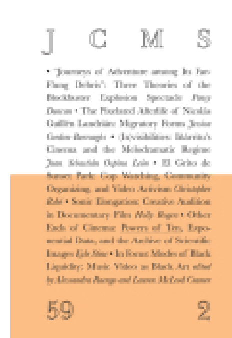
Other Ends of Cinema: *Powers of Ten* , Exponential Data, and the Archive of Scientific Images

Kyle Stine



JCMS: Journal of Cinema and Media Studies, Volume 59, Number 2, Winter 2020, pp. 114-137 (Article)

Published by Michigan Publishing
DOI: *https://doi.org/10.1353/cj.2020.0005*

Other Ends of Cinema: *Powers of Ten*, Exponential Data, and the Archive of Scientific Images

by Kyle Stine

Abstract: From 1957 to 1977, the Office of Charles and Ray Eames worked with IBM on a series of films and exhibitions to promote the social benefits of the computer. Across these projects, the office developed strategies of programming spectator journeys through spaces of information. It is in this context that one should understand the Eameses' most iconic film, *Powers of Ten* (1968, 1977). Recognizing film as an information medium, the Eames Office produced *Powers of Ten* as a form of visual software capable of preprocessing a vast archive of scientific images for the viewer, just as a computer executes its most fundamental processes behind the interface. Their efforts, alongside developments in microfilm storage and retrieval, point to film's role as the first universal medium to process image, sound, text, and data.

Among his notes for the 1971 IBM exhibition *A Computer Perspective*, the designer Charles Eames wrote under the heading "Possible New Directions" a buried insight: "the need for imagery created by the pressure of data."[1] Census figures, medical records, corporate bookkeeping, and all manner of other forms of accounting and measurement had grown so prodigiously, as Eames saw it, that the sheer mass of information resisted human understanding, requiring the unity of the image for comprehension. Recognizing imaging in this way as part of the history of computing was prescient at a time when the graphical user interface tarried in its experimental infancy. Notwithstanding a handful of special-purpose design workstations installed at prominent automobile and aerospace manufacturers following Ivan Sutherland's breakthrough application Sketchpad in 1963, computer graphics remained largely unknown at a moment when "end users" meant scientists and engineers.[2] For this reason, Eames viewed

1 Charles and Ray Eames Papers, Manuscript Division, Library of Congress, Washington, DC (hereinafter "Eames Papers"), box I:134, folder 7. *Computer Perspective*, History Wall, 1969–1971. The note is dated January 4, 1969.

2 The DAC-1 graphical workstation developed at General Motors using IBM equipment in the mid-1960s is a good example.

Kyle Stine is a member of the faculty in the Film and Media Studies Program at Johns Hopkins University. His articles on cinema and technology have appeared in Critical Inquiry, Discourse, Grey Room, *and* Image and Narrative.

the topic of imagery in computer history as supplemental, a potentially beneficial addendum, space permitting, but not entirely necessary.[3] The eventual exhibition would attend to imagery implicitly in its array of visual materials—the back cover of the book would call it "the first truly graphic history of the origin and development of the computer"—and explicitly in heeding the role that motion pictures played in depicting the "dark visions" of new technologies.[4] But it would forgo elaborating this striking reflection on its raison d'être.

That Eames chose not to thematize this research in the exhibition, however, belies his belief in its importance.[5] Since as early as 1953, when Eames cotaught a business course, "The Language of Vision," at the University of California, Los Angeles, with György Kepes and George Nelson, he had been interested in the comprehensibility of information. He sought to understand under what conditions information would be meaningful for his students and, more broadly, citizens of the modern world. His method of choice, consistently across his projects, was to use vision as an antidote to the malady of excess information, to make data "beautiful," as Orit Halpern so aptly describes it, which is to say, valuable and useful.[6] It is in this context of using imaging techniques for data processing that one should consider Eames's most iconic film, *Powers of Ten*, the two versions of which, released in 1968 and 1977, fell on either side of *A Computer Perspective* and were researched concurrently with the Eames Office's work on the exhibition.

Powers of Ten is remembered as one of the films that the Eames Office produced for IBM, and the company did fund the second version, but the project derived initially from another source. The Commission on College Physics, formed in 1960 to promote science education, hired the Eames Office to produce an instructional film for debut at the organization's annual meeting in 1968.[7] This earlier version of the film has come to be called the "Rough Sketch" version, but the designation is somewhat misleading because, although the film differs in important ways from the later 1977 version, it was a professional production that the office openly distributed in the late 1960s and early 1970s, particularly to science educators. The template for the film came from a 1957 book, *Cosmic View*, by the Dutch schoolteacher and education reformer Kees Boeke. An introduction to logarithmic scale for schoolchildren, the book features hand-sketched illustrations to outline forty "jumps" between the universe's different orders of magnitude. Its first sketch centers on a girl in the courtyard of Boeke's community school, and each succeeding picture jumps outward until the school, the Netherlands, and the whole Earth recede into invisibility, then outward still until the frame approximates the

3 The other reason weighing against its inclusion was that the exhibition was set to cover a period from 1890 to 1950, when the graphic possibilities of computing were less obvious.

4 Charles Eames and Ray Eames, *A Computer Perspective* (Cambridge, MA: Harvard University Press, 1973), 100.

5 The omission may also have owed to IBM's slow take-up of the graphic possibilities of computers, as several other lines of research were dropped in deference to the patron's own history.

6 Orit Halpern, *Beautiful Data: A History of Vision and Reason since 1945* (Durham, NC: Duke University Press, 2015). I also acknowledge Halpern's research for the above information on Eames's course at UCLA.

7 That the commission was formed on a grant from the National Science Foundation (NSF) is interesting in connection with Charles Eames's later correspondence with Vannevar Bush, who played an important role in the design and creation of the NSF.

edges of the scientifically known universe. Reversing direction, the sketches enlarge on the original image, passing from the small to the microscopic. As Boeke explains, he based the project on a belief in "the importance of developing a sense of scale," a sense of spatial orientation without which, he feared, one's views were likely to become narrow and provincial.[8] The film's major departure from the book came in using photographic materials rather than hand-drawn animation.[9] It was a decision that would significantly broaden the scope of the project. Although the directing credits for both versions of the film go jointly to Charles Eames and his wife, Ray Eames, the Eames Office as a whole played an important role, with numerous employees serving as technicians and researchers in handling the production's wide-ranging correspondence and sweeping photographic archive.

The Eames Office's diverse expertise and collaborative working environment is important in understanding the reciprocal lines of influence between the Eameses' films and exhibitions. At any given time in the 1960s and 1970s, the office was engaged in producing short films for IBM and various US government agencies, including the State Department and the Corporation for Public Broadcasting, and in creating a range of gallery exhibitions for not only IBM but also clients such as the Smithsonian Institution and the furniture manufacturer Herman Miller.[10] Across these ventures, the office cultivated a signature didactic style and a set of intermedia techniques to achieve it. The key, for the Eameses, was that the presentation should offer an experience of whatever it was it intended to teach. Spectators of films and attendees of installations learn best, the insight went, when they do so heuristically, when they enjoy an active role in a process of discovery. Although it remains unclear in what aspect of their work these ideas initially took hold, in part because the works ran in parallel and even more so because nearly all the exhibitions involved films, it is clear that the techniques that Charles and Ray Eames developed in their films leading up to and including *Powers of Ten* crossed with the heuristic methods they devised in their gallery exhibitions, particularly for IBM.

The Eames Office entered into a relationship with IBM in 1957 that would last until the end of Charles Eames's life, shortly before the release of the fully realized second version of *Powers of Ten* in 1977. In the late 1950s, IBM struggled with public fears about the company's intensified defense business and far-reaching commercial presence. In response, IBM's president Thomas Watson Jr. hired the industrial designer Eliot Noyes to revamp the company's image and reshape public perceptions around the computer's social benefits. Central to Noyes's strategy, along with hiring the graphic designer Paul Rand to craft a new corporate logo and assembling a team to reinvent IBM's product lines, was to approach Charles and Ray Eames to make a series of films that would make computers more personally relatable, beginning with

8 Kees Boeke, *Cosmic View: The Universe in Forty Jumps* (New York: John Day, 1957), 4.

9 That the Eames Office opted to produce a film version using photographic materials rather than animation is yet another reason to think that the "rough sketch" designation is imprecise. Producing the film in this way required professional image making and expert input from a wide range of fields.

10 Charles Eames also brought a program of films on a lecture tour sponsored by the US Information Agency. See Eric Schuldenfrei, *The Films of Charles and Ray Eames: A Universal Sense of Expectation* (New York: Routledge, 2015), 185.

the animated *The Information Machine: Creative Man and the Data Processor* (1958).[11] "IBM recognized early," John Harwood explains, "that its problem of creating a mass market for computers was . . . one of visuality, space, and experience."[12]

In his research for *The Information Machine*, Eames reviewed IBM's prior publicity films and noticed that the company had struck an almost threatening tone in its efforts to make the computer appear socially significant.[13] Eames's insight was that IBM should step away from this forbidding image and adopt a posture of openness. In *The Information Machine*, this meant positioning modern-day calculators in the longer human history of seeking to control and manipulate the environment through prediction, connecting computer technologies to processes of human thought, and casting the computer as a problem-solving machine meant to help humankind. The resulting animated short was playful, approachable, and—significantly—not forbiddingly expert. The Eameses continued these strategies in subsequent films for IBM and extended them also to the exhibitions that the company went on to commission for its corporate showrooms and several museums, beginning with *Mathematica* (1961).

