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The Production of Multiform Narratives in the Heterotopic Space of Technoscience: A Critical Instance Case Study of a Western Canadian Genomics Research Facility

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Abstract

Broadly speaking, this thesis explores the practices used by employees of a Western Canadian genomics research facility to build four-dimensional models of the human body; models which will be used to study genetic diseases. Using actor-network theory as both a theoretical and methodological foundation, I consider the ways in which both the social (human) and the technical (nonhuman) actors that comprise the genomics research facility work together to construct these models. The work is divided into two sections. First, I investigate the setting of the genomics research facility. I argue that the genomics research facility constitutes a heterotopic site of cultural production. Second, I question what the genomics research facility produces. Ultimately I argue that by using fully immersive virtual environments, and building generic and extendible virtual models of the human body, employees at the genomics research facility are able to produce complex, multiform narratives of biological processes.

Keywords: technoscience, science and technology studies, heterotopia, science fiction, genomics, ethnography, Latour, virtual reality.

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Prelude

On November 29, 2001 a large American software development company unveiled what they described as a "a bold and innovative project in the field of computational biology" (Aronson, 2001). The project was to be developed at a large Western Canadian research university and would be directed by an internationally renowned molecular biologist and biochemist. The project was a co-funding venture between the software company, the research university, Genome Canada, as well as other public and private funding bodies.[1] The pleasantly vague motive was to "enhance research and development opportunities" between the Canadian research university and the large American software company. The project would involve a team of bioinformaticians developing a system to help genomics researchers make sense of complex and diverse genomics data. As a representative for the software company stated, "one of the biggest challenges we have in post-genomics is finding ways of understanding the tremendous amount of complex data that is generated" (quoted in Aronson, 2001). The system was to allow researchers to store, organize, combine, and project a range of data sources, but would also be used as a tool for the study of genetic diseases. Some of the initial components of the project were the development of specialized genomics software, a comprehensive Web portal, bioinformatics training software, and the opportunity to participate in a variety of Genome Canada funded projects. The most fascinating component, however, was the

[1] Genome Canada is a not for profit organization, established in February of 2000, which was given a mandate by the Government of Canada to develop a national strategy for supporting genomics and proteomics research that "benefits all Canadians" (genomecanada.ca). Genome Canada funds research in areas as diverse as agriculture, medicine, bioinformatics, fisheries, forestry and technological innovation. Projects funded by Genome Canada are multiple stakeholder endeavours and researchers are encouraged to foster public-private partnerships. Genome Canada must carefully balance social and health risks with the economic benefits of the projects they choose to fund (Saillant & Genest, 2007, 12). My doctoral dissertation will investigate the potential influence these social, political and economic actors have on the fostering of useful and innovative genomics research projects in Canada.

proposed development of a four-dimensional virtual "representation biological system with a Java-3D enabled Cave Automatic Virtual Environment [CAVE]" (Aronson, 2001). The proposed model was notable for its addition of "a fourth dimension that simulates real-time activities including a beating heart, flowing blood and breathing" (McCarl, 2007, p. 1). Cave Automatic Virtual Environments:

> consist of multiple stereo displays, from two to six walls; round displays have been described as well. To achieve a cubed display, which provides the full CAVE functionality, at least four walls are necessary, with three of them forming a U-shaped enclosure and the fourth wall being a floor display. Each wall is operated through a separate graphics unit (graphics card or processor on a multi-processor graphics card), ultimately providing the illusion of a three-dimensional view with the help of stereo goggles, which allow each eye to experience a slightly different perspective. (Turinsky & Sensen, 2009, p. 602).

The goal was to build a functional virtual model of the human body, which could be sold as a genomics training and research software kit to research universities and hospitals.

In June of 2004, the genomics research facility submitted a proposal for the development of the four-dimensional model of the human body. In April of 2005 the facility was awarded funding for the project. The development team was staffed in September of that year. By February of 2006 a system prototype was assembled. In September of 2006 the facility opened a massive display, featuring an early version of the four-dimensional model, at a science centre owned by a large Western Canadian cellular phone company. In April of 2007 an exhibit of the four-dimensional model was unveiled at the American software company's headquarters in California. In May of 2007 the director of the genomics research facility and his team unveiled what they referred to as the "four-dimensional modeling project."

The four-dimensional modeling project was organized into five components. Four of these components were separate Canadian biomedical case studies with their own research objectives.[2] These four components served as sources of experimental data and user expertise. The fifth component was the genomics research facility, which combined the knowledge gained from these four components into a unified four-dimensional system for data analysis and visualization.[3] This system featured a virtual anatomical atlas of the human body, which researchers referred to as the CAVEman.[4]

The four-dimensional modeling project and the CAVEman were meant to help researchers "create visual maps of information about diseases that have a genetic component, such as cancer, diabetes, and Alzheimer's" (4D mapping). As the genomics research facility's homepage explained, to "accomplish these goals, the team is building an environment where data derived from advanced medical imaging techniques is merged with omics information (genomics, proteomics, and metabolomics) to create a unified physiological model of an organism" (4D project overview). Researchers hoped that this system would be capable of handling diverse case studies, and would be generic and extendible to new research scenarios: "[i]ts goal is the development of a complete...3D-enabled anatomical atlas of the human body, and to create a generic data mapping mechanism between the atlas and biomedical patient data" (4D mapping). The project

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[2] These projects included the study of developmental genetics of craniofacial shape in mice, genomic markers of Multiple Sclerosis and responsiveness to drug therapy in humans, the polygenetic causes of obesity in mice, and the metabolomics in humans, mice, and rats.

[3] In this thesis, when I refer to the "genomics research facility" I am speaking specifically about the facility located at the Western Canadian research university.

[4] Anatomy texts have historically been described as atlases, speaking to their ability to "map" out the space of the human body. According to David Armstrong, "the anatomical atlas directs attention to certain structures, certain similarities, certain systems, and not others, and in so doing forms a set of rules for reading the body and making it intelligible. In this sense the reality of the body is only established by the observing eye that reads it. The atlas enables the anatomy student, when faced with the undifferentiated amorphous mass of the body, to see certain things and ignore others (Armstrong 1983: 2).

supported, and combined, three main sources of biomedical data: 1) Medical imaging data such as those derived from functional Medical Resonance Imaging (fMRI), Computed Tomography (CT), Positron Emission Tomography (PET), and microscopy; 2) Anatomical organ reconstructions in the form of 3D surface-based models and digital atlases of the organism's anatomy; 3) Time-varying biochemical concentration data such as those from gene expression microarrays, proteomic studies, pharmaco-kinetic studies, and metabolomic experiments (Development core visualization).[5] For the head programmers at the genomics research facility, it was crucial that these various data sources be seamlessly combined:

> The image-based visual environment needs to adapt to this variation to provide the user with the best possible imagery of genomic data in a given context. As more and more Web-based tools and services become available for biologists, such a visual environment should also be able to integrate and link to those seamlessly. (Soh, Gordon, & Sensen, 2009, p. 396).

