3 EXPLORING UNCERTAINTY IN KNOWLEDGE REPRESENTATIONS: CLASSIFICATIONS, SIMULATIONS, AND MODELS OF THE WORLD

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Know ye now, Bulkington? Glimpses do ye seem to see of mortally intolerable truth; that all deep, earnest thinking is but the intrepid effort of the soul to keep the open independence of her sea; while the wildest winds of heaven and earth conspire to cast her on the treacherous, slavish shore?

—Herman Melville, *Moby Dick*

The world is not a solid continent of facts sprinkled by a few lakes of uncertainties, but a vast ocean of uncertainties speckled by a few islands of calibrated and stabilized forms.

—Latour 2005, 245

Uncertainty is often explained as a lack of knowledge, or as an aspect of knowledge that implies a degree of unknowability. Such interpretations can result in commitments to acquire more information about a particular situation, system, or phenomenon, with the hope of avoiding further surprises. In addition, in some cases uncertainty is interpreted as evidence that "objective" knowledge cannot be attained. The above quotation from Latour's *Re-assembling the Social* may appear to echo such ideas, but, as Latour admits, "[p]aradoxically, this 'astronomical' ignorance explains a lot of things. . . . We have to be able to consider both the formidable inertia of social structures and the incredible fluidity that maintains their existence: the latter is the real milieu that allows the former to circulate." (2005, 245) Latour suggests taking up this backdrop of fluidities from which more stable and less stable structures coagulate into existence. In other words, rather than reading uncertainty as a deplorable property of knowledge, Latour proposes to recalibrate, or realign, knowledge with uncertainty, and thereby remains open to a productively disruptive aspect of uncertainty.

In this chapter, we continue to trace the lines of inquiry suggested by Latour's notion of an "ocean of uncertainties." We do so by looking at how uncertainty can be a source of knowledge that can disrupt categories that provide epistemological bearing, much like the "solid continents" Latour mentions. We ask how new forms of knowledge production dealt with the challenge of uncertainty in the past, how they tried to reduce or capture uncertainty, and in what instances they produced new uncertainties. We undertake these excursions into science history with new virtual-knowledge practices in mind and with the aim to discover what lessons can be learned. Owing to their innovative nature, the new practices of knowledge production characterized and analyzed in this book imply uncertainty. They are also supposed to alter our understanding, and they almost always occur at the boundaries between different disciplines. What is at stake here is whether different sciences want to keep their feet firmly on solid ground or whether they are open to new insights offered by oceans of uncertainties. We argue that having a strong inclination to *either* islands (which provide epistemological bearing) *or* oceans (which set objectivity adrift) puts researchers at risk of not tapping into uncertainty as a source of knowledge. This may be tantamount to developing a closed system of explanations that leaves a *particular* (and potentially *restricted)* arena for knowledge production.[1] An emphasis on both forms of knowledge is necessary, which implies a balancing act between relying on firm epistemic grounds and carefully broadening one's scope so that new avenues of knowledge can be explored. In terms of virtual knowledge, persistent attention to uncertainty opens up potentials otherwise veiled. Put somewhat provocatively, what we consider to be problematic about problems is the ways in which they invite solutions. As the historian of cartography John Brian Harley has argued, "[i]nstead of just the transparency of clarity we can discover the pregnancy of the opaque." (2001, 159)

Ideally, it is the dynamic interplay between the two forms of knowledge production that is needed. In practical terms, however, this interplay is not free of tensions, fights, and struggle. This dialectic relationship can be found at all levels of knowledge production, whether inside a specialty or across disciplines. We want to emphasize the creative potential of embracing uncertainty by looking into ambitious research projects in the history of science. Recalling examples from the past, we also wish to emphasize that uncertainties that can be associated with current forms of virtual knowledge are not new. The production of virtual knowledge implies a necessity to increase awareness of elements of uncertainty. This applies to all periods in which foundations of scholarship are subjected to change. In phases of profound reorganizations of academia—cognitive and epistemic, as well as social and organizational—we would like to call for carefulness, thoughtfulness, and a certain modesty when embracing new media, new techniques, and new concepts. (See the introduction to this volume.) Knowledge production is a path-dependent process. Current fractures and controversies cannot be understood without mapping the networks of evolving schools of thought (Collins 1998; Börner and Scharnhorst 2009) and specialties in science. (See chapter 7 below.) Science history is an indispensable source of knowledge about how to judge, evaluate, and moderate current controversies. Last but not least, the current emphasis on visual elements in the production of virtual knowledge can be related to our historical cases. (See chapter 4 below.) The use of visual elements in the design and development of the theoretical models of the selected cases, in their application to practice, and in their final presentation provides another link to current debates about the relationship of uncertainty and visual representations of knowledge.

We begin by discussing some of the ways in which the natural sciences, the humanities, and the social sciences have engaged issues of uncertainty. Discussions pertaining to uncertainty in science and technology studies have often focused on research practices in the natural sciences. We show how various authors in the humanities and the social sciences have problematized this focus on practices of the natural sciences when it comes to analyzing research practices in the social sciences, and how they emphasize the need for approaches that distance themselves from the natural sciences, or seek to augment the natural sciences with more qualitative methods. However, we do not wish to advocate either the scientific methods used in the natural sciences, those used in the social sciences, or those used in the humanities as proper epistemological approaches for embracing uncertainty. We conclude the first section by discussing why we think a degree of cross-fertilization between these areas is necessary.

To support the claims that uncertainty can be a source of knowledge while acknowledging that this source can best be utilized through a combination of elements from the humanities, the social sciences, and the natural sciences, we present three historical examples in the second section. Rooted in a variety of disciplines (namely the emerging science of documentation and information, architecture, and the then-new field of cybernetics and operations research), each of the three examples shows a certain drive to provide knowledge about the world. This goal is highly appealing but hard to reach. All three cases departed from "solid continents of facts" to find their (representation of the) world. We take this goal of "total" or "all-encompassing" knowledge of the world as an attempt to provide a "complete" system in which the world is framed, and ask to what extent this still leaves room for an appreciation of a "vast ocean of uncertainties." The examples were chosen to show historical precedents to present-day notions about uncertainty, to ask whether and how approaches to uncertainty have developed over time, and to indicate what can be learned from history. They concern the role of data and classification, the design of interactions, and the inclusion of dynamics in formal approaches to complex systems. By means of these examples we want to show how uncertainty can lead to new knowledge, and how the feature of uncertainty is addressed, as well as partly suppressed or lost, in attempts to develop complete theories of the world. Straddling serendipity and formalization, our historical examples show to what extent disruptive dimensions of uncertainty have been taken up in attempts to provide explanations of the world. In addition, we continue our review of existing approaches to uncertainty by showing how approaches informed by the natural sciences already contain ideas emphasized in the humanities and the social sciences. Rather than claiming victory for one particular approach, we invite the reader to think about possible interactions between different ways of approaching uncertainty.

Finally, we draw lessons from the historical cases and assess their effects on several aspects of current and future e-research. We believe that our historical studies of classifications, designed interactions, and models can inspire future e-research. Our case studies reveal differing approaches to dealing with uncertainty. Each has important implications for the way knowledge is codified. Science history can help us to understand this variability. E-research brings codification of knowledge to a new level, and this makes it even more important to have a firm understanding of the way researchers are dealing with uncertainties in practice. (See chapter 2 above.) We hope that our analysis will provide ways for researchers, particularly those pursuing e-research in the humanities and the social sciences, to engage uncertainty and appreciate its productive (and disruptive) effects.

To summarize, our discussion of the potential value of uncertainty with regard to knowledge representations revolves around three questions: In what ways can uncertainty be a source of knowledge, and how does appreciating this dimension of uncertainty require a combination of natural sciences, humanities, and social sciences? How can historical examples of knowledge representations of the world provide insights into ways of thinking about uncertainty as a source of new knowledge? How can these examples inform present-day approaches to uncertainty in e-research in the humanities and the social sciences?

UNCERTAINTY IN THE NATURAL SCIENCES, THE HUMANITIES, AND THE SOCIAL SCIENCES

Although uncertainty has been a subject of scrutiny throughout the history of the natural sciences, it has received less attention in the social sciences and the humanities. Although the body of work on uncertainty in the humanities and the social sciences is fragmented, a number of authors working in these fields have recently explored uncertainty and risk from a multidisciplinary perspective (Bammer and Smithson 2009). It can be argued that the characteristics of data and scholarly practices in the humanities and the social sciences warrant paying more attention to uncertainty. For example, the highly ambiguous meaning of data in the humanities (American Council 2006, 6) was already an object of study in 1824, when Leopold von Ranke tried, in his *History of the Latin and Teutonic Nation*, to separate historical facts from fiction, myth, and legend in order to create an objective historical science. This view was challenged a century later by historians (among them Benedetto Croce and Carl Becker) who emphasized the role of interpretation and argued that the present desires, fears, and anxieties of historians shaped their understanding of the past. This longstanding debate about whether there is sufficient historical evidence to enable us to know the "truth" of the past has later been framed using the concept of uncertainty. It is "part of historians' stock in trade, yet historians differ enormously in how uncertain they are" (Curthoys 2009, 127; also see chapter 7 below).

