CHAPTER 3

Hollywood's R&D Complex

In the 2019 animated feature *Spider-Man: Into the Spider-Verse,* heroes Miles Morales and Peter B. Parker are trying to steal a piece of technology from an evil mega-corporation called Alchemax. To do this they must infiltrate the company's research lab. Rather than looking like the classic super villain's lab, Alchemax looks more like a contemporary tech company or digital animation studio. Indeed, it bears more than a passing resemblance to promotional photographs of Sony Pictures Animation's headquarters in Vancouver B.C., where the film was made. The lab is full of glass walls, floor-to-ceiling windows, and gleaming white surfaces. People work in large open workspaces, they ride bicycles to work, they sit on yoga balls at their desks, and they have a luxurious cafeteria. As the two heroes try to abscond with a computer, the villain Dr. Octavius (a head scientist at Alchemax) blocks their way. "Could you give that back to me, young man?" she asks in a polite voice, before thundering menacingly "It's proprietary!" The reference to proprietary technology is something of an inside joke. While it means little to the average audience member, it rings true for anyone familiar with the economic, organizational, and discursive logic of large animation and visual effects studios. Studios like Sony Pictures Animation invest considerable resources into developing proprietary technology, and they protect that intellectual property (IP) through a variety of methods including non-disclosure agreements, patents, litigation, and security. This scene offers a satirical demonstration of how fundamental R&D has become to the business of animation and VFX.

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Cinema has always been a field of constant technological change, and animation studios like Disney have historically been agents for technological change.[1] Yet the past thirty years have seen a shift in cinema's relation to technological development under the logic of R&D. This is a logic that sees media companies like Walt Disney operating research institutions like Disney Research, a private R&D lab that funds postdoctoral and tenure-track researcher's work on subjects from acrobatic robots, to performance capture, to software that can estimate children's physical characteristics based on their voices (really).[2] This entanglement of Hollywood and technological development first started to take shape in the 1980s, as the U.S. government began to replace Cold War federal research funding with tax-break incentives for private research, and it has intensified since.

Thinking about animation and VFX as both culture industries and technology industries transforms our understanding of how they function. Since the bankruptcy of Rhythm & Hues, a studio that had been receiving public recognition for their work in *The Life of Pi* (2012), the instability of the VFX industry has been the subject of discussion by industry press, workers, and scholars. While many have rightly pointed to the internationalization of labor and the competitive bidding system in VFX,[3] getting to the bottom of this economic instability requires understanding the substantial upfront costs and risks of developing new technologies.

Nonlinear animation offers the clearest case of how Hollywood became involved in supporting R&D. The film industry did not simply pluck animation technologies like nonlinear animation ready-made from the field of computer graphics. Instead, it supported research on nonlinear simulation, taking over for Cold War sources of support, drawing in researchers from other fields, and supporting research labs in universities. As audiences were starting to see early nonlinear animation in films like *Star Trek II: The Wrath of Khan* (1982), an extensive institutional and industrial reconfiguration was taking place behind the scenes. Since 1980 Hollywood has played an ever-expanding role in supporting the development of computer graphics technologies like nonlinear animation. It has become such an effective engine for technology development that "Hollywood software" is now used in a variety of other fields, from architecture to geophysics.

As Chap. 2 established, in order to understand the dramatic changes cinema has undergone in the past few decades, we need to look not only to the nature of the digital but to the institutional context of R&D. Seen from this angle, the film industry was not transformed by the appearance of some external technology, but instead it underwent institutional, economic, and discursive changes that resulted in new technologies. Hollywood R&D shaped many of the technologies that are supposed to have transformed cinema so dramatically since 1980. This chapter studies in detail exactly how this process works and how it came about.

This emphasis on the role of technology in VFX and animation might sound somewhat uncritical to readers who are familiar with the promotional bluster of these studios, which often promote their technological advances through a Silicon Valley-styled rhetoric of innovation. But a clear picture of the role of R&D in these industries undoes many of these promotional myths. In particular, this chapter counters the neoliberal myth of entrepreneurialism as the innovative antidote to ossified bureaucracy. Far from being mavericks working in isolation, studios tapped into Cold War research infrastructures and built new relationships with public institutions. R&D has also proven to be an effective tool for economic hegemony, keeping strategically valuable technology in the hands of the studios with the biggest budgets.

Complexes, Military-industrial and Otherwise

Hollywood's relationship to R&D in the past few decades is that of a *complex*. This is a term that requires some historical context. 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."[4] In psychoanalytic terms, a complex is a collection of unconscious thoughts grouped together around a specific subject, as in an "inferiority complex." One might also refer to a group of buildings sharing a common space as a complex. This concept of parts becoming a whole through their interrelation gained new meaning and political significance in the 1961 when President Dwight D. Eisenhower famously warned against the growth of a "military-industrial complex" in a speech at the end of his presidency.[5] Eisenhower spoke from a moment in American history that saw military spending continue to rise after the immense mobilization of the World War II, long outliving its practical utility. The war led to the creation of an organizational entity, a whole made of interrelated parts, a complex, yet one that was self-sustaining, even as the conditions that created it changed.

The military-industrial complex saw a co-dependent entanglement form between private industry, the government, and the military. Political science scholars describe this phenomenon as an "iron triangle," where policies made by Congress support bureaucratic institutions that benefit private interest groups, which in turn support congressional representatives.[6] Congressional committees allot funding for military programs that benefit defense contractors, who in turn support members of congress with campaign funds and by creating jobs in their constituencies. The term military-industrial complex thus does not only describe the emergence of a new institutional-economic collection of parts, it also describes a self-sustaining entity with its own internal logic. 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."[7] A complex such as this took shape in Hollywood at the end of the Cold War. It was not a complex of military hardware procurement but one of R&D.