By combining a variety of data sources, the four-dimensional models could enable researchers to see patterns in a patient's data that would be impossible to discover by simply observing a flesh and blood human body, or by observing static images produced by individual imaging technologies. Both the CAVEman, and the virtual environment in which it would be projected, would be generic. This meant that they would not only be open to new genomics research scenarios, but also compatible with most computer systems and display units:

> While CAVE systems, operating based on proprietary software environments, were in use approximately 10 years before we installed our machine, our system was the first one to operate based on a generic programming environment, as Java 3DTM can be used on almost any Java-enabled computer, from Windows and Macintosh personal computers, to Linux servers and mainframes. In addition, Java is a generic programming environment that is often taught as the first

[5] Microarrays "enable a biologist to view the expression levels of many genes in parallel. These data as a whole provide a snapshot of the transcriptional processes within a cell" (Soh et al., 2009, p. 397).

> programming language to Computer Science undergraduate students. (Turinsky & Sensen, 2009, p. 602).

Researchers initially hoped that the four-dimensional modeling project would be completed in September of 2007. By the middle of August of 2008, however, researchers were still grappling with a number of issues, including software and hardware limitations, and the difficulty of knowing what exactly their virtual models could and would be used for. With these concerns in mind, and no definitive conclusion in sight, the genomics research facility was and is a ripe resource for inquiries into the changing face of biomedicine and technoscience in the twenty-first century.

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Chapter 1
Introduction and Literature Review

Introduction

Studies of technoscience are full of presumptions, proclamations and premonitions of a postmodern, posthuman and postbiological future. This future is often described as one that emphasizes patterns over presence (Hayles, 1999), which sees biology not as corporeality, but as coded information to be extracted, stored, organized and retrieved by a wide range of medical, social, political and economic actors (Haraway, 1997).[1] Those who attempt to describe this future emphasize the complexity of technoscience, and the difficulty technoscientific innovators have coming to universal conclusions about the processes of the natural and social worlds. As Donna Haraway argues, "this is the culture within which contingent facts—the real case about the world—can be established with all the authority, but none of the considerable problems, of transcendental truth" (1997, p.23). This culture is marked by an increasing reliance on complex and dynamic instruments, databases and imaging technologies.

As Catherine Waldby argues, "these devices are not simply adjuncts to scientific knowledge but are often the condition upon which knowledge can exist at all" (2000, p. 32). Fields such as genomics research simply would not exist without a diverse range of data storage and imaging technologies. The four-dimensional modeling project, introduced in the prelude, was developed to help researchers store and organize, but also make sense of large, complex, and diverse quantities of genomics data. According to the

[1] For brevity's sake, this thesis has to bracket the political and economic implications of the work being done at the genomics research facility. These are issues I hope to deal with more directly in my doctoral work. It is important, however, that the reader keep in mind that part of the genomics research facility's mandate is to build a training and research software kit, which can be sold to research universities and hospitals.

genomics research facility's postdoctoral students, computers and virtual models were good for helping them develop massive data files, and keeping them organized, but also for helping researchers recognize patterns that would otherwise not be observable.[2] As one of the postdoctoral students told me, humans simply could not do this work by simple observation.

Unlike a lot of the work done in the field of science and technology studies (STS), this thesis does not focus on the construction of scientific facts. Instead, I use a range of STS scholarship to study the production of a technological system that could, one day, be used to facilitate the construction of biomedical knowledge. The four-dimensional modeling project's CAVEman is not, as of yet, a widely accepted and proven tool for the study of genetic diseases. Instead of looking back on the production of a technoscientific project, my research focuses on technoscience in action. I have done this by conducting a participant observation of the genomics research facility. I study the practices used to build the four-dimensional modeling project, with a specific focus on the development of the CAVEman. As a result, I am able to offer some preliminary insights into how the CAVEman might be used, and what it might mean for the future of genomics research and biomedicine.

As N. Katherine Hayles has argued, "biomedical research seeks to work the body in more and more detail, at smaller and smaller levels of scale and at more profound depths of intervention" (1999, p. 49). This trend has lead to the development of a wide range of technologies designed to visualize that which the human eye is incapable of seeing on its own. As Waldy argues, "contemporary scientific knowledge is replete with

[2] Maxine is one of the main characters of my story. She will be introduced in more detail in Chapter two. All names of the human actors described in this thesis are pseudonyms.

a seemingly endless array of remote visual sensing apparatuses which bring the recessive, microscopic, remote or obscured life of the world to the perception of the scientist through screen technologies" (2000, p. 31).[3] Increasingly, however, it is important to implement "the visual integration of genomic and related biological information into a single unified genomic context" (Soh et al., 2009, p. 396). Virtual reality technologies, such as CAVEs, and unified virtual models (or atlases), such as the CAVEman, can provide researchers with powerful genomic contexts. As a result, it is useful for media as well as science and technology scholars to analyse the construction of these technologies, and to theorize the ways in which their construction could alter academic, as well as public perceptions of contemporary genomics research. As Donna Haraway argues, "the control of genes means access both to naturally occurring diversity and to the material, social and semiotic technology to recraft its riches to produce beings new to Earth" (1997, p. 57). These 'beings' can include anything from genetically modified mustard seeds to new methods for storing, organizing, projecting, combining and visualizing biomedical data. I think it is important to investigate which new beings are produced, by whom, for whom, and for what purposes.

In this thesis, I endeavour to answer a number of seemingly simple theoretical and methodological questions, such as: How can I describe the place of the Western Canadian University's genomics research facility? How can I describe the virtual environments within which much of the work done at the genomics research facility is stored, organized and projected? How do the human and nonhuman actors that occupy the genomics

[3] Other apparatuses—to borrow from a list assembled by Donna Haraway and amended by Catherine Waldby—include sonography systems, magnetic resonance imaging, scanning electron microscopes, computer-aided tomography scanners, satellite surveillance systems, micro-photography, endoscopy, interplanetary exploratory satellites and more.

research facility interact with one another in the construction of these four-dimensional models? How can one describe what this assemblage of humans and nonhumans produces? Do they produce scientific knowledge, or do they produce nothing more than a technological system which will, they hope, facilitate the future construction of scientific knowledge about the processes of genetic diseases?