Within the humanities, only a few studies try to link scholarly practices with aspects of uncertainty. For example, in their study on spatial vagueness and uncertainty in the computational humanities, Kemp and Mostern (2001) observed that the traces created, defined, and shaped by communities cannot easily be reduced to quantitative data. They therefore proposed to follow the example of environmental modeling implemented in GIS applications of the 1980s and the 1990s by "asking scholars to change their methods to suit technology, rather than making the technology work for them," thereby reducing uncertainty (ibid., 1). Jack Owens turned the question about the demands of technology around by asking "What do historians want from GIS?" However, Owens still proposed that historians (in collaboration with mathematicians) experiment with the use of algorithms and fuzzy logic. By doing so, they would be able to acquire more rigor in the methods they use to handle ambiguity and uncertainty in historical records and the complexities of history, particularly world history (Owens 2007a, note 42; Owens 2007b, 2030; Coppola, Owens, Szidarovszky 2008; Owens 2009). These approaches show a commitment to reducing uncertainty, and display a tacit endorsement of ideals pertaining to knowledge production from the natural sciences, which points to the need to do away with a multitude of interpretations and lack of objectivity.

We argue that it is characteristic of the humanities and the social sciences to come across uncertainty in the form of heterogeneity and ambiguity, and that this is due, at least in part, to differences in scholarly practices in the humanities and the social sciences. According to Latour, defining and ordering the social should be left in the first place to the actors themselves after having characterized the full range of controversies, rather than leaving it to analysts to impose order beforehand. "Re-assembling" the social in this way is a time-consuming process in which the movements of the actors "will be constantly interrupted, interfered with and dislocated by . . . uncertainties" (Latour 2005, 23). Uncertainty should not necessarily be lamented. It can also be understood as an aspect of knowledge that might be appreciated more positively. Uncertainty may point to knowledge otherwise downplayed or ignored, and it may encourage scholars to assess their own understanding, knowledge, and intuitions.

We argue that recent work on the subject is able to open up such features of uncertainty. Its ability to do so relates to the fact that such work unsettles well-established boundaries between the natural sciences, humanities, and the social sciences.

Brugnach et al. (2008, 11–12) make the important observation that "uncertainty cannot be understood in isolation, but only in the context of the socio–technical–environmental system in which it is identified." They suggest developing a relational concept of uncertainty, which "involves three elements: 1. an object of perception or knowledge (e.g. the socio–technical–environmental system); 2. one or more knowing actors (e.g. a decision maker) for whom that knowledge is relevant; and 3. different knowledge relationships that can be established among the actors and the objects of knowledge." (ibid., 5) In this framework, there may be three causes of uncertainty. First, we may be dealing with systems whose behavior can only be predicted to some extent. Second, we may have incomplete knowledge of the system in question. Third, there may be different or even incompatible frames of reference for the system in question. In the case that Brugnach et al. consider (that of adaptive strategies in water management), uncertainty is also approached as a potentially fruitful aspect of knowledge: "Handling uncertainties shifts from elimination toward exploring other options by reconsidering our relation to the water management situation and the other actors involved." (ibid., 13) Although this communicative approach to uncertainty is devoid of the desensitization that occasionally accompanies other approaches in the natural sciences, it leaves a number of issues unaddressed.

A first objection is that the aforementioned authors do not carefully distinguish between epistemic and ontic uncertainties. Whereas epistemic uncertainty is a consequence of incomplete or fallible knowledge, ontic uncertainty is a claim about intrinsically indeterminate or variable properties of systems (Petersen 2006, 52). However, ontic uncertainty may turn out to be epistemic uncertainty—new means of knowledge production may become available as a result of technological, institutional, economic, and socio-political factors. This shifting boundary between ontic and epistemic uncertainties means that distinctions between these types of uncertainty may (or may not) change over time. In other words, the claim that epistemic and ontic uncertainties cannot be distinguished is itself an uncertain statement. What should be studied are the dynamics between these two types of uncertainties and the extent to which different groups of actors agree or disagree about such demarcations.

Second, in the approach of Brugnach et al. it is difficult to assess the sources of uncertainty. Petersen (2006) distinguishes a number of locations of uncertainty in the case of climate models. Uncertainty may be due to conceptual and mathematical models. In other words, the way in which systems have been schematized and formalized may introduce simplifications that leave insufficient room for detail. Also, the model inputs may be a source of uncertainty. What is more, the technical implementation of the model may introduce uncertainties, for example, in the form of coding errors that may or may not be debugged.

Third, the processed output and interpretation can be a source of uncertainty. The resulting typology is displayed in figure 3.1. Although this typology warrants more explanation, we emphasize its value in finding the source of an uncertainty. Typologies of this kind are necessary in attempts to find out to what extent uncertainties can be explained.

A final and related objection is that the focus of Brugnach et al. (2008) on multiple frames of reference tends to ignore the role of knowledge instruments in facilitating knowledge about uncertainty. Access to uncertainties is, to some extent, shaped by technological practices, which at least partly constitute the conditions under which similarities and dissimilarities between various frames of knowledge are observed.

Petersen's work is relevant to our discussion of uncertainty not only because it encompasses quantitative and qualitative aspects of uncertainty but also because Petersen creates an analytical space in which both aspects can be studied. For example, value diversity can affect model inputs as much as statistical uncertainty. Petersen's approach makes it difficult to adhere to a rigid division of the natural sciences, the humanities, and the social sciences, and can thereby inform studies of uncertainty. This important work also highlights problems with *a priori* distinctions between quantitative and qualitative approaches to uncertainty. Our examples further reveal how making such distinctions beforehand can be problematic. This will lead to recommendations for present-day e-research to refrain from clinging to either quantitative or qualitative methodologies exclusively.

EXAMPLES: UNCERTAINTY IN REPRESENTATIONS OF THE WORLD

We discuss uncertainty in relation to representations of the world because such representations concern an enormous number of components and a dense fabric of interactions, which are very likely to lead to some degree of uncertainty. We discuss three historical cases of representations of knowledge of the world, and elaborate on their ability to tap into the disruptive and productive potential of uncertainty.

First, we discuss Paul Otlet's attempt to develop a system of universal classification, focusing on aspects of uncertainty in the organization of

Sorts of uncertainty

UNCERTAINTY MATRIX		Nature of uncertainty		Range of uncertainty (inexactness/imprecision or unreliability,/inaccuracy)		Recognized ignorance	Methodological unreliability (unreliability,)	Value diversity
Location/source of uncertainty ↓		Epistemic uncertainty	Ontic uncertainty / indeterminacy	Statistical uncertainty (range+chance)	Scenario uncertainty (range of 'what-if' options)		• Theoretical basis • Empirical basis • Comparison with other simulations • Peer consensus	• General epistemic • Discipline-bound epistemic • Socio-cultural • Practical
Conceptual model								
Mathematical model	Model structure							
	Model parameters							
Model inputs (input data, input scenarios)								
Technical model implementation (software and hardware implementation)								
Processed output data and their interpretation								

FIGURE 3.1
Typology of uncertainty in simulation. Source: Petersen 2006, 5. Reprinted with permission.

knowledge systems and their interfaces. Our second case is Buckminster Fuller's World Game, a simulation of the world in the form of a game. Here we concentrate on the interaction of users with data that takes places within the parameters of a pre-designed environment, and whether this designed interaction allows users to question their means of interaction. Third, we look at Paul Forrester's development of a mathematical model that deals with world equilibrium. This case explores the limitations and possibilities of using formal, mathematical language and computer-based simulations to emulate complex features of the social world.

We claim that each of these three engagements with uncertainty (classifications, designed interactions, and modeled landscapes) has its own problems of uncertainty. In our discussion of these engagements, we talk about quantitative (completeness, exactness, accuracy) and qualitative (evidence, authority) aspects of data. In addition, our case studies elaborate on the ability of the representation in question to tap into the potentially disruptive dimensions of uncertainty. In the third and final part of this chapter, we ask how our discussion of historical representations of the world can inform approaches to uncertainty in e-science.

OTLET: A VISUAL CLASSIFICATION OF UNIVERSAL KNOWLEDGE OF THE WORLD

One geometry cannot be truer than another; it can only be more convenient.

