation* (London: Anthem Press, 2013).

will show how the ongoing development of simulation FX was supported by various public and private sources of research funding, and also how Hollywood began to play a larger and larger role in sponsoring scientific research. A key part of my research into R&D will be a study of the computer science scholarly and professional organization ACM SIGGRAPH. SIGGRAPH is the main contact zone where the VFX and animation industries coordinated with research institutions.

Looking at SIGGRAPH and what I will refer to as the R&D complex opens up our understanding of cinema‘s recent past. Many film scholars writing in the vein of media archaeology and early cinema studies have noted how the seeming proliferation of new kinds of moving images in the digital age should prompt us to pay attention to the many ways cinema has always been varied. We should be attentive to the many histories of cinema. Thomas Elsaesser notes how this should prompt us to pay closer attention to the ―S/M perversions" of cinema, in other words, the way moving image media, and indeed cinema, have been used in science, medicine, surveillance and military applications.[11] These are ―parallel histories" of cinema. [12] My study of simulation FX and of R&D complex organizations like SIGGRAPH does exactly this. In the following chapters I will uncover a variety of connections between cinema and other technologies in various disciplines and industries. Simulation is a parallel line, or perhaps a diagonal one, that cannot be reduced to *the digital*. It passes through cinema as well as other varied applications distributed throughout society.

As Raymond Williams notes in his work on television, R&D in a key site where we can observe society‘s influence on the shape of media technologies. Media like television were ―looked for and developed with certain purposes and practices already in mind," and R&D is one place where those social desires were turned into reality.[13] Television was not discovered as some entity external to society. On the other hand, R&D can be a very uncertain process. It can

[11] Thomas Elsaesser, ―Afterword - Digital Cinema and the Apparatus: Archaeologies, Epistemologies, Ontologies," in *Cinema and Technology: Cultures, Theories, Practices*, ed. Bruce Bennett, Marc Furstenau, and Adrian Mackenzie (New York: Palgrave Macmillan, 2008), 17.

[12] Ibid., 22.

[13] Raymond Williams, *Television: Technology and Cultural Form* (London: Fontana/Collins, 1974), 14.

be difficult and expensive, sometimes even impossible, to develop a new technology. As I will demonstrate, the unpredictable nature of R&D has real economic consequences, many of which can be seen in the precarity of the VFX industry. Sometimes a company can invest a fortune searching for a solution that just does not exist. Appreciating the role of R&D in animation, and especially VFX, contributes to scholarship on the precarity of the contract-based nature of the VFX industry by scholars such as John Caldwell, Michael Curtin and John Vanderhoef.[14] This is a topic I will cover in chapter 3.

The concept of R&D allows us to attend to the way the uncertainty and risk of research is managed as well. The history of simulation FX demonstrates how a given set of scientific principals was shaped toward very specific applications over time. Indeed I will demonstrate in chapter 2 how the logic of technological spectacles in the Hollywood blockbuster directed basic scientific research via the animation and VFX industries. This work contributes to existing scholarship relating to the relationship between the Hollywood blockbuster and technological development, including Charles Acland's concept of the ―technological tent-pole" film.[15]

Simulation is deeply connected to the epistemology behind R&D. At the core of each is an appreciation for the value of the unpredictable and contingent, coupled with a desire to manage and exploit it. This is a logic that even extends to the management of media industries, as I will demonstrate in chapter 3. This offers a contribution to the growing field of media management studies, as championed by Derek Johnson, Derek Kompare, Avi Santo and Mark Deuze.[16] Both animation and VFX industries have developed ways of embracing the dynamic, nonlinear ―chaos" of creativity, while managing it and directing it toward certain goals. I therefore see the relationship between simulation and the institutions and businesses that sponsor

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[14] Michael Curtin and John Vanderhoef, ―A Vanishing Piece of the Pi," *Television & New Media* 16, no. 3 (February 20, 2014): 219–39; John Thornton Caldwell, *Production Culture: Industrial Reflexivity and Critical Practice in Film and Television* (Duke University Press, 2008).

[15] Charles Acland, ―Avatar as Technological Tentpole," *Flow Online Journal*, January 22, 2010, https://www.flowjournal.org/2010/01/avatar-as-technological-tentpole-charles-r-acland-concordia-university/.

[16] Mark Deuze, *Managing Media Work* (Los Angeles: SAGE, 2011); Derek Johnson, Derek Kompare, and Avi Santo, *Making Media Work Cultures of Management in the Entertainment Industries* (New York: New York University Press, 2014).

simulation R&D as a kind of epistemic feedback loop, with neither technology nor practices nor discourses nor institutions being the sole source of the conditions of knowledge, but instead with each feeding into the other. I believe the R&D complex, as an institutional phenomenon and an organization paradigm, and simulation FX, as a set of technologies, practices and production conventions, must be understood as a dyad, with each feeding into the other. In the Foucauldian sense, then, I am trying to uncover the “archive” of this place in history, the “system of enunciability,” the totality of both knowledge and forms of management and organization.[17]

Special FX

The last term used to refer to simulation FX I will address is *FX*. Like the terms technical animation and physical simulation, FX captures some important conceptual aspects of simulation FX without quite encompassing its totality. It is common for large animation studios to have an FX department, which specializes in technical forms of animation like simulation FX. In a way, the FX department is like the special effects department of an animation studio. FX demarcates a special kind of animation, one that is different from the other jobs in the studio. These departments are a big part of what visually separates a Disney, Dreamworks or Pixar feature from a small budget studio. These large studios can support their own R&D; they can develop new ways of animating a character's hair or fur, or the way their clothing bunches and folds. Although the term is only used is the animation industry, this logic of simulation FX as an extra special form of separate labour is also at work in the VFX industry. As one artist who worked in both VFX and animation explained to me, FX is the extra flair, “the icing on the cake” of a VFX or animation project.[18] FX demarcates a special kind of image making within industries that we would already consider special. The concept is useful in light of recent scholarly discussions over whether we should consider animation and VFX special or exceptional.

At the 2013 GRAFICS *Magic of Special Effects* conference held in Montreal, a preponderance of scholars addressed the question of whether *special effects* is the correct term to use to describe their object of study. How special are special effects anymore? Were they ever

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[17] Michel Foucault and Alan Sheridan, *The Archaeology of Knowledge and the Discourse on Language* (New York: Vintage Books, 2010), 129.

[18] Patrick Parenteau, Interview with Technical Director and FX Artist Patrick Parenteau, August 9, 2016.

special or exceptional? Many noted that in the film industry special effects refer only to practical effects done in front of the camera, the more traditional work of triggered explosions, car crashes and so forth. VFX, on the other hand, describes manipulating the image itself. John Belton pointed out in his presentation that the disappearance of the term special effects suggest that visual effects are no longer special but standard practice. [19] Much filmmaking labour is done in digital post-production now, after all. So is there any reason to differentiate between post-production work like colour correction and VFX work like keying in a background? Other presenters, such as Sean Cubitt, argued that we ought to preserve the concept of specialness, even as digital tools seem to blur old categories. He argues that rather than defining specialness through exceptionality or lack, we should use it to label examples that help us to ―imagine otherwise."[20] The emergence of the FX department offers a novel answer to these questions. While the general tasks of animation and VFX are perhaps the new normal, these industries are seeing the emergence of new special forms of image making like simulation FX.

As VFX and digital animation have become more ubiquitous and quotidian, simulation FX seem to have taken the role of spectacular technical novelty they once did. A new specialness (simulation FX) seems to have emerged from within an existing specialness (VFX and animation) that is perhaps not as special as it once was. Simulation FX's special production practices, which emphasis technical work rather than manual work, and its heavy emphasis on technological development, make it special. This is an important concept I address in chapter 2, where I discuss the economics of R&D and the Hollywood blockbuster. Building on work on the economics of blockbusters and their relationship to technological change by scholars such as Steve Neale, Sheldon Hall, Michael Allen and Anita Elberse, I find that the search for cutting-edge technical novelty in the blockbuster drives investment in simulation FX.[21]

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[19] John Belton, "Images as Special Effects" (presentation at the ARTHMEIS Magic of Special Effects Conference, Montreal, November 5-10, 2013).

[20] Sean Cubitt, "Of Time and Special Effects," (presentation at the ARTHMEIS Magic of Special Effects Conference, Montreal, November 5-10, 2013).

[21] Sheldon Hall and Stephen Neale, *Epics, Spectacles, and Blockbusters: A Hollywood History* (Detroit: Wayne State University Press, 2010); Michael Allen, ―Talking About a Revolution: The Blockbuster as Industrial Advertisement," in *Movie Blockbusters*, ed. Julian Stringer (Florence: Taylor and Francis, 2013), 101–14; Anita Elberse, *Blockbusters: Why Big*

The Particularity of Simulation FX

By briefly covering the concepts of nonlinear and physical simulation, technical animation, R&D, and FX, I have intended to convey to the reader the particularity, the specificity, of simulation FX. Simulation FX is something different. It is a form of specificity one can study, in a time when some observers see specificity waning.

In his influential book *The Seduction of Reality*, Stephen Prince takes the position that different forms of digital image making like VFX, post-production and animation essentially belong to one big category.[22] Although he sees continuity between digital and historical forms of image making, he also buys into this idea of digital tools having flattened former conventional differences. Other scholars have contested this assumption however. For example, Wendy Chun argues that digital technology leads to divergence and variety rather than convergence.[23] Julie Turnock contends with Prince‘s position, arguing that there are still important differences between things like VFX and feature-length animation. Their practices and tools are still conventionally very different.[24]

In my research I have found examples of both convergence and divergence. I have found many ways that the VFX and animation industries differ from each other, consistent with Turnock‘s findings. Examples will be spread throughout the following chapters. But simulation FX is one substantial point of overlap, where VFX and animation can become virtually identical. I will demonstrate over and over again how simulation FX technologies and people move back and forth between these industries with ease. Simulation FX is thus an emergent specificity that cuts across existing boundaries. Old categories like film and animation may be dissolving or mutating, but new specificities are also emerging. Simulation FX is different from animation and other cinematic forms in the specific epistemology of simulation that premises it, in the way

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Hits - and Big Risks - Are the Future of the Entertainment Business (London: Faber and Faber, 2015).

[22] Stephen Prince, *Digital Visual Effects in Cinema: The Seduction of Reality* (Rutgers University Press, 2012), 56.

[23] Wendy Hui Kyong Chun, ―Did Someone Say New Media?," in *New Media, Old Media: A History and Theory Reader*, ed. Wendy Hui Kyong Chun and Thomas Keenan (New York: Routledge, 2005), 1.

[24] Turnock, *Plastic Reality*, 5.

simulation FX technologies are developed, and in the unique particularity of simulation FX production practices.

The approach to simulation FX that I have laid out so far, which accounts for the conceptual specificity of simulation FX as a nonlinear form of physical simulation sustained by a nexus of public and private R&D institutions, and as a form of image making that integrates technological development on a fundamental level, is a break with the limited existing media studies scholarship on the subject. Other scholars have touched on some of these individual aspects. As I noted, certainly some contemporary scholars are grappling with issues relating to algorithmic media, though none that I can find engage substantially with simulation FX specifically. Sean Cubitt touches on some aspects of simulation FX in his discussion of ―vector" animation. A vector is a way of mathematically describing a shape through an equation rather than Cartesian coordinates. Cubitt sees ―physical simulation" as a type of vector animation, and he notes some concepts I will discuss in this thesis, such as the idea of open-ended, autonomous forms of animation.[25] But his category of vector animation is very large, one of only three forms of material engagement in animation he identifies, the other two being ―direct" and ―profilmic."[26] Indeed, so capacious and abstract is the vector category, he includes some hand drawn key-frame examples such as Emile Cohl's *Phantasmagoria* (1908) in it as well. I will be approaching simulation FX much more specifically and concretely.

By far the most common place to find mentions of simulation FX in media studies scholarship is as part of a long list of other naturalistic computer graphics technologies. Scholars such as D.N. Rodowick, Lev Manovich and Scott Bukatman all mention ―physical simulation" in their work in this capacity.[27] While it is true that simulation FX are developed by the same R&D institutional structure and are used in the same context as other realistic computer graphics techniques, this thesis will demonstrate the importance of their particularity. By not subsuming

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[25] Sean Cubitt, ―Ecocritique and the Materialities of Animation," in *Pervasive Animation*, ed. Suzanne Buchan (London: Routledge, 2013), 110.

[26] Ibid., 94.

[27] Bukatman, Scott, ―Some Observations Pertaining to Cartoon Physics; Or, The Cartoon Cat in the Machine," in *Animating Film Theory*, ed. Karen Redrobe Beckman (Duke University Press, 2014), 312; Manovich, *The Language of New Media*, 191–92; David Norman Rodowick, *The Virtual Life of Film* (Cambridge: Harvard University Press, 2007), 129.

simulation FX into these other discourses, we can begin to see their historical relevance, how they are imbricated in historical ways of seeing and managing the world. Nonlinear simulation is vital for understanding things as diverse as climate science and labour management, and simulation FX offer a medial look into this episteme that has been playing a larger and larger role in shaping history for at least the past sixty years.

Chapter Summaries

The layout of the following chapters follows a sort of progression. In chapter 1 I will start at the furthest point from cinema, discussing the history of certain scientific concepts and scientific institutions. In chapters 2 and 3 I will discuss the Hollywood film industry, and VFX and animation production practices. In chapter 4 I will study the aesthetics and themes in some key films that feature simulation FX as technological spectacles. This arc will gradually build a case for how a set of scientific concepts and a network of institutions influenced the way films were made in Hollywood from 1979 to the present.

Chapter 1 establishes important concepts and a historical context, all of which will be vital for the following chapters. Although I have offered a brief explanation of nonlinear simulation in this introduction, I will go into greater conceptual depth in chapter 1. Here I will cover different kinds of nonlinear simulation, starting with examples from the 19th century, before moving on to the very early days of the reprogrammable computer. These are the common roots shared between simulation FX and several other applications of nonlinear simulation such as finance and meteorology. I have made a chart that lays out the connections between these different kinds of nonlinear simulation as they developed over time (figure 1). The other part of chapter 1 regards the institutional and organizational context of the development of nonlinear simulation. Here I discuss the role of the military-industrial complex and the concept of R&D, formulating the concept of the R&D complex, which describes the way scientific research institutions and government funding are integrated with private enterprise in order to foster technology development. This will be an important concept not just for understanding the origins of simulation FX but also the context of its sustained development.

Chapter 2 covers how the R&D complex came to influence the VFX and animation industries, and how simulation FX emerged from this context. A key subject of analysis here will be the academic and professional association SIGGRAPH, which is a contact zone between research institutions, federal agencies, and private industries. Studying the communications of

SIGGRAPH year over year, I note some marked changes. Starting in 1979 one can begin to see the ascendance of media industries. In many ways media industries began to develop their own R&D complex. At the forefront of this change were the Hollywood film industry and the blockbuster. I demonstrate that the Hollywood blockbuster‘s insatiable need for novel spectacles of technology and it ability to garner substantial upfront capital investment made it an ideal sponsor for speculative R&D investment. I refer to this phenomenon as the *blockbuster R&D complex.* I demonstrate a variety of examples of how the blockbuster R&D complex made the development of simulation FX possible, and indeed how it has caused it to flourish as a globalized phenomenon. I have made a flow chart the maps out how one simulation FX technology, fluid simulation, has developed over time in this context (figure 2).

While chapter 2 studies the effects of the film industry on R&D research infrastructures, chapter 3 conversely studies the effects the R&D complex had on both the Hollywood film industry and film production. I do this by looking at the VFX and animation organizational concepts of *workflow* and *pipeline* and how they are connected to both the episteme of nonlinear simulation and the organizational philosophy of R&D. I focus on two key concepts to demonstrate this. First I look at how technology development is inseparable from image making in the simulation FX workflow. Not only are technologists and scientists an integrated part of specific image making projects, but there are many workers with hybridized roles like R&D artist. Second I look at how the management philosophies of VFX and animation studios seek to capitalize on the risk and uncertainty of both scientific research and artistic creativity. Here, I argue, we can see an example of both the epistemology of simulation and the organizational logic of R&D. Understanding why, however, will require reflection on chapters 1 and 2.

Having demonstrated how certain forms of film production and industry have been shaped by the logic of nonlinear simulation and R&D, in chapter 4 I move on to look at changes in the formal and thematic content of Hollywood blockbusters from 1982 to 2004, using the films *Star Trek II: The Wrath of Kahn* (1982), *Jurassic Park* (1993), *Twister* (1996), *The Perfect Storm* (1999) and *The Day After Tomorrow* (2004). I focus on this period because this was when simulation FX were most salient as hero effects in spectacular films, and the films I study are all landmarks in the history of VFX. Each of these films also addresses some aspect of nonlinear simulation in their narrative, whether it is chaos theory in *Jurassic Park*, fractals in *The Wrath of Kahn*, or climate modeling in *The Day After Tomorrow*. I contend that the simulation FX spectacles in these examples actually make certain aspects of these topics in nonlinear simulation sensible. For example, certain films represent events like catastrophic storms through the paradigm of nonlinear simulation, while at the same time animating the storm with simulation FX. My argument is based on Kristen Whissel‘s theory of the special effect ―emblem,” which theorizes a relationship between special effects spectacles and narrative. Whissel argues that special effects spectacles can be understood as ―allegorical assemblages” or ―spectacular elaboration(s) of concepts.”[28] Thus, simulation FX spectacles can allegorically represent topics relating to nonlinear simulation. Simulation FX do not always play this role in film texts, but this chapter demonstrates that they can, and they frequently did during a period in history when the public was increasingly seeing their world through the frame of nonlinear simulation.

Conclusion

Simulation FX demonstrate how imbricated film production and technological development can be, and recognizing this connection opens up a different way of understanding film‘s historical significance. The development of simulation FX tools, the way they are used, and the images they are used to create, all demonstrate the historical significance of nonlinear simulation.

The following study of Simulation FX production practices, tools and R&D offers original contributions to the study of film special effects and the study of animation. In both cases I will weigh in on some particular debates in these fields, as well as engage some very fundamental questions they raise about film and animation, and about the relationship between technology and film.

This thesis offers a way forward for some of the impasses in special effects studies I described above. As scholars such as John Belton question whether special effects still exist in the age of ubiquitous post-production, simulation FX offers a very clear answer. There are still types of special technical production work in the film industry, but we need to look in new places for them. Furthermore, simulation FX can offer a contribution to existing work on the relationship between spectacular images, blockbusters and technological change. My contribution will build on the existing work of scholars such as Charles Acland and Michael

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[28] Kristen Whissel, *Spectacular Digital Effects: CGI and Contemporary Cinema* (Duke University Press, 2014), 6–8.

Allen to show how simulation FX are part of an economic system where blockbuster films provide the capital for R&D investment, which connects research institutions with the film industry. [29] This thesis will further contribute to the study of VFX labour. By investigating how technical and scientific work are merged into production, it offers insights into how both creativity and R&D are managed in contemporary animation and VFX. Finally, this research will contribute to studies of the meaning produced by special effects, by scholars such as Tom Gunning, André Gaudreault, Dan North and Kristen Whissel, noting how simulation FX spectacles mediate a whole realm of connected technologies that permeate different aspects of society, from economics to climate science. [30]

Perhaps most fundamentally, this thesis contributes to the now decades-old controversies surrounding film in the age of digital technology. In particular, this work will counter once influential prophesies by the likes of D.N. Rodowick and Dudley Andrew about the death of cinema that hinge on either the Percian semiotic category of indexicality or a dichotomy that pits automated realism against manually manipulated formalism. [31] The following study of simulation FX demonstrates, above all, that cinema is far from dead, and that theoretical questions facing film in the past few decades are in many ways the same questions cinema has been facing for over a century. For example, I will compare my work to that of Mary Ann Doane, who studies the way early cinema controls the unpredictable contingency of reality in a ―representational system," ―while maintaining both its threat and its allure." [32] I will contend that much the same can be said about simulation FX.

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[29] Michael Allen, ―Talking About a Revolution: The Blockbuster as Industrial Advertisement," in *Movie Blockbusters*, ed. Julian Stringer (Florence: Taylor and Francis, 2013), 101–14.

[30] Tom Gunning, ―The Cinema of Attraction: Early Film, Its Spectator, and the Avant-Garde," in Early Cinema: Space, Frame, Narrative, ed. Thomas Elsaesser (London BFI, 1990); Dan North, *Performing Illusions: Cinema, Special Effects and the Virtual Actor* (London: Wallflower Press, 2008).

[31] David Norman Rodowick, *The Virtual Life of Film* (Cambridge: Harvard University Press, 2007); Dudley Andrew, *What Cinema Is!: Bazin's Quest and Its Charge* (Chichester, West Sussex, U.K.; Malden, MA: Wiley-Blackwell, 2010).

[32] Mary Ann Doane, The Emergence of Cinematic Time: Modernity, Contingency, the Archive (Cambridge: Harvard University Press, 2002), 138.

Both the cinematograph and simulation FX are automated representations of the world that are shaped by their operators, and their ongoing technological development can tell us a great deal about historical ways of seeing and representing. The history of cinema is full of technical and aesthetics changes, such as the introduction of sound-on-film or colour systems, which can be studied in broader technical and scientific contexts. In the same way I am studying simulation FX through professional organizations like SIGGRAPH and various scientific research labs, cinema technology throughout history can be studied through professional organizations like SMPTE and through research labs going all the way back to Thomas Edison‘s very first lab in Menlo Park. While simulation FX are very much a product of their place in history, they are also very much a part of the cinematic tradition. Studying them not only informs our understanding of recent and contemporary changes, it also informs our understanding of cinema throughout its century-long history.

Chapter 1: Nonlinear Simulation and the R&D Complex

This chapter covers the two central historical components of simulation FX: the integrated organizational and institutional conditions of the Cold War period in American science and industry, the epistemic and conceptual conditions of scientific simulation, and nonlinear (dynamic and stochastic) simulation. These organizational and epistemic subjects are intimately related, but I will treat each individually in turn in this chapter.

It is important to establish this context before I delve into a more specific account of how the VFX and animation industries developed simulation FX technologies. One cannot properly understand simulation FX simply by focusing on the people, studios and software companies that developed it, because these agents are themselves connected to a more broad knowledge infrastructure consisting of different disciplines, fields, and industries. Although a history of any technology could perhaps be described in this way, the historical circumstances of simulation FX development make it particularly important to attend to these connections. In following chapters I will study the many points of overlap between VFX and animation companies with other industries and research institutions. This chapter shows where those connections came from.

The first part of this chapter will establish a precise definition of the concepts of scientific simulation, and nonlinear forms of dynamic and stochastic simulation. Each of these concepts will be vital for understanding the conceptual specificity of simulation FX in following chapters. In each case I will start with the historical origin point of a given concept, and then follow it through different institutions and technological applications, concluding with a brief example from VFX or animation. This section will demonstrate how the concepts at the core of simulation FX are also at work in a variety of other applications, such as social science, finance, structural engineering and meteorology.

The second section of this chapter is concerned with the broad organizational context that preceded the development of simulation FX and that, as I will investigate in chapter 2, continues to shape it. I refer to this context as the R&D (research and development) Complex. Put briefly, the R&D complex describes how scientific research was married to the practical demands of design and engineering by the integration of industry, government and academia into a hybrid whole. In the following sections I will describe how the logic of the R&D Complex gave rise to the discipline of computer science, the field of computer graphics and the concept of nonlinear simulation. To do this, I will rely on the accounts of historians and philosophers of science and technology, scientists, engineers, research administrators, politicians, technology companies and professional organizations.

This chapter will set up the key concepts that will be central to the follow chapters. In chapters 2 and 3 I will explore how the Hollywood film industry met the R&D complex, and how the two influenced each other, with Hollywood money funding scientific research, and publicly funded researchers working in the VFX and animation industries. In chapter 4 I will look at how the epistemic paradigms I define in the follow section of this chapter began to appear in Hollywood films themselves, altering the way the public thinks about topics such as contingency, change, risk, emergence, prediction and management as they relate to issues such as meteorology and financial markets.

Scientific Simulation and Nonlinearity

On its own, simulation is a rather imprecise term. Its Latin root, similis, means likeness or similarity. In common speech, simulation can simply refer to representation by what C.S. Peirce would call an ―iconic" form, that is to say, the representation of something by means of similitude, or a Peirce put it, by ―a mere community in some quality."[33] A person might, for example, *simulate* the barking of a dog by attempting to make a sound like barking. Another common use of simulation refers to simulation as an interactive reproduction, like a flight simulator for example, which simulates interaction with a given aircraft. The definition of simulation I am concerned with, scientific simulation, is more particular than either of these uses. Scientific simulation refers to the process of making a functioning model of some kind of process.

Offering perhaps the broadest possible definition, philosopher of science Stephan Hartmann defines simulation as ―the imitation of a process by another process."[34] A scientific simulation is basically a scientific model that has been put into action. Mario Bunge defines a

[33] *The Writings of Charles S. Peirce: A Chronological Edition Vol. 5*. Eds. Peirce Edition Project. (Bloomington: Indiana University Press, 1982), 56.

[34] Stephan Hartmann, ―The World as a Process," in *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, ed. Rainer Hegselmann, Ulrich Mueller, and Klaus G. Troitzsch, Theory and Decision Library 23 (Springer Netherlands, 1996), 79.

scientific model as ―a general theory and a special description of an object or system."[35] In other words, a model is a theory for how some mechanism or process in the world functions. A simulation is a synthetic copy of that mechanism, used to test the validity of a scientific theory. A real test of a theory would be an experiment. This is why scientific simulation is frequently referred to as a halfway point between experiment and theory.

It is tempting to refer to this practice as physical simulation, a term that is often used in reference to simulation FX. But physical simulation refers to a scientific simulation that specifically models the laws of physics. Scientific simulation, and also simulation FX, do not necessarily model physics. For example, if one sets out to model the behaviour of a crowd of people, they will create a set of rules for those people based on behaviour rather than physics. As I will show later in this section, this is a technique used by sociologists, engineers and VFX researchers.

A scientific simulation can be rather simple, especially when it seeks to model a rather regular, predictable, process. For example an orrery, or physical model of the solar system, models how the planets move around each other. The orrery in fact demonstrates how old the practice of scientific simulation is. There are some very old examples of orreries, such as the 900-year-old ancient Greek Antikythera mechanism. In order to describe more precisely the sorts of simulations being used in simulation FX, like fluid simulation for example, we need to address the concept of nonlinearity.

The orrery is a linear simulation. It is highly predictable. The movements of the planets are, after all, are as predictable as the rising and setting of the sun or the movement of the tides. Most processes in the world are not so predictable. Changes in weather, for example, are nonlinear and therefore far less predictable. As computer scientist Melanie Mitchell puts it, ―A linear system is one you can understand by understanding its parts… A nonlinear system is one in which the whole is different from the sum of the parts."[36] In a nonlinear system you may start with relatively simple conditions, but the result of those conditions is wildly different. You cannot deterministically predict a single outcome based on initial conditions. As Mitchell further

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[35] Ibid., 82.

[36] Melanie Mitchell, *Complexity: A Guided Tour* (New York: Oxford University Press, 2011), 23.

writes, ―Linearity is a reductionists dream, and nonlinearity can sometimes be a reductionist‘s nightmare.”[37] This concept is immensely important for understanding the significance of simulation FX. Simulation FX are concerned with nonlinear processes, with unpredictable things in nature. Scientists have developed a variety of ways of modeling the mechanisms of nonlinear systems, and these concepts have formed the groundwork for simulation FX. These concepts have also been developed for a variety of other related applications as well though. Figure 1 is a far-from complete map I have made of the development of different forms of nonlinear simulation in design and engineering, meteorology, VFX, financial economics, systems management, social science, and genetic algorithms. This flow chart illustrates how interconnected simulation FX is with other facets of society through the concept of nonlinear simulation. I will explain the specific technologies and concepts mapped in figure 1 in the remainder of this section.

[37] Ibid.

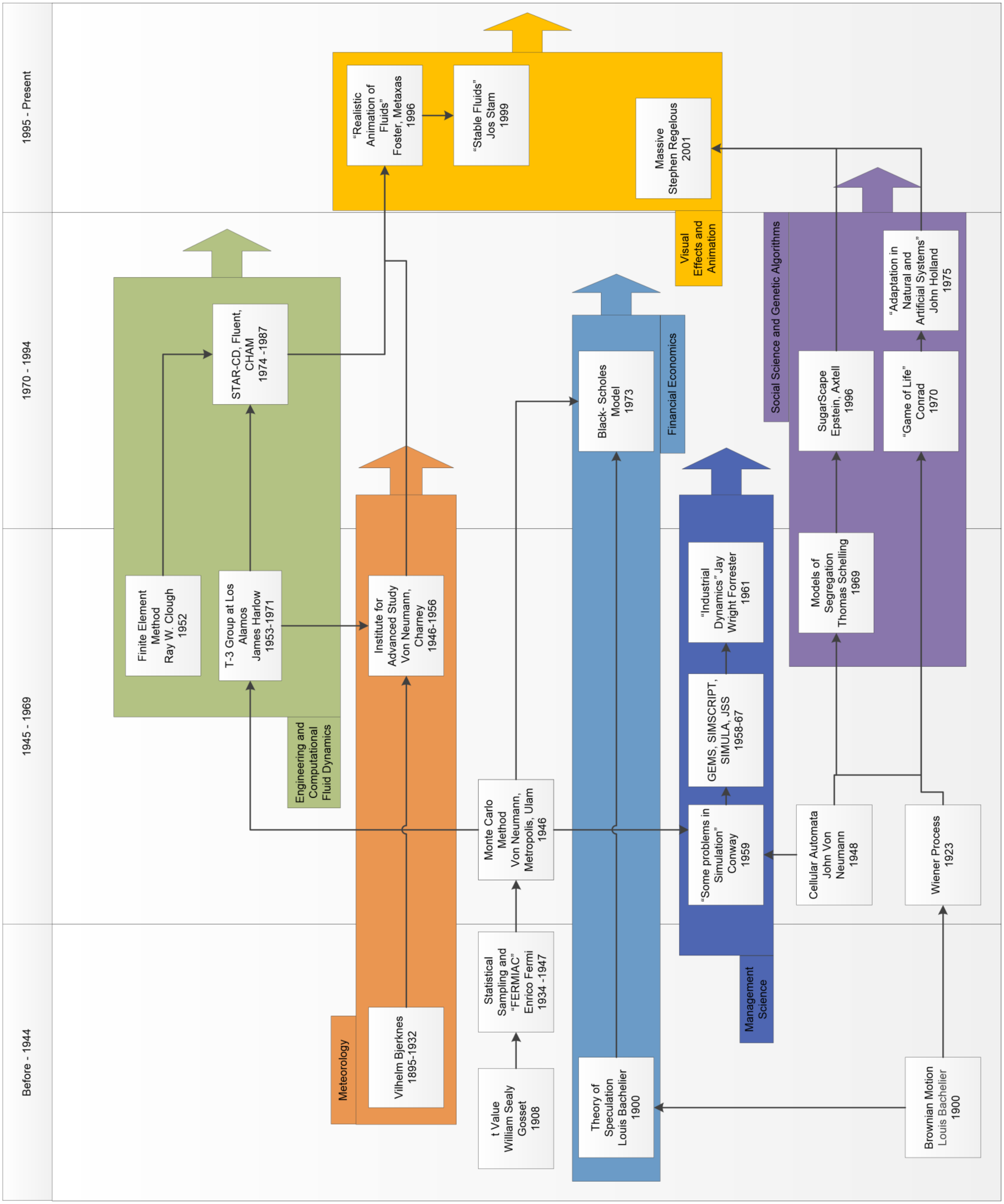

Figure 1. Nonlinear Simulation: Techniques Tools and Applications

Stochastic Nonlinearity

The two primary ways scientists model nonlinear systems are stochastics and dynamics. I will address each of these in turn, noting the way they have informed simulation FX as well as other simulation technologies in other facets of society mapped in figure 1. Stochastic nonlinearity is slightly simpler, so it is the more logical place to start. A stochastic process is, put simply, a function with a random variable in it. Stochastics use randomness to model the non-determinism of a nonlinear system. While it may sound absurdly reductive to model an unpredictable process through the use of proverbial dice rolls, it is a concept that has had profound effects on society.

The core concept of using randomness to model the real world goes back to 1900 and a model for a phenomenon called Brownian motion. Botanist Robert Brown observed that pollen suspending in water moved on an unpredictable and seemingly random path. This strange behaviour was named for Brown. What Brown was seeing was the effect of water molecules bouncing around and unpredictably hitting the pollen from different directions, imparting different vectors of momentum.[38] Although mathematician and early computer theorist Norbert Weiner is most often cited when discussing mathematical models of Brownian motion, French mathematician Louis Bachelier was the first to formulate a model in 1900.[39] Brownian motion posed a particular problem because it was the result of a process too complex to completely model. In essence the solution to modeling it is to use a *random walk*, where, rather than calculating the collisions of myriad particles, a random direction is given to the particle at a given or random interval. In other words, if you take a moving point and choose random directions for it you will produce a path like pollen suspended in water without having to simulate millions of molecular collisions. This random simulation produced behaviour that was, for immediate purposes, the same as the natural complex phenomenon.

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[38] Werner Ebeling and Igor M. Sokolov, *Statistical Thermodynamics and Stochastic Theory of Nonequilibrium Systems* (World Scientific, 2005), VIII.

[39] Louis Bachelier, *Louis Bachelier's Theory of Speculation: The Origins of Modern Finance* (Princeton University Press, 2011); Norbert Wiener, ―Differential-Space," *Journal of Mathematics and Physics* 2, no. 1 (October 1, 1923): 131–74.

Bachelier believed this concept could be applied to other unpredictable things. He attempted to use this concept to model the change in stock prices, for example. If you take what you know about the factors influencing the change in value of a commodity, and then put a random variable in to simulate the unpredictability of the real world, you can model its movement. This was, in essence, the first formal stochastic simulation. At the time his idea garnered little interest, but his ideas essentially describe modern approaches to options pricing and the field of financial mathematics. More on that later.

Stochastic simulation re-emerged in the mid 1940's in response to problems raised by modeling nuclear reactions. Los Alamos National Laboratory researchers Nicholas Metropolis, Stan Frankle and Stanislaw Ulam were trying to solve the problem of how to predict the paths of neutrons in a nuclear fission reaction, a problem that they found could not be solved through linear means. The problem is that neutrons bounce around in unpredictable ways. Nuclear scientist Enrico Fermi suggested they try a randomized method, where they would simulate a variety of paths based on a random factor, generating a wide variety of outcomes that could be statistically analysed in aggregate. The process would not produce a single deterministic answer, but a range of statistical likelihoods. Fermi had actually been attempting this technique using a mechanical apparatus of his own invention back in Italy.[40] Around this time, Los Alamos consultant John Von Neumann suggested they use the new ENIAC programmable computer to solve the problem as a sort of test for the machine. The ENIAC was designed and built for the purpose of calculating firing tables for the Ballistics Research Laboratory, but it seems Von Neumann was keen to explore its potential. The newly invented computer proved an ideal way of conducting such a simulation, because it could automatically run a variety of simulations based on an initial set of instructions.

The team at Los Alamos dubbed their new process the ―Monte Carlo method,” based on the idea that it employed randomness like one finds in a casino. Such simulations became vital for the development of nuclear technology. This was far from an obvious use of the computer, it was not driven by any high-minded theorization, and computers are notoriously bad at generating

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[40] Nicholas Metropolis. "The Beginning of the Monte Carlo Method" *Los Alamos Science* Special Issue 15 (1987): 128.

random numbers.[41] It was a clever solution to a practical problem. The first computer users, mostly military-sponsored research labs and large corporations, soon found the Monte Carlo method to be a powerful tool though. As one can well imagine, many institutions wanted a method for quantifying things that had formerly been unpredictable.

Two fields that have made extensive use of stochastic simulation are management science and finance. Management science grew from these early activities at Los Alamos and from contemporaneous research in the field of logistical *operations research*. Large institutions such as the United Steel Company, the U.S. Air Force, the RAND Corporation (short for Research and Development Corporation) and General Electric were keen to explore the potential benefits of these concepts, and sponsored their own research.[42] These institutions valued nonlinear simulation both for its predictive capacity and its ability to test systems against unpredictable events. The use of concepts like the Monte Carlo method and discreet-event stochastic simulation allowed organizational structures to cope with unpredictability in coordinated systems like supply chains. *The Encyclopaedia of Operations Research and Management Science* offers the following example. Say a small company signs a new supply contract and they want to be prepared to fulfill it, they can simulate the stages of manufacture using discreet-event simulation and simulate the orders coming in at random intervals, thus testing their preparedness for an unpredictable amount of orders.[43] Nonlinear simulation is thus a powerful tool for testing management systems against the unpredictability of reality.

These disparate research programs at institutions like GE and the RAND Corporation were eventually united by professional and academic associations like the Association for Computing Machinery (ACM). These associations provided a way of sharing knowledge and forming connections between different researchers and public and private institutions. According to a history of simulation by the ACM's special interest group on simulation (SIGSIM), the watershed moment when these varied research programs crystalized into the coherent discipline

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[41] The Monte Carlo team used the "middle square" technique for creating "pseudorandom numbers." Ibid., 127.

[42] David Goldsman, R.E. Nance, and J.R. Wilson, ―A Brief History of Simulation Revisited," in *Simulation Conference (WSC), Proceedings of the 2010 Winter* (2010), 569–70.

[43] Saul I Gass and Michael C Fu, *Encyclopaedia of Operations Research and Management Science* (New York: Springer, 2013), 626.

of management science was simulation researcher Richard W. Conway's 1959 essay ―Some Problems of Digital Systems Simulation."[44] This essay took a variety of simulation based management technologies already being developed by corporations and government institutions, such as GEMS, SIMSCRIPT SIMULA, JSS, and theorized them as a whole for the first time, identifying their commonalities and shared challenges.

As I mentioned earlier, Bachelier had thought his stochastic techniques could be used in finance, but this idea did not begin to change finance until it remerged some twenty-five years after his death in the 1970's with the development of the Black-Scholes model.[45] Just as Brownian motion reduced the complexity of water molecules to a random factor, so too did Black-Scholes condense the unruly unpredictability of the world to randomness. Like the Monte Carlo method, the Black-Scholes model takes a statistical sample of many discreet simulations in order to find a range of future outcomes. This new approach to determining options pricing changed the face of modern economics.[46] The Black-Scholes model effectively gave speculators a range of outcomes that they could reasonably expect. Risky wagers that were once considered tantamount to gambling all of the sudden became quantifiable.

