One Sinister Hurricane: Simondon and Collaborative Visualization

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One Sinister Hurricane: Simondon and Collaborative Visualization

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This article offers a theory and methodology for understanding and interpreting collaborations that involve visualization technologies. The collaboration discussed here is technically a geovisualization—an immersive, digital "fulldome" film of Hurricane Katrina developed by the Advanced Visualization Laboratory (AVL) at the University of Illinois at Urbana–Champaign, produced in collaboration with atmospheric scientists at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. The project, which brought together AVL's programmers, visualization experts, and artists with NCAR's scientists, required the integration of diverse disciplinary perspectives. In the language of such collaborations, the term *renaissance team* was coined to capture the collective expertise necessary to produce modern, high-end visualizations of large data sets. In this article, we deploy Simondon's concepts of technical objects and collective individuation to analyze the development of AVL's Katrina simulation. One extended sequence of team member collaboration suggests that technical objects also be treated as "collaborators," for they have the capacity to transform such collectives through the unique problems they present. *Key Words: Advanced Visualization Laboratory, geovisualization, Gilbert Simondon, renaissance teams, science studies.*

本文为理解及诠释包含可视化技术的 "合作"，提供理论与方法论。此处所讨论的 "合作"，是技术上的地理可视化——一个由伊利诺大学厄巴纳—香槟分校的先进可视化实验室（AVL），与位于科罗拉多州博德的国家大气研究中心（NCAR）共同合作生产，所发展出的卡翠娜飓风的沉浸式、数位化的球幕影片。该计画协同AVL的程序员、可视化专家、艺术家与NCAR科学家，需要整合不同的领域视角。在此般 "合作" 的话语中，"复兴团队" 的概念，被创造来捕捉生产大数据集的现代、高端可视化所需的集体专门技术。我们于本文中，运用西蒙顿的 "技术目标与集体个人化" 之概念，分析AVL的卡翠娜飓风模拟发展。团体成员合作的其中一向延伸序列，主张技术目标亦应被视为 "合作者"，因其透过其所呈现的特殊问题，具有改变此般集体之能力。 *关键词： 先进的可视化实验室，地理可视化，吉尔伯特. 西蒙顿，复兴团队，科学研究。*

Este artículo presenta una teoría y la metodología para entender e interpretar las colaboraciones que involucran tecnologías de visualización. La colaboración que aquí se discute técnicamente es una geovisualización—una película de sumersión, a "domo pleno" digital sobre el Huracán Katrina, desarrollada por el Laboratorio de Visualización Avanzada (AVL) de la Universidad de Illinois en Urbana-Champaign, producida con la colaboración de científicos atmosféricos del Centro Nacional para la Investigación Atmosférica (NCAR), en Boulder, Colorado. El proyecto, que concertó a programadores del AVL expertos en visualización y artistas con científicos de NCAR, demandó la integración de diversas perspectivas disciplinares. En el lenguaje de tales colaboraciones, se acuñó la expresión equipo de renacimiento con el cual captar la necesaria expertícia colectiva para producir visualizaciones de punta, modernas, de grandes conjuntos de datos. En este artículo desplegamos los conceptos de objetos técnicos e individualización colectiva de Simondon para analizar el desarrollo de la simulación del Katrina en el AVL. Una secuencia extendida de colaboración de miembros del equipo sugiere que los objetos técnicos también se traten como "colaboradores" porque ellos tienen la capacidad de transformar tales colectivos a través de los problemas únicos que ellos representan. *Palabras clave: Laboratorio de Visualización Avanzada, geovisualización, Gilbert Simondon, equipos de renacimiento, estudios de ciencia.*

A data visualization artist, an animation chore-ographer, and a software developer huddle over a computer screen, discussing the techni-cal details of a time-lapse 3D visualization. Members of the University of Illinois at Urbana–Champaign's Advanced Visualization Laboratory (AVL), their attentions are captured by a simulation of Hurricane Katrina, the massive and deadly weather event that occurred along the U.S. Gulf Coast in August 2005. The spiraling image grows and shrinks, becomes trans-lucent and then opaque as the team manipulates its different layers of moisture, wind speed, and tempera-ture data. As their wranglings and renderings con-tinue, new questions emerge about data resolution and meteorological conditions not yet included in the visualization. Fine-tuning will mean negotiating for additional time with the university's supercomputer at the National Center for Supercomputing Applications (NCSA); it will mean more phone calls and e-mails to Boulder, Colorado, asking for clarification from mem-bers of the meteorological team at the National Cen-ter for Atmospheric Research (NCAR), the suppliers of the data; and there will be more late nights, more backaches, and more take-out dinners. For all its mun-daneness, the scene recalls some of the most exhilarat-ing laboratory ethnographies (e.g., Latour and Woolgar 1979; Galison 1987, 1997; Myers 2006, 2008; Suchman 2007), during which science becomes a meeting place of human practices and technical objects, sites that blend indelibly with the banalities of everyday social and bureaucratic life.

Our research at AVL, part of a larger project on art–science collaborations, is aimed at teasing out the everyday negotiations and transformations at work within jointly produced geovisualizations.[1] Such col-lective intellectual labor is ongoing in every quarter of the visualization community (e.g., Lin, Chen, and Lu 2013). Like all varieties of industrial production, the end products of visualization are complex assemblages of the raw materials that go into them: collections of different specialists, different sets of data and a variety of technologies, and so on, all of which are inflected by their site-specific settings. What is more, the pro-duction process includes, in addition to the interac-tions of these components, the influences of the technologies and visualizations on the very thought patterns, practices, and interactions of their producers.

In this article we expand the critical methodology for analyzing the collaborative practices of visualiza-tion. Drawing on the work of Simondon (1958), we extend the notion of the autonomy of industrial technical objects to those produced through exercises of collaborative visualization. In what sense, we ask, might technical objects "communicate" in the collec-tive process of a visualization's design and develop-ment? And, by extension, in what ways are the collaborations among AVL's diverse and creative peo-ple—so-called renaissance teams composed of artists, designers, programmers, and scientists—inflected by the objects they produce?

In light of these questions, our primary concern here is not with the qualities of AVL's finished product but rather with the practical minutiae of human–com-puter interactivity that constitute the collaborative process of building complex visualizations. What we offer is therefore not original with respect to the tech-niques of visualization—although, as we describe later, AVL is certainly at the forefront of such work. It is, instead, an approach for studying the processual com-ponents (people, data, technology, sites) of collabora-tions. Here, critical analysis of the interacting dimensions of technologies, knowledges, and practices spotlights the immanence of technology-in-use, as well as the political and ethical consequences of the "changing relationships between bodies and spaces and technologies" (Elwood 2010, 353; see Schuurman 2004; Wilson 2009). These interactions must be engaged and observed, because what is at stake is often not the end result representational content of the product but the gradual—often intuitive—transforma-tions of the actors.