The military-industrial complex supported R&D extensively through the World War II and after. Eisenhower recognized the effect the military-industrial complex was having on research. He observes in his speech, "a government contract becomes, virtually, a substitute for intellectual curiosity." Indeed, historian Douglas Brinkley claims the original subject of Eisenhower's speech was supposed to be the "military-industrial-scientific complex."[8] Three years after Eisenhower's speech, Sen. J. William Fulbright offered a more focused critique of the effects of the military-industrial complex on scholarship. He worried that the amount of funding directed toward supporting technological advances for the military was creating a "distortion of scholarship."[9] Fulbright was responding to trends in research and education that seemed to be intensifying rather than dissipating after the end of the World War II. In the 1950s, the Department of Defense accounted for 80% of federal research spending, which was higher than any time during the World War II.[10] In 1964, research spending accounted for 25 % of total federal discretionary spending.[11] The government earmarked this outsized spending for R&D that might offer national strategic value. In his history of how defense spending shaped American technical universities like MIT and Cal Tech, Stuart Leslie uses the term "golden triangle" to describe this military-academic-industrial complex.

Part of what made Eisenhower's original speech so striking was the suggestion that the logic of the military-industrial complex influences the very fiber of the nation. Its effects were "political, economic, even spiritual." The complex could make the nation more warlike or less free. This applied to R&D in particular. Eisenhower and Fulbright feared that the complex was influencing the products of research, producing technologies of death and misery instead of doing research that might help humanity understand itself and the world.

The military-industrial complex endures to this day. The government continues to buy M1 Abrams tanks despite the fact that the U.S. Army does not want them. And reasons to use military hardware, wars cold, hot, proxy, drug, or otherwise, have certainly been numerous since 1945. Yet much has also changed. Federal funding for research, for one, has changed dramatically since the 1960s. After the end of the Cold War, in the context of President Reagan's neoliberalism, the U.S. government's approach switched from directly funding R&D to providing tax credits for private research. While the total amount of R&D funding has continuously risen since the 1950s (except for a short period of stagnation during the 1990s recession), starting in 1985 federal funding began to level off, failing to keep pace with economic growth, while private industrial funding more than made up for its absence (Fig. 3.1).[12]

This decline in earmarked federal funds promised an end to complexes, especially for neoliberal free market apologists. It promised to "starve the

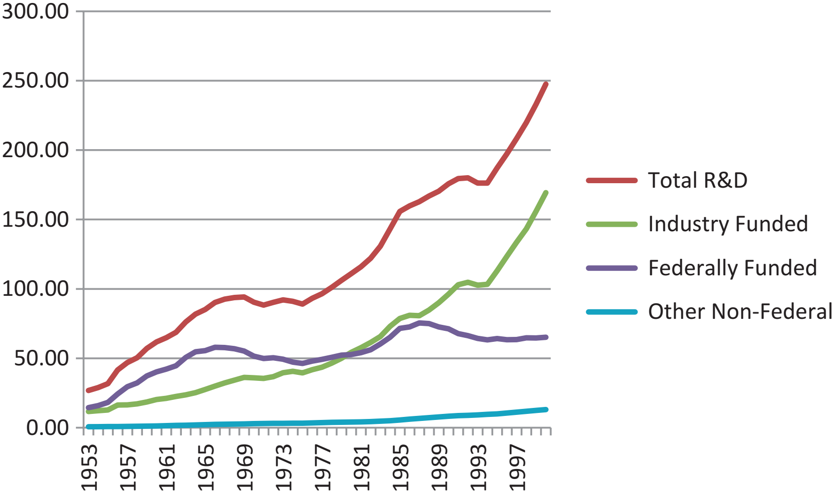

Fig. 3.1 R&D spending in the United States in billions of constant 1996 dollars

beast" rather than feed it, to use Reagan's term. Without the distorting effects of a complex, technology and the nation's "spirit" would finally be free or, to use Karl Popper's famous term, "open." Silicon Valley embodies this promise. These tech companies are supposed to be delivering innovation for economic growth through entrepreneurial autonomy: research directed not by the hand of the government but the invisible hand of the market. This is a discourse that has shaped the animation and VFX industries in America since the 1980s. Pixar co-founder Ed Catmull describes George Lucas' Skywalker Ranch production facilities (where he once worked) as being halfway between Silicon Valley and Hollywood, both in terms of travel time and metaphorically.[13] Pixar is itself a paradigmatic Silicon Valley tech company.[14] Yet this discourse of free and open technology and of a technology-driven industry that does not rely on the state is not borne out by history.

For one, this discourse elides the tech industries' reliance on training and research that public universities and remaining federal funding continue to provide. Economist Mariana Mazzucato has extensively documented how, for example, companies like Apple rely on government R&D and public research institutions.[15] It also neglects the fact the Silicon Valley was a clear product of the Cold War R&D complex, and that letting markets shape the course of research in place of the government does not necessarily produce better outcomes for humanity. While neoliberal fantasies like Silicon Valley's technological utopianism seem to promise a totally open field of R&D unencumbered by "distortions of scholarship" and governmental interference, new complexes have proliferated. Industries have begun to take on the directive role the military used to play, recruiting researchers and institutions, both private and public, into developing technologies for their specific commercial interests. Hollywood's R&D complex offers examples of all of this. It grew from institutions and organizations established by the military-industrial-academic complex, it built significant ties with public and private research universities, and the demands of the industry shape the technological products of all of this research. The use of nonlinear simulation for animation is a clear example of this.

Cinema and other media have a long history with the military. Some recent work on this subject offers examples of media technologies being developed between the military and media industries. Haidee Wasson and Lee Grieveson note that technologies like radio and cinema had important strategic and technical utility beyond their role as entertainment media.[16]

Rebecca Prime's recent work chronicles how a former special effects technician from Paramount developed wide-screen technology for training aircraft gunners, which he then marketed back to Hollywood as Cinerama. Prime also notes the intimate relationship between this new projection format and the aesthetics of aerial photography, and how this spectacular combination played a role in the imperialistic soft power of the US Information Agency.[17] Hollywood's R&D complex sees this transactional relationship between Hollywood and the military continue over the 1980s and 1990s, but gradually the locus of technological development changed from the military to Hollywood. Now Hollywood develops technologies for other research fields and industries to use.