Stochastic simulation proved useful for VFX and animation. Consider the advantage randomness can offer over repeating the same pattern over and over again. Say, for example, you want to show a rough surface up close with lots of detailed bumps, but drawing or modeling each bump is tool labour intensive, and repeating the same pattern looks unrealistic. A stochastic process can automatically create a varied and detailed surface without repeating any patterns.[47] Stochastics also played an important part in the first ray tracing simulations, developed by Boeing engineer and Pixar co-founder Loren Carpenter, a person I will cover in greater detail

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[44] R. W. Conway, B. M. Johnson, and W. L. Maxwell, ―Some Problems of Digital Systems Simulation," *Manage. Sci.* 6, no. 1 (October 1959), 92–110.

[45] Donald Mackenzie, *An Engine, Not a Camera: How Financial Models Shape Markets* (Cambridge, Mass.: The MIT Press, 2008), 31; Fischer Black and Myron Scholes, ―The Pricing of Options and Corporate Liabilities," *Journal of Political Economy* 81, no. 3 (May 1, 1973): 637–54.

[46] Ibid., 30.

[47] Alain Fournier, Don Fussell, and Loren Carpenter, ―Computer Rendering of Stochastic Models," *Commun. ACM* 25, no. 6 (June 1982): 371–384.

later in chapter 2.[48] Ray tracing is a method for rendering light effects by simulating the way light interacts with materials. It calculates things like reflection, refraction, scattering, and dispersion, throwing in randomness to substitute for the subtle details and variations that affect these phenomena. Another use for stochastic simulation is the animation of fracture in rigid objects.[49] Consider the random path a crack in a vase or statue makes. These cracks can result from very subtle imperfections in a uniform material. In many cases it is therefore easiest to simply generate them through randomness. I will cover a few examples of stochastic simulation techniques in the following chapters. In some cases stochastic simulation has been overshadowed by more detailed and complex dynamic simulations, which I will cover next, but it continues to be useful for certain applications, especially ones where detail can be traded off for efficiency.

Dynamic Nonlinearity

Stochastic nonlinearity, as applied in nuclear science, management science and finance, deals with complexity through randomness. By contrast, the other branch of nonlinear simulation, dynamics, does not substitute complexity but attempts instead to model it. To understand the nature of dynamic complexity one has to go back to Bachelier's mentor Henri Poincare and his solution for the ―three-body problem.” This classic problem saw three heavenly bodies in each other's gravitational fields, with each body influencing the other in turn. The difficulty of the problem stems from the fact that every force exerted from one body onto another feeds back to the first body via the mediation of the third. The problem cannot be *solved* in the traditional deterministic sense based on initial conditions. Poincare's solution was to describe the range of possible outcomes, but another way to model this problem is to use a ―continuous simulation.” A continuous simulation would constantly take the resulting forces and re-input them into the problem, continuously revising the conditions. Continuous simulation is different from discreet-event simulation because the latter only calculates outcomes at specific points. Imagine making three balls in a 3D digital animation suite, giving each of them a mass, setting a

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[48] Robert L. Cook, Thomas Porter, and Loren Carpenter, ―Distributed Ray Tracing,” in *Proceedings of the 11th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '84 (New York: ACM, 1984), 137–145.

[49] Lawrence Lee and Nikita Pavlov, ―Procedural Fracturing and Debris Generation for Kung-Fu Panda,” in *ACM SIGGRAPH 2008 Talks*, SIGGRAPH '08 (New York: ACM, 2008), 59:1–59:1.

general rule for the force of gravity, and giving each of the balls a vector (direction and speed). This would be a continuous dynamic simulation. Dynamic simulation has become influential in physics, engineering, meteorology and sociology. These applications have overlapped over time with technologies in media industries in the form of certain simulation FX.

Let us start with the example of metrology. As with financial markets, the challenge with a subject like the weather is that history does not help us predict the future. We cannot use the weather from the past few days to guess what it will be like tomorrow.[50] This is a key feature of nonlinearity. Founder of modern metrology Vilhelm Bjerknes identified this challenge back in 1904, when he likened it to Henri Poincare's three-body problem. [51] It was not until the 1940s, however, that researchers began to engage this problem through simulation.

The complex problem that Bjerknes laid out was too great a temptation for researchers working with the earliest computers. Jon Von Neumann described it as ―the most complex, interactive, and highly nonlinear problem that had ever been conceived of."[52] In 1946 Von Neumann and fellow researcher Jule Charney organized a research group to explore computer weather simulation at The Princeton Institute for Advanced Study using grants from the Navy and Air Force, and soon after the ENIAC (the same computer used for the Monte Carlo Method) was producing short predictions with relative accuracy.[53] This research lead to leaps in the understanding and modeling of weather systems and was followed by many other developments by the likes of Edward Norton Lorenz, who would develop his ―chaos theory" based on weather simulations.[54]

At the same time computational meteorology was taking shape as a research discipline, other researchers were forming a parallel branch of research at Los Alamos named the T3 Group, which focused on the dynamic modeling of fluids of all kinds. This research took much the same

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[50] Ian Roulstone and John Norbury, *Invisible in the Storm: The Role of Mathematics in Understanding Weather* (Princeton: Princeton University Press, 2013), 232.

[51] Roulstone and Norbury*, Invisible in the Storm,* 127.

[52] Ibid., 191.

[53] Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, Mass.: The MIT Press, 2013), 117.

[54] I will discuss Lorenz's work and chaos theory in chapter 4.

approach as weather modeling because the problem was basically the same. Both approached fluids by breaking them into cells and calculated the vectors of movement of those cells based on things like momentum and pressure difference.[55] Apart from meteorology, research into computational fluid dynamics (CFD) also promised benefits for engineering and design. For example, while high-speed aircraft were formerly designed using physical models and wind tunnels, now they could potentially be designed virtually using fluid simulations that simulated high-pressure air. CFD also allowed for the simulation of combustion in internal combustion, jet and rocket engines.

This design application for fluid dynamics could not be realized without the parallel development of software for design and mechanical simulation. The key concept in the development of computational mechanics was finite element method (FEM). This method breaks structures and forces into smaller elements that can be expressed as differential equations. FEM was developed for the design of an airplane wing. In 1952 Berkley scholar Ray W. Clough participated in the Boeing Summer Faculty Program, where academics would spend their summers doing project-oriented research sponsored by Boeing.[56] Clough developed FEM as a way to facilitate computer aided design of the forces acting on a wing.

These techniques would be further developed as they were married with real time user interfaces and with the introduction of general-purpose computer aided design (CAD) software such as DAC-1. The respective developments in CAD, CFD and FEM eventually converged into general purpose software for commercial engineer with projects like Klaus-Jürgen Bathe's ADINA software, developed in 1974 while he was at MIT, and applications like PHOENICS, Star-CD and Fluent, all developed by scholars who had worked at Imperial College's CFD Unit in the late 1970s.[57] These tools allowed engineers to design things that involved dynamic forces by incorporating the dynamic simulation into the design.

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[55] These vector-based calculations were based on the work of French mathematician Joseph-Louis Lagrange.

[56] Boeing was one of the largest contractors for the U.S. Air Force at this time.

[57] "PHOENICS Overview," *CHAM Limited* (2005), http://www.cham.co.uk/phoenics/d_polis/d_docs/tr001/tr001.htm; "The Simulation Solution of Choice for Internal Combustion Engine Development," *CD-Adapco*, http://www.cd-adapco.com/products/star-cd%C2%AE; "Fluent," *ANYSYS*, http://www.ansys.com/Products/Fluids/ANSYS-Fluent.

In the 1990s these technologies began to be adapted and applied for animation and VFX with tools like Arete's Digital Nature Tools, Next Limit's Real Flow, Exotic Matter's Naiad and Digital Domain's FSIM and STORM, which were used to animate the motion of dynamic nonlinear phenomena like splashing water or clouds of smoke. These animation tools basically share the same user environment and principals of simulation as the ones designed for commercial design and engineering. The ability to simulate the deformation of an object, or to simulate the movement of fluids, is of substantial importance to contemporary VFX and animation. The one subtle distinction between media and engineering applications was that while engineering put a strong emphasis on fidelity, empirical reliability and prediction, animation and VFX tools were more preoccupied with simulation speed and the *directability* of simulations. As a result, simulation software for VFX and animation diverged somewhat from engineering and scientific research tools. This is not to say that media-oriented technology has diverged from scientific and engineering applications though. As I will demonstrated in chapter 2, there are constant transactions between media and other industries through professional organizations, academic institutions and the circulation of researchers. Scientific applications often employ spectacular and cinematic images, while media industry applications often employ a measure of scientific realism.

Another parallel line of dynamic nonlinear simulation focused not on fluids or weather but on agents and evolving systems. This type of simulation developed into a different kind set of simulation FX tools. The point of origin for this research was John Von Neumann's concept of *cellular automata*, which he formulated in the same era he was directing research groups on weather simulation. The principals of cellular automata are deceptively simple: a given grid has either black or white squares, and the squares change state depending on rules about the state of their neighbouring squares. This is an example of dynamic nonlinearity because one square can change the conditions of the others, which in turn change the conditions of the initial square. As with weather and fluid simulation, simple conditions lead to dynamic complexity. Cellular automata was the earliest example of a dynamic simulation of life. This concept would later be developed by the conceptually similar technologies of agent-based simulation and evolutionary simulation (genetic algorithms), technologies which would be used for sociological research, infrastructure planning, architecture, and certain kinds of simulation FX.

An agent-based simulation entails putting many virtual agents with a set of behaviours into a virtual world and seeing how they will interact with each other and their environment. This technique was eventually developed as a way to study human and animal behaviour on a population level, and it has become an important method in social science. One early example of this type of simulation, Ithiel de Sola Pool and Robert Abelson's Simulatics was used to attempt to predict the outcome of the 1960 U.S. Presidential election.[58] CBS sponsored this research and featured it in their coverage of the election.[59]

In addition to interest in simulation's predictive capacity, researcher also employed it as a way of studying the dynamic behaviour of populations. If you believe certain rules govern behaviour, you can run a simulation to see what sort of behaviour results from those rules. For example, in 1971 T.C. Schelling published a study where he attempted to understand neighbourhood racial segregation by designing a grid with two different kinds of agents that were programmed to move if a certain number of the other kind of agent lived next to them. This research was conducted at Harvard and sponsored by the RAND Corporation.[60]

An important event in the development of this type of research was the foundation of the Santa Fe Institute. Founded in 1984 predominantly by researchers from the Los Alamos National Laboratory, the Santa Fe Institute funds and facilitates research on various topics that employ complexity as a research paradigm. While the institute has contributed to subjects relating to physics and theoretical mathematics, it has also sponsored a variety of agent-based and evolutionary simulations. For example, the institute co-sponsored a project called Sugarscape by Joshua M. Epstein and Robert Axtell. In their 1996 book *Growing Artificial,* Epstein and Axtell describe their simulation, where agents gather, trade, consume and excrete a consumable commodity. Through their research they hoped to learn something about humanities' consumption of natural resources.

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[58] Uhrmacher, Adelinde and Weyns, Danny, *Multi-Agent Systems: Simulation and Applications* (Boca Raton: CRC Press, 2009), 57.

[59] Ithiel de Sola Pool, Robert P. Abelson, and Samuel L. Popkin, ―A Postscript on the 1964 Election," *American Behavioural Scientist* 8, no. 9 (May 1, 1965): 39–44.

[60] Thomas C. Schelling, ―Dynamic Models of Segregation," *The Journal of Mathematical Sociology* 1, no. 2 (July 1, 1971): 143–86.

In cases such as Sugarscape, a complex and intricate system with unpredictable shapes and behaviours emerges from what was once a relatively simple set for rules. While this type of emergence can be useful for understanding those initial conditions, it can also be used to analyse the process of development and change, in other words, its evolution. While agent-based simulations are interested in the systems that form from simple rules, evolutionary researchers are interested in how an agent might itself learn or change. A good example of the crossover between these two disciplines is John Conway's influential Game of Life simulation from 1970. Based directly on Von Neumann's original concept of cellular automata, Conway's version sees pixels on a grid sometimes form into self-sustaining entities that interact with each other. Examples of these entities include the –glider” and the –glider gun,” which seem to fly across the grid like birds. Conway's work fostered the idea that one could create virtual living organisms through relatively simple simulations, a concept I will address in more detail in chapter 4. After this, researchers began testing to see if simulated agents could optimize their behaviour through evolution and perhaps even learn. In 1975 John Holland laid out the fundamentals of genetic algorithms and learning in his book *Adaptation in Natural and Artificial Systems.* Examples from his book included a robot that could learn the most efficient way to pick up cans through a process of trial and error learning.

Much like weather and fluid simulation, both agent based simulation and genetic algorithms have been taken up and further developed by VFX and animation. Multiple Agent Simulation System in Virtual Environment (MASSIVE), developed by VFX industry veteran Stephen Regelous at Weta Digital, draws specifically on technology and concepts from agent based simulation.[61] Weta developed MASSIVE as a way of animating hordes of moving and fighting creatures, which were too numerous to stage in real life. Past efforts to render large groups suffered from the appearance of patterns. If every character behaves the same it looks unnatural. If you vary characters amongst a finite set of key-frame animated behaviours, uniform patters still emerge which spectator perceive as too regular and artificial. MASSIVE produced a far more naturalistic (an arguably realistic) effect by setting simple behaviour rules for agents and running a dynamic simulation where they reacted to each other. WETA put MASSIVE to

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[61] "About Massive," *Massive Software*, http://www.massivesoftware.com/about.html.

use in *The Lord of the Rings: Fellowship of the Ring* (2001). Regelous has since left Weta Digital and formed his own independent company that now sells MASSIVE 2.0.

MASSIVE is a good example of the transactions that occur between media industries and other applications of simulation technology. It is a VFX tool that was based on a scientific research technology, but it has now spawned an engineering tool of its own. MASSIVE now markets its products to engineers and architects, not just as a visualization tool, but also as way to simulate the movement of people through a building.[62]

Genetic algorithms have similarly proven useful for animating characters. Indeed, there is at least one case where genetic algorithms and agent-based simulations have been used together in VFX and animation. This technology was not developed by a VFX studio but by a third party software company called Natural Motion, founded by software engineer Colm Massey and researcher in evolutionary and adaptive system Torsten Reil. Natural Motion developed the concept of *stuntbots* which are simulated character that are programmed to try to stand upright and learn how to react to external forces. They will attempt to steady or right themselves in response to getting knocked over of thrown. Natural Motion's Endorphin software has been used in a variety of Hollywood movies such as *Troy* (2004) and *The Lord of the Rings: Return of the King* (2003). Like MASSIVE, Endorphin solves the problem of how to naturalistically animate the movement of characters when it would be unfeasible to do it with key-frame animation or motion capture.[63]

This section has established the concept of nonlinear simulation, and the subcategories of stochastics and dynamics, and demonstrated how they are used for simulation FX as well as other applications in science and engineering, including aerospace, meteorology, finance and sociology. This concept of nonlinearity, of a simulation that exceeds its initial conditions, will be very important in the following chapters because it reformulates the division between developing technology and making moving images. I will expand upon this idea in chapter 3.

A second, related issue has also been in the background of this section though. These nonlinear simulation technologies were developed in historically specific institutional conditions

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[62] "Engineering Simulation," *Massive Software*, http://www.massivesoftware.com/about.html.

[63] Oliver Morton, ―Attack of the Stuntbots," *WIRED*, January 1, 2004, http://www.wired.com/2004/01/stuntbots/.

that saw a great deal of synergy between industry and academy. Take for example the way FEM resulted from the Boeing Summer Faculty Program, or the way the Monte Carlo method was developed with federal military spending, but went on to be used for management science research by some of the world‘s largest corporations. This institutional and organizational context is the focus of the following section.

R&D: Engineering and Science in Modernity

Simulation FX sits on a threshold between many different institutions. It straddles industry and academics and, by extension, science and engineering. It is part of a leading-edge field of scientific research, and it is closely connected to useful tools for design and engineering. This liminal position between endeavours of science and technology is indicative of historically specific epistemological and institutional conditions. In order to understand this context, and by extension simulation FX itself, we must address the concept of research and development (R&D).

Implied in the words research and development is a relation between theoretical and practical knowledge, basic science and applied engineering, or ―knowing and knowing how."[64] By definition basic science is not supposed to be oriented toward a specific application. Science is traditionally constructed as being an open process of discovery. One cannot anticipate what will be discovered, or whether it will be of any use to industry. To use the phrasing of influential research policy maker and computer science researcher Vannevar Bush, basic scientific research must have ―freedom of inquiry" in order to explore the ―endless frontier" of science.[65] By contrast, engineering and development apply scientific principals in order to organize or design some sort of artifice or apparatus.[66] While R&D seeks to preserve the knowledge-producing aspects of science, it also attempts to direct that force toward practical engineering applications.

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[64] These terms come from philosopher Gilbert Ryle. They are often used by philosophers of engineering. Gilbert Ryle and Daniel C. Dennett, *The Concept of Mind* (Chicago: University of Chicago Press, 2000).

[65] Vannevar Bush, "Science The Endless Frontier," *Office of Scientific Research* (Washington, 1945), https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.

[66] Artifice is a term used by philosophers of engineering and technology. Although it can sometimes connote falsity in discussions of media and culture, here is specifically refers to a human designed and built thing.

This process is designed to deliver the newer, better and more marvellous technologies we have come to expect from modernity. Rather than limiting engineering and design to existing knowledge, it attempts to marshal new knowledge, directing it toward application.

R&D is in effect a theory of how technology is created in modernity, of how scientific knowledge is applied to develop new techniques or artifices. This follows from a modern definition of technology which first emerged in the late 19th century in Germany in the form of the term *technik*, meaning “industrial arts,” and more generally the application of scientific thought, both for the construction of artifices and for the proposes of organization or systemization.[67]

Thomas Edison's Menlo Park research laboratory is the most historically significant archetype for modern R&D in North America.[68] This new form of institution brought scientists together to conduct research that was directed toward developing specific technologies. It was made possible by changes in patent laws that saw the employer retaining the rights to discoveries made by researchers.[69] Following the Menlo Park paradigm, the drivers of American industry soon all had research labs. Soon after industry recognized the potential of R&D, the U.S. government sought to take advantage. In 1915 the Navy formed a science advisory committee, chaired by Edison. The following year the United States government formed the National Research Council with a board also populated by industry figures.[70] The marriage of science and engineering was now recognized as a matter of national importance. This was also the period when educational institutions such as MIT and Caltech, which merged science and engineering,

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[67] Carl Mitcham and Eric Schatzberg, “Defining Technology and the Engineering Sciences,” in *Philosophy of Technology and Engineering Sciences*, ed. Anthonie Meijers et al. (Elsevier, 2009), 38-40.

[68] The importance of Menlo Park is widely acknowledged, but Hughes offers a definitive argument for the importance of Edison's contribution. Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (JHU Press, 1993).

[69] Catherine Fisk's book contains a history of intellectual property ownership via a study of Du Pont. Catherine L. Fisk, *Working Knowledge: Employee Innovation and the Rise of Corporate Intellectual Property, 1800-1930* (Chapel Hill: Univ of North Carolina Pr, 2009). Steven W. Usselman, "Research and Development in the United States in 1900: An Interpretive History" (presentation at Economic History Workshop, Yale University, November 11, 2013), 2, http://economics.yale.edu/sites/default/files/usselman_paper.pdf;

[70] Ibid., 5.

began to flourish with the help of government funding for R&D oriented projects.[71] Funding for R&D would one day raise technology oriented educational institutions such as these to the point where they rivalled the old elite universities, some of which resisted the integration of engineering and technical training.[72] Although it quickly spread as a paradigm throughout industry and government, research and development did not take hold as a common term until the early 1940's, a notable milestone being the formation of the United States OSRD (Office of Scientific Research and Development). [73]

The concept of scientific simulation has a long historical connection to R&D. For example, the NACA (National Advisory Committee for Aeronautics), contemporary to Edison's Navy Committee and predecessor to NASA, made simulation a key component of its mission. NACA-sponsored researchers at Stanford made important early advances in propeller design through wind tunnel work. The construction of new wind tunnels such as the VDT (Variable Density Tunnel) in 1922 and the FST (Full Scale Tunnel) in 1931 lead to significant discoveries that put the United States at the head of aeronautic research.

Wind tunnels offered the opportunity to better understand the dynamic properties of air in motion, but they also allowed the practical testing of aerodynamic designs. The wind tunnel was a tool for physical simulation. Computer simulation would be developed to serve very similar uses. Looking back at some of the examples of nonlinear computer simulations in the preceding section, one can see where they serve a similar testing function. Both wind tunnels and computer simulations can take an idea and test it in an environment that behaves like the real world. Indeed technologies such as fluid simulation have effectively replaced the wind tunnel's role in R&D, making these expensive physical apparatuses far less common than they used to be.

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[71] Ibid., 10.

[72] Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford*, Reprint edition (New York: Columbia University Press, 1994); Matti Tedre, *The Science of Computing: Shaping a Discipline* (Boca Raton: Chapman and Hall/CRC, 2014), 35 - 59.

[73] "Research and Development 1900-2000," *Google Ngram*, https://books.google.com/ngrams/graph?content=research+and+development+&year_start=1900&year_end=2000&corpus=15&smoothing=3&share=&direct_url=t1%3B%2Cresearch%20and%20development%3B%2Cc0.

R&D eventually caused philosophers of science to re-think the epistemic value of science and engineering. In an influential essay from 1966, Mario Bunge argued that "technology is as theory laden as science" and that there should be a distinction made between "substantive theories," such as the principals of airflow, and "operative theory" such as how airplanes are designed and how airports are organized.[74] He supported this argument by using examples from the world of R&D. For example, he observes that rather than being driven solely by curiosity, scientific research often investigates problems for the military or industry.[75] These new forms of inquiry are producing new forms of knowledge. Many historians and philosophers would investigate this issue further, giving greater consideration to the many forms of knowledge produced by engineering and technology.[76]

Aeronautical engineer and historian Walter Vincenti argues that engineering produces empirical knowledge through the testing of designs.[77] For example, testing a new wing design in a wind tunnel is a kind of experiment that produces knowledge. This newly recognized form of knowledge also applies to simulation. Philosopher of science Herbert Simon makes this connection in his book *The Science of the Artificial*, where he demonstrates that computer simulation is in essence a form of engineering epistemology: it understands the world through the design and testing of artifices**.**[78] Simulation, whether physical or computational, provides a form of knowledge that is not exactly empirical (it does not come from actual events), yet it is not entirely theoretical either. Many philosophers of science such as Eric Winsberg argue for the

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[74] Mario Bunge, "Technology as Applied Science," *Technology and Culture* 7, no. 3 (1966): 331.

[75] Ibid., 330.

[76] These two monographs and one volume offer a basic overview of the field. Jr. Edwin T. Layton, "Technology as Knowledge," *Technology and Culture* 15, no. 1 (1974): 31–41; Walter G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, Reprint edition (Baltimore: Johns Hopkins University Press, 1993); Anthonie Meijers et al., eds., *Philosophy of Technology and Engineering Sciences* (Elsevier, 2009).

[77] Vincenti, *What Engineers Know and How They Know It*.

[78] Herbert Simon, *The Sciences of the Artificial - 3rd Edition* (Cambridge, Mass: The MIT Press, 1996), 13.

need to see simulation as a new form of science that is neither theory nor experiment.[79] The R&D paradigm, which was born of an industrial and governmental desire for technological advance, was thus connected to a new form of knowledge. This new hybrid form of knowledge proliferated over time as the hybrid conditions that lead to its formation intensified. The relations between institutions of knowledge and industry would become inextricably integrated over time. This set of sustained relations is best understood through the concept of a complex.

Complexes

The noun *complex* is perhaps not very useful as an analytical tool at first glance. According to the OED, a complex is ―A whole comprehending in its compass a number of parts, esp. (in later use) of interconnected parts or involved particulars; a complex or complicated whole."[80] If we look at some specific uses of the term that apply to the Unites States following the Second World War, some more specific meaning emerges, and this particular definition poses greater potential as an analytical tool. A prime example of this sense of the word can be found in president Dwight D. Eisenhower‘s description of the ―military-industrial complex," which he discussed in a speech at the end of his presidency in 1961.[81] Eisenhower spoke from a moment in United States history that saw military spending continue to rise after the immense mobilization of the Second World War, long outliving its practical utility. The military-industrial complex saw a co-dependent entanglement between private industry, the government and the military. The need to produce the newest most capable weapons created jobs, and congressional representatives were loath to give up good factory jobs in their constituencies. Political science scholars describe this phenomenon as an *iron triangle*, where policies made by Congress supported bureaucratic institutions that benefited private interest groups, which in turn supported congressional representatives.[82] In the case of the military-industrial complex, congressional

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[79] Eric Winsberg, *Science in the Age of Computer Simulation* (Chicago: University Of Chicago Press, 2010).

[80] ―Complex, N.," *OED Online* (Oxford University Press, February 10, 2016), http://0-www.oed.com.mercury.concordia.ca/view/Entry/37671.

[81] "Dwight D. Eisenhower, "Farewell Address," speech, Washington, January, 1961, https://www.eisenhower.archives.gov/all_about_ike/speeches/farewell_address.pdf

[82] Gordon Adams, *The Iron Triangle* (Transaction Publishers, 1981).

committees allot funding for military programs that benefit defence contractors who support members of congress with campaign funds and by creating jobs in their constituencies.

Eisenhower's formulation demonstrates two important functions of the complex. Conventionally, the complex describes a whole made of connected parts. The concept of the military-industrial complex adds to this the concept that those parts are set into relation with each other by a self-perpetuating system. A set of relations such as the iron triangle can maintain itself long after the conditions that set it into place (the Second World War) have disappeared. A consequence of this co-dependency is that once discreet bodies are merged into a whole. Lines of division become less distinct.

This is an important concept for understanding R&D because the military-industrial complex did not just apply to factories, it applied to research. In 1964 R&D spending accounted for 25% of total federal discretionary spending.[83] The Second World War saw the development of several technologies that were perceived to have immense strategic value. Nuclear technology is of course the best example of this. Both industrial and governmental demand for research that would aid in the development of new technologies transformed the face of scientific research in the United States. Indeed, historian Douglas Brinkley claims the original subject of Eisenhower's speech was supposed to be the ―military-industrial-scientific complex.”[84] Speaking in 1967, Sen. J. William Fulbright cautioned against how the spirit of science and universities were themselves being altered by this configuration. He worried that the amount of funding directed toward supporting technological advances for the military was creating a ―distortion of scholarship.”[85]

Fulbright was responding to trends in research and education that seemed to be intensifying rather than dissipating after the end of the Second World War. In the 1950s the Department of Defence accounted for 80 percent of federal research spending, which was higher

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[83] ―Historical Trends in Federal R&D,” *AAAS - The World’s Largest General Scientific Society*, February 10, 2016, http://www.aaas.org/page/historical-trends-federal-rd.

[84] Douglas Brinkley, ―Eisenhower the Dove,” *American Heritage* 52, no. 6 (September 2001): 58.

[85] William J. Fulbright, ―Science and the Universities in the Military-Industrial Complex,” in *Super-State; Readings in the Military-Industrial Complex*, eds. Herbert I. Schiller and Joseph Dexter Phillips (Urbana: University of Illinois Press, 1970).

than any time during the Second World War.[86] In his history of how defence spending shaped American technology-oriented universities like MIT and Cal Tech, Stuart Leslie uses the term “golden triangle” to describe this complex. He argues that this merger of military and academia, and the resulting dependence on military research funds has, “blurred distinctions between theory and practice, science and engineering, civilian and military.”[87] A discipline that used to be driven by curiosity has been reconfigured toward problem solving. As the prior section of this chapter on R&D demonstrated, this was not exactly a new phenomenon. Fulbright was describing the results of the intensification and extension of the logic of R&D, which dates back to the turn of the century. Institutions like the Navy's science advisory committee and NACA were early examples of what would later be theorizes as the complex. The military also loomed larger than it had before. In the period immediately following the Second World War the R&D paradigm was visible as an extensive institutional change, a change sufficient in extent that observers were beginning to worry about its effects.

What the complex describes is not simply an intentionally configured, centrally planned set of relations. Complexes are sets of relations that endure because they are self-sustaining. In his *Marxist Theory of Bureaucracy,* Ernst Mandel describes the military-industrial complex as “a near-perfect feedback mechanism of self-expansion.”[88] Historian of architecture Reinhold Martin refers to this organizational logic of the complex as the “organizational complex.” For Martin the organizational complex originated in the military-industrial complex but it then spread to all facets of society as an “aesthetic and technological extension.”[89] He links the organizational complex to theories of distributed self-regulating order in neo-liberalism, which he studies through theories such as Michel Foucault's concept of biopolitics and Gilles Deleuze's “Post-Script on the Societies of Control.” He describes the architecture of this time as “empty skins full

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[86] Leslie, *The Cold War and American Science,* 1-2.

[87] Ibid., 2.

[88] Ernest Mandel, *Power and Money: A Marxist Theory of Bureaucracy* (London ; New York: Verso, 1992).

[89] Ibid., 35.

of consumer-subjects, that like giant televisions sets, organize through the agency of an auratic delirium."[90]

A key component of this organizational logic, as Martin sees it, is contemporaneous concepts such as cybernetics, information theory and systems theory. These concepts all emerged from the golden triangle of the military-industrial-scientific complex. Systems theory comes from research during the Second World War and after that pertained to the management of complex integrated organizational bodies, fields of research variously called *operations research* and *systems engineering*. Early research institutions that developed these approaches to systems management in the 1950s included the Ramo-Wooldridge Corporation, which designed the first intercontinental ballistic missile systems, MIT's Lincoln Laboratory, the MITRE Corporation, the Systems Development Corporation, the Air Corp Systems Command, and the U.S. Navy Special Projects Office.[91] These R&D labs sought to understand fundamental properties of systems, so that they could be applied to organization and management tasks. Norbert Weiner's concept of cybernetics follows a similar sort of logic. Cybernetics studies self-correcting systems that can process information and make mid-course corrections.[92] Like systems theory, cybernetics was both a science and an engineering tool. While Weiner used cybernetics to theorized animal cognition, the newly formed U.S. Air Force used cybernetics to develop a sophisticated computer controlled anti-aircraft system called SAGE (Semi-Automatic Ground Environment). At successive conferences throughout the 1940s and 50s, figures such as Norbert Weiner, John von Neumann and Claude Shannon (the Bell Labs scientist who formulated information theory) met to explore the multidisciplinary possibilities of cybernetics for both understanding and managing the world. Martin argues we can see these cybernetic principals of self-regulating homeostatic systems at work in the organizational complex. In other words there was a sort of feedback loop between research produced by the organizational complex and the organization of the complex itself.

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[90] Reinhold Martin, *The Organizational Complex: Architecture, Media, and Corporate Space* (Cambridge, Mass.: The MIT Press, 2005).

[91] Thomas Parke Hughes, *Human-Built World: How to Think about Technology and Culture* (Chicago Ill.: University Of Chicago Press, 2005), 83.

[92] The word cybernetics comes from the Greek *kybernetike* meaning "steersman" or "governor."

Martin limits his analysis to the early Cold War, mostly the 1950s and early 60s, but this link between research and management certainly did not stop there. Slowly research deviated away from the study of the self-correcting cybernetics systems to unstable and nonlinear systems. Here techniques for nonlinear simulation fed into new principals of management, which in turn shaped the ever-evolving organization of the R&D complex. In 1961 MIT researcher Jay Wright Forrester, who had contributed to cybernetic projects including SAGE, published a paper on industrial dynamics, which started the shift in management science away from thinking in terms of homeostatic stability and toward thinking in terms nonlinear dynamics. This led to management concepts like *organizational resilience*, which is concerned with both planning for sudden change and adapting to gradual change. This was the product of ecological work by Canadian ecologist C. S. Hollings, who parted with existing orthodoxy that saw ecosystems as self-regulating and argued that instead they are in a constant state of dynamic change.[93] The interest in unpredictability and emergence fostered by this movement will be a reoccurring theme in subsequent chapters.

The R&D complex is vital part of simulation FX for two main reasons. First, it describes the institutional context that gave rise to nonlinear simulation, and indeed to simulation FX itself, as I will demonstrate in chapter 2. The way the R&D complex brings together research institutions and industries, and thus the way it brings together science and application, will be important for chapter 2, as it shows a new kind of complex taking shape between the Hollywood film industry and scientific institutions. Second, following Reinhold Martin, it is important to understand the feedback between management research produced by the R&D complex and the organization of the complex itself. This is important because nonlinear simulation has been a key component of the ongoing organization of the R&D complex. Thus, the concepts and technologies at the core of simulation FX are also at the core of ongoing developments in management science and the R&D complex itself. I will pick up this thread in chapter 3, where I study how the management approaches in the VFX and animation industries are based on the same nonlinear paradigms as simulation FX tools themselves. Before I discuss these topics though, I first need to address the formation of the discipline of computer science in the context of the R&D complex.

[93] C. S. Holling, ―Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics* 4, no. 1 (1973): 1–23.

Computer Science and the R&D Complex

Computer science is a particular combination of science, engineering and technology, and it developed in an institutional context fuelled by military and industrial funding. Perhaps no discipline better demonstrates the changes to scientific research and academia brought about by the R&D complex. In following chapters, I will look more closely at how computer science organizations, most notably the Association for Computing Machinery's Special Interest Group on Computer Graphics and Interactive Techniques (ACM SIGGRAPH), developed a complex between universities, government agencies and the film industry. This new complex is the one that has supported the ongoing development of simulation FX. In this section, I will demonstrate how the discipline of computer science has always sat at a nexus between government and industries, and between science and engineering.

From the outset it is necessary to establish what computer science is. There are two possible definitions for computer science that posit two different start points. On one hand we might include all academic research that was in retrospect conceptually relevant to the computer avant la lettre. Here we would include things such as Alain Turing's theoretical work in the 1930's, Lord Kelvin's and Charles Babbages' work on a differential analysis machines, and so forth.[94] The second definition of computer science would instead be limited to the formation of computer science departments in universities: computer science qua computer science. Situated as it is right at the trailing edge of the Second World War in the United States, this second definition is inseparable from the R&D complex.

A key distinction between these two definitions is the difference between theoretical work and the actual construction of functioning technologies. We should not take for granted that these two activities should be together. A good illustration of this is the contrast between early British computer science and American computer science. For example, historian of science Mark Bowles contrasts physicist Lord Kelvin's unrealized efforts to build an analog differential analysis machine in 19th century Britain with Vannevar Bush's successful efforts in the 1930's and 40s in the United States. Invoking the concept of ―technological style," Bowles argues that

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[94] Lev Manovich's genealogy of new media, for example, privileges Babbage as the technical starting point of computers. Lev Manovich, ―What Is New Media?," in *The New Media Theory Reader*, ed. Robert Hassan and Julian Thomas (Maidenhead: Open University Press, 2006), 6.

the American style was one of engineering and optimism, while the British style was one of theory. The Americans just wanted to build the machine and see what they could do with it.[95] While there may be something to Bowles cultural observations, there are also some very important institutional and organizational reasons for this difference. As historian of computer technology Paul Ceruzzi argues, the U.S. was able to develop computer technology because it struck a good balance between state and private involvement in academics, unlike Europe or the USSR.[96] Though the idea that only the U.S. could have invented the programmable electronic computer sounds like a step too far towards exceptionalism, it is true that different cultures sought to make use of the same concepts for different purposes. Different contexts led to different kinds of computer sciences. The propose of American computers science, the version of computer science that came to dominate globally as a paradigm, is clearly oriented toward developing new technologies that might benefit industrial and national interests.

The beginning of the discipline of computer science in the U.S. starts with the construction of a new artifice: the programmable electronic computer. The ENIAC (Electronic Numerical Integrator And Computer) was designed and constructed for the United States Ballistic Research Laboratory by two members of the University of Pennsylvania's Moore School of Electrical Engineering: physicist John Mauchly and electrical engineer J. Presper Eckert. This was a synergistic coupling of researchers, who wanted funding, and the military, which wanted technologies that might give them a strategic edge. The ENIAC's purpose was to calculate ballistic firing tables, a labour intensive job that was at the time done by human ―computers."[97] While this event precedes the first computer science department in a university, it sets the stage for the integration between science and engineering, as well as academia, government and industry, which defines computer science.

The ENIAC was supposed to calculate firing tables, but it was also an irresistible tool for research. For this reason it was soon appropriated for different kinds of research. Indeed, as I

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[95] M.D. Bowles, ―U.S. Technological Enthusiasm and British Technological Scepticism in the Age of the Analog Brain," *IEEE Annals of the History of Computing* 18, no. 4 (October 1996).

[96] Paul Ceruzzi, *A History of Modern Computing, 2 Edition* (MIT Press, 2003), 11.

[97] Ibid., 15.

have already noted, the ENIAC was key in developing the Monte Carlo method, a type of stochastic nonlinear simulation. On one hand the researchers wanted a tool they could use to explore different potentialities, and on the other the government wanted scientists to do specific research for them that might benefit their interests. This dynamic of research sponsor and researcher using each other for their own respective ends carries through all computer science up to contemporary simulation FX, including examples in the film industry, as chapter 2 will demonstrate.

Paul Ceruzzi argues Mauchly and Eckert's next computer, the UNIVAC (Universal Automatic Computer), was the first to embody the reprogrammable ―spirit" of the modern computer because it was the first commercial product. Mauchly and Eckert developed the UNIVAC after they went into business for themselves. According to Ceruzzi, the ENIAC was too entrenched in military secrecy and bureaucracy to have its potential realized.[98] Entering into private industry hardly allowed the computer to escape the shaping force of the R&D complex though. The UNIVAC was sustained by the R&D complex every bit as much as the ENIAC had been before it. Indeed it is a good early demonstration of the continued integration of industry, science and government. The first UNIVAC was supposed to go to Northrop Aviation.[99] While Northrop was a private company, they produced fighting aircraft and they relied on the U.S. Air Force for both R&D funding and the consumption of their products. The first UNIVAC in fact went to the U.S. census bureau though, and later ones would go to private corporations like G.E., which used theirs for the mundane task of payroll. Thus, although many historians of computer technology tend to fetishize the free market and independent enterprise, Mauchly and Eckert's entrepreneurial turn certainly did not mean that they were leaving the embrace of the R&D complex. Computer manufacturers need computer science, and vice versa.

Once the computer became a product, demand for trained professionals to design and maintain systems grew. Products like the IBM 650 were sold to universities if, and only if, those universities agreed to teach a course in computer science.[100] The fact that a private company would offer a special deal to universities demonstrates the logic of the R&D complex. IBM had

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[98] Ibid., 31.

[99] James W. Cortada, *The Computer in the United States* (M.E. Sharpe, 1993), 92.

[100] Ceruzzi, *A History of Modern Computing,* 44.

an interest in increased academic use of computers for several reasons. First, researchers might discover new uses for the computer, thus leading to future products. Second, IBM ensured that future workers who would go on to jobs in government and industry would be familiar with their equipment. Third, IBM had an interest in hiring new researcher and engineers, and developing relationships with universities ensured they would have access to the best minds of the future.