—Henri Poincaré (1952, 50)

The Belgian "utopist" Paul Otlet (1868–1944) is considered a pioneer of modern information sciences. In his *Traité de documentation* (1934), Otlet attempted to formulate a theory of documentation that, as Boyd Rayward has pointed out, has several characteristics in common with modern information science. He also introduced new disciplines that are still relevant for modern information science, such as "bibliometrics" (Rayward 1994). Otlet is often mentioned as a forerunner of the World Wide Web. Although we want to avoid the suggestion of a causal historical relationship, similar characteristics can be recognized in Otlet's theory on documentation and in the more recent concepts of the Internet, hypertext, the World Wide Web, Web 2.0, and the Semantic Web (Rayward 1994; van den Heuvel 2009, 2010). In the context of this chapter, Otlet is of particular interest because of how he organized knowledge, because of his quest to reveal scientific "facts," and because of the inclusion of uncertainty in his model.

Otlet is probably best known for his Universal Decimal Classification (UDC), based on Melvil Dewey's Decimal Classification. For Otlet, the UDC was a tool for the organization of documents that in their totality form a "graphic memory of mankind, the material body of our sciences and our knowledge" (La Fontaine and Otlet 1908, 177). According to a process referred to as the "Monographic Principle," documents of whatever content or medium can be reduced to the most elementary "items of information with [their] own identity" and re-ordered into new combinations (Rayward 1990, 1). The UDC was crucial in this process, as becomes clear from Otlet's metaphor of "mapping": [I]t allows us to find a place for each idea, . . . for each part of a document. Thus it allows us to take our bearing in the midst of the sources of knowledge, just as the system of geographic coordinates allows us to take our bearing on land or sea. (Rayward 1990, 153) However, the UDC would not only allow for navigation of a vast array of knowledge; Otlet also thought it would enable "special classification to group facts into scientific laws" (ibid., 12). In *Monde: Essai d'Universalisme* (1935), Otlet tries to capture the complete reality of the world in one equation. According to Otlet, the synthesis of the world is the product of object and subject, but also, importantly, of the unknown. Figure 3.2 shows how this synthesis is expressed, first in words and then in a letter code based on the first letters of the words. In order to make this equation independent of language, Otlet proposed a numerical annotation of decimal fractions.

Figure 3.3 shows two spheres. The outer sphere represents the objects—(0,1) things (nature, man, society and divinity), (0,2) space, and (0,3) time. The inner sphere represents the subjects—(0,5) Creations, (0,6) Expressions), and (0,7) the Unknown and Mystery—circling around the central globe representing (0,4) the Self. This representation of Monde as a whole, indicated with the numerical code (0,8), is visualized on one page of an oblong folder in which all eight elements are represented separately and, in the last one, turn in circles around the world documentation center (0.9) Mundaneum. On this representation of the World, Otlet wrote: "The equation of the world develops like this. It is at the same time its classification." Ducheyne (2009, 234) uses this representation to underline Otlet's attempt to connect the microcosm of human beings with the macrocosm of the universe so that all knowable elements of reality and the relations between them could be overseen, comprehended, and contemplated.

At first sight this interpretation of Otlet's use of the universe metaphor as a macro- and microcosm in which every aspect of reality (and the unknown)

$$\text{WORLD (Monde)}\left\{\begin{array}{l}\text{Object}\left\{\begin{array}{l}\text{Things}\\\text{(Nature, Man,}\\\text{Society, Divinity)}\\\text{Space}\\\text{Time}\end{array}\right.\end{array}\right.\left\{\begin{array}{l}\text{Subject}\left\{\begin{array}{l}\text{the Self (le Moi) (knowledge,}\\\text{sentiment, action)}\\\text{Creations (synthesis,}\\\text{harmony, organization)}\\\text{Expression}\end{array}\right.\end{array}\right.\left\{\begin{array}{c}\text{Unknown}\\\text{and}\\\text{Mystery}\end{array}\right\}$$

This equation will be even more concise if one expresses it with the first letters of the terms

$$W=\left\{\begin{array}{l}T\,(N+M+S+D)\\[2em] S\\[2em] T\end{array}\right.\left\{\begin{array}{l}S\,(k+s+a)\\[2em] C\,(s+h+o)\\[2em] E\end{array}\right.\left\{\begin{array}{c}(x+y)\end{array}\right\}$$

$$1=\left\{\begin{array}{l}0.1\,(0.11+0.12+0.13+014)\\[2em] 0.2\\[2em] 0.3\end{array}\right.\left.\left\{\begin{array}{c}0.4\\[2em] 0.5\\[2em] 0.6\end{array}\right\}\;0.7\;\right\}$$

Then these letters are replaced by their numerical symbols all preceded by zero (0).
This is followed by the custom to simplify the notation by the suppression of zero […].
Thus:

$$0=\left\{\begin{array}{l}1\,(11+12+13+14)\\[2em] 2\\[2em] 3\end{array}\right.\left.\left\{\begin{array}{c}4\\[2em] 5\\[2em] 6\end{array}\right\}\;7\;\right\}$$

FIGURE 3.2
Otlet: Equation of the World, *Monde* 1935, pp. XXI–XXII. Translation by Charles van den Heuvel from Otlet 1935.

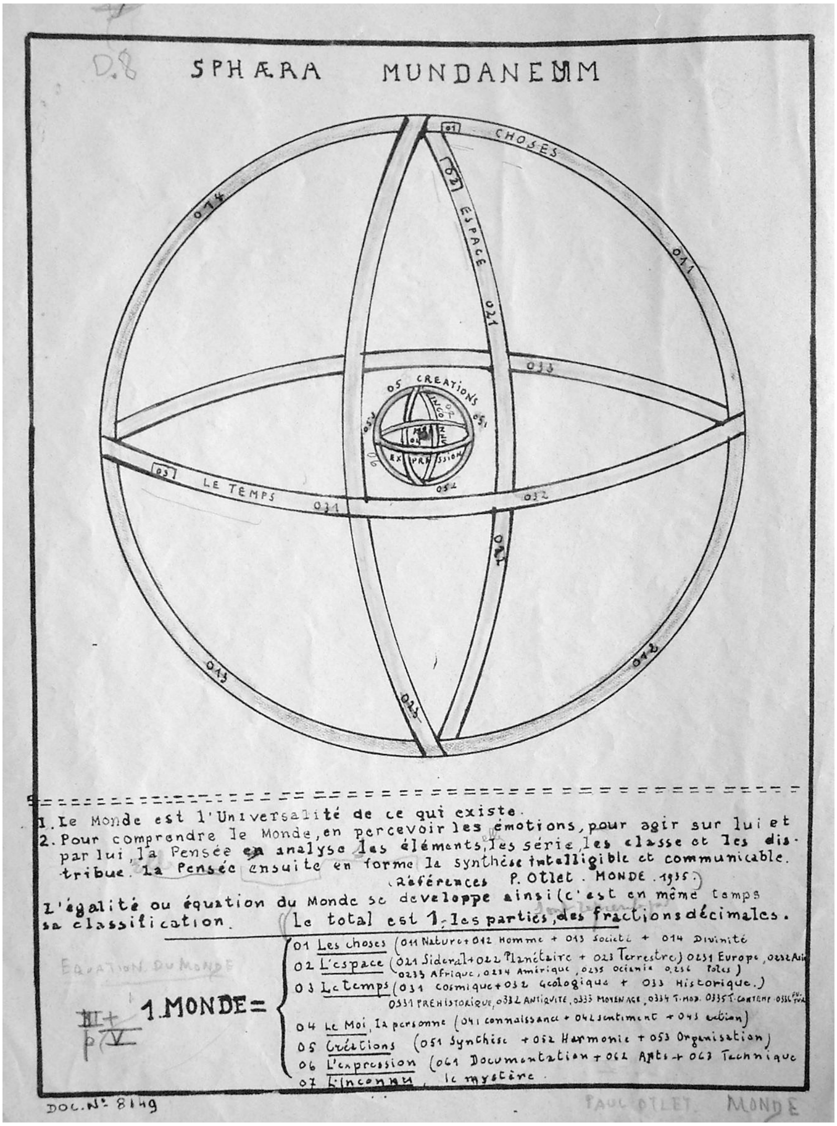


FIGURE 3.3
Otlet: Sphaera Mundaneum (July 31, 1937). Photograph by Charles van den Heuvel of an object in the Mundaneum archive. © Mons, Mundaneum EUM 8149.

has a clear and designated space seems coherent, but a comparison with other representations reveals a picture that is less clear. Uncertainty is not restricted to the place to which Otlet had assigned it, a fact of which he must have been at least somewhat aware. He made many different representations of the world, some spherical, some cubic, and some attempts to combine the spherical and the cubic. Whereas uncertainty is visible in the spherical representation, it remains unclear where uncertainty is located in the cubic representation. The three visible faces of the cube show the domains, the sectors, and the instruments of Otlet's plan of the world, but we cannot see which sort of information he projected on its three other faces, and whether these included a representation of uncertainty.