I chose these specific questions because they allowed me to account for more than just the technical merits of the technoscientific instruments and imaging technologies I analyzed. It is, I think, important to be reminded that these technologies, and the informational images they produce, are cultural products; products with historical, geographical, artistic and aesthetic, as well as scientific, value. As James Elkins argues, informational images should not be viewed as purely technical, "inherently informational and without aesthetic value", nor as merely being "encased in the technical conventions of their fields" (1995, p. 557). Instead, one should be reminded of "the centrality of 'make-believe' in the conception and design" (Laurel, 1993, p. 29) of the software and imaging technologies that make technoscience possible. It is helpful to be reminded that biomedical models and databases are culturally specific products of human imagination. As Haraway argues, "[a]ll the trappings of universal science aside, amending a database is a pretty culturally specific thing to do" (1997, p. 268). This thesis treats the genomics research facility as a site of cultural production. As such, the genomics research facility provides evidence of what many have described as the collapse of fact and fiction, subject and object, as well as nature and society in contemporary technoscience (Livingston, 2006; Haraway, 1997; Hayles, 1999).

This thesis uses actor-network theory (ANT) as both a theoretical and methodological foundation. In ANT, a researcher "integrates human and nonhuman actors into the same conceptual framework. ANT is an approach to structuring and explaining the links between society and technology, documenting how technology becomes accepted and used" (Randall et al. 2007, p.105). ANT affords agency to nonhuman actors, allowing researchers to better account for the increasing dependence on complex technologies in technoscience. It also allows for seemingly mundane objects (like memos or telephones) to play important roles within a given site of technoscientific production. I consider the ways in which both the social (human) and the technical (nonhuman) actors that occupy the genomics research facility work together to construct the four-dimensional modeling project's CAVEman.

After a review of relevant literature, my analysis will begin with a brief overview and summary of the key human and nonhuman actors that occupy the genomics research facility. The rest of the work is broadly divided into two sections. First, I investigate the setting of the genomics research facility. I argue that the genomics research facility constitutes a heterotopic site of cultural production where both humans and nonhumans negotiate, working to transmit patterns of meaning to one another. "Heterotopia" is a medical term that Michel Foucault introduced to social theory in the 1960s. Heterotopias are alternate sites of social and technical ordering. Heterotopic sites provide "unsettling juxtapositions of incommensurate 'objects' which challenge the way we think, especially the way our thinking is ordered" (Hetherington, 1997, p. 42). The genomics research facility, for instance, provided unsettling juxtapositions of both human and nonhuman actors, all of which had to work together in the production of coherent models of the human body. The models themselves, and the virtual spaces within which they were developed and projected, were also heterotopic. These models were built from a combination of disparate data sources that have been gathered from a range of seemingly incommensurate biomedical case studies.

Important to my application of the concept to the genomics research facility is Robert F. Reed-Pharr's definition of heterotopic sites as prophetic visions "of society that allow for the presence of constant change and improvisation" (1994, p. 348). In this sense, a heterotopia is treated as a place that emphasizes the "possibility of possibilities" (Reed-Pharr, 1994). I viewed the genomics research facility, and the virtual spaces within which its employees stored, organized and visualized their work, as sites of constant change, improvisation and uncertainty.

The goal of this first section is to highlight the complexity and contingency of genomics research. One of the most striking things about studying the genomics research facility was the difficulty employees had pinning down clear definitions and descriptions of genomics and bioinformatics research. This uncertainty seemed to stem from the fact that these fields have "married the two most powerful technologies of the 20^{th} century—computer science and molecular biology" (DeLisi, p. 28). The unsettling juxtaposition of various human researchers, as well nonhuman virtual models, virtual environments, and a complex array of data sources, generated a number of problems for the employees I observed. It was, for instance, very difficult for biologists and computer scientists to communicate their goals to one another. As a result, the computer scientists I observed had to develop novel methods for communicating with biologists, especially when it came time to combine their individual contributions into unified virtual models of human anatomy.[4] The difficulty, I argue, stemmed from a shared characteristic of computer science and genomics research. Computer science and genomics research are dynamic, fluid fields that are constantly changing in terms of both meaning and practices. At the same time, there is the constant development of new biotechnologies, new hardware and software, as well as new methods for abstracting and visualizing biomedical data. This makes it very difficult to determine what exactly genomics researchers and bioinformaticians do, and what they produce.

In the final section, I theorize what employees of the genomics research facility were producing. To be completely honest, when I began this project, I was under the impression that I was studying a facility already well on its way to producing knowledge about the complex patterns, and processes, of genetic diseases. It turned out, however, to be quite difficult to say exactly what these workers were producing. It wasn't quite scientific facts, nor was it simply instruments for the future construction of scientific facts. For one thing, the practices used by genomics research facility employees shared a number of similarities with other cultural fields, like graphic art and video game development. As a result, the decisions these employees made were both aesthetic and instrumental in nature. The models, for instance, needed to not only be interactive and accessible to both computer scientists and molecular biologists. The models also needed to be seamless and visually appealing.

Ultimately, I found that genomics research facility employees were in the business of building what I refer to as productive narrative fictions. I argue that by using four-

[4] On my first day observing the genomics research facility's employees I made the following note: "[v]ery few people seem to work together at this facility. Everyone appears to be here for a different reason, serving a different role with little crossover. I wonder just how much everyone understands each other's jobs here. It will be interesting to see how everything comes together" (from Field Notes, August 7, 2008).

dimensions (both space and time), fully immersive virtual environments, and building generic and extendible virtual models of the human body, employees at the genomics research facility are able to produce complex, multiform narratives (Murray, 1997) of biological processes. Rather than linear narratives, with definitive conclusions, the four-dimensional modeling project facilitated the construction of loose and contingent interactive narratives; narratives which could be altered—by adding or removing various components and data sources, or by viewing images from different angles or at different speeds. What makes the four-dimensional modeling project so compelling is its malleable and generic nature; its ability to be extendible to new research scenarios, and its capacity to deal with the constant addition of new information about the processes of genetic diseases.

Sure, the models built by the genomics research facility are means "of bringing the obscured bodily interior into visuality" (Waldby, 2000, p. 31), but it is the practices used to build them that fascinate me. The CAVEman could be regarded as a piece of interactive narrative performance art; art which is intended to aid in the production of scientific facts. Since the CAVEman is a generic, four-dimensional model—which was built from a number of disparate and seemingly incommensurate data sources—it could be regarded as a powerful fictional character; more powerful than any prior representation of human anatomy.