This exchange between IBM and academic institutions at the key moment of the emergence of the discipline of computer science demonstrates how central the dynamic of the R&D complex has been, and it further demonstrates how science became entangled with engineering. By the account of computer scientist and historian Matti Tedre, the one trait shared by all of the academic institutions that were key to the development of computer science in the 1940s (MIT, Princeton, Pennsylvania and Columbia) was support from government agencies and industry.[101] Furthermore, academic pursuits of computation in other nations, which did not have an R&D complex, took on a particularly different shape at first. Programmable electronic computers were more than a technical means to a scientific end; in the R&D complex the investigation of the potentialities of the computer was inextricable from its technical development.

Interestingly there was some resistance to the logic of the R&D complex in some of the more prominent and established universities in the United States. Historian of computer science Matti Tedre writes, ―Having engineers and technicians populate the university hallways was new to some traditional universities, and many were unhappy about it."[102] For example, William Aspray claims that Harvard was highly resistant to the inclusion of any kind of engineering field.[103] Presumably Harvard imagined itself educating the leaders of tomorrow, rather than the technical workers. Building technical things was not part of the traditional liberal education. Similarly, Tedre notes that although the University of Pennsylvanian's Moore School was pivotal in inventing the programmable computer, when computer science first started to take shape as an academic discipline the school chose to outsource the operation of the actual

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[101] Tedre, *The Science of Computing,* 41.

[102] Ibid., 35.

[103] William Aspray, ―Was Early Entry a Competitive Advantage? US Universities That Entered Computing in the 1940s," *IEEE Ann. Hist. Comput.* 22, no. 3 (July 2000): 52–53.

devices.[104] While Tedre attributes this to anti-engineering bias, Aspray also notes that the University of Pennsylvania had specific guidelines intended to undermine certain forms of overlap between industry and academics.[105]

Rather than being a discipline that advanced the design of ever bigger and better hardware and software that worked in congress with industrial and governmental interests, universities such as these imagined computer science more as an extension of mathematics, much the way it was imagined in the British context. This approach protected this new discipline from undue direction and shaping. If computer science is theoretical and largely useless to military and industry, then it is free to explore the potentiality of computation in any direction it sees fit, without influence from directed funding: computer science as basic science. As computer scientist Michael R. Fellows argued at the time, ―computer science is not about machines, in the same way that astronomy is not about telescopes.” The engineers responsible for building and running computers were mere service people, hardly the contemporaries of the mathematical researchers.[106] These criticisms have endured in the form of philosophical discussions about the epistemic role of computer science. Is it a science? Is it bad science?[107] The role of design and engineering in computer science today is beyond question though. To today's computer scientists, this resistance sounds like pure elitism and the result of stodgy out of touch professors. Matti Tedre, a computer scientist himself, argues that without engineering computer science would be mere speculation.[108]

These seemingly out of touch universities were not the only critics at this important juncture though. Indeed, they were likely informed by campaigning conducted in 1945 by Vannevar Bush, one of the central figures of the R&D complex, who was publishing work that

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[104] Tedre, *The Science of Computing*, 35.

[105] Aspray, ―Was Early Entry a Competitive Advantage?,” 60.

[106] Ibid., 10.

[107] Computer Scientist Stephen Frezza et al. give a good overview of this these discourses. Stephen T. Frezza et al., ―Applying a Knowledge-Generation Epistemological Approach to Computer Science and Software Engineering Education,” 2013, https://peer.asee.org/applying-a-knowledge-generation-epistemological-approach-to-computer-science-and-software-engineering-education.

[108] Tedre, *The Science of Computing*, 88.

expressed similar concerns.[109] Bush published two important texts at the end of the Second World War: ―Science: The Endless Frontier," a whitepaper addressed to president Roosevelt, and ―As We May Think," an article published in *The Atlantic*.[110] Bush had been responsible for administering funding for scientific research during the war. He lead the National Advisory Committee for Aeronautics and directed government funding during the Second World War as head of the OSRD (Office of Scientific Research and Development), the forerunner of ARPA (Advanced Research Projects Agency) and the NSF (National Science Foundation). He was also an active cyberneticist. In many ways he is the person most responsible for the R&D complex. Yet in both of these essays he is making a case for an end to military influence on scientific research. Instead he envisions a future where scientific research is oriented toward benefitting humanity and advancing the cause of knowledge and understanding.

―Science: The Endless Frontier" acknowledges that during the war most of the scientific research done was of an ―intermediate" nature, halfway between basic scientific research and engineering. He defines intermediate research as the kind that is directed toward practical goals but factors in enough time and discretionary funding to allow for the basic necessary research.[111] Bush, much like Eisenhower and Fulbright after him, recognized some aspect of the R&D complex at work. A future where science was tied to military funding seemed at best to be a missed opportunity. Despite Bush's influence and his passion for basic research, the hybrid or intermediate nature of scientific research continued unabated. Many of the institutions Bush set into place continue to be mainstays of the R&D complex. Raytheon, a technology company he founded, which first focused on refrigeration, is today the United States' top producer of guided missile systems.[112] The connections he helped form were already locked into a self-perpetuating

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[109] Layton argues Vannevar Bush has caused a generation to privilege basic research and undervalue forms of engineering knowledge. Edwin T. Layton, ―Technology as Knowledge," 34.

[110] Vannevar Bush, ―As We May Think," *The Atlantic*, July 1945, http://www.theatlantic.com/magazine/archive/1945/07/as-we-may-think/303881/; Vannevar Bush, "Science The Endless Frontier," *Office of Scientific Research* (Washington, 1945), https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm.

[111] Ibid.

[112] "Raytheon Company History," *Raytheon Company*, http://www.raytheon.com/ourcompany/history/.

logic. While the influence of Bush's two publications persist to this day, and basic science is perhaps valued more now that it was in 1945, the intermediate nature of science has become too entrenched. For example, by far the most well remembered idea from these two essays today is Bush's ―Memex," a theoretical machine that he believed would aid human thought. The Memex is remembered today for the way it laid the groundwork for concepts like hypertexts and digital archives. In other words his most influential idea from the period saw technology and knowledge, knowing and knowing how, intimately, inextricably, linked.

Those who resisted the R&D complex's version of computer science largely lost out in their bid to define the discipline. Over time the engineering aspects of computer science, the design and construction of hardware and software, came to be an important part of the discipline. This is due in no small part to industrial demand for trained professionals and also the abundance of research resources made available by both industry and government institutions. Today the many varied applications of computers and fields of computer science all to some degree require the ability to build software. The merger of knowing and knowing how, of science and engineering, of research and development, was irresistible in the end. This will all be very clear in following chapters, as I begin to look more specifically at the development of simulation FX. As I will begin to explain in the next chapter, the film industry became part of the R&D complex, indeed it became so involved in computer graphics research it filled the vacuum left by decreasing military research funding in the post-Cold War period. I will investigate this using a key institution of American computer science: the ACM's special interested group SIGGRAPH, the scholarly and professional association where state funding bodies, university and private business meet.

Conclusion

This first chapter has established the two key components of simulation FX: nonlinear simulation and the R&D complex. Not only is simulation FX the product of a unique scientific paradigm that has been slowly gaining importance since the Second World War, it is also the product of the unique historical circumstances that brought together science and industry. Both of these subjects will become all the more important as I begin to discuss the involvement of the VFX and animation industries.

Although film and media studies has been grappling for quite some time with the changes computer technology has brought over the past few decades, simulation FX offers a different perspective on this period in history. Nonlinear simulation demonstrates that the essence of the digital does not entirely explain epistemological changes in this period, even for subjects that provided such important talking points as VFX and digital animation. Though it is inextricably tied to computers in many ways, nonlinear simulation has its own epistemic particularity. The rise of both nonlinear simulation and computer technology was linked to institutional change. As I will show in following chapters, this institutional change has influenced the VFX and animation industry. Media industries did not simply appropriate existing technologies. They were, and are, involved in a constant process of research and development. In chapters 2 and 3, I will show how the VFX and animation industries formed their own R&D complex, and how simulation FX is sustained by this complex. Uncovering this complex reveals important epistemic and institutional connections between animated images and different ways of understanding and managing the world, from meteorology to management science.

Chapter 2: The Blockbuster R&D Complex

As chapter 1 established, the simulation FX tools used in the contemporary film industry have their origins in the Cold War R&D complex, where government, research universities and private industry are integrated together in a project of technological development and scientific research. The connections between simulation FX and other industries and research disciplines are not limited to mere origins though. This chapter will cover the sustained R&D infrastructure that continues to support the development of simulation FX over time. The encounter of Hollywood with the R&D complex created a new complex, which saw both film production and R&D brought together, changing both in the process. This merger took place in the context of a shift in R&D funding in general, which saw federal grants replaced in part by tax credits, elevating the role of private sector funding.[113] Technologies like simulation FX are a paradigmatic product of this new entity, which I refer to as the blockbuster R&D complex.

This chapter will examine how exactly Hollywood became involved with computer science and its sub-disciplines of computer graphics and computer simulation. The following sections will demonstrate that the film industry did not simply pluck animation technologies read-made from these fields. Simulation FX tools, and computer graphics tools in general, are not discreet, abstract or singular. Instead they consist of sustained research disciplines, supported by different institutions. Hollywood participates in this R&D process via the VFX and animation industries, employing researchers and funding research projects with the goal of developing new tools.[114] Studying film technology from this perspective uncovers new substantial connections between film and other industries and technologies. It also reveals connections between media in cultural industries and media used in other applications such as scientific visualization. This work therefore situates media industries in a broader institutional and epistemic context.

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[113] National Science Foundation, ―Chapter 4: U.S. and International Research and Development: Funds and Alliances: R&D Support in the United States," 4, accessed June 26, 2016, http://wayback.archive-it.org/5902/20150817205722/http://www.nsf.gov/statistics/seind02/c4/c4s1.htm.

[114] I refer to the VFX and animation industries separately. Although they often use the same technologies and skilled workers, there are some key points of distinction I will address in this chapter.

The changes that brought about the development of simulation FX took place around 1980, only a few years before the first digital VFX and animated images started appearing in Hollywood films. I want to stress, though, that this is not simply the story of how digital technology changed everything. Research by scholars such as Julie Turnock and Dan North has highlighted the many continuities in VFX over this period, noting many changes in production that took place before the digital turn that are every bit as important for explaining the contemporary state of affairs.[115] For example, Turnock focuses on how the seamless aesthetics of contemporary Hollywood special effects took shape in the 1970s. This type of work undermines the narrow focus our discipline formerly had on the transformative effects of digital technology, which was intensely focused on VFX marvels of the early 1990s like *Jurassic Park* (1993) or *Forest Gump* (1994). My work on simulation FX is consistent with the work of Turnock and others in that it shifts the focus away from the digital revolution. For me this means shifting attention toward the institutional and epistemic changes beneath it, and it means focusing on one specific technology with its own specific history: nonlinear simulation. However, my focus is still on the much-discussed subject of VFX and animation in the 1980 to the 2000s. Film production changed substantially in this period. But it did not change as the result of a transformative singular technology appearing out of nowhere. These changes were industrial, they were economic, and they were influenced by federal scientific research policy. They entailed the forming of new universities departments, new research labs, new film production companies and new forms of film production labour.

Section one of this chapter will cover the Association for Computing Machinery‘s Special Interest Group on Computer Graphics and Interactive Techniques (ACM SIGGRAPH), and how it coordinates between computer science research and various governmental and industrial bodies. This section will mostly cover the early years of military-focused research at SIGGRAPH, while further sections will cover the rise of the influence of media industries. The next section will address the phenomenon that caused the Hollywood film industry to become involved in this research network: the blockbuster. Next, I will look at how blockbuster budgets actually translate into research funding via R&D in the VFX and animation industries. After

[115] Julie A. Turnock, *Plastic Reality: Special Effects, Technology, and the Emergence of 1970s Blockbuster Aesthetics* (Columbia University Press, 2014); Stephen Prince, *Digital Visual Effects in Cinema: The Seduction of Reality* (Rutgers University Press, 2011); Dan R. North, *Performing Illusions: Cinema, Special Effects and the Virtual Actor* (Wallflower Press, 2008).

establishing the general character of VFX and animation R&D, I will then move on to take a more granular look at how simulation FX R&D has taken place over the past few decades by focusing on one specific kind of simulation effect: dynamic fluids. This section provides many good examples of how the film industry played a more important role in driving research over time, with scientists, software companies, and eventually university research labs building a research infrastructure oriented toward developing fluid simulation tools for VFX and animation. In the final section of this chapter I will note how SIGGRAPH has changed as a result of the influence of Hollywood by studying visual communications at SIGGRAPH over time.

ACM SIGGRAPH

The connections between the film industry and computer science research infrastructure are most clear in the professional and academic organizations where researchers share their work. The organization at the core of computer graphics and simulation FX research is SIGGRAPH. Although a special interest group may not sounds like a particularly extensive entity, SIGGRAPH is one of the largest sections of the ACM, and the ACM is one of the two oldest and most important computer science research associations in the world.[116] Founded in 1947, the ACM has a membership in excess of 100,000 and features dozens of special interests groups, which specialize in different aspects of computing, including artificial intelligence (SIGAI), bioinformatics (SIGBio) and genetic and evolutionary computing (SIGEVO) to name a few.[117] The ACM is the main hub for both presentations and publications in the discipline of computer science.

SIGGRAPH is a perfect example of the R&D complex I discussed in chapter 1. It folds together different industries, research institutions and federal funding sources, facilitating the marriage between science and technological development. It should come as no surprise that the military-industrial-academic complex heavily sponsored SIGGRAPH in its early days. An examination of SIGGRAPH during the peak period of the development of simulation FX, from 1980 to the 2010s, shows a marked change at SIGGRAPH though. The type of research being done, the institutions sponsoring it, and even the character of the images circulating at the

[116] The other being the IEEE, the Institute of Electronic and Electrical Engineers.

[117] ―ACM History," accessed June 15, 2016, http://www.acm.org/about-acm/acm-history.

conference all changed. During this period media industries, and especially the Hollywood blockbuster, became a vital force shaping SIGGRAPH.

Conferences and professional associations provide particularly effective contact zones for the overlap between academia, government, industry and media. These are the places where scientific research resources are mobilized for specific technological applications. They can also demonstrate how a media technology like simulation FX took shape over time as a result of infrastructural, institutional, economic and political forces. The meetings and communications of these organizations have a logic and a culture which stems from these forces. By studying the publications of SIGGRAPH, one can see what institutions and businesses support research over time, what sort of research is being done, and how researchers move between businesses and public institutions. Studying SIGGRAPH also reveals that the computer technologies utilized by the film industry are far from being singular or discreet. An endless process of development and improvement requires tapping into broad knowledge networks that constantly share resources.

Andy Van Dam, a professor at Brown University, and Sam Masta, a researcher who worked for companies like IBM and General Motors, formed SIGGRAPH as a newsletter in 1967. Their newsletter was geared toward computer science researchers who were interested in the visual and interactive potential of computers. This was a hot topic at the time, Ivan Sutherland‘s Sketchpad project having been unveiled four years earlier.[118] In an interview Van Dam cites Sketchpad as the aha moment that lead to SIGGRAPH.[119] Before Van Dam and Masta's newsletter, computer graphics was a niche interest. But with conferences, newsletters and technology demonstrations, it soon developed into a field of its own.

Yet another key moment in the computer graphics field came a year later with Douglas Engelbart's 1968 demo at the Joint Computer Conference (a conference sponsored by both the ACM and the Institute of Electrical and Electronics Engineers). Engelbart was a Berkley

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[118] Sketchpad consisted of a light pen and cathode ray screen that allowed users to draw graphics. It was built on fundamental concepts developed for the SAGE anti-aircraft system. Sutherland would go on to work as a professor at the University of Utah where he would oversee countless contributions to the development of computer graphics and he would be an important figure at SIGGRAPH.

[119] The second contributing factor was the availability of IBM's 2250. Van Dam's department at Brown had managed to acquire one of these costly new devices because IBM founder Thomas J. Watson's was a Brown alumnus. ―Andy van Dam,” accessed June 15, 2016, https://www.siggraph.org/conferences/reports/s2004/interviews/vandam.html.

electrical engineering research who started his own ARPA (Advanced Research Projects Agency) -funded business to do research. His demo at the Joint Computer Conference demonstrated a wide range of graphic and interactive functionality that defines much of the modern computer to this day.[120] Engelbart's demo is widely referred to in retrospect as *the mother of all demos*.

There is a tendency in histories of computer graphics to point to the mother of all demos as a transformative technology, an idea that put into place all of the many changes digital media would bring about. But while Engelbart's ideas were extremely influential, the real story of technological development is in the organizational entities beneath iconic touchstones such as these. Without the Joint Computer Conference, without Masta and Van Dam's newsletter and the annual SIGGRAPH conferences that followed, without university computer science departments, and without military-fuelled research funding from the government, none of this would have happened, and computer graphics would have likely developed in a very different way.

In 1974 SIGGRAPH became an annual conference that was the central hub of both academic and industrial computer graphics research, mostly sponsored in some way by the military R&D complex. And although SIGGRAPH attracted interest from various industries, for the first thirteen years the film industry was utterly disinterest and uninvolved. The account of Ed Catmull, one of Ivan Sutherland's students, attests to this fact. When he was studying computer graphics as a graduate student in Sutherland's computer science department at the University of Utah, the university sent Catmull to Disney Animation to propose an exchange program. According to Catmull's account, Disney had no interest in computer graphics at that time and instead offered him a job as a theme park imagineer.[121] Years later, when he was funded by the New York Institute of Technology's Computer Graphics Lab, Catmull again tried to find a film studio that might be interested in opening a computer graphics research department. Once again he was rejected.[122]

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[120] Van Dam actually contributed some coding help to Engelbart's project.

[121] Ed Catmull and Amy Wallace, *Creativity, Inc.: Overcoming the Unseen Forces That Stand in the Way of True Inspiration* (Random House of Canada, 2014).

[122] Ibid.

Clearly the world of computer graphics was interested in getting more involved in media industries. Indeed even in the early days of computer graphics there was a great deal of interest in exploring the artistic potential of these new tools. Not only were there numerous artists and engineers interested in this potential, such as pioneering experimental digital animators and artists John Whitney, Charles Csuri and David Em, but so too were the key facilitators of R&D. Some of the earliest support for computer art came from private industry. In 1966 John Whitney was the first person to be awarded the position of artist in residence at IBM. In 1967 Bell Labs founded its EAT (Experiments in Art and Technology) program, which facilitated joint projects between artists and engineers. Xerox PARC employed artist David Em in 1975 to explore the potentialities of interactive graphic software they were developing, and he went on to be artist in residence at JPL (NASA‗s Jet Propulsion Laboratory at the California Institution of Technology) from 1977 to 1984.

While it seems clear that this sort of research was propelled in part by a general zeal for the transformative potential of computers, it is also explicable through the speculative logic of R&D. Companies like Xerox and IBM were hoping to develop software that might be widely adopted by various industries for image making. What they lacked though, was actual coordination with such an industry. For example, David Em was working with Xerox's Superpaint software. Xerox ended up abandoning the development of this software, and key Superpaint engineer Alvy Ray Smith ended up joining Ed Catmull in the very first film industry computer graphics department.

Smith and Catmull finally found a home at Lucas Film in 1979. This marks the point where research supported by media industries began to appear at SIGGRAPH. In 1980 Catmull and Smith published their first paper under the institutional affiliation of Lucas Film.[123] Although computer art had been sporadically displayed at SIGGRAPH throughout its history, it was not until after this turning point in 1981 that the first formalized Art Exhibition was held at SIGGRAPH. In following years further art-oriented events would be introduced, such as the SIGGRAPH Animation Festival. More papers sponsored by VFX and animation-oriented companies were published at SIGGRAPH in following years with gradually increasing

[123] Ed Catmull and Alvy Ray Smith, ―3-D Transformations of Images in Scanline Order," in *ACM SIGGRAPH Computer Graphics*, vol. 14 (ACM, 1980), 279–285, http://dl.acm.org/citation.cfm?id=807505.

frequency as well. Early examples include a paper by Canadian computer graphics researcher William T. Reeves affiliated with Lucas in 1983,[124] a paper on fluid simulation by computer science researchers Larry Yaeger, Robert Myers and Craig Upson, affiliated with Digital Productions and Poseidon Research in 1986,[125] another paper by Reeves from the same year, now affiliated with Pixar,[126] and further work in the following years supported by Pacific Data Images (PDI).[127] Contributions from other VFX and animation companies would pick up more in the mid-1990s as computer graphics began to proliferate in Hollywood and other media industries.

Today there are a variety of conferences associated with various organizations around the world similar to SIGGRAPH such as NICOGRAPH in Japan, CSIG and CCIF in China, SIGRAD in Sweden, ANZZGRAPH in New Zealand, AFRIGRAPH in Africa and SEAGRAPH in South East Asia.[128] At its peak in 1997 SIGGRAPH had 48,000 members worldwide.[129] Responding to the varied potentialities computer graphics pose, SIGGRAPH has developed into an interdisciplinary conference with members including ―researchers, developers, and users from

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[124] William T. Reeves, ―Particle Systems—a Technique for Modeling a Class of Fuzzy Objects," in *Proceedings of the 10th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '83 (New York: ACM, 1983), 359–75.

[125] Larry Yaeger, Craig Upson, and Robert Myers, ―Combining Physical and Visual Simulation—Creation of the Planet Jupiter for the Film ‗2010,‘" in *Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '86 (New York: ACM, 1986), 85–93.

[126] Alain Fournier and William T. Reeves, ―A Simple Model of Ocean Waves," in *Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '86 (New York: ACM, 1986), 75–84.

[127] Digital Productions was an early digital VFX studio founded by John Whitney. Pacific Data Images would one day become Dreamworks, the main rival to Pixar studio. I expand upon this early research later in this chapter.

[128] One topic I was not able to cover in this research project is how governments other than the United States are involved in the sponsorship of computer graphics R&D. This is a topic I would like to pursue in future work.

[129] ―SIGGRAPH 97 Fact Sheet," accessed June 15, 2016, http://www.siggraph.org/s97/media/facts/.

the technical, academic, business, and artistic communities."[130] Companies from aircraft manufacturers to TV networks have provided financial assistance to SIGGRAPH in hopes of recruiting the best possible professionals for their own R&D projects. Lockheed Martin, Boeing, Apple, MTV, The Encyclopaedia Britannica, Swedish Energi Company and Symantec have all provided sponsorship and have had recruiting tables at the conference. But of all these varied industries, the film industry was arguably the most important, and had the biggest influence on the organization.

In the case of specific technologies at SIGGRAPH like simulation FX, Hollywood VFX and animation have come to dominate the industrial landscape. Research papers on simulation FX are as likely to be sponsored by Disney Research, Autodesk's Maya division, DreamWorks or Industrial Light and Magic (ILM) as a research university. And even when a research university is the affiliated institution on a paper, a VFX or animation company sometimes sponsors the research jointly. In the case of technologies like simulation FX it seems as though the film industry has taken on the role that the military used to play at SIGGRAPH.

Focusing on organizations like SIGGRAPH and the institutions they connect runs somewhat counter to the conventional wisdom of the history of digital technology. Historical accounts of innovations in computer technology are often framed as appropriations that resulted from individuals tinkering with technology. This is a paradigm that continues to shape Silicon Valley, with policies like Google's *20 Percent time* policy, where employees are encouraged to use company time to pursue their own projects. Computers seem to offer a platform that makes such individual innovations possible. Anyone can write an app that will become the next Facebook or Twitter. This is a key premise of start-up culture and media platforms in general. One example of this mythology is the first interactive graphic computer game *Spacewar!* (1962), which was built on a PDP-1 computer, one of the first computers built by a private company, Digital Equipment Corporation (DEP). *Spacewar!* was the result of tinkering rather than focused, funded research. Indeed the PDP-1 is described by the Computer History Museum as the platform that gave birth to individualized appropriations of computer technology such as

[130] "Special Interest Groups — Association for Computing Machinery," accessed June 17, 2016, http://www.acm.org/sigs/.

hacking, long before minicomputers.[131] Thus, programs like *Spacewar!* are constructed as lines of flight, bifurcations, disruptions, or appropriations from an otherwise rigidly structured field of technology.

Historical accounts of computer graphics offer similar narratives. One example is Tom Sito's *Moving Innovation: A History of Computer Animation*. Sito acknowledges that computer graphics emerged from academic research and military programs, but from there he seems to see computer animation following its own trajectory. Sito describes the early computer graphics innovators as ―oddball scientists who looked at the huge mainframe computers of IBM and Honeywell and thought, let's make cartoons with them."[132] For this reason he focuses on figures like Ed Catmull, a person who clearly wanted to make animation from a relatively early point in his career. What this approach neglects is the necessity of sustained relations between different industries and research institutions. Catmull has made great contributions in retrospect, and he clearly had a vision for computer animation. But without generous speculative government funding, without the interest of a robust media industry, and without SIGGRAPH to coordinate these different bodies, efforts like his probably would have taken a very different shape. They would probably seem more like avant-garde experimentation. Catmull would be counted among the ranks of other early experimental artists, instead of being a figure that changed the way movies are made. Computer graphics technologies like simulation FX result from large economic and political forces working in concert through organizations like SIGGRAPH.

The Hollywood Blockbuster

With Lucas Film's initial investment in computer graphics R&D in 1979 and the founding of Pacific Data Images in 1980, an existing media industry was finally taking an interest in computer graphics R&D. SIGGRAPH would soon be transformed, and the conditions were set for the development of tools like simulation FX. While it is true that some research funds were already being directed toward creative or artistic computer graphics tools, such as the aforementioned failed Xerox project Superpaint, the involvement of a substantial industry like Hollywood turned what was once speculative experimentation into an industry-driven research

[131] ―Introduction | PDP-1 Restoration Project | Computer History Museum," accessed June 17, 2016, http://www.computerhistory.org/pdp-1/introduction/.

[132] Tom Sito, *Moving Innovation: A History of Computer Animation* (MIT Press, 2013), 12.

infrastructure for constant technological advance. In this section and the following one, I will profile how money started to find its way from the movies to computer science labs. There are two key steps in this process. The first step requires understanding the economics of the Hollywood blockbuster and its historical relationship to technological change. The second step requires understanding the economics of the VFX and animation industries, especially in regard to the cost of R&D. First, the blockbuster.

Over the years, more and more research funds and research infrastructure was provided by the *big five* VFX studios (ILM, Rhythm and Hues, Sony Image Works, Digital Domain and Weta Digital), large animation Studios such as Dreamworks and Pixar, and software companies such as Silicon Graphics and Alias | Wave front. Although VFX and animation companies generally had several sources of revenue, including music videos, television commercials and technology licensing, the Hollywood blockbuster was the driving economic force behind the R&D they conducted. The Hollywood blockbuster is the answer to why R&D became such an important activity in the film industry, where previously film studios seemed content to simply use proprietary technology when it became available.

The logic of the Hollywood blockbuster proved to have some important synergistic correspondences with the research infrastructure of SIGGRAPH. Its voracious hunger for visual novelty and technological display proved in the long run to be a perfect fit for the established governmental-industrial-academic R&D infrastructure of computer science. When the two met they grew together, changing both the structure of computer graphics research and the shape of film production. The mark of the film industry is evident in the proceedings of SIGGRAPH, with a trend toward buzz generation and visual spectacles, while conversely the logic of R&D has spread to film production. This is the integrated logic of the blockbuster R&D complex. Following the definition of a complex I established in chapter 1, the blockbuster R&D complex integrates different disciplines and industry together through a shared, self-sustaining logic. Just as the military shaped research during Eisenhower and Fulbright's time, so too did the Hollywood blockbuster shape the development of computer graphics technologies like simulation FX.

Although the Hollywood blockbuster seems like an obvious driver of research for VFX and animation technologies like simulation FX, I am not taking this fact for granted. In this section I will take the time to justify my focus on the Hollywood blockbuster. I do this because it is perilous, and perhaps suspect, to privilege an entity that so often promotes itself as central and dominant. While this is something of an aside, my investigation of the blockbuster in this section also explains an extremely important mechanism that drives the development of simulation FX, and I will demonstrate its effects in following sections. In order to justify my choice to focus on the Hollywood blockbuster, I will respond to the following questions. 1) Why focus only on American cinema? 2) Why focus on the film industry at all when other completely new forms of media like video games seemed to be sprouting from the R&D complex at the same time? 3) Am I ignoring the digital animation industry? 4) Why privilege big films? 5) What is a blockbuster exactly, and is it a useful category in this case? All of these questions need to be answered in turn as part of an explanation of why the Hollywood blockbuster played such an important role in the complex that created simulation FX.

1) Why focus on American cinema? As Chapter 1 should have made clear, the Cold War R&D complex is specifically American, but we should not assume that the media industries that became so involved at places like SIGGRAPH in 1980s were also exclusively American. Although during the early days of simulation FX up to the later 1990s the majority of VFX companies were based in California, the only VFX studio left in California today that employs more than 1000 people is ILM. New studios have emerged and old ones have moved the bulk of their labour to countries such as Canada, New Zealand, Australia, Singapore and India.[133] Also, Weta Digital, one of the most important VFX Studios since the early 2000's, is based in New Zealand. Furthermore, the VFX industry is globalized in general, with many studios setting up branches in various international cities. For example Rhythm & Hues spread the production work for *Life of Pi* over offices in Mumbai, Hyderabad, Malaysia, Vancouver and Taiwan through a cloud-based production pipeline.[134] As the work of VFX researcher Leon Gurevitch

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[133] Film L.A., ―Feature Film Production Report," accessed June 17, 2016, https://www.hollywoodreporter.com/sites/default/files/custom/Embeds/2013%20Feature%20Study%20Corrected%20no%20Watermark%5B2%5D.pdf.

[134] ―A Glimpse of Rhythm & Hues (Asian Facilities) Work on Ang Lee's Masterpiece ‗Life of Pi,'" *AnimationXpress*, January 2, 2013, http://www.animationxpress.com/index.php/animation/a-glimpse-of-rhythm-hues-asian-facilities-work-on-ang-lees-masterpiece-life-of-pi.

demonstrates, the VFX industry sees workers moving across the world constantly, often staying in one country only long enough to complete one six or nine month contract.[135]

Focusing on the Hollywood Blockbuster does not necessarily mean excluding these international production connections though. For example *The Lord of the Rings* trilogy, though produced largely in New Zealand, helmed by a Kiwi director and distributed throughout the world, was in essence a Hollywood blockbuster. In this period Hollywood was a structure built on the sedimented superstructure of an American industry that mutated to become an international, overdetermined entity with studios owned by international conglomerants that make content for both domestic and international audiences. As Toby Miller argues, ―Hollywood's real location is in its division of labour."[136] Thus, using the Hollywood blockbuster does not necessarily mean that I am limiting myself to an American context. Rather I am looking at a film industry and a mode of film making that is anchored in what was historically the American film industry.

2) Why focus on the film industry? Clearly there are a variety of media industries that demand the latest developments in computer graphics. The video game industry is the most blatant rival. Although it is difficult to compare the respective markets of film and video games, especially given that media conglomerants might adapt a movie property into a game or vice versa, the size of the two industries globally seems at least comparable. A *Variety* article from 2013 points out that *Grand Theft Auto V* (2013) grossed more in its first day of sales than most Hollywood blockbuster grossed that entire year.[137] Furthermore, some current computer graphics technologies used in VFX are also used in the video game industry. But while games play a part in simulation FX today, during the first few decades of the development of simulation FX the games industry played a relatively small part. Animating a scene for a film can take days of rendering on a massive server farm, while video games need to be rendered on a user's computer

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[135] Leon Gurevitch, ―Digital Workshops of the World: The Transactional Cultures of Images and Skills in the VFX Industries" (Magic of Special Effects Conference, Montreal, Canada., November 2013).

[136] Toby Miller et al., *Global Hollywood:* (British Film Institute, 2004), 7.

[137] Marc Graser, ―‗Grand Theft Auto V' Is Top Selling Video Game for Second Month in a Row," *Variety*, November 15, 2013, http://variety.com/2013/biz/news/grand-theft-auto-v-is-top-selling-video-game-for-second-month-in-a-row-1200833303/.

or console in real time. This means that emerging technologies like simulation FX would only come to games later. For example the aforementioned *Grade Theft Auto V* features an ocean simulation that is less detailed than what one would see in a feature film from a decade ago.

3) Am I ignoring the digital animation industry? The definition of blockbuster I am working from here is capacious enough to include animated features. If one looks at the top international theatrical sales from the past few decades, digital animated features such as *Frozen* (2013), *Toy Story 3* (2010) and *Kung Fu Panda* (2008) are some of the top ranked films. Furthermore it is undeniable that features such as these are some of the best examples synergistic coordination across ancillary markets by large media conglomerants.

4) Why privilege big films? Even within the VFX industry the film industry can make up as little as a third of an FX studio's revenue, alongside television, advertisements and technology licensing.[138] The answer boils down to a question of scale. The budgets for commercials and television are, with few exceptions, smaller. Smaller budgets do not have room for the most costly and newest technology. As sections below will illustrate, developing new technologies requires substantial investment in risk-laden forms of R&D. An examination of research on simulation FX at SIGGRAPH reveals that large VFX and animation studios were the most active entities involved and the R&D conducted by those studios was supported mostly by big films. This claim will be expanded upon in following sections.

Hollywood blockbusters were therefore the place the newest experimental technologies like simulation FX were developed first. In general, simulation FX technologies were deployed first in a blockbuster before being turned into software that might be used on smaller projects and perhaps sold to other companies. Similarly, a new technique that at first took hours to render on a large server farm might become applicable for video game application many years down the road. It is true that this trend slowly changed over time, and today video games drive more research than ever, shifting the focus somewhat towards techniques that are applicable for real-time rendering.[139] But during the period of 1980 to the 2010s when simulation FX development was at its peak, the Hollywood blockbuster was still king.

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[138] Michael Curtin and John Vanderhoef, ―A Vanishing Piece of the Pi: The Globalization of Visual Effects Labor," *Television & New Media*, February 20, 2014.

[139] One example of this is work of Jerry Tessendorf, which is focused on efficiency in fluid simulation and can be applicable to both VFX and the games industry.

5) What is a blockbuster and is it a useful category? Like so many categories that try to group films together, the definition of the blockbuster is the subject of discussion and contention. Julian Stringer notes that the term blockbuster means different things when used by different people; it can be a term of derision to a reviewer or praise to a studio executive.[140] It can refer to a film that was planned to be *big*, or it can be used to describe a film that was an unplanned hit.[141] Charles Acland finds that the first use of the term blockbuster was closer to the latter definition, something akin to a sleeper hit, and studios used the term to sell films to theatre owners.[142] For many the birth of the modern blockbuster did not come until the New Hollywood era with a picture like *The Godfather* (1972), or more likely, *Jaws* (1975), which had a nation-wide simultaneous release coordinated with a TV ad campaign. This was the beginning of front loading big films, and of the key importance of the communication of opening weekend figures. Thomas Schatz and other film scholars such as Jon Lewis agree that these opening weekend box-office figures, once meant only for industry insiders, have become a way to communicate to audiences which films are *must see* event films.[143] In this sense the term blockbuster still functions much the same way it did in Acland's account.

According to business scholar Anita Elberse, the logic of blockbusters is common to ―entertainment markets," from sports to books to television, and the rise of digital technology has done nothing to disrupt this logic.[144] Her analysis of the film industry shows that even though big films are risky ventures, they on average produce bigger returns than smaller budget films.[145]

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[140] Thomas Schatz, ―The New Hollywood," in *Movie Blockbusters* (Routledge, 2013).

[141] Some scholars such as Steve Neale exclusively define the blockbuster as planned, thus excluding cult hits. Arguably what is useful about blockbuster studies is the way it examines how studios plan and coordinate big releases.

[142] Charles R. Acland, ―Senses of Success and the Rise of the Blockbuster," *Film History* 25, no. 1–2 (2013): 11–18.

[143] Schatz, ―The New Hollywood"; Jon Lewis, ―Following the Money in America's Sunniest Company Town: Some Notes on the Political Economy of the Hollywood Blockbuster.," in *Movie Blockbusters* (Routledge, 2013).

[144] Anita Elberse, *Blockbusters: Why Big Hits - and Big Risks - Are the Future of the Entertainment Business*, 2015, 6–11.

[145] Ibid., 20.

Consumers can only be aware of so many films at a time, so it makes sense to utilize stars, VFX spectacles and marketing to make a few special films stand out from the rest.[146]

Having a hit film also creates opportunities for diverse forms of income in ancillary markets, especially since the rise of home video and cable. As Schatz points out, the TV and home video markets are dominated by big films because those are the ones people remember.[147] Planning a hit in advance allows a conglomerated media company to plan all sorts of coordinated synergies. Hence, today the green-light process for a Hollywood blockbuster is overseen by forty individuals who are each focused on different markets for the film's brand.[148] But how does one create a blockbuster? As *Jaw*s illustrates, release schedules and advertising are important tools. An early example of this is the road show, which generated buzz and anticipation as it moved from city to city. But perhaps the most historically consistent method for creating an event film has to do with creating a unique spectacular experience: to show things on an unprecedented scale, to create a novel viewing experience that must be seen.

Such spectacles are frequently paired with a new technology of presentation. Steven Neale and Sheldon Hall note that ever since the “special” and “super special” films of the 1920s there have been “large scale, high cost” films that feature special distribution strategies, epic content and spectacular images. Films that demanded a premium price and went on road shows would feature epic subject matter and present it with the spectacle of special effects and sheer production scale.[149] They see nothing but continuity between the special and the contemporary Hollywood blockbuster. The scale of the spectacles in road show remakes like *Ben-Hur* (1959) and *The Ten Commandments* (1956) went hand-in-hand with Camera 65 and Vistavision anamorphic technologies. As Neale writes, “one of the elements that affects both (the blockbuster's) cost and their presentation is their deployment of expensive, up-to-date

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[146] Ibid., 23.

[147] Schatz, "The New Hollywood," 28.

[148] Peter Grant and Chris Wood, *Blockbusters and Trade Wars: Popular Culture in a Globalized World* (D & M Publishers, 2009), 101.

[149] Sheldon Hall and Steve Neale, *Epics, Spectacles, and Blockbusters: A Hollywood History* (Wayne State University Press, 2010).

technology.”[150] This might include novel special and visual effects, or also some sort of novel technique for exhibition such as Cinemascope, Technicolor, synchronized sound or 3D. For this reason, I believe it is appropriate to include digital animated features as blockbusters. Much like these technologies, the techniques used in a feature like *Toy Story* (1995) attracted audiences because of its representational novelty. And with each passing season top animation studios compete in an arms race to deliver new animation technologies and techniques for their biggest features. The upfront costs of all of the technology, production and promotion for films like these of course mean that planned blockbusters generally belong only to big studios.