The consequence is what Petersen has referred to as an unclear distinction in the distribution of ontic and epistemic uncertainty, which we addressed above. However, this is not just a matter of representation; it is also a matter of scalability. Otlet expresses a clear-cut distinction between time and space in his visual representation of the world, giving them separate classification numbers. But in the text of *Monde, essai d'universalisme* he writes: "Substances, Movement, Space and Time are . . . the four most fundamental categories that constitute for us the World. These categories are not separable but occur simultaneously." (Otlet 1935, vi) This means that matter-energy and space-time cannot be separated into clear-cut categories. Otlet seems to be aware of this scalability problem: "the laws applicable to macro-physical objects are not applicable to micro-physical objects" (ibid., 30).

In this case, Petersen's exploration of the source of uncertainty is of interest. He refers to a dimension in the location of uncertainty that owes its existence to conceptual and mathematical models and data input. Otlet's input of simplified concepts, such as matter, energy, space, and time, here results in uncertainty. Otlet believes that the problem can be solved by mathematics, which in his view not only had become "an instrument to realize a higher level of abstraction: it becomes 'thought' (*la pensée*) itself. . . . Mathematics is not just a translator of concepts, but a producer of concepts." (ibid., 31) However, by giving the same decimal codes to concepts that differ in meaning, Otlet's mathematics merely bypasses these differences, and at the same time introduces complexity and uncertainty to the implementation of his model. Finally, there is the problem of mediation between knowledge representation and users/producers located around it. Ducheyne focused on images that positioned the individual in the center of Otlet's representation of knowledge in spheres. However, there are many representations of Otlet's *Monde* in which the human being is an observer from the outside, which creates a different perception of the world. When the person is in the middle, that person is surrounded by his or her own complete knowledge universe (including uncertainty). However, the external observer, together with other viewers, gets an outside, often partial view of the world in which the location of uncertainty is not always clear.

Several sketches of eyes in Otlet's knowledge representations allude to the fact that he tried to map how the world could be perceived. The importance that Otlet attributes to perception becomes clear in his *Monde*, where "The Conception of World" is discussed: ". . . the world presents itself before our eyes as a multiplicity and variety. . . . Placed before the panorama of things—the most general expression to indicate these particular elements of which the whole is composed—we perceive substances, beings, phenomena, viewed either by themselves or in their environments." (Otlet 1935, v)

The position of the human being has consequences not only for the perception but also the production of knowledge within this model. Otlet was thinking of mechanical and manual data enrichment in a universal network of documentation (Rayward 1983; van den Heuvel 2009). In his view, scholars would work together, assisted by machines for complementary operations of analysis and synthesis, to extract desired elements mechanically (van den Heuvel 2008, 2009, 2010). The UDC is an important instrument in this process. An important difference between the UDC and purely topical classification schemes is that the former does not just order subjects or topics in classes by numeric codes. Through its auxiliary tables or connector signs, the UDC also enables linking to additional information, such as place, language, and/or physical characteristics. On a technical level, the classification system made it possible to link annotations to specific documents, or parts of (interrelated) documents, that, following the Monographic Principle, were (re)composed around a classification number. The linkage characteristics of the UDC not only allowed the connecting of various classification systems but also created a space for contributors around documents. The latter could annotate documents ranging from simple additions to comments that express various points of view.

The process seems at first sight similar to Wikipedia, in which the involvement of many people who add and edit certain lemmas aims to improve those lemmas in particular and the digital encyclopedia in general

(Wright 2007). However, Otlet's knowledge system and collaboratory is more top-down than Wikipedia. For Otlet, the producer of knowledge is first and foremost an outsider to the system whose contribution would be recognized only after a long process of editing. Such experts would nowadays be called domain experts (van den Heuvel 2009, 2010). In his plea for digital disorder, Weinberger states that "the real problem is that any map of knowledge assumes that knowledge has a geography, that it has a top-down view, that it has a shape" (2007, 63). However, Weinberger's assumption that the World Wide Web does not have a shape or a hierarchy is not completely correct. (See Barabási 2003, 236–237.) Weinberger's "power of the new digital order" has (implicit) hierarchical relationships as well.

This brings us to another aspect of uncertainty, which Petersen labels as uncertainty at the source of the output and interpretation. If users cannot see implicit hierarchies, and cannot see who or what is accountable for this output, how should the results be interpreted? There is no doubt that Otlet's attempt to come to an objective classification to structure the world stands in a positivist tradition. It displays a certain degree of ignorance, and the components of Otlet's atomist architecture of knowledge do not always fit. This chapter questions the correctness of Otlet's visualizations of hierarchical relationships between knowledge classes, but also his designs for protocols to regulate the various forms of data enrichment. Otlet's orders of knowledge and protocols have a higher degree of accountability than Weinberger's new digital order, in which "everything is miscellaneous." As such, Otlet's visualizations might be usefully investigated in discussions of the role of accountability and authority in distributed authorship.

Still, this will take place in a different way than Otlet intended. As we have already noted, Otlet had tried to design places for the unknown and for mystery, putting them next to everything he considered to be known. Formalized in this way, these factors could not really disturb the static model. However, Otlet feared tensions at the fringes of his model of classification. At the nodes of the auxiliary tables, which are at the interfaces between the hierarchical order of the classification system and the disorder of data enrichment by machines and human beings, there was a higher risk of uncertainties interfering with his model (van den Heuvel 2009; van den Heuvel and Rayward 2011). Otlet tried to control these by developing protocols for updating the UDC, accepting that it would be temporarily out of control before a new zenith of stabilization was reached. "The ideal resembles a regular, but elastic sphere. Deformed and compressed, the sphere forms itself according to the pressures on it. Thus, the ideal can only regain its integral form when the circumstances that caused its deformation are eliminated." (1935, 363)

We stated that uncertainty is not necessarily problematic and that it may even open up new vistas of thought and serendipity. Rather than follow Otlet's protocols that streamline and even silence the input of uncertainties by uncontrolled or partially controlled data enrichment, we could analyze, and extrapolate from, these frictions. In the visualizations of knowledge objects, Otlet is not bypassing problems of data integration; he is, quite literally, facing them in a creative way. The study of incompatibility and inoperability might lead to a better understanding of the forms of uncertainties that need either to be prevented or to be cherished as new creative solutions in knowledge production (van den Heuvel and Rayward 2011). Or, as Randall Collins put it in his attempt to discover a universality of patterns of intellectual change, "[c]reativity is the friction of the attention space at the moment when the structural blocks are grinding against one and another hardest" (1998, 76).

FULLER: SIMULATING THE WORLD IN A GAME

Otlet's classification scheme is data driven and sees human interaction as a necessary (albeit disruptive) activity, although some human intervention is needed to update data and to fine-tune existing classification schemes. In the context of Fuller's World Game, users come to the foreground as (among other things) a source of uncertainty: users may have completely diverging beliefs about the amount of data that is sufficient to support an interpretation or theory, even whether model validation and verification is needed at all. The interaction enabled by Fuller's World Game hints at empowerment: playing the World Game supposedly increases awareness of world issues, their complexity, and the need to approach them in a holistic fashion. However, we argue that the determination of these experiences by underlying design issues and the differing appreciations of users should also be taken into account. In order to study these aspects of uncertainty, the case study of Fuller's World Game mainly looks at design-related decisions, which is where Fuller's modernist view of the roles of design and technology in society comes into play.

In 1963, in an attempt to counter ecological, economic, and political problems facing humankind, Fuller set out to collect all knowledge he considered relevant to the future of the Earth by creating a World Resources Inventory of Human Trends and Needs. He then combined this inventory with the so-called Dymaxion World Map—a map of the world projected onto a polyhedron, resulting in a depiction of the continents as nearly contiguous land masses.[2] Fuller's work led to the development of the World Game Integrative Resource Utilization Planning Tool in 1971. A year later, Fuller and others established the World Game Institute, which developed "the world's largest and most accurate map of the world, one of the most detailed and substantive databases of global statistics available anywhere and educational resources designed to teach interdependence, collaboration, respect for diversity, and individual participation in a global society" ("Global Simulation Workshop," O.S. Earth, at http://www.osearth.com).

The World Game was also proposed as an alternative to another form of gaming that was dominant at the time: war games. In the World Game, the process of governing the world is simulated in debates in which solutions to problems are negotiated with other players. Players need to engage with issues such as hunger, illiteracy, and environmental damage. As a result, players are expected to develop critical insights that will enable them to truly address and solve these problems on a global scale. Thus, Fuller explicitly takes the entire world as his object of study. We need, he argues, to study societal problems at a global scale, so that we do not limit our reasoning to "local-focus hocus-pocus" (Fuller 1963, 272).

The environment in which Fuller developed the World Game was very much shaped by the intellectual traditions of cybernetics and systems theory, which emphasized the need to study the functioning and the design of systems on a macro scale for the purposes of understanding, control, and regulation. Fuller's own background in architecture and design aroused an intellectual commitment on his part to deliver instruments or tools for improving systems that would contribute to holistic understandings of such systems.

