The System of Simulation and Modeling in Computer Graphics

Kyle Gonzalez

Introduction

Simulation and modeling are important applications within computer graphics. In technical papers from this field, one often comes across adjectives such as “accurate,” “plausible,” or “realistic” that are used to describe the output of a simulation visualization system. What are the relationships between things that make it possible to use these kinds of terms? And how do these relationships produce the visual work formally? In this paper, I am interested in analyzing computer graphics and simulation as a system or discursive formation that produces statements and formal effects. I will explore multiple theoretical and historical points[1] according to themes of modernity, exchange, the history and epistemology of photography/film, and the differences introduced by digital media, along with analyzing the visual output of my implementation of two modeling systems.[2] The first of these systems procedurally produces an urban model and is described in a classic paper by Parish and Müller, while the second system procedurally generates terrain and is described in a more recent paper from SIGGRAPH 2013. By trying to understand simulation and visualization on these various levels and analyzing my implementation visually, I also hope to show some of the interventions and effects that are possible at the level of production, at perhaps the position of the subject, in relation to simulation systems.

Representation of the real

In considering the meaning and what makes possible the meaning of words like “plausible” or “realistic,” the most obvious path is in thinking about the real, which is what the plausible or realistic is to be compared against. We should ask, what is the real in our time? To answer this question, I will follow Heidegger and begin by describing the relationship between modern man and the world, for the world includes the real and its ground. Heidegger states that for the modern age the world is fundamentally representation for man. That is, “what is, in its

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[1] The writers through whom I will articulate my argument could be read as contradicting each other at points. For example, what might be considered the “anthropology” of Martin Heidegger does not sit well with Michel Foucault’s project. However, my concern is not to establish a system of axioms on which to draw conclusions, but to describe and thus give a sense for what gives meaning to a kind of statement. The writers I discuss have approached the topics we are concerned with here from different angles, according to different series of knowledge which I think illuminate each other at their own paces.

[2] I wrote their implementation in C++ on top of my own OpenGL graphics library and vector/matrix math library.

entirety, is now taken in such a way that it first is in being and only is in being to the extent that it is set up by man, who represents and sets forth" ("The Age of the World Picture," 129). Thus, in contrast to man of the middle ages and antiquity, modern man occupies a central position in relation to the world, and "makes depend upon himself the way in which he must take his stand in relation to whatever is as the objective" (AWP, 132). Under modernity, man has become a free subject in relation to the objective world. Underlying Heidegger's philosophy here are historical facts involving the transition to modernity, which include the development of town culture and its special rationality, power, and freedom, the destruction of traditional values, and changing patterns of labor and consumption, which, as we will see, has a profound impact in the production of mass culture and its corresponding technologies of mechanical reproduction, that is, technologies which manifest our relationship to the real.

Keeping this background in mind, when Heidegger says in a later essay that "now the real presents itself in the taking place of consequences… the real now shows itself as object, that which stands over against" ("Science and Reflection," 162), we should understand that this means the real not only shows itself as object, as representation under modernity, but is because man himself has become a subject. For Heidegger, the relationship between the real and man is dominated by the essence of technology. This leads us to a further question: what is the relationship between the real and science and technology? In contrast to the medieval and ancient forms of science, theory, and reality, modern "science is the theory of the real" where "entrapping representation… is the fundamental characteristic of the representing through which modern science corresponds to the real" (SR, 157-168). Modern sciences, within which we can include computer science with its subfield of simulation and visualization, are driven in their ongoing activity toward specialization and institutionalization in following the objective character of the real through research. Precisely in order to remain rigorous, methodology continuously adapts itself for the new procedure appropriate to the object area according to the results of research. Through its method, science has "decisive priority" (SR, 169) over the object as it refines reality - as a system.

It is by this process that in the most extreme form of the subject-object relationship developed through science and, more fundamentally, technology, the object disappears into pure standing-reserve. According to Heidegger, this process is properly called enframing, the essence of technology. It is "the way in which the real reveals itself as standing-reserve," and this way demands that nature, or more generally, the world, "remains orderable as a system of information" ("The Question Concerning Technology," 23). As to our initial question about the ground of modeling, simulation, visualization, and their terms, we can now say that, through simulation as its method of research, computer science sets upon reality as its object in the manner appropriate to its methodology in order to represent reality for standing-reserve. Although the field of computer simulation seems of a different kind when compared to the sciences that Heidegger refers to, such as mathematical physics, historiography, or linguistics (and it is tempting to even ask, is computer simulation a "real science?"), we can see that fundamentally all of these spheres of science derive from the relationship of man to the world as representation and its domination in enframing, and all of them have their own procedure and methodology.

Let us look more closely at the notion of the real as a system in order to connect what we have covered so far with what lies ahead.

i. System, simulacrum

What is the difference between the real as an object and the real as a system of information? In both cases, the real is represented. But in the latter case, "the subject-object relation thus reaches, for the first time, its pure 'relational,' i.e., ordering, character in which both the subject and the object are sucked up as standing-reserves" (SR, 173). That is, when the subject and its objects form a "total" system of information, the subject is always in danger of losing its primacy, and its position is in fact continuously reordered in accordance with the specific technological demand.[3] It is the modern subject-object relationship at this extreme that leads to thinking that we are post-modern.

In light of this, the writings of Jean Baudrillard let us see how deeply the technological system of information has taken hold in our time. I would hesitate to use the word "representational" to qualify the "technological system of information" here as I have above because of how it could be misunderstood, and it is unfortunate that we must use the same word that for Heidegger means the world as it comes to stand for the subject and which for Baudrillard means a manifestation based on an equivalence between a sign and its real ("The Precession of Simulacra," 4). But I would still argue that we have not strayed from the essential point, even if, at least according to Heidegger, Baudrillard has fallen into that danger of forgetting the subject. The essential point at which these two thinkers meet is that for both Baudrillard and Heidegger, the world now has the character of a technological or operational system, whether or not the subject has been elided into the order of standing-reserve even in thinking.