The centrality of the blockbuster, and the exclusivity of its “representational prowess” might be an important component of what makes a film profitable in ancillary markets and secondary distribution, but its centrality and exclusivity also carry a tacit meaning.[151] Paul Allen argues that the Hollywood blockbuster allows studios to promote new technologies and effectively “renegotiate the industry status” of Hollywood.[152] In other words, these films author what Hollywood cinema is, and what it will be in the future. “Only a blockbuster - big, expensive, star-laden- could hope to carry the weight of expectation that a major new type of cinema technology brought with it.”[153]Allen believes one can see this logic at work even in the aesthetics of Hollywood blockbusters. In films as diverse as the *Jazz Singer* (1927) and *Jurassic Park* (1993) there are moments which are given over to pure spectacle, and in these moments of suspension a new technology that is set to transform the industry is put on display.[154]

Allen's account of the Hollywood blockbuster is consistent with interpretations of special effect aesthetics by other scholars. For example Dan North builds off of the concept of the incredulous spectator from Gunning and Gaudreault's concept of the “cinema of attractions” to

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[150] Neale, Steven “Hollywood Blockbuster: Historical Dimensions,” in *Movie Blockbusters* (Routledge, 2013), 48.

[151] This is a phrase used by many scholars who write about blockbusters. It is attributed by Hall and Neale to an unpublished dissertation by Ted Hovet. Ted Hovet, “Realism and Spectacle in Ben-Hur [1888-1959],” PhD dissertation, Duke University, 1995.

[152] Michael Allen, “Talking About a Revolution: The Blockbuster and Industrial Advancement,” in *Movie Blockbusters* (Routledge, 2013), 101.

[153] Ibid, 103.

[154] Ibid, 112.

argue that visual effects are meant to be recognized and enjoyed as illusions and that they speak to the nature of technological mediation.[155] Special effects are about the medium, they are about the illusion of cinema. Even the status of consumer media technologies can be renegotiated by a well-positioned and well-designed blockbuster. As Charles Acland observes, blockbusters such as *Avatar (2009)* function as ―technological tentpoles," that set into place new protocols for technologies.[156] For example *Avatar* was designed to introduce Stereoscopic 3D as a new standard for spectacle films, both in theatres and in homes. It successfully drove a range of technological adoption, from camera systems (designed by James Cameron) to digital cinema systems and consumer electronics. The Hollywood blockbuster therefore has a very particular relationship to both VFX and technology. It is both symbolically and economically positioned to be the site where important technological changes take place.

The Hollywood blockbuster embodies a logic that defined a variety of activities at SIGGRAPH during the period of 1979 to the 2000s, and although it sounds like a very narrow and specific form of media, I am using it as a concept that is already transnational and intermedial and therefore more capacious that is might seem. While it is true that there were a variety of different industries at SIGGRAPH during this period, including the sustained role of the military, my research finds that VFX and the Hollywood blockbuster were of substantial importance during this period, and that they are the clear driving force behind the development of simulation FX.

The Cost and Risk of R&D in VFX and Animation

The Hollywood blockbuster proved to be a good fit for computer graphics research. The blockbuster's scale and the front-loaded nature of investment, its relationship to spectacles of technology, its focus on creating buzz, and the struggle to define the industry, all make the involvement of computer graphics technology seem practically inevitable. However, the relationship between blockbuster production and computer graphics technological development

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[155] North, *Performing Illusions*; André Gaudreault, ―Theatricality, Narrativity, and Trickality: Reevaluating the Cinema of Georges Méliès," *Journal of Popular Film and Television* 15, no. 3 (1987): 110–119; Tom Gunning, ―The Cinema of Attraction," *Wide Angle* 3, no. 4 (1986).

[156] Charles R. Acland, ―Avatar as Technological Tentpole," accessed June 17, 2016, http://www.flowjournal.org/2010/01/avatar-as-technological-tentpole-charles-r-acland-concordia-university/.

is not immediate and direct. In between the two sits the mediating body of the VFX and animation industries. Thus, in order to understand the blockbuster R&D complex we must understand how the VFX and animation industries fund their R&D activities.

The film industry is unlike many other industries, and the VFX and animation industries are more unique still. Like most cultural products, the cost of creating a film mostly comes from the content and the promotion. Actually delivering the product to customers, whether in theatres, on storage media or over the internet, is relatively insignificant. In economics terms this means cultural goods are akin to public goods because their value is not affected by scarcity.[157] The value of a film is instead that insubstantial fugitive quality of meaning and affect. In the case of a blockbuster, VFX, like a celebrity performer, a director with name recognition, or an ad campaign, gives a film value. Yet unlike these other factors, blockbuster VFX and animated features also require some kind of technical advance or originality. The inseparable nature of technology and culture makes these industries unique even amongst either technological or cultural industries.

As VFX industry veteran and co-founder of the trade website *VFX Insider* Mike Seymour points out, other industries that make use of technology often outsource much of their technological heavy lifting. Apple, for example, puts a lot of research into the design of their products but they do not build the actual components of their products. Instead they coordinate closely with manufactures who might offer a custom or off-the-shelf solution.[158] For example, different generations of Apple's iPhone contain processors, memory and LCDs from various different third party suppliers like Samsung, Foxconn or Qualcomm. One might contend that all tech companies by definition develop technologies. But what is less common is for a company to develop the most basic building blocks of their technology. By contrast, VFX and animation studios have the unique challenge of developing some of the most basic technological components of the products and services they sell. The uncertainty, the contingency, of the research these business support is both immensely valuable, and immensely risky. It affirms how uncertain scientific research can be, but it also demonstrates the potential value of shaping it. In addition to all this, the products these industries produce are highly qualitative and symbolic.

[157] Grant and Wood, *Blockbusters and Trade Wars,* 56.

[158] Mike Seymour, ―A Way Forward for the VFX Industry," *Fxguide*, December 1, 2014, https://www.fxguide.com/featured/a-way-forward-for-the-vfx-industry/.

Seymour‘s comments should be taken with a grain of salt. Clearly there are some very R&D driven industries, like the pharmaceutical industry, and clearly VFX and animation studios do not develop all of their own technologies. During the 1980s and 90s they all would have used Silicon Graphics hardware and software as a basic platform, and more recently they would all using software like Autodesk's Maya. But a high percentage of jobs in both VFX and animation require the development of a special tool or the customization of an existing one. In the case of tools like simulation FX, this can entail funding basic scientific research into physics and mathematics. Sometimes custom work and even scientific research can be subcontracted to specialist companies. But in either case the cost and the risk of this R&D is all the VFX or animation studio‘s responsibility. The uncertainty of the research process, and the financial precarity it entails is a source of risk. This is a key consequence of the way VFX and animation are suspended between the blockbuster and the R&D complex, between film production and technical research.

In the VFX and animation industries R&D broadly describes all of the work put into building technology so that a job can be completed. This can entail mobilizing networks of scientific researchers and institutions to build unique simulation software, but it can also entail building what is referred to as the production pipeline. The pipeline essentially refers to all of the different pieces of software needed to complete a job and the infrastructure that fits them all together. The pipeline allows all of the different departments working on different aspects of a project to work together. Because each job is different, even a small or moderate sized project will require having technical directors or TDs to customize software and write the *glue code* that connects different pieces of software together. Effectively all R&D jobs, large and small, are about building software to technically facilitate actual production work. Some jobs simply require more fundamental R&D.

On moderate sized jobs there will likely be some shots with specific challenges, but sometimes these can be solved with a piece of *off the shelf* software, and thus the task of R&D is simply to have technical directors build out the pipeline. However, sometimes a certain shot, or series of shots, cannot be accomplished with any available software. Shots that demand simulations often demand custom solutions. In their best practices manual, the Visual Effects Society (VES) addresses this problem in a section titled ―To Build or Purchase?" written by Pixar technical director Stephan Vladimir Bugaj. Bugaj's opinion is that if you can buy software you probably should. It can be risky and expensive to build custom software.[159] Sometimes the demands of a project require the originality and spectacle of something new, but Bugaj points out that anything a moderate sized VFX or animation studio can build will be eclipsed by the work of larger studios with more resources. Thus the most fundamental work is done only for the largest projects: Hollywood blockbusters.

For Hollywood blockbusters that sell themselves on the quality and novelty of the VFX and animation they feature, it would never do to have the same tech as everyone else. Novel images that differentiate a film from its rivals require R&D. This is particularly true of simulation FX. Having the same hair, cloth, pyro or water as every other studio would defeat the purpose of VFX, and blockbuster animation releases seem to follow a similar logic. Custom work like this is sometimes contracted out to other companies. Indeed, most software companies offer customization services to make their product do what it needs to for a certain project. But often times it still makes more sense to keep that sort of labour in-house. As a technical director at Disney Animation Studios told me, ―It's best to have in house developers, in a sense that support and development time is much more rapid and flows naturally, as your artists and technical directors are working in the same place as software developers. This means rapid prototyping, integration, testing, execution, and support."[160] In short, if a VFX or animation studio is large enough to afford in-house R&D, then they can offer services that smaller studios simply cannot, and they can fold R&D process into the animating process more effectively.

Setting aside the animation industry for a moment, understanding R&D helps explain the particular economics of the VFX industry, an issue that has been the subject of considerable discussion in the past few years. Some critics in the VFX industry consider the necessity of building technology to be a considerable source of risk and one of the major factors that makes the VFX industry so vulnerable. This finding comes in the wake of the bankruptcy of big five VFX studio Rhythm & Hues, just after it had won an academy award for its work in *The Life of Pi* (2012). There is a general perception in the industry that there is something fundamentally defective in the way they do business. VFX supervisor Ben Grossman has advocated for a new model that separates technology building from animating and overhauls the VFX bidding

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[159] Stephan Vladimir Bugaj, ―To Build or Purchase?," in *The VES Handbook of Visual Effects: Industry Standard VFX Practices and Procedures* (CRC Press, 2014).

[160] Natt Mintrasak, Interview with Disney Technical Director, September 7, 2015.

process.[161] Exactly why people like Grossman see a problem with the bidding process requires some explanation.

Unlike the animation industry, where most work is done in-house, the VFX industry sees VFX studios bidding on contracts with film studios. In the majority of cases, the details of what R&D will be required for a VFX job are not factored in the initial planning stages. This may sound like a controversial statement, given that I have established how fundamental technology is to the blockbuster. It is true that certain iconic films like *Avatar* seem to factor VFX technological development in early planning. Publicity for *Avatar* touted the fact that James Cameron had to wait a decade until technology was sufficiently advanced to film his screenplay for *Avatar*.[162] But the films helmed by techno-Auteurs like Cameron or George Lucas are exceptional cases. In the case of an average blockbuster in the past few decades, VFX work is entirely contracted out to a large VFX studio that is invited to bid on the project. It has become common on large projects for the above-the-line studio staff to include a VFX Supervisor who will be able to help plan and coordinate with VFX studio, but it is the sole responsibility of the contracted VFX studio to come up with solutions to all of the many challenges a blockbuster presents.[163]

Once a VFX studio is invited to bid on a project they will go through a *breakdown* of the film, approximating the costs for each shot in the film. Bidding VFX studios are relatively opaque in their proposals to the studio. All the studio sees is the price per shot.[164] Folded into this single number is a variety of costs including facilities costs, labour and R&D. In other words, the contract between the film studio and the VFX studio does not say ―these shots will require us to

[161] Seymour, ―A Way Forward for the VFX Industry."

[162] Anne Thompson, ―How James Cameron‘s Innovative New 3D Tech Created Avatar," *Popular Mechanics*, January 1, 2010, http://www.popularmechanics.com/technology/digital/visual-effects/4339455.

[163] The "Pre-Production" section of the VES Handbook and an instructional book titled "The Visual Effects Producer" offer a good overview of how this process works. Scott Squires, ―Pre-Production," in *The VES Handbook of Visual Effects: Industry Standard VFX Practices and Procedures* (CRC Press, 2014), 17–79; Charles L. Finance and Susan Zwerman, *The Visual Effects Producer: Understanding the Art and Business of VFX* (Elsevier/Focal Press, 2010).

[164] Seymour, ―A Way Forward for the VFX Industry."

invent a new way of animating water, so they will cost this much," they simply state how much the shots will cost. The problem with this is that R&D in intrinsically uncertain and risky.

As I discussed in chapter 1, the nature of R&D mediates between the unpredictable exploratory nature of science and application-oriented nature of engineering and design. All R&D is thus uncertain to some degree. Nature asserts its agency through its implacable affordances and limitations. Thus if a VFX studio signs a contract to complete a shot with a technology they have no built yet, they are exposed to considerable risk. Problems could very easily present themselves that make development much harder. What they set out to do may turn out to be impossible. All of the extra costs associated with these overruns are invisible to the film studio, which makes it difficult to justify overruns. This is a fact openly acknowledged by VFX studios. According to a 10-K public report filed to the Securities and Exchange Committee by Digital Domain in 2011, which lists the sources of revenue, costs and potential risks of the company, R&D is a major source of financial cost and risk.[165] This is why Ben Grossman proposed that the bidding process be transformed, and that technology development be offset to a third company that will complete its work before the main VFX contract is agreed upon. This, he argues, would make the VFX industry more stable and more like other industries. R&D is less of a problem for big animation studios, for example, because they are not bound by restrictive contracts.

One might argue that proprietary software already solves the problem of R&D. There are some examples of software companies attempting to standardize VFX tools, eliminating the need for VFX and animation studios to do R&D. Companies such as Autodesk do not make money directly from movies but from selling software used to make movies. The logic of these companies follows the idea that as proprietary software gets better, more studios will opt to *purchase* instead of *build*. If the software companies were ever to take over the task of building new technology completely, VFX would be more like other industries, and perhaps it would become more sustainable. In the case of blockbuster releases though, off-the-shelf software will never entirely replace in-house R&D.

[165] All publicly traded companies must file a 10-K form in the U.S. Unfortunately many other studios are owned by parent company and thus do not file individually. Digital Domain Media Group, ~~"S~~EC Form 10-K," 2011, http://www.sec.gov/Archives/edgar/data/1490930/000104746912003713/a2208461z10-k.htm.

Although people like Grossman might see the VFX industry as dysfunctional, its logic is certainly self-perpetuating. Just as the upfront costs, scale and horizontal integration of the blockbuster ensure that it is a type of film only available to the largest conglomerated studios, the demands of R&D ensure that only the biggest VFX studios will be the ones winning the contracts for blockbusters, and only the biggest animation studios will release features with cutting edge animation. The spectacle of rarefied technology ensures the maintenance of this system. This is the self-sustaining organization of the complex at work.

For most large studios the economics of this system are perfectly logical. Software that is developed for blockbusters can be spun into licensed software and sold to other studios. Indeed licensing software can be a substantial source of revenue for a VFX or animation studio. The document filed with the Securities and Exchange Committee by Digital Domain states that approximately one third of their revenue comes from licensing software and doing specialized sub-contracted work.[166] One example of an animation studio licencing software is Disney‘s Xgen hair simulation software, which they are publishing in association with software giant Autodesk.[167] The risk of R&D does not come without reward for those studios that are large enough to afford it. Big studios are thus the place where new computer science technology generally is developed and disseminated into the larger filmmaking context.

The Hollywood blockbuster therefore does not drive the development of new technologies directly. The VFX and animation industries shoulder this burden, both bearing the risk of R&D while also benefitting from the dissemination of the technologies that result from it. The R&D these studios conduct is not trivial either. They seek more than incremental technological advance. The advances they seek require real scientific research, and this means tapping into a network of researchers and institutions via organizations like SIGGRAPH. The following section on simulation FX research at SIGGRAPH will demonstrate these relations in action.

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[166] Digital Domain Media Group, ―SEC Form 10-K.‖

[167] ―Mouse‘s XGen to Autodesk,‖ *Variety*, August 9, 2011, http://variety.com/2011/digital/news/mouse-s-xgen-to-autodesk-1118041067/.

The Development of Fluid Simulation

Thus far my description of the relation between SIGGRAPH, the VFX and animation industries, and the Hollywood blockbuster has been fairly abstract. In this section I will provide a more concrete example of these connections. In doing this I will also demonstrate the gradual shift at SIGGRAPH away from the military-industrial R&D complex and toward the blockbuster R&D complex. I will do this by looking closely at the development of one specific type of simulation FX: fluid simulation.

This section starts with the earliest computation fluid dynamics research, then moves on to specific research sponsored by the VFX and animation industries. I will also note some of the films these technologies were developed for or featured in. This section mentions a great many scientists and engineers by name, and it may be difficult to keep track of them. The reader's primary concern should be the institutions supporting these people rather than the individuals themselves though. I have put together a chart that can be used as a reference to help orient the reader (figure 2). Figure 2 illustrates the three historical phases in the development of fluid simulation technology, ―calm large bodies of water, scaled dynamics and hybrids." Some of the early research I cover in this section can also be found in the ―design and engineering" and ―meteorology" sections of figure 1 in chapter 1.

Figure 2. Fluid Simulation for Computer Graphics: Research Tools and Applications

Before delving into the development of fluid simulations for VFX and animation, it is worth briefly noting the origins of some key concepts in the field. Hydrodynamics is of course not a new discipline; irrigation and aqueducts require some ability to predict how fluid behaves, and they are as old as civilization itself. Polymath Leonhard Euler formalized the first theory of fluid dynamics in the mid-18th century. His work provided an equation that understood the dynamics of fluid through factors like pressure and momentum. Further work by engineers Claude-Louis Navier and George Gabriel Stokes in the 19th century added further nuance and new factors like viscosity and thermal conductivity. The *Navier Stokes equation* they developed continues to be the essential standard for calculating the varying factors that affect the dynamics of fluid movement, but doing these calculations continues to be very difficult. As I noted in chapter 1, the movement of fluid is a nonlinear problem, where an outcome cannot be determined based on initial conditions, thus it is a prime candidate for simulation. This background demonstrates that a tool like fluid simulation cannot be reduced to being a digital technology. However both computers and fluid simulation were developed together by the same R&D complex following the Second World War.

The first research into computational fluid dynamics was conducted under the aegis of the Los Alamos National Research Laboratory. In fact the first publication of the Monte Carlo method (which I discussed in chapter 1) was a 1953 paper on fluid simulation research.[168] The majority of early work was conducted from 1955 to 1971 by the T3 (Third Theoretical) Group at Los Alamos Research Laboratory, headed by physicist Francis Harlow. The T3 group took concepts like the Navier Stokes equations and made computer simulations of fluid dynamics. Through their work they produced mathematical methods for modeling fluid such as Particle in Cell (PIC), Implicit Continuous Field Eulerian (ICE), and Lagrangian Incompressible (LINC). Many of these continue to be used in fluid simulation FX software. Los Alamos is of course the once-secretive research facility where the Manhattan Project was conducted. It was a federal defence initiative that was run by the University of California. It therefore comes as no surprise that T3 Group was funded by weapons research initially, but as their official history relates, the period after the Second World War saw a gradual opening up of restrictions and the growth of a

[168] Nicholas Metropolis et al., ―Equation of State Calculations by Fast Computing Machines," *The Journal of Chemical Physics* 21, no. 6 (June 1, 1953): 1087–92.

culture of ―free exploration."[169] Clearly though, the Unites States government provided the first push for computational fluid dynamics, and even to this day it continues to have research support and application in the military.

While computational fluid dynamics proved to have many applications in many research disciplines and industries, notably meteorology and computer-aided design, it started to be explored for computer graphics in the mid 1980's. While visual outputs of some kind had been used in computational fluid dynamics before, this was the first time, visual simulation was combined with physical simulation.[170] The two main challenges involved in adapting computational fluid dynamics for computer graphics were simplifying the very complicated and resource-intensive math to the point that it could be usable and converting simulation data into the geometric shapes used in 3D software. The first example of computer graphic computational fluid dynamics at SIGGRAPH was specifically developed for a visual effect in a Hollywood film. The film was *2010* (1984), a sequel to Stanley Kubrick's *2001: A Space Odyssey* (1968). The effect was a simulation of the swirling atmosphere of the surface of Jupiter. This simulation was strictly 2D, but it was mapped onto the spherical surface of Jupiter. Douglas Trumbull's effects company Entertainment Effects Group did the effects for the film, but researchers who designed the effect came from subcontracted VFX companies.[171] Two of the authors, Larry Yaeger and Craig Upson, were employed by Digital Productions and the third author Robert Myers was from Poseidon Research.[172] Although the training and experience of the researchers and the concepts they used came from research institutions and government agencies (Yaeger had worked on computational fluid dynamics at Grumman Aerospace for example) this first fluid simulation effect was solely billable to a single Hollywood film.

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169 Normal L. Johnson, ―Computational Fluid Dynamics Group | History," *Los Alamos National Laboratory*, December 28, 2013, https://web.archive.org/web/20131228022146/https://www.lanl.gov/orgs/t/t3/history.shtml."

170 Jos Stam, ―Stable Fluids," in *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '99 (New York: ACM Press/Addison-Wesley Publishing Co., 1999), 121–28.

171 Trumbull is the special effects guru who is famous for his work in *2001: A Space Odyssey*.

172 Yaeger, Upson, and Myers, ―Combining Physical and Visual Simulation—Creation of the Planet Jupiter for the Film ‗2010.'"

A military R&D company, an Apple Computer R&D group and a few research universities sponsored the next steps in fluid simulation sophistication. All found their first application in Hollywood blockbusters though. The first techniques for animating water in 3D only really dealt with the surfaces of large calm bodies of water. These were much easier to simulate because they required less detail. The first of these was developed by Stanford electrical engineering PhD Michael Kass and Cambridge computer science PhD Gavin Miller at Apple Computer's Advanced Technology Group.[173] This early technique could not simulate breaking waves, nor could it simulate water coming in contact with other bodies, but it could do shallow undulations. The next major step in this line of research was published by J.X. Chen from George Mason University and three other researchers from the University of Central Florida, all of them members of computer science faculties.[174] Their technique was ―full Navier-Stokes," which is to say it was much closer to a total scientific simulation of fluid dynamics. Although it only solved movement in two dimensions, it was employed in convincing 3D animations. This era of the early-to-mid 1990s in fluid simulation FX can be identified in Hollywood films like *Waterworld* (1995) and *Titanic* (1997), where relatively large areas of relatively calm water are animated in the background.

The two major tools which implemented this simulation technology were Alias | Wavefront's Dynamation and Arete Entertainment's Digital Nature Tools. Alias | Wavefront is a combination of two software companies that were purchased by SGI (formerly Silicon Graphics) in the 1980s. The best-known product of this company was the 3D animation suite Maya. SGI supported a variety of its own research. In fact Gavin Miller had worked with them before moving to Apple. SGI's approach was to develop tools that could contribute to their larger software and hardware ecosystem. They wanted to *own* computer graphics. Their Dynamation software was designed to run on their IRIS operating system, which ran on their MIPS workstations. In contrast, Arete Entertainment basically only made fluid simulation software program and they had no aspirations of standardization.

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[173] M. Kass and G. Miller. "Rapid, Stable Fluid Dynamics for Computer Graphics."*ACM Computer Graphics* (SIGGRAPH '90), 24(4):49–57, August 1990.

[174]J. X. Chen, N. da Vittoria Lobo, C. E. Hughes, and J. M. Moshell."Real-Time Fluid Simulation in a Dynamic Virtual Environment." *IEEE Computer Graphics and Applications*, pages 52–61, May-June 1997

When it was founded in 1976 Arete was supported exclusively by military contracts. Arete was founded in response to a call from the Department of Defence for new sensor technologies. Their research involved computer simulations of fluids, the basic principal being that you could better detect the presence of an object in a fluid if you understood the shape of the perturbations an object made in a fluid medium. Searching for new markets in 1996, they managed to catch on to a new demand in computer graphics for naturalistic looking fluids. Arete merged with German VFX studio SZM and developed new products specifically for animation and VFX such as Arete Image Software and the Digital Nature Tools Plugin. Their presence is quite evident at SIGGRAPH during this period. They were a sponsor and hosted a recruiting table, their researchers presented their work in publications, and their technology was on display in technology demonstrations. Arete is a weathervane for a general shift from military to media industries at SIGGRAPH. They did not seek out the VFX and animation industries because they had a dream like Ed Catmull did, they simply sought out opportunities and research funds. When one source of revenue dried up, they sought a new one. SIGGRAPH made this transition only too easy.

The next major developments in fluid simulation, full 3D Navier-Stokes simulations, were supported by yet more research universities and further research by Alias | Wavefront. Nick Foster and Dimitris Metaxas, both researchers at the University of Pennsylvania, published their work on the first 3D Navier Stokes simulation at SIGGRAPH in 1996. Their work was based on research conducted by Francis Harlow and Eddie Welch at Los Alamos some 30 years earlier. The key concept they utilized was the *marker and cell* method (MIC), published in 1965.[175] While Foster and Metaxas' work was a big advance in terms of scientific realism, it was still resource intensive and unstable. One key issue that many researchers have noted is that greater scientific fidelity often comes at the cost of being able to modify or customize a simulation.

Three years later a researcher at Alias | Wavefront, Jos Stam, published an approach that was less resource intensive and more ―interactive."[176] In other words it was more apt to handle external inputs without causing the simulation to collapse. Thus, not all research was directed

[175] Francis H. Harlow and J. Eddie Welch, ―Numerical Calculation of Time-Dependent Viscous Incompressible Flow of Fluid with Free Surface," *Physics of Fluids (1958-1988)* 8, no. 12 (December 1, 1965): 2182–89.

[176] Stam, ―Stable Fluids."

toward realism. These contributions made robust scientifically based fluid simulation much more practical and apt for implementation into the SGI platform. The increased interactivity of this technology meant artists could go further in manipulating a simulation to get the look they wanted. This push toward the *directability* of simulations, to make them more apt for art direction, became a key development goal after Stam's work, to the point that it rivalled the quest for realism.[177] I will pick up this topic of directing simulations again in chapter 3.

It is worth noting that Stam is the first researcher named here who was educated completely outside of the United States. Born in the Netherlands, he received a PhD in Computer Science from the University of Toronto (the same as Gavin Miller) and did post-doctoral study at French Institute for Research in Computer Science and Automation and VTT Technical Research Centre of Finland. He and Miller are two good examples of the strong relationship between the University of Toronto computer science department and development for the Maya software suite. This relationship continues to this day with SGI's successor Autodesk.

These developments lead to a proliferation of fluid tools both produced in-house at the big five VFX studios and by independent software companies. These include the Maya Fluid Effects System, Next Limit's Real Flow, and on the studio side, Pacific Data Image's FLU, Rhythm and Hues' Fluid Dynamics Tools, ILM's OCEAN and Digital Domain's FSIM. One can see this era of fluid simulation technology at work in the VFX and animation spectacles of the late 1990's and early 2000's, from the droplets of water in *Antz* (1998), to the devastating waves and storms in *The Day After Tomorrow* (2004) and *The Perfect Storm* (2000).

Through the 2000s researchers continued to propose new techniques that offered a higher level of realism, were less resource intensive or allowed a greater degree of control. The best approaches tried to achieve all of these traditionally contradictory demands. One example is Rhythm & Hues researcher Jerry Tessendorf's *fast-Fourier-transform* technique for animating oceans, which was highly influential both for film and real-time gaming applications.[178] Tessendorf had actually worked at early fluid simulation software company Arete Entertainment

[177] Jeffrey A Okun, Susan Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects: Industry Standard VFX Practices and Procedures* (Amsterdam; Boston: Focal Press, 2010), 639–40.

[178] Jerry Tessendorf and others, ―Simulating Ocean Water," *Simulating Nature: Realistic and Interactive Techniques. SIGGRAPH* 1, no. 2 (2001): 5.

before coming to VFX studio Rhythm & Hues. Another substantial contribution in this era came from Stanford mathematician Ron Fedkiw, who took his mentor Stanley Osher's *level set* approach for the numerical analysis of curved shapes and applied it to fluid simulation geometry.[179] He developed this approach while working both as a professor at Stanford and as a consultant at ILM.

Up to this point animating something like a churning ocean would involve a composite of many different techniques, some to do the waves, others to do the spray, and others still to do the foam on the surface of the waves. One persistent challenge has been that fluids tend not to scale well, requiring different tools for small splashes versus big waves.[180] For example Houdini, a multi-featured software package published by Side FX, has three different fluid solver options that a simulation artists can choose for different applications. One of the primary focuses of recent research has been to create tools that innately solve these problems, thus eliminating the need for studios to do the costly work of cobbling together different software and plugins for one effect. A popular solution in this era has been to combine formerly separate particle and grid based solutions together into a single solution.

In 2008 a researcher who trained under Ron Fedkiw at Stanford and helped build the fluid simulation technology at ILM, Robert Bridson, developed a new technique called the *fluid implicit particle* approach as a way of providing a totally scalable fluid simulation.[181] Together with his business partner and fellow fluid simulation researcher Marcus Nordenstam, Bridson formed the software company Exotic Matter and released a product based on this method called Naiad. This latest era of computational fluid dynamics technology can be observed in films like the blockbuster *Battleship* (2012), a project so large in scale it allowed ILM to completely re-engineer its simulation FX pipeline.

The new technologies being implemented for these films require custom work that goes all the way down to the fundamental science. A VFX studio or a software company will likely

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[179] Nick Foster and Ronald Fedkiw, ―Practical Animation of Liquids," in *Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '01 (New York: ACM, 2001), 23–30.

[180] Mike Seymour, ―The Science of Fluid Sims," *Fxguide*, September 15, 2011, https://www.fxguide.com/featured/the-science-of-fluid-sims/.

[181] Robert Bridson, *Fluid Simulation for Computer Graphics* (CRC Press, 2008).

have one of the scientists that did the fundamental research, or one of their students, working directly on a film project. For example Ron Fedkiw is credited as a ―fluid simulation engineering” on the flopped blockbuster *Poseidon* (2006), Robert Bridson is credited as ―research and development” on *The Hobbit* (2003), and Jerry Tessendorf is credited as ―principal graphic scientist” on *Superman Returns* (2006). All of these researchers were professors at research universities while they were doing this work. Often their academic presentations and papers about their research will contain illustrations from the films they worked on. I will discuss the use of animations in visual materials at SIGGRAPH in greater detail in the next section of this chapter.

Following the paths of these scientists between different industries and research disciplines from the 1990s through to the 2010s illustrates how this blockbuster R&D complex functions in even greater detail. Because there was no such thing as simulation FX at one point, the researchers who contributed to it in the first decade all came from other disciplines. This is an important place to see the technological overlap between the film industry and other industries. Most researchers came from computer science, but there are many notable exceptions. For examples researcher Jerry Tessendorf started out with a PhD in physics from Brown before moving on to work at Arete, which then changed from doing military research to doing VFX and animation research. Next he moved on to VFX studio Cinesite, then Rhythm and Hues where he was ―principal graphics scientist.” Another interesting example is John Anderson, who was a professor of atmospheric sciences at the University of Wisconsin-Madison before he became the head scientist behind fluid simulation FX at ILM in the late 1990s. Yet another research, Mark Stasiuk at Fusion CI, was working on the fluid dynamics of volcanic eruptions before getting into VFX and animation.

Tracing these research links also reveals how international such a seemingly domestic industry was as well. As I mentioned, Alias | Wavefront researcher Jos Stam's education was entirely outside of the United States. He continues to work for Autodesk on application for Maya while at the same time heading the Dynamic Graphics Project at the University of Toronto. The founders of software company Next Limit, Víctor González and Ignacio Vargas, were trained in aerospace and naval engineering at the University of Madrid. Their company developed the popular fluid simulation FX software Real Flow and an engineering oriented fluid dynamics simulator called Xflow. González now co-directs a Master's program at the University of Madrid.

Ken Museth, another important researcher in simulation FX, was also educated in a different discipline in another country before doing research for VFX and animation. Museth received a PhD in quantum physics in Denmark before continuing his study at Caltech. From there he moved to NASA's Jet Propulsion Laboratory (JPL), where he worked on "trajectory design." He moved from JPL to the VFX industry. Museth worked at prominent studios such as Digital Domain and Rhythm and Hues while simultaneously working as a professor at Linkoping University, Caltech and Aarhus University. During his period at Digital Domain he helped develop solutions for simulating fluid that would become their proprietary simulation software FSIM and STORM. He is currently head of R&D at Dreamworks Animation and also continues to do aerospace engineering work with Space X.

Holding a professorship while also working for studios is quite a common practice for fluid simulation scientists. This first generation of researchers that came from a variety of backgrounds are now advising graduate students who work specifically in simulation FX. Some of these early researchers have even established labs in computer science departments that help train graduate students to do simulation FX for media industries. Stanford and The University of Toronto's computer science departments are both good examples of this. This means that younger researchers in this field tend to come from some other disciplines like geology or quantum physics less often. This is not the end of interdisciplinary or inter-industry exchange however, but rather a sign of the maturity of the field.

Many of these computer science labs have one key industrial connection. For example, The University of Toronto's main industrial connection is to Autodesk. Stanford's key industrial connection is with ILM. A collection of simulation FX technologies developed at Stanford called PhysBAM makes up the core of ILM's simulation technology.[182] This program is headed up by Ron Fedkiw, the researcher who developed the *level set* method for simulation. He has worked extensively with ILM for over 14 years, receiving five screen credit and an Academy Award. PhysBAM is not solely the product of his work, but also the work of many of his graduate students.

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[182] "PhysBAM," accessed June 18, 2016, http://physbam.stanford.edu/.

Over their careers these researchers benefit from a variety of sources to fund their work. For example, Fedkiw's various research projects for were funded by The Office of Naval Research Young Investigator Program, a Packard fellowship, and an Alfred P. Sloane fellowship. Each of these funds carries with it a mission of promoting research in technology that will benefit national interests in some way. The Sloane fellowship, for example, tries to fill the gap between government and industrial research funding. It supports ―broad-based education related to science, technology, and economic performance; and to improve the quality of American life," and ―drive... the nation's health and prosperity."[183] Alfred P. Sloan started his foundation while he was still president and CEO of General Motors, a role where he made significant advances in scientific management. The Sloane foundation is clearly still motivated by a belief in the importance of R&D as a driver of national prosperity. The fact that this classic R&D complex institution now supports a simulation FX researcher who works with ILM is further evidence of the importance of the blockbuster R&D complex.

All of these researchers have been prolific at SIGGRAPH, producing research that has led to new software and in turn lead to new kinds of moving images. Many of these researchers also count an academy award for science and technology in addition to their many academic achievements. This award makes it clear that simulated fluids have had a substantial influence on the way movies are made. While their careers and the technologies they developed all show the indelible trace of the R&D complex in computer science, it is clear that media industries, led by the Hollywood blockbuster, have created a new set of imperatives that have transformed this field of research.

Clearly, animation technologies like the ones described here were not plucked from other industries or from the military-industrial complex and adapted for the film industry. There is ample evidence that the Hollywood film industry drives its own R&D. This history of fluid simulation for VFX and animation demonstrates the blockbuster R&D complex in the fullest sense. Just as Sen. William Fulbright and Vannevar Bush once observed that scientific research was being shaped by the substantial demand for military R&D, one can see a very similar transformation being wrought with the VFX and animation industries. These changes are only

[183] ―About Us," *The Alfred P. Sloan Foundation*, accessed August 4, 2016, https://sloan.org/about#mission.

intensified by a concerted shift in the 1990s away from federal R&D funding toward a system of tax credits that encourages private companies to fund their own R&D.[184]

SIGGRAPH Visual Proceedings

The archived visual communications of SIGGRAPH's annual conference offer further evidence of the increased involvement of the Hollywood film industry after 1980. That SIGGRAPH features a great deal of moving images is likely not that surprising, given that it is a conference on computer graphics. But one can see the creeping influence of Hollywood and other media industries in the aesthetics and content of these moving images. Indeed some scholars have criticized the conference for becoming too spectacle driven. Like Fulbright and Bush, these critics worry about the influence of the R&D complex. This time it is not the military but media industries that threaten science though.

Each year the SIGGRAPH archives have a section on paper proceedings that records the academic papers presented that year. But beginning in the 1980s new peripheral proceedings begin to proliferate in the archive, and many of these are focused on visual display rather than scientific data. There had been an ongoing interest in artistic uses of computer graphics since the beginning of SIGGRAPH, indeed SIGGRAPH played an important role in supporting the nascent field of computer art, but it was not until 1981 that a formal *Art Gallery* was organized and archived. The SIGGRAPH *Art Gallery* proved a success, with some of the first year's exhibits even touring other galleries in Washington, San Francisco, Dallas and Toronto.[185] A trend also developed in the 1980s where art shows were coordinated all over a city in order to coincide with a SIGGRAPH conference. For example in 1985, when SIGGRAPH was held in San Francisco, there were coordinated exhibits in the Moscone Centre, the Academy of Art College Gallery, the north Gallery at the Museum of Modern Art and two exhibits at the Palace of Fine Arts.[186] In 1989 SIGGRAPH published a journal issue in association with *Leonardo*, MIT Press's journal on science and technology in the arts. The issue featured figures such as

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[184] National Science Foundation, ―Chapter 4: U.S. and International Research and Development: Funds and Alliances: R&D Support in the United States."

[185] Patric D. Prince, ―A Brief History of SIGGRAPH Art Exhibitions: Brave New Worlds," *Leonardo. Supplemental Issue* 2 (1989): 3.

[186] Ibid, 4.

digital media theorist Gene Youngblood, philosopher and artist Timothy Binkley, and inventor of fractals Benoit Mandelbrot.

These cultural and artistic activities at SIGGRAPH can all be grouped into one of two discourses. This first discourse promotes high-minded theoretical work that explores the potentialities of new technologies, exemplified by the art gallery, especially in its early days. For example, in his book *Expanded Cinema*, Gene Youngblood highlights the possibilities new technology offered to expand cinema beyond its conventional borders into new expressive territories.[187] In his article in the *Leonardo* SIGGRAPH special issue, Youngblood writes that ―each new medium modifies and extends the linguistic possibilities of the moving image." He thought that the potentialities of digital tools had yet to be discovered.[188] By contrast, the second arts and culture discourse at SIGGRAPH shapes technological advance and creativity toward more conventional industrial goals. This second discourse extends from the involvement of established media industries like Hollywood. While this second discourse is still oriented toward developing new techniques, it tends to reify old definitions of media rather than trying to explode them as Youngblood does. While the first artistic discourse tended to be relatively compartmentalized, this second one became ubiquitous, influencing all sorts of aspects of the conference, in large part because it had the weight of a large industry behind it that supplied funds and research infrastructure for R&D.

The influence of Hollywood and the ascendancy of this second discourse became clear in 1992 with the formation of the first *Visual Proceedings*. This new formation encompassed the already extant *Art Gallery* and added a *Computer Animation Festival*.[189] The era of the *Visual Proceedings* sees the once separate enterprises of R&D and artistic experimentation begin to meld together, as it becomes more and more clear that the future of SIGGRAPH will be lead predominantly by media industries.

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[187] Gene Youngblood, Expanded Cinema (Dutton, 1970).