In the following section, we contextualize our empirical work through a brief review of those aspects of critical geographical information systems (GIS) that have paid particular attention to the problematics that arise in technology-in-use. We offer that ethno-graphic accounts—such as those found in science stud-ies—are necessary for unravelling the entanglements of collaboration, a process that involves not only situ-ated actors who bring their own discourses and practi-ces but also technical objects. We then turn to an introduction to AVL and its joint effort with NCAR to create a cinematic-quality visualization of Hurri-cane Katrina. The section that follows then begins to engage both theoretically and empirically with the concept of renaissance teams; here we draw on Simon-don to suggest that theorizing collaboration in narrow terms—for example, in terms of the interacting exper-tise of team members—might be inadequate for describing what occurs during the creative process. A fine-grained analysis of a back-and-forth set of e-mails among team members enables us to glimpse the role

that technical objects—which pose "problems" in need of solutions—play in the dynamics of the process. A concluding section aims to clarify theoretically the contributing role of the technical object.

The Visualizers

Vermeer's painting, *The Geographer* (1668–1669), typifies for many the discipline's historical archetypical figure: a single, sovereign, visualizing subject, surrounded by the tools of his trade. Within the tradition of critical cartography, there has been no end of theoretical resources by which to critique this caricature of Vermeer's geovisualizer. We might draw on feminist critiques to position this geographer's distanced masculinity—informed perhaps by Bondi and Domosh (1992), Rose (1993), and Kwan (2002a). Such a critical reading might converge with Gregory's (1994) epistemological assessment of an early geography's "cartographic anxiety" (see also Pickles 2004), and this, in turn, could be augmented by an analysis of the figure's presumed location within a royal-science state apparatus preparing for colonial excursions (e.g., Sparke 1995; Driver 2005). These critiques, individually and in combination, will today resonate not only with critical geographers but also with those who work in the tradition that we, following Goodchild (1992), refer to as GIScience. For, as Schuurman made clear over a decade ago in her series of reflections on the early "science wars" divisions between critics and GIScience practitioners-researchers (1999, 2000; Schuurman and Pratt 2002), even then these two areas of scholarship were poised to overcome antagonistic dualisms—in part through institutional arrangements such as the National Center for Geographic Information and Analysis' Initiative 19 (see Pickles 1995) and in part through greater understanding by critics of the "computational and theoretical bases that underlie GIS" (Schuurman 2000, 587). As she explained, in a view consistent with the immanent technology-in-use focus of this article, "GIS is not an end product of the Enlightenment and scientific rationality. Rather, a myriad of practices sustains the technology; GIS incorporates intuitive, cognitive, visual and textual elements in its use and structure" (Schuurman 2000, 586).

In the years since, the discipline has trained a generation of geovisualization specialists well versed in both the technological architectures of GIS and its sociopolitical implications. This is not to say that today's researchers are homogeneous with respect to their allegiances to, say, practical applications, tool development, basic science, social justice, theoretical advancement, and so on. But it is to say, at the very least, that the new generation of critics is technologically savvy and that the new generation of GIScience practitioner-researchers is cognizant of the social, political, and epistemic critiques that developed during the 1990s. Indeed, many of this generation might well feel as if they have transcended this binary, whether through the strategies of empowerment found in participatory GIS (Elwood 2006a, 2006b) or in the blurring of users and producers of geovisualizations under the influence of volunteered geographic information and "neogeography" (Elwood 2008; Haklay, Singleton, and Parker 2008; Elwood, Goodchild, and Sui 2012). Hence, what were once described as divided fields are now increasingly working on a common ground—albeit one that is constantly shifting along with technology. Although computational competencies remain key to some technologically based discussions, increasingly valued are the skills of people who can deploy the capacities of virtual platforms to represent heterogeneous sets of data (Kwan 2002b; Kraak 2006). In doing so, they intersect with and manipulate new technologies to create tools to enable "better" visualizations, foregrounding their intelligibility, as well as their social and political potentials (Jankowski and Nyerges 2001; Sieber 2006; Bailey and Grossardt 2010; Elwood 2010, 2011; Fabrikant, Rebich-Hespanha, and Hegarty 2010; Wilson 2011).

At the same time, comprehending the emergent role of technical objects in AVL's creative process requires, we believe, further perspective on geovisualization technologies and production. This view does not negate critical GIS's "upward glance" at power in representational terms, asking what institutions, subjectivities, and practices are given privileged spots on the map; nor does it delimit its "downward search" for more participatory and democratic strategies of empowerment through GIS. It offers instead a "close-up" into the processes through which "orientations, landmarks, and linkages" (Deleuze and Guattari 1987, 493) become points of "relative solidarity" (Simondon 2009, 19) between computers and humans. There, technical objects pose problems that enlist and reprogram users' eyes, hands, necks, feet, and sensoria, giving rise to a variety of new gestures and interactions at the human–nonhuman interface (Wilson 2009; Elwood 2010; Vertesi 2012). Grappling with these relations is all the more urgent in light of the uneven velocities of human knowledge and technical

development. As Harrower (2007) explains, the processing power and flexibilities of cartographic technical objects have far outstripped the cartographer: "When it comes to designing animated maps, the bottleneck is no longer the hardware, the software, or the database—it is the human user" (350).

To be sure, it is thanks to the digital cartographer, the geotechnician, and the GIScientist that geographers have asked, in reflexively textured ways, "What can the technology do?" MacEachren's (1995) *How Maps Work* offered the first systematic answer. This wide-reaching, synthetic approach blends philosophy, semiotic theory, and cognitive, perceptual, and computer science to propose a set of interacting capacities across the human–computer interface. "Graphic displays," for example, "can be designed to take advantage of human perceptual organization tendencies leading to nearly automatic identification of certain relationships via a mental structuring ability (defined here as schemata)" (MacEachren 1995, 209). But we should recognize the philosophy that undergirds these assertions. Here, MacEachren's use of "image schema" (derived from cognitive linguist Lakoff) introduces a transcendental formalism whereby relational "tendencies" reduce to a priori perceptual and cognitive structures. Similarly, Fabrikant and colleagues employed a "congruence principle," which states that "well designed external representations such as graphic displays show a natural cognitive correspondence in structure and content with the desired structure and content of the internal (mental) representation" (Fabrikant et al. 2008, 201). Although their assumptions might invite question, the practical and experimental foci remain trained on capacities: "Visual analytics is based on the intuition that highly interactive and dynamic depictions of complex and multi-variate databases amplify human capabilities for inference and decision making, as they facilitate cognitive tasks such as pattern recognition, imagination, association, and analytical reasoning" (Fabrikant et al. 2008, 201).[2]