For Baudrillard, the real has a meaning more like the referent in semiotics, which for him is impossible. Instead, there is only the production of the real and strategies of the real, which are merely the double of a strategy of deterrence on the side of power. This is an insight which we ought to consider seriously. Is simulation and visualization in computer graphics like the "imaginary stations that feed reality" to "a network of incessant, unreal circulation" (PS, 9)? If the world has become a technological system of information, or a circulation of the standing-reserve, then we we must admit that simulation and the model are ordered along other technologies such that "the real" as object can disappear from the series according to the development of methodology. Now we must consider that "the real" can reappear not as object but as an element of circulation produced technologically. And within the operational, systematic world, power has at its disposal the technologies that circulate the real: the photograph, the film, the simulation.

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[3] There is in a echo of this situation in *The Archaeology of Knowledge*, a text which is really an attempt at counter-anthropology during an age that, as Heidegger writes, increasingly interprets the world anthropologically (AWP, 133). The danger of the disappearance of the subject arises here also because Foucault, through historiographical research, cancels anthropological motifs such as the progress of human consciousness or the persistence of historical memory only to more fully secure historiography as archaeology in the order of discursive formations.

ii. System, medium

Let us take up again the description of the world and the real as representation that has now become a total system of information. Put this way, the formal relationship, of the real represented as information ordered in sequence with the rest of the standing-reserve, is emphasized over the "content" of the real, as in specific technological works which perform the operations of the real (i.e. *a* photograph, *a* film, and in another way, *a* simulation). What we are interested in is not merely examples of technology. Our thinking is similar here to Marshall McLuhan's when he writes that "the 'content' of any medium blinds us to the character of the medium," and that rather, "the 'message' of any medium or technology is the change of scale or pace or pattern that it introduces into human affairs" ("The Medium is the Message," 1-2).

The notion of medium we get from McLuhan at this juncture is important to have in view, as it brings up the issue of remediation. Remediation is, according to McLuhan, a fundamental property of media wherein, properly, "the 'content' of any medium is always another medium" (MM, 1). While the photograph, film, or computer are similar in that they are all technologies that mediate and build man's relation to the world as standing-reserve, we should still ask, how is the computer as a "metamedium" or remediation machine similar or different from older technologies that have their own procedures for representing the world? If the photograph is a medium for perspective (among other things), is the computer a medium for perspective in the same way? And what is the relationship of simulation to remediation? Here we are questioning technology on a different scale than Heidegger. What is the specific pattern or pace that the computer introduces into the representation of the real?

iii. System, knowledge

Finally, we should note that while the real as a system of information is constituted in part by an order of statements, it also has an institutional and material character, as the statements are ordered in sequence along with material and social instruments as standing-reserve. Thus I would argue that the real as an essentially technological system has the character of knowledge, as Foucault describes it. He states, "knowledge is that of which one can speak in a discursive practice, … is also the space in which the subject may take up a position, … is also the field of coordination and subordination of statements in which concepts appear, and are defined, applied and transformed, … [and] is defined by the possibilities of use and appropriation offered by discourse." Finally, "any discursive practice may be defined by the knowledge that it forms" (*The Archaeology of Knowledge*, 182-183).

If we consider the representation of reality as a system of information, and thus a field of knowledge, then it should be possible to identify the elements that constitute this discursive practice. Foucault also hints that archaeological analysis, which "reveal[s] the regularity of a body of knowledge," could also apply to non-scientific production such as painting. In this case, "it would try to discover whether space, distance, depth, colour, light, proportions, volumes, and contours were not, at the period in question, considered, named, enunciated, and conceptualized in a discursive practice… to show that, at least in one of its dimensions, it [painting] is discursive practice that is embodied in techniques and effects" (AK, 192-194). This suggests that we can situate the formal elements of a work, like those composing the output of a visualization system, within a discursive practice and thus characterize the circulation of formal effects through this discourse.

Modernity as fragmentation and exchange

Our goal now is to identify the historical elements which form the discourse of the real and its representation as it is related to simulation. We can begin by first noting the increase of the exchange relation in history with an eye toward its role within modernization, which is, as Jonathan Crary states, “the process by which capitalism uproots and makes mobile that which is grounded, clears away or obliterates that which impedes circulation, and makes exchangeable what is singular” (*Techniques of the Observer*, 10). Following Henri Pirenne, in medieval Western Europe the growth of the exchange relation can be identified with the merchants and the artisans who supplied their needs that gathered into the burgs and depleted ecclesiastical towns as trade revived after the 9th century. The cities which formed out of these settlements were characterized by a new form of rationality and initiative based on exchange and profit that contrasted with the traditional disposition of the peasantry and aristocracy. The development of money and its ascendant position within the economy liquidated older values and legal structures as burghers wrested economic and municipal privileges from their seigneurs. By the 18th century, the status of cities within the wider economy of a country varied, but it was still circulation through the metropolis that disintegrated the culture of the hinterlands into new patterns of consumption and labor. The corresponding industrialized mass population became the market for mechanical reproduction, such as photographs and films. The development of mechanical reproduction technology closely follows the growth of the bourgeoisie and its culture and power of exchange, that is, of modernization.