The World Game can indeed be seen as a tool, though one more oriented toward delivering knowledge by enabling people to explore complex systems and issues. The World Game aims to fill a knowledge gap that Fuller considers extremely problematic: people are unaware of some of the causes of environmental and economic problems that continue to plague the Earth, and as a result they are not equipped with the knowledge to act. The word 'game' was used to make this rather daunting task as accessible and appealing to as many individuals as possible. Fuller was firmly convinced that the problems mankind faced could only be dealt with in a participatory manner. This required insight into the collective dimensions of existence that the World Game was meant to instigate. Fuller formulated this as follows:

> I am certain that none of the world's problems—which we are all perforce thinking about today—have any hope of solution except through . . . society's individuals becoming thoroughly and comprehensively self-educated. Only thereby will society be able to identify, and inter-communicate the vital problems of total world society. Only thereafter may humanity sort out and put those problems into order of importance for solution in respect to the most fundamental principles governing man's survival and enjoyment of life on Earth. (1971, 1)

Fuller celebrates what he sees as the computer's empowering potential, which is related to its ability to manage data and to present complex problems in a reliable and accessible manner: "the computer will keep constant track of where the resources are geographically located or where they are travelling" (Fuller 1981, 221). Moreover, the computer was expected to extend human senses in an empowering manner: "the natural and physical, and human resource data thus made available, will expand the decision makers' awareness of all possible alternatives for resource utilization, and can lead to better solutions and clearer directions in achieving national goals" (221). Fuller's definition of models is also based on his idea of making explicit the means for acquiring efficiency and optimization: "Models: the graphical, functional and mathematical orderings and simplifications of the omni-complicated and inter-related processes of the World. The conceptual simplifications of 'reality' into the vectors of an interacting process which can be dealt with on a scientific basis." (104) The game's goal is thus to provoke a process of self-education through which society will be able to "identify, and inter-communicate the vital problems of total world society" (Fuller 1971, 1).

The World Game provides the means to articulate clearly the consequences of better, more advanced designs by making explicit the collective consequences of actions by individuals playing the game. Winning the game involves "making the world work, making mankind a success, in the most efficient and expeditious way possible" (Fuller 1981, 95). Equipping users with the means to gain these insights requires that the tools used to produce knowledge be accessible to everyone, that knowledge be updated and presented in real time, and that the produced knowledge be easily disseminated.

In that sense, functionalities attributed by Fuller to the computer played an important role: its efficiency in handling data was considered to be crucial for the optimization of the World on a scientific basis.

The Dymaxion world map is a visual representation of the world that serves an important rhetorical purpose in Fuller's work, since it helped underline the idea that humanity is a collective enterprise. The map is chosen because it projects the Earth as a collection of adjacent continents, thereby emphasizing the fact that humanity co-exists rather than being dispersed over different, insulated continents.

Fuller tried to get universities to incorporate the World Game in their curricula, and in 1964 he proposed it as a contribution to the 1967 International and Universal Exposition in Montreal. Since 2000, the World Game has been facilitated by O.S. Earth, a company co-founded by Fuller, which organizes "workshops" at which participants can play the World Game (albeit without maps). The organization claims that the older version of the global simulation was a series of guided activities combined with lectures, and that participants mainly listened passively instead of being engaged in a more interactive fashion. More emphasis is now put on the perceived need for "authentic" and "personal" experiences of the individual players. Interactive experiences are ensured by making extensive use of negotiation, which enables "experiential learning" in which "participants proactively shape their own identities within the world and, in fact, the state of their entire world."[3]

Concerns related to time and money may seem trivial, but they do show how differing priorities can eventually shape the content and the experience of the game. In fact, Fuller may not have appreciated the high priority given to the fast-paced, more entrepreneurial experience that O.S. Earth emphasizes. Earlier versions of the World Game came with the advice that, to be able to fully understand and appreciate the intent and scope of the World Game, users should submerge themselves in the work of Fuller: "[F]or any group or individual who wishes to pursue his or their interest in Design Science exploration and the World Game, the most powerful place to begin is with the writings of Dr. Fuller. All of his books plus the World Design Science Decade documents are first priority." (Fuller 1971, 97) In the worst case, simply allowing uninformed people to play a World Game could, in Fuller's view, lead to wild and rampant imaginings and unfounded speculations regarding the future of humanity.

Though the underlying sources of information about the world's resources and population are constantly updated, and the World Game provides calculations according to scientifically developed models, it bears a suggestive and not a literal relationship toward the world it portrays. The use of data, the calculations, and the platform on which the game is played are largely aimed at incorporating the user's findings into a designed domain of exploration. Fuller expected that playing the World Game would develop the ability of the general public to come to more politically defined deliberations based on values incorporated into the World Game. This strong bond between intention and representation is something that the World Game shares with war games, a form of gaming that Fuller disdained. In her study of war games, Sharon Ghamari-Tabrizi makes clear that the purpose underlying such games is not to bear objective semblance to reality. Her analysis of war games shows how they center around narrative, partly based on lived experiences and expertise of military personnel, but also relies on the "demand of realism" as part of the dramatization (Ghamari-Tabrizi 2000, 199). The demand for realism can also be found in Fuller's World Game—it frames the world in a particular way, which is shaped by data, calculations that process data, interactional principles that reflect a highly political worldview, and a visual-interactional component that supposedly opens up issues that plague the world to users. So how does this lead to uncertainties?

One form of uncertainty is related to the use of data in the World Game. In his writings, Fuller does not reflect on how data are collected, on their availability, or on their quality. The possibility of collecting and managing data is taken for granted, which may introduce uncertainties into the process of playing the World Game—through incomplete or fallible datasets or inaccurate calculations. The game's intention was never to give a completely accurate description of the world's problems, though Fuller does claim that its underlying models have a "scientific" base. These models involve approximations (in varying levels of detail) of more specific situations, and are far from innocent. These models mobilize epistemic authority in the sense that they are expected to be able to answer questions the designer of the model deems relevant.

Another form of uncertainty comes from the differences between individual users' experience and knowledge. This issue also applies to more recent "serious games." Since the World Game fulfills the aforementioned "demand for realism" by being constructed in a certain manner, its users straddle discovery and manipulation: by playing the game, they may expand their knowledge of the world, and thereby incorporate Fuller's political ideas into their thinking. However, the World Game offers a particular view of the world. Even though there is the possibility for interaction, this occurs according to designed parameters that limit the scope of users' experiences.

The design principles incorporated into Fuller's World Game constitute the means by which users engage with issues, but whether playing the World Game indeed changes or informs their worldview remains in question. We believe that expertise on the part of model users is also important. However, the emphasis on immersive game experiences, which can be found in Fuller's World Game as well as in other present-day "serious" games, can lead users away from the principles underlying their experience of such games. The question is whether there can be such a thing as user reflexivity and engagement in the face of opaque or authoritative simulation technologies. The development and use of games and simulations is not exclusively a technical matter; it also should take into account users' perceptions, desires, and capacities. Approaching interaction design as an exclusively technical matter risks ignoring these crucial aspects of users' experiences. Fuller's World Game attempted to provide a practical solution to the problem of accessing specialized, isolated, and scattered knowledge, normally available only to well-educated experts. Though the need for a "comprehensive approach" to problem solving and the need for wide public participation are undisputed, it is questionable whether an "institution" such as the World Game is the ultimate answer. There is arguably a tension between in-depth and specialized knowledge and the ability to operate on a more general level that allows knowledge exchange between very different forms of knowledge acquisition. Obviously, there is neither a single nor an easy way to achieve that—as we will also see in the next case. Nevertheless, Fuller's experiment should at least be seen as encouragement to strive for forms—both inside and outside an academic environment—that allow learning and knowledge production through user interactions.

FORRESTER: WALKING THROUGH DYNAMIC LANDSCAPES

With each downpour,
more than ever, Your dear valley changes too:
In the self-same stream you'll never, Swim again,
I promise you.

—Goethe (1950, 512)[4]

The two representations of the world discussed above dealt with uncertainty in different ways. Otlet's classification was an attempt to order all possible available knowledge of the world in designated places, reduce factors of uncertainty, and extract the most elementary "facts." Fuller's World Game created a space in which actors could play out scenarios related to issues facing the Earth. In this section we discuss a model that creates a playing ground for the exploration of scenarios: the "world model" of Jay Wright Forrester.

Forrester's model is based on a systemic approach in which knowledge about actors, interactions, and spheres of action (such as the economy, politics, and the natural environment) are acquired by empirical observation. Once the main relevant variables are identified, the well-defined, isolated units are recombined again. System dynamics (Sterman 2007)—to which Forrester's model belongs—departs from simple assumptions about cause and action and embraces insights into the presence of various feedback cycles, which make social processes anticipative, adaptive, self-empowering, and therefore partly unpredictable. Using advances in mathematics and computing, a complex systemic "machinery" is built to model the world. The resulting model gives space to uncertainty in the form of producing a variety of possible scenarios and allows the user to test hypotheses about causalities and correlations. At the same time, it contains the same sources of uncertainty that Petersen (2006) classified: ambiguity of the modeling process in terms of the extraction of the "right" processes, lack of knowledge about processes and data needed to validate the model, and the principal unpredictability of some complex processes.