Still another approach to the question of what technology can do has come from those concerned with developing dynamic languages that speak to the complex technics—social as well as physiological—that are emerging from modern interactive geotechnology (Shaw and Warf 2009; Ash 2010; Shaw 2010; Gregory 2014). For these critical analysts of geotechnology, research must engage not only finished products and targeted uses but also the diversity of microprocesses animating their production and adoption. This, in turn, asks for a different approach to technology-in-use, one that is ethnographically "ambulatory" and consistent with theories capable of describing the emergence of problematic fields within technosocial collaborations. Key in this regard was Suchman's (2007) foundational ethnography devoted to "human–machine reconfigurations." In contrast to the schematic assumptions of user design approaches, Suchman's study found that "there is a profound and persisting asymmetry in interaction between people and machines, due to a disparity in their relative access to the moment-by-moment contingencies that constitute the conditions of situated interaction" (182–83). Here, the impasse is the *situatedness* of communication across the human–computer interface, the "circumstantial and interactional particulars of actual situations" (183) that fall beyond the purview of a "plan" or representational schema. Meanwhile, Woolgar's (1990) "ethnography of computers" troubles the idea of "the user" altogether. He argues that "by setting parameters for the user's actions, the evolving machine effectively attempts to *configure* the user" (61; see also Grint and Woolgar 1997; Kinsey 2010, 2011; Ash 2012). Methodologically speaking, these studies support an attentive, in-depth strategy, involving what Braun and Whatmore (2010) called "a redirection of research energies and resources toward . . . the fora, media, and devices in and through which technoscientific objects are rendered affective and amenable to effective political interrogation" (xxvii; see also Kwan 2007). As we see later, just as the hurricane's visualization stretched each member's individual expertise, so too does the sovereignty of Vermeer's geographer continue to dissolve in the problematic field of contemporary technology.

The Advanced Visualization Laboratory

The AVL (avl.ncsa.illinois.edu) is an outgrowth of the NCSA, which was established at the University of Illinois at Urbana–Champaign in 1985 by the National Science Foundation (NSF). For this research, AVL provided our research team with a nine-month window into their collaborative visualization process.[3] Led by graphic artist Donna Cox, members of AVL—including a cinematic choreographer, programmers, and software developers—collaborate with scientists to create "visualizations that are data-driven, aesthetically designed, and cinematically presented" (Cox 2008, 33). The resulting collections of variously skilled

collaborators are known as renaissance teams, a term coined by Cox to refer to

> active organisms in the constant process of exchanging parts and co-participating in the recombination of creating the visual imaginary. A collective group with a diversity of expertise is both auto-poetic [sic] and forward-thinking. Renaissance Teamwork implies a symbiotic process, one that is especially crucial for artistic production within unconventional settings, which is the case with aesthetically-oriented scientific visualization within scientific domains. The strategy makes especially good sense as a long-term approach for interfacing creative cultural workers, their expertise and products, with those of scientific ones, who are better funded and institutionally sustained. (Cox 2008, 63)

Renaissance teams thus encompass both AVL staff members and the scientists who collaborate with them on specific projects. In the process, AVL articulates one of the central projects of twentieth-century contemporary art: to "render visible" aspects of the material world that are not otherwise available to experience.

As aesthetic creations, the visualizations AVL produces also work as augmentations to science, operating explicitly to produce not an objective, systematic, or intellectual response but rather a sensory experience predicated on the audience's embodied reaction to "scientific reality." In spite of this artistic-sensorial aim, AVL is distinguished by the fact that its products are based on observed or simulated scientific data. Fidelity to scientific data sets the parameters of the

computer–human interface of AVL, but within those limits there exist a variety of options based on data manipulation (e.g., smoothing and interpolation), color enhancement, and visual object integration. As Cox (2008) put it:

> Creating scientific visualizations from computational science presents many additional challenges that transcend the traditional entertainment arts. Computational simulations must align within a scientific narrative as it is being developed for a show. Scientific visualizations are designed and rendered from large-data, supercomputer simulations using some of the most advanced technologies available while retaining the highest quality standards for aesthetic and cinematic treatment in order to provide production quality necessary for general audiences. We confront the truth and beauty paradox in our everyday operations. (67)

Because AVL's products are grounded in scientific data, its artists and programmers sometimes find patterns or anomalies that were obscured from their scientific collaborators, whose own expertise in scientific visualization might be limited. For example, while working with atmospheric scientists to produce animations of trajectories within a developing tornado and its parent thunderstorm, "AVL's team identified the presence of a second tornado rotating clockwise—opposite the main tornado. Its presence, known to occur only rarely in nature, came as a surprise" to the scientists involved (M. Gilmore, interview, March 2011 and e-mail clarification, July 2011). The main tornado appears in the background of Figure 1 and the
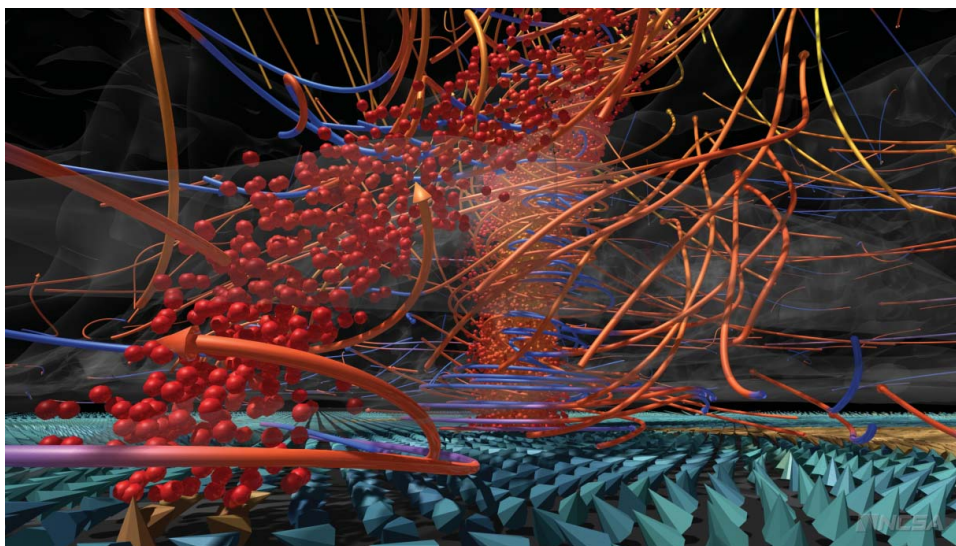

Figure 1. Rendering of a tornado. *Source:* Image courtesy of Advanced Visualization Laboratory, University of Illinois at Urbana–Champaign. (Color figure available online.)