So, why does this matter? Well, as constructed products of human imagination, developed within sites of improvisation and uncertainty, the four-dimensional models being built at the genomics research facility could, and seem to have, a liberating and humbling influence on genomics research. As malleable, generic and extendible narrative fictions, these models could teach genomics researchers that "the point is to learn to remember that we might have been otherwise, and might yet be, as a matter of embodied fact" (Haraway, 1997, p.39). These models could facilitate the future development of loose and contingent, as opposed to universal facts about the processes of the natural world. This does not, however, make these facts any less productive. It is not a failure of contemporary technoscience for its practitioners to acknowledge the chaotic complexity , and the sheer impossibility of coming to universal conclusions about, the processes of the natural and social worlds. Technoscience seems to have done nothing but force more problems and more questions upon researchers. At the same time, however, it also provides researchers with the means for developing improvised resolutions to these new problems and questions. The value of technoscience is, therefore, twofold. For one thing, it has the ability to facilitate the building and management of databases of retrievable, malleable, and contingent knowledge. It has also lead to the development of a range of media for displaying or projecting said knowledge.

What I found at the genomics research facility was a group of humble graphic designers and computer scientists. These employees were quick to discuss the limitations of their work, and that "there can always be more detail added later" (From field notes, August 19, 2008). They never once deluded themselves into thinking their work would be complete, and they saw the importance of building a system which could deal with new information as well as new methods of analysis and interpretation.

Science and Technoscience Studies

In his essay, "That it is a folly to Measure Truth and Error by our own Capacity", Michel De Montaigne argued that "[w]e must bring more reverence and a greater recognition of our ignorance and weakness to our judgment of nature's infinite power" (1958, p. 88). As was the case with much of his writing, Montaigne was arguing for a more modest and self-aware approach to measuring one's knowledge. In Montaigne's account, truth and error, fact and fiction, were contingent properties, based on a number of social, political and historical factors:

> Why do we not remember how many contradictions we find even in our own opinions, how many things we regarded yesterday as articles of faith that seem to us only fables today? Pride and curiosity are the two scourges of our souls. The latter prompts us to poke our noses into everything, and the former forbids us to leave anything unresolved and undecided (Montaigne, 1958, p. 91).

Writing more than four hundred years ago, Montaigne questioned why so many people seemed incapable of acknowledging how quickly the facts of life dissolved into mere fictions. He also questioned why it was so important for people to come to, and stand by, definitive conclusions, particularly when those conclusions could easily be contradicted. In Montaigne's reasoning, what people refer to as knowledge is the result not of objective observations but one's comfort and familiarity with their surroundings and experiences. "When we consider", Montaigne argued, "through what mists and how gropingly we are led to our knowledge of most of the things within our grasp, we shall assuredly conclude that it is familiarity rather than knowledge that takes away their strangeness" (1958, p. 87). This familiarity has a peculiar set of consequences. The problem is that "the habitual sight of things makes the mind accustomed to them; it feels no wonder and asks no questions about what is constantly before the eyes" (Montaigne, 1958, p. 88).

Montaigne implored people, scholars and lay alike, to ask more questions, especially of phenomena to which they had become too accustomed.

For the last three or four decades, a small but growing academic field has attempted to pose these same types of questions to the practices and practitioners of contemporary science and technoscience. Science and technology studies (STS) is interested in uncovering the sociotechnical construction of scientific knowledge and technological innovations. The motivation for most STS scholarship is to highlight the diversity of practices used by scientific researchers and technological innovators (engineers, computer scientists, designers, etc.). When applied to the investigation of scientific projects, STS is interested in the "complex and contingent methods or strategic negotiations by which scientific facts are produced in laboratories and other micro-level settings" (Garlick, 2007, p. 260). In this field, local knowledge and partial perspectives reign. There is no need, nor perhaps even a desire, for a universal scientific paradigm.[5] As Garlick puts it, "[f]rom this perspective, local assumptions and micropolitical strategies are crucial factors in giving shape to scientific practice and its products" (2007, p. 260). By uncovering and criticizing the sticky tissues of scientific explorations and

[5]The scientific paradigm, "which dates back to Francis Bacon, is the process of forming hypotheses and testing them through experiments; successful hypotheses become models that explain and predict phenomena in the world" (Denning, 2005, p. 28). While not the man who set off the scientific revolution, Bacon, a predecessor to Descartes, is recognized as the man who developed what has come to be known as the basic template for any scientific investigation: "Bacon has been eulogized as the originator of the concept of the modern research institute, a philosopher of industrial science...and as the founder of the inductive method by which all people can verify for themselves the truths of science by the reading of nature's book" (Merchant,1982, p.164). With Bacon's method, scientists were provided with an excuse to think of their work as an objective collection of neutral facts (Bronowski, 2008, p.562). Science studies scholars argue that there is a lot more to producing scientific knowledge than the mere testing of hypotheses.

technological innovations, STS scholars work towards the development of local and contingent rather than universal narratives of technoscientific progress.[6]

"Technoscience" is a term coined by Bruno Latour. In *Aramis, or, the Love of Technology*, Latour cheekily argues that researchers studying the development of technologies were "free to study engineers who were creating fictions" (1996, p.23). Unlike the scientist, who was supposed to be studying a world which came to being "without men and without sciences" (1996, p. 22), technological engineers were responsible for the construction of worlds that had yet to exist. It was, and still is, Latour's goal to highligt that scientific knowledge was similarly constructed, being composed of natural, social and, as a result, cultural components. This was, at least partially, the result of contemporary science's reliance on complex technological systems. Technoscience is therefore used to "emphasize the networking involved (technic deriving from tekth- to weave, build, join) in the process of troping, or actively making sense of something" (Nelson, 2003, p. 253). As Haraway puts it, "[t]echnoscience extravagantly exceeds the distinction between science and technology as well as those between nature