Walter Benjamin explains the significance of mechanical reproduction to mass culture, writing of modern culture’s “perception whose ’sense of the universal equality of things’ has increased to such a degree that it extracts it even from a unique object by means of reproduction,” and of “the desire of contemporary masses to bring things ’closer’ spatially and humanly” (“The Work of Art in the Age of Mechanical Reproduction,” 223). Technologies such as photography, film, and now simulation thus occupy a central area within modernity, as they are some of the most important capabilities of the modern world for reproducing everything that is unique and inaccessible for a global market that demands access to everything as standing-reserve. These technologies mediate the demands of the exchange relation through the commodification of reality. And this mediation takes its technical form in the “cutting” actions proper to modernity, in its methods of fragmentation. Benjamin states that “the cameraman penetrates deeply into its [reality’s] web,” and that “[the picture] of the cameraman consists of multiple fragments which are assembled under a new law,” where “mechanical reproduction is inherent in the very technique of film production” (WAAMR, 233-234, 244). That is, the technological system in general is itself expanded as a series of “cuts” under modernity. Computer graphics operates under the same technical regime of cutting not only in its similar sequencing of frames, but also in its execution of code as a series of instructions, as the assembly of data within memory and hardware under new laws, such as the laws of the canonical view and of rasterization. Correspondingly, computer simulation is concerned with the discovery of procedures that would "adequate" reality to fragmentation and arrangement under new laws of computability.

How has visuality itself fragmented under modernity? Crary states that "in the early nineteenth century there was a sweeping transformation in the way in which an observer was figured in a wide range of social practices and domains of knowledge" (TO, 7). It is within this transformed field that we first see the major formal elements that will be rearticulated within computer graphics simulation. These elements have their basis in "a radical abstraction and reconstruction of optical experience" and the "priority of models of subjective vision" (TO, 9). For example, the stereoscope, which works on the basis of stereoscopic vision and the independent visual treatment of both eyes, appears during this time and contains the the basic optical technique of virtual reality headsets. The new problem of the observer lay at the intersection of several transformed fields of knowledge, and thus "the same knowledge that allowed the increasing rationalization and control of the human subject in terms of new institutional and economic requirements was also a condition for new experiments in visual representation" (TO, 9).

Rationalization and control with its corresponding requirements characterizes the circuit between an industrial (or postindustrial) paradigm of knowledge and visual representation that we see also in relation to computer simulation and visualization. In an article published in 1992, the geographer Michael Batty describes the impact of new advances in visual computing on fields dealing with spatial relationships: "it is not too ambitious to suggest that visualization represents both a new way of doing science and new ways of generating designs and policies which characterize the goals of planning and management" ("Urban modeling in computer-graphic and GIS environments," 667). Here we see that the simulation of reality and its visualization is already being considered as an industrial tool in the planning of physical and social reality. A 2010 paper on the state of the art of urban modeling and simulation notes the growing number of applications, including mapping and visualization, entertainment, emergency response, and urban planning ("Modelling the Appearance and Behaviour of Urban Spaces," 1). Modeling and simulation research in academic computer science is already oriented toward the market as well as administrative and policing functions. In this brief way we can clearly see that computer simulation and visualization takes place within a larger assemblage relating technology to power.

Realism: detail, movement, perspective

The appearance of the photograph and its ontology, and its further development through film, is a critical point in the history of modern visual representations of reality. Computer graphics not only takes many of its techniques after photography and its concepts, but in the field of modeling and simulation we come up against the epistemological claims belonging to photography again and again, as evidenced by people explicitly taking "photorealistic" or "non-photorealistic" as a quality and the criteria of a visualization system. It is as if the goal of the field really were to attain mastery over the ontology of photography, in its positive form through simulation or its negative form through the other areas of computer graphics, such as non-photorealistic rendering. Using one of Benjamin's terms, it would like to destroy more totally than photography the cult value belonging to the world. But in order to understand what computer graphics simulation does or not do when compared to photography, we should first ask, what are the claims that photography and film have to representing reality?

In an analysis of the function of description in realist literature, Roland Barthes states that "Flaubert's barometer, Michelet's little door finally say nothing but this: we are the real; it is the category of 'the real' (and not its contingent contents) which is then signified" and thus "the reality effect is produced, the basis of that unavowed verisimilitude which forms the aesthetic of all the standard works of modernity" ("The Reality Effect," 148). In other words, the presence of "insignificant" details in realist literature feeds the operation of the referent and the real. Can we see an analog in photography or film and computer graphics visualization? About the early history of photography, Siegfried Kracauer writes that "along with the familiar photographic leitmotif of the leaves,… undulating waves, moving clouds, and changing facial expressions ranked high in early prophecies. All of them conveyed the longing for an instrument which would capture the slightest incidents of the world about us" ("Basic Concepts," 148). I would say that in the operation of photography, it is often the "slightest incidents," the insignificant details captured within the frame, which circulate the "reality effect" of the photograph. In cinéma vérité this effect operates when insignificant details or long takes begin to threaten the continuity of narrative. I would also argue that in simulation, it is precisely the saturation of detail in a strictly localizable sense that feeds the reality effect, whether they are plastic effects (detail derived from spatial relationships, i.e. the arrangement of vertices within a vector space) or surface effects (detail derived from raster or texture manipulations). Here, a shape and its surface become a passage for the reality effect within the frame. But perhaps we should not speak of the reality effect in relation to simulation, and rather of a kind of "simulation effect" where we accept the substitute as an equivalent sign for the real - of a second-order reality effect.