In 1971, Forrester attended a meeting of the Club of Rome, a "think tank." consisting of academics, entrepreneurs, diplomats, and politicians, that dealt with problems related to the rapid growth of the world's population, such as famine, pollution, and water shortages. One of the results of this encounter was the proposal to use a model approach of system dynamics developed at MIT to create a "world model." Its main aims were to address uncertainty, to counter crisis, and to minimize risks in the world in a "scientific" manner. The decision—comparable to Fuller's World Game initiative—must be seen in the light of attempts within the field of cybernetics to formulate solutions to global problems. (Wiener 1954; von Foerster 1984)

In Forrester's model, the world was seen as a system modeled by a network of processes, which he organized in workflows:

By "world system" we mean m[e]an his social systems, his technology, and the natural environment. These interact to produce growth, change, and stress. It is not new to have great forces generated from within the socio-technical-natural system. But only recently has mankind become aware of rising forces that cannot be resolved by the historical solutions of migration, expansion, economic growth, and technology. (Forrester 1971, 1)

The visualization of Forrester's world system model shows the world as a large set of variables, which change. Change is caused by a network of positive and negative influences (feedback loops). The size of the population, the availability of natural resources, the current capital investment, the development of agriculture, and pollution are the main areas for which variables are defined. The variable "quality of life" is introduced to measure the performance of the world system. The availability of food is its main factor, followed by material standard of living, effects of pollution, and crowding (figure 3.4).

Forrester tries to map the complexity of the world in ways similar to the work of Otlet, since he tries to identify the main relevant factors for human development, analogous to the identification of the main components or streams of knowledge. However, Forrester's approach is more dynamic, and focuses on processes and flows rather than the exact designation of potentially relevant categories that Otlet had in mind. Whereas Otlet develops a generic but adaptive language to describe all knowledge, and Fuller developed a setting in which humans can appropriate and alter knowledge. Forrester develops a plot describing how, in a given, pre-defined situation, the world would develop based on the best available knowledge. With newly acquired knowledge this plot might alter. The modular structure of Forrester's model allows for such adaptations. But social dynamics entail other feedback loops. Knowing the plot and the scenarios, people might change their behavior as depicted in the model. In other words, we can change the plot. Although Forrester is aware of this, such options are not encapsulated in the model:

Forrester expects that new knowledge and understanding (including learning from the World Model) can alter the decision making of mankind, leading to a different course of events than those described by the World Model. Such consequences are not included in the model. Therefore the book does not incorporate the possible changes in human aspirations and values that might come from widespread recognition of the predicament facing mankind. (Myrtveit 2005, 15)

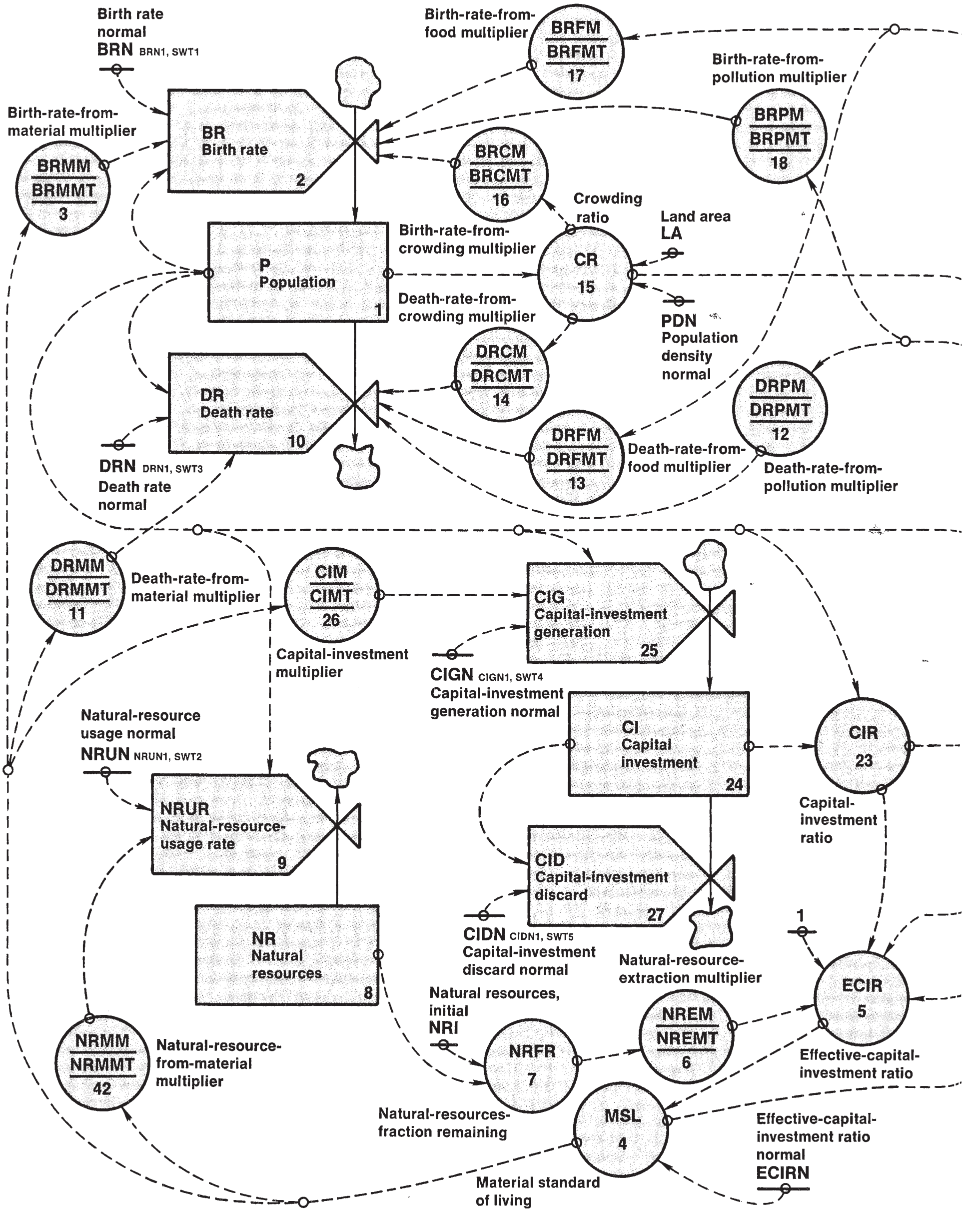
Once developed as a computer program, this plot produces long-term forecasts for the "quality of life," for the population, and for natural resources. Forrester represented such forecasts in growth curves of such variables as size of population, capital investment, and pollution (figure 3.5).

For Forrester it was important to demonstrate that his model contradicted theories of unlimited growth, a very timely consideration during a period when the dominant credo was (as it still is) unlimited consumption as the driving economic force. Instead, Forrester set out to examine "some of the forces that will become barriers when growth goes too far" and "the changes that can arise to stop exponential growth" (Forrester 1971, 5). As a result, Forrester hoped to study "the transition from a world of growth to a world of equilibrium" (ibid., 5).

One should not imagine this "equilibrium" as an inevitable static final stage. A more accurate understanding is the notion of *Fliessgleichgewicht* (equilibrium in flow), a term coined by Ludwig von Bertalanffy (1949, 42) to characterize a steady state in biological systems. It means that the system is stable (in homeostasis) but also open, and that internally processes take place continuously.. The idea of limited growth was not new. Forrester himself pointed to Malthus and explained that his model was just richer in the processes it included:

> This book examines the structure of the countervailing forces at the world level when growth overloads the environment. The world will encounter one of the several possible alternative futures depending on whether the population growth is eventually suppressed by shortage of natural resources, by pollution, by crowding, and consequent social strife, or by insufficient food. Malthus dealt only with the latter, but it is possible for civilization to fall victim to other pressures before the food shortage occurs. (1971, 8)

The idea of equilibrium warrants more attention. First, equilibrium is a state of relative stability in which processes either stop or enter a cycle of reproduction. Since this equilibrium is a moment captured in the flow, this state is not the end of the process. Second, equilibrium can be seen as a quasi-stationary state, and can be interpreted as a specific location in a hypothetical landscape. For some systems, this landscape can be defined or measured in advance. Think, for example, of the energy landscape for a mechanical system, which explains why a ball always rolls downhill. Mathematical theories of dynamic processes provide connections between dynamic processes of



Complete diagram of the world model interrelating the five level variables — population, natural resources, capital investment, capital-investment-in-agriculture fraction, and pollution.