[6] Narratives of scientific and technological progress have permeated Western society for quite some time. These stories are linked with the emergence of the modern Enlightenment, with the scientific revolution, and an increased emphasis on what has been termed Cartesian rationality. According to Kevin Robins, Cartesian rationality "is about the pursuit of cognitive certainty and conviction" (Robins 1996: 157). This rationality characterizes a scientific process which unfolds over time until finally, as Descartes puts it, "as if with prejudices weighing down each side equally, no bad habit should turn my judgment any further from the correct perception of things" (Descartes, 1998, p.62). Within this framework each scientific and technological development is perceived to be inherently superior to those which preceded it, eventually leading to a complete and certain knowledge about the natural world. In order for the Cartesian promise of cognitive certainty to unfold, scientific knowledge had to be removed from its contemporaneity and subsequently placed within, what Donna Haraway (1997) calls, a "culture of no culture." As Robins puts it, Cartesian rationality, "must dissociate itself from cultural accretion...it must become self-sufficient and self-valorizing" (Robins, 1996, p.157). So, historical narratives (stories) of scientific and technological progress, are created in order to outline a steady trajectory of knowledge as humanity gets ever closer to a self-certain and self-sufficient understanding of the natural world. This understanding of knowledge is unimpeded by the cultural, institutional, social, political or economic contexts within which new technologies and discoveries are made.

and society, subject and object, and the natural and artifactual that structured the imaginary time called modernity" (1997, p. 3). Technoscience blurs these distinctions by mashing together two worlds which were previously thought to be mutually exclusive: technology and science.[7]

Scientific knowledge, at the height of modernity, was believed to be objective, while technology was believed to be subjective; a contingent product of human imagination. Haraway provides a useful summary of the modern separation of technology and science: "once upon a time, in another, closely related, ethnospecific narrative field called Western philosophy, such entities were thought to be subjects and objects, and they were reputed to be the finest and most stable actors and actants in the Greatest Story Ever Told—the one about modernity and man" (1997, p. 4).[8] As technoscientific investigations revealed themselves to be much more complex, constructed and contingent enterprises, distinctions between subject and object, nature and society, fact and fiction began to disintegrate. For Haraway:

> In the imploded time-space anomalies of late-twentieth-century transnational capitalism and technoscience, subjects and objects, as well as the natural and the

[7] It is important to remember that not all new technologies contribute to scientific advancements. Technology, therefore, does not necessarily find its origins in science. As Gordon Graham has argued, "a great number of advances generally heralded as 'technological' have been made largely in ignorance of the scientific explanations that underlie them. For example, the invention of the printing press, the spinning jenny, the steam engine, the telephone, the motor car, the combine harvester, the aeroplane, hire purchase and the credit card, have owed relatively little to the investigations of science as we normally understand it" (2002, p. 15).

[8] It is very difficult to determine when exactly the "modern era" began. Artists, philosophers, musicians, political economists, historians and literary theorists all have different understandings of what constitutes "modernism" or "the modern era". According to Milton Scarborough, "one might argue that modernity began with Copernicus or Kepler, but there might be more agreement on Galileo" (p.9). In philosophy, the modern era is "often tied to Descartes' turn to the subjective realm and to the rise of epistemology. Postmodernists see modernity's fullest expression and, perhaps, the beginning of its termination in the philosophy of Hegel" (Scarborough, p.9). Regardless of whether we can come to precise date, one of the important components of modernity is its "hostility towards myth" and its emphasis on the importance of human reason.

> artificial, are transported through science fictional wormholes to emerge as something quite other. Even drenched with all the hype about revolution and technoscience that pervades contemporary discussion, the ferocity of the transformations lived in daily life throughout the world are undeniable (1997, p. 4).

These constant shifts do not make up a linear narrative of technoscientific progress. Each new technoscientific innovation, in this account, is not to be considered inherently superior, more powerful, or capable of producing more accurate knowledge than its predecessors. There is not, within a technoscience studies framework, any way to make such a powerful (and arrogant) claim. Rather than privileging new against old technoscientific innovations and practices, inquiries into the products and practices of technoscientific workers "might then think about them all...in their contemporaneity" (Robins, 1996, p. 165).

Latourian Nonmodernism

By acknowledging the contingency of technoscientific innovations, STS scholarship works to refute what Latour (1993) refers to as the "modern constitution". This constitution was marked by the needless and disastrous separation of the natural and social worlds. In *We Hàve Never Been Modern,* Latour describes why it became so necessary to question what he describes as an utterly arbitrary separation:

> The critical power of the moderns lies in this double language: they can mobilize Nature at the heart of social relationships, even as they leave Nature infinitely remote from human beings; they are free to make and unmake their society, even as they render its laws ineluctable, necessary and absolute (1993, p. 37).

The separation between nature and society is, in this account, a convenient fiction. By refuting the modern constitution, Latour acknowledges that theories, scientific facts, social assemblages and cultural artifacts are all complex constructions. As a result, Latour argues that one must come to the liberating conclusion that these things have always been complex constructions. Therefore, "we have never been modern".[9] Instead, "we" (Western society) have merely created conveniently rigid categories to place inconveniently blurry and dynamic juxtapositions of natural phenomena and social assemblages. Rather than clear distinctions between the social and natural worlds, Latour argues that everything is a socio-natural hybrid. Latour has made a career out of providing new, more nuanced and more detailed methods for explaining what these hybrids are, how they are constructed and what their implications might be. For Latour:

> nonmoderns have to stress the relations between them [nature and society] if they are to understand both the moderns' successes and their recent failures, and still not lapse into postmodernism. By deploying both dimensions at once, we may be able to accommodate the hybrids and give them a place, a name, a home, a philosophy, an ontology and, I hope, a new constitution (1993, p. 51).[10]

There is, of course, also a cultural component that must be taken into consideration. It is not just the natural world and the social world, but the products developed by socio-natural hybrids. Technoscientific innovations, as loose and contingent products of human imagination, which blur distinctions between nature and society, subject and object, are, in this account, perhaps best described as cultural products (a point to which I will return a little later).

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[9] Latour's argument has been supported by a number of prominent science scholars and feminist science scholars. Donna Haraway, in an endnote from OncoMouse, states that "Latour claims that We Have Never Been Modern, a point with which I largely concur" (1997, p. 283).

[10] In *We Have Never Been Modern*, Latour has a difficult time holding back his disdain for the postmodern theories of Lyotard and Baudrillard: "am I behaving as though we were entering a new era that would follow the era of the moderns? Would I then be, literally, postmodern? Postmodernism is a symptom not a solution. It lives under the modern Constitution, but it no longer believes in the guarantees the Constitution offers. It senses that something has gone awry in the modern critique, but it is not able to do anything but prolong that critique, though without believing in its foundations[Lyotard, 1979]. Instead of moving on to empirical studies of the networks that give meaning to the work of purification it denounces, postmodernism rejects all empirical work as illusory and deceptively scientistic [Baudrillard, 1992]" (Latour, 1993, p. 51).