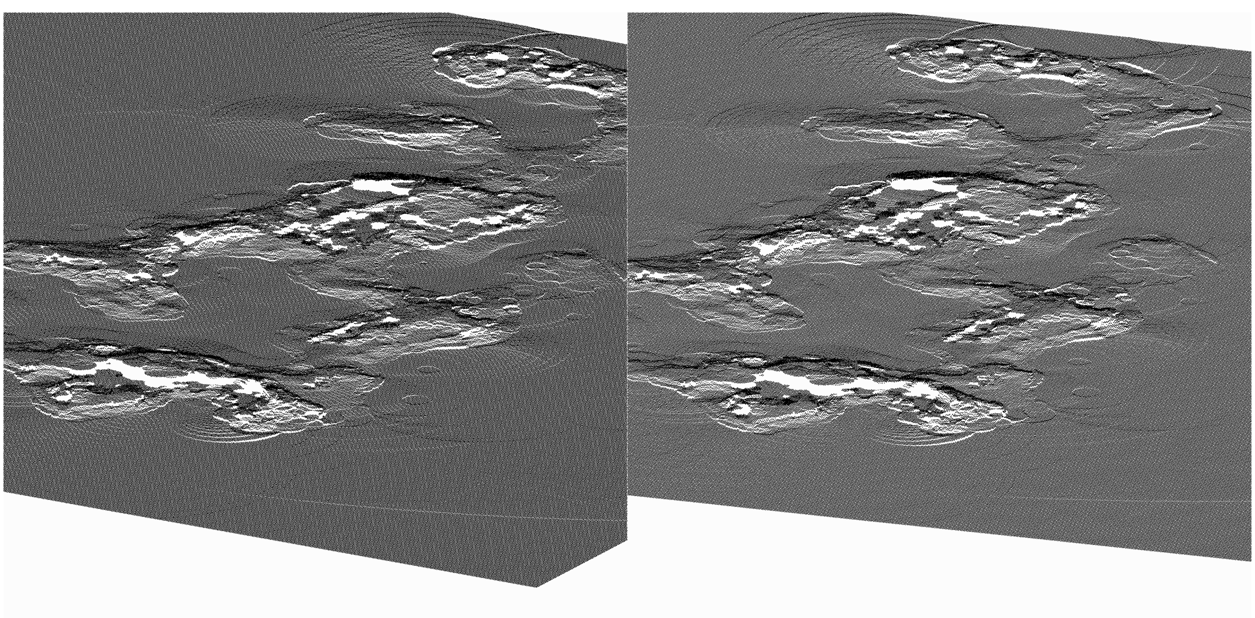

Figure 1. Two views of the same rotating landscape, about a hundred frames apart.

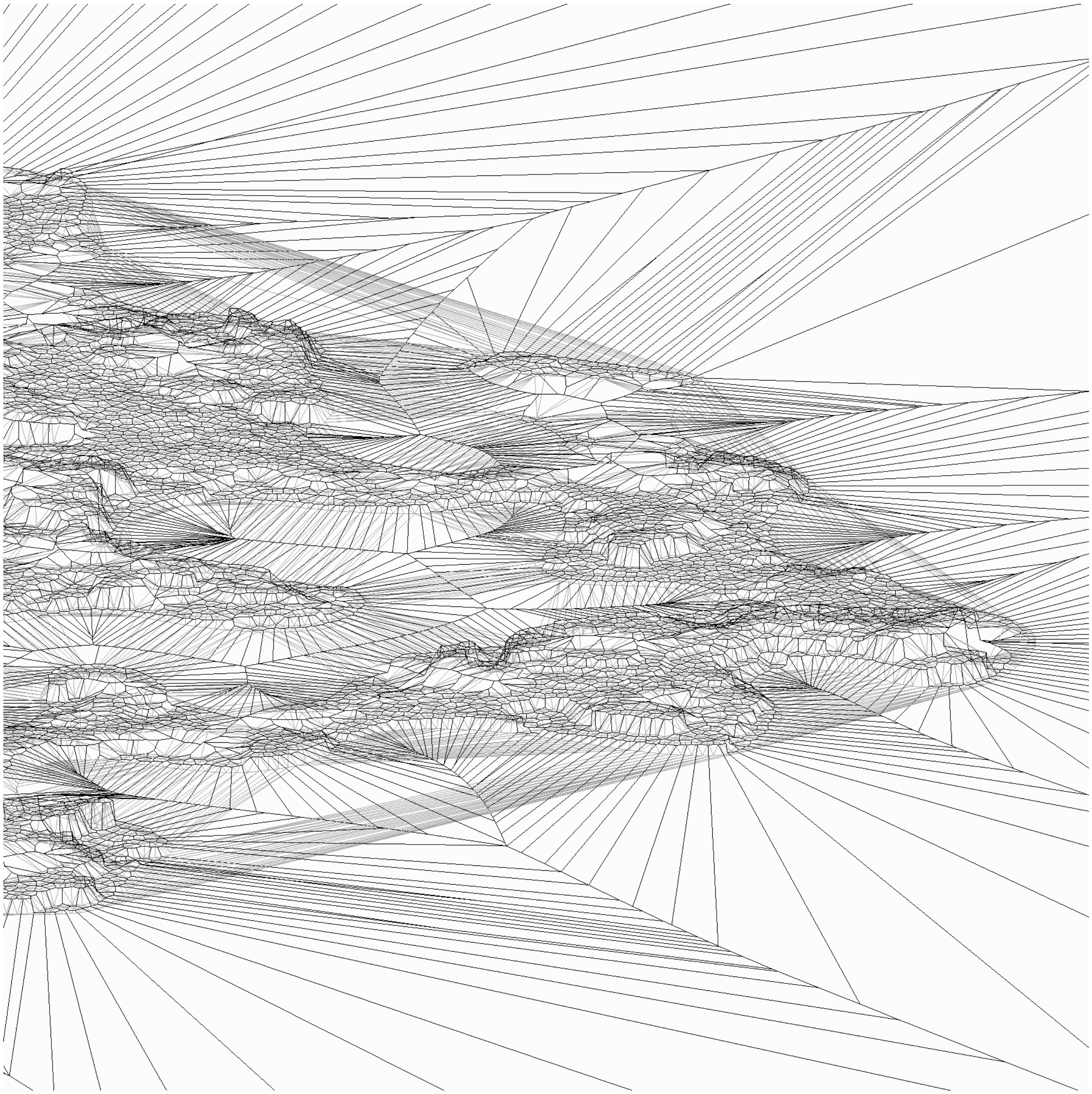

Figure 2. Superimposition of the Delaunay triangulation and Voronoi diagram of a river network model.