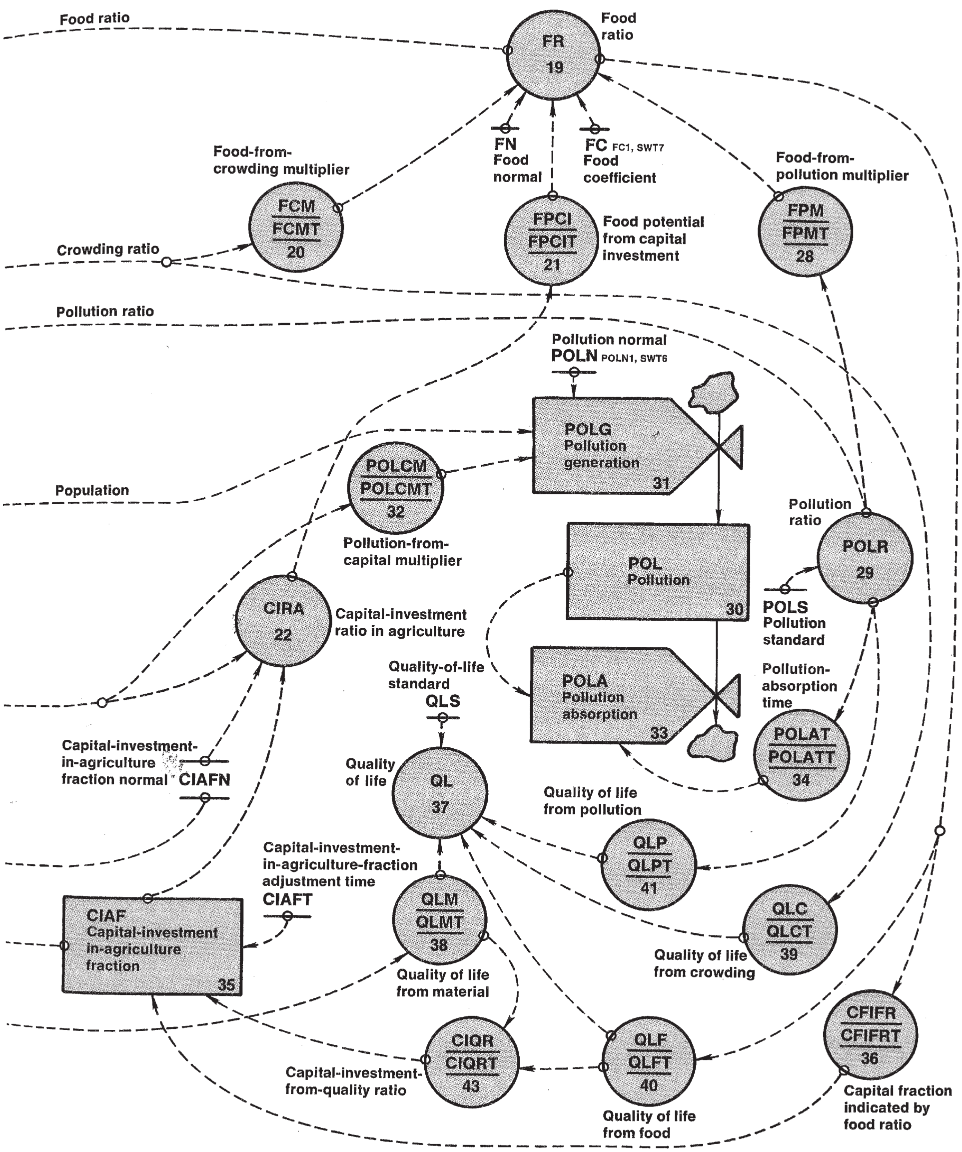
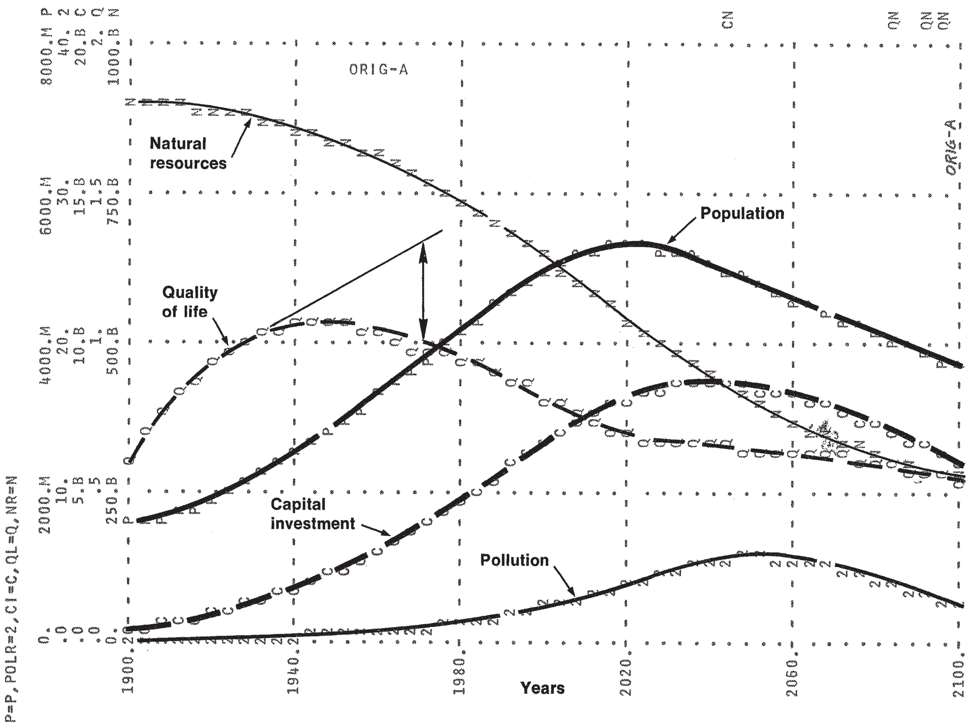


FIGURE 3.4

Forrester's diagram of the world as a mapping of processes. Adapted from Forrester 1971, 20–21. Reprinted with permission.



Basic behavior of the world model, showing the mode in which industrialization and population are suppressed by falling natural resources.

FIGURE 3.5
Forrester's visualization of one possible behavior of the world model expressing limits to growth. Adapted from Forrester 1971, 70. Reprinted with permission.

change at the micro level and the search of the whole system for a balance. This can take the form of an ordered state, or an equilibrium, but only for a limited period in time. Just as a river always descends, the system develops in such a way that it finally reaches a low point in such an imaginary landscape (Scharnhorst 2001).

Functions that shape the system's landscape have to be found within the system description itself in the form of principles which govern its dynamics. Simulations are tools to explore the model. It has been argued that the advantage of simulation over thought experiment is the higher speed of calculations or the higher accuracy (Myrtveit 2005). However, a simulation is never only a tool or method; it is also, at the same time, a process of problem solving and negotiating epistemic stands (Beaulieu, Ratto, and Scharnhorst, 2011). From a mathematical point of view, numerical simulations are a way to obtain results if no closed analytic treatment of the system's dynamics is possible—in other words, if the possible solutions cannot be obtained *a priori,* as is the case in Forrester's world model. Once all correlations between variables are fixed and parameters are set, a computer is able to calculate the mutual dependencies of variables and their correlated temporal change. This computer simulation is used as an approximation for exact solutions, but also as a tool to explore the possible landscape of scenarios. However, the idea of a specific stable state that will be reached still guides the explorative search through different computer scenarios. Thus, Forrester's "world in equilibrium" can be seen, using the metaphor of the landscape, as a moment of rest in a "fertile valley," which has been reached after a dangerous journey over icy mountains and through hot deserts. It is a state that is stable and that promises stability (although the stability may be temporary).

In general, two different approaches to complexity can be differentiated: "as complex as required and as simple as possible" and "as complex and complete as possible" (Scharnhorst, Marz, and Aigle 2009). In the first case, a reduction is made to extract laws needed to reproduce complex phenomena, leaving aside all disturbing details. The second, contrasting approach constructs a model that is as complex as possible and contains all information available, all the while assuming that any detail overlooked by the first approach might just be significant to the overall functioning of a model. Concerning uncertainty, neither of the two approaches is privileged. In the first case, the uncertainty about scenarios entailed by the model is reduced, but it is the selection of the few constitutive mechanisms that carries most ambiguity. In the second case, empirical evidence might be found for most of the influences and correlations taken on board, but the space of possible developments might be infinite, never to be fully explored, which creates ambiguity toward the relevance of the simulated scenarios. The world model of Forrester, though criticized for oversimplifications and for largely leaving out social and political elements, belongs more to the second approach.