second, smaller, and developing funnel is to the left in the foreground. The storm's force is indicated by AVL's unique system of "glyphs"—graphic aids that variously represent the wind speed, temperature, and direction.[4]

In their early years, AVL's renaissance teams collaborated on producing visual representations solely for scientific communities. The rapid transformation of visual technologies, however, has meant that in the last ten or so years AVL has expanded its activities to visualization productions that provide a high-resolution, immersive experience in planetarium dome settings and IMAX theaters, as well as in passive stereo theaters, digital reality theaters, and television. This new focus has taken their work in more popular directions, expanding from museum-funded dome shows to, most recently, mainstream cinema. Although their dynamic 3D simulations include everything from stellar exploration to music and dance, many of their graphic models help visualize scientifically derived data on natural phenomena (e.g., tornadoes, floods, marine pools), often for popular circulation and public outreach in outlets such as PBS/NOVA, the Discovery Channel, and National Geographic (see www.avl.ncsa.illinois.edu/who-we-are/collaborators).

AVL's animated visualization of Hurricane Katrina was developed as a contribution to *Dynamic Earth*, an immersive film project coproduced with NASA, the Denver Museum of Nature & Science, and frequent AVL collaborator Tom Lucas, of Thomas Lucas Productions. This popular account of the earth's climate

is specifically made to be "screened" in full-dome cinemas, a 360 degree, more-than-periphery visual environment that produces the sense of being "in" and moving through the projected space. *Dynamic Earth*, like many of AVL's past full-dome work, such as the award winning *Black Holes: The Other Side of Infinity* (2006), is billed as an educational film, but it is also an illustration of how art–science can incorporate rich experiential dimensions into the process of visualizing and animating massive scientifically generated data sets.

The Katrina visualization begins far above the earth, looking over the top of the hurricane as it circles off Florida's southern coastline (see http://www.youtube.com/watch?v=0Gp7bvX0rq0&feature=em-share_video_user, a short filmic version prepared for scientific rather than popular audiences). The visualization's camera path carries the viewer downward, toward the storm and its bubbling convection towers, granting a specialized view of the hurricane's anatomy as it moves inland. The dome version affords a more sensorial and dynamic sense of the storm itself, orienting viewers by way of AVL's "iso-tubes" indicating wind motion and speed, as well as air temperature and pressure (Figure 2). Rendered from the forecasting simulation of the storm produced by NCAR as the weather event unfolded, the Hurricane Katrina visualization blends an excruciating level of data fidelity with dazzling supplemental signage.

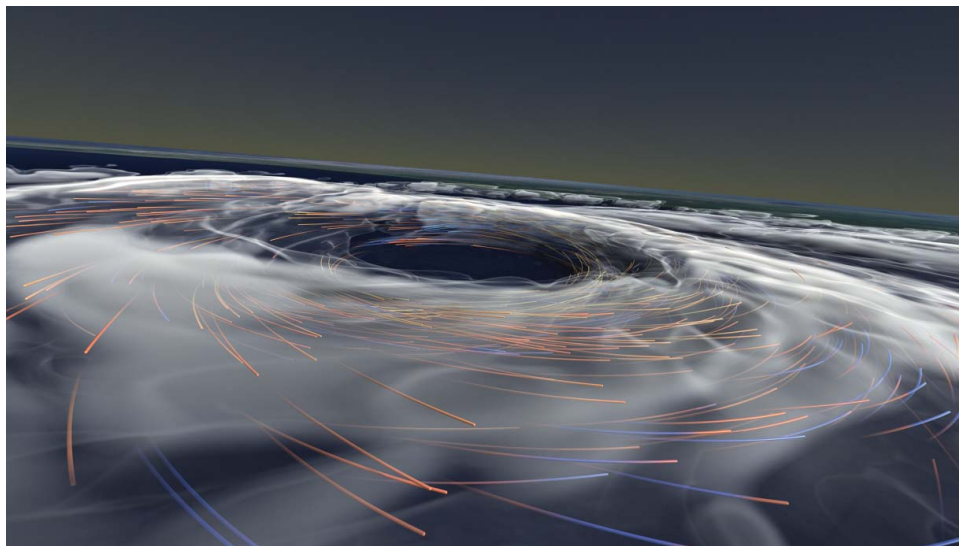Advances in supercomputing technology and visualization software allowed the team to develop a

Figure 2. Rendering of Hurricane Katrina. *Source:* Image courtesy of Advanced Visualization Laboratory, University of Illinois at Urbana–Champaign. (Color figure available online.)

dynamic, fluid representation out of the three terabytes of data (33,000 files) from the original NCAR simulation run during the weather event in the summer of 2005. The immense size of the data set produces a level of complexity that is unusual in the art of animation (although it is common in scientific modeling). As mentioned, AVL's Katrina visualization is built on NCAR's own hurricane simulation, which deployed the Weather Research and Forecasting Model (WRF; www.wrf-model.org), a research-oriented numerical atmospheric prediction and simulation system (Davis et al. 2007; Skamarock et al. 2008). The WRF simulation was developed by a research team that included Wei Wang, a scientist at NCAR's Mesoscale and Microscale Meteorology Division. She became the scientific advisor on the AVL renaissance team that produced the Katrina visualization.

The decision to visualize Katrina evolved out of a meeting that Lucas and Cox initiated with Wang in a visit to NCAR to discuss storm data sets. In a return meeting, members of AVL went to Boulder with three objectives: (1) to glean more descriptive information about the Katrina simulation; (2) to convince Wang to rerun her simulation at the higher temporal resolution AVL needed to create a visualization of cinematic quality; and (3) to engage, face-to-face, in a dialogue that would sustain the renaissance team's subsequent virtual collaboration over many months. Our organizational ethnography of AVL corresponded with the production process for *Dynamic Earth*'s Katrina simulation. We were privy to team meetings and e-mails and were afforded "fly-on-the-wall" access as AVL team members engaged in their individual and collaborative work. Interviews with key informants supplemented the data, as did audiovisual recordings and written field notes taken over the nine-month period. Out of these data we submit a key moment in the development of the visualization to a fine-grained analysis that highlights both the creative dimension of renaissance team collaborations and the immanent contributions of technical objects to collective production. Before we turn to that analysis, however, we first discuss some of the theoretical frames that guided its interpretation.

Computer–Human–Computer–Human . . .