Apart from producing the reality effect, photography also lays claim to representing reality through its purely mechanical action. Bazin writes in regard to painting that “the fact that a human hand intervened cast a shadow of doubt over the image,” while photography is capable of “completely satisfying our appetite for illusion by a mechanical reproduction in the making of which man plays no part” (“The Ontology of the Photographic Image,” 161). Here, the ontology of the photograph is revealed as machine technology that produces the reification of the real, where the real can be represented only without the involvement of a subject. Heidegger would say that this is an example of the danger belonging to enframing, while Baudrillard would perhaps consider photography as implicated in a strategy of the real. Computer graphics simulation is an accelerated form with the same character as photography in that, without the action of a subject, the real is reified, but with simulation reality has already disappeared as an object. The methodology of simulation has taken precedence over reality as an object. Accordingly, simulation research is characterized by the uncovering of armatures, such as a computational hydrology or a computational road network, around which computer graphics can fill a depleted representational space, the screen, with the detail of “reality effects.”

Kracauer writes that “film was expected to bring the evolution of photography to an end - satisfying at last the age-old desire to picture things moving.” He quotes Cook and Bonelli who predicted a “complete revolution of photographic art, … we will see … landscapes … in which

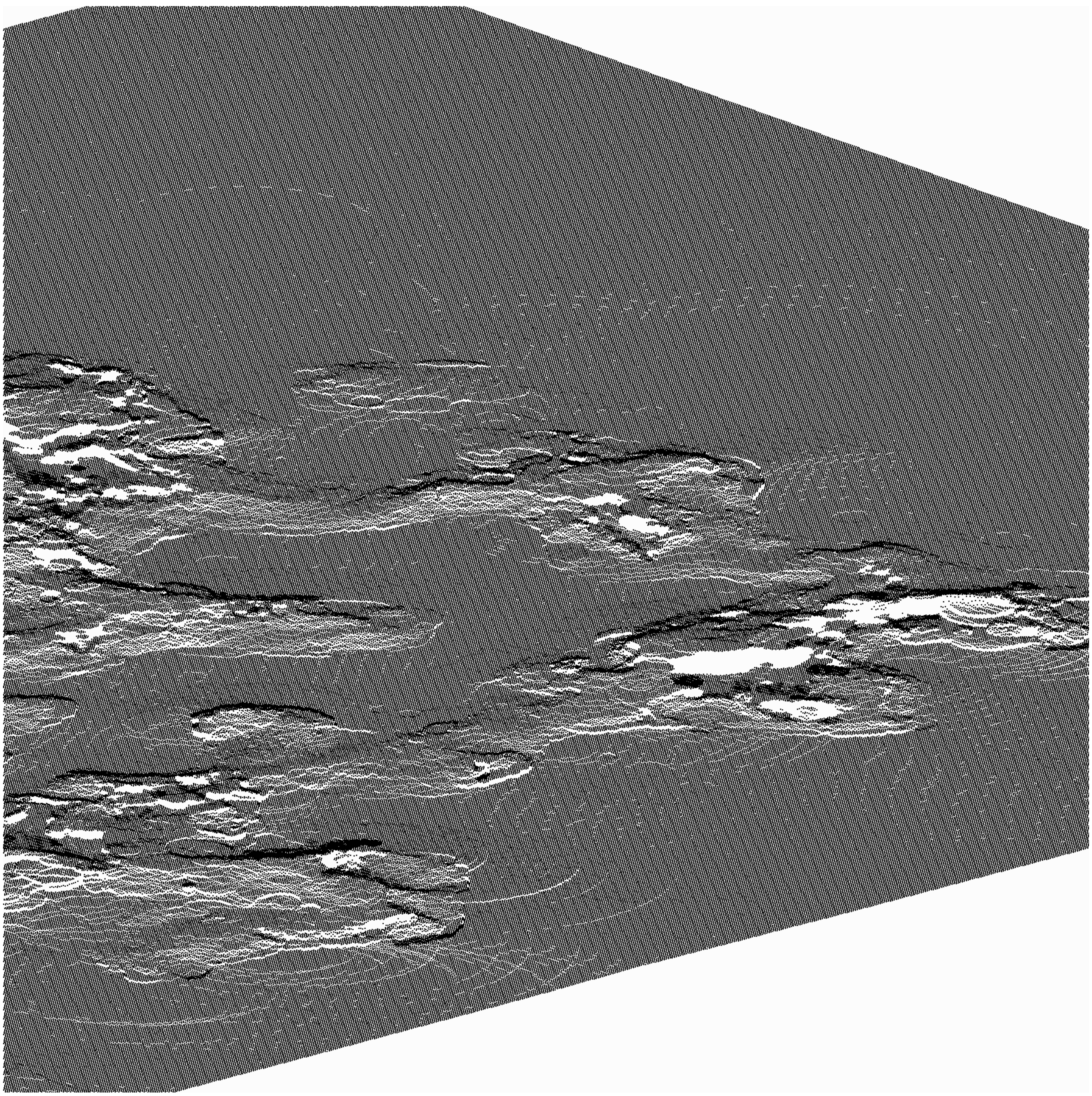

Figure 3. Point-cloud sampled with an equation derived from the information shown in Figure 2.