Furthermore, Forrester's model is an example of how different epistemic traditions can meet at a trading zone of models, where thought experiments, observations, and concepts meet. The model is, in principle, open to any insight into human behavior. It relies on insights of psychology, sociology, economics, political sciences, and cultural studies. However, the use of mathematics as a language creates a barrier to participation. This does not apply to Forrester's model exclusively; it applies to any encounter between domain sciences and computer sciences. In spite of possible mappings between mathematical principles and natural language, some expertise in formal approaches is needed to avoid misunderstanding and misinterpretation. Here the comprehensive education required by Fuller, with the aim of avoiding restriction of the world to closed-circle "experts," becomes relevant again. Such a comprehensive approach to problems requires recombination of isolated knowledge streams and creative use of the ambiguous nature of knowledge. Otlet's language for describing the world's knowledge offers the possibility to at least mark (or classify) objects of knowledge in such a way that ambiguity can be addressed. This concerns, in particular, the use of facets and auxiliaries. It is the envisioned mixing of various epistemic traditions in all three world models that makes them so interesting in relation to current challenges to crossing epistemic boundaries in e-research and e-science.

STRATEGIES FOR E-RESEARCH AND THE NEED FOR EXPERIMENTS WITH INTERFACES, INTERACTIONS, AND MODELS

How can our discussion of the role of uncertainties in the previous three historical examples lead to more affirmative and multi-disciplinary approaches to uncertainty? Our case studies demonstrate that the inclusion of uncertainty is often a result of design decisions in knowledge production that can remain implicit. Otlet tried to reduce the complexity of the world by designating places for all factors he deemed relevant, such as uncertainty, but at the same time he suppressed inconvenient and complicating factors. The interfaces between the various components of Otlet's knowledge system can be observed to study how his system can lead to an appreciation of uncertainty. We saw how in Fuller's World Game players could develop scenarios of interaction and thus get a firmer grip on uncertainties. However, the possibilities of these interactions were largely determined by Fuller's design. Such analyses are important for understanding previous forms of interaction and games, since in both cases underlying processes of framing issues and narrative forms embedded in the user experience may remain hidden or opaque. It can be argued that some reflexivity on the part of the user is needed for a meaningful interaction with simulations and serious games, though we also showed that designers can play an important facilitating role in this respect. Forrester's World in Equilibrium is both exclusive and inclusive of uncertainties: exclusive in the sense that potentially important political and social factors are left out, with the risk of oversimplifying the world's reality, but inclusive in the sense that Forrester's mathematical model strives for a complete set of parameters needed to calculate possible future scenarios based on complex phenomena. In line with our three historical cases, we now look further at present-day examples of interfaces, interactions, and modeling future scenarios.

INTERFACES

A present-day example of interfaces is the tagging of cultural artifacts by non-professionals in online collections in the *steve.museum research* project, which enhances access to cultural heritage collections and engages users with museum objects (Trant 2009). Similar experiments are needed in which researchers shape the classification of data and conceptualize tools that provide access to various forms of knowledge organization. However, such experiments should not be aimed at a smooth transition of data between expert-generated and user-generated content, but should allow for an extrapolation of tensions and frictions in order to better understand the meaning of uncertainty in the social sciences and the humanities. The design of such experiments and their execution should be objects of analysis at the same time.

INTERACTIONS

As the recent work of Noah Wardrip-Fruin (2009) shows, computer games that remain sufficiently open allow users to enter into a productive dialogue with these designed interactions. Games designed according to this principle "create a surface-level experience that will make it possible for audiences to build up an appropriate model of the system internals" (ibid., 300) and thus express "the evolving state of the underlying system." (415) This so-called SimCity Effect (named after a popular computer game that is representative of the kind of interaction Wardrip-Fruin discusses here) "leads to audience understanding of the operations of an underlying system." (420) This raises the question whether Wardrip-Fruin is perhaps positing a free-floating Cartesian user that will be able to tap into the potential of the SimCity Effect. Although his design proposals may lead to enhanced interactions of users with computer systems, we argue that Wardrip-Fruin cannot simply assume these designs lead to or improve user empowerment, and that he reasons too much from the perspective that well-designed applications will automatically yield solutions and profound experiences for the users. (See chapter 1 above.)

MODELS

In a recent volume on issues regarding the modeling of complex systems, McDaniel and Driebe (2005) argue that models can fulfill a crucial role in appreciating uncertainty. The behavior of complex systems will inevitably introduce what they call "the unexpected," though they urge that such surprises are both inevitable and upsetting (ibid., 9), They suggest that a "different attitude" is needed, "one that enables healthier responses" (9). Common responses to uncertainty emphasize that more information should be acquired, and that methods of measuring and observation should be improved, which leads to an avoidance of surprise (3). In this regard, McDaniel and Driebe admit: "Uncertainty challenges us and often upsets us. Our natural desire to have the world a predictable place and to be in control of situations as they unfold can lead to dysfunctional responses to uncertainty. . . . We are in the process of finding out what does and does not work. Wisdom is an essential tool to have in the face of uncertainty and wisdom is an attitude rather than a skill or a body of knowledge." (9) What does this "healthy attitude" consist of? We emphasize again that "models" are not restricted to certain mathematical apparatus, but rather encompass a variety of concepts and theoretical approaches ranging from thought experiments to data models and predictive models. It is important that both the advantages and the limitations of such models be made explicit whenever they are applied. For the humanities, it is important that models not reduce the uncertainty usually present in these areas, but are used to complement traditional methods through unexpected innovative perspectives. Ideally, these models are not primarily problem solvers but intellectual troublemakers.

EPILOGUE

An important lesson to be learned from the Modernist examples of exploring uncertainty in knowledge representations, as we described them in this chapter, is that history appears to repeat itself in terms of how uncertainty is approached. Although e-research is sometimes hailed as a new paradigm that will radically transform scientific practice, it also reproduces the often-celebrated and often-performed distinction among the natural sciences, humanities, and social sciences. This is not to say that collaborations in e-research among scientists, social scientists, and humanist scholars in handling uncertainty cannot be beneficial; we just need different strategies. The three explorations (one of interfaces, one of interactions, one of models) serve as a conclusion to our chapter by exploring the question of how uncertainty can be appreciated, and what design principles can facilitate that appreciation.

As our case studies demonstrated, social scientists and humanities scholars took a particular approach to handling uncertainty: they were inclined to adopt approaches developed within the natural sciences to reduce uncertainty, in order to make their methods more rigorous. On the other hand, natural scientists are confronted with the tension of extracting relevant processes without ignoring the historicity, the contextuality, and the anticipatory nature of human actions. A comparative analysis of approaches to uncertainty from multidisciplinary points of view suggests that certain disciplines emphasize the positive effects of this concept, such as serendipity, creativity, artistic freedom (visual arts, music), stock-in-trade (history), preference of ambiguous agreement (psychology), engagement (theology), and accepting the impossibility of truth finding (law) (Bammer and Smithson 2009, 306).

On the basis of these potential effects of uncertainty in the humanities and the social sciences, we claim that these disciplines might have something to offer the natural sciences. We can even go a step further. Without taking into account the experiences collected and the epistemic strategies developed by scholars in the social sciences and the humanities to deal with a plurality of perspectives, the influence of history (path dependency), and the ephemeral sources of creativity, the natural sciences will not be able to deal with complex phenomena. This will apply especially to cases about the social world. Rather than favoring approaches from the natural sciences as more rigorous and desirable, the question is how potential positive tradeoffs among the natural sciences, the humanities, and the social sciences can be facilitated. Institutional support and funding might lead to broader engagements with e-research in the humanities and the social sciences in the long term. Changes in curricula are also required. However, in the short term, we need experimental interventions in which critical analysis is combined with design. Apprehension that institutional support and funding based on an expected outcome might nip creativity and innovation in the bud calls for careful managing of expectations (Beaulieu and Wouters 2009, 61–63).

NOTES

1. We speak of knowledge production, not of acquisition of knowledge. In a Latourian framework, knowledge is not something ready-made that may subsequently be acquired; it is (in Latour's own terms) a product of chains of actors who perform translation: "chains of translation refer to the work through which actors, modify, displace, and translate their various and contradictory interests" (Latour 1999, 311). As a result, knowledge can only be explained by a rigorous focus on practice: "[s] cience studies is not defined by the extension of social explanations to science, but by emphasis on the local, material, mundane sites where the sciences are practiced. . . . What has been revealed through the study of practice is not used to debunk the claims of science, as in critical sociology, but to multiply the mediators that collectively produce the sciences." (Latour 1999, 309) Thus, a focus on practice reveals the various elements of chains of translation, or mediators, whose performances and persistence articulate "knowledge."

2. For examples of the Dymaxion World Map, see the enhanced publication website of this book.

3. "Introducing the New Global Simulation" (at http://www.osearth.com).

4. Johann Wolfgang von Goethe, *Sämtliche Werke in 18 Bänden*, Band 1: *Sämtliche Gedichte* (Artemis, 1950: 512); English translation by Nigel Cooper.

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