Harwood has shown incisively how the Eameses pursued "a heuristic design strategy" in constructing these exhibition environments for IBM. Importantly, he explains, the environments largely concealed their didactic intentions, leading onlookers through "a space that appeared to be free of any formal or overriding regulation" while using that perceived freedom to ensure "the invisibility of a rigorously conceived and executed pedagogical program."[14] As Olivier Lugon relates, on the one hand, the Eameses struggled with the pedagogical effectiveness of controlling spectator movements in these environments; on the other hand, they questioned the degree to which freedom and indetermination were "compatible with the intelligibility of the presentation."[15] Weighing the balance of these considerations, their design practices tended to err on the side of control. Andrew Uroskie, for instance, draws a direct line from the Eameses' overt propaganda efforts in *Glimpses of the USA*, which the US Information Agency commissioned for the 1959 American National Exhibition in Moscow, to their design practices in *Think* for the IBM Pavilion at the 1964 New York World's Fair, saying that the latter exhibition "was no less didactic."[16]

Among the strategies that the Eameses developed for these heuristic environments was to present the spectator with an overwhelming abundance of data, often using multiscreen video and elaborate, multimedia walls of information. As Beatriz Colomina

11 Throughout his career and in his collaboration with IBM, Charles Eames worked in tandem with his wife, Ray Eames, so it makes sense to speak of their projects collaboratively.

12 John Harwood, *The Interface: IBM and the Transformation of Corporate Design, 1945–1976* (Minneapolis: University of Minnesota Press, 2011), 63.

13 For Harwood's discussion of *The Information Machine*, see *Interface*, 170–172.

14 Harwood, 14. For Harwood's complete discussion of heuristic techniques in the Eameses' works, see "The Heuristic Environment: The 'IBM Museum,'" 195–208.

15 Olivier Lugon, "Dynamic Paths of Thought: Exhibition Design, Photography, and Circulation in the work of Herbert Bayer," in *Cinema beyond Film: Media Epistemology in the Modern Era*, ed. François Albera and Maria Tortajada (Amsterdam: Amsterdam University Press, 2010), 140.

16 Andrew V. Uroskie, *Between the Black Box and the White Cube: Expanded Cinema and Postwar Art* (Chicago: University of Chicago Press, 2014), 167.

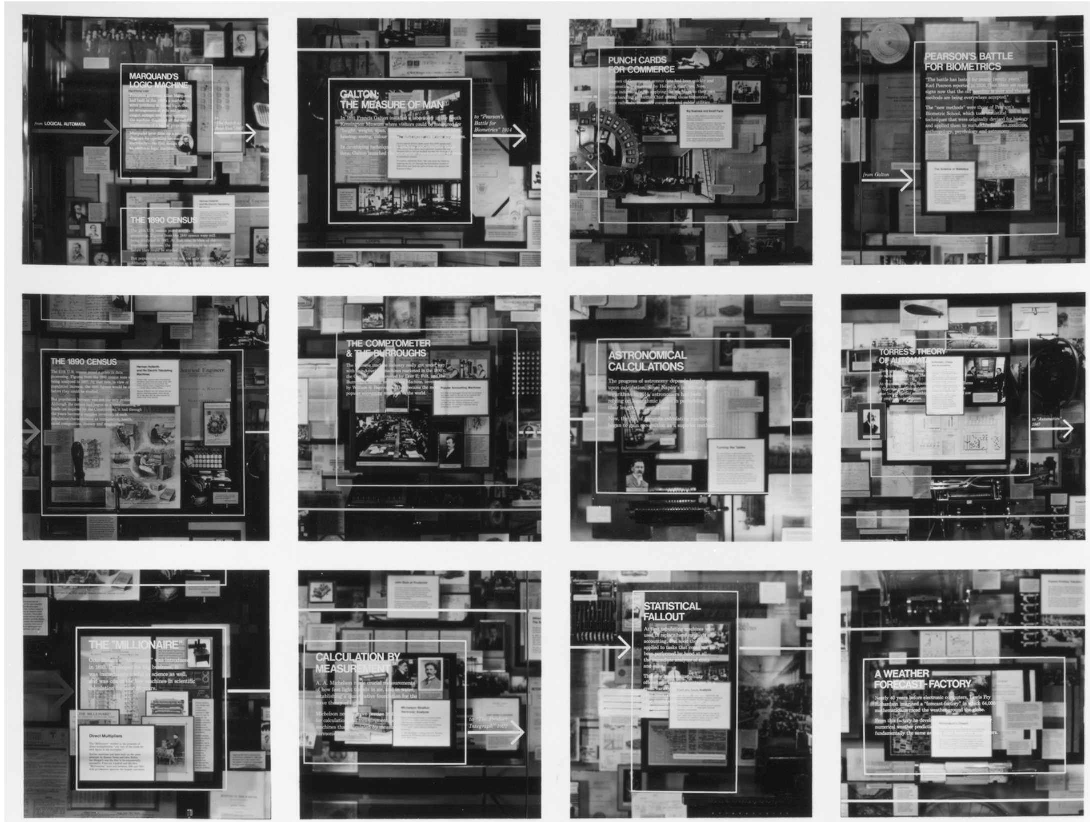


Figure 1. Flowchart of the IBM exhibition *A Computer Perspective*, Eames Papers, box I:134, folder 8.

explains, the goal of these presentations was to promote a consumerist picture of the home as a system of communication.[17] The exhibitions served as test experiences for spectators in their acculturation to the new home electronics of television and, later, personal computers. In this regard, Lugon has shown how, with *A Computer Perspective*, the Eameses departed from their earlier cinema-inspired exhibitions, which were modeled after the sequential lesson plans of films like *The Information Machine*, to pursue the fragmented perceptual overload of television, a trajectory that also prefigured, in combining controlled design and perceptual freedom, the interactive data experiences of computing and the internet. In these spaces, as Lugon explains, spectators were confronted with "a deliberately uncontrollable profusion of elements, images or text," and their "powers of concentration were tested by the multiplicity of options."[18] To the extent that the Eameses designed their environments to maximize active participation, however, they nevertheless maintained an eye to the didactic intentions of the overall program, an idea that Branden W. Joseph distills using the concept of the immersive suture: "The individual's connection of diverse, fragmentary bits of information . . . actually produces a more active form of suture, an identification with and subjection to the [presentation]."[19]

Indeed, in a very literal sense, the Eameses' exhibitions for IBM were *programmed*. The space of *A Computer Perspective*, for instance, was itself organized as a computational experience, laid out by means of a flowchart (Figure 1). The flowchart, as Philip Agre has argued, has an important place in the history of computing.[20] First introduced by Frank and Lillian Gilbreth in connection with their motion-picture labor studies, the "flow process chart," as it was formally called, quickly became the dominant mode of representing not only human labor processes in industry but also those same processes as they came to be performed by computers, first in accounting and later in more complicated manufacturing. In designing the IBM exhibition environment using a process chart, the Eameses in a sense exported this representational technique once again to organize the flow of people through a computationally organized environment. People's movement through the various displays was meant to simulate the movement of data through computational pathways. Connecting these two types of movement provided an experience of technology by way of the visitor's own transit through space, so that the exhibition performed its most difficult work in the background, similarly to how a computer executes processes behind the interface and allows the user to assimilate the information without concern for its delivery. What was learned in this didactic

17 Beatriz Colomina, "Enclosed by Images: The Eameses' Multimedia Architecture," *Grey Room* 2 (2001): 12–13.

18 Lugon, "Dynamic Paths of Thought," 139, 140.

19 Branden W. Joseph, "'My Mind Split Open': Andy Warhol's Exploding Plastic Inevitable," *Grey Room 8* (Summer 2002): 94. Relatedly, for an excellent overview and synthesis of the literature on the Eameses' didactic exhibitions and the "sensory-affective politics of expanded cinema" (51), see Justus Nieland, "Midcentury Futurisms: Expanded Cinema, Design, and the Modernist Sensorium," *Affirmations: Of the Modern* 2, no. 1 (2015): 46–84.

20 Philip Agre, "Beyond the Mirror World: Privacy and the Representational Practices of Computing," in *Technology and Privacy: The New Landscape*, ed. Philip E. Agre and Marc Rotenberg (Cambridge, MA: MIT Press, 1998), 29–61. Agre writes: "The first methods for representing human activities on computers were derived from the work-rationalization methods that industrial engineers had been developing since the 1910s. Hence the phrase 'information processing': the idea was that computers automate a kind of factory work whose raw material happens to be information rather than anything physical or tangible" (33).

environment, something that would only expand as computers gained in power and performance, was enculturation in the complexity of the information society and a willingness to surrender oneself to a preplanned navigation.