[188] Gene Youngblood, ―Cinema and the Code," in *SIGGRAPH 89 Art Show Catalog - Computer Art in Context*, SIGGRAPH '89 (New York: ACM, 1989), 27.

[189] The visual proceedings also usher in a new era of archive and access, as they are soon made available on CD ROM, then later DVD and eventually the internet. Open access websites can still be reached on the web going back to 1995.

The values of creativity, expression, imagination, innovation and, tacitly, spectacle became more important each successive year at SIGGRAPH starting in 1992. This is most explicit in the *Animation Festival.* While the *Art Gallery* is couched in the academic tradition of fine arts, the film festival is a far more hybridized affair. As curator Ines Hardtke writes in the introduction to the 1998 festival, they celebrate, “the technical, the artistic, the technically artistic, the artistically technical.”[190] Here one can find scientific visualizations, car commercials, demonstrations of new rendering or animation technologies, clips from Hollywood blockbusters, independent experimental animations, and a variety of examples that are somewhere in-between. As the introduction to the 2002 festival states, the jury looked for “exceptional accomplishment in technique, innovation, design, and/or aesthetics.” [191]

The *Animation Festival* blends together various types of commercial, artistic and scientific media just as it blends visual display with technological development. Indeed the technical paper presentations at SIGGRAPH begin to overlap with the *Animation Festival* content. The festival enshrines the important role that *demos* play at SIGGRAPH. Since even before SIGGRAPH, tech demos (technical demonstrations) have played an important role in solidifying the shape of technologies and projecting a path for the future. Douglas Engelbart's 1968 Mother of All Demos, which was mentioned earlier, is a classic example of this. Starting in 1992 at SIGGRAPH, the demo begins to change shape though. Gradually the idea of demonstrating the function of a new technology is succeeded by a new logic of visual display, a logic that resulted from the increased role of media industries, primarily the Hollywood blockbuster. The archives of the *Visual Proceedings* demonstrate this progression.

While traditional technical and scientific research presentations at SIGGRAPH have always included visual demonstrations, the *Animation Festival* sees their logic modified. Typically a demo shows off the specific function of something through a behind-the-scenes sort of view that is usually only partially rendered. By contrast, many demos in the *Animation Festival* show how a given technology can be used and the sorts of images that can be created

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[190] SIGGRAPH and Association for Computing Machinery, eds., *Electronic Art and Animation Catalog CD-ROM: SIGGRAPH* (New York, NY: Association for Computing Machinery, 1998).

[191] SIGGRAPH and Association for Computing Machinery, eds., *Electronic Art and Animation Catalog CD-ROM: SIGGRAPH* (New York, NY: Association for Computing Machinery, 2002).

with it. In other words, the clips in the festival are meant for more than just technical scrutiny and artisanal virtuosity, they are about what can be achieved through new technologies in terms of creativity, expression or storytelling. For example, the 2000 festival featured finished clips from films ranging from *Mission to Mars* (2000)*, Galaxy Quest* (2002), *Magnolia* (1999) and *The Perfect Storm,* which appeared just as they would in theatres.[192] In these clips a variety of technologies and techniques for compositing and animating are combined, along with live video plates, which include filmed performers, conventional production design and cinematography. No one technique is being made visible. For example, the clip from *Magnolia* features a sequence where frogs are falling from the sky. More than a display of technology, the clip simply functions to show this amazing image. These clips demonstrate a technical achievement but they also demonstrate what can be done, what is possible, the frontier of moving images. The clips seem to say, ―look what we can do now, isn't that amazing?" They demonstrate how the logic of the Hollywood blockbuster has influenced SIGGRAPH. The demo and the VFX spectacle seem to meet each other halfway. Hollywood films become more about technical displays and academic and industry demos become more polished and cinematic.

This logic of producing high-quality images to demonstrate the technology at work extends well beyond Hollywood VFX demos. Even the scientific visualizations featured in the festival are rich and visually arresting. The jury of the 2002 festival observed this trend. Noting with admiration how high the standard of production values had become, they write ―Scientific and medical visualizations require good science, great animation, and near broadcast-ready presentations."[193]They also note how many shots each clip contained. In years past one would expect a simple demo to contain only one long shot. Camera movement was more common than edits in most early examples, likely because it contributed to the novel sensation of virtual 3D space. By contrast, the 2002 demos are considerably more cinematic, utilizing the century-old cinematic technique of cutting and joining linear time and three-dimensional space. While the jury observes this as a sign of progress, one can see the progress of the influence of the film

[192] SIGGRAPH and Association for Computing Machinery, eds., *Electronic Art and Animation Catalog CD-ROM: SIGGRAPH* (New York, NY: Association for Computing Machinery, 2001), 2001.

[193] SIGGRAPH and Association for Computing Machinery, *Electronic Art and Animation Catalog CD-ROM*, 2002.

industry here. Whereas before these demos were more enamoured with the potential of digital virtuality, prominently featuring black backgrounds and three-dimensional wireframe grids, now they appear to be aping the aesthetics of film.

This logic also leads to demos that are hybrids of different genres, conflating what one might expect to be unrelated purposes. An interesting case of this is the early work of Chris Landreth at Alias | Wavefront. Although he is now well renowned for his NFB short film *Ryan* (2004), Landreth got his start as an animator producing scientific visualizations of fluid simulations. Landreth is a trained engineer who did research in fluid dynamics at the University of Illinois. When he moved to Alias | Wavefront he had the opportunity to make short demos as a function of testing and development. His demos were unique because they clearly betrayed an artistic aspiration. His first work to be featured at SIGGRAPH in 1995 *The End* is a sort of parody of self-reflexive modernist conventions, yet it was built for the purpose of testing a new facial animation technique. His next short *Bingo,* featured in the 1998 festival program, is a work of existentialist absurdity. Made during the development of the Maya animation suite, *Bingo* seems to demonstrate both the technical potential of the software as well as the expressive potential. Characters are naturalistically rendered with shadows and textures, yet they are also squashed and stretch in cartoonish ways. One character is made of human flesh stretched into the shape of a tree. Landreth has been quoted as saying that he values computer graphics for their ability to create this surreal combination of caricature and realism.[194] These early works by Landreth fit in-between what one would expect from a film festival review, an academic presentation and an industry trade show. While we might think of them as the singular works of a creative individual given too much autonomy, their hybrid nature suits exactly the paradigm created by the ever increasing influence of media industries at SIGGRAPH. This is the enfolding, integrating effect of the complex.

Some have argued that SIGGRAPH has become more about presenting the most spectacular images than about sharing substantial scientific research findings. In 2006, University of Utah alum named Michael Ashikhmin posed exactly this criticism. He had been an academic in computer graphics research for eight years, contributing to VFX projects at ILM

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[194] "Interview with Chris Landreth | 3D Artist - Animation, Models, Inspiration & Advice | 3DArtist Magazine," accessed June 26, 2016, http://www.3dartistonline.com/news/2013/11/interview-with-chris-landreth/.

such as *Poseidon* and *Iron Man* (2008). In 2006 he quit and published an open letter explaining his “Deep disgust for the state of affairs within computer graphics research.”[195] In order to understand why a criticism of SIGGRAPH leads one to quit their career entirely, one must understand how central this organization is to the discipline, both as a conference and as the source of peer-reviewed publications. Although localized alternatives such as EUROGRAPHICS have sprung up in recent years, SIGGRAPH has historically been the gatekeeper of computer graphics research. In this way the very shape of the technology of computer graphics is subject to the judgments of SIGGRAPH committees. As Ashikhmin writes, it is very difficult to find funding if you are not producing “SIGGRAPHable” work.

Ashikhmin's main complaint regards how “incremental” research is often rejected by selection committees, while papers on “hot” subjects that “oversell” what are potentially “trivial” advances take the forefront. He is not opposed to the use of visuals in presentations. Images are the products of their work, after all. But he argues that recent trends have seen flash valued over substance. For instance, he recounts a presentation at SIGGRAPH where the audience noted several problems with the images used, noting how they were inconsistent with the technical information presented. When pressed, the presenter admitted that he had used those images simply because “the images looked good to him.”

While it may seem from Ashikhmin's account that SIGGRAPH is somehow in decline, this is likely not the case. His complaints are in many ways a classic of the R&D complex. He is describing many of the same concerns Vannevar Bush did decades earlier. Science is supposed to be open to exploration and discovery. It should be open to “alternate viewpoints.” But R&D combines scientific research with some sort of orientation toward specific technological advance. Thus organizations like SIGGRAPH feel restricted because only certain paths of research are being supported. But since the very beginning of SIGGRAPH funding and research infrastructure has been set up with certain expectations. What Ashikhmin is observing is a change in direction as new sources of funding lay new expectations for research: from military to media industries. Perhaps it is true that the blockbuster R&D complex is marginally more restrictive than the military-industrial R&D complex was. But since the very first SIGGRAPH newsletter, scientific research and technological development have always been shaped toward

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[195] Michael Ashikhmin, “Leaving,” *University of Utah School of Computing*, 2006, http://www.cs.utah.edu/~michael/leaving.html.

certain directions. And since the 1980s they have been increasingly shaped toward visual novelty and spectacle.

Conclusion

Simulation FX took shape in a very particular set of historical circumstances in the period between 1980 and the 2010s. The abundant federal R&D funding that had been flowing since the Second World War began to taper off, while private investment, motivated in part by tax breaks, replaced it. SIGGRAPH, an entity that had always tried to promote the creative applications of computer graphics, developed a relationship with a large media industry with an economic desire for sustained technological advance, driven as it was by the logic of the blockbuster. A new R&D complex was born. The influence that this new industry had on SIGGRAPH is evident in a variety of cases, but what is perhaps most noteworthy is the way the SIGGRAPH demo became more like a Hollywood blockbuster while simultaneously the Hollywood blockbuster became more like a technology demo.

Simulation FX and the R&D complex offer an original account of this key period of change in Hollywood. Rather than seeing technological change as an external force, this approach reveals how technological change was in fact integral. Whole new types of businesses emerged in the space between SIGGRAPH and Hollywood, and important new research roles emerged in VFX and animation studios that unlike anything the industry had seen before. The following chapter will continue to examine the changes brought about by this blockbuster R&D complex and by the technologies it produced. Whereas this chapter mostly focused on the research side of things, the next chapter will examine changes in production practices. The principals of R&D will continue to be important in the following chapters, both in terms of how it brings together scientific research and industrial application, and in how it seeks to direct the unpredictable emergence of new discoveries toward specific ends.

Chapter 3: R&D and Simulation in VFX and Animation Production

In chapter one I established the concept of R&D as a merger of science and engineering that became a dominant institutional paradigm in the United States beginning in the Second World War. This context brought about the development of the discipline of computer science and the sub disciplines of computer graphics and computer simulation. These disciplines are paradigmatic products of the R&D complex, both because of the way they were developed in the nexus between industry and public research, and because of the way they combine the open-ended and exploratory nature of science with the ends-directed application of engineering. Computer science is labeled a science, yet instead of studying any aspect of nature, it studies a technology, and computer simulation opened up a new epistemic space in-between abstract theory and experimental testing. In chapter two I demonstrated how the logic of R&D is at work in the VFX and animation industries, and how an R&D complex has taken shape between Hollywood studios, VFX studios, and computer graphics research institutions. My primary example for this was SIGGRAPH, the Association of Computing Machinery (ACM)'s special interest group on graphics, where film and other industries connect with academic and governmental research institutions. I also argued that the logic of the Hollywood blockbuster's representational prowess and spectacle of technology drive this new complex. While chapter two focused mostly on the research side of this R&D complex, this chapter will focus on the production side. I will examine how the logic of R&D has shaped film production in general, and also how the use of simulation tools has shaped the production process in particular.

VFX and animation production have followed the paradigm of R&D in two key ways: through the management of image development and through the integration of technological development. Concerning the former, VFX and animation studios have developed organizational structures that exploit and control the uncertainty of creativity in much the same way R&D exploits and controls the uncertainty of science. Concerning the later, making images has in many ways become indistinguishable from developing technologies. More and more jobs in the production process have to do with making tools than making images, and nowhere is this phenomenon more obvious than in the case of Simulation FX, where the Simulation artist makes a tool that makes an image, rather than making an image directly.

This chapter will address each of these points in turn. First I will address the control of creativity and image development found in VFX and animation by looking at the nature of their organizational *workflows* and *pipelines.* The production pipeline will act as a bridge to begin looking at the role technology development plays in VFX and animation production respectively. Moving on to a more specific case, I will look at how simulation FX is a particularly good example of how technology development and image making have been merged together. Finally, in conclusion, I will consider how these findings fit in to existing scholarly work on the VFX and animation industries.

Workflows

The best way to understand creative control in contemporary VFX and animation is through the concepts of workflow and pipeline. In the common quotidian parlance of VFX and animation, workflow and pipeline refer to all of the work that needs to be done in order to achieve a final product. Although people in the industry often conflate workflow and pipeline, these two terms each have important distinct technical definitions. Workflow refers to labour management, and the different roles in the production process, while pipeline refers to the technical infrastructure of data exchange that makes workflow possible.

The Visual Effect Society handbook defines a workflow as ―a specific set of procedures and deliverables that defines a goal."[196] Workflow describes each stage of a production, all the jobs that need to be done in order to ship the final product. The concept of workflow has its origins in Fredrick Taylor's concept of scientific management. It is a technology of labour management for industry. The design of the first modern production lines, where different departments make different parts so that they can be assembled in other departments, is a workflow avant la lettre.[197] In this sense, the production style of the classic Hollywood studio

[196] Jeffrey A Okun, Susan Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects: Industry Standard VFX Practices and Procedures* (Amsterdam: Focal Press, 2010), 789.

[197] The term ―workflow" was used sporadically in the context of technical labour from the 1920s to 1940s, but its popularity surged significantly in the post-war period. https://books.google.com/ngrams/graph?content=workflow&case_insensitive=on&year_start=1920&year_end=2000&corpus=15&smoothing=3&share=&direct_url=t4%3B%2Cworkflow%3B%2Cc0%3B%2Cs0%3B%3Bworkflow%3B%2Cc0%3B%3BWorkflow%3B%2Cc0%3B%3BWORKFLOW%3B%2Cc0

can also be understood as a workflow. As many critics have observed over history, major film studios, such as those in the Hollywood film industry or the Weimar film industry, operate like factories.[198] David Bordwell, Janet Staiger and Kristin Thompson argue that scientific management is a key component for understanding the classic Hollywood studio system, even its aesthetics.[199] The key conceptual difference between the factory production line and an animation or VFX workflow is their respective relationships to change and contingency. Factory lines are regular, once set-up and fine-tuned they change very little. VFX and animation workflows are more project-based. Each new project requires the design and implementation of a new workflow, a new production line. VFX and animation workflows are thus equally indebted to the work of Taylor's contemporary in scientific management research, Henry Gantt, inventor of the still popular Gantt chart. In a Gantt chart a planner maps out multiple parallel jobs along a grid with a time-based axis. The planner carefully times each job in order to avoid slowing subsequent jobs that will rely upon its completion. In this sense the modern animation or VFX project is more like building a skyscraper or a bridge than turning out a uniform product in vast quantities. But this analogy really only begins to describe the relationship these workflows have to change.

This thesis has treated VFX and animation as virtually identical up to this point. Chapter 2 demonstrated that they are extremely similar from a technological development perspective, sharing many of the same tools and researchers. But in the case of workflows the two diverge. Indeed, Stephan Vladimir Bugaj, a technical director who works in visual effects for animated features, argues that workflow is the one and only place where one can make a clear distinction between contemporary VFX and animation.[200] The key difference is that the job of animation, at least in the case of the largest feature film-making digital animation studios like Pixar and

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[198] David Bordwell, Janet Staiger and Kristin Thompson take the factory analogy quite seriously. They find that studios are factory-like in their division of labour and standardization, yet they take some issue with the idea of studios having mass production. David Bordwell, Janet Staiger, and Kristin Thompson, *The Classical Hollywood Cinema: Film Style & Mode of Production to 1960* (Routledge, 1985), 92–95.

[199] Ibid., 128–38.

[200] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 739.

Dreamworks, includes developing story, look and sound completely, while VFX involves matching an already-established story and aesthetic. An animation job includes extensive writing and art direction, and while many large VFX jobs require many original designs, they are also subject to the direction of a film studio‘s above-the-line staff. VFX studios work as vendors who competitively bid against each other for a given film project, and they are bound by a contract that specifies what they will deliver to the film studio. The large digital animation studios, by contrast, keep most of this work integrated in-house. The animation industry constructs the job of animation on the whole as a creative task. VFX work, on the other hand, is constructed as “supporting the director‘s vision” and “getting his (sic) vision on screen.”[201] These two different approaches, of the singular and totalizing studio and of the precarious and temporary contractor, each have their own relationship to change and contingency. The animation and VFX workflows each in their own way seek to foster and direct uncertainty and emergence through flexible management approaches.

The earliest stages of pre-production are perhaps the point where VFX and animation are least similar. For an animation studio like Pixar or Dreamworks, the first stage of work is simply coming up with an idea for a film. Indeed these film project ideas are an important part of the studio mythos at Pixar. A teaser for the film *Wall-E* describes how Pete Docter, Andrew Stanton, John Lasseter and Joe Ranft, the original members of Pixar‘s so called creative “brain trust,” came up with the ideas for four original films in one energetic casual lunch: *Bug's Life* (1998), *Monsters Inc*. (2001), *Finding Nemo* (2003) and *Wall-E* (2008).[202] Of course, planning a film involves more than just a story idea scribbled on the back of a napkin. Raw ideas have to be refined and developed into workable scripts and a vision for art direction. Script writing and refinement takes place within the studio, and it is in many ways integrated with the other tasks of pre-production. As writers and directors develop a character, for example, they will work with character artists who will draw early thumbnail sketches. They may also do some early voice

[201] Charles L Finance and Susan Zwerman, *The Visual Effects Producer: Understanding the Art and Business of VFX* (Amsterdam: Elsevier/Focal Press, 2010), 37.

[202] Media Graveyard, *WALL-E (2008) - Teaser Trailer*, n.d., https://www.youtube.com/watch?v=cwphRMqrAx0.

recording work to help build the character.[203] Early story development and art direction come together in storyboarding. This process, which has been a staple in animation since long before Pixar's time, sees various directors, include the animation directors, art directors, sequence directors and cinematographers, working with storyboard artists to figure out both the narrative progression and mise-en-scene of the film. This is also the time when directors and supervisors will decide what technology needs to be researched and developed in order to accomplish certain shots.

With the basic outline of the characters and settings established, the work of visual designers, character designers, concept artists and sculptors can begin. These are the departments that further develop and refine the look of certain parts of the film. This sort of work can have wide-reaching effects, as characters can be carried over onto subsequent sequels and various ancillary forms of media and merchandise. Layout artists can also begin their work planning the 3D blocking and framing of shots once the storyboarding is done.[204] The storyboard is not the last time different departments are brought together to plan holistically though. This is an ongoing process. As layouts and designs evolve they will be inputted in to animatics, which are like real-time storyboards with sound.

Although, as I will demonstrate, VFX involves a great deal of creative work, it is not constructed as a creative job the way animation is. Though a given VFX studio can be charged with creating a variety of 3D models and animated sequences from the ground up, the film studio does much of the above-the-line creative work. On a given production, the film studio will employ an art director, production designer and costume designer, as well as dozens or even hundreds of art department staff, who develop the look of the film. By contrast, all of this pre-production design and planning work is done in-house in the animation industry. For this reason, a great deal of thought and planning goes into how to facilitate and manage creativity through the animation production workflow.

Given that much of this creative development happens on the film studio side in the case of VFX, the most important part of the VFX pre-production workflow has to do with film studio

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[203] Steven Withrow, *Secrets of Digital Animation: A Master Class in Innovative Tools and Techniques* (Mies: RotoVision, 2009), 80.

[204] Rick Parent, *Computer Animation: Algorithms and Techniques* (Burlington, MA: Morgan Kauffman, 2008), 16.

integration. On large projects a movie studio will likely employ its own VFX producer and VFX supervisor, and possibly some VFX production coordinators.[205] The studio-side VFX producer is basically a unit production manager who is concerned only with VFX.[206] In other words, the producer is mostly concerned with logistics, management and budget. Supervisors are by contrast the peers of art directors or cinematographers; they are distinctly executive, creative and above-the-line.[207] Indeed they sometimes work as second unit directors.[208] *The VFX Society Handbook* writes that VFX supervisors take ―artistic desire and turn it into a technical plan."[209] The studio-side VFX producer and supervisor will have their counterparts in the many contracted VFX studios. For the sake of clarity I will used the term studios-side and vendor-side to distinguish them.

The planning of the workflow starts with the process of contracting VFX companies. The studio-side producer will assemble a short list of VFX studios based on existing relationships, reputation, experience, and the VFX studio's show reel. [210] The show reel is a brief video clip that shows off the VFX studio's previous work, often by separating a finished film clip into its various composited elements. This is a process that one VFX producer's handbook likens to casting actors: certain vendors are suited to certain roles, and a studio-side VFX supervisor can judge their fit based on their past work.[211] Once the studio-side VFX producer has established a short-list, they will ask for competitive bids from the VFX vendors. Sometimes one large VFX studio will take the responsibility for all of the VFX, but in these cases they will often sub-contract certain specialized jobs. Contracts between studios and VFX vendors will specify

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[205] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 20; Charles L Finance and Susan Zwerman, *The Visual Effects Producer*, 37–47.

[206] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 39.

[207] Finance and Zwerman, *The Visual Effects Producer*, 2010, 38.

[208] Ibid., 39.

[209] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 789.

[210] Finance and Zwerman, *The Visual Effects Producer*, 2010, 99.

[211] Ibid.

budgets and also delivery *turnover* dates, the specific dates when the VFX vendor will turn over their work to the film studio. [212] Turnovers do not necessarily come at the end of a production. For example, the film studio may need a fully rendered sequence fairly early on for trailers and other promotional material.[213] These sequences may not be the same as the final product that is seen in theatres. Close analysis of trailers and features reveals how different they can be. For example, if one compares the first trailer for *Guardians of The Galaxy* (2014), a film co-produced by British visual effects studio Motion Picture Company (MPC), with the final version shown in theatres, one can see a great many differences.[214] Over the course of the production of a film there will need to be constant coordination between a film studio and a VFX studio.

Once the studio establishes a contract they will need to determine what a shot is supposed to look like and exactly what work and technology will be needed for each shot. *Pre-vis* or pre-visualization, a kind of digital storyboarding, is an important step in this process. Pre-vis entails making a sort of low-quality mock-up of a sequence, including camera position, camera movement, blocking, framing and so forth. It is a way for above-the-line workers, the director, cinematographer, art director, and VFX supervisor, to work through exactly what a sequence will look like. This is the first step towards figuring out what technically needs to be done in order to create a sequence. *The VES Handbook* describes pre-vis as ―the best way to collaboratively link the variety of departments, technologies, and points of view that have come together in a modern production to bring the sequence to life."[215] In this way it facilitates coordination between the VFX vendor and the film studio. Pre-vis is akin to storyboarding, but while storyboarding establishes the fundamental look and story of a film, pre-vis is more practically oriented and detailed. Story boarding is also a very fundamental in-house practice, but by contrast VFX studios will sometimes subcontract pre-vis work to pre-vis specialists. This clearly demonstrates the different roles these seemingly similar practices have.

[212] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 22.

[213] Finance and Zwerman, *The Visual Effects Producer*, 2010, 46.

[214] Keen-eyed fans that made side-by-side comparisons noticed this difference. corporalcadet, ―Guardians of the Galaxy - CG and Colour Updates. Interesting Watching Shots Develop throughout Trailers These Days.," *Reddit*, accessed December 22, 2016, http://i.imgur.com/RxhqvUF.jpg.

[215] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 53.

Once the studio and VFX vendor establish what they need for each shot, the VFX vendor can begin building the organizational infrastructure they will need for the job. While much of the in-house hardware infrastructure, such as office space, workstations and server farms, will likely be the same from project to project, the studio will need to arrange a great many things before a project can start. For starters, they may sub-contract certain jobs to other VFX studios. At the very least the studio will need to hire workers on a project-specific six-month contract. The number of workers generally follows a bell curve, with few workers staying on from the very beginning to the very end.[216] As one VFX producer's manual writes, a VFX unit “may spring into life almost any time during production or post production. Its life may be as short as a mayfly... or it may last several months.”[217] VFX studios and their workflows are profoundly flexible and re-programmable.

Many of the core activities of production are actually quite similar between VFX and animation. Both involve the very fundamental work of building digital elements or assets.[218] Assets are basically digital content: characters, backgrounds and objects. 3D modellers will take the work of concept artists, either from within the studio in the case of animation, or from the film studio, in the case of some VFX, and make a 3D digital version. A model is simply a shape, of course, so the next step is to add textures and skins to the model. Once the shape of the model is finished, it then must be *rigged* with virtual joints and linkages. Animators can supplement rigging with different automatic and simulated function to make animating a character easier and more naturalistic. Joints might have limited ranges of motion, and even the movement of muscles and the stretch of skin can be simulated based on the articulation of joints.[219] There may also be call for character effects or CFX such hair or cloth simulations that are attached to a character

[216] Renee Dunlop, *Production Pipeline Fundamentals for Film and Game*, 2014, 14.

[217] Finance and Zwerman, *The Visual Effects Producer*, 2010, 215.

[218] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 591.

[219] Ibid., 619.

model and their movement.[220] The pipeline will input these digital assets into various different scenes, allowing many people to use the same characters and objects simultaneously.

The major distinction to be made between VFX and animation in terms of assets is that VFX contains not just in-house digital assets but also assets from the film studio and other VFX studios. Although sometimes sequences are entirely animated, the vast majority of VFX shots contain at least some content shot on a set or location by the film studio. This is another kind of content that the VFX workflow needs to manage. The studio-side VFX producer and the vendor-side VFX producer have to plan the gathering of content from shoots that will be vital for composting VFX elements with the film. Contrary to what one might expect, there are often several VFX workers on site during film shoots. These workers include the Data Coordinator, the Data Collector, and the vendor-side VFX supervisors. The Data Coordinator and Data Collector's purview includes all of the information that will make compositing animation with film as seamless and easy as possible.[221]

The main type of content the VFX studio traditionally needs from the film studio is the *plates*. Plates are the video files from the film shoots. Plates will contain some information that needs to be kept, for example an actress‘s performance, and some that needs to be removed and replaced by a composited effect, for example wires from a special effects sequence. Although plates are the traditional standard of content produced by studios, other forms of data collection are slowly eroding their importance. Likely the most well known kind of non-photographic information commonly gathered during shoots in motion-capture, but there is a variety of data that is often collected on sets and locations. Data coordinators keep a data sheet that records lens types, frame counts, file format info, and pictures of sets and locations. [222] High dynamic range imaging (HDRI) devices record ambient light conditions so that they can be virtually reproduced. Light detection and ranging (LIDAR) volumetric scanners can automatically produce 3D models of buildings and objects. There is even a form of LIDAR specifically for scanning performers

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[220] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 60; Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 606.

[221] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 21.

[222] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 10.

called Cyberscan.[223] A production photo of any contemporary Hollywood blockbuster will reveal just how prolific these forms of data collection have become. It is not uncommon to see a performer in a green leotard covered in motion capture tracking points, holding a green madrill (stand-in object) in front of a green screen set.

Whether it is an animation job consisting of in-house assets or a VFX job consisting of a variety of assets from different sources, an important part of production workflow control has to do with controlling the look of the content being produced. Above-the-line workers do not simply set a plan and then hand it off to be completed, they keep control throughout the process of development. This mechanism is referred to as *look-dev*, or look development. The core mechanism of look-dev consists of teams sending preview versions of their work to above-the-line decision makers to get feedback and direction.

Look-dev is at once more simple and more complex in VFX than it is in animation. It is simpler because some of the look of a VFX job is set in stone by the plates the studio has supplied. The VFX studio cannot re-invent the way a scene is lit, for example. On the other hand the contract-based nature of VFX adds a great deal of complexity. Clients must be able to communicate direction to vendors. This can introduce some latency into the directing process that can lead to revisions and wasted work. Animation is of course the inverse of this. Because animation studios keep most work in-house, the control of look-dev is immediate and integrated.[224] Because animation is so representationally open-ended though, the volume of creative decision-making can be much greater.

In sum, animation and VFX workflows are clearly different in some important ways. VFX is a more flexible, re-programmable form of production that is bound to the directives of the contracting film studio. Animation, on the other hand, is a more open-ended process, yet one that is contained within a singular cohesive entity. Each manages creative work in their own way.

Given that studios like Disney and Pixar are singular units that keep the majority of their work in-house, one might expect that they would not be terribly flexible or apt to change. They sound quite similar to the classic Hollywood studio formula: a conveyor belt, a production line

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[223] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 46.

[224] Ibid., 740.

for culture. Because relatively little work is contracted on an animated feature project, they are less re-programmable than a VFX production. They also tend to employ workers on a more permanent basis, keeping the same workers for several projects.[225] But other kinds of re-programmability and change are built-in to the ethos of large animation studios. If one looks at the differences and similarities between Pixar‘s management philosophies and the approaches found in VFX, the nature of flexibility in animation workflows becomes quite clear.

VFX studios exist in a field of uncertainty due to the nature of contracts, yet the industry on the whole is more stable than it looks. Even if some studios collapse and others emerge, VFX jobs are always being completed and someone is making money. The industry itself is a relatively stable container. An animation studio like Pixar endeavours to make itself such a container for change. Instead of existing in a field of profound change, they contain and regulate the field itself. The structure of management at Pixar is designed to facilitate total instability and flexibility within a larger container. While this may sound like a very abstract description, the influential management philosophy of Pixar co-founder and former CEO Ed Catmull makes it more concrete. Catmull‘s philosophy can be summarized as follows: don‘t try to avoid the unexpected, don‘t even try to avoid failure, manage your business so that failure isn‘t fatal, because risk-taking and experimentation are what keeps a business at the forefront. In the *Harvard Business Review*, he writes ―we as executives have to resist our natural tendency to avoid or minimize risks.” Continual change and reinvention must be the norm and executives must structure their companies to facilitate it.[226] Catmull argues that this is what differentiates the new animation industry versus the traditional film industry, which is so risk averse it languishes.[227] In essence this is the same principal that drives change in the VFX industry: innovate or die.

Technological change is of course a part of this philosophy. New tools emerge; they obviate some jobs and create new jobs and new opportunities. The goal of studios like Pixar is to

[225] Ibid., 741.

[226] Ed Catmull, ―How Pixar Fosters Collective Creativity," *Harvard Business Review*, September 1, 2008, https://hbr.org/2008/09/how-pixar-fosters-collective-creativity.

[227] The classic example of Hollywood‘s risk aversion is of course the sequel. These comments that Catmull made in 2008 are rather ironic now, since at the time of writing Pixar seem to have made an intentional shift toward producing sequels.

drive that change, to make it an integral force, rather than to have to constantly respond to change as an external force.

These approaches to uncertainty and technological development are both classics of the logic of R&D and of the management paradigm of post-cybernetic resilience and ecology I touched on in chapter 1, where researchers began to see systems as constantly changing rather than self-correcting. Of course it is no small co-incidence that Catmull himself was once a computer science researcher who was funded by ARPA. By his own account, Catmull was entirely happy working with federal military R&D funding. He appreciated that the government did not ―hover over (his) shoulder" or ensure that his research actually had a military application.[228] The hands-off approach of Cold War R&D funding afforded him the creativity he needed.[229] This model of military-academic R&D funding informs many of the managerial values Catmull promotes to this day.

This approach to creative management is a prime example of what is historically unique about VFX and animation‗s approach to filmmaking. The VFX and animation studios do not see themselves as moving-image factories, instead they are developers, and they harness creativity in much the same way R&D harness science. The uncertain and exploratory process of science is simply replaced with the equally unpredictable creative process. They treat filmmaking as the same process as developing technology. This is evident in the language used to describe these production practices, like look development. As one handbook on *Production Pipeline Essentials* says, ―the main difference between factory goods and art is that art goes through a review and refining process."[230] Making moving images is a *process* that uses an integrated, flexible form of management to make use of uncertainty.

This management approach that privileges flexibility and process has its own history. Management thought has gone through several different periods since Taylor and Gantt, and these developments have influenced the intricate and flexible organization of VFX and animation workflows. The most significant of these was the development of management science as a

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[228] CACM Staff, ―A Conversation with Ed Catmull," *Communications of the ACM* 53, no. 12 (December 1, 2010): 42.

[229] Edwin E Catmull and Amy Wallace, *Creativity, Inc.: Overcoming the Unseen Forces That Stand in the Way of True Inspiration*, 2014, 16–17.

[230] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 3.

scholarly discipline. Although it is a seemingly minor name change, management science is distinct from scientific management in many important ways. While it is true that Taylor and his contemporaries conducted research, they did not seek to understand the nature of organization and systems themselves. This is precisely what management science does though: it uncovers fundamental principles of systems in order that they can be applied as organizational techniques. As historian of management thought Morgen Witzel writes, ―Scientific management was about exploring new methods; management science was and still is engaged in the quest for systems."[231] This implies a different way of seeing the world, a different epistemology, an epistemology that is by no small coincidence entwined with computer science and nonlinear simulation.

This new development has its roots in the Second World War and the R&D complex. The war spurred a renewed interest in logistics, and following the R&D paradigm, this lead to increased institutional support for research into the nature of organisation and systems. The British military made the first major contribution with development of operations research, which the Americans took and developed further.[232] As the Americans supported reconstruction to bolster their Cold War allies, they also spread this new paradigm of management. A key facilitator of this knowledge sharing was the RAND Corporation. [233]

University departments and journals such as *Administrative Science Quarterly* and *Management Science* began to study systems as a sort of universal phenomenon, something that could be seen in nature as well as in corporations, administrative districts or militaries. The study of management began to look more like a natural science.[234] This new science was predicated on concepts like Claude E. Shannon‘s Information Theory and Norbert Weiner's Cybernetics. For example, one key early text of management science was Stanford Beer‘s *Cybernetics and*

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[231] Morgen Witzel, *A History of Management Thought* (New York: Routledge, 2011), 180.

[232] Ibid., 177.

[233] Ibid., 179.

[234] Matthias Kipping and Behlul Usdiken, ―Buisness History and Management Studies," in *The Oxford Handbook of Business History*, ed. Geoffrey Jones and Jonathan Zeitlin (Oxford: Oxford University Press, 2008), 100.

Management.[235] Management science quickly became associated with emerging ideas about ecology, dynamic systems and resilience though. While cybernetics saw systems as homeostatic, this new approach saw systems as constantly changing. A key text in management science that addressed both the concept of nonlinear dynamics and of simulation was MIT Sloane School of Management professor Jay Wright Forrester‘s *Industrial Dynamics*.[236]

As management science developed over time, nonlinear dynamics and simulation continued to play an important role. The contemporary discipline of information systems and its application of business process management (BPM), which makes extensive use of computer modeling, is the result of these ideas.[237] The combination of computational tools and an epistemology of dynamic nonlinear systems have led to forms of management that are more flexible and responsive, more at home with uncertainty and contingency. If Taylor was focused on increasing output on a regulated, standardized, repetitive, linear production line, these newer techniques are more focused on processes with uncertain outcomes, on flexible, responsive forms of management, and on leveraging management technologies for more intricately integrated systems.

While there is little trade or scholarly information available on VFX and animation studio‘s involvement with BPM and management science research, there is ample evidence that these concepts are at work in the management of their workflows. Without actually intending to, VFX studios have made an important contribution to the scholarly field of information systems research. For instance, German researcher Stefan Seidel‘s influential Theory of Managing Creativity-Intensive Processes (TMCP), which is an analytical device for BPM, is based on his study of VFX production workflows.[238] Seidel finds in his research is that VFX studios have developed an approach that is process-oriented, or ―process-aware,” rather than ends-oriented.

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[235] Beer‘s research was sponsored by United Steel. Stafford Beer, *Cybernetics and Management* (London: English Universities Press, 1987).

[236] Witzel, *A History of Management Thought*, 181; Jay W Forrester, *Industrial Dynamics.* (Cambridge, MA: MIT Press, 2013).

[237] Witzel, *A History of Management Thought*, 181.

[238] Stefan Seidel et al., ―Creativity-Aware Business Process Management: What We Can Learn from Film and Visual Effects Production,” in *Handbook on Business Process Management 2*, ed. Jan vom Brocke and Michael Rosemann (Berlin: Springer, 2015), 715–39.

He writes, ―The recognition of the importance of a process-oriented view as opposed to an outcome-oriented perspective is comparable to the emergence of total quality management (TQM), which proposed to focus on the process quality as the ultimate cause for the end product‘s quality.” [239] Clearly the end product is the key outcome of a VFX, but the way a studio brings about that outcome is not through direct intervention. Creativity cannot be forced. Instead VFX companies set-up the conditions for ideas to emerge and to be refined. This entails setting up a system that can deal with ―high levels of uncertainty.”[240]

Although Seidel‘s work is specifically on VFX, one cannot help but notice that his ideas are extremely similar to those of Ed Catmull. As I already noted, Catmull‘s approach to animation management embraces uncertainty. He writes that executives ―have to resist (their) natural tendency to avoid risk.”[241] He is also explicitly a process-oriented thinker. As he writes in the *Harvard Business Review*,

> People tend to think of creativity as a mysterious solo act, and they typically reduce products to a single idea: This is a movie about toys, or dinosaurs, or love, they‘ll say. However, in filmmaking and many other kinds of complex product development, creativity involves a large number of people from different disciplines working effectively together to solve a great many problems. The initial idea for the movie—what people in the movie business call ―the high concept”—is merely one step in a long, arduous process that takes four to five years.[242]

Catmull‘s approach to this process is to empower every worker with the ability to have input on the project. He writes, ―It must be safe to tell the truth. We must constantly challenge all of our assumptions and search for the flaws that could destroy our culture.”[243] This is a concept Catmull first formed when working at ILM. He observed that unlike Disney, ILM showed their dailies to

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[239] Stefan Seidel, ―Toward a Theory of Managing Creativity-Intensive Processes: A Creative Industries Study,” *Information Systems and E-Business Management* 9, no. 4 (December 1, 2011): 408.

[240] Ibid., 407.

[241] Catmull, ―How Pixar Fosters Collective Creativity.”

[242] Ibid.

[243] Ibid.

the whole crew and not just the above-the-line workers.[244] This is also exactly what Seidel observes in VFX. Seidel likens this approach to total quality management (TQM), and indeed, Catmull explicitly cites this as an influence. He is a self-proclaimed early adopter of TQM, after first reading about Japanese car manufacturing management techniques.[245] TQM started as a manufacturing management paradigm where every employee is expected stop the production line if they find a quality problem. This was in stark contrast to the American convention at the time, where stopping the line was verboten due to the costs entailed.