Since the 1980s, new research labs oriented toward media industries applications have begun to appear in academic computer science departments like Stanford and the University of Toronto. In the case of nonlinear animation, as a following section will demonstrate, many scholars and technologies migrated from a military institutional environment to animation and VFX studios and software companies. The desire for new nonlinear animation technology became so strong that it encouraged the recruitment of researchers from other fields such as aerospace and geophysics. While the stakes may be lower than the militarization of the country, Hollywood's R&D complex raises the same issues Eisenhower, Fulbright, and Leslie raise. How has the "spirit" of computer graphics research been transformed? What new epistemic paradigms are at work here? The stakes of these questions are not only about scholarly freedom and the shape of scientific knowledge, but also about the transactional relationship between media industries and technological change.

ACM SIGGRAPH

One of the best places to observe Hollywood's expanded role in R&D year-over-year is the Association for Computing Machinery's Special Interest Group on Graphics and Interactive Techniques (ACM SIGGRAPH), and its annual conference of the same name. SIGGRAPH has been the most important computer graphics research organization since the 1970s, shaping the direction of the field and the technologies it produces. At its peak in 1997, SIGGRAPH had 48,000 members worldwide, and it continues to be a dominant (and now international) force in computer graphics research. Researchers sometimes assess the value of computer graphics research is in terms of how "siggraphable" it is.[18]

Conferences and professional associations provide particularly effective contact zones for the overlap between academia, government, industry, and media. These are the places where institutions and businesses mobilize scientific research resources for specific technological applications. They can also demonstrate how a given media technology took shape over time as a result of infrastructural, institutional, economic and political forces. These organizations' meetings and communications have a logic and culture that stem from these forces. As Raymond Williams notes, R&D is a site where we can look for the way "social needs, purposes and practices" shape media technologies.[19] Study of SIGGRAPH's publications reveals which institutions and businesses support research over time, what sort of research is being done, and how researchers move between businesses and public institutions.

It should come as no surprise that the military-industrial-academic complex heavily sponsored SIGGRAPH in its early days. But starting in 1980 the type of research being done, the institutions sponsoring it, and even the character of the images circulating at the conference began to change. During this period, media industries (especially Hollywood and its blockbusters) became a vital force shaping research fields such as nonlinear animation at SIGGRAPH. This history demonstrates that Hollywood was not disrupted by some external technologies developed for other uses; rather that it played an important role in shaping the development of computer graphics technologies.

There is a tendency in histories of computer graphics to focus on key ideas that crystalized the field and inspired further research. The two most common examples are Ivan Sutherland's 1963 demo of his project Sketchpad and Douglas Engelbart's 1968 demo at the Joint Computer Conference, also known as the "mother of all demos." These histories particularly single out Engelbart's Advanced Research Projects Agency (ARPA)-funded project as having demonstrated a wide range of graphic and interactive functionality that defines much of the modern computer to this day: from the computer mouse to Google Docs. Ideas do not change history on their own though. These researchers needed institutional support and a means of disseminating their ideas. The Joint Computer Conference that hosted Douglas Engelbart's 1968 demo, for example, was made possible by coordination between the two key computer science research organizations, the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). Without the Joint Computer Conference or the SIGGRAPH publications and conferences that followed, without university computer science departments, and without military-fuelled research funding from the government, computer graphics would have likely developed in a different way. And the course of computer graphics research has been directed by prevailing institutional, political, and economic conditions ever since.

SIGGRAPH started as a newsletter in 1967, founded by Andy Van Dam, a professor at Brown University, and Sam Matsa, a researcher who worked for companies like IBM and General Motors. Their newsletter was geared toward computer science researchers who were interested in the visual and interactive potential of computers, many of whom were inspired by Sutherland's work. In 1974 SIGGRAPH became an annual conference that was the central hub of both academic and industrial computer graphics research. At this point it was still heavily sponsored by the military-industrial- academic complex. And although SIGGRAPH attracted interest from various industries, for the first thirteen years the film industry was utterly disinterest and uninvolved. According to Ed Catmull, Disney had no interest in computer graphics when the University of Utah sent him as a graduate student to propose an exchange program. Instead, they offered him a job as a theme park imagineer.[20] Years later, when he was funded by the New York Institute of Technology's (NYIT) Computer Graphics Lab, Catmull tried to find a film studio that might be interested in opening a computer graphics research department. Once again, he was rejected.[21] Even as he and his colleagues at NYIT were working toward making an animated 3D feature, they could not attract the interest of Hollywood.

The world of computer graphics was, conversely, extremely interested in getting more involved in media industries. 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 attracted to 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. 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 Experiments in Art and Technology (EAT) program, which facilitated joint projects between artists and engineers. NYIT employed several researchers in an unsuccessful bid to make the first fully 3D animated feature, *The Works*. Xerox PARC employed David Em in 1975 to explore the potentialities of interactive graphic software they were developing called SuperPaint, and he went on to be artist in residence at NASA's Jet Propulsion Laboratory at the California Institution of Technology from 1977 to 1984.

While it seems clear that a general zeal for the transformative potential of computers in part propelled this sort of research, 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 media industries for image making. What they lacked though, was actual coordination with such an industry. They needed a market for their tools and computer graphics needed an audience. Without an industry like Hollywood, they were a hammer in search of a nail.

In 1979, someone in Hollywood finally took an interest. Lucas film started hiring computer graphics researchers, including Ed Camull and SuperPaint researcher Alvy Ray Smith. The effects of this new industrial influence were immediately evident at SIGGRAPH's annual conference. In 1980, Catmull and Smith published their first paper under the institutional affiliation of Lucasfilm at SIGGRAPH.[22] In the following years, VFX and animation-oriented studios and software companies sponsored papers at SIGGRAPH with gradually increasing frequency as well. Early examples include a paper by Canadian computer graphics researcher William T. Reeves, affiliated with Lucasfilm in 1983,[23] 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,[24] another paper by Reeves from the same year, now affiliated with Pixar,[25] and further work in the following years supported by Pacific Data Images (PDI).[26] Contributions from other VFX and animation companies would pick up more in the 1990s as computer graphics began to proliferate in Hollywood and other media industries. VFX studios like ILM, Rhythm and Hues, and Digital Domain, large animation studios like Dreamworks and Pixar, and software companies that serviced these studios like Softimage and Alias| Wavefront, all began to support substantial research.