Harley (1989) opened his famous essay on critical cartography with an evocative passage from Markham's (1942) memoir, *West with the Night*. A map is a "cold thing" she wrote, "humourless and dull, born of calipers and a draughtsman's board . . . [a] ragged scrawl of scarlet ink" (245). But despite this materialist nod to the craft's tools—itself no doubt born of Markham's life as a thoroughbred trainer, aviator, and adventurer—the processes of doing visualization are often overlooked within the critical literature, not far from how Harley chastened his fellow cartographers years ago, with their "culture of technics" run rampant (Harley 1989, 2) under the sway of the "virtuoso mackintosh" (Harley 1990, 7). In following the evolution of the Katrina visualization, we step into the midst of those relations of human–computer interaction.

Cox's (1988) philosophy of renaissance teams provides an appropriate starting place. In her longer elaboration of the concept, she explains that the logic behind the NSF's "increased investment in data-viz is the general recognition that huge problems, such as climate change, require resources at multiple institutions and the expertise of many disciplines to explore and attempt to solve them" (Cox 2008, 65). Such problems require a contemporary art–science collaborative community standing in direct contrast to the traditional imaginary of artistic (or even scientific) endeavor, as Vermeer himself (along with his subject in *The Geographer*) so well illustrates. As she described it:

> From the European cult of the individual and its Romantic view of exceptional, imaginative genius, we have inherited an image of the lone artist who creates in isolation within an impoverished studio, moved to express a personal vision that may remain poorly understood until someone recognizes his vision (the pronoun is meaningful). However, the laboratory-driven environment of scientific visualization—in which artists, scientists, technologists, and technology work in partnership—shows how limited and limiting this model can be. (Cox 2008, 61)

Cox's renaissance teams (Cox 1988, 1991, 2006) operate through a behavioral code for successful collaboration: agreement on a common goal; mutual respect and a willingness to learn from others; recognition of each team member's intellectual territory; and credit for each individual's contribution. Members also rely on a software platform to facilitate collaboration: the AVL-designed Virtual Director software (Cox, Patterson, and Thiebaux 2000; Cox 2004), which allows team members with access to CAVE (Cruz-Neira, Sandin, and DeFanti 1993) and other advanced collaborative technologies to simultaneously explore dynamic visualizations in an immersive environment:

Our design provides each user with an independent point of view, enabling the user to navigate independently while creating and sharing camera paths. Users share the visual "space"; they see the same environment, but they can fly to different locations within that space. Using Virtual Director™ software, a user is represented over the network as an avatar and can see other avatars (i.e., other collaborating users) floating and flying in cyberspace. (Cox 2008, 97)

Here, team members and their interactions are theorized through the spaces of technical objects of production. For Cox (2008), renaissance teams "produce a synergy of expertise that we might call *collective intelligence*, which helps us to solve complex problems by examining them from a variety of perspectives and experiences" (104, italics added). We observed this problem solving in action one day in an AVL lab as three principals—the artist Cox, the camera choreographer Robert Patterson, and the software engineer and astrophysicist Stuart Levy—discussed a technical issue: how to properly illuminate the Katrina visualization so as to mark the passage of time (see Table 1).

Their conversation reflects the informal, cross-disciplinary shorthand of long-term collaborators. Although the linear text hardly does justice to their often interrupted cross-talking, it reveals, deeply embedded within the conversation's fits and starts, a triangle of expertise. The concerns expressed—over light, over the technics of animation, and over the viability of rendering the sun (given the data's size and time constraints)—are each initiated in ways that are congruent with the positionalities of the speakers: the artist Cox, who specializes in light and color and views the sun as an affective "force"; the camera choreographer Patterson, who registers his concerns around animation and movement; and the data expert Levy, who continually gauges the problem in computational terms.

Yet in this reading there lurks an oversimplified approach to the subject: Each speaker contributes according to the horizons of our expectations of them.[5] As Cox (2008, 63) noted, any large-scale visualization is "greater than [the] decomposable functions" of its renaissance team, suggesting that its objects are ontologically excessive in relation to the components of the production process. This implies that we should avoid interpretations that treat visualizations as functionally derivative rather than problematic. How might we articulate a theory of collaborative visualization that, first, avoids mapping expertise onto contributions—which otherwise leaves the account of participants relatively untroubled and

subjectivized—and, second, exposes the active role of the technical object in its own production?

This is what Simondon (1924–1989) tried to accomplish. A French philosopher of technology, he influenced the work of Deleuze (1994), Virno (2004), Stiegler (1998), and Stengers (2004). If we were to sum up the implications of his contributions for visualization in a single phrase, it might be appropriate to say that he turns the formulation, "human–computer–human" (e.g., Nyerges et al. 2006), inside out, to "computer–human–computer." As LaMarre (2013, 82) wrote, "Simondon methodologically situates the role or function of the human *between* machines." The effect is to "flatten" the ontological relations without rendering the relating entities symmetrical or equal (Jones, Woodward, and Marston 2007; Woodward, Jones, and Marston 2010). He answers the preceding problem by arguing that an engaged human's thoughts, practices, and "becomings" are immanent to the workings and becomings of the computer: "[s/he] has a role to play between machines rather than over and above them, if there is to be a true technical ensemble" (Simondon, quoted in LaMarre 2013, 82). This "inversion of the cybernetic perspective" (LaMarre 2013, 82)—which tended to leave the human in a position of control or dominance—has the capacity, we argue here, to broaden our focal point from renaissance team members to the more subtle, transindividual relations produced across the asymmetrical workings of technical objects and team members.

It is not enough, in Simondon's view, to say that technical objects relate individuals to the production process. Rather, technical objects actively produce individuals, participating in what Simondon calls *individuation* (Simondon 1964, 1989; Dodge and Kitchin 2004). By this, he means the processes (material, biological, psychic, collective, and technical) by which humans, technical objects, and collectives emerge as individuals; that is, become specified and "concretized," taking shape as operators in relations in their own right. Here, the technical object's passivity disappears—shown to be nothing more than a humanistic privileging of the wondrous power of invention. In a computer–human–computer formulation, the problematic field of creativity includes, rather than hovers over, the technical object. Simondonian objects, endowed with a spectrum of active capacities, transform humans and contribute to their own production. This is a crucial distinction for the relationship between experts engaged in developing the Katrina visualization. Methodologically, this insight invites

Table 1. Rendering the sun: A discussion of lighting Katrina's path, recorded October 13, 2010

RP: I think I like the current setting for the opacity. Now I'm just experimenting with the light and the shadow. I'm trying to see a difference by raising the value of the shadow.

DC: What about where the light is? Why not make? . . . Where is the light? . . . uh. . . . We've actually got to be cognizant of the sun moving during this visualization because it is happening in days. I mean, we wouldn't see that all in one . . .

RP: I like the idea of having an animating light . . .

DC: Like, where is the light at? Where is the sun at in day 28.5?

SL: Well, so it's Greenwich time, so it's um, so sunrise is probably happening about twelve hours and then sunset is about zero hours, or something like that.