VFX and animation workflows are therefore couched in the history of the R&D complex. They approach the management of creativity much in the same way R&D approaches science: as a productive form of uncertainty that can be utilized if managed with flexibility. This flexibly takes different shapes in VFX and animation respectively. In VFX it takes the shape of the contract system, and of the profound re-programmability of the studio‘s labour and workflow. In the case of animation, it takes the shape of different management philosophies and approaches to workflow. This philosophy of management is reflexive. The study of how to manage uncertainty with flexibility is itself a subject of study within the R&D complex. Indeed this reflexivity extends into contemporary animation and VFX; Pixar has its own ―management development" department.[246]

Approaching VFX and animation from the perspective of workflows and the influence of the R&D complex offers a new angle from which to view recent studies of labour in these industries. VFX and animation seem to be the leading edge of labour changes in the Hollywood film industry. Some key issues have been the displacement of risk from employers to employees, the increased flexibility, and indeed precarity, of work, the decline of the once robust role of labour unions and the offshoring of labour to tax friendly locations. In other words, the industry seems to have turned toward a general race to the bottom, that decreases the labour costs of film production. As John Caldwell and others have noted, the expanded role of VFX and general

[244] Ibid.

[245] Catmull and Wallace, *Creativity, Inc.*, 50.

[246] Ibid., 126.

post-production has destabilized many tradition production labour roles.[247] This plays into parallel industry developments. For one, it has led to a strong shift away from the once dominant studio paradigm, to a system where work is contracted out to vendors that competitively bid on contracts and subcontracts.[248] This in turn is connected to what Toby Miller refers to as the “new international division of cultural labour” (NICL), where international cities like Vancouver, Toronto and London compete with ever-increasing tax incentives to lure studios.[249] As Michael Curtin and John Vanderhoef write, many simple VFX tasks like wire removal can be done by “a couple guys in a garage in Van Nuys or a small shop in Chennai.” [250]

There are of course many connections to be made between the organization of the VFX and animation industries and broad political changes, such as the rise of neoliberalism in the late 1970s and 1980s, and the turn in policy making toward seeing culture as a form of information exchange.[251] One could also make connections to broad theories of power that apply to this era, such as Gilles Deleuze‘s *Postscript on the Societies of Control* (a connection Caldwell makes) or the work of Marxist autonomists like Paolo Virno, Michael Hardt and Antonio Negri.[252] The decentralized, self-organized nature of these emerging industries, which, as Caldwell‘s work finds, see subjectivity play a particularly important part in managing workers, seems a perfect fit. The increased autonomy given to creative workers that scholars like David Hesmondhalgh note, can also be understood in the context of the self-management of such regimes of power.[253]

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[247] John T. Caldwell, “Stress Aesthetics and Deprivation Payroll Systems,” in *Behind the Screen*, ed. Petr Szczepanik and Patrick Vonderau (Palgrave Macmillan US, 2013), 95.

[248] Michael Curtin and John Vanderhoef, “A Vanishing Piece of the Pi,” *Television & New Media* 16, no. 3 (February 20, 2014): 7.

[249] Toby Miller, *Global Hollywood* (London: BFI, 2005), 52.

[250] Curtin and Vanderhoef, “A Vanishing Piece of the Pi,” 11.

[251] David Hesmondhalgh, *The Cultural Industries* (SAGE, 2007), 112.

[252] Gilles Deleuze, “Postscript on the Societies of Control,” *October* 59 (1992): 3–7; Paolo Virno, *A Grammar of the Multitude: For an Analysis of Contemporary Forms of Life* (MIT Press, 2004); Michael Hardt and Antonio Negri, *Empire* (Cambridge, Mass: Harvard University Press, 2000).

[253] Hesmondhalgh, *The Cultural Industries*, 67.

My intention is not to contend with these understandings of power or policy, but to offer a different, supplemental, perspective on the forms of management at work here. A focus on the R&D complex and nonlinear simulation reveals an important epistemological history that is connected to technological developments. The parallel examples of VFX and animation workflows also show that there is some nuance in the way different approaches to labour have developed. In some ways Pixar‘s approach to management does not conform to broad shifts in the film industry. They are a big studio with many full-time employees. But as I have shown, if we approach Pixar‘s organization through the R&D complex and nonlinear simulation, we can observe how their approach to management is a different version of the same ideas. Understanding discourses of management is only half of the story though. In order to see the other half, we must turn our attention to the technology that makes these forms of organization possible.

Pipelines

Pipelines are mutable, they change with every project, and building a pipeline is a major task on any large project.[254] The structure and organization of workflow would be impossible on its own without a technical infrastructure. This is where the production pipeline comes in. To borrow the phraseology of Bruno Latour, pipelines are workflows *made durable*. The VFX and animation pipeline are the reprogrammable infrastructure that allows workflows to be flexible, and allows collaboration between different departments and workers though the exchange of assets while also facilitating creative control. In the case of animation, the control is within the studio, while in the case of VFX much of the control is from the film studio.

A pipeline facilitates the exchange of data by connecting the outputs from jobs to the inputs on other jobs. In other words, it allows workers to share assets between different departments. Once again, the industrial production line is a useful metaphor here: at its simplest, the pipeline is like the conveyor belt, moving the product from one department to another, and spitting out a finished product at the end. However the production pipeline is far from simple or linear. Instead it is like a conveyor belt that has innumerable convergences and bifurcations that

[254] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 807.

engineers can divert and reprogram.[255] Every project has specific challenges that require a specific combination of software, plug-ins and workers, and the pipeline facilitates the integrations of these parts.

An important part of pre-production is figuring out what software is needed to make a given sequence. This can entail developing new software from the ground up, as I showed in chapter 2, or, more commonly, it entails choosing the right off-the-shelf software for the job. Once the software is chosen, it falls on the technical directors (TDs) and software engineers to connect them to the pipeline and do any necessary customization. Sometimes software companies design their products to work with other programs. For example there are innumerable programs that are designed to work with Autodesk's Maya, because Maya is the central hub of most 3D animation work. Sometimes, though, a job will necessitate bringing together pieces of software that were not designed to be connected. In these cases TDs and engineers may need to transcode file formats and protocols and deal with all of the subtle problems that arise from using custom scripts and programs. The construction of this connective infrastructure of the pipeline is mostly the work of TDs. These are workers with extensive coding experience in different programming and scripting languages. Sometimes TDs are people who have worked in the industry long enough to intimately understand the inner workings of popular software, but they can also be people with strong general computer science backgrounds.

When one considers the complex and interweaving workflows described in the workflow section, one can begin to imagine how difficult it is to build this connective infrastructure. One job may require inputs or assets from multiple other jobs, and the output of their work in turn may go out to multiple other workers. And any single job will have several artists working on it simultaneously.[256] The metaphor I used at the bringing of this chapter, of making an animation as building a bridge or a skyscraper, seems particularly apt here. As an animation pipeline manual puts it, “it is not uncommon for a single creature in a VFX movie to comprise hundreds, if not thousands, of individual assets that must be assembled to generate a working render.”[257] One can

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[255] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 14.

[256] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 807.

[257] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 5.

almost imagine scores of workers assembling a life-sized model of King Kong or a tyrannosaurus with cranes and scaffolds. But what happens when, for example, multiple parties can access or modify an asset like a character model? It sounds like a recipe for constant conflict. These challenges are dealt with through the careful design of a production pipeline.

The first most important technology for organizing the inputs and outputs of different jobs is digital-asset-management (DAM) software. DAM software keeps track of versions and editing permissions. But this is only the begging of pipeline design and control. The need for simultaneous work is handled through several clever techniques. The first is the use of *placeholder assets*.[258] These stripped-down abstractions allow artists to work on advanced levels of production while necessary components of the sequence are not yet completed. The next level above placeholder assets is low level-of-detail (LOD) assets.[259] These are partially completed elements that artists may not have fully rendered or animated yet. For example, character animators can input early working versions of character effects, such as hair simulations with a fraction of the detail, into their work, giving them some idea of how the hair will move. This asynchronous approach to production has become so advanced that it enables some forms of *virtual production* in the case of VFX.[260] Here a monitor with an early visualization is used on-set to help studio workers plan and record their shots. A notable and novel version of this technology is the Simulcam, which is a motion-captured virtual camera with a composited low LOD preview in its viewfinder LCD screen. This allows a cameraperson to shoot a motion capture scene while watching a preview of what the effects will look like. The camera‘s movement is then recorded as motion-capture data itself, which can be used to animate a virtual camera.[261] Production pipeline planning has become so sophisticated that even the studio shoots are integrated into a VFX production.

The complexity brought on by the need for many people to work with the same content simultaneously is even further complicated by the iterative approach to look-dev and process

[258] Ibid., 3.

[259] Ibid., 11.

[260] Ibid., 305.

[261] ―Simulcam," *Animatrik*, accessed December 22, 2016, http://animatrik.com/services/solidtrack-simulcam/.

management, which sees creation as a process of refinement. It is easy to imagine how late changes happen on VFX projects. The above-the-line studio workers likely have a clear visions of what they want, but often they may not be technically versed, or able communicate that vision into VFX language. The studio-side VFX producer and studio-side VFX supervisor are supposed to minimize such problems, but VFX studios can still be faced with many ―that's not right, do it again" type demands. Animation production has similar issues. This is especially true of Pixar, which cultivates an un-compromising approach to creative development. The most noteworthy example of this is *Toy Story 2* (1999). Due to the challenges of running multiple productions at once, *Toy Story 2* reached a high level of completion before key decision maker John Lasseter had scrutinized it.[262] When he finally did, he decided it needed it needed extensive re-working at the most basic level. Pixar's approach to creative management warranted such a costly and seemingly impossible teardown and re-build.

Such events are rare, of course. But smaller versions are constantly happening in VFX and animation. Imagine assembling an intricate sequence filled with hundreds of layered elements and having a director ask for one basic element to be changed. Late revisions are an inevitable issue.[263] Pipeline design has to be so flexible it can accommodate this approach to workflow. The integration of different elements is so flexible that artists in one department can go back and change a single element without it adversely affecting all of the cascading subsequent work that relies on it.

Some of the challenges that workflow and pipeline planning and design deal with are not new to film production. It seems obvious that studio film productions throughout history must have employed some kind of workflow planning. A review of major industry journals over the past 100 years reveals little evidence of theorization of this management. A search of Mediahistoryproject.org's ―Lantern" returns relatively few hits from the major trade journals, mostly in the 1950s and 60s and mostly in reference to things other than production. Yet is seems clear that any large film studio would require careful management. Clearly, some jobs relied on the completion of other jobs, and strict deadlines and shooting schedules no doubt demanded organizational efficiency. Shooting a film is an extreme logistical challenge, and the efficiency

[262] Catmull and Wallace, *Creativity, Inc.*, 69.

[263] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 5.

of the studio system, with its shared equipment, labour and assets, is an organizational marvel in its own right.

The studio production system and the VFX and animation workflow and pipeline represent two different approaches to management though. While the studio was a static production line that used the same resourced and salaried skilled staff for every film, the VFX and animation industries are reprogrammable and project based.[264] Key to VFX and animation's flexibility is both their approach to management and their approach to technological development. Being able to re-program the pipeline for every different project allows for flexible workflows.

VFX and animation pipelines demonstrate how fundamental technological development is to production in VFX and animation. Building pipeline technology is an indispensable part of any production, and this is yet again a way this form of production is different from the studio precedent and factory production line model. VFX and animation studios re-fit the factory for every job, even during the job. It is true that some things stay the same, there are full-time staffs, there are permanent buildings, workstations, networks, servers etc., this is the stuff of first-order infrastructure, or superstructure. But the pipeline and workflow are the systems that produce the film. The building of pipelines is not the only way technology development has taken over image making though. As the following section on simulation FX production demonstrates, the distinction between making images and making technologies may have disappeared completely in this case.

Simulation FX

Simulation FX is a special sort of animation, which both the VFX and animation industries compartmentalized own its own. If you look at a flow chart of VFX or animation workflows, simulation FX have their own branch.[265] As I note in the introduction, simulation FX

[264] Although I noted above that large animation studios resemble the old Hollywood studio in some ways, their integrated approach to creative control and embrace of contingency set them apart from the old studio model.

[265] For example, in a flowchart of the VFX pipeline drawn by Double Negative VFX supervisor Andrew Whitehurst you can see ―effects animation" (which is one of many names for what I call ―simulation FX") in a box next to lighting and rendering. ―Andrew Whitehurst . Net," accessed July 28, 2017, http://www.andrew-whitehurst.net/pipeline.html.

are the special effects of these already special forms of image making. Although the implementation of simulation FX into workflows is different in animation and VFX, the actual work of making simulated images is very similar between the two. A closer look at this process reveals how creative control is exercised in these industries, both on the level of managing creative workers and on the level of managing simulated nonlinear contingency. In sum, a study of simulation FX production shows how a director gets splashes of water or a character's simulated hair to look exactly the way he or she wants. Studying this subject reveals how the paradigms at work in the simulated nonlinear complexity of simulation tools are connected to the management principals I have been describing in this chapter. It also demonstrates how technological development has become inseparable from making moving images. In both of these cases we can see the influence of R&D on film production.

As I noted in the introduction to this thesis, people in the industry often refer to simulation FX as technical animation.[266] This term is extremely revealing: simulation FX is still animation, but animation as a technical process. Animation and VFX studios do not make simulated animations; they make algorithms that make animations. Getting a certain phenomenon to look a certain way, the gathering of a character's clothing for example, or the splash of a turbulent sea, can require writing new code, developing new plug-ins, or even writing new simulation software. This is a perfect example of the logic of R&D. Not only does it merge technology development with filmmaking, it also leverages and manages uncertainty. Indeed Simulation FX takes the management of uncertainty to a whole other level. As I covered in chapter 1, simulation scientists base simulation FX software on the same technologies that are used in engineering, climate science and economics. These different forms of nonlinear simulation seek to understand complex forms of contingency in the world. Uncertainty is built into the software itself. As I noted in chapter 2, fostering improved directability of simulations through improved interactivity in simulation software has been a major development goal. Simulation FX both uses uncertainty as a valuable resource but also they also seek to manage it.

But how exactly does one control a splash of water? How do you control something that looks realistic because it is complex and unpredictable? There are two answers to this question: one, through selecting or building a specific combination of software programs, and two, through

[266] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 58.

a management system that puts the director in control of the development process and that allows constant, specific revisions, in other words, through pipelines and workflows.

As an example, let us imagine a case where a film studio contracts a VFX studio to animate a stormy ocean. A film studio might choose to animate water because it will make shooting easier, or because it will extend the range of possible shots. Controlling the look of a simulation effect starts in the very earliest planning stages. The studio-side VFX producer and supervisor will work with the director to determine what exactly they need. As I covered in the workflow section, they will then invite certain VFX studios to bid on a contract based on their past work and reputation in a process not unlike casting performers. So, for a series of shots with a turbulent ocean, a VFX supervisor might seek out ILM based on their well-respected proprietary fluid simulation software and their work on films like *Battleship* (2012). The casting of a certain VFX studio will shape the kind of effect the film will have. The VFX studio will then work through what‘s called a *breakdown* of the relevant shots, and try to approximate what kind of work and technology will be required, and then they will bid based on a price-per shot structure.

Going any further into this process will require me to describe a few new positions in the simulation FX production workflow. A team tasked with animating a specific effect, like the splashes of a turbulent ocean, will consist of an FX lead, senior simulation artist, and junior simulation artist as well as TDs who specialize in simulation software[267]. The junior-senior-lead hierarchy reflects both technical ability as well as creative authority. The FX lead is the contract point with higher-up decision makers such as sequence directors or art directors. Some labour division can be very blurry though. Sometimes a senior simulation artist will be credited as a TD if they have a high enough level of technical involvement.[268]

As I established, the first step in VFX preproduction is planning the workflow and building the pipeline. For a simulation effect, the vendor-side VFX supervisor and the FX lead will figure out exactly what software, people and infrastructure they will be need to achieve the desired look. Even relatively simple jobs will require a combination of certain software plug-ins

[267] Sometimes simulation artists are referred to as FX artists.

[268] Patrick Parenteau, Interview with Technical Director and Simulation artist Patrick Parenteau, August 9, 2016.

and some customization. Nearly every simulation effect is made of several different effects combined. For example, animating a stormy ocean requires animating the larger scale flow of waves, the smaller scale turbulence and splashes, the foam braking off the waves, wind effects, and so forth. All of these are specific simulations in their own right. Simulation artists refer to this combination of effects is as the *master FX recipe*.[269]

There are several different directions an FX studio might take at this stage. The question is really how far they need to go to get the desired look of an effect. If the effect contracted by the studio is a simple background effect not used in many shots, then perhaps an existing recipe will do. If there is only one brief shot, it may even be easier to simply fake it using composited libraries of footage.[270]

The most basic simulation FX recipe will consist of existing software and plug-ins in which the studio's simulation artists are already well versed. By far the most popular core software for this sort of effects work is SideFX's Houdini. Houdini provides the basic infrastructure upon which to assemble the FX recipe. In turn Houdini is then connected to Autodesk's Maya, feeding effects and assets back and forth.

Side FX makes is own simulation effect suite called Houdini FX, with fluid, particle, rigid-body-dynamics, fur, cloth, fire and smoke solvers. A low-budget effects job might only call for a one-stop-shop suite like Houdini FX, and indeed these types of solutions have gotten so good recently that they are used more and more. This is a marked change from the early days of simulation FX in the 1990s, where VFX studios developed most of their special software in-house.[271] A good example of this trend is Autodesk‘s purchase of Naiad. Autodesk, the software giant that publishes Maya, purchased the industry-leading fluid simulation software company Naiad and built their technology directly into Maya. Using these off-the-shelf suites can dramatically cut costs. Buying new software is expensive not just because it needs to be built into the pipeline, but also because workers will need to be trained on it.[272] But, as chapter 2

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[269] Ibid.

[270] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 640.

[271] Ibid., 397.

[272] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 13.

demonstrated, the demand for specialized solutions seems to be persistent, especially in the case of blockbusters. Simulation artists I have spoken to confirm that there will always be a place for proprietary technology development.[273] Houdini's value to customers is not, after all, its simulation FX suite, but the way it can bring together various disparate pieces of software and plug-ins together through its nodal pipeline design.[274]

The vast majority of FX jobs fall in the middle ground, somewhere between using a single packaged solution and building a completely new program from the ground up. On the simpler end of the scale would be buying a few specific plug-ins to work with a program like Houdini. Anyone who has used an internet browser or word processor should have some basic understanding of what a plug-in is, but it is worth taking a moment to consider the definition. A plug-in is a kind of modification that adds functionality to a piece of software. The difference between software and plug-ins is that a software program can run on its own, without being built into something else. The concept behind the plug-in is that software companies can make it easier for third parties to add things to their software. Without the framework to accommodate plug-ins, the modification of software would be very difficult, and in some cases illegal. Software like Houdini or Maya is designed to be as flexible as possible because there are so many different possible modifications for different jobs.[275] The more readily these programs can accommodate plug-ins, the less labour needs to go in to building the pipeline and therefore less money needs to be spent.

A given plug-in might be as simple as a small modification to Houdini, or it might be a sophisticated physics simulation. Maybe it adds a certain kind of spray to ocean waves. A simulation artist or TD would combine such a simulation plug-in with other plug-ins in Houdini to try to get the recipe right for a certain look. Programs like Houndini can also connect to other independent simulation programs. A good example of this is Next Limit Technology's program Realflow. When different programs do not work well together, the FX TDs must build their own

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[273] Parenteau, Interview with Technical Director and Simulation artist Patrick Parenteau; Natt Mintrask, Interview with Technical Director Natt Mintrask, September 25, 2016.

[274] Mintrask, Interview with Technical Director Natt Mintrask.

[275] Ibid.

custom pipeline infrastructure. TDs refer to this as writing *glue code*. The more customized the job is, the more elaborate and customized the pipeline infrastructure will be.

The next step in technical complexity beyond employing plug-is is writing scripts. This is the sort of thing done by the more experienced senior simulation artists and also FX TDs. Much like plug-ins, scripts can only run within a program. By contrast, a programming language runs directly on a computer‗s processor. In other words, programming is writing instructions for the computer, while scripting is writing instructions for a specific program. Writing a script is really no different than any action in the graphic user interface of a program, but scripts enable a certain level of customization and automation. For example, you can open up a script editor console in Maya and write scripts in their MEL scripting language. Artists and TDs will do this to tweak setting not available through the graphic user interface, or to automate something to improve work efficiency. An artist might combine several repetitive jobs into a batch with a script, eliminating the need to do them one-by-one. This sort of efficiency work is all done in the name of minimising the amount of clicks an artist must make to do their work. Thus, work is done faster, or with fewer people.[276]

The distinction between programming and scripting is important to understand, because while script writing is a common practice even sometimes done by junior simulation artists, programming is generally only done at the biggest studios. As one TD and former simulation artist told me, ―Modification of scripts or creation of plug-in is pretty usual. Software change requires foresight about what your need will be in the future...” [277] Script writing also demonstrates that the line between developing tools and using tools is blurry. At a certain point the quotidian work of script writing becomes so complex that it becomes an entire plug-in.[278] And in essence every customization of software is technology development. This blurriness is further supported by labour roles. As I previously noted, TD and senior simulation artist are sometimes interchangeable titles. One might expect there to be a strict division between technical and artistic roles, but this is clearly not the case. Making an image and developing a technology are indistinguishable.

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[276] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 161.

[277] Parenteau, Interview with Technical Director and Simulation artist Patrick Parenteau.

[278] Dunlop, *Production Pipeline Fundamentals for Film and Game*, 162.

These blurry lines notwithstanding, the scale of tool development clearly tracks closely with the size of VFX and animation studios and their projects. Developing software from the ground up requires immense foresight, planning and resources.[279] The largest studios do the most fundamental technology development. As one FX TD explained, they do this because of the “immediacy and customizability” provided by in-house software.[280] Having the people that made the software down the hall makes service immediate, and makes getting the exact image the director wants easier. Furthermore, proprietary simulations sometimes provide a unique technological spectacle, the type of thing that is featured prominently in promotional material for blockbusters. Indeed in the 1990s and early 2000s it was pretty common to build a lot of technology just for one film. This has been gradually changing, with both VFX and animation studios seeking better efficiency through both implementing more universal tools and licencing those tool, as I noted in chapter 2. But the need for special technical work is never totally eliminated, and it will always be fuelled in specific cases by the desire for novelty and spectacle.

Sometimes software companies themselves offer custom services. There are also some VFX studios that specialize in just one type of effect and even one piece of simulation software. These studios defy categorization as either software developers or production studios. The best example of this is Fusion CI Studios, a Vancouver-based company that specializes in Realflow simulation software. One of the two founders of Fusion CI, Mark Stasiuk, is a scientist who did research on the fluid dynamics of volcanic eruptions before coming to the VFX industry. Stasiuk used RealFlow in his research, but he customized it for his own specific projects.[281] He became so proficient at this customization that he began doing contract work for its publisher, Next Limit, and eventually co-founded Fusion CI. Fusion CI does extensive R&D work and now has its own specific fluid simulation that operates within RealFlow, called Smorganic, that specializes on animating the ultra-thin sheets fluids make when they splash. Fusion CI models itself as a “plug and play” company, which can be brought on for a specific job, bringing its own artists and technicians, and attaching itself seamlessly to the greater VFX pipeline and workflow. This approach makes economic sense for studios that have important fluid simulation scenes to

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[279] Parenteau, Interview with Technical Director and Simulation artist Patrick Parenteau.

[280] Mintrask, Interview with Technical Director Natt Mintrask.

[281] “About Us,” *Fusion CI Studios*, February 20, 2015, http://fusioncis.com/about-us/.

do, but do not have the operational scale to justify, or indeed fund, extensive R&D. Fusion CI's hybrid role once again demonstrates how indistinguishable technology development and animation are in simulation FX.

Beyond contracting a company like Fusion CI, the highest end simulation FX solutions involve building custom software from the ground up. This is a process that entails extensive speculative financial investment and a large time scale, as I described in chapter 2. In these cases the influence of the logic of R&D is most obvious. But let us return for a moment to the most basic case, where a small VFX or animation studio has limited resources to invest in their effect. A case like this one demonstrates the conflation of image making and technological development just as well as a large-scale project. I will use the example of a fluid simulation, a very basic example, demonstrating a bare minimum of customization. For this example we will use Maya, two plug-ins for Maya, called Krakatoa and Nuke, and Realflow, a fluid simulation program that outputs to Maya through the use of a plug-in.

The simulation artist is the last step in the simulation FX workflow. They are involved in any scale of simulation FX work. The simulation artist is the last and arguably most important stage in the process of control and look-dev. Once TDs and FX leads put all of the tools into place and customize them, it is the simulation artist who will actually make the animation. Their work demonstrates most clearly how simulations are created and shaped.

To demonstrate the job of a simulation artist, let us briefly imagine a simple job. Our hypothetical simulation FX job starts in Realflow, where the artist makes a particle-based simulation of a fluid. The first steps will likely involve putting in any boundaries or containers, or any objects that the fluid might splash off of. Next the artist inserts the fluid, either as something already there, sitting in a container, or as something flowing out of what is called an emitter. The size, direction and amount of flow from an emitter can of course be changed by changing different values either in a script, or more likely in a tool-specific user-interface window. At this point the artist can insert different forces into the fluid over a time-line, which will cause perturbations and movement. They can also potentially add random noise to make the movement more interesting and naturalistic. They might also adjust the force of gravity. At this stage the artist can also change the proprieties of the fluid, such as the vorticity (how many swirls the fluid forms) or the viscosity (how thick the fluid is). All of this is done by changing the value of a given modifier. It is important to emphasize here that these are all pre-programmed conditions. The artist cannot directly shape the fluid. With any significant adjustment they will have to run a low-LOD simulation in order to see what the outcomes of these conditions will be.

At this point the artist has made a flowing volume of particles. The next job is to draw a mesh onto the particles. Particles are like a volume without a surface, and adding meshes gives the water a surface. At this point more values can be tweaked, such as the thickness of splashes. It is also common practice for the animator to make a second particle simulation that will stay as particles and not have meshes added. These little points of water will act as mist droplets.

Next the artist outputs the simulations to Maya. Here lighting and camera position can be set, as they would be with any animation, although another department may do this work. They may even have HDRI data recorded on set, in the case of VFX. The artist will also give shading and reflective properties to the mesh surfaces, as well as surface textures and coloring. In the case of water, the surface will obviously be transparent. Here the artist can also change the look of the second particle simulation using the Krakatoa plug-in, giving the particle points shade or color, for example. Finally, the two simulations will be composited together and composited into a scene with other elements using Nuke. This is pretty much the simplest possible example of how a simulation artist would go about making a simulation.

The simulation artist will of course make many iterations of this simulation, both on their own, through a sort of trial-and-error process, but also through the look-dev process, where VFX supervisors, sequence directors or animation directors see a low-LOD preview of their work and give them direction. Their work will be composited with other department's work through some sort of DAM system, and of course they will likely be using assets sourced from other departments in their work. Perhaps the wave will run through the hallway of a building, for example. Perhaps the model of that building was originally captured through LIDAR.

Although the work described here sounds, and indeed looks, not unlike the work of any digital animation artist, there are some important distinctions to be made. For one, the artists cannot directly control the outcome of their simulation. The best they can do is use trial and error and make choices based on their own experience with the behaviour of a given simulation. Further, the artists is using nonlinearity, and even adding additional randomness, as an important part of achieving the right look. Just like so many of the different forms of management covered so far in this thesis, every simulation seeks to foster unpredictable complexity as a resource while also shaping it to their own needs. Simulation FX production demonstrates how imbricated R&D and image making have become.

When confronted with the R&D-influenced practices in VFX and animation, especially simulation FX, one has the urge to put them in either the automatic or the manual category. It is either the work of an artists or of a technician. But in fact these practices cut across these divisions in unique ways. In a sense simulation artists and technicians are re-inventing their representational apparatus for every project. Imagine if filmmakers re-invented the camera every time they made a film. This unsettles some well-established divisions within film production labour. In order to illustrate this point, I will turn to a brief example: a recent Pixar short title *Piper* (2016).

Although Pixar is very much embedded in the R&D complex, they are also heavily invested in the animated creativity that is tied to the concept of manual control. Nothing demonstrates this better than their shorts. Since the very first animation produced under the name Pixar, *Luxo Jr.*(1986), Pixar has defined itself through expressive manual manipulation. Everything is told efficiently and effectively through gesture in Pixar shorts, and there is never any dialogue. The animated short is how Pixar demonstrated to the world that a cold calculating computer could carry on the tradition of animation. This is all quite clear in *Piper*.

Piper tells the story of a sand piper learning to hunt for food in the ever-changing landscape of an ocean shoreline. Following the paradigm of Pixar shorts, the animators communicate an incredible amount of storytelling through the subtle character animation of gestures and facial expressions. The birds, though relatively naturalistic, convey a range of emotions that are universally intelligible to humans. These expressions are the result of work that requires painstaking manual labour done by people who fit our tradition definition of what a key-frame animator is. Contrary to what one might expect though, every frame of *Piper* also abounds with simulation FX.

Everywhere one can see simulation at work. The feathers, a key expressive part of the birds, automatically ruffle in the wind and react to movement. They are bound to the deformable movement of the skin of the birds, which is likely connected in turn to a simulation of musculature.[282] Thus, while the bird's core model is moved manually, the overall animation of

[282] Okun, Zwerman, and Visual Effects Society, *The VES Handbook of Visual Effects*, 605.

the bird consists of at least as much simulation as key-frame animation. As this chapter has illustrated, these simulated animations still result from human intervention and creativity, but understanding how requires us to think differently about the animation process. The creativity is not consolidated in a single act. It is part of a long distributed process that involves the work of technologists, artists, and artist-technologists.

The most impactful aspect of *Piper* is arguably the way it renders the material experience of being very small. The tiny waves seem huge, the grains of sand are more like pebbled and blades of grass are the size of trees. The animated material quality of all these things is the result of careful, detailed simulation, from the flow of the grass, to the crash of the waves, to the way the sand moves as the bird tumbles across tiny dunes. These simulations are not self-evident and they are not easily achieved. They require intense thought about the material world and the combination of laws and unpredictable complexity that produces motion. They also require imagination, picturing one's self in the world on a different scale. This creative thought was part of building the FX recipe and pipeline infrastructure. TDs and software engineers customized and altered certain tools, simulation artists manipulated different parameters, wrote scripts, and created many different low LOD iterations, all in the name of arriving at this final product.

Piper demonstrates very keenly how the manual and the automatic have been renegotiated to include technological development. Given the immense discursive importance I see Pixar shorts having, I believe we can get a glimpse of how the studio is renegotiating these ideas in this short. The technical work of simulation building is clearly being subsumed into the image Pixar has worked so hard to cultivate all these years as a fount of creativity in the tradition of Disney Animation. Much in the way Pixar originally used their shorts to convey that3D computer graphics are genuine animation, they now convey that simulation is part of animation. The job of making a crashing wave look just right has been elevated to the same level as the job of animating the expressive gestures of an animated character.

This new image of creative work in animation raises some questions about animation and VFX labour. An important subject of study in the field of production labour concerns the subjectivity of the self-identified creative worker, and the role the discourse of creativity plays in organizing labour. Production studies scholar Vicki Mayer has noted how the attributes of creativity and professionalism are used to create hierarchies in media industries, above the line and below. Above the line are the professionals who manage themselves and others, and the creatives who have control over the content being produced. Below the line are the trades people and manual workers. She specifically observes a dichotomy between intellectual labour versus technical manual labour at work in these divisions.[283] In her work she studies the construction of this discourse and demonstrates how it sorts workers into different categories, deserving of different levels of compensation and credit.[284] Another important production scholar who focuses on the discourse of creativity is John Caldwell. Caldwell is interested in understanding the socio-cultural factors that make possible the current state of the industry, where workers log long hours for little, or sometimes no, pay. He finds that there is an ―invisible economy” of ―symbolic” payroll, where workers are motivated by discourses like creativity instead of material compensation or security.[285] The idea of creative work makes possible the state of precarious ―deprivation” employment practices in industries like VFX and animation.

If the idea of creativity is so important for organizing labour, and if, as Mayer argues, it follows a division between technical trades and creative or management roles, where do simulation FX and R&D roles fit in? Do the roles of simulation artist, technical director or principal scientist disrupt these labour divisions? Technical director and simulation artist certainly sound like they belong in different categories, with the former playing a technical support position and the latter playing the role of above-the-line creative. Yet, as I noted, these two positions are often interchangeable, and generally speaking TD is a more prestigious role than simulation artist is. Therefore simulation FX must disrupt these divisions of labour.

Yet, I have found that essentially simulation FX and R&D do not complicate the dichotomy of creative and technical work. Indeed, it is interesting to note how readily these seemingly unique roles fit into established ways of thinking. Neither Mayer nor Caldwell are writing about the old Hollywood, with its localized production, studio control and labour unions. They are both describing the new, globalized, liberalized, conglomerated Hollywood. Their work gives us the tools to understand the labour subjectivity and identity of the simulation artist, technical director and principal scientist.

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[283] Vicki Mayer, *Below the Line: Producers and Production Studies in the New Television Economy* (Durham, NC: Duke University Press, 2011), 6.

[284] Mayer, *Below the Line*.

[285] Caldwell, ―Stress Aesthetics and Deprivation Payroll Systems,” 99–102.

A key finding of Mayer‘s is that below-the-line workers see themselves as making creative contributions to the production of media, but from the outside they are invisible and excluded. Mayer writes, ―. . . all of us increasingly define ourselves through our productive work while at the same time industries devalue our agency as producers…"[286] It is exactly this dynamic that makes it possible to benefit from the motivating discourses Caldwell describes, while at the same time having labour spread across many contracted companies scattered throughout the world. Caldwell categorizes production and post-production work below the line, yet he also demonstrates how the workers in these categories are strongly motivated by the discourse of creativity and the symbolic payroll. He obverses that low level VFX workers work so hard in large part because they want to imagine themselves as artists who are a part of the movies they love.[287] Even if you only did some match-moving work on Jar Jar Binks in a scene that ended up being cut, you still worked on a *Star Wars* movie.

All of my research only reinforces what Mayer and Caldwell find. Simulation FX and R&D work in general are in no danger of being recognized by the industry as valued creative or professional work. Indeed, it is interesting to note how reliable I have found the description of VFX work to be on the public level. I have observed many iterations of the same refrain from high-ranking people in VFX: our job is to make the director‘s vision come to life.[288] The only pushback against this has come from labour organization initiatives, and from calls to recognize the work of VFX supervisors. The role of VFX supervisor is truly commensurate with director of photography or art direction, yet they continue to lack recognition in the most visible places, like the Academy Awards. It is worth noting that the focus is not on the average worker here, but on the highest executive position.

What my work offers to this field of research is the observation of how far the logic of creative work extends into the world of R&D and scientific research. The symbolic payroll and the invisibility of technical work do not end at the VFX and animation studios. I have noticed that simulation FX researchers really revel in their association with the film industry. At the very least, association with Hollywood seems to be a good way of promoting your work. Evidence of

[286] Mayer, *Below the Line*, 3.

[287] Caldwell, ―Stress Aesthetics and Deprivation Payroll Systems," 101.

[288] Finance and Zwerman, *The Visual Effects Producer*, 2010, 37.

this can be found in profiles in researcher‘s personal websites and blogs, on official university webpages, and, of course, in SIGGRAPH presentations. Take for example a scholarly publication by Jerry Tessendorf (a researcher I profiled in chapter 2) and several other scholars at Rhythm and Hues, which was presented at SIGGRAPH and can be accessed both through Tessendorf‘s personal website and through his University page.[289] The paper concerns a new technique for animating realistic clouds. This research was conducted at the Rhythm and Hues for a specific project: the film reboot of the 1980s television show *The A-Team* (2010). The title of this peer-reviewed research paper is *I Love it When a Cloud Comes Together,* a play on the famous catchphrase from the show ―I love it when a plan comes together." The researchers seem to be playfully suggesting an analogy between their work and the work of the A-team. It seems quite clear to me that researchers enjoy being a part of making spectacular movies. It no doubt differentiates them from their peers in other fields. How many mathematicians have academy awards? While these valued scientists at the forefront of their field probably are not exactly exploited, this is a phenomenon that no doubt suffuses networks of graduate students and more precarious academic labourers. To reiterate a quote from Mayer, ―. . all of us increasingly define ourselves through our productive work while at the same time industries devalue our agency as producers…" [290]

Conclusion

This chapter has demonstrated the influence of both simulation FX and the R&D complex on VFX and animation production. I have drawn connections between R&D, simulation FX and the management of creative work for how they all seek to direct and capitalize upon unpredictable contingency and emergence. Ultimately I believe this demonstrates different manifestations of a broad historical episteme, but I have also sought to trace how these ideas circulated between different disciplines and industries within the R&D complex. Perhaps the most central node in this network of connections is management science literature like Jay Wright Forrester‘s *Industrial Dynamics,* where one can see both the formation of modern management science, but also the influence of nonlinear simulation. From here we can imagine

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[289] Sho Hasegawa et al., ―I Love It When a Cloud Comes Together," in *ACM SIGGRAPH 2010 Talks*, SIGGRAPH '10 (New York: ACM, 2010), 13:1.

[290] Mayer, *Below the Line*, 3.

two parallel lines running through history, one developing as further management science in the form of concepts like BPM, and the other developing into further simulation technologies that would eventually be used in VFX and animation studios.

Another important topic from the latter part of this chapter is the way technological development and image making have become imbricated, once again demonstrating the influence of the R&D complex. This is evident both in the ongoing role pipeline-building plays in production, and also in simulation FX production practices. Looking at the work of figures like the simulation artist, the TD and the lead scientist, we can see all of the different elements I have covered in this chapter at work, including workflow management, pipeline construction and the role of R&D. If we approach a film like the Pixar short *Piper* with a thorough understanding of how simulated animations are made, we can see how profoundly animation and VFX production has been changing over the past few decades, not just because of the introduction of digital tools, but also because of the spread of technical, scientific and organizational paradigms.

Chapter 4: Nonlinear Simulation in the Cinema

In chapter 3 I examined how the production practices in VFX and animation were shaped by both the context of the blockbuster R&D complex and the emergence of computational tools for nonlinear simulation. As I have argued in every chapter, the concept of nonlinear simulation is intimately linked with the R&D complex, both institutionally and conceptually. R&D and nonlinear simulation both seek to foster and manage unpredictable complexity and open-ended processes. In chapter 3 I showed how both production workflows and business management philosophies in the VFX and animation industries have been influenced by this way of thinking. My examination of the simulation FX production workflow and the roles of simulation artists, technical directors and FX leads, showed how technical development and image making are merged together in a process designed to shape, or *develop*, the look of unpredictable nonlinear simulations. I also showed how this approach to shaping nonlinearity has influenced the business management philosophies of VFX and animation studios as well.