The visual culture of SIGGRAPH changed markedly over this period because of these changes, shifting the aesthetics and function of tech demos to serve media industries. The computer graphics tech demo had been an important part of the computer science world since Engelbart's "mother of all demos." Furthermore, SIGGRAPH has always made space for experimental computer art. But the involvement of media industries like Hollywood created different forms of visual culture that did not fit neatly into these categories. Demo reels by 3D animation studios that mostly made short commercials or 3D logos such as Robert Abel & Associates and Pacific Data Images began to appear from 1980 to 1983, as did clips from features like *Star Trek II: The Wrath of Khan*. New venues for visual culture like the Computer Animation Festival, started in 1984, might feature artistic experimentation, tech demos, demo reels, or clips from films. The aesthetics of animation also changed. While long shots with 3D moving cameras were the norm in the early 1980s, shorter shot lengths and continuity editing techniques borrowed from cinema starred to become more common.[27]

Chris Landreth's work for 3D software company Alias | Wavefront is an interesting example of how art, tech demo, and demo reel were blurred together at SIGGRAPH. Although he is now well known for his Canadian National Film Board short *Ryan* (2004), 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 betrayed his artistic aspiration, and this aspiration proved well suited to the new hybrid logic of SIGGRAPH's visual culture. *The End*, his first work to be featured at SIGGRAPH in 1995, is an ironic parody of self-reflexive modernist conventions, yet Alias |Wavefront made it for the purpose of exhibiting new facial animation techniques. His next short *Bingo,* exhibited in 1998, which promotes the company's new Maya animation suite, is even more artistically ambitious. Based on a play by experimental theater group the Neo-Futurists, this supposed tech demo is a work of existential absurdity and grotesque surreal imagery. 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. These early works by Landreth fit in-between what one would expect from a film festival, an academic conference, and an industry trade show. While we might think of them as the singular works of a creative individual given too much autonomy, the fact that he was able to make furthermore elaborate demos suggests that his work served a useful promotional function for Alias |Wavefront. 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, just as the critics of the military-industrial complex like Fulbright described. Media industries like Hollywood transformed the "spirit" of computer graphics research and the tools it produced.

Since the early 1980s, SIGGRAPH has developed into an interdisciplinary conference with members including “researchers, developers, and users from the technical, academic, business, and artistic communities.”[28] Companies as diverse as Lockheed Martin, Boeing, Apple, MTV, Swedish Energy Company, NVIDIA, and Symantec have sponsored events and recruiting tables at the conference. These represent a diversity of industrial and cultural applications for computer graphics. But of all these varied industries, the film industry has played an outsized role in how SIGGRAPH has changed since the 1980s.

Focusing on organizations like SIGGRAPH and the institutions they connect runs counter to popular narratives about the history of computer graphics. The public, and even some historians, frame innovations in computer graphics technology as appropriations that resulted from individual tinkering, détournement or appropriations of military technology. This is the ideology of the hackers and maverick entrepreneurs of Silicon Valley. This way of thinking is at work in the self-promotion of companies like Pixar and it can also be found creeping its way into histories of computer graphics such as 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 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.”[29] For this reason he focuses on figures like Ed Catmull, a person whom he sees as singularly driven toward making cartoons with computers. Yet 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 public institutions, without the interest of a robust established media industry, and without SIGGRAPH to coordinate these different bodies, efforts like his would have been a subject for curious media archeologists, like Nikolay Konstantinov’s experiments with computer animation in the 1960s in the Soviet Union. Such examples are important, but they cannot explain the dominant norms of an industry like Hollywood or Silicon Valley. VFX and animation companies do not pluck technologies out of thin air or appropriate them ready-made from unrelated fields. They are constantly involved in the development of tools made specifically for their needs. Looking at the development of a particular computer graphics technology over time helps to make this clear.

Developing Fluid Simulation for Animation

Fluid simulation is a technology that was initially developed in the military-industrial-academic complex before being transformed into nonlinear animation tools by Hollywood's R&D complex. This was not a question of Hollywood simply importing tools developed for other purposes. Rather, the VFX and animation industries built their own research infrastructure, funding basic research, developing relationships with universities, supporting research labs, and employing researchers. Through this they developed their own technology. Indeed, some of the very earliest research into visualizing fluid simulations was done to achieve a visual effect. Looking longitudinally at the development of fluid simulation animation tools demonstrates how this R&D complex took shape, and how it replaced military sources of funding (Fig. 3.2).

The history of fluid simulation begins with hydrodynamics: the study of the forces acting in fluids. Hydrodynamics is in some ways a very old discipline. Irrigation and aqueducts require some ability to predict how fluid behaves, and these are as old as civilization itself. Polymath Leonhard Euler formalized the first theory of fluid dynamics in the mid-eighteenth century. His work provided an equation that understood the dynamics of fluid through factors like pressure and momentum. Further work by physicists Claude-Louis Navier and George Gabriel Stokes in the nineteenth century added 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 complex calculations continues to be difficult. As Chap. 2 noted, 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.

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, the first nonlinear simulation, was a 1953 paper on fluid simulation research.[30] The T3 (Third Theoretical) Group at Los Alamos, headed by physicist Francis Harlow, conducted the majority of early work from 1955 to 1971.[31] The T3 group took concepts like the Navier Stokes equations and made computer

Fig. 3.2 Fluid simulation research tools and applications

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 software.