Actor-Network Theory

Within this framework, where technology and science, subject and object, nature and society are so intimately intertwined, it becomes more appropriate to acknowledge the agency of nonhumans than in most other analytic postures. In actor-network theory (ANT)—one of the main methodological and theoretical tools used in STS, and the foundation of this thesis—the goal is to demonstrate that scientific knowledge and technological innovations are the result of negotiations between a loose, complex and contingent assemblage of socio-technical actors.[11] For Latour, "an 'actor' in the hyphenated expression actor-network is not the source of an action but the moving target of a vast array of entities swarming toward it. To retrieve its multiplicity, the simplest solution is to reactivate the metaphors implied in the word actor" (2005, p. 46). The use of the expression is meant to highlight the complexity and contingency of actor-networks, and the indeterminacy of the actors involved. Latour borrows this understanding of 'actor' from theatre studies: "to use the word actor means that it's never clear who and

[11] Scientific researchers have also embraced a more contingent view of scientific knowledge. In the last two or three (depending on who you read) decades, another broad and difficult to define theoretical framework has permeated both the scientific and cultural landscapes. The field known as chaos theory, complexity theory or self-organizing systems theory is touted as a tool for dealing with the small fluctuations and variables which comprise the natural world. Chaos theory was popularized as a theoretical device in 1987 by a physicist named James Gleick. According to G. Lively, chaos or complexity theory has "informed innovative new explanations for the workings of complex systems—from weather patterns and flu epidemics to penguin populations. The origins of chaos theory go back to the 1960s when a meteorologist named Edward Lorenz was developing computer models for weather prediction. According to Resnicow and Page (2008), one day Lorenz decided to run a predictive equation a second time, "[b]ut to save time he started the calculation in the middle of the sequence, manually plugging in some key numbers. To his surprise, the predicted output diverged sharply from the original" (p. 1383). The conclusion drawn from this test was that, "[e]ven with large computers, it is impossible to predict weather patterns accurately more than a couple of days in advance. Weather prediction is difficult because small fluctuations quickly amplify into large-scale changes" (Hayles, 1991, p. 10). This effect, often referred to as the butterfly effect, makes it very difficult to trust universal assertions about everything from the innerworkings of human bodies to social assemblages. As Hayles continues, "[t]he ability for minute fluctuations to cause large-scale changes holds for a wide variety of systems, from cream swirling in coffee to the thundering turbulence of Niagara Falls. Chaos is all around us, even in the swinging pendulum that for the eighteenth century was emblematic of a clockwork universe" (1991, p. 12).

what is acting when we act since an actor on stage is never alone in acting. Play-acting puts us immediately into a thick imbroglio where the question of who is carrying out the action has become unfathomable"(2005, p. 46).[12] In this account, actors are not static, but dynamic, their actions determined by negotiations and interactions with other actors in a given network.

Many approaches to science studies share a belief that "[o]ne thing is clear: making 'facts' is a social enterprise. Individuals cannot just go off and dream up vast amounts of facts" (Hubbard, 1988, p. 119). ANT, as well as certain approaches to feminist science studies, however, go beyond traditional social constructivism.[13] As John Law and Vicky Singleton argue, ANT and feminist science studies are unique constructionist approaches that "wouldn't call themselves 'social constructivist' because according to those theories hybrid material-and-social performances explain change and stability, not social factors alone" (2000, p. 767). Rather than distinguishing between social and technical actors, ANT considers the ways in which both the social (human) and the technical (nonhuman) work together to assemble a socio-technical network. It is within these networks that specific scientific and technological projects are advanced, and accepted by the broader technoscientific community (Michael, 1996). The overall goal, therefore, is to do away with socio-centric methods of studying the power and influence wielded by scientific and technological innovators. As Latour argues, "[i]n order to understand domination we have to turn away from an exclusive concern with social relations and weave them into the fabric that includes non-human actants, actants that

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[12] The use of the word actor must be distinguished from the word actant. The word actant, borrowed from the study of literature, is much broader, and is meant to describe types of characters in a story. Actors are the specific examples of those broader categories which act in a given story.

[13] Donna Haraway (1997), for instance, is also willing to acknowledge the agency of nonhumans.

offer the possibility of holding society together as a durable whole" (1991, p.103). In Latour's account, the only way to make society comprehensible is to incorporate nonhumans into the same conceptual framework as humans: "[i]t is only when we remove the nonhumans churned up by the collective that the residue, which we call society, becomes incomprehensible, because its size, its durability and its solidity no longer have a cause" (1993, p. 111). Within this framework, the "power" wielded by a technoscientific innovator is not a cause, but the consequence of his/her interaction with nonhuman actors in the assemblage of a specific socio-technical network. As Mike Michael argues:

> ANT is interested in looking at the social and political resources that allow scientists to become powerful in order to show that this power is not the inexorable outcome of science's technical and intellectual monopoly of the truth" (1996, p.59).

Latour refers to practitioners of ANT as 'scientific relativists' who "believe representations to be sorted out among themselves and the actants they represent", and not product of objective discoveries of what is "actually out there" (Latour, 1987, p.98).

More specifically, the goal of ANT research is to open up the "black boxes" of technoscientific innovation. Latour borrowed the term "black box" from cybernetics. Black boxes are stability points; foundations from which actors in a given network can take further steps in the development of scientific knowledge or technological innovations (Latour, 1987, p. 3).[14] Black boxes, when closed, represent accepted components of a technoscientific project. The problem, however, is that these black boxes are often left closed, and therefore unquestioned, as technoscientific innovators

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[14] This is not to be confused with a behavioural psychology understanding of the human mind as a black box.

move forward. As Latour argues, "no matter how controversial their history, how complex their inner workings, how large the commercial or academic networks that hold them in place, only their input and output count" (1987, p. 3). Latour argues that by opening up these black boxes, STS researchers can reveal the social, political and economic components of specific technoscientific innovations.[15] To justify opening up these black boxes, Latour asks the following question: "how are we going to account for the closing of the boxes, because they do, after all, close up?" (Latour, 1987, p. 7). This is important, if only to highlight the constructed nature of technoscientific innovations. More specifically, if one wishes to describe technoscientific innovations as culturally specific products of human imagination, then they should be able to account for the ways in which those innovations are produced.