This chapter will build on chapter 3's investigation of VFX and animation production by studying how the episteme of nonlinear simulation is at work in the narratives and aesthetics of Hollywood blockbusters from a specific period. The films I will address in this chapter are *Star Wars 2: Wrath of Kahn* (1982), *Jurassic Park* (1993), *Twister* (1996)**,** *The Perfect Storm* (2000), and *The Day After Tomorrow* (2005). These examples offer fairly well spaced intervals of a key period of time in Hollywood, both when simulation FX was at its most salient and spectacular in VFX, and when epistemic issues relating to nonlinear simulation were finding their way into popular discourses.

As nonlinear simulation was transforming VFX and animation production, this new epistemology was simultaneously being addressed more and more in popular culture. People were beginning to mark this new epistemology at work in fields such as meteorology, climate science, evolutionary biology and management science. Terms from the science of nonlinear simulation, such as The Game of Life, chaos theory, catastrophe theory and fractals, were also starting to enter the general vocabulary. As I will show, these films engage these topical issues in varying ways.

A key argument I will make in this chapter is that the VFX and thematic registers in these films work in congress to address the epistemology of nonlinear simulation. Thus, I am contending that the VFX spectacles in these films have meaning as legible forms of computational mediation. In four of the cases I discuss in this chapter, the one exception being *Jurassic Park*, a key spectacular moment of VFX is driven by simulation FX. I believe these VFX spectacles are able to aesthetically convey a sense of simulated nonlinearity. This chapter is therefore about both the way Hollywood films changed aesthetically as a result of changes in technology and industry, but it is also about the larger epistemic context of these changes, how we culturally began to understand the world through new scientific and technical paradigms.

Several scholars have theorized the connection between film and historical epistemes. Much of this work has focused on early cinema and industrial modernity. Mary Ann Doane‗s work on contingency and the archive in early cinema has been particularly influential for me. In her work she demonstrates how various examples from silent cinema exhibit ―the pressure to rethink temporality in the nineteenth century (as) a function of the development of capitalist modernity....‖[291] She also sees scientific concepts like the thermodynamic law of entropy as influencing the way films represented time and contingency.[292] Thus, by studying films from a given period she is able to show the emergence of a new way of making sense of the world that was spreading throughout society.

Doane‗s work on contingency and catastrophe is also worth noting, as it describes a different conceptualization of the same topics I will be addressing here. In her work on early cinema she finds that contingency had an almost irresistible appeal. The camera was unique for its ability to capture unexpected occurrences. These once singular events could now be frozen in time and viewed repeatedly. Contingency could now be contained in a ―representational system while maintaining both its threat and its allure.‖[293] She finds a similar sort of dynamic of appeal and containment in breaking television news in some of her other work, she writes,

> The televisual construction of catastrophe seeks both to preserve and to annihilate indeterminacy, discontinuity. On the one hand, by surrounding catastrophe with commentary, with an explanatory apparatus, television works to contain its more

[291] Mary Ann Doane, *The Emergence of Cinematic Time: Modernity, Contingency, the Archive* (Cambridge, Mass.: Harvard University Press, 2002), 20.

[292] Ibid., 117.

[293] Ibid., 138.

> disturbing and uncontainable aspects. On the other hand, catastrophe's discontinuity is embraced as the mirror of television's own functioning and that discontinuity and indeterminacy ensure the activation of the lure of referentiality.[294]

Clearly she is referring to a different point in history from silent cinema here, with a slightly different way of seeing contingency, but there is also a lot of continuity between early cinema and television news in her account. Indeed, this idea of contingency having appeal but needing to be controlled resonates with findings I have made in previous chapters. I would like to build on Doane's observations, offering my own interpretation of how unpredictable contingency and catastrophe was starting to be understood in this period, but I will be approaching my examples in s slightly different way than she.

Doane's account assumes that the episteme of industrial modernity was adopted in a rather matter of fact way in the films she studies. It is simply the a priori for how time and contingency were understood at a given point in history. There is no explicit acknowledgment of a different way of thinking in the films she studies, no negotiation of something new; they simply exhibit a historically specific way of thinking. While I do believe this sort of work could be done for nonlinear simulation in the period between the 1970s and the present, writing about all films made during this period would clearly be far too broad in scope. Instead this chapter is focused on the most explicit, most salient examples. This is why this chapter will focus only on VFX. There is an existing body of academic literature concerning how VFX make technical mediation sensible. This work will provide the theoretical groundwork for this chapter.[295]

Special effects scholar Dan North sees special effects spectacles as reflexively addressing the nature of technical mediation. The relation between special effects and technology is perhaps most obvious in the case of science fiction movies, where technology is explicitly being portrayed, as Annette Kuhn has observes, but North's argument applies to all use of special effect.[296] A sequence with a raging storm or a dinosaur can be about technology if the spectator

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[294] Mary Ann Doane, ―Information, Crisis, Catastrophe," in *Logics of Television: Essays in Cultural Criticism*, ed. Patricia Mellencamp (Bloomington: Indiana University Press, 1990), 259.

[295] I use the term special effects here to match other scholar's phraseology. Here special effects can be taken to include both practical (pro-filmic) and visual effects.

[296] Annette Kuhn, *Alien Zone* (London: Verso, 1990), 7.

can tell the images they are seeing are synthetic. North is clearly inspired by Tom Gunning and Andre Gaudreault‘s highly influential concept of ―the cinema of attraction,” where early cinema spectacles are re-interpreted as an anti-illusionist address to spectators that foregrounds the trick of film.[297] North holds that special effects are never invisible, that spectators always register, on some level, the interplay between ―profilmic” and ―synthetic” elements. As North puts it, special effects are always about the relation between ―the real and its technological mediation.”[298] This is certainly true in his examples, although he ignores the more quotidian uses of special effects that are not meant to be noticed, like matte painting. Thus his theory should probably be limited to spectacles.

Kristen Whissel offers a similar theory of special effects spectacles that integrates elements of both Doane and North‘s approaches while also offering an answer to the question of how special effects are meaningfully connected to narrative and thematic content. While Gunning or North treat moments of spectacle as interludes of visual novelty that undermine narrative, Whissel argues that spectacles engage important themes or concepts that are central to a film.[299] She theorizes that special effects spectacles function as ―emblems,” ―allegorical assemblages” or ―spectacular elaboration(s) of concepts.”[300] She bases her theory on the illustrative emblems found in 16th, 17th and 18th century manuscripts. Here emblems appear along with epigrams that related to both the text and the image. For example, she describes a book called *Moral Emblems,* where an emblem of a herd of oxen defending themselves from wolves is joined by epigrams such as ―union gives strength” and ―singly we succumb.”[301] The epigram, body text and emblem add up to something more than the sum of their parts because of their different registers. Whissel argues that in a similar fashion the visual register of blockbuster

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[297] Tom Gunning, ―The Cinema of Attraction: Early Film, Its Spectator, and the Avant-Garde,” in *Early Cinema: Space, Frame, Narrative*, ed. Thomas Elsaesser (London BFI, 1990).

[298] Dan North, *Performing Illusions: Cinema, Special Effects, and the Virtual Actor* (London: Wallflower Pr, 2008), 1–5.

[299] Kristen Whissel, *Spectacular Digital Effects: CGI and Contemporary Cinema* (Duke University Press, 2014), 4.

[300] Ibid., 6–8.

[301] Ibid., 10.

spectacle can work in congress with narrative to form a “mutual elucidation” that reveals a broader theme.[302]

Whissel also works from the idea that spectacular effects can be broken into types.[303] These types are not just defined by the use of a certain technology, but a combination of technology, narrative and style. She gets this concept from Bob Rehak, who studied the different cases of the bullet time effect, made famous in *The Matrix* (1999).[304] Rehak uses the term “micro-genre” to describe this typage of special effects. Whissel holds that spectators can recognize these different types of effects, and that each of these types tend to make meaning in a similar way across multiple films. I find Whissel‘s approach an extremely useful way of understanding the aesthetic and thematic role of simulation FX, which I believe function as an identifiable type of micro-genre and can be rich in meaning when deployed as spectacle.

Based on this existing scholarship, I argue that simulation FX spectacles have meaning as nonlinear simulations. Simulation FX images are not merely naturalistic. Their chaotic, unpredictable, nonlinear movement is sensible as a specific kind of animation. As sensible forms of computational mediation, simulation FX can convey specific meaning. In each of the following films there is some sort of nonlinear complexity, some sort of unpredictable contingency or chaos in the narrative, and in each film we see scientists trying to grapple with this unpredictability through simulation. In four of these cases these narrative elements are joined by a simulation FX spectacle, which connects to the narrative as a kind of emblem.

Star Trek II: Wrath of Kahn (1982)

The “Genesis Sequence” in *Star Trek II: Wrath of Kahn* is universally considered a landmark in VFX as well as computer graphics. It was the product of one of the many early crossovers between military research and the film industry at SIGGRAPH. In 1980 Loren Carpenter, an engineer at Boeing's Computer Service Department, presented a short animation titled *Vol Libre,* which showed off his technique for drawing realistic looking geological topographies using a combination of fractals and nonlinear computational processes. By

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[302] Ibid., 12.

[303] Ibid., 13.

[304] Bob Rehak, “The Migration Of Forms: Bullet Time As Microgenre,” *Film Criticism*, October 1, 2007, 26–48.

inputting a few parameters, Carpenter could automatically generate a realistic landscape of mountains and valleys. When Carpenter showed *Vol Libre* in at the end of his 1980 SIGGRAPH presentations, the crowd erupted in applause and demanded a second viewing. After his talk, he was immediately offered a job by Alvy Ray Smith and Ed Catmull at the Computer Division of Lucas Film.[305] Lucas Film would put Carpenter's technique to use almost immediately on *The Wrath of Kahn's "*Genesis Sequence." As a founding member of Lucas Film Computer Division (the future Pixar studios), Carpenter would soon go on to design other techniques, like the L-system technique used to generate realistic foliage in *The Adventures of Andre and Wally B* (1986).

In *The Wrath of Kahn* Captain Kirk's (William Shatner) United Federation of Planets has developed a technology called the ―genesis device," which can terraform barren planets, making them viable for habitation. This seemingly benign technology is stolen by the genetically modified super-villain Khan Noonien Singh (Ricardo Montalban) who intends to use it as a weapon. The sequence Carpenter made for the film is basically an explanatory interlude where the genesis device's function is demonstrated through the use of computer graphics. The entire sequence takes place on a diegetic computer console screen, with Kirk, Dr. McCoy (DeForest Kelley) and Mr. Spock (Leonard Nimoy) gathered around the screen, viewing the demonstration. In the computer graphics sequence the camera flies over the surface of a dead and flat planet. Then, an explosion takes place on the surface, causing some sort of reaction that causes the flat surface to grow into mountains ranges and valleys. Troughs fill with water and exposed surfaces grow green with vegetation.

Like the other digital VFX milestone from the same year, *Tron* (1982), *Wrath of Kahn* contains digital effects within the frame of a diegetic computer rather than attempting photorealism. The images are presented as a computer simulation of what would happen if the device were used. The ―Genesis Sequence" visualization is both really and diegetically a futuristic nonlinear simulation. In all of the following films I will discuss there will also be examples of diegetic digital screens displaying data and simulations. In all of those cases though, the VFX spectacle lays somewhere else in the film as a photorealistic image. Here, the diegetic simulation and the simulation FX coincide. While critical discussion of digital effects over the

[305] Michael Rubin, *Droidmaker: George Lucas and the Digital Revolution* (Gainesville, Fla.: Triad Pub. Co., 2006).

last few decades has been dominated by the discourse of synthetic photorealism, there is a different sort of realism at work here: the realism of computational mediation and nonlinear simulation.

Beyond the mere presence of a simulation, the film taps into several concepts from the science of nonlinear systems and simulation, which were becoming familiar to the public at the time. One important concept is fractals.[306] A fractal is an algorithm that outputs into a self-similar algorithm, which inputs into the same again, and so forth ad infinitum. In the 1970's mathematician Benoit Mandelbrot discovered that these algorithms had the potential to describe shapes and processes in nature.[307] Fractals provide a way of representing infinitely complex shapes like topographies, which yield more and more detail the closer you study them.[308] Fractals can also accurately model the mechanisms behind certain natural shapes, such as the spacing of tree limbs. This type of equation is referred to as an L-system. While they can be very simple equations, fractals can also include nonlinear complexity.

Fractals had a level of popularity in the 1980s and 90s that far outpaced their utility. They exceeded computer science and mathematics circles to become a part of popular culture. The visually compelling way fractals rendered nonlinear complexity made them extremely popular: fodder for dorm room posters and blockbuster movies. This trend started with Heinz-Otto Peitgen and Peter Richter's book *The Beauty of Fractals* (1986). Although the book was fairly technical, it featured large full color prints that anyone could appreciate.[309] Three years later, The

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[306] As I explain in Chapter 1, nonlinear simulation can be broken into two subtypes: stochastic, which involves the use of random factors, and dynamic, which involves the complexity of multiple co-influencing factors.

[307] P Campbell and S Abhyankar, ―Fractals, Form, Chance and Dimension: Benoit B. Mandelbrot," *The Mathematical Intelligencer* 1, no. 1 (1978): 35–37.

[308] To understand the fractal nature of topography, consider the problem of how to measure the length of a coastline. The more detailed the measurement, including more and more shapes, the longer the total length of the coastline becomes.

[309] Heinz-Otto Peitgen and P. H Richter, *The Beauty of Fractals: Images of Complex Dynamical Systems* (Berlin; New York: Springer-Verlag, 1986).

New Museum in New York featured an exhibit titled ―Strange Attractors" (1989) which featured fractal renderings of chaotic phenomena.[310] Fractals soon became a household name.

The animation in the genesis effect sequence is a modified fractal. Carpenter's major contribution was to add a stochastic process, a process that introduces randomness, in a way that seemed to mimic the unpredictable processes that actually formed the earth's surface. As the narration in a Lucas Film making-of video titled *Computer Graphics in Star Trek II: The Wrath of Kahn* describes it, ―the fractal technique is a form of controlled randomness which ads a nature-like dynamic complexity to simulated scenes."[311] The way one can grow the crystalline structure of a fractal, and the way that structure in some cases perfectly mimics patterns in nature, tempts one toward the assumption that mathematics or computation are not simply theories that model reality, but rather than they *are* reality in some respect.

As I established in chapter 1, as early as the 1940s John Von Neumann was thinking about how to model evolving systems through creating a grid of squares with specific rules, a concept he called cellular automata. It was not until the 1970s that this idea captured the public's imagination though. Mathematician John Conway built on the cellular automata concept and produced a grid-based simulation where squares seemed to coalesce and form functioning entities. He called it The Game of Life. Much like fractals, the game of life became a popular program to play with on expensive institutional computer systems. Enthusiasts developed a taxonomy of different life forms that emerged from the game of life simulations with names like ―glider guns."[312] The appeal of Conway's program is easy to imagine. These simulations are capable of the same unpredictable emergent forms as reality itself. They conjure the idea of re-

[310] Richard Wright, ―Technology Is the People's Friend: Computers, Class and the New Cultural Politics," in *Critical Issues in Electronic Media*, ed. Simon Penny (Albany: State University of New York Press, 1995), 82.

[311] Lucasfilm Computer Graphics Division, *Computer Graphics in Star Trek II: The Wrath of Kahn"*, 1982, https://www.youtube.com/watch?v=Qe9qSLYK5q4.

[312] Manuel DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason* (London: Continuum, 2015), 24.

creating life‘s development on earth in a virtual realm. With greater sophistication, how complex might these life forms become?[313]

The ―Genesis Sequence" in *The Wrath of Kahn* taps in to these discourses. The idea of a technology that could catalyze a process that gives rise to life is conceptually very close to nonlinear simulations like fractals or the game of life. The fact that this weapon is represented through a diegetic simulation strengthens this connection. As Whissel theorizes, the narrative and the spectacle are conspiring to emblematically convey some sort of concept. They make this discourse of emergent virtual life sensible in a unique way that pure narrative, aesthetics or VFX spectacle could not.

Jurassic Park (1993)

The concept of emergent virtual life is still at work almost a decade later in another VFX landmark film, perhaps the single most iconic digital VFX film, *Jurassic Park*. *Jurassic Park* is unique among the examples in this chapter because, for all of its technical innovations, it does not feature any significant form of simulation FX. It is nonetheless worth including both for its historical significance and for the way it discursively addresses the concepts of chaos, management, risk and disaster as they relate to dynamic nonlinear complexity and nonlinear simulation. *Jurassic Park* sits at the point in history when the discourse of digital film technology became a prominent matter of public and academic concern. Stephen Prince‘s article ―True Lies: Perceptual Realism, Digital Images, and Film Theory" was published only three years after *Jurassic Park* was released, and Prince uses the film as one of his key examples. Indeed, much more has been written about *Jurassic Park* than any of the other films discussed in this chapter.

For all of the discussion it inspired, *Jurassic Park* surprisingly features relatively little digital animation. Although the use of digital VFX techniques like compositing are abundant in the film, only a scant few minutes of screen time contain any digital animation.[314] Many

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[313] This is discourse is an excellent example of what Philip Mirowski terms ―cyborg science." Philip Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (Cambridge: Cambridge University Press, 2006).

[314] Stephen Prince, *Digital Visual Effects in Cinema: The Seduction of Reality* (New Brunswick: Rutgers University Press, 2012), 26.

techniques used in the film were surprisingly old fashioned. For instance, many of the scene featuring dinosaurs, especially close up, were created using puppets and even costumes designed by special effects guru Stan Winston. Even the digital workflows were tied to old ways of doing things. Rather than virtually model dinosaurs, ILM handmade physical models and then digitally scanned them. Similarly, instead of animating the motion of the dinosaurs through digital key-frame and tweening, they used physical dinosaur models rigged with sensors that inputted positional data into animation software. This allowed stop-motion animator Phil Tippett to create animations by hand. Tippett was famously credited as ―Dinosaur Supervisor." Despite all of this, *Jurassic Park* has been a key talking point for discussions of the transformative effects of digital animation in film. This is an excellent example, therefore, of how the themes in and around a film can gesture toward VFX, even when those VFX are in some ways a ruse. While the production of the film clearly utilized many emerging digital technologies and innovated many more techniques and technologies besides, this is one case where the themes outpace the actual VFX technology.

Jurassic Park is clearly a film about emerging technologies. The core science fiction conceit of the film is that cloning technology has made it possible to bring back the dinosaurs. But it also addresses important issues concerning nonlinear simulation. Let us address each in turn. *Jurassic Park* was made during a period of time when DNA was a major cultural cause celebre.[315] Arguably DNA was to the 1990s what nuclear technology was to the 1950s. The discourse of DNA overlapped with the discourse of virtual life in important ways. DNA is a code, an alphanumeric representation of life. Much like fractals, DNA‘s existence suggests that the virtuality of code is every bit as real as reality. *Jurassic Park* addresses this discourse in several ways.[316]

Although *Jurassic Park* is a landmark in photorealistic visual and special effects, it is worth noting that it also contains representations of computational mediation, a sort of digital

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[315] Dorothy Nelkin and Mary Susan Lindee, *The DNA Mystique the Gene as a Cultural Icon* (Ann Arbor: University of Michigan Press, 2007).

[316] It is worth noting that Kristen Whissel discusses *Jurassic Park* in her book on digital effects. Our interpretations are different but not contradictory. She finds that the dinosaur‘s vitality emblematize ―the unprecedented technological mediation of organic life and death in the late twentieth and early twenty-first century." Whissel, *Spectacular Digital Effects*, 92.

realism, much like *Wrath of Kahn's* ―Genesis Sequence." Just like in *Wrath of Kahn*, this digital realism takes place during an explanatory interlude, in this case a sort of theme-park edutainment ride. In the film we see scientist using 1990s sci-fi computer technologies, like virtual reality and motion tracking gloves, to study the dinosaur DNA and repair it. The code of the animals has passed through a computer and been modified. Here the DNA is represented through a stripped-down 3D visualisation that uses simple colors and no shading: the type of 3D digital images people were used to seeing up to this point: legible digital images. The film is thus building a link between the code of the digitally animated realistic dinosaurs and the diegetic dinosaurs, which are themselves simply programmed data.

This idea of DNA as computer code is sometimes reinforced by the mise-en-scene as well. For example, in one scene an escaped velociraptor wanders in front of a projection of DNA code in alphanumeric form. The code is projected onto the dinosaur's skin for a moment, the implication being that these animals are made of code. Just like in *Wrath of Kahn*, we are being prompted to perceive the dinosaurs as both diegetically simulated and really simulated. This theme was not lost on scholars at the time, many of whom observe that the realistic looking synthetic dinosaurs convey the impression that they are simulated life. [317] Science fiction scholar Warren Buckland makes this observation, for example.[318] He uses the simulated aesthetic of the realistic dinosaurs to support his argument that *Jurassic Park* belongs to a special category of film that is in-between the imagination of science fiction and the ontological commitment of science fact, because it portrays not a fanciful imaginary world, but a possible future world. *Jurassic Park* imagines ―extreme consequences from a nonfictional state of affairs in the actual world."[319] The effects used in the film support the believability of this possible future. Indeed Buckland even recognizes simulation-based effects (which he refers to as ―invisible effects") as a

[317] One example of this argument can be found in Nigel Clark, ―Panic Ecology: Nature in the Age of Superconductivity," *Theory, Culture & Society* 14, no. 1 (February 1, 1997): 78.

[318] Warren Buckland, ―Between Science Fact and Science Fiction: Spielberg's Digital Dinosaurs, Possible Worlds, and the New Aesthetic Realism," *Screen* 40, no. 2 (July 1, 1999): 184.

[319] Ibid., 181.

component in this.[320] Once, again, we are prompted to think of both the diegetic dinosaurs and the VFX as forms of simulation.

The discourse of virtual life clearly taps in to the history of nonlinear simulations like *The* game of life and cellular automata. The second important theme in *Jurassic Park* makes this connection even stronger. The second important discourse in the film is chaos theory. In the film a doubting chaos mathematician named Dr. Malcolm (Jeff Goldblum) anticipates that the park will inevitably descend into entropy and disorder. Of course, it eventually does. Dr. Malcolm‘s theories are meant to represent a generalized sense of the sciences of nonlinear complexity, rather than chaos theory itself. Chaos theory is a culturally important subject though, especially during this moment in history, much like fractals and the game of life were in the 1980s, so it is worth taking a moment to note the meaning of this term and its historical context.

Edward Norton Lorenz first developed chaos theory when he was working on early computer simulations of weather patterns. Lorenz discovered that any minuscule input into his simulations resulted in wildly different outputs. If he changed one tiny thing in a complex system, everything would be affected. Lorenz also eventually discovered that certain mysterious patterns emerge in wildly complex and unpredictable systems. It was highly counter-intuitive to find regular patterns in what should have been unpredictably complex systems. He referred to the mysterious causes of these patterns as ―strange attractors.” Chaos theory thus concerns the mysterious forms of order in what should be order-less systems. Thus the term chaos in common speech does not mean the same thing as the mathematical concept of chaos.

The Pulitzer Prize nominated book *Chaos: Making a New Science* brought these strange yet compelling mathematical ideas to the lay public.[321] The popularity of chaos theory was also helped by its connection to fractals. Fractals proved to be a good way to visualize chaotic systems. Just like a chaotic system, a fractal can contain both repeating patterns and a high degree of nonlinear messiness. Indeed, the New Museum 1989 exhibit I mentioned above was as

[320] It is unclear exactly what techniques Buckland is referring to here. It is possible he is thinking of ―ray tracing” technology, which simulates the reflection of light. Perhaps he is also thinking about the way dinosaur models are ―rigged” with joints that bend only in certain ways. At the very least he is correct in assuming there are all manner of mundane computations that approximate the function of real things in the interest of realism.

[321] James Gleick, *Chaos: Making a New Science* (London: The Folio Society, 2015).

much about chaos theory as it was about fractals. As knowledge of chaos theory spread it became less conceptually nuanced, though, as so many ideas do. The term came to refer generally to any concept relating to dynamic nonlinear systems. This is the definition of chaos theory we see at work in *Jurassic Park*.

As the preceding chapters have explained, by 1992 there was substantial interest in how unpredictable, emergent processes could be harnessed and made useful. The management styles of the emerging VFX and animation industries illustrate this, and the principals of R&D had already made this clear for quite some time. Indeed, the VFX industry that made *Jurassic Park* possible functioned much in the same way the fictional park did: both used the unpredictable nature of science (and in the case of VFX, creativity) as a resource with which to develop a profitable industry. The difference is that VFX studios only occasionally explode into entropy the way the titular park did, thanks to management techniques developed in the R&D complex. Indeed, *Jurassic Park* proved to be an entertaining illustration for management science literature. At least three academic articles on management use the film to discuss the management of nonlinear dynamic systems.[322] Two of the research articles focus on education administration and one on healthcare. These are not facile attempts to grapple with these concepts, but rather specialized research that used the wildly popular film as an illustration.

Jurassic Park‘s glaze on dynamic nonlinear systems forefronts the question of why and how unpredictable changes occur. This is a theme that I find in all of the remaining examples in this chapter, and many more besides. It is tempting to conclude that this is a feature of disaster films in general. Certainly the examples I address here all conform in one way or another to some kind of genre formulation. For example, *Jurassic Park* fits well with Maurice Yacowar‘s disaster category of the ―ship of fools" where a disparate group of people are brought together in a survival situation.[323] *Jurassic Park's* lawyer, financier, palaeontologists, children, and ―rock

[322] Peter Galbraith, ―Organisational Leadership and Chaos Theory: Let‘s Be Careful," *Journal of Educational Administration* 42, no. 1 (February 1, 2004): 9–28; Helen Gunter, ―Jurassic Management: Chaos and Management Development in Educational Institutions," *Journal of Educational Administration* 33, no. 4 (October 1, 1995): 5–20; David A. Katerndahl, ―Lessons from Jurassic Park: Patients as Complex Adaptive Systems," *Journal of Evaluation in Clinical Practice* 15, no. 4 (August 1, 2009): 755–60.

[323] Maurice Yacowar, ―The Bug in the Rug: Notes on the Disaster Genre," in *Film Genre Reader III*, ed. Barry Keith Grant (University of Texas Press, 2003), 279.

star" mathematician bare a strong resemblance to *Stage Coach's* (1939) unlikely combination of a prostitute, lawman and society lady. There are more capacious definitions of the disaster genre that would include all of the examples in this chapter as well. Certainly all of the films in this chapter would conform to Yacowar's more expansive definition of a disaster film as any film that depicts ―a situation of normalcy [that] erupts into a persuasive image of death."[324] This definition is perhaps too capacious, given that it would include all horror films, but it does highlight an issue that all of the films addressed in this chapter are dealing with: the ontology of radical unpredictable change.

This is a question far too large for any one historically or culturally specific genre. Indeed, this is a very fundamental *big question*, a question at least as old as the *Book of Job*. For this reason, I do not find genre to be a very useful way to understand these films. Instead, Whissel's use of micro-genre is more useful. I am interest in how specific effects engage the meaning of disaster or catastrophe through the paradigm of nonlinear simulation. While *Jurassic Park*'s narrative brings up relevant topics and its photorealistic dinosaurs convey a sense of emergent virtual life, they do not speak to that life as chaotic or unpredictable specifically. The remaining examples all demonstrate how simulation FX sequences can do exactly this, how they can function as an emblem for chaos and unpredictability as understood through nonlinear simulation.

Twister (1996)

In the 1996 film *Twister,* a tornado-chasing scientist (Helen Hunt) is motivated by the way tornados unpredictably appear and follow seemingly random paths, the way they ―skip this house and that house and come after you." Her solution is to build a model of a tornado using a sort of motion tracking system. The climax of the film sees the scientists successfully inserting dozens of motion trackers into a tornado. This is represented both through the realistic animation of the actual tornado and through a parallel visualization on the scientist's computer. ILM animated the complex, detailed swirling of particles in the tornado with Wavefront's recently released software Dynamation.[325] As with the other examples I have addressed thus far, the film

[324] Ibid., 277.

[325] Dynamation was noteworthy at the time for its usability because it had a build-in user oriented scripting language.

makes a connection between a digital display and a diegetically real phenomenon, thus reinforcing the realism of the digital VFX.

The scientist‘s quest for an answer to why tornados happen once again taps in to contemporaneous discourses in science and computation. The computer visualizations in *Twister* recalls the National Centre for Supercomputing‘s 1989 *Visualization of a Numerically Modeled Severe Storm*. This computer visualization, which also used an early version of Wavefront software, was so visually compelling it was nominated for an academy award.[326] The visualization was based on a National Centre for Supercomputing simulation of a devastating weather system in Oklahoma in 1964.[327] Scientists took atmospheric conditions from that event and tried to see if they could precipitate similar events in a dynamic nonlinear simulation. This simulation was therefore directed at answering exactly the question that bedevils the scientist in *Twister*: what complex interaction of conditions causes tornados to form and behave the way they do? Where do disasters come from?

This question recalls mathematician Rene Thom‘s famous catastrophe theory. Thom studied the moment a dynamic nonlinear system goes from a state of ―smooth change" to a state of ―abrupt response."[328] In other words, he investigated what happens at the moment when a predictable situation ―bifurcates" into unpredictable dynamic change. British mathematician Erik Christopher Zeeman developed Thom‘s initial ideas further in the 1970s. Zeeman‘s work lead to a greater popularization of the concept, likely because he also developed a compelling visual model for his ideas: the Catastrophe Machine. The catastrophe machine is a pendulum with an extra point of articulation in its arm. When the pendulum is turned by an electrical motor in a regular pattern the articulated arm moves in crazily unpredictable directions. Catastrophe theory goes alongside fractals and chaos theory as a nonlinear mathematical theory that grew to have cultural meaning. Although *Twister* does not explicitly reference it, the way the film makes sense of the question of catastrophe is informed by the history of this mathematical concept. *Twister* is

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[326] M. Pauline Baker and Colleen Bushell, ―After the Storm: Considerations for Information Visualization," *National Centre Supercomputing Applications University of Illinois*, http://vis.iu.edu/Publications/Storm.pdf (accessed 12 January 2015), 1.

[327] John Vince and Rae EarnshawI, *Visualization and Modelling* (Morgan Kaufman, 1997), 2.

[328] Vladimir Igorevič Arnolʹd, *Catastrophe Theory* (Springer, 1992), 2.

about understanding the ontology of change through the paradigm of dynamic nonlinear simulation.

The scientists want to gather enough data so they can make a predictive model. The model will finally provide some answer to the menacing unpredictability of the tornado. The animated tornado is an emblem for these ideas. It conveys a sense of simulated catastrophic unpredictability.

Following in the path of *Twister*, the remaining examples in this chapter both focus on weather phenomena. Weather is in many ways the archetypal dynamic nonlinear system. As I noted, Lorenz‗s discoveries about chaos came from weather simulations. And as I have covered in previous chapters, weather modeling and prediction has been a major driver of research in nonlinear simulation in institutions like the Los Alamos National Research Laboratory. Weather is also a familiar and relatable kind of contingency. Humans have always been at the mercy of the unpredictable nature of changes in weather. These combined factors make an ideal way of addressing the epistemology of nonlinear simulations. I will pursue this idea further in the following examples.

The Perfect Storm (1999)

The Perfect Storm follows a fishing crew during a historical weather event which took place in the fall of 1991 in the North Atlantic, referred to as the Halloween Nor‗Easter, The No-Name Storm or The Perfect Storm. While the plot of the film concerns the fishing crew‗s decision to risk adverse weather in exchange for a big haul, the themes of the film concern why events such as these occur. In one scene a meteorologist (Christopher McDonald) explains, with the help of computer visualization, how pressure systems and air masses are interacting with the already-formed Hurricane Grace to create a super-storm. He says, ―you could be a meteorologist all your life and never see something like this; it would be a disaster of epic proportion..." Every one of these unlikely factors had to be in place at the exact right time in order for a storm of this magnitude to take shape. Again, like *Twister, The Perfect Storm* approaches these events as though they were dynamic nonlinear simulations. They use the same logic as the National Centre for Supercomputing. Indeed this film, and the book it was based on, popularized the term *perfect storm* as a way of describing when a set of conditions happen to coincide in such a way that they precipitate a negative event.[329] This term has taken on even more specific meaning in the last few years, as it was used frequently in press stories regarding to the global financial crisis.[330] As I have noted in past chapters, financial markets are akin to weather in that they are highly unpredictable dynamic systems that certain groups would benefit immensely from understanding better. Like weather disasters, economic disasters are also a form of contingency that is important to the average person. The average worker with retirement savings is not unlike the farmer of past centuries, both must contend with the knowledge that their prosperity relies on changes that are beyond their ability to predict. The term perfect storm demonstrates how important the epistemology of complex systems and nonlinear simulation has become, not only to weather but also to financial markets. Indeed the generalization of this term suggests that we have begun to think of all sorts of phenomena in these terms.

Digital media and games scholar Mark Wolf has proposed that this way of thinking about past events through the paradigm of simulation opens up a new category of documentary, which he refers to as ―subjunctive documentary.” Wolf believes that computer simulations can be used to represent ―what could be, would be or might have been” rather than what *was* or *is*.[331] Much like Warren Buckland‘s thoughts on *Jurassic Park*, Wolf‘s subjunctive documentary fits halfway in-between fiction and documentary, it is imaginative, but it is also oriented toward understanding reality. Citing Jonathan Crary‘s studying of optical tools, Wolf suggests that in the same way we began to understand reality through the new visibilities created by microscopes and telescopes, our understanding of reality is changing once again through the episteme of

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[329] A Google Ngram search reveals the term was used little before the book‘s publication in 1997, https://books.google.com/ngrams/graph?content=%22perfect+storm%22&case_insensitive=on&year_start=1980&year_end=2008&corpus=15&smoothing=3&share=&direct_url=t4%3B%2C%22%20perfect%20storm%20%22%3B%2Cc0%3B%2Cs0%3B%3B%22%20perfect%20storm%20%22%3B%2Cc0%3B%3B%22%20Perfect%20Storm%20%22%3B%2Cc0. ―Perfect Storm - Definition of Perfect Storm in English | Oxford Dictionaries,” *Oxford Dictionaries | English*, accessed March 4, 2017, https://en.oxforddictionaries.com/definition/perfect_storm.

[330] For one of many examples see: Manav Tanneeru, *"How a 'perfect storm' led to the economic crisis," CNN ,* 29 January 2009, http://articles.cnn.com/2009-01-29/us/economic.crisis.explainer_1_housing-bubble-housing-market-wall-street?_s=PM:US (accessed 12 January 2015).

[331] Mark J. P. Wolf, *Abstracting Realty* (U P of America, 2000), 262.

simulation. The laws of physics used in computer simulations are simply new ―conceptual indices" to reality.[332] While Wolf is thinking about scientific visualization tools, his ideas can be applied more broadly here. Perhaps, following Buckland, we can think about VFX this way. This is a subject I will pick up in my conclusion chapter.

It is also worth noting that, once again, *The Perfect Storm* creates a parallel between data visualization and a simulated VFX. The simulation FX in this film represented a significant advance in fluid simulation. The bulk of the film takes place at sea in the storm, and while the actors and the boat set were shot in a wave tank, the ever-present ocean setting was entirely animated through ILM's OCEAN fluid simulation technology. It is perhaps the best example of the second generation of fluid simulation I describe in chapter 2. These images were therefore created with tools that were designed around this same epistemology of simulation: artists set conditions and then see what sort of movement results, they do not control the waves directly. Just as a real storm can be understood as the result of unpredictably interacting factors, an animation of a storm can be made with virtual factors. The audience is prompted to think about phenomena on screen through an epistemology of nonlinear simulation while they are also simultaneously presented with animated photorealistic images that were created using simulation. Simulation FX are an emblem for the concept of a perfect storm.

The Day after Tomorrow (2004)

Released just four years after *The Perfect Storm*, *The Day After Tomorrow* takes a similar approach to weather catastrophes, but with the added dimension that it is oriented toward imagining possible futures rather than representing the past. The epistemology of nonlinear simulation lends itself to this sort of temporal flexibly. Just as simulations of past events speculate about how phenomena can emerge from specific conditions, simulations of the future can speculate about how current conditions might give rise to events that have not yet happened. This ability to predict the future is, as I have noted in past chapters, a key factor driving research into simulation tools. For example, the United States Air Force, an organization that clearly had an interest in predicting weather conditions, funded early weather research.

Along with *An Inconvenient Truth* (2006), *The Day After Tomorrow* is one of the two key films of the 2000s that sought to promote awareness of anthropogenic global climate change to

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[332] Ibid., 269.

the public.[333] The title of the film is meant to evoke the widely watched 1983 telefilm *The Day After,* which portrayed a hypothetical global nuclear war and its aftermath. The implication being that climate change is the present generation‘s version of the global peril of nuclear war.[334] Like *The Perfect Storm*, *The Day After Tomorrow* is notable for its use of new fluid simulation tools. Promotional material, especially trailers, heavily featured clips from a sequence where a colossal wave crashes into New York City, engulfing the statue of liberty and carrying freight ships downtown, crashing into buildings. This wave was animated using Digital Domain‘s FSIM dynamic simulation software. As I noted in chapter 2, this effect belongs to the same second-generation technology of fluid simulation techniques as *The Perfect Storm.*

The Day After Tomorrow imagines a future where anthropogenic changes in global temperatures set off dramatic changes in weather. The weather phenomena portrayed in film are, however, so dramatic, so rapid and on such a great scale, they generally detract from verisimilitude. Events featured in the film include the aforementioned wave in New York, which is as high as a skyscraper, a series of tornadoes that tear apart buildings in downtown Los Angeles, and the sudden onset of a new ice age that renders most of the United States uninhabitable. All of these events occur in the matter of a few days. The film follows in the many disaster genre tropes of its time, established by films like *Independence Day* (1996) and *Armageddon* (1998), where a great deal of visual novelty (and perhaps perverse pleasure) is derived from seeing recognizable landmarks and locations catastrophically destroyed.[335] *The Day After Tomorrow* is noteworthy, however, for the way it poses thematic tropes, conceptual frames and visual spectacles relating to nonlinear dynamic systems and simulation.

Much like the other films I have looked at so far, *The Day After Tomorrow* features sequences where a scientist explains the causes that lead to these catastrophic events. Indeed *Twister*, *The Perfect Storm* and *The Day After Tomorrow* all feature a strikingly similar scene

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[333] The idea for *An Inconvenient Truth* was reportedly formed at the world premier for *The Day After Tomorrow*. Andrew C. Revkin, ―An Inconvenient Truth - Al Gore - Movies," *The New York Times*, May 22, 2006, http://www.nytimes.com/2006/05/22/movies/22gore.html.

[334] Interestingly, *The Day After* was the next film project of director Nicholas Meyer after *Star Trek II: The Wrath of Kahn*.