DC: I think that's a great way to—

RP: If we knew—The data steps go from one to fourteen thousand four-eighty or whatever, five-eighty.

RP: Yeah

RP: If we knew—If I knew what day—what noon was, what the frame numbers were—

RP: Oh, OK. Yeah that's easy.

RP: And what it started with I could animate the sun going round and see how that might—

RP: Yeah.

DC: I think that animating the sun is a terrific idea. It's going to create shadows, it's going to create its own force on this visual. . . .

RP: We could see how it looked. If it looks good and is interesting, that's one thing. If it doesn't look that good and we really want to craft how the light is to highlight the shadows—

DC: Oh, I think if we don't have the sun going around, something's missing. And if it's going too fast, maybe we need to slow things down.

RP: Yeah, well, having the sun on a slant is nice—

DC: Absolutely.

RP: Yeah, because if it's straight down, you're not going to see any variance. [Pulls up visualization] So right now you're seeing the highlight and shadows . . .

DC: Where is the light coming from?

RP: Looks like it's from the upper right.

DC: Right. It's upper right.

RP: Yeah. I thought I had it on the sunset, but see over here it looks like it's coming from over there [points to the left].

RP: Oh yeah, I see, maybe that does make sense. I guess if you look at the right side of the eyewall . . .

RP: Yeah right here.

DC: I think you'd better plan on the light being a force . . .

RP: We need to do light experiments.

DC: Light is a force and it is a visual force as well. [Begins to walk away, returns] At least until we get down to the anatomy and then the light, you know, you don't think about—When you're doing an X-ray of the body, you don't think about the light . . .

RP: Unless we—

DC: But there is something powerful about the fact that there is the day and night, and how that affects people.

RP: Unless when we do the anatomy, if we do something like— What if we cross-section and we have, you know, volume on this side [begins drawing on a sheet of paper] And we have tubes and graphical metaphors on this side. . . . Maybe the rain band iso. . . . You know, we could do some hybrid, where the lighting's still important.

DC: But for this Denver dome experiment, we should have the light moving on a small portion. And it may actually need . . .

RP: Okay, well let's work on that tomorrow then, because it may need a test.

RP: Yeah.

RP: Is that what you think or should we?

RP: Um, yeah that's fine. It doesn't seem like—We're not going to know enough to make a, you know—It's not worth doing an every-frame-big-deal, but to do a survey that sounds really good.

RP: So you're wanting to do subsections throughout the whole thing? Or should we . . . ?

RP: Well, we could. I had done subsections before because I wanted to test motion and I didn't want to have to render absolutely everything. And so that might not be a bad thing. Maybe it is worth testing motion because then when we're doing this kind of thing we'd want to see not just how well do the crevices show up, but what happens as they move. So maybe I would do subsections.

RP: Well, if we're trying to get a thousand or eighteen-hundred frame render of a section . . .

RP: Well that's what we're going to end up with but we don't even know what section we want.

RP: Okay.

Note: DC = Donna Cox; RP = Robert Patterson; SL = Stuart Levy (all are members of the Advanced Visualization Laboratory).

not only an ethnography of individuals coming together to make visualizations but also an ethnography of visualizations that give rise to further avenues of individuation.

The Problem of the Eye

If there is an individuating force in technological encounters, then we are likely to find it at work where renaissance team members sense and confront problems—as they did over the course of a week in October 2010, when several members of the team held a discussion about the diameter of the storm's eye. The principals in this case were Stuart Levy and Alex Betts of AVL, Tom Lucas of Thomas Lucas Productions, and Wei Wang of NCAR. Produced using the commercially available Maya 3D animation software,[6] Katrina's sample renderings appear with an eye that

seems too large. Exceeding any single member's area of technical or scientific expertise, neither the problem's source—the data, the supercomputer's algorithms, the Maya software, or the rendering process—nor its solution are easily determined. Following along with this e-mail exchange, we trace the cues in the language and shifts in thought initiated in the production process. The technical object's active role evolves over the course of four "sequences" of e-mails, presenting novel problems to human participants, who, in turn, come to think differently. The resulting on-the-fly problem-solving process offers insights into the nature of collaborative visualization, as well as how social scientists of technology might deploy Simondon's theories, particularly where the social and the technical are enrolled in the same project. We begin with AVL's Levy, who e-mails three resolutions of a Katrina test animation that will be "composited" later in the animation process.

Sequence 1: Emergence

From: Stuart Levy

Sent: Sunday, October 3, 2010 11:27 PM:

Hello all,

Here are some test animations at last, for Wei Wang's Hurricane Katrina simulation, rendered with Alex's Maya setup, using Bob's initial animation path [. . .]

Right now, the three grids (coarsest, middle, and finest resolution) are rendered separately—they'd be combined in a later step.

This uses one choice of mapping from Qtotal values to the color/opacity map in Maya (Qtotal of 0 to 0.015 are mapped to . . . well, I'm not sure what, but maybe Alex can explain if need be). We can make the cloudy areas more or less pervasive by adjusting the mapping [. . .]

Offering team members a late Sunday night visual update on the rendering process, Levy opens by acknowledging the expertise and technical skills (i.e., the decomposable functions) of contributing team members—"Wei Wang's Hurricane Katrina simulation, rendered with Alex's Maya setup, using Bob's initial animation path." The collective nature of the call-out performs the renaissance team behavioral code, where "each member must recognize other's *intellectual territory*." Although the visualization would seem at first to be cornered by these knowledge domains, the second and third paragraphs reveal a not-yet-stabilized product. There, Levy identifies his own comfort zones,

excusing his technical limitations with the Maya animation software and hailing Alex as the resident expert (who, in an interview, self-identified as "the Maya guy"). Also presaged in Levy's uncertainty surrounding Qtotals and opacity is the emergence of a problem, one that is unanticipated by the team members and the solution of which, as we will see, exceeds their individual specializations. Lucas and Wang respond the following day.

Sequence 2: Articulation

From: Thomas Lucas

Sent: Monday, October 4, 2010 8:51 AM

How exciting! I especially like the detail in the D3 series [the finest resolution]. You can really see the convection popping up all around the storm.

Two questions for the moment . . .

1. Is the storm the correct size with respect to the land areas. The eye in particular seems big.

2. When you get the high-frequency time steps of D3, that's our chance to go in really close. I was wondering if there is a way to get more detail on the cloud surfaces? I'm not sure if it's a texture thing added to those surfaces or if it might be in the data.

Whether or not we can get more detail, I'm thinking that with the high res data we'll get the most action and interesting information if we emphasize airflow trajectories (shown with your tubes/arrows) in and around the eye.

From: Wei Wang

Sent: Monday, October 4, 2010 6:50 PM

You are right, and the eye size looks large. I will check a bit on my end to see if there are any problems with the data.