Powers of Ten, as I show, served in its own way to familiarize audiences with the new scales of technological action taking hold in the mid-twentieth century, and it did so by many of the same means. As Charles Eames once said in an interview with Paul Schrader, the film aimed to satisfy the rigor of an assembly of physicists and nevertheless "appeal to a ten-year-old."[21] It was to be sophisticated and yet simple, even deceptively simple. Just as the IBM exhibition ostensibly taught the history of the computer but really intended to seduce visitors into accepting computers as commonplace and beneficial, *Powers of Ten* ostensibly taught generations of college students about logarithmic scale but ended up exposing them to a complex assembly of visual techniques from various scientific fields. Charles and Ray Eames organized the film in much the same way they designed their exhibition spaces, but with the relations reversed. Whereas *A Computer Perspective* presented artifacts, images, and texts up front to conceal their underlying pedagogical program (which visitors learned via the experience of walking through the exhibition space), *Powers of Ten* presented an experience of flying through space that concealed its underlying artifacts, images, and texts. To be sure, the Eameses never explicitly envisioned this outcome; however, as a cosmic zoom spanning from the human scale outward to the farthest reaches of the known universe and inward to the nucleus of a carbon atom, it acclimated viewers to significant new telescopic and microscopic realities from fields as wide as astronomy, aerial photography, and electron microscopy, which were just at that time coming into representation.

One of the common critiques of *Powers of Ten* centers on its flattening of these different scales of representation into a seamless experience. Most recently, Derek Woods has held up the film as the antithesis of "scale variance" for the way it depicts atomic and cosmic spheres as simple analogies of one another and thus suggests that the world is composed of a series of continuous systems rather than being marked by disjuncture and fundamentally incommensurable levels of action.[22] David Wittenberg recognizes the same problem from the point of view of the screen in noting that all vantages in the film are confined to the academy ratio frame, a technical fact abetting "the radical domestication of scale."[23] While the journey ventures inward and outward, the frame always "remains the same size," delineating a world conceived of and reduced to picture, as Wittenberg remarks with reference to Martin Heidegger's philosophical critique of technology.[24] Reinhold Martin argues that the film follows the program of the Eameses' friend György Kepes in his writings on vision in art and science and seeks to reinscribe the human into the various nonhuman scales of its voyage, "from the intergalactic to the subatomic levels."[25] In clearing a space for the human at each level, it naturalizes the wide new scales opened up by

21 Paul Schrader, "Poetry of Ideas: The Films of Charles Eames," *Film Quarterly* 23, no. 3 (Spring 1970): 10.

22 Derek Woods, "Scale Critique for the Anthropocene," *Minnesota Review* 83 (2014): 133.

23 David Wittenberg, *Time Travel: The Popular Philosophy of Narrative* (New York: Fordham University Press, 2013), 224.

24 Wittenberg, 224.

25 Reinhold Martin, "Organicism's Other," *Grey Room* 4 (Summer 2001): 42.

the space race and the atomic age and subordinates them to the discursive control of human politics. Mark Dorrian points to the film's acousmatic, voice-of-God narration as central to this seeming mastery over the microscopic and macroscopic scales of Cold War science.[26] And yet it is precisely this flattening that deserves attention as a heuristic design strategy. For it is its seamlessness that conceals the film's being the dense technical object it is, the exposure of which can provide great insight into the "user-friendly" interfaces of the computer and cinema.

In the decades after its release, *Powers of Ten* endured as a teaching aid and cultural artifact in part because of its professional production, particularly its notable score by Elmer Bernstein, who was well known at the time for his work in Hollywood on *The Magnificent Seven* (John Sturges, 1960) and *The Great Escape* (John Sturges, 1963), and professional script and voice-over by Phillip Morrison, a Massachusetts Institute of Technology (MIT) professor of physics who had worked on the Manhattan Project. But its principal appeal, given its large educational audience, was its scientific rigor. Whereas contemporaneous films, such as the National Film Board of Canada's *Cosmic Zoom* (Eva Szasz, 1970), used animation to realize the concept of zooming between orders of magnitude, *Powers of Ten* used photographic images. The film drew on the most advanced imaging systems in use at the time of its production in the late 1960s and subsequently updated its primary research for the second version in the 1970s. Charles Eames indeed marveled at the expanded archive of new satellite and microscope images available in 1977 that had not been available in 1968.

In analyzing *Powers of Ten*, I draw on the archives that the Eameses amassed in producing these two versions to provide a glimpse into the visual technologies that are the basis of their images. For several years in the lead-up to making the film, the Office of Charles and Ray Eames conducted extensive research on phenomena for each of the orders of magnitude beyond those that could be captured by traditional photography. The office's correspondence, now in a permanent collection at the Library of Congress, shows lengthy exchanges with researchers in astronomy, aerial photography, cell biology, and molecular chemistry that attest to the Eameses' effort to make the images as scientifically accurate as possible.[27] To guarantee adequate resolution for the images, which were intended for a theatrical setting, the research team sought professionally produced government and scientific images of various spatial scales. The quality of these images would allow viewers to look through the film toward the objects themselves, masking the scientific means of visualization that enabled the images and the way the film automated a pedagogical program that captured the viewer in its flight. For purposes of clarity it makes sense to go through

26 Mark Dorrian, "Adventure on the Vertical," *Cabinet* 44 (Winter 2011–2012), http://www.cabinetmagazine.org/issues/44/dorrian.php.

27 Charles and Ray Eames Papers, Manuscript Division, Library of Congress, Washington, DC. Orit Halpern has recently described the Eameses' archive as central to the wide field of their work: "Their archive at the Library of Congress is extremely extensive, and was well catalogued, by themselves, upon donation, and their office still contains endless rows of cabinets where Ray Eames would store every button, doll, piece of cloth, yarn, string, and other objects—often toys from around the world—used in their work. Almost all their movies have a scene using footage, just like their found education, from earlier work." Halpern, *Beautiful Data*, 108.

the office's research in the opposite direction of that presented in the film, beginning with the inward journey first.

The Inward Journey. The elegance and simplicity of *Powers of Ten* is the payoff for years of meticulous research, trial and error, collaboration, consultation, feedback, and adjustment. After distributing the "Rough Sketch" version of the film in 1968, the Eames Office received a letter from Geoffrey A. Moore, a professor who had screened the film for a group of postgraduate medical students and thirty electron microscopists. Moore relates several flaws detected by the group, particularly in the sections of the inward journey representing the cell and its internal structures:

> There was little comment on the higher powers of ten but those from 10^{-2} to 10^{-10} were considered somewhere between inaccurate, and poor quality reconstruction. The inner shell of electrons of the carbon atom was thought to be a more appropriate position for the 1Å frame; no attempt was made to indicate co-valent bonding of the outer electrons which could have been simple in the DNA molecule. The largest number of objections from the micropists [*sic*] concerned the poor quality of ultrastructure in sequences from the blood vessel to the molecular structure of the chromosome. Excellent microphotographs of these have been published since the mid 1960s.[28]

For this early version of the film, Charles Eames himself had consulted several experts and amassed a range of texts on cellular and molecular biology. It is unclear exactly where the research went wrong for the representation of the molecular structure of the chromosomes and DNA, except for the exceeding difficulty of making a specialist's film with a generalist's knowledge. Nevertheless, Eames had certainly done his homework. For the first stages of the inward journey, Eames contacted the University of California, San Francisco (UCSF) Medical Center seeking photographic slides of the skin to use as models for zooming in on the hand. In a letter dated June 29, 1968, Jesse L. Carr, a medical doctor at the center, responded to Eames's inquiry: "Enclosed are twenty-three slides which represent step sections cut from the base of the skin down through the malpighian and basal layers through the corium and down into the subepithelial fat." Other items in the same folder suggest that Eames was working on the different scales of the inward journey all at the same time. We find models of chromosomes, notes from several books detailing the history of cellular biology, hand-drawn sketches of the molecular structure of DNA, information on the scanning electron microscope, and a complete scene sketch.[29]

Elsewhere, Eames's handwritten notes provide a glimpse into the extent of the research conducted, including several library cards and numerous notebook pages confirming that the office consulted a wide range of books on cytology, histology, and other

28 Box I:206, folder 5. Films, *Powers of Ten*, 1968 Version, Miscellany, 1969. The notation Å, which comes up frequently in Eames's notes, refers to an angstrom, or one ten-billionth of a meter.

29 Box I:209, folder 10. Films, *Powers of Ten*, 1977 Version, Research and Notes, Inward Journey, General, 1968–1976, n.d. As a note on citation, wherever materials have come from the same box and folder, I have withheld citation until the end of the paragraph.

areas of biology and biochemistry. The points of interest ranged from the history of scientific discovery to current events. Eames collected notes about Leonardo da Vinci's ideas on heredity, Gregor Mendel's founding of genetic science, and Friedrich Miescher's discovery of nucleic acid. An etymological note on graph paper traces the word "cell" back to its Latin root meaning "room," adding, "Divisions of organic matter were identified and named cells [in] 1663 [by] English scientist Robert Hooke." Eames also kept up on the news, appending an October 1968 article on "Prizes for Cracking Genetic Code" to a March 1968 review in *The Nation* of James Watson's *The Double Helix*. All this research seems to have been to prepare for the long-term goal of making the material accessible to audiences with widely differing backgrounds. For instance, one senses Eames's compelling interest in condensing information to sensible scales when he jots a note specifying, "Average human cell 1/2000 cms. diameter," and as if immediately not content with the abstraction, continues, "If we took the DNA from one cell of every human being alive today (to give a complete blueprint of the human race)—it would fill the space about the size of a small drop of water."[30]

Most interesting, Eames finds several models in these texts that are already attempting to address the multiple scales of spatial magnitude the film seeks to animate. The problem of scale seems to be on the minds of researchers in disciplines far and wide. A printout from a chapter on "The Natural History of the Cell" includes a graph comparing the expanse between the "atomic world" and the "cosmic world" to that spanning the living world between amino acids and whales.[31] Another shows a diagram of the dimensions of objects, from 10^{27} meters in the "distance to the farthest galaxies ever seen" to 10^{-12} meters in the nucleus of an atom.[32] We can imagine Eames, who was always seeking to elucidate abstract ideas using concrete images, being drawn to this equation in a text on "The Lore of Large Numbers" that measures "man" as "the geometric mean between the atom and the sun":

$$\frac{\text{ATOM}}{\text{MAN}} = \frac{\text{MAN}^{33}}{\text{SUN}}.$$

Eames cites an article by John T. Bonner in the January 1969 issue of *Natural History* "re: his treatment of several orders of magnitude variation in the size of living organisms."[34] In the same year, Bonner, a professor of biology at Princeton, published a book on *The Scale of Nature: A Panoramic View of the Sciences* that sought the same "sense of scale" Eames was attempting to provide in his film by outlining the various

30 Box I:207, folder 7. Films, *Powers of Ten*, 1968 Version, Research and Notes, Inward Journey, 1968, n.d.

31 Box I:207, folder 7.

32 Box I:207, folder 6. Films, *Powers of Ten*, 1968 Version, Research and Notes, General, 1969, n.d.

33 Box I:207, folder 8. Films, *Powers of Ten*, 1968 Version, Research and Notes, Outward Journey, 1967–1968, n.d. The book appears to be Philip J. Davis, *The Lore of Large Numbers* (Washington, DC: Mathematical Association of America, 1961).