Early fluid simulations were numerical; they were not visualizations that looked like the things they were simulating. Hollywood played a key part in supporting initial research in the mid-1980s that addressed the particular challenge of visualizing fluid simulations, which entailed working out how to make 3D models of undulating surfaces and how to make simulations less resource intensive. The first fluid simulation research presented at SIGGRAPH was not military or scientific, instead it was for a VFX sequence in the sequel to Stanley Kubrick's *2001: A Space Odyssey* (1968), *2010* (1984). The effect in question was a 2D simulation of the swirling atmosphere of the surface of Jupiter. Researcher Robert Myers worked on this project as an employee of Poseidon Research, a company that usually worked on military projects. The other two authors were employees of VFX studio Digital Productions, but one of them, Larry Yaeger, was former employee of Grumman Aerospace.[32] Thus, while one can already see the film industry's influence on fluid simulation research, the military-industrial-academic complex was also part of the picture.

A military R&D company, an Apple Computer R&D group, and a few research universities sponsored the next papers on fluid simulation for computer graphics. The first of these was a paper on simulating large calm bodies of water in 3D by Stanford electrical engineering PhD Michael Kass and Cambridge computer science PhD Gavin Miller at Apple Computer's Advanced Technology Group.[33] Other similar work soon followed by computer science researchers at George Mason University and the University of Central Florida.[34] Hollywood films like *Waterworld* (1995) and *Titanic* (1997), where VFX studios created large areas of relatively calm water, exemplify this era in fluid simulation of the early-to-mid 1990s.

The two major tools that implemented this simulation technology were Alias | Wavefront's Dynamation (a subsidiary of SGI, formerly Silicon Graphics) and Arete Entertainment's Digital Nature Tools. Arete was founded in 1976 in response to a call from the Department of Defense for new sensor technologies. Their research involved using computer simulations of fluids to detect the presence of an object by observing the perturbations the 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 water. 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 plug-in. 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 of making cartoons as Ed Catmull is supposed to have. They simply sought out opportunities and research funds. When one source of revenue dried up, they sought a new one.

The next major developments in fluid simulation were supported by yet more research universities and further research by Alias | Wavefront. University of Pennsylvania researchers Nick Foster and Dimitris Metaxas based their 1996 research paper on work done by Francis Harlow and Eddie Welch at Los Alamos some thirty years earlier, adapting exotic scientific concepts from 1965 so that they could make animations on conventional hardware quickly.[35] While Foster and Metaxas' work was a major advance in terms of physics accuracy (and thus naturalism) it was still relatively 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 at SIGGRAPH that was less resource intensive and more "interactive."[36] In other words it was more apt to handle external inputs without causing the simulation to collapse. Thus, not all research was directed toward an ideal of scientific realism. These contributions made robust fluid simulation much more practical and economically viable. The increased interactivity of this technology also 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 controllable, became a key development goal after Stam's work, to the point that it rivaled the quest for realism.[37]

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 directability. The most successful approaches tried to achieve all of these traditionally contradictory demands. For example, Rhythm & Hues researcher Jerry Tessendorf's *fast-Fourier-transform* technique for animating oceans was so efficient it could be used in real-time for gaming applications.[38] Tessendorf had actually worked at early fluid simulation software company Arete Entertainment before coming to VFX studio Rhythm & Hues. Another substantial contribution in this era came from Stanford mathematician Ron Fedkiw, who took his mentor mathematician Stanley Osher's *level set* approach for the numerical analysis of curved shapes and applied it to fluid simulation geometry.[39] 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 to not scale well, requiring different tools for small splashes versus big waves.[40] One of the primary foci of recent research has been to create tools that work on all scales.

In 2008, Robert Bridson (a researcher who trained under Ron Fedkiw at Stanford and currently teaches at the University of British Columbia) helped build a fully scalable simulation technology for ILM called the *fluid implicit particle* technique.[41] 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. The blockbuster *Battleship* (2012), which provided the capital for ILM to do significant R&D, offers an example this latest era of fluid simulation technology.

The implementation, and indeed the basic research, for many of these technologies were funded by a single film. In these cases, a VFX studio or a software company employed one of these scientists to do custom work for a specific effect in a specific sequence. 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 these researchers were professors at research universities while they were doing this work and most published their results. Many of their academic presentations and papers contain illustrations from the films they worked on. The proliferation of fully rendered Hollywood animation and VFX sequences is yet more evidence of the influence of the film industry on SIGGRAPH.

Though many early fluid simulation researchers working in computer graphics have computer science backgrounds, many were also drawn from other fields. 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 & Hues where he was "principal graphics scientist." John Anderson was a professor of atmospheric sciences at the University of Wisconsin-Madison before he became the head scientist behind nonlinear animation at ILM in the late 1990s. Mark Stasiuk, co-founder of nonlinear animation studio Fusion CI, was working on the fluid dynamics of volcanic eruptions before getting into VFX and animation. Kenneth Museth, former principal engineer at Dreamworks and researcher at Digital Domain, started with a PhD in quantum physics. Before working in VFX he did "trajectory design" at NASA's Jet Propulsion Laboratory (JPL) and he also worked for private space company Space X. During his tenure at Digital Domain, he helped develop solutions for simulating fluid that would become their proprietary simulation software FSIM and STORM. Like so many other researchers, Museth is a tenured professor as well. The fact that so many accomplished researchers with a diversity of backgrounds have started to work in Hollywood demonstrates how much capital investment has moved into R&D and how strong the media industry's influence on this field of research has become.

All these researchers have been prolific at SIGGRAPH, producing research that has led to new software and computational concepts, which 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 is a clear sign from the industry that simulated fluids have had a substantial influence on the way movies are made.

This first generation of researchers that came from a variety of backgrounds are now advising graduate students who work specifically on computer graphics animation problems. Many of these early researchers have established labs in computer science departments that help train graduate students to do fluid simulation for media industries. The University of Toronto's Dynamic Graphics Project, where Jos Stam works, has had strong connections to Alias | Wavefront and its successors. Stanford Computer Science Department's PhysBAM program, headed by Ron Fedkiw, makes up the core of ILM's simulation technology.[42] As a result, 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, but rather a sign of the maturity of the field, and of the influence of media industries research funding.