I don't know if you can see more from the data, even at 6.6 sec interval, perhaps a bit more. But even then it is still some version of smoothed cloud. It probably won't look like watching the cloud in motion in real atmosphere. The limited vertical layers in the data could also be a factor.

For Lucas, the film producer, the question of the eye's size emerges within a series of aesthetic observations concerning resolution, surface detail, the movement of "popping" convection, and the "action" of airflow trajectories. Similarly safely positioned, Wang, who modeled the original NCAR Katrina simulation, offers to return to the data and to recheck it for errors that might have affected the quality of the render.

Meanwhile, what will become the driving problem of this exchange—the size of the hurricane eye—is articulated, not through well-defined terms and expert assertions but through vague observations: It "seems big" and "looks large." As we will see, the correlation between member expertise and contribution will grow increasingly difficult to calculate as the conversation unfolds. As the team attempts to define it, the problem will drag team members past their territories of expertise and into a more complicated relation of collective production with the technical object.

Sequence 3: Uncertainty

From: Wei Wang

Sent: Wednesday, October 6, 2010 8:46 PM

It looks to me that the data projection isn't quite right—the data from domain 3 is projected to a much larger area. Or is it my perception is wrong?

From: Wei Wang

Sent: Monday, October 11, 2010 5:37 PM

Stuart,

Are you sure there is no cutoff value used in the mapping, and you mapped everything starting from qtotal = 0? It seems that if a cutoff value is used, it could explain the large clear center.

From: Stuart Levy

Sent: Tuesday, October 12, 2010 9:56 AM

I tried adjusting the threshold, so that Qtotal from 0 to 0.005 (instead of 0 to 0.015) was mapped to the opacity ramp. This enhanced the clouds and did reduce the size of the eye, but not hugely—maybe 10%.

For example at frame 5000 (2005–08–27_18:46:40) the eye looked about 90 km diameter with the lower threshold, 100 km diameter with the higher one.

At frame 10124, it looks to be about 1/4 of the d03 box diameter, or 80 km across.

Looking with ncview at both the Qtotal and W fields for frame 10124 = 2005–08–28_23:14:40, at say $z = 4$ level (~280m altitude), the eye seems maybe 60–65 grid cells across, or about 80–85 km in diameter, if "eye" means what I think it does. That's not far from the size in the rendered view—right?

Does this seem a reasonable size?

Negotiating the limits of their respective knowledge and skills, the team members are edged into an experimental zone. Zeroing in on a set of adjustments to the

visualization through the rendering software, Wang speculates that data projection and the use of a cutoff value might account for the size of the eye but does so only after distancing herself in her previous e-mail by allowing that her perception might be wrong. Having made Wang's suggested adjustments, Levy observes what he thinks is a slight change in the diameter of the eye, but he, too, demures, adding "if 'eye' means what I think it does." Each is convinced that there is a problem, but both remain unsure of what or where it is. A resolution, it seems, cannot be found by appealing to the technical and specialized knowledge of individual team members, although the source of the problem—the technical object—is the product of their collective knowledge. Thus Levy's inquiry as to whether the new adjustment has produced a "reasonable size" is overshadowed by the possibility that what counts as reasonable has begun to detach itself from appeals to the reality of the data.

In Simondonian terms, the problem of the eye exemplifies the visualization's semiautonomy. As a technical object, the visualization's creative capacities exceed the expectations of its inventors. At this point the eye's diameter becomes a generative relation that gazes not only backward (i.e., to the hurricane, the Gulf, or the available data) but also forward, as it enrolls team members in extraspecialist conversations, enlisting them as perceivers and thinkers in its problematic territory. So pulled, team members become points of relation within the self-refining field of the technical object. As such, the object becomes a gravitational force behind a new collective individuation.

Sequence 4: Resolution

From: Thomas Lucas

Sent: Tuesday, October 12, 2010 9:45 AM

Stuart … it's hard to find info on the diameter of Katrina's eye. This note says 30 miles wide on August 28th …

http://epod.usra.edu/blog/2005/09/eye-wall-of-katrina.html

At landfall, it was 37 miles wide …

http://www.wunderground.com/hurricane/surge_details.asp

"Katrina, though, had a large 37 mile diameter eye, and hurricane-force winds extended out 120 miles to the east of the center. Katrina's radius of maximum winds was about 30 miles, double Camille's." …

From: Wei Wang

Sent: Tuesday, October 12, 2010 10:44:53AM

Stuart, Thomas,

70–80 km is about [what] I see from my plotting software. The model is not perfect by any means. And it is likely that we are not simulating (forecasting) the eyewall structure correctly.

I wonder if you could try to lower the value more to about 0.000001 and see what happens.

From: Stuart Levy

Sent: Tuesday, October 12, 2010 12:20 PM

OK, here's a survey with various Qtotal values, from 0.000001 to 0.015, for times near frame 5000 ∼ 2005–08–27_18:47:xx: […]

From: Wei Wang

Sent: Tuesday, October 12, 2010 2:00 PM

I'll go with either 0.0001 or 0.0005 if 0.0001 tends to "overcast" the eye too much . . .

From: Stuart Levy

Date: Wed, 13 Oct 2010 12:00:44 -0700

Here are the latest things, rendered last night:

Two animations of the innermost d03 grid—still based on the first, not the new run. Both are 1024×768, with same settings—only the camera path and frame range differs between these […]

Opacity (for both): Qtotal of 0 . . . 0.0005 is mapped onto a new opacity ramp that Bob designed last night.

(Compare this with Qtotal of 0 . . . 0.015 from the earlier animations!) […]

That's one sinister looking hurricane.

Combing through online resources, Lucas cites two estimates of the eye diameter at 30 miles on 28 August and at 37 miles at landfall the following morning. The estimate from Wang's plotting software opens the eye to 70 to 80 km (43.5–50.0 miles), a considerable difference to the team. Seeming to recognize this, she allows that the model is not perfect and that "it is likely that we are not simulating (forecasting) the eyewall structure correctly." Following his own noodling, tweaking, and experimenting with the simulation, Levy offers a broad survey of Qtotal values for the team to explore. Wang expresses a preference for her

previously suggested value but subjects it to conditions of perception rather than data: "I'll go with either 0.0001 or 0.0005 if 0.0001 tends to 'overcast' the eye too much." The recommendation emerges as a response to aesthetic rather than scientific considerations prompted by the problem of the eye. Thus, it would be insufficient to analyze Wang's later responses from within a matrix of the "speaking subject" qua climate scientist, hurricane modeler, or WRF technical expert. Indeed, when asked later to reflect on the visualization, Wang will observe that, although it is beautiful, she is unsure of its scientific value. It would also be incorrect, however, to trade one subjectivity for another by suggesting that the Katrina collaboration has caused her to switch "teams." The final sequence illustrates that it is rather the technical object that is enlisting team members in experiments and discoveries, reoriented by a problem whose solution they can only guesstimate. Thus, when left with a choice between the higher resolution value of 0.0001 and the more aesthetically pleasing value of 0.0005, Levy returns from an evening's rendering with an affirmation of the latter: "That's one sinister looking hurricane," he observes.