34 Box I:207, folder 6.

large-scale disciplines of geology, astronomy, and ecology in comparison with the microscopic scales of cellular biology and atomic physics.[35]

Eames also worked directly with the photographic records the office collected and shot on set. He drew framing rectangles in colored pencil on various photographs to determine the zoom between different orders of magnitude, marked significant features of the images to ensure consistent centering of the frames, and wrote out various calculations. Materials included a photo series of a hand magnified at different degrees and frame enlargements from the test film with the corresponding information panel (Figure 2).[36]

In updating the sections on the skin cell in 1977, the Eames Office contacted several specialists to address earlier criticism, such as the points Moore had relayed from medical students and microscopists upon seeing the "Rough Sketch" version. Alex Funke, a cinematographer and special effects artist who worked for the Eames Office in the 1970s and later went on to an award-winning career in Hollywood, seems to have been the point person for research at this time. Funke corresponded in particular with professors Jean-Paul Revel and Robert Dickerson at the California Institute of Technology (Caltech) and physicist Kenneth A. Johnson at MIT. A series

Figure 2. Charles Eames's handwritten notes on images for the zoom on the human hand. Eames Papers, box I:206, folder 8.

35 John Tyler Bonner, *The Scale of Nature: A Panoramic View of Sciences* (New York: Harper & Row, 1969). Bonner continued this concentration on scale throughout his career, including popular science works. See, e.g., John Tyler Bonner, *Why Size Matters: From Bacteria to Blue Whales* (Princeton, NJ: Princeton University Press, 2006).

36 Box I:206, folders 8–9. Films, *Powers of Ten*, 1968 Version, Inward Journey.

of notes in early January titled "Dr. Revel Questions" appears to be in preparation for a letter or phone conversation. Seemingly in direct response to earlier critiques, the notes remind whoever would have the exchange with Revel to ask about the strength of the color scheme, the accuracy of the sizes, and how "real" the nucleus picture appears.[37] Revel replies by noting that the "globular form is normal" and the "sizes seem screwed up," offering some advice for representing the connective tissue and capillaries. Included in his letter are several pictures of the basic structure of lymphocytes and a suggestion that they could have the photographs airbrushed.[38] Moving on from the cell design in February, Funke contacted Dickerson about the molecular structure of the methyl group and asked Johnson for advice on the layout of the electron shell of a carbon atom.[39]

From the time the film was conceived in the mid-1960s, the extent of this research had complicated the production of the inward journey. The office's papers show a long and intensive period of experimenting with different production techniques, as seen in several frame and speed calculations, graphs, timelines, and composite sketches.[40] One of the most pressing concerns was how to explore phenomena of such small scale. At issue was the difference between the "cosmic zoom" of the outer journey, which faced no obstacles in the vastness of space, and the penetration into the skin, which involved the passage through various layers. To solve this problem, the office opted to simulate a tracking shot in the outward journey and a zoom in the inward journey.

Notes from the 1977 version show that Eames reconsidered the choice of zooming in on the human hand. He entertained the idea of using, for instance, a blood vessel on the surface of the eye, and the team accordingly collected photographs of red and white blood cells (Figure 3). An even more attractive idea was also abandoned, namely to use a virus because it would facilitate "three more powers worth of actual photographs" using the transmission electron microscope. As examples, he clipped several microphotographs from texts on histology and microphotography, noting that newer photos would be better. Before making his final decision, Eames sketched out several other possible "road maps" for the inward journey by comparing microphotographs of human skin, chrysanthemum petals, and pollens.[41] Although the microphotographs of viruses and pollens would be set aside in favor of going again with a human skin cell, it would not be the end of the office's research in electron microscopy.

The choice of a carbon atom as the final destination was simple enough, because carbon is the basis of all living things. However, representing the carbon atom, particularly the passage from the outer shell to the nucleus, was much trickier. First of all, at the atomic scale it becomes necessary to work with models rather than photographs. But the real issue was to find a way to deal with the several empty orders of magnitude

37 Box I:209, folder 7. Films, *Powers of Ten*, 1977 Version, Production Notebooks, "Wonder" Book, 1977, n.d.

38 Box I:209, folder 12. Films, *Powers of Ten*, 1977 Version, Research and Notes, Inward Journey, Revel, Jean-Paul, 1976.

39 Box I:209, folder 11. Films, *Powers of Ten*, 1977 Version, Research and Notes, Inward Journey, General, 1977, n.d.

40 Box I:207, folder 5. Films, *Powers of Ten*, 1968 Version, Production Notes, 1968, 1976, n.d.; Box I:207, folder 6. Films, *Powers of Ten*, 1968 Version, Research and Notes, General, 1969, n.d.

41 Box I:209, folder 14. Films, *Powers of Ten*, 1977 Version, Research and Notes, Inward Journey, Scanning Electron Microscope, 1974, n.d.

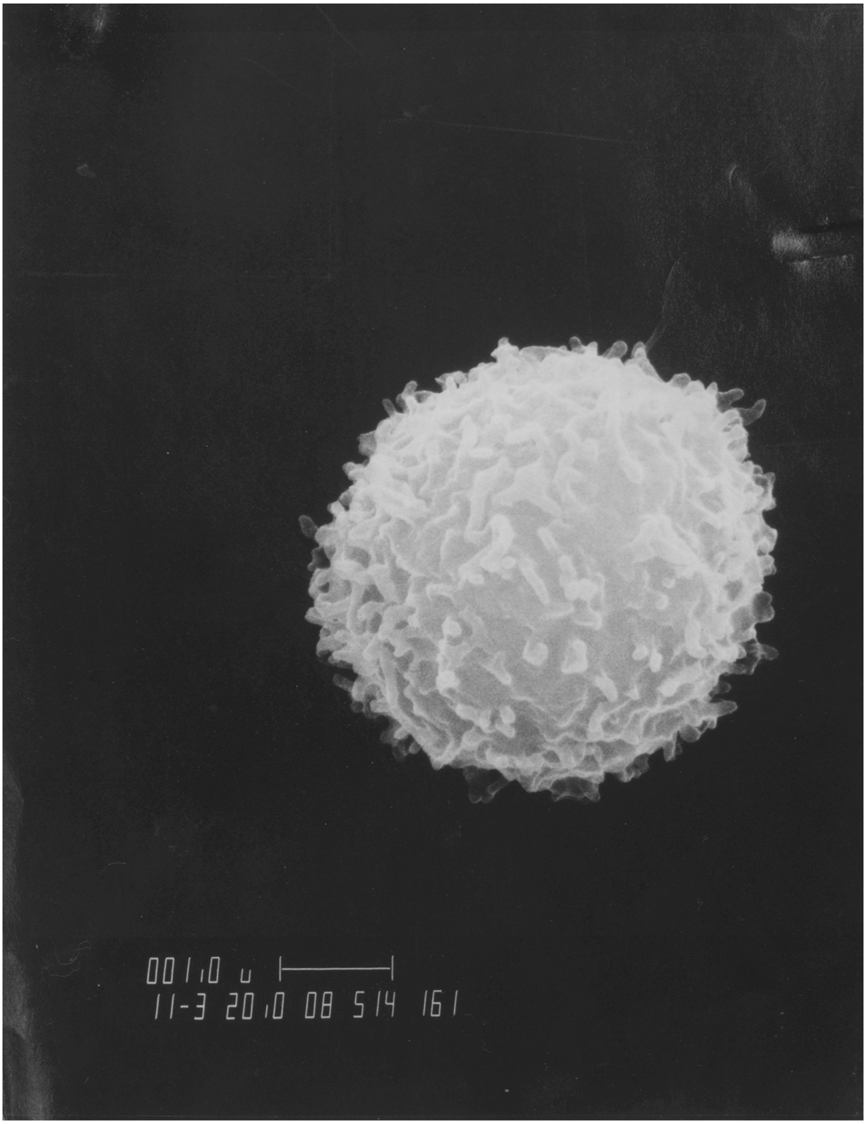


Figure 3. Scanning electron micrographs of lymphocytes and erythrocytes. Eames Papers, box I:208, folder 9.

where nothing exists between the outer electron shell and the nucleus. According to Eames's calculations, the exploration into the carbon atom left one-third of the inward journey blank if the film used a constant zoom.[42] In the end, Eames would opt to follow through all the way to the nucleus of the atom, having the voice-over narration explain the empty space.