Hollywood thus did not pluck animation technologies like the ones described here from other industries or from the military-industrial complex. Rather, Hollywood drives its own R&D. Just as Sen. William Fulbright once observed that scientific research was being shaped by the substantial demand for military R&D, a remarkably similar transformation has taken place with the VFX and animation industries. This technological change was not an external force being exerted on the film industry; it was an internal, directed force, shaped by the demands of the industry.

Blockbuster Technology

The history of fluid simulation demonstrates Hollywood's computer graphics R&D complex at work. Money was flowing from Hollywood for research projects and for jobs, and new computer labs were emerging to do the research and train future workers. In some cases, this new source of research funding replaced the role the military used to play. This situation resulted in part from the aforementioned switch from federal R&D funding to tax credits for private research. But on its own, this does not explain where the money came from. It was only when the Hollywood blockbuster met the logic of R&D that Hollywood's R&D Complex properly took shape. With its particular economic model and its strategic relationship to technological change, the blockbuster proved a perfect fit for supporting R&D. This institutional and economic configuration is every bit as important for understanding changes in film production over the past three decades as any discussion about the nature of digital technology itself.

Julian Stringer notes that the term blockbuster means different things in different contexts; it can be a term of derision or praise, a planned hit or a "sleeper."[43] The majority of scholarship thus far on the subject has focused on the blockbuster as a planned must-see event: a big film. In New Hollywood films like *Jaws* (1975), this meant a nation-wide simultaneous release coordinated with a TV ad campaign and the promotion of opening weekend box office figures in following weeks.[44] According to 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.[45] Her analysis of the film industry shows that even though big films are risky ventures, on average they produce bigger returns than smaller budget films.[46] Consumers can only be aware of so many films at a time, so it makes sense to utilize stars, special effects spectacles, and marketing to make a few special films stand out from the rest.[47]

Studios frequently pair blockbuster spectacles 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, spectacular images, and new technologies.[48] They see continuity between the special and the contemporary Hollywood blockbuster. The scale of the spectacles in road show features 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 technology."[49] 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.

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.[50] Paul Allen argues that the Hollywood blockbuster allows studios to promote new technologies and effectively "renegotiate the industry status" of Hollywood.[51] 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."[52]Allen believes this logic is at work in the aesthetics of blockbusters. In films as diverse as the *Jazz Singer* (1927) and *Jurassic Park* (1993) there are moments that are given over to pure spectacle, and in these moments of suspension a new technology that is being positioned to transform the industry is put on display.[53]

Allen's account of the Hollywood blockbuster is consistent with interpretations of special effect aesthetics by other scholars. For example, Dan North builds on the idea of the incredulous spectator from Gunning and Gaudreault's concept of the "cinema of attractions" to argue that visual effects are meant to be recognized and enjoyed as illusions that speak to the nature of technological mediation.[54] Special effects are about the medium, they are about the illusion of cinema. A well-positioned and well-designed blockbuster can even renegotiate the status of consumer media technologies. As Charles Acland observes, blockbusters such as *Avatar (2009)* function as "technological tentpoles," that set into place new protocols for consumer and professional technologies.[55] *Avatar* was designed to introduce Stereoscopic 3D as a new standard for spectacle films, both in theaters 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 (though the latter eventually fizzled). The Hollywood blockbuster therefore is both symbolically and economically positioned to be the site where important technological changes take place.

The blockbuster is a tool available only to the wealthiest studios, as it requires mountains of upfront capital. Blockbusters are also a competition though, as each studio strives to put forward their vision for the industry. R&D is a similar bet to a blockbuster. It is an upfront cost that only certain companies can afford, made in an effort to gain some sort of competitive edge. It keeps the powerful in power and it enables them to define the industry. R&D also produces new technologies that provide precious visual novelty to attract blockbuster audiences. The logic of the Hollywood blockbuster thus has some important synergistic correspondences with the R&D. Its voracious hunger for visual novelty and technological display proved to be a perfect fit for the established military-industrial-academic R&D infrastructure of computer science.

The blockbuster remains relatively unchanged over time in its function. Yet the logic of the R&D complex represents something new. While prior blockbusters hinged on new technologies like widescreen formats, sync sound, or color, the budgets of the films themselves did not support the R&D that created those technologies. It is possible there were such cases, but it would be uncharacteristic of the time. R&D represents a new way to use financial scale in the interest of competition.

"Hollywood Software" and the Cost and Risk of R&D

While the Hollywood blockbuster is perhaps the most visible place where computer graphics R&D started to transform parts of Hollywood in the 1980s, the economic and organizational significance of R&D does not stop there. Once a VFX or animation studio develops a new image-making tool for a given project it leads to several strategic and economic implications. Defending IP ownership and profiting from it has become a significant part of animation and VFX studios' operations.

According to former Pixar CFO Lawrence Levy, before his arrival at Pixar in 1995 the company did not know how to make money. Steve Jobs was hoping that Pixar would make 3D animation like desktop publishing and that they could sell their software to millions of computer owners. At that point however, they were only selling their products to film and animation studios. This was a difficult business to be in because it meant their marketplace was very small. In Levy's words, "…when studios are making films with special effects they need lots of Renderman… otherwise, they don't need it at all."[56] Pixar's self-image is that of a company that always knew it wanted to be a studio. But from Levy's account it is clear that at one point they did not know whether they were a technology company or an animation studio. In truth they are still both, as are most of the top animation and VFX studios. Although Pixar markets itself as a studio, it still earns a great deal of revenue from selling its technology. It is telling that Levy's first consequential move at Pixar was to threaten to sue rivals Silicon Graphics and Microsoft for using their proprietary technology without permission.[57] That single move brought in millions in annual revenue. To this day, their technological IP is extremely valuable to them. In filings to the Securities and Exchange Committee (SEC) Pixar and rival Dreamworks cite technological IP as a key assets.[58] VFX studio Digital Domain assessed the value of its IP in 2017 as 7% of its total value.[59]