It is important to remember that ANT, like the feminist science studies of Donna Haraway, is founded on the principle that the best research is conducted on specific sites of technoscientific innovation.[16] The goal, therefore, is to avoid trying to come to universal conclusions, in favour of local understandings of specific technoscientific innovations. Critics of such a relativistic approach worry that STS and feminist science scholars are engaged in an apolitical mode of analysis. The goal of many applications of ANT—as well as feminist theory—is to demonstrate that this is simply not the case. ANT is, therefore, used to describe the ways in which one can define technoscientific

[15] In the case of the production of the CAVEman it was important for the models to be transparent, seamless and coherent: when a biologist needs to investigate a particular organism or a set of related organisms, these resources will be put to good use only if they are integrated and linked in a way that is transparent to the user. Although powerful methods are available for analyzing various types of data on their own, the challenge for systems biology is to unify these analyses into a coherent model of an organism (Soh, Gordon & Sensen, 2009, p. 396).If, however, one thinks about the individual components which make up the CAVEman, it becomes possible to say something about the practices employed in its construction.

[16] As a result, ANT works to combat a peculiar fear that, "if we abandon the ordering Leviathan of the scientific method, then anyone could believe anything that they wished" (Law, 1991, p.5).

production and its implications as local, yet still be able to make ethical and moral judgments about its products. "Refusing to explain the closing of a controversy by its consequences", Latour argues, "does not mean that we are indifferent to the possibility of judgment, but only that we refuse to accept judgments that transcend the situation" (1991, p.130). The point is to avoid the construction of meta-narratives (Lyotard, 1984), to avoid making unnecessary links to broader issues, past sciences or older technologies. "There is no need", Latour argues, "to go searching for mysterious or global causes outside networks" (1991, p.31).

Scientific knowledge and technological innovations are, by this account, localized, but also dynamic and fluid. While there are fleeting moments when a technological innovation, or a scientific theory, is accepted, or black boxed, it can only go so far as the small corner of the technoscientific world in which it was developed allows it. The fields which make up contemporary technoscience, such as genomics and bioinformatics research, and their products, are constantly changing, as are the practices technoscientific innovators employ to construct their facts and innovations.

Like laboratory technicians, the human and nonhuman actors who produce virtual models of the human body are often ignored by STS scholarship (Barley & Bechky, 1994). This is troubling because, like technicians, the work of the computer scientists that make up sites of research, such as the Western Canadian genomics research facility, will ultimately ground "the construction of knowledge in which modern sociologists of science are interested" (Barley & Bechky, 1994, p. 87). While numerous authors have noted the disintegration of the boundaries between technology and science inherent in the development of technoscientific innovations, very few authors have provided detailed ethnographic evidence. Books have been written about the laboratory practices of biologists (e.g. Latour & Woolgar, 1979; Knorr-Cetina, 1999) and physicists (e.g. Pickering, 1984; Knorr-Cetina, 1999). Similarly, books have also been written about the development of technological systems (Latour, 1996; Bijker et al, 1987; Law, 2002). Too often, STS scholars focus simply on either the construction of facts or the construction of technological systems instead of the ways in which various researchers and technicians build and make sense of the instruments and devices which make technoscience possible (Barley & Bechky, 1994, p. 86). It is, I think, useful to take into consideration how the various technologies that might facilitate the future of knowledge production are themselves produced. As genomics research facilities incorporate more and more virtual models into their research regime, it becomes important to construct ethnographic narratives of the sites in which these innovations are produced.

These narratives require two goals. First, the researcher should endeavour to describe and theorize the places and virtual spaces within which a given technoscientific innovation is being produced. Second, researchers should attempt to describe and theorize the technoscientific innovation itself and its potential social, political, cultural, economic, medical and scientific implications. In order to understand the implications of any technoscientific research object, it is necessary to recognize the contexts within which that object was created, developed, accepted, and improved upon. This is, of course, only a partial, or *situated*, knowledge:

> Any interesting being in technoscience, such as a textbook, molecule, equation, mouse, pipette, bomb, fungus, technician, agitator, or scientist, can—and often should—be teased open to show the sticky economic, technical, political, organic, historical, mythic, and textual threads that make up its tissues (Haraway,1997, p.68).

In order to do this, it is important for researchers to acknowledge the agency not only of the human and nonhuman actants, but also the places and virtual spaces which make technoscientific production possible.

Acknowledging the Agency of the Spaces and Places of Technoscientific Production

Sociologists, anthropologists, and cultural geographers have all acknowledged the agency of the spaces and places occupied by social actors. In geographical terms, space suggests "dimensionality (depth, volume, area), infinitude, and emptiness, as in 'outer space'" (Oakes & Price, 2008, p. 254). Place is less abstract; the use of the term suggests "familiarity, finitude and immediateness" (Oakes & Price, 2008, p. 254). Place is often described as "space infused with meaning", and in cultural geography the term can be "viewed as a fluid nexus of lived social relations on a variety of scales, from abstract to concrete, and from global to the local" (Oakes & Price, 2008, p. 254). Rather than neutral environments in which social activities are situated, places are now described as "the active and interactive context[s] within which social relations and social structures are produced and transformed" (Moore, 1996, x).[17] Place, it can be argued, plays an active role in the construction of social assemblages.[18] As McCoy Owens argues, "it is as inappropriate to consider places as mere locations in which the work of socio-cultural construction occurs as it is to consider a point on a watch dial to be a culturally neutral way to situate an 'event' in time" (2002, p. 271). To summarize: the places in which

[17] I am using a very general definition of what constitutes place. In this text I will only refer to emplacements, or places. Place in this context simply refers to a location in space.

[18] The idea of what constitutes 'place' has been opened up by numerous philosophers and human geographers. Cultural and human geographers, for instance, argue that, what Heidegger referred to as *Dasein*, our being in the world, our engagement with our surroundings, has been altered. For many, the global context within which we live requires that the process of 'being there' involve "connections across scale and space" (Oakes & Price, 2008, p. 254).

social actors situate themselves have an impact on the ways in which those actors make sense of their world.

Places and virtual spaces, in science and technology studies (STS), play crucial roles in the construction of scientific knowledge and technological innovations (Barnes, 2004, p. 570). I refer to virtual spaces in this instance because much technoscientific work is conducted in specific places like laboratories but also across and within various representations of space. For instance, a great deal of genomics and bioinformatics research is conducted within the virtual space of computers, and Cave Automatic Virtual Environments (CAVE). CAVE technologies are often described as being located in finite places, but they also offer "the illusion of infinite, open space" (Robins, 1996, xv).

As I have noted, technoscience "never arrives from pure brainpower, from only sparking synapses. It is the outcome of embodied practice" (Barnes, 2004, p. 570). In Haraway's formulation of the same argument nothing comes "without its world" (1997, p.37). Technoscientific innovators are not faceless, disembodied organs of reason and objectivity, but people, with finite histories, who conduct their work in real as well as illusory environments. Within these environments technoscientists are influenced by and interact with assemblages of humans and nonhumans. All of these factors "make a difference in the kind of knowledge produced" (Barnes, 2004, p. 570).