42 Box I:207, folder 13.

The office conducted extensive research on electron microscopy, filing away diagrams of different devices, the proceedings of the annual meeting of the Scanning Electron Microscope Symposium, and catalogs from different companies offering services, such as the Japanese Electron Optics Laboratory (JEOL).[43] One note in particular lists the various machines available to the office, including two Cambridge StereoScans, one at UCLA Engineering and another at Micrographics in Newport Beach, and several JEOL machines operated in the Los Angeles area.[44] Eames took a personal interest in researching the microscopes, as shown in his notes on an article by two experts at the University of California, Berkeley, titled "The Scanning Electron Microscope," from *Scientific American* in January 1972. He underlines: "The best transmission electron microscopes have a resolution of between two and five angstroms, so that the maximum effective magnification exceeds a million diameters."[45] Significantly, by the end of the 1970s, these same electron microscopes would be used for analysis in the production of microchips and charge-coupled devices (CCDs) at the same time that they were being equipped with CCDs as their image sensors.[46] Although Eames had considered several other small-scale phenomena to explore for the inward journey, such as passing through the structure of a plant or a blood vessel in the eye, he never considered electronics, this domain of human action beyond human sensibility that, using integrated circuits and CCD imagers, would soon capture the type of astronomical images used for the film's outward journey.

The Outward Journey. A barely noticeable dissolve separates the live-action zoom of the opening scene from the first still images of the outward journey, similar to the dissolve in the inward journey between the overhead view of the picnic scene and the first scientific photos Eames received from the UCSF Medical Center showing the minute texture of skin. Also like the inward journey, this dissolve marks the end of images the production team could capture using traditional photography and the beginning of images the office had to purchase from aerial surveys and astronomical observatories.

A detailed shooting script from 1977 explains how the different materials were to mesh in the final film, including the two dissolves at the start of each journey and additional dissolves continuing between photographs and models. The first animated effect, or piece of "direct art," as Eames called it, occurs in the outward journey with a cloud effect accompanying the narration: "[L]ong parades of clouds, the day's weather in the Middle West." Other pieces of direct art include the orbits of the moon, planets, and Halley's Comet; the constellation map and models of the local stars, star groups, and galaxies; and various aids to orient the viewer in the rapidly widening expanse of space, such as a light beam signifying the length of a light year and square frames representing

43 Box I:209, folder 13. Films, *Powers of Ten*, 1977 Version, Research and Notes, Inward Journey, Scanning Electron Microscope, 1969–1973, n.d.

44 Box I:209, folder 14.

45 Box I:209, folder 14. Thomas E. Everhart and Thomas L. Hayes, "The Scanning Electron Microscope," *Scientific American* 226, no. 1 (January 1972): 54–69.

46 See, e.g., Kenneth H. Downing, Ming-Hsiu Ho, and A. M. Glaeser, "A Charge Coupled Device Readout System for Electron Microscopy," in *Proceedings of the 38th Annual EMSA*, ed. G. W. Bailey (Baton Rouge: Claitors Publishing, 1980), 234–235.

the different orders of magnitude.[47] At the far outer end of the journey, Eames adopted a "starback" approach consisting of tiny pinholes punched through black cardboard, using these models to convey stretches of space unavailable to photography and to suture together the various astronomical photographs of different galaxies and star clusters.[48]

In the same shooting script, Eames lists available photographs, adding "new material not available last time round," such as significant new satellite photographs "in god's plenty," as Eames elsewhere noted.[49] The most famous images of Earth from outer space, such as *Earthrise* and *Blue Marble*, taken respectively from Apollo 8 in 1968 and Apollo 17 in 1972, had not been available at the time the Eames Office made the "Rough Sketch" in 1968. *Blue Marble*, in particular, was significant for being the most famous "Whole Earth" image, capturing the face of the planet in full sunlight on a relatively cloudless day over Africa. Among the materials the Eames Office compiled for the 1977 version of the film were similar whole-Earth images centered on the United States and several location images over the Chicago area also taken by satellite.

In 1976, probably in September when the Eames Office was making similar inquiries, Funke ordered satellite images from the Center for Earth Resources Observation and Science (EROS), a division of the US Geological Survey, for an area centered on Chicago (latitude 41°32′, longitude 87°38′),[50] requesting maximum-quality color imagery with coverage from Skylab or NASA aircraft between the months of July and December.[51] These images likely connected the whole-Earth image to the vantages showing Chicago, making up regional views of the American Midwest and the Northern Hemisphere. For more detailed images of the city, the office contacted local photogrammetric services. Two invoices from October and November show that Funke signed for several rolls of "processed aero-color negative film" from the Chicago Aerial Survey (CAS), with images looking down at an area near Soldier Field (Figure 4).[52] Dissolving between the images from EROS and CAS brought the zoom from the picnic scene to the cusp of outer space, but the outward journey required more than images looking down from airplanes and satellites. It needed to simulate the effect of looking back on Earth from positions where no human-built craft had ever gone.[53]

47 Box I:209, folder 5. Films, *Powers of Ten*, 1977 Version, Production, Misc. Notes, n.d.

48 Box I:209, folder 7. Films, *Powers of Ten*, 1977 Version, Production Notebook, Sizing Book, 1977, n.d.

49 Box I:210, folder 1. Films, *Powers of Ten*, 1977 Version, Research and Notes, General, 1974–1976, n.d.

50 The EROS inquiry form allowed for either a point search or an area rectangle, and the Eames Office requested a point search, meaning that it would accept "imagery with any coverage over the selected point." This is to say that the office could not request a specific image and had to make use of survey images already in the EROS collection, hence the specificity only to minutes and not seconds.

51 Two other orders from September request materials from the Eros Data Center located in Sioux Falls, South Dakota. In one, Funke orders a photograph from NASA Aircraft Photography. The other is directed to Manned Spacecraft Photography. Box I:208, folder 6. Films, *Powers of Ten*, 1977 Version, Photographs and Drawings, Catalogues, Aerial, 1975–1976, n.d.

52 Box I:208, folder 6.

53 In this connection, Janet Harbord has argued that *Powers of Ten* "offered a mode of perception that is impossible to construe as human," participating in a relocation of perception from the human eye to the machine and a shift within cinema from representation to visualization, drawing tools from space travel, cartography, and physics. Janet Harbord, "Ex-Centric Cinema: Machinic Vision in the *Powers of Ten* and Electronic Cartography," *Body & Society* 18, no. 1 (2012): 100.

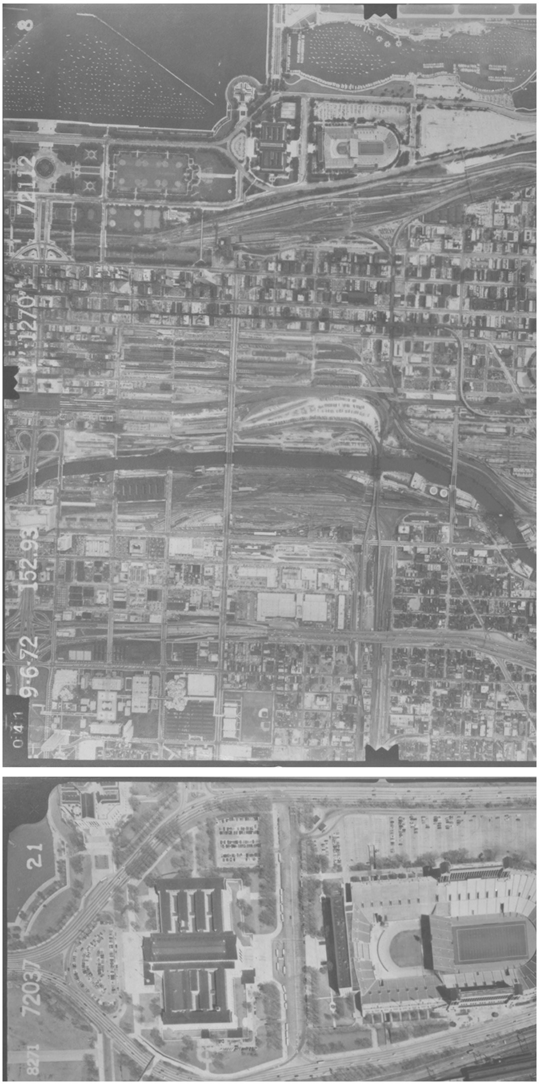
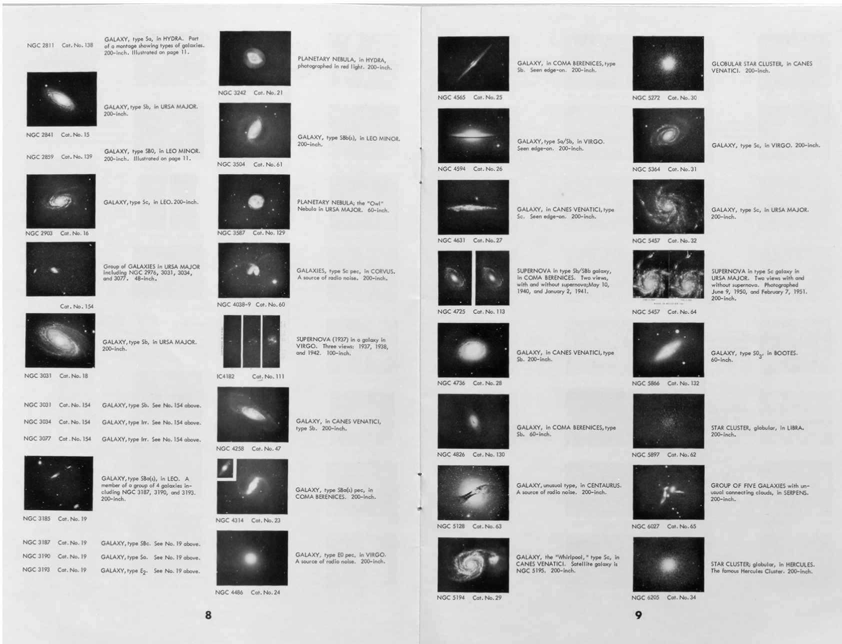


Figure 4. Aerial photographs over Soldier Field from the Chicago Aerial Survey. Eames Papers, box I:208, folder 16.