To try to quantify how much R&D VFX and animation studios do, I conducted a study where I searched the records of the US Patent Office for the names of the largest studios in operation today (see Fig. 3.3). This does not show us the patents of studios that have closed, but it does offer a longitudinal image of contemporary studios. The data shows that Pixar was an early leader in patents, and that it has continued to lead the way, peaking in 2008 with about 48 patents awarded that year. Since 2003, several other studios like Dreamworks and Digital Domain have been filing many patents per year on average. When comparing large animation studios to large game studios, the number of patents seems be about equal when you factor for the scale of their revenues.[60] While this approach does not account for any secret technologies, or technologies registered to parent or holding companies, it provides clear evidence that R&D is a major

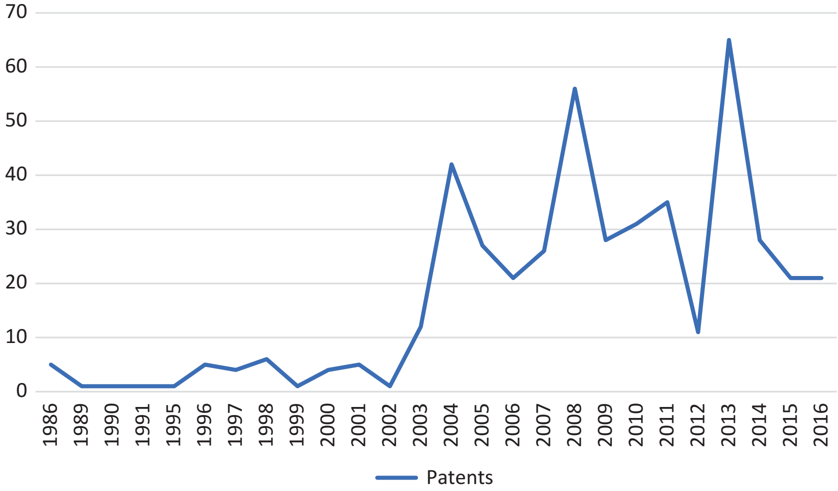

Fig. 3.3 Total patents filed by top VFX and animation studios

activity for these studios, and that research activities have generally risen over time.

Animation and VFX studios do not build all of their own technology, of course. During the 1980s and 1990s many studios would have used Silicon Graphics hardware and software as a basic platform, and more recently they would all use software like Autodesk's Maya for basic modeling and animation. Often specific challenges in a given project can also be solved with licensed or off-the-shelf software. In their best practices manual, the Visual Effects Society (VES) addresses this problem in a section titled "To Build or Purchase?" written by Stephan Vladimir Bugaj, Pixar's technical director. Bugaj's advice to readers is if you can buy software you probably should, as it can be risky and expensive to build custom software.[61] Furthermore, anything a moderate sized VFX or animation studio can build will be eclipsed by the work of larger studios with more resources. However, if expectations and budgets are high, there are also good reasons for large studios to invest in R&D.

Often it makes more sense to keep that technical labor in-house and build custom technology. 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."[62] 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 production process more effectively. Furthermore, some projects call for a high degree of visual novelty, especially so called "hero" effects in blockbusters that are designed to draw the attention of audiences. This has been particularly true of nonlinear animation throughout much of its history. Looking at the promotion of a film like *The Day After Tomorrow* or *The Perfect Storm*, it is clear that the spectacular uncanny appearance of the gigantic simulated waves in those films was a key selling feature.

If a studio chooses to build their own technology, there are also potential financial benefits down the road. R&D produces assets, and those assets have multiple kinds of value. For one, animation and VFX studios all note the value of technological exclusivity in their business.[63] Exclusivity allows studios to produce images no one else can, but it can also serve a strategic value. Keeping competitors from having access to a technology can raise their operations cost, a key factor in the ultracompetitive VFX bidding system. This is especially devastating when a company withdraws a technology that was formerly available, forcing their competitors to scramble to build their own. Studios cite this as a major risk in both the animation and VFX industries.[64]

The second major source of value R&D can produce is through technology licensing. Companies such as Pixar and Digital Domain list millions of dollars in annual revenue streams from licensing.[65] Sometimes licensing is as simple as taking money from a company who has infringed on your studio's patents. Lawrence Levy's move at Pixar is a good example of this. Many companies were using ray tracing to render 3D images without Pixar permission. They were not necessarily using Pixar's software, but they were using an idea Pixar owned. Thus, Levy was able to threaten to sue them and to start charging annual licensing fees from them. In other cases, licensing is a much more full-service contract. Companies will pay not just to use software, but also to receive help implementing the software and to receive ongoing support. Here the line becomes somewhat blurry between doing contracted production work and software licensing. The difference between a studio and a software company can thus be indistinct. For example, Fusion CI, a nonlinear animation company co-founded by geophysicist Mark Stasiuk, offers custom solutions for nonlinear animation that utilizes their proprietary technology.[66] It is difficult to say exactly whether they are a software company or a VFX studio. But this is true of many animation and VFX studios that conventionally style themselves as studios. Digital Domain, for example, gets approximately one third of their revenue from licensing software and doing specialized sub-contracted work.[67]

The third way R&D can produce revenue is through selling technology as part of an off-the-shelf product. Again, the lines between licensing technology and selling software are blurry here, but the distinction basically boils down to target market and volume: a studio can charge select studios large amounts for a custom technology, or they can develop a sleek user-friendly adaptable piece of software and market it to any would-be animators in the professional and prosumer markets. One example is Disney's Xgen hair simulation software, which they are publishing in association with software giant Autodesk.[68] The history of fluid simulation is full of examples of technologies that started in studios and ended as off-the-shelf solutions. In some cases, an individual researcher will leave a studio or software company to found their own company to offer these services. Robert Bridson, the researcher who developed a fluid implicit particle method for fluid simulation, started doing work for ILM but ended up co-founding Exotic Matter. Eventually Autodesk bought Exotic Matter so that it could build their technology into the Maya software suite.