[335] It is worth noting that Roland Emmerich directed both *The Day After Tomorrow* and *Independence Day*, and he has a signature style of spectacular destruction.

where a scientist looks at a computer model and predicts the impending disaster, only when it is already too late, of course. *The Day After Tomorrow* additionally features a scene where the protagonist scientist Jack Hall (Dennis Quaid) uses visualizations of his climate simulations displayed on a large video wall to warn a group of world leaders about climate change. He explains that changes in global temperatures could upset the regular flow of air and ocean currents, causing the system to collapse into wild disarray.

Like the other films discussed in this chapter, *The Day After Tomorrow* creates an ontological connection between diegetic data models, display screens and the VFX events that follow. The animation of the great wave that hits New York was the actual product of simulation FX and diegetically the catastrophe is understood through the epistemology of nonlinear simulation.

The explanation the film offers of the mechanisms driving the wildly destructive events it features is actually more detailed than the other examples in this chapter. The description the character Jack Hall offers of how global air and ocean currents could be destabilized by a change in temperature is, at its core, based on the same principals as real climate change science. The global flow of sea and air currents and their exchange of heat is a complex yet stable system. In the phraseology of Rene Thom, it is *smooth*. The introduction of anthropogenic warming threatens to throw this stability into disarray though. Just as Lorenz found that small change in input can result in massively different results, such an abrupt change destabilises the whole system: jets streams move, dry areas become wet, warm areas become hot, etc. This is one of the key anticipated adverse effects of climate change.[336] Given recent events like Hurricane Sandy, the core principal of climate change causing destruction does not seem quite so remote as it once did, and *The Day After Tomorrow* likely affected how some of the public apprehended such an event. Indeed stills from the film were circulated on social media at the time, deceptively labeled as real images of the hurricane.[337]

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[336] James E. Overland et al., ―Nonlinear Response of Mid-Latitude Weather to the Changing Arctic," *Nature Climate Change* 6, no. 11 (November 2016): 992–99.

[337] Amanda Holpuch, ―Hurricane Sandy Brings Storm of Fake News and Photos to New York," *The Guardian*, October 30, 2012, https://www.theguardian.com/world/us-news-blog/2012/oct/30/hurricane-sandy-storm-new-york.

It is worth noting how much of our understanding of actual climate change does rely of data models and simulation. Although it may seem that simple data points such as historical ocean temperature recordings are the primary source of our understanding of climate change, these data points are meaningless until climate researchers put them into a model. As Paul Edwards argues in his book *A Vast Machine*, ―everything we know about the world's climate - past present, and future- we know through models.”[338]

The Day After Tomorrow is a unique case. *Twister* and *The Perfect Storm* prompt us to think differently about subjects that were generally already pretty ontologically stable: the viewer has a general idea of what a tornado or a wave is. By contrast, climate change is still relatively remote and abstract. It cannot be understood by any means other than nonlinear simulation. Although the VFX spectacles in the film are risible for being so over-the-top, the simulation FX emblems in the film make climate change sensible. They even make it feel present and menacing. In some ways *The Day After Tomorrow* is very similar to a more recent work of science fiction about climate change that has been received by critics much more positively, Claire Vaye Watkins' novel *Gold Fame Citrus*. On the surface Watkins' book is an inversion of *The Day after Tomorrow,* instead of focusing on New York it focuses on Los Angeles, and instead of rising sea levels and cold, climate change brings about crushing heat and a massive deserts. The desert is what I want to focus on. Watkins puts a lot of focus on what she calls the ―Amargosa Dune Sea,” a desert of massive sand dunes that slowly spreads and envelops everything in its path. She writes,

> Still rose the dune sea, and like a sea now making its own weather. Sparkling white slopes superheated the skies above, setting the air achurn with funnels, drawing hurricanes of dust from as far away as Saskatchewan. Self-perpetuating then, the sand a magnet for its own mixture of clay, sulphates and carbonate particles from the pulverized bodies of ancient marine creatures, so high in saline that a sample taken from anywhere on the dune will be salty on the tongue.[339]

[338] Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, Mass.: The MIT Press, 2013), xiiv.

[339] Claire Vaye Watkins, *Gold Fame Citrus* (London: Riverrun, 2017), 118.

Her descriptions of the dune make it feel material and present. She animates it through her descriptions of its churning movement. The dune in turn makes climate change itself material, present and indeed implacable. *The Day after Tomorrow* attempts something similar with the scene where an improbably giant wave engulfs Manhattan. The difference is that the film uses simulation FX to make the wave feel material and present. The film uses the same epistemology that makes knowledge of climate change possible in an attempt to make it sensible.

Conclusion

Clearly there are two different medial registers at work in all of these examples. On one hand, there are the VFX images themselves, which (*Jurassic Park* aside) employ some sort of simulation FX technology. On the other hand, these films have clear thematic preoccupations with topics such emergence, contingency and risk, and they mediate these concepts through the lens of complex systems, computation, data visualization and nonlinear simulation. The way these films understand things like the development of life, catastrophic weather events and climate change is informed by this episteme. I have offered examples that I believe establish that these two registers are united by more than just sharing the same historical context; the narrative and VFX work together. They are more than the sum of their parts, as Whissel theorizes.

It is worth noting that in other areas where nonlinear simulation tools are employed in symbolic and cultural creation such a connection very clearly exists. For example, in architecture the tools of computation and nonlinear complexity merge with themes and theories of design. There is general consensus that architecture went through a sort of *turn* in response to the concepts and technologies I have been studying in this chapter. Early writing on the subject by theorist Greg Lynn is a good example of this. In his book *Animate Form* Lynn advocates for ideas like using simulated forces to shape designs.[340] Lynn advocated for these techniques as a way of exceeding architecture‘s historical bind with stasis. Writing in 2011, scholars Achim Ahlquist and Sean Menges observe this change as a shift from ―computer-aided design" to ―computational design." They believe that this shift resulted from both changes in tools and changes in theory, together.[341]

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[340] Greg Lynn, ―Animate Form," in *Animate Form* (Princeton Architectural Press, 1999), 9–30.

[341] Achim Menges and Sean Alquist, *Computational Design Thinking* (Wiley, 2011).

Architecture and VFX are in many ways quite similar. Like VFX, architecture has a liminal position between academics and industry, with professors and graduate researchers often working on private projects. They are quite historically distinct in other ways though. Unlike the VFX industry, architecture has a substantial emphasis on theorization and on putting that theorization to work in designs. Architects and theorists have put a substantial amount of effort into understanding what concepts like computation and dynamic complexity mean and how they should inform design in architecture. One might therefore conclude that VFX tools and film narratives are not meaningfully connected. The VFX for a scene is made after the script is written, after all. Yet I believe this chapter has brought persuasive evidence to the contrary. In every film studied in this chapter there is some sort of digital display: the computer console on the USS Enterprise, VR helmets in *Jurassic Park*, motion tracking field equipment in *Twister*, meteorological models displayed on digital maps in *The Perfect Storm*, and global climate models visualizations in *The Day After Tomorrow*. Each of these is a sort of legible form of computational mediation that makes a connection between the realistic VFX images and the idea of their computation. These screens connect VFX images with narrative.

Thus, my findings sit somewhere in between the theories of Dan North and Mary Ann Doane. Consistent with Doane's work, I think there is an episteme forming the conditions for knowledge at work in these films. There is an epistemic a priori at work here that conditions how we can even being to think about these subjects, and indeed the very fact that we think about these subjects at all. Before the phrase perfect storm ever entered into our vocabulary, we were primed for that particular explanation of catastrophe. There was a reason it became such a popular way of making sense of other events, like the 2008 financial crisis. This is not to say that these texts are not reflexive about how they are making sense of these subjects though. The inclusion of screens and little gestures like the projection of DNA code onto the cloned dinosaur are clear signs that the films are thinking through these subjects. Consistent with Dan North's theory of VFX, there is something being negotiated here. Indeed, there seems to be evidence that the simulated VFX in these films are meant to be apprehended consciously as mediation effects. The way *Jurassic Park's* discourse of digital animation outpaces the actuality of the VFX techniques used offers proof of this. All of the effects I study in this chapter are absolutely designed as spectacles. They feature prominently in promotional material, and the aesthetic pacing of the films leave ample time to marvel at them. These are not background effects; they are there to be seen.

As I noted in the beginning of this chapter, Kristen Whissel‘s concept of the special effects ―emblem,” offers the best way I have found to make sense of the respective roles of VFX spectacles and narrative. As emblems, the VFX spectacles are not suspensions of narrative, they punctuate the themes of the narrative. They are an illustration. The narrative primes us to think about events through the paradigms of nonlinear complexity and computation, and then the film hits us with an illustration that can be experienced aesthetically. First the audience is prompted to think about events through simulations using digital displays and explanations from scientist characters, then they witness these events as nonlinear simulations. The VFX spectacles are not simply fakes, they are not deceptions, they are simulations. They have an important connection to reality that goes far beyond visual semblance. Indeed, many of these simulated VFX sequences are not photorealistic. The ―Genesis Sequence,” for example, is meant to look like a simulation of data, it does not mimic how something would appear to the eye. This is a different kind of realism. And this different kind of realism comes from an epistemic frame that is being established all around us, through meteorology, economics, and even the language we use to describe certain events and phenomena.

One qualification I should make to these findings is that they only apply to a specific sort of VFX in a specific sort of film in a specific time period. Many of the techniques employed in these films have become commonplace background effects, something more akin to a moving matte painting. I should also reiterate that effects-oriented films have a special relationship to the way they employ and represent technologies. Other types of film obviously do not have the same approach to spectacles of technology. Novelty is clearly important here, but this novelty is not trivial. New ideas and new technologies are being negotiated here; this is a period of change. Soon these concepts and technologies will become settled and commonplace. They will become a too-familiar part of how images are made and how we think about the world to be worth noticing.

Conclusion: Nonlinear Simulation and Realism

In this thesis I have set out to use simulation FX to explain how a historically specific technology, epistemology and form of institutional organization influenced the way Hollywood films are made. In doing this, I have also covered many of the ways nonlinear simulation and the R&D complex are at work in several other facets of society where businesses or institutions attempt to model and manage unpredictable complexity. I hope that I have offered a novel way of understanding this period in recent history, and of understanding how Hollywood cinema, especially the blockbuster, fits in to this historical context. Nonlinear simulation and R&D demonstrates that we need to look deeper than *the digital* to understand this period of time.

In chapter 1 I covered the fundamental concept of nonlinear simulation, including dynamic nonlinearity and stochastic nonlinearity. These concepts use either random numbers or the dynamic complexity of co-influencing factors to simulate the unpredictability of reality. In this chapter I also introduced what I refer to as the R&D complex, the organizational and institutional context that developed nonlinear computer simulation, and I explained how these types of simulations are emblematic of the logic of R&D, which seeks to direct the unpredictable process of scientific discovery toward specific technical applications. In chapter 2 I showed how the R&D complex became connected to the Hollywood film industry, focusing on SIGGRAPH as a contact zone between research institutions, state funding and various kinds of industries. Over the period of 1980 to the early 2000s SIGGRAPH saw the rise of the importance of media industries R&D investment, which shaped development toward applications like computer animation and VFX. This was the institutional context that gave birth to simulation FX. Chapter 3 demonstrated how these changes affected the Hollywood film industry, noting the particular character of the VFX and animation industry, and demonstrating how R&D and nonlinear simulation shaped the management philosophies governing VFX and animation studios. I also looked more closely at the simulation FX production process and how it folds together R&D and image making. Finally, in chapter 4 I studied the how nonlinear simulation was represented in popular culture by looking at a few specific films. Several films that addressed nonlinear simulation in their narrative also featured simulation FX spectacles, and I theorized that simulation FX sequences have a sort of legibility as nonlinear simulated images, and that they make the themes addressed in the film aesthetically sensible as a kind of special effect emblem.

The concept of the R&D complex has been a vital part of explaining simulation FX. As I explained in the introduction, I believe this is a function of the nature of R&D. R&D combines both open ended discovery and application-oriented direction. It combines what Raymond Williams calls ―looked for" technology with the unlooked-for contingency produced by the physical world.[342] This puts the agency of the social and of institutions in balance with the agency of the physical world. Thus, I believe the R&D complex, as an institutional phenomenon and an organization paradigm, and simulation FX, as a set of technologies, practices and production conventions, must be understood as a dyad, with each feeding into the other. Each has relevance outside the other, of course. The R&D complex shaped a variety of things in the modern world, including computer graphics in general, and all potential uses of simulation FX are not necessarily contained within the R&D complex. But if we are to understand the impact of either, their emergence and the forces that shape them over time, we must understand both.

On Hyperrealism

Simulation FX and R&D's mutual desire to both foster unlooked-for unpredictability while also shaping and controlling it make them unique in the history of moving image media. As I established in the introduction to this thesis, this is a very different way of thinking about simulation than the approach post-modern theory and the concept of hyperrealism offers us. Hyperrealism is used by post-modern theorists such as Jean Baudrillard to describe a kind of artificial realism that is more perfect and flawless than reality itself. Throughout this thesis I have tried to offer a more nuanced understanding of nonlinear simulation, one that is connected to real and historically important ways of understanding reality. This is a very different way of understanding the era of post-modernity and its visual culture. I have approached simulation not as a by-product of late capitalism, but as an epistemology that both influenced and is influenced by economics, politics and culture. In this sense I have taken an archaeological approach to this subject, studying a historically specific epistemology discreetly, without trying to weave it into a larger overarching narrative like post-modernity.

Some scholars use the term hyperrealism without connecting it to post-modernity though. And these uses of the term also warrant consideration. Hyperrealism can be a way for film

[342] Raymond Williams, *Television: Technology and Cultural Form* (London: Fontana/Collins, 1974), 14.

theorists to identify new digital threats to cinematic realism. For exampling, in *What Cinema Is!* Dudley Andrew roundly criticizes the film *Amelie* (2001) for its seamless digitally retouched, hyper-realistic appearance.[343] Conversely though, hyperrealism can also be used by animation and digital media scholars to identify forms of moving images that seem to copy past forms of representation. Here the terms ―second-order realism" and photorealism are very close to hyperrealism.[344] It is this latter use of the term I would like to examine further, because this is often how simulation FX images are interpreted by scholars.

Animation and digital media scholars generally work from the assumption that all realism is illusory and that objective realism is an unrealistic or ideologically suspicious goal. When animation and digital media scholars use the terms hyperrealism, they are not criticizing an image for being meretriciously realistic, they are criticizing an image for aping an old way of seeing the world. Animation and digital media scholars take issue with this because, converse to the way a traditionalist film theorist might celebrate cinema‗s fidelity to reality, they then to celebrate a total lack of representational fixedness. Hyperrealism thus stands not for a betrayal of cinematic realism but for a betrayal of the representational fluidity and openness of animation.

A majority of animation scholars celebrate animation‗s capacity for formless fluidity**.** It could perhaps be called the central principal of animation studies. The oft-cited ur-theory of this discourse is Sergei Eisenstein‗s description of the ―plasmatic" nature of early Disney shorts. Though Eisenstein sees animated plasmaticness as an escapist symptom of capitalism, he cannot help but appreciate the anarchic potential in the formless transformation of Disney characters.[345] There seems to be no consistent rules controlling their world, there is nothing but change. Much contemporary theory follows in this logic. Contemporary scholar Paul Wells uses *Felix the Cat* cartoons as an example of how animation‗s capacity to present a topsy-turvy anarchic world has

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[343] Dudley Andrew, *What Cinema Is!: Bazin's Quest and Its Charge* (Malden, MA: Wiley-Blackwell, 2010), 18.

[344] Andrew Darley, ―Second-Order Realism and Post-Modern Aesthetics in Computer Animation," in *Animation Reader: A Reader in Animation Studies*, ed. Jayne Pilling (Sydney: John Libbey, 1997), 16.

[345] Sergei Eisenstein, ―On Disney," in *The Eisenstein Collection*, ed. Richard Taylor (London; New York: Seagull Books, 2006).

subversive potential.[346] Similarly, animation scholar Norman Klein celebrates animation‗s ability to create ―animorphs," images that are suspended in an in-between state of a process of transformation.[347] Examples abound, and the animation studies canon is full of examples of this kind of formlessness, from Emil Cohl‗s *Phantasmagoria* (1908) to Ryan Larkin‗s *Walking* (1969).

This way of thinking about animation situates it as a place to question and destabilize the rigid representational form of photographic cinema. A good example of this is animated documentary, which tends to question the authority of objectivity in favour of different, often subjective or experiential, epistemologies. In examples like *Waltz with Bashir* (2008), animation is used to convey the affective quality of the experience of memory and dreams, for example.

These commitments dictate the use of the term hyperrealism for animation scholars as a kind of antithesis. For example, Paul Wells uses the term to describe the look of Disney‗s animated features. Wells argues that the films that follow in the tradition of *Bambi* (1942) and *Snow White* (1937), which use techniques like the multi-plane animation stand, generally try to mimic the perspective and appearance of photographic film. The characters do not squash or stretch, or defy physics, they exist in a stable world of rules that mimics our settled ways of seeing.[348] For Wells this is a betrayal of the immense potential of animation.

As animation theorists struggle to make sense of the numerical and logical nature of digital animation, hyperrealism once again proves a useful point of distinction. While animation scholar Pat Power acknowledges that digital animation‗s origin in the military-industrial complex and Cartesian single point perspective cause it to mostly take the shape of hyperrealism, he defends digital animation because individual artists can use these tools to be expressive.[349] Digital animation can escape hyperrealism when it appeals to the realm of ―emotion, memory

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[346] Paul Wells, *Understanding Animation* (New York: Routledge, 1998), 21.

[347] Norman Klein, ―Animation and Animorphs," in *Meta-Morphing: Visual Transformation and the Culture of Quick-Change*, ed. Vivian Carol Sobchack (Minneapolis: University of Minnesota Press, 2000).

[348] Wells, *Understanding Animation*, 24.

[349] Pat Power, ―Animated Expressions: Expressive Style in 3D Computer Graphic Narrative Animation," *Animation* 4, no. 2 (2009): 111.

and imagination," when it portrays subjective realism rather than objective realism.[350] This is a sort of appropriation of the objective, discretizing DNA of digital tools.

This discourse of hyperrealism leads animation and digital media scholars to view simulation FX, couched as it is in objective science and the R&D complex, with extreme scepticism. A good example of this is Scott Bukatman‘s study of ―cartoon physics," where he addresses the subject of ―physical simulation" (a term more or less synonymous with simulation FX). Bukatman draws our attention to a long under-examined feature of animation: the unwritten codes that guide the rules of animated worlds. He argues that cartoons like *Felix the Cat* or the early Disney cartoons are not guided by total plasmatic openness like Eisenstein would hold; instead they are guided by consistent cartoon-world rules.[351] The rules of cartoon physics may be wacky, but they are still rules. They are an invention, like everything else in the animated world. Cartoon physics have real potential, according to Bukatman, because they can challenge a singular, dominant ―logic of the cosmos."[352] Thus, they are still representationally open. Even though he sees a great potential in the idea of imagined physics, Bukatman writes off simulated physics as hyperrealism. Simulated physics is too reliant on a rigid and objective way of seeing the world. The only time he sees potential in them is when their rules break, when there is a glitch in the system, thus revealing the frailty of their realism.[353]

Part of Bukatman‘s scepticism stems from physical simulation (or simulation FX)‘s embeddedness in contexts like the military-industrial complex or the blockbuster system, although he does not elaborate on this. This way of thinking is made extremely clear by Lev Manovich. In *The Language of New Media* Manovich puts physical simulation into a category of hyperrealism, alongside other computer graphics techniques like sophisticated lighting and lens effects.[354] Manovich notes the involvement of SIGGRAPH as a reason realism has become such

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[350] Ibid., 109.

[351] Bukatman, Scott, ―Some Observations Pertaining to Cartoon Physics; Or, The Cartoon Cat in the Machine," in *Animating Film Theory*, ed. Karen Redrobe Beckman (Duke University Press, 2014), 302.

[352] Ibid., 311.

[353] Ibid., 312–13.

[354] Lev Manovich, *The Language of New Media* (Cambridge, Mass.: MIT Press, 2002), 191–92.

an important concern in computer graphics (when he was writing in 2001). Manovich bases his critique of SIGGRAPH on a precedent set by David Bordwell and Janet Staiger. They argue that the society for motion picture engineers (SMPE) ―rationally adopted" realism ―as an engineering aim."[355] Manovich finds that SIGGRAPH does much the same, and he believes this is because of the influence of the U.S. Military and Hollywood. The former wanted realism for immersive simulators, and the later wanted it for VFX and animation. He writes,

> What determined which particular problems received priority in research? To a large extent, this was determined by the needs of the early sponsors of this research – the Pentagon and Hollywood…. The requirements of military and entertainment applications led researchers to concentrate on the simulation of the particular phenomena of visual reality, such as landscapes and moving figures.[356]

As a product of the R&D complex, simulation FX offers a restricted way of seeing the world that was simply given to artists by techno-scientific institutions that seek only empirical utility and authoritative objectivity. Simulation FX is mere hyperrealism, a betrayal of the immense potential of animation and digital media.

Is animation studies' version of hyperrealism a good way of making sense of simulation FX? Do I agree with Manovich and Bukatman's relatively cursory accounts? Based on my research, I would answer a qualified yes. I have demonstrated in the preceding chapters that simulation FX offer a way of seeing and representing that is deeply related to industrial techno-scientific ways of seeing and managing the world. This conforms exactly to the settled, dominant, authoritative and objective form of representation that the animation studies cannon so often questions and undermines. Indeed, by attended to the ongoing development of simulation FX and the way it continues to be sustained by the R&D complex, my research gives greater nuance to the way we can be critical of these connections. Simulation FX's relationship to other industries and to scientific research is not just an origin myth. I noted earlier how Pat Power sees something redemptive in computer animation when it exceeds its origins and finds ways to undermine its Cartesian discretization. But what I have shown is that simulation FX's connections to the R&D complex are not a case of mere origins. And, although I do not have

[355] Ibid., 191.

[356] Ibid., 193.

time to go into detail about other specific cases, this is true of many other computer graphics technologies at SIGGRAPH, to some extent, as well. While I am studying nonlinear simulation in a period of transition, a period when this paradigm is not totally settled yet, it is a way of seeing that is deeply connected to structures of power.

Simulation FX as Speculative Realism

Writing off simulation FX completely as hyperrealist would be too simple though. It would minimize the variety of different practices and different types of meaning we might extract from it. We should view simulation FX more complexly, complete with its variations, differences and contradictions. I believe there is a blind spot in the animation literature profiled above that offers a different way of thinking about certain cases of simulation FX. Scholars like Power, Bukatman and even Manovich assume that objectivity is synonymous with settled hyperrealistic ways of seeing, which are shaped by power and ideology. From this standpoint, only things like subjectivity and plasmatic formlessness can exceed mere hyperrealism. This way of thinking puts emphasis on the animator or the artists (and not the scientist or technician) as the person who is processing reality and expressing themselves. I would like to counter this way of thinking by highlight how simulation FX can break with hyperrealism and conventional ways of seeing, and the power and ideology those things imply, while at the same time continuing to be technical, scientific, objective, even realistic.

Simulation FX is certainly a product of its time. It is the product of the R&D complex, and it is based in scientific research. But perhaps these facts are not reason enough to write off simulation FX as representationally closed. Science is by definition about finding new ways of understanding the world, and engineering is an act of invention and creativity. If one brackets these activities as forms of animation and takes away the authoritative and singular epistemic claims they are usually attributed, perhaps there is a way to see them differently. Simulation FX open up novel forms of understanding, and they are, in many ways, very concerned with the limits of knowledge. Simulations are not as wildly unrestricted as the flowing lines of early Disney cartoons or Larkin's *Walking*, but they are also not bound to a single rigid form of representation. To build a simulation is to attempt a new way of understanding the world. This is why, as I noted in chapter 3, R&D and technological development are inseparable from making simulation FX images. Whether a team of scientists is doing fundamental research for a key hero effect in a blockbuster, or an artists is writing simple scripts to manipulate the parameter of a simulation in Blender or RealFlow, simulation artists and engineers make models as a way of making images. They represent the world through the models they build.

As I noted in chapter 1, simulations are a combination of theory and experiment. They tentatively test a given understanding of how a certain process functions. A simulation is but one attempt to model the mechanism behind some real phenomenon. It will never encompass the world in its entirety. In this sense simulation is similar to animation. Indeed, it could perhaps suit Bukatman‵s definition of cartoon physics. While simulations are more restrictive than cartoon physics, they are still arbitrary and invented. They are a theory, a speculation.

Gertrud Koch argues that animation is ―isomorphic" with scientific experimentation, in the sense that they both work at the threshold of our understanding of the world and invent theories for what is beyond.[357] In other words, animation and the experiment both speculate about reality in an iterative and contingent ongoing process. Perhaps we should not be so quick to assume that the product of teams of engineering and scientists working within the R&D complex will always be the opponent of the individual artist. On a certain epistemic level, artistic experimentation is the same as scientific experimentation.

As a way of gesturing toward the direction I believe further research in simulation FX might go, with the remainder of the conclusion I would like expand on this concept of the experiment, and of how the objective, science-based aspects of simulation FX might test our understanding of animation itself. As I noted, animation theory generally seeks to relativize stable establish epistemologies and objectivity through the subjective and the expressive. The fluidity of animation, and the way all drawn things must pass through the animator rather than a machine, seems to suggest that this is animation‵s key strength, or perhaps even its *telos*. Perhaps we need not think of animation in this way. Perhaps animation can be objective, even realistic, while still seeking out radically new epistemologies and relativizing old ones. It is possible to relativize an epistemology without using subjectivity.

My argument must be understood in the context of recent developments in philosophy concerned with the ―mind independence" of reality. An early example of this thinking was ―thing

[357] Koch is more focused on perceptual experimentation in her essay, but I believe her ideas are still useful here. Gertrud Koch, ―Film as Experiment in Animation: Are Films Experiments on Human Beings?," in *Animating Film Theory*, ed. Karen Redrobe Beckman, 2014, 132.

theory.” To call something a thing is to acknowledge its firstness, its existence before our attempt to perceive it, understand it or describe it. As Bill Brown writes, before “that green thing in the hall” is given a color or position by an observer, it is already a “thing.”[358] A variety of scholars have since taken up this line of thinking under banners like “speculative realism” or “new materialism.” Two key early figures of this movement to re-think realism are Quentin Meillassoux and Manuel DeLanda. I will briefly discuss these philosopher's ideas before explaining how simulation FX might apply to them.

For Quentin Meillassoux, advocacy for speculative realism took the shape of a critique of modern philosophy. In his book *After Finitude,* Meillassoux argues that since Kant, western philosophy has been shaped by “correlationism,” where we are unable to discuss reality without also considering humanities' access to it.[359] He argues that we have become so invested in critiquing and relativizing realism that we have tipped over into virtual solipsism. We risk becoming completely divorced from factuality. His response is not a credulous embrace of science authority though. In order to be able to think about a reality independent of human thought without falling into the trap of naive scientific realism, Meillassoux suggests that reality is difficult for us to understand not because of shortcomings in our understanding but because reality is constantly changing. We have to keep updating theories about scientific laws because those laws are actually constantly outstripping our ability to define them. This is what he refers to as the necessity of contingency. He replaces any basic assumptions of causality or sufficient reasons with what he refers to as “hyper-chaos,” where new things are constantly inexplicably emerging.[360]

It must be said that Meillassoux's philosophy looks from certain angles like a massive contradiction. How exactly do we *think* about *mind* independence? What is philosophy without humans or thought? Another prominent early philosopher of speculative realism, Manuel DeLanda, offers an answer to this question, and this is where the subject of nonlinear simulation comes in.

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[358] Bill Brown, “Thing Theory,” *Critical Inquiry* 28, no. 1 (Autumn 2001): 4.

[359] Quentin Meillassoux, Ray Brassier, and Alain Badiou, *After Finitude: An Essay on the Necessity of Contingency* (London: Bloomsbury, 2015), 5.

[360] Ibid., 64.

DeLanda's primary initiative is to interpret the ontology of Gilles Deleuze in a realist context, articulating his own version of process ontology. Focusing only on his work *Difference and Repetition*, DeLanda argues that Deleuze, “grants reality full autonomy from the human mind, disregarding the difference between the observable and the unobservable, and the anthropocentrism this distinction implies.”[361] Like Meillassoux, DeLanda also feels the need to accommodate objective sciences in some qualified way. In his book *Intensive Sciences and Virtual Philosophy* DeLanda takes examples of nonlinear sciences and argues for their compatibility with a process ontology that sees things becoming actual within a space of possibility. Like Meillassoux's work, this is an effort to formulate a realist position without locking things down into naïve scientific realism. DeLanda is highly critical of scientific positivists who only believe in the mind-independence of things that can be schematized within their established laws.

So how could we ever mediate the world in this way? How could we represent reality as the result of a non-deterministic process of becoming that is autonomous from human perception and understanding? The answer DeLanda offers is computer simulation. His book *Philosophy and Simulation: The Emergence of Synthetic Reason* runs through a variety of examples of how simulation can be useful as a tool for realist philosophy. DeLanda argues that simulation allows us to conceive of things, not merely in terms of their properties but also in terms of the virtual qualities of their tendencies and capacities. Simulation defines things in terms of what they may become. Simulation does “justice to the creative powers of matter and energy.” It is a way to explore the “structure of the space of possibility.”[362]

The key ontological gesture of this approach is that it allows us to see anything in the world as having been composed of an assemblage of interacting factors. DeLanda uses the example of a storm to illustrate this point. In a way it is obvious that a storm is composed of an assemblage of factors, it is an event that emerges as a result from things like temperature, air flow and moisture, but DeLanda's larger argument is that all things in the world are in fact

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[361] Manuel De Landa, *Intensive Science and Virtual Philosophy* (London: Continuum, 2002), 4.

[362] Manuel DeLanda, *Philosophy and Simulation: The Emergence of Synthetic Reason* (London: Continuum, 2015), 6.

ontologically the same as a storm.[363] Animals and even rocks are all material things that came-to-be as the result of an assemblage of contingent factors. Simulation therefore confronts us with the indeterminacy of reality, and the impossibility of schematising it using stable laws. It demonstrates reality's continued capacity to surprise us, to assert its autonomy. DeLanda's approach is akin to Meillassoux's concept of the necessity of contingency insofar as it undermines our ability to schematize reality by emphasising contingency and the singularity of every individual thing or event.

In order to imagine a speculative realist philosophy DeLanda effectively merges mediation and philosophy; he makes thought ―synthetic.” This sounds every bit as contradictory as Meillassoux‘s approach at first. Mediation is human after all. A medium is what sits between us and the world. Mark Hansen and W.J.T. Mitchell note the importance of the human in theorizing media in their *Critical Terms for Media Studies*, they write, ―Before it becomes available to designate any technically specific form of mediation, linked to a concrete medium, media names an ontological condition of humanization – the constitutive operation of exteriorization and invention.”[364] But this definition of media is not as far from DeLanda‘s approach as it may seem at first. DeLanda is describing a sort of ―humanization” through invention. Simulations are a sort of translator. Simulations can think without us, yet they are also ultimately our ―inventions.”

There is good cause to be a little sceptical of DeLanda's use of simulation. A few critics have noted how uncritical he is of simulation. Philosopher of science Matthijs Kouw writes in a review of DeLanda's book that simulation has more explanatory power for DeLanda than it does even for the objective sciences.[365] Could it be that he believes the virtual character of computer simulation is an effective homolog for his process ontology? Is he reducing reality to mere computation? Is this simply naïve scientific realism?

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[363] Ibid., 13.

[364] W. J. Thomas Mitchell and Mark B. N Hansen, *Critical Terms for Media Studies* (Chicago; London: The University of Chicago Press, 2010), xiii.

[365] Matthijs Kouw, ―Towards a Robust Realism?,” *Science as Culture* 21, no. 3 (September 1, 2012): 393–98.

I would argue that this is not the case. The commonality between Meillassoux and DeLanda that I have tried to bring out is not only their desire for mind-independent realism but also their advocacy of a speculative disposition. Any attempt to use simulation would be but a speculation, an anecdote, an experiment, a fictionalization that could at best glimpse some aspect of the character of reality. More than anything it confronts us with the limits of our understanding. In her book *The Invention of Modern Science*, Isabella Stengers writes, ―Computer simulations not only propose an advent of the fictional use of mathematics, they subvert equally the hierarchy between the purified phenomenon, (responding to the ideal intelligibility invented by the experimental representation), and anecdotal complications."[366] Simulations, in other words, offer us unlooked-for things that might confound our understanding of the world. Simulation can exceed the settled, restrictive epistemology that the arts generally attribute to science and technology. They speculate about reality.

DeLanda's uses examples from the history of simulation in his monograph. He discusses the National Centre for Supercomputing's 1989 *Visualization of a Numerically Modeled Severe Storm*, which I discussed in chapter 4, and he also looks at cellular automata and The Game of Life, which I discussed in chapter 1. His examples are all very scientific. But I would like to propose here that, as a fictional product of scientific research and technical work, simulation FX can be understood in the same way. Indeed, I think simulation FX might be an even better example, because while the scientists that work on these technologies are still part of the academic community, the evolving character of organizations like SIGGRAPH and the influence of media industries has carved out a unique niche where their commitments are not quite the same as other disciplines. Even the blockbuster's thirst for visual novelty could give rise to a truly new way of seeing.

It is true that the production workflows of simulation FX put a great deal of emphasis on control, and that in many cases simulations are *directed* to match some sort of perceptual quality of realistic appearance. But at the core of most of these animations and effects are the principals of scientific simulation. Each simulation is a machine for understanding and representing the world, but simulations can be adopted and abandoned at will, and they are only ever a theory: a guess at how things work. From this perspective the whole R&D and technology development

[366] Isabelle Stengers, *The Invention of Modern Science* (Minneapolis, Minn.: Univ. of Minnesota Press, 2007), 135.

process can be seen as the construction of temporary medium, one that will be modified and eventually replaced. Simulation FX pose a challenge for animation studies, with its tradition emphasis on the subjective and expressive. Simulation FX are imaginative and inventive, and they have the capacity to relativize epistemologies, but they do not pass through the mind of an animator the way tradition animations do. True, the simulation artist and all of the other workers build these animations with their imaginations. But they do not make the animations themselves. As I argued in chapter 3, they make the simulations that make the animations. The simulation software has some agency in this process. Its nonlinearity produces unlooked-for outcomes. To make an animated nonlinear simulation is to employ synthetic thought, to wonder about the world. Animation and media studies in general needs to better understand this type of work.

I would argue that some of the examples I have addressed in this thesis realize some aspect of this potential. It may at first seem controversial to claim that the blockbusters I studied in chapter 4 are anything more than classic hyperrealism, but as I have already argued, these films are clearly thinking about the epistemology of nonlinear simulation. Indeed, I believe chapter 4 demonstrates that these films address the mind-independence of the world through the concept of catastrophe. Catastrophe confronts us with the agency of a world that is beyond our ability to predict or control. The disasters in films like *Jurassic Park*, *The Perfect Storm*, or *The Day After Tomorrow* all demonstrate the non-anthropocentrism of the world. People are merely caught up in the chaotic processes.

The catastrophic, and even eschatological, themes in these films point to a world without us. This is in fact a feature in Meillassoux‘s philosophy as well. He uses the terms –ancestrality” and –dia-chronicity,” the idea of the world before and after humanity, as ways of thinking beyond humanity. He writes, –to think ancestrality is to think a world without thought – a world without the givenness of the world.”[367] When we think about the world before humans or after humans we must confront the existence of a reality independent of the mind. I believe this speculative realist approach dovetails very well with the way I observe these films representing catastrophe in chapter 4.

Of course these films are highly ideological and they reinforce many settled, ideological, ways of thinking, but in the way they address the specific topic of contingency and catastrophe I

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[367] Meillassoux, Brassier, and Badiou, *After Finitude*, 28.

see a glimmer of speculative realist thought. While simulation and R&D at first glance seem to offer only a way to control and contain contingency, and thus to tame or compromise it, this definition does not capture what is epistemically unique about them. The contingency of nonlinearity represents the threshold of our understanding, past this point reality is beyond our control and beyond our ability to predict. This is, again, the nature of catastrophe.

The tendency in animation studies to condemn closed forms of representation and celebrate things like plasmaticness is well founded. But a bias emerges from this, one we might even call correlationist, to focus on human experience, on subjectivity. Scholars like Pat Power are willing to tolerate the numerical discretization of digital animation only if it is used for expression. I think perhaps that animation theory is sometimes over-critical of all things technical and scientific and of efforts to understand or imagine objective reality in general. We should be highly critical of the authority scientific fact is socio-culturally granted, of course. But if inquiry into objective reality takes the shape Meillassoux and DeLanda describe, if it is imaginative and speculative, it might open new horizons for animation. It might help us to imagine what the world is like when we are not around.

Conclusion

It may seem as though this investigation of speculative realism contradicts much of the other work I have done in this thesis. I spent a good portion of my research investigating how simulation FX are linked with the way people like financial speculators, meteorologists and business managers see the world. To discuss simulation FX as imaginative and experimental is counter-intuitive. Few artists aspire to see the world the way a business manager does.

This final section demonstrates the breadth that studying simulation FX can yield though. Above all, I have focused on situating simulation FX and R&D historically, in an archaeological moment with a specific epistemology. Such a synchronic slice encompasses all opposing and competing discourses. Simulation FX are complex and varied. Indeed, I believe they demonstrate the need to think beyond several widely held assumptions in film studies.

Above all, this thesis demonstrates the need to understand simulation FX and R&D as part of film production. Doing this reveals the narrowness of certain contemporary assumptions in film studies, and puts others (finally) to bed. For one, there can be no doubt that cinema continues to live into the supposed age of the digital. Indeed, some of the most fundamental issues of cinema, like the interplay between automation and manual manipulation, continue to be fecund and evolving topics. Film and animation do not line up simply or obviously with automation and manual manipulation though. Furthermore, as I hope the preceding section on speculative realism demonstrates, a simple dichotomy between ideological realism and expressive subjectivity proves insufficient in the face of cases like simulation FX.

Although I have been at pains to chart historical changes in this thesis, I want to finally reiterate that R&D's relationship to film production did not begin with simulation FX or even computer graphics. Certainly simulation FX represents a particular kind of relationship between the two, contingent on a variety of developments I have highlighted, such as the United States government's post-Cold War shift from R&D funding to tax breaks, or the institutional development of computer science. But this is a link that goes all the way back to Edison at least. Recognizing technical and scientific work as part of production and exploring the theoretical consequences of that recognition is not an activity that needs to be limited to the past few decades or to the supposed digital era. The meeting of nonlinear simulation with VFX and animation presents an important case of scientific and technical production work though. One that gives us a unique access point with which to study the way we have been seeing and managing the world in the past few decades.

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