For these more distant vantages of stars, planets, and galaxies, the office turned to images from several observatories. Research on observatories began with the 1968 version of the film. Between 1961 and 1968, the Eames Office collected a series of catalogs from the Lick Observatory at the University of California, the Mount Wilson Observatory in Los Angeles, and the Palomar Observatory at Caltech. It appears that someone at the office clipped several thumbnail pictures directly from the 1965 Lick catalog, perhaps to be used as storyboards for the "Rough Sketch" film, although the star clusters they depict do not appear to have been used for the film itself. In July 1967, Annette Del Zoppo, a photographer who worked at the Eames Office throughout the 1960s, placed an order for three black-and-white prints from the Lick Observatory, including D4 Plei ades Cluster, S10 Andromeda Galaxy, and S15 Spiral Galaxy, attaching a check for $10.61 to cover the expense. Interestingly, the codes refer to photographs still available today from the Lick Observatory. Another order in January 1968 seeks three prints from the Astronomy Department at Caltech: Spiral Nebula M51 in Canes Venatici, NGC 4736 Canes Venatici, and M74 Pisces.[54] Nearly a decade later, in the final stages of the second version of the film, the office put in a purchase order to Caltech for several black-and-white prints to touch up the astronomy section (Figure 5).[55]

54 Box I:206, folder 6. Films, *Powers of Ten*, 1968 Version, Photographs and Drawings, Catalogues, 1961–1968.

55 Box I:208, folder 7. Films, *Powers of Ten*, 1977 Version, Photographs and Drawings, Catalogues, Astronomical, 1973–1977, n.d.



NGC 2811 Cat. No. 138 GALAXY, type Sa, in HYDRA. Part of a montage showing types of galaxies. 200-inch. Illustrated on page 11.

GALAXY, type Sb, in URSA MAJOR. 200-inch.
NGC 2841 Cat. No. 15

NGC 2859 Cat. No. 139 GALAXY, type SB0, in LEO MINOR. 200-inch. Illustrated on page 11.

GALAXY, type Sc, in LEO. 200-inch.
NGC 2903 Cat. No. 16

Group of GALAXIES in URSA MAJOR including NGC 2976, 3031, 3034, and 3077. 48-inch.
Cat. No. 154

GALAXY, type Sb, in URSA MAJOR. 200-inch.
NGC 3031 Cat. No. 18

NGC 3031 Cat. No. 154 GALAXY, type Sb. See No. 154 above.
NGC 3034 Cat. No. 154 GALAXY, type Irr. See No. 154 above.
NGC 3077 Cat. No. 154 GALAXY, type Irr. See No. 154 above.

GALAXY, type SBa(s), in LEO. A member of a group of 4 galaxies including NGC 3187, 3190, and 3193. 200-inch.
NGC 3185 Cat. No. 19

NGC 3187 Cat. No. 19 GALAXY, type SBc. See No. 19 above.
NGC 3190 Cat. No. 19 GALAXY, type Sa. See No. 19 above.
NGC 3193 Cat. No. 19 GALAXY, type E_2. See No. 19 above.

PLANETARY NEBULA, in HYDRA, photographed in red light. 200-inch.
NGC 3242 Cat. No. 21

GALAXY, type SBb(s), in LEO MINOR. 200-inch.
NGC 3504 Cat. No. 61

PLANETARY NEBULA; the "Owl" Nebula in URSA MAJOR. 60-inch.
NGC 3587 Cat. No. 129

GALAXIES, type Sc pec, in CORVUS. A source of radio noise. 200-inch.
NGC 4038-9 Cat. No. 60

SUPERNOVA (1937) in a galaxy in VIRGO. Three views: 1937, 1938, and 1942. 100-inch.
IC4182 Cat. No. 111

GALAXY, in CANES VENATICI, type Sb. 200-inch.
NGC 4258 Cat. No. 47

GALAXY, type SBa(s) pec, in COMA BERENICES. 200-inch.
NGC 4314 Cat. No. 23

GALAXY, type E0 pec, in VIRGO. A source of radio noise. 200-inch.
NGC 4486 Cat. No. 24

8

GALAXY, in COMA BERENICES, type Sb. Seen edge-on. 200-inch.
NGC 4565 Cat. No. 25

GALAXY, type Sa/Sb, in VIRGO. Seen edge-on. 200-inch.
NGC 4594 Cat. No. 26

GALAXY, in CANES VENATICI, type Sc. Seen edge-on. 200-inch.
NGC 4631 Cat. No. 27

SUPERNOVA in type Sb/SBb galaxy, in COMA BERENICES. Two views, with and without supernova;May 10, 1940, and January 2, 1941.
NGC 4725 Cat. No. 113

GALAXY, in CANES VENATICI, type Sb. 200-inch.
NGC 4736 Cat. No. 28

GALAXY, in COMA BERENICES, type Sb. 60-inch.
NGC 4826 Cat. No. 130

GALAXY, unusual type, in CENTAURUS. A source of radio noise. 200-inch.
NGC 5128 Cat. No. 63

GALAXY, the "Whirlpool," type Sc, in CANES VENATICI. Satellite galaxy is NGC 5195. 200-inch.
NGC 5194 Cat. No. 29

GLOBULAR STAR CLUSTER, in CANES VENATICI. 200-inch.
NGC 5272 Cat. No. 30

GALAXY, type Sc, in VIRGO. 200-inch.
NGC 5364 Cat. No. 31

GALAXY, type Sc, in URSA MAJOR. 200-inch.
NGC 5457 Cat. No. 32

SUPERNOVA in type Sc galaxy in URSA MAJOR. Two views with and without supernova. Photographed June 9, 1950, and February 7, 1951. 200-inch.
NGC 5457 Cat. No. 64

GALAXY, type $S0_3$, in BOOTES. 60-inch.
NGC 5866 Cat. No. 132

STAR CLUSTER, globular, in LIBRA. 200-inch.
NGC 5897 Cat. No. 62

GROUP OF FIVE GALAXIES with unusual connecting clouds, in SERPENS. 200-inch.
NGC 6027 Cat. No. 65

STAR CLUSTER; globular, in HERCULES. The famous Hercules Cluster. 200-inch.
NGC 6205 Cat. No. 34

9

PURCHASE ORDER CHARLES EAMES 901 WASHINGTON BOULEVARD VENICE, CALIF. 90291 EX 6-5991

TO: Calif. Institute of Technology Bookstore
1201 E. California Bl.
Pasadena Ca.

DATE: 1 Mar 77

№ 27545
SHOW THIS NUMBER ON ALL INVOICES, PACKAGES AND SHIPPING PAPERS.

SHIP TO: VIA:

QUANTITY	ARTICLE	PRICE
	One 8 x 10 black and white print of: #16 #18 #29 #31 #32 #150 @ \$2.75 + 6 %	16.50 .99 \$17.49

EAMES OFFICE INFORMATION

CHECK URGENT PROJECT 76-11
~~CASH~~ TODAY REQUEST BY Alex
CHARGE BY APPROVED

Figure 5. Caltech Hale Observatory catalog and Eames Office purchase order. Eames Papers, box I:208, folder 7.

The research seems to have been very effective. The office's correspondence shows extraordinary interest from different observatories seeking a copy of the film after its completion. The greatest wave of letters came in January 1978, just months after the film's release, and nearly all mention having purchased the first version in 1968. A letter from Claude Faure, dated January 4, 1978, requests a French version of the film based on a recommendation from the Institute of Nuclear Physics in Lyon, noting that it was played on French television in September 1977. A few weeks later, a letter from Dr. R. C. Maddison of the Observatory at the University of Keele mentions needing a replacement for the physics department's copy of the original 1968 film. Apparently, Maddison and M. J. Smyth of the Royal Observatory, Edinburgh, among others who wrote, had seen the film when the Smithsonian astrophysicist Owen Gingerich screened it at the Royal Astronomical Society in London. Smyth, too, requested to purchase a copy to show to his astronomy students. Other letters poured in from the Royal Greenwich Observatory, the Max-Planck-Institut, and the Université de Paris, all seeking to buy a new copy of the film. One letter from October 25, 1978, stands out, coming from Stephan L. Chorover in the MIT Department of Psychology. Chorover opens the letter with his sincere condolences about the passing of Mr. Eames and his "profound admiration and respect" for *Powers of Ten*, calling it "*the* definitive 'Cosmic Zoom' film."[56]

Chorover's letter goes on to suggest—however inopportune the moment—that the film could be of more interest to fields outside physics if it could take into consideration issues of temporality, asking rhetorically, "Would it not be possible (indeed desirable) to explore a possible variation on the 'Powers of Ten' theme? One in which the time-line was sufficiently 'relaxed' periodically (or at varying points in one of several 'journeys') so as to permit us to 'view' events-over-time at several interesting levels?" In fact, in one of his notes for the outer journey, Eames himself had shown an interest in representing different time scales, jotting down a quotation on the "Evolutionary Development Theory of Solar Systems": "We have partially learned how to correlate the human time scale to the planetary time scale, but this is not to say that we yet understand the solar system time scale—or galactic time scales."[57] If Eames chose to confine the project to the frame of physics, it was certainly not for lack of considering the other possibilities. Moreover, Chorover's intuition was strong. The materials that Eames had to leave in his notes, materials that could never make it into the final film, would have to wait until the computational possibilities that he sought in film could be fulfilled on another platform, even if some of these were already taking hold in a different application of film technologies in document storage and retrieval.