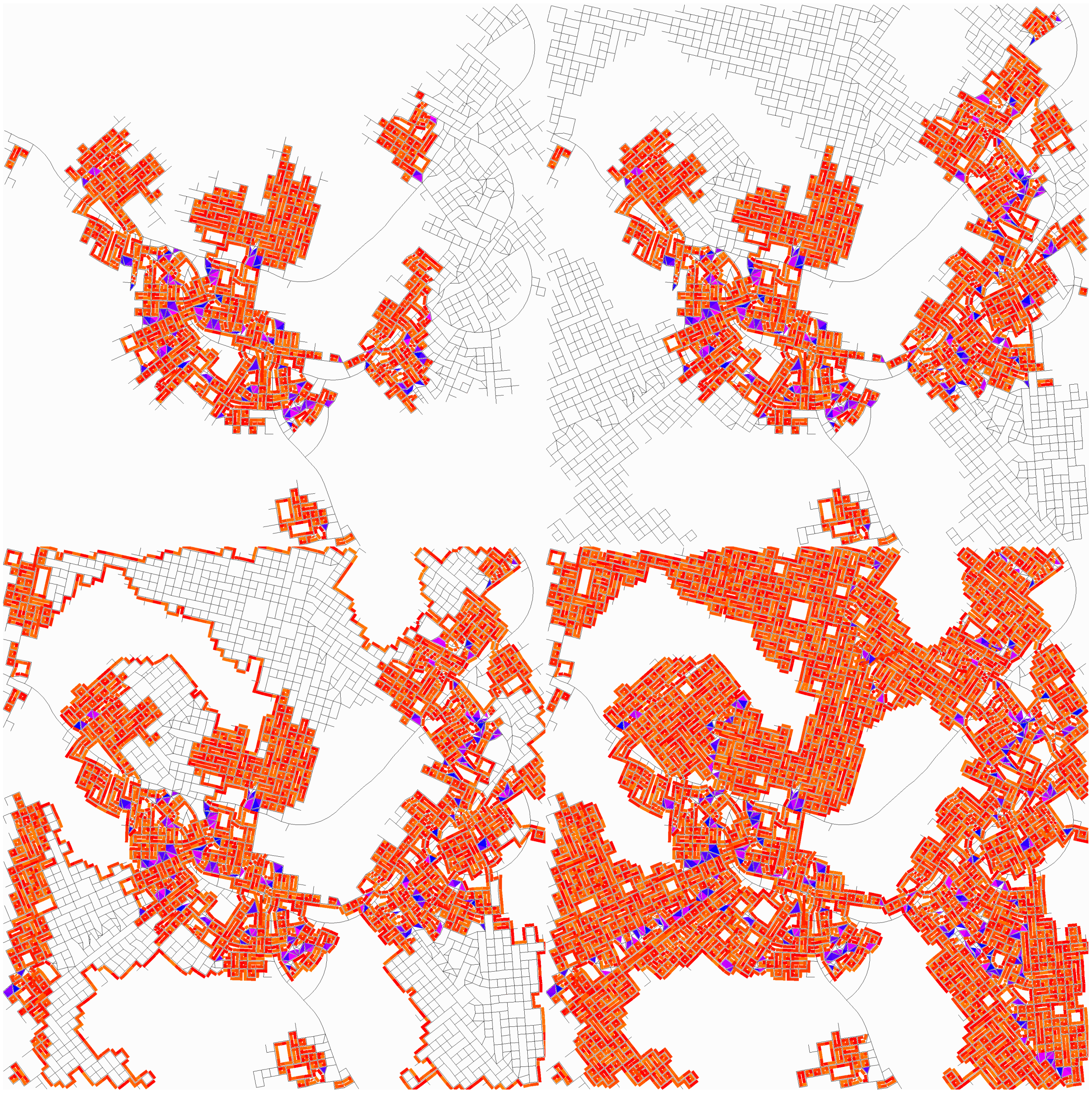

Figure 4. Plan view of a road network and lots model at different “stages of development.”

the trees bow to the whims of the wind, the leaves ripple and glitter in the rays of the sun” (“BC,” 148). This emphasis on the realist desire to represent the movement of nature is reflected again in the aims of computer graphics modeling and visualization, which are described by Parish and Müller when they write that the “visual modeling of large, complex systems has a long tradition in computer graphics,” that “these approaches address the appearance of natural phenomena,” and that “much of the appeal of such renderings lies in the possibility to depict the complexity of large-scale systems, which are composed of simpler elements,” including “the simulation of erosion, particle based forests and cloud modeling” (“Procedural Modeling of Cities,” 1). The ideal modeling system for this kind of computer graphics research produces