Conclusion

Taken in its entirety, the e-mail exchange reveals a flow of statements operating at the limits of team members' domains of expertise, discourses of authority, and technical knowledge. Because they are unfamiliar with the problem, however, the subsequent experiments depend not on team members' "concrete" specialties but on their "abstract" cognitive and practical capacities to learn and experiment. This uneasy negotiation of emerging conditions suggests two pathways for theorizing collaborative work. On the one hand, there is Cox's (2008) notion of autopoietic (immanent, self-organizing) renaissance teams whose specialist members collectively produce visualizations. To be sure, their interactions are situated, complex, symbiotic, evolutionary, and synergistic, yet they remain decomposable into their multidisciplinary parts, even though the visualizations they create exceed the sum of their expertise. On the other hand, there are nondecomposable relations that can emerge between human collaborators and technical objects. Just as autopoietic, these Simondonian-inspired collaborations allow that some technical objects have the capacity to participate in relations of invention. We suggest that such

relations can destabilize the sovereign agency and redirect the energies of their human collaborators. The repolarization of relations between human collaborators and a now active, problem-producing technical object creates a new collective individual.

Importantly, neither pathway just described can be decided in advance, for each is the site-specific (Woodward, Jones, and Marston 2010) outcome of a particular sociotechnical collaboration. To illustrate, consider first the dialogue in Table 1. It shows the important individual contributions of a diverse renaissance team, where each participant adds nuance to the visualization based on his or her distinct expertise. Although accurately and aesthetically animating sunlight is no small technical feat, we can nevertheless decompose the result into each team member's specific contributions. In the case of the eye, however, this is not so. We see in those sequences a transition from the identification of a problem to the articulation of a broader problematic field that destabilizes the relations between the collaborators and the technical object. In this second instance, the visualization (i.e., the technical object that combines hardware, software, and data) becomes a productive member of the collective through the problematic eye. Team members are enrolled and transformed in ways that are not resolvable with reference to their regimes of expertise.

Within the fine-grained details of this collaborative effort, then, we discover a kind of individuation forged through a double movement: where the technical object actively introduces its own problematic field, the experts are swept up as participants in its resolution, just as the technical object, in Simondon's account, brings with it some of the human in its constitution:

> The object that comes from technical invention bears with it something of the being that produced it, expressing with this being what is the least attached to a *hic et nunc* [here and now]; one could say that there is human nature in technical being, in the sense that the word nature could be employed to designate what remains original, anterior even to the constituted humanity in the human. (Simondon 1958, 247–48, quoted in Barthélémy 2009, 30)

Just as an abstract technical object is "concretized" through this autonomous movement—going from visualization in general to the eye as a problem—the concrete expertise of team members gives way to their "abstract" deliberative capacities (they go from experts to negotiators to a collective individual). Such relations of abstraction and concretion (Simondon 1958;

Chabot 2013) describe many technosocial collaborations: a continuous shuttling back and forth in the ongoing dance between experts and technical objects. Yet these movements tend to be veiled behind the woof and weave of countless everyday interactions or hidden in the tapestry of their final product.

In sum, such movements enroll both technical objects and experts as members of renaissance teams. Although many have been tempted to read the relationship between experts and technical objects hierarchically—at the top of which sits a group of human specialists producing an object-product—Simondon was not among them; nor did he subject technical objects to anthropomorphic representationalism. He did, however, write decades before contemporary theory's posthumanist turn (Latour and Woolgar 1979; Haraway 1991; Stengers 1997; Hird 2009). So, in spite of his own fixation with all manner of technical objects, the human–nonhuman divide (Braun and Whatmore 2010) lingers in his descriptions of them and collective individuation. In our view, the problem of the eye—the concretization of the technical object—contributes to the renaissance team in ways that trouble this binary. The visualization's enlistment of human team members beyond their specialist territories, such that team members and technical objects move "as a piece," raises questions about the autonomy of both the human and the nonhuman, not only in complex productions such as this but in theory more generally.

Finally, we offer that "hylomorphic" approaches to production—that is, those that assume that visualizations, like Katrina's, are manifestations of an originary, even if collective, vision—are misguided, precisely because objects can forge new relations among their "inventors" in the midst of their production. Processes of collective individuation suggest that researchers should not ignore the messiness of positionality, or the productive roles of the object, as these jointly unfold during the complex shuffles of production. By implication, one should be wary of looking to a completed object to initiate a critique of, for example, the political dispositions of its creators. This in no way suggests that we should abandon political critiques of visualizations—the past twenty-five years of cultural criticism in geography confirm that there is too much at stake for that. To the contrary, it asks that we embrace more dynamic languages and analytics to understand the "continuous variation" (Deleuze and Guattari 1987, 493) immanent to both visualizations and their human and nonhuman collaborators.

Acknowledgments

Notes

1. AVL is one among many art–science–technology collaborations using the computer as the organizing object. For more on the history of these collaborative endeavors, see Goodman (1998).
2. The study of technological developments and learning processes of geovisualizers sits alongside a tradition of using the audiences to examine the cognitive elements of visual and spatial literacy, including way-finding (Crampton 1992; Lewis 1993; Fabrikant and Buttenfield 2001; Kraak and van de Vlag 2007). There is, too, a rich vein of research that explores the challenges posed by the variable sensory acuities of audiences in the design of geovisualizations (Fabrikant, Rebich-Hespanha, and Hegarty 2010). Whereas some studies are based in an appreciation of difference in physiological conditions, such as color blindness, others combine this with experimental designs to examine a visualization's legibility (Pike and Thelin 1992; Lobben 2008).
3. Co-author Vigdor was responsible for the organizational ethnography of AVL. Woodward accompanied Vigdor and the AVL team to their initial visit to NCAR at Boulder, and Jones paid a site visit and conducted interviews with AVL members in Urbana.
4. For a dynamic view, see AVL's coproduced PBS/NOVA documentary, *Hunt for the Supertwister* (2004).
5. See Woodward, Jones, and Marston (2012) for more on theorizing without preconfigured positionalities.
6. Maya is an extendable, commercially available 3D software (www.autodesk.com/Maya). It is used often by professional animators to create photorealistic imagery. AVL's programmers have adapted the software to create, among other features, the colored glyphs used in many of its visualizations.

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