There is a pretty clear progression in cases such as these. A researcher with a background in physics, mathematics, or computer science does some fundamental work as a graduate student or postdoctoral fellow, perhaps in a lab with connections to a studio or software company. Next a studio hired them to do specialized work for a specific type of animation for a blockbuster spectacle. Over time the field moves forward, software become refined and more efficient and computer power becomes cheaper, and eventually the technology goes from being an exclusive property deployed for spectacular effects to being something anyone can purchase for a few hundred dollars and implement into their production pipeline without much difficulty. This is a system that is always producing the new, and one that creates potential for profit at every step from the emergent to the dominant, until someday becoming what Charles Acland refers to as "residual media" of the past.

A clear sign of how valuable R&D can be is how carefully its products are protected. Dreamworks writes, "Our revenue may be adversely affected if we fail to protect our proprietary technology or enhance or develop new technology… We rely on a combination of patents, copyright and trade secret protection and nondisclosure agreements…"[69] Indeed litigation against infringers seems to be a way of life for many studios. Digital Domain notes multiple ongoing lawsuits in its annual filings. These companies must also be careful to not infringe on other potentially litigious competitor's IP.

While R&D can produce extremely valuable products, it can also be extremely risky. 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 uncertain to some degree. Materiality 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 not 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. This is something VFX studios openly acknowledge. According to a 10-K public report filed to the SEC 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.[70]

Other industries that make use of technology often outsource much of their technological heavy lifting. This is a point VFX industry veteran Mike Seymour makes in his trade website *VFX Insider*. 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.[71] 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 and contingency of the research these businesses support is both immensely valuable, and immensely risky. It affirms how uncertain R&D can be, but it also demonstrates the potential value of shaping it.

Clearly there are some industries where it is common for companies that deliver a final product to do extensive R&D. The pharmaceutical industry is one example. Perhaps Seymour overstates the situation somewhat, but his observation points to the way R&D is connected to the volatility of the VFX industry. This is an issue that has been the subject of considerable discussion since the bankruptcy of Rhythm & Hues and in the related labor organization of VFX workers. There is a general perception in the industry that there is something fundamentally defective with the way they do business.

The VFX industry is built around fixed contracts and competitive bidding. In the majority of cases, the film studio does not factor in the details of what R&D will be required for a VFX job in initial planning stages. If an effect requires a new technology, it will be the VFX studio's problem. This may sound like a controversial statement, given how fundamental technology is to the blockbuster. If a film studio employs their own VFX Supervisor, they will have some vague idea of how much work a given shot will take.[72] Furthermore, iconic films like *Avatar* (2009) seem to factor extensive VFX technological development in early planning. Publicity for *Avatar* touted that James Cameron had to wait a decade until technology was sufficiently advanced to film his screenplay for *Avatar*.[73] 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, planning and budgeting for R&D is entirely the VFX studio's responsibility.

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. Bidding VFX studios are relatively opaque in their proposals; all the studio sees is the price per shot.[74] A number of costs are folded into this single number, including facilities costs, labor, and R&D. In other words, the contract between the film and VFX studio does not say "these shots will require us to 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 is intrinsically uncertain and risky. This has prompted VFX supervisor Ben Grossman to advocate for a new model that separates technology building from animating and overhauls the VFX bidding process.[75] Under this plan production and technology development would be done by separate companies.

Although people like Seymour and 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 largest contracts, and only the largest animation studios will release features with cutting edge animation. The spectacle of rarefied technology ensures the maintenance of this system. It also ensures that the studios large enough to do extensive R&D can utilize their technological IP either to license it out or strategically maintain exclusivity. It is a way for the studios currently at the top to stay at the top.

These calls to separate production from technology from people in the film industry are telling because they point to just how imbricated the two have become. It is difficult to imagine the two ever being disentangled at this point. Indeed, the following chapter will demonstrate how in the case of nonlinear animation it is difficult to tell the difference between animation work and engineering work.

The animation and VFX industries have become such a force for R&D that other fields and industries use and adapt their tools. In an interview on digital technologies in architecture, engineer and architect Chuck Hoberman describes how he used "Hollywood software" to design the complex folding spheres he is known for.[76] His use of this term demonstrates what an extensive machine Hollywood's R&D complex has become for producing computer graphics technology. The ability to render photorealistic images is clearly useful in architecture as well as a variety of other industrial and educational applications. But the utility of Hollywood software even goes beyond rendering. For example, nonlinear animation tools can provide the basis for rudimentary scientific simulations. Fusion CI co-founder Mark Stasiuk used to make plug-ins for the popular nonlinear animation software Realflow to study geophysical fluid mechanics.[77] In recent years, Dreamworks has raised thirty five million dollars as part of an initiative to sell software to new industries, and Digital Domain has sold their technology to companies such as Samsung.[78]

The film industry thus does not rely on readymade generalized computer graphics tools. Instead, it has played a key role participating in computer graphics R&D since the 1980s. Engaging the military-industrial-academic complex that was already established, Hollywood slowly began to fund its own projects and shaped research toward its own ends. Tireless promoters like Pixar's Lawrence Levy might style this R&D turn in VFX and animation as the result of their bringing "Silicon Valley bravado to the film industry." Pixar indeed plays a pivotal part in this history, and it is a paradigmatic product of the Dot-com boom. But much of what is implied in the Silicon Valley discourse is easily refuted. Far from being the product of entrepreneurial mavericks, the rise of the logic of R&D extends from the military-industrial complex, and it is sustained through cooperation with researchers at public institutions and public funds. Furthermore, it is hardly a field in which one start-up can disrupt the whole industry. The high cost and risk of R&D ensures the maintenance of the economic status quo. It would perhaps be more accurate to say that VFX and animation resemble the reality of Silicon Valley rather than its lofty discourse; given the way tech companies like Amazon, Alphabet, and Facebook dominate their respective markets.

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