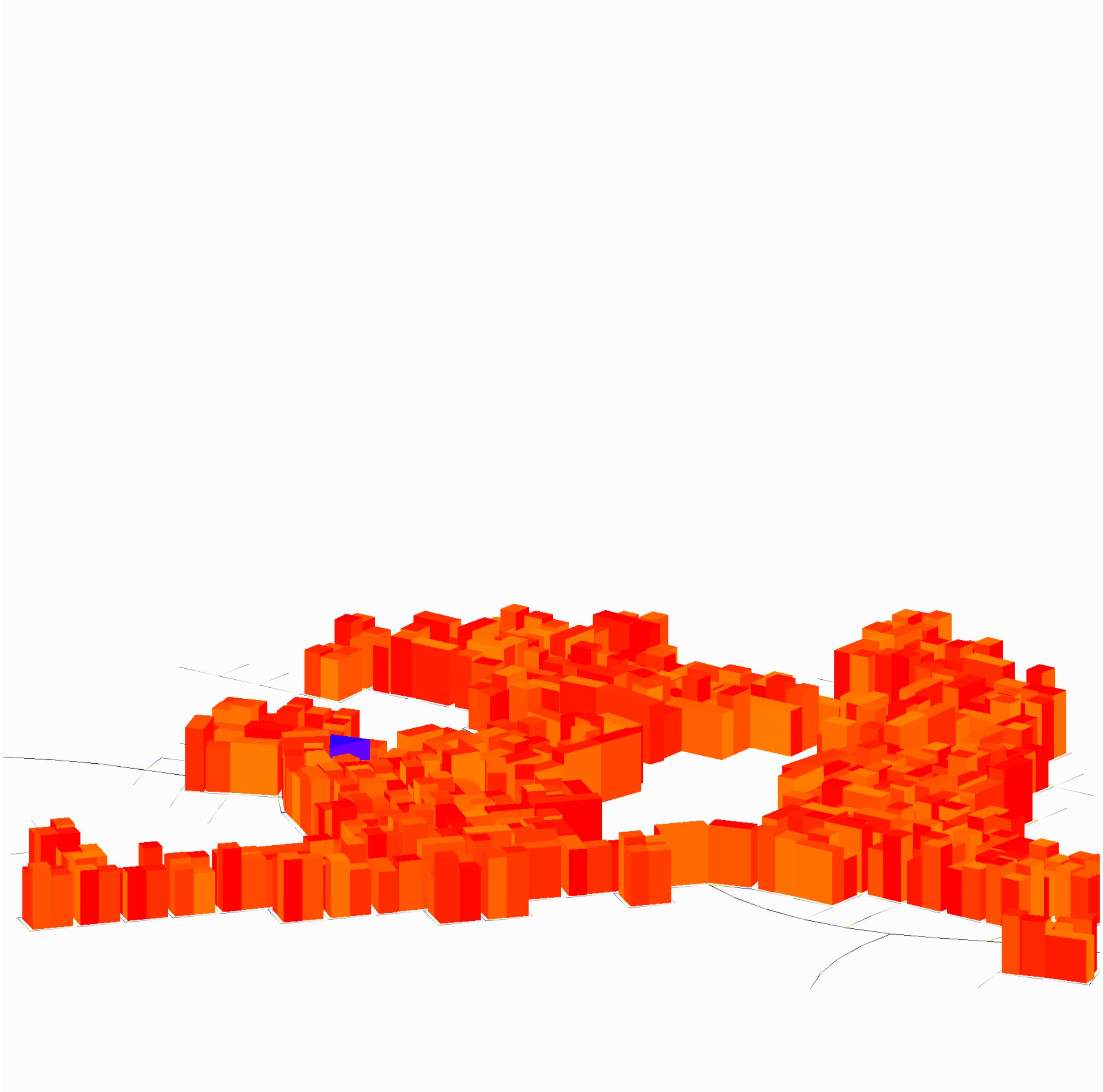

Figure 5. Detail shot in projection of the road network and lots model.

compositions consisting of simple elements that totally saturate representational space in detail and movement through their acceleration in the computational procedure. Acceleration is the capacity belonging to computation, and it is the fundamental method of composition in computer graphics simulation.

But computational acceleration does not merely preserve old forms at a new speed. We can focus on perspective as the site for a technological series to see more clearly how formal elements are remobilized in a transformed field of knowledge. Bazin describes perspective as allowing the artist "to create the illusion of three-dimensional space within which things appeared to exist as our eyes in reality see them," and as being "the first scientific and already, in a sense, mechanical system of reproduction," but one that "had only solved the problem of form and not of movement," with the latter being solved in film (OPI, 160). Is it true that realism required the solution to two problems, form and movement, and that perspective solved the first? Is perspective something that can be "added on" to the capacities of a medium without deforming it or being deformed? In his essay on perspective, Erwin Panofsky qualifies the concept, and suggests that systematic perspective, which is what Bazin is really talking about, was a technique itself reflective of a culture and way of thinking. He states that "the history of [systematic] perspective may be understood with equal justice as a triumph of the distancing and objectifying sense of the real, and as a triumph of the distance-denying human struggle for control" (*Perspective as Symbolic Form*, 67). This may seem to suggest a teleological view. However, in the same essay, Panofsky also shows how systematic perspective in the Renaissance was developed from the synthesis of perspectival motifs which were retained in Byzantine art and the the coherent grounds and surfaces of the medieval period. That is, he shows how perspective is constructed.

In computer graphics, perspective is the site for a technological series involving concepts and material technology. It is usually taught through the concept of a pinhole camera which explains perspectival projections, with parallel projections as a special case. Here, computer graphics uses a very old concept going in order to cover the normative use of visual transformations. However, in accordance with the demand placed by the computer that perspective must be computable, computer graphics also covers the mathematics which describe the transformation between vector spaces and which is representable within a computer-readable language. In this way, normative visual transformations are found to be adequate to mathematical techniques, which are found to be adequate to the computer. Against Bazin, perspective involves a technological series (which is here described only in part and ended at an arbitrary point) that mobilizes the formal elements which we designate under the term "perspective," and it is the different construction of the series under photography and now computer graphics that we can say perspective has been deformed.