Exponential Data. *Powers of Ten*'s techniques of exponential scale partook of a wider fascination with exponentials in the 1960s. Biologists and demographers had long observed exponential trends in phenomena such as bacterial cultures and human and animal populations. In the postwar years, however, information scientists and historians

56 Box I:208, folder 4. Films, *Powers of Ten*, 1977 Version, General Correspondence, 1976–1985, n.d.

57 Box I:207, folder 8.

noticed striking exponential trends in their own fields. In 1963, looking back across three centuries since the first scientific journal, Derek John De Solla Price penned a foundational account of the exponential growth of science evidenced by the regular doubling of the number of scientific publications.[58] Reflecting on such growth, Price argued that the capabilities of big science in the mid-twentieth century had extended so far in advance of the small-scale science that preceded it and had produced "manifestations of scientific hardware so monumental" that it was clear that science had entered a new epoch.[59] In 1965, Gordon Moore confirmed Price's conclusions about scientific hardware, drawing on the data available since the invention of integrated circuits in 1959 to forecast the exponential growth of the semiconductor industry.[60]

The exponential increase Price mapped for scientific abstracts was not incidental to the growth of hardware. It coincided with the centuries-long arc of enhanced techniques of writing, communication, and printing in the sciences that were all reliant on new material resources, such as mining, manufacturing, and new forms of labor. At the same time that these advances contributed to the paper and ink of scholarly publishing, they also supplied the medium of alphabetic script with a host of new phenomena to address, such that the exponential growth of scientific abstracts followed also from a precipitous rise in artifacts and relations for science to report on and explicate. As material artifacts themselves, scientific texts fostered this predicament at another level, serving both as a control medium capable of analyzing, coordinating, directing, and managing new material gains and, for scientists, as a new material obstacle—a confounding pile of data in the strict sense of a mounting assortment of *things given* that had to be dealt with. In response to *data* in its Enlightenment sense of the givens of the natural world, science had proliferated *data* in the modern sense of computable information. The trouble, of course, was that the texts could not on their own coordinate all the new knowledge in circulation. Unlike the encyclopedias and indexes of old, no single modern document or series of volumes could satisfactorily reference all the others. The problem required a change in scale, a higher-order medium capable of containing texts, sorting them, and relating them. What was necessary was a medium that could reduplicate texts while also materializing the relations between them, making them addressable on the same level. The earliest medium to take on this function, before digital computing, was photographic film.

As early as the 1920s, while scientists at the major photographic laboratories in the United States and Europe explored solutions for microfilm search and retrieval, academic researchers in nontechnical fields turned to retail film technologies to photograph documents. Notable in this regard is the influential French historian Fernand Braudel,

58 Derek John De Solla Price, "The Exponential Curve of Science," *Discovery* 17 (1956): 240–243; and Price, *Little Science, Big Science* (New York: Columbia University Press, 1963). Although subsequent accounts have shown that Price's curve was slightly too steep, they have roundly supported his overall conclusion that publication growth has been regular and exponential. See, e.g., Arif E. Jinha, "Article 50 Million: An Estimate of the Number of Scholarly Articles in Existence," *Learned Publishing* 23, no. 3 (2010): 258–263.

59 Price, *Little Science, Big Science*, 2.

60 For a reprint of Moore's original 1965 article, see Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Proceedings of the IEEE* 86, no. 1 (1998): 82–85.

who often considered himself the inventor of using cinematographic film in historical research. Writing in a "Personal Testimony" in 1972, Braudel relates the fortuitous discovery of special purposing a cine-camera to capture materials at the castle at Simancas in Spain:

> I had to wait for the summer vacation of 1927 to undertake my lengthy labors in the archives of Simancas. But I had an unusual piece of luck: when I tried to buy an ordinary camera (microfilm is a postwar invention), an American cameraman offered me an ancient apparatus intended for making movies, and proved to me that it could perform marvels in photographing documents. I aroused envy and admiration among the archivists and buscadores [searchers] of Simancas by taking 2,000–3,000 photos a day and rolling some thirty meters of film. I used it and abused it, in Spain and in Italy. Thanks to this ingenious cameraman, I was no doubt the first user of true microfilms, which I developed myself and later read, through long days and nights, with a simple magic lantern.[61]

Filming archival materials allowed Braudel to continue research well beyond the hours and days he could spend in the archives. When in 1935 he took a position at the new university at São Paulo in Brazil, he found "fantastic possibilities for reading" and was able to pore over the many "kilometers of microfilm" he had amassed in the archives of the Mediterranean.[62] Such novel access to historical documents, Braudel admitted, greatly contributed to his emphasis on the broad mosaic and grand movement of history, where traditional narrative accounts had concentrated on only one or another narrow aspect.[63]

Film had advantages as a research medium. It was a simple, relatively low-cost way to store a wide range of documents in photographic form, lending itself to reproducing text as well as charts, diagrams, and photographic inlays. It was capable of containing a computing track and of wholly being a computing track, as in the case of Gordon S. Brown and Norbert Wiener's Cinema Integraph, and in this way it could coordinate between different media.[64] Considering its uses across different industries, film was the first medium capable of storing text, image, and sound while also functioning as a command or computing medium. Even commercial cinema made use of this multioperationality in designating part of the filmstrip as a conveyor of sound while reserving part for the image and still another part—the sprocket holes—for mechanical transfer. This last possibility is too often overlooked: film was

61 Fernand Braudel, "Personal Testimony," *Journal of Modern History* 44, no. 4 (December 1972): 451–452. Elsewhere, Braudel relates: "I bought this machine in Algiers: it belonged to an American cameraman and was used to make rough images of scenes for films. On it you had a button that allowed you to take one photo at a time, or you pressed it and you took the whole shoot at once. When I was offered it, I said to the cameraman, 'Photograph me that: if I can read it, I'll buy it.' He made me a magnificent photo. And that's how I made kilometers of microfilm." Oswyn Murray, introduction to Fernand Braudel, *Memory and the Mediterranean*, trans. Sián Reynolds (New York: Vintage, 2002), xi.

62 Braudel, "Personal Testimony," 452.

63 See Fernand Braudel, "History and the Social Sciences: The *Longue Durée*," in *On History*, trans. Sarah Matthews (Chicago: University of Chicago Press, 1980), 27–38.

64 See Kyle Stine, "The Coupling of Cinematics and Kinematics," *Grey Room* 56 (2014): 34–57.

a representational medium especially amenable to undergoing flexible mechanical movement. For this reason, engineers across fields adopted it in place of punched tape as a more rugged medium for repeated mechanical use, as in Konrad Zuse's Z3 computer (1941) and Felix P. Caruthers's automatically controlled machine tool system (circa 1950).[65] Such varied applications were also interlinked: film was capable of operating in the one-dimensional linearity of code, the two-dimensional layout of the image, and the three-dimensional movement of mechanical transfer; and through these multidimensional possibilities, it was capable of translating between their different orders of magnitude.

Film's ability to capture image and text on a moveable medium made it ideal for document storage and retrieval. At the time of Price's thesis on "the exponential curve of science," microfilm and microfiche were already becoming staples of library archives and research practice. Microfilm storage media generally relied on external alphabetical indexing to locate materials, although even without means of automated search and retrieval, they could readily speed up access to documents. High-speed drive mechanisms significantly accelerated finding time, and compact storage facilitated quick and easy transport. Many of the functions that would later become commonplace with computers, such as automated indexing, search, and retrieval, were first tested on microfilm. As Michael Buckland has detailed, it was while working at Zeiss Camera in Jena in the early 1930s that Emmanuel Goldberg produced one of the first microfilm search and retrieval systems using a photographic coding system on film.[66] While working at Kodak in the late 1930s, Richard S. Morse drew inspiration from motion picture soundtracks and devised what he called "data soundtracks" for, among other envisioned applications, enhancing the speed of searching police records.[67] The most famous and enduring example, though it was never completed, was Vannevar Bush's Memex, which was designed as a comprehensive workstation for reading, marking up, searching, and retrieving documents, complete with visionary prototypes for the computer display and hypertext.[68]

As with these efforts to coordinate the proliferating archives of textual production, the Eameses similarly sought to task a machine with automating the display of documents. The goal of *Powers of Ten* was not simply to harness image data in bulk and store it away on film but to preprocess it for the human eye. Above all, this was the aim of its

65 For more on Zuse's Z3 computer, see Lev Manovich, *The Language of New Media* (Cambridge, MA: MIT Press, 2001), 25–26.