A contrapuntal formal analysis

We have been teasing out how computer simulation and visualization operates as a system, and it is our goal now to understand the circulation of this system in terms of formal effects. I will attempt this by reading a few visual objects derived from two computer graphics simulation papers. Because the methods for representing the visual output of a simulation system are so varied, we will necessarily have to consider each visual object contrapuntally, where we are interested not just in what we see but also its interrelationships with what the modeling system, programmer, and computer makes possible to see. We should keep in mind the computer's function as a remediation machine, supported by the mechanisms of numerical representation, modularity, automation, variability, and transcoding, which, according to Lev Manovich, define "new media" (*The Language of New Media*, 20). By doing this, we can note how computer simulation and visualization operate differently from older media.

Figures 1 and 3 are views of the same landscape derived from a river network model. They show a regular grid of points elevated according to the height sampled from an underlying structure.[4] In this respect, the process is a counterpart to Lidar and other forms of 3D scanning (i.e. the fragmentation and representation of the world's spatial relationships). The results are represented similarly as point clouds, and so in both cases we adopt the same form of looking as a reading of information. I also programmed the views in Figures 1 and 3 with a continuous rotational transformation, I suppose because I wanted to be able to see the entire scene from multiple perspectives, to ensure its "correctness." But really, the rotation is a form of movement which we identify with as we may identify with the camera of film, and this movement takes on the character of surveying, which is a mode of seeing appropriate to information.[5] Additionally, rotation emphasizes the plasticity of the scene (I am reminded here of the "perspectival motifs" in medieval and, later, Renaissance art; the coffered ceiling, the flanking walls of an interior) through depth by parallax. A surface facing away from the viewer is signified by a clustering of points and the region's corresponding darker value within the frame, whereas a white fissure signifies a large change in elevation of the underlying surface facing the viewer. These are in themselves classes of details that belong to the reality effect, which point to an underlying "reality" just as the visuals of Lidar point to an underlying reality. The conditions for both of these kinds of details are secured by the angle of projection, which, relative to a plan view of the same data, clusters the surface and opens fissures.

Figure 2 shows an abstract structure in relation to Figures 1 and 3, a kind of phase within the modeling system. This phase shows at what point abstraction meets the requirements of simulation, which is plasticity. That is, we can read the abstract surface as representing the same landscape, the simulated and realistic landscape, through the correspondence of value, which is clustered and declustered and distributed across cells. The abstraction is an armature and necessary for generating the visualization of the simulation at exactly this point; the mesh is a stand-in for a landscape precisely because the plastic effect is adequate as a representation, a simulation of reality.

Figures 4 and 5 are views generated by the same road network and lots modeling system. In Figure 4, the reality effect is secured by the cadastral character of the view, insofar as a cadaster in itself reveals reality. Unlike with the cases of the other views in projection, the view in Figure 4 does not require plasticity to be a realistic simulation, and I did not program it with a rotation. In fact, I think the effect would be "unnatural" here. Instead, I split the visualization of the model into a sequence of steps in time. Instead of instantly composing the entire frame, the visualization process emphasizes the development of the model through time and points to the temporal nature of land development, but as a series of frames, which is the only possibility for a mechanical reproduction of time. The animation simulates the development of a cadaster through

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[4] This underlying structure is a continuous function, which is often preferred in simulation because of the demand for control over the level of detail. The continuity of the function is a stand-in for the "infinite resolution" of reality, which has now itself become adequate to the notion of "resolution."

[5] In all the visual objects we are examining, the mode of distracted surveying dominates, especially in cases where the scene rotates. Put another way, there is nothing to be "interpreted" in these images.

time, and acts as a feed for the reality effect. Figure 5 features a return of plasticity through rotation and the projective character of linear shapes, emphasizing the screen as a window into a miniature reality. But at the same time, the effects of color threaten to collapse the frame into a pure surface by canceling shade cues. Note that these are so many formal effects circulating through the same system that produced Figure 4, which operates quite differently.

How can we understand the computer as a platform which supports all of the views we have covered? Let us reconsider the mechanisms which distinguish the computer. The possibility of moving between one visualization of a model to another as so many phases is due to their character as data presented within memory. This “variability” belonging to computation relies on the numerical representation of data. Indeed, at its limit, computer graphics as a science is concerned with the correct transformation and ordering of data for the monitor.

The modularity of computation has a fundamental relationship with the calculation of details. The frame is simply a composition of the effects produced by a finite set of instructions organized into modules and then executed in an accelerated manner. As with the point-cloud generated from the river network model, the calculation of a single surface is the same in all of its regions. And as with the lots from the road network model, the calculation of a single shape is the same throughout the entire space. The system of computer code is total, cannot create anything that is not defined by its set of instructions, and it derives its fundamental use from the acceleration of “flattened” procedures, which is the principle of automation. The fact of its modularity results in a profoundly homogenous character belonging to computation and its visual forms, even if there are local differentiations or levels. Visual objects generated by the computer, from the simplest visualizations of models to the most complex video animations, are constituted by a finite set of effects that are repeated in the frame’s space and time.

Conclusion

In this paper we have explored the system that produces the meaning of statements and visual objects in computer graphics simulation. We have gone through several key areas: modernity and the roles of technology, fragmentation, exchange, and the market; realism by the ontology of photography/film and the reality effect; and the formal structure of visual objects from simulation including their material organization through the computer. The computer functions as a transcoder because our entire world is already mediated by transcoding. We can see that the computer not only excels at remediating media developed in the 19th century such as photography or film, but also laser scans and city diagrams, that is, technological series - remediating not just the paper, but also the map upon it. This reflects the position of the computer itself within a technological series that connects up with the subject; the corollary is that computer simulation and modeling also circulate the operations of the subject.

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