66 See Michael Buckland, *Emanuel Goldberg and His Knowledge Machine: Information, Invention, and Political Forces* (Westport, CT: Libraries Unlimited, 2006). Buckland deserves additional recognition for restoring Goldberg's place in the history of information science, which was nearly forgotten in the shadow of Bush's Memex.

67 Morse, "Rapid Selector-Calculator," U.S. Patent 2,295,000 (September 8, 1942), filed 1938.

68 Bush coined "Memex" as a portmanteau of "memory" and "index." The device was to be essentially a personal computer capable of storing a researcher's references and using a coding system to navigate them. In a passage that in many ways echoes Braudel, Bush writes: "There is a growing mountain of research. But there is increased evidence that we are being bogged down today as specialization extends. The investigator is staggered by the findings and conclusions of thousands of other workers—conclusions which he cannot find time to grasp, much less to remember, as they appear." Vannevar Bush, "As We May Think," *Atlantic Monthly,* July 1945, 48. For further media-historical perspective on this coding system and the history of Memex, see Belinda Barnet, *Memory Machines: The Evolution of Hypertext* (London: Anthem Press, 2013).

seamless zoom. As Halpern explains, Charles Eames had long aspired to join together and synthesize the widely varying pursuits of modern science, and he enlisted designers in his effort to use visualization "to reduce 'discontinuity' between disciplines."[69] In this way, he shared in the efforts of Braudel and Bush. The Eames Office, it could be said, was developing the visual software necessary to process the massive new data inheritance captured by imaging techniques. Indeed, Benjamin Bratton has recently described *Powers of Ten* as a "telescoping stack," an example *avant la lettre* of the software-computing-network stack at the basis of modern information systems.[70] As Bratton argues, the stack, or the multilayered structure of software arranged vertically from user to computer to network, coordinates different orders of magnitude by design: "It draws links between technologies, places, processes, and cultures that may exist at different scales but which are also deeply interrelated."[71] Just as the stack coordinates different scales of computing infrastructure, *Powers of Ten* coordinates multiple interdependent levels of visualization.

In doing so, the film permits more than simply "a gut feeling" about the relative size of things, as Eames reflected in his interview with Schrader.[72] It also provides an experience of the new breadth of imaging capabilities being developed in the sciences. The new scales of visual and textual information emerging in the postwar years established the climate for *Powers of Ten* to serve as a coordinating experience of large-scale technological growth. The film offers a seamless archive of the many resources the Eames Office assembled in its research, such that the whole enterprise of scientific imaging must be thought to have contributed to the film in some way.[73] Throughout its production, the medium of film was a means of coordinating these tools and submitting them all to the same order of representation, materializing the relations between lens-based seeing and the technical images thus registered, as from telescopes and microscopes, just as it had materialized the relations between documents in Bush's proposal for the Memex and Goldberg's microfilm system.

A Computer Perspective. In the early 1970s, the Eames Office applied some of the same insights gained from producing *Powers of Ten* to convey the spatial and temporal complexity of over a century of computing. Integrating material artifacts, historical documents, and a host of photographs, *A Computer Perspective* debuted at the IBM company showroom at 590 Madison in New York City in 1971. At the center of the exhibition was the History Wall, a comprehensive panorama of the development of computing. One of Charles Eames's earliest handwritten notes for the project, scrawled on a sheet of notebook paper seemingly before the timeline was extended back to Charles Babbage's Analytical Engine in the 1840s, stresses: "The wall is a three-dimensional exhibition of objects, machinery, printed material, photographs, and captions that gives the viewer a

69 Halpern, *Beautiful Data*, 108.

70 Benjamin Bratton, *The Stack: On Software and Sovereignty* (Cambridge, MA: MIT Press, 2015), 52.

71 Bratton, 18.

72 As quoted in Schrader, "Poetry of Ideas," 10.

73 As one reviewer later said of *For All Mankind* (1989), *Powers of Ten* might be deemed among the most expensive films ever made for its debt to the billions of dollars spent on the space program.

look at the world of data processing, starting with the innovations of Herman Hollerith in the 1880's, and ending with the introduction of electronic computers in the early 1950's."[74] Eames in a sense sought to give the ambling crowds of the IBM showroom a cinematic view, "a sense of scale" for the developments of computing.

The response to the exhibition was overall celebratory, with a bundle of letters issuing from IBM employees to congratulate Eames and one notably coming from company president Thomas Watson Jr. himself. His letter of May 10, 1971, reads:

> Dear Charlie,
>
> That was a terrific write-up by Walter McQuade in LIFE about your computer exhibit at 590 Madison, and I enjoyed it immensely.
>
> Over the years you have made a great many contributions to American life in general and, as we like to think here at IBM, to our company in particular. I just wanted you to know we are all very appreciative.
>
> Best regards,
> Sincerely yours,
> Tom

But the most interesting letter considering Eames's convergent techniques of visualization and information processing came from an admirer in Belmont, Massachusetts, on April 22 of the same year:

> You have evidently created a remarkable exhibit. Many thanks for the pictures, some of which I have not seen for many years. I was especially impressed by the one of the profile tracer. All I could find for you was a print in rather sad condition. Yet your photographer has somehow brought it back to life. Please tell him I admire his skill.
>
> Cordially yours,
> V. Bush[75]

As if in a nod to Bush's Memex, Eames had already repaid the compliment, having expressed in his early notes a desire to show "the impact of imagery techniques on the general categories of computer application."[76]

Powers of Ten Interactive. In 1968 and still in 1977, the medium of film was the closest the Eameses could come to programming a spectator's experience. With the rise of personal computers in the 1980s and 1990s, however, the Eames Office recognized a new opportunity in creating a software version of *Powers of Ten*. In a way, the project's extension into software reveals that its design had been computational from the outset. As

74 Box I:134, folder 7. Exhibits, *A Computer Perspective*, History Wall, Notes, Lists, and Outlines, 1969–1971, n.d. His emphasis.

75 Box I:134, folder 3. Exhibits, *A Computer Perspective*, General Correspondence, 1968–1975, n.d.

76 Box I:134, folder 7.

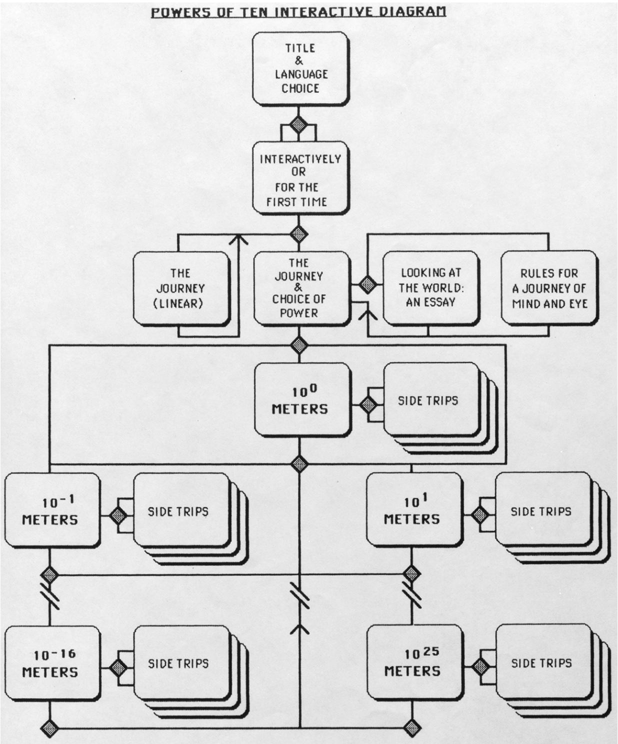


Figure 6. Flowchart for the design of *Powers of Ten Interactive*. Eames Papers, box I:211, folder 9.

with the layout of the exhibition space for *A Computer Perspective*, the design of *Powers of Ten Interactive* (CD-ROM, 1999) was set out using a flowchart that programmed its possible journeys, including unique possibilities not available in the film, such as "side trips" within the different orders of magnitude and options to experience the journey out of order and to double back and revisit sections (Figure 6).[77] Of no less importance, the menu allowed one to "relax" the timeline—as Chorover had hoped—or proceed at one's own pace and view different aspects of the journeys. In this way, the software restored some of the possibilities available in the Eameses' walkthrough exhibitions, enabling greater personal freedom of movement and creating a sense of control over the presentation.

More recent variations on the cosmic zoom, such as Neil deGrasse Tyson's use of the *Powers of Ten* idea in *Cosmos: A Spacetime Odyssey* (Fox, 2014) and in Google Earth's interactive scaling technique, further expand the intermixing of cinematic and computational techniques explored by the Eames Office. Given what it would become, and in its broadest significance, *Powers of Ten* suggests that cinema is defined by the multiple tools of visualization it coordinates as much as it is a series of images thus produced. Like the computer, which would take over many of its functions, film is a system as much as it is an inscription medium. *Powers of Ten*, perhaps more than any other film, enables insight into this coordinating function. It suggests that digital technologies emerged not as an end to techniques of visualization in favor of abstract code but rather to continue them in another domain, at new temporal and spatial scales. Reflecting on the film's immersive journey through the reaches of the physical world, we see that at its center, cinema is its ends. ✻

77 Box I:211, folder 9. Interactive Videodisc Programs, Administrative File, 1987–1988.