I am, however, interested in a very specific way of conceptualizing the places and virtual spaces occupied by the genomics research facility's socio-technical actors. I argue that the genomics research facility is a heterotopic site of cultural production. While my focus is on Foucault's expansion of the concept of heterotopic sites, it would be useful to say a few words about the concept's origins.

"Heterotopia" is a term derived from the Greek word "heteros" which means "other" and the Greek word "topos" which means "place". In medical terminology "heterotopias" refers to the displacement of an organ or another body part in an improper location (Engel & Pedley, 2008). In the study of diseases of the nervous system, for instance, heterotopia refers to gray matter in the brain found in the white matter of the cerebrum, the top section of the brain (Engel & Pedley, 2008, p.2580). This gray matter *looks* normal, but causes problems due to its abnormal location (Johnson, 2006). This gray matter heterotopia can affect the brain's ability to function at higher levels, characterized by the loss of fine motor skills (Engel & Pedley, 2008, p.2581). Patients with gray matter heterotopia often suffer from severe forms of epilepsy.

Gray matter heterotopia is defined in medical terms as an "error in neural development". The medical heterotopia represents an error in the natural, or physical, ordering of the body. In social theory, however, heterotopia has been appropriated to refer to alternate sites of social ordering (Hetherington, 1997). Like medical heterotopias, social heterotopias comprise classifiable elements situated and juxtaposed in abnormal locations (Johnson, 2006). A key distinction is that social heterotopias provide different, rather than inherently incorrect, ways of ordering social actors.[19]

Foucault introduced the heterotopic imperative to social theory in the mid-1960s. His first reference to heterotopic sites can be found in the preface to *The Order of Things*. Foucault claims that the idea for *The Order of Things* first arose from reading a passage from Jorge Luis Borges, which opened up a way of theorizing:

> all the familiar landmarks of my thought - our thought, the thought that bears the stamp of our age and our geography - breaking up all the ordered surfaces and all the planes with which we are accustomed to tame the wild profusion of existing

[19] Or, in my case, *socio-technical* actants.

> things, and continuing long afterwards to disturb and threaten with collapse our age-old distinction between the Same and the Other (Foucault, 1970, xv)

The passage sparked Foucault's concern about the relationship between time and space in the ordering of the natural and social worlds.[20] In the passage, Borges describes an entry in a fictional Chinese Encyclopedia in which animals are divided into:

> (a)belonging to the Emperor, (b) embalmed, (c) tame, (d) sucking pigs, (e) sirens, (f) fabulous, (g) stray dogs, (h) included in the present classification, (i) frenzied, (j) innumerable, (k) drawn with a very fine camel hair brush, (1) et cetera, (m) having just broken the water pitcher, (n) that from a long way off 'look like flies' (Foucault, 1970, xv).[21]

Foucault acknowledges that each of the categories listed has a precise meaning and a legitimate content. He claims, however, that it is impossible to understand why and how these categories could come to be juxtaposed outside of the "the immaterial sound of the voice pronouncing their enumeration, or on the page transcribing it?" (1970, xvi). He briefly considers two possibilities: utopias and heterotopias. The former is determined to be inappropriate because utopias are "no-places", the roads to them being "chimerical" (Foucault, 1970, xix).[22] Heterotopias on the other hand do exist in external space. A heterotopia is a site of Otherness, the existence of which "sets up unsettling

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[20] "Our age and our geography" is an effective way of describing an important consideration in most of Foucault's books: the influence of both time and space on the ways in which humans order and classify the *existing* things around them.

[21] This passage is taken from Borges' "The Analytical Language of John Wilkins". In the story the fictional Chinese encyclopedia is referred to as *The Celestial Emporium of Benevolent Knowledge*.

[22] As a result, a utopia is a strictly internal space, a figment of one's imagination. When Thomas More first used the term in his book, *Utopia*, he was collapsing two Greek words: *eu-topia* which means 'good place' and *ou-topia* meaning 'no-place' or nowhere. A utopia is therefore "a good place that exists nowhere, except in the imagination."

juxtapositions of incommensurate 'objects' which challenge the way we think, especially the way our thinking is ordered" (Hetherington, 1997, p. 42).[23]

Foucault's second use of heterotopia can be found in a lecture presented to a group of architects in 1967. The lecture was published in English in 1986 under the title "Of Other Spaces". Offering a more concrete description and specific examples of heterotopic sites, Foucault begins the lecture by arguing that space, as opposed to time, characterizes the epoch of contemporary society. In contemporary society, Foucault argues, people experience the world less like "a long life developing through time than of a network that connects points and intersects with its own skein" (2004, p. 22). Space, however, is not static. How we live in and make sense of space changes over time ("our age and our geography"). It is not just that the twentieth century marked the epoch of space, but that it marked a specific conceptualization of space.[24]

As Peter Johnson argues, Foucault is positing that "the question today is once again about finite space...but also about the relations between different sites and our place within them" (2006, p. 78). In 21st century technoscience, however, one's understanding of the relations between sites has to expand in order to include the dynamic representations of space provided by computers and immersive virtual

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[23] In this thesis, I take a broad understanding of the word "objects", choosing to include human researchers, and nonhumans such as computers, CAVEs, and a wide range of biomedical data sources and software. It is, I think, important also to remember that there is no universal order of things, but constantly shifting definitions and classifications.

[24] In the Middle Ages, Foucault argues, space was a finite and hierarchical concept, one which signified a person's proper place in the world. This space was defined by a hierarchy of "places where things found their natural ground of stability and...places where things had been put because they had been violently displaced" (2004, p. 230). This all changed with Galileo and the scientific revolution. Foucault argues that in the seventeenth century Galileo opened up these enclosed and localized places. Rather than the *re*discovery that the Earth revolves around the sun, Foucault believes Galileo's greatest achievement was his conceptualization of "infinitely open space" (2004, p. 230). This marked the emergence of the space of extension within which "a thing's place was no longer anything but a point in its movement" (2004, p. 230). In modern society "emplacement has been substituted for extension" (Foucault, 2004, p. 230). Emplacements are defined by relations of proximity between points or elements (Foucault, 2004, p. 230).

environments. At the genomics research facility, for instance, it is important to account for the relations between the human and nonhuman actors that occupy the meaningful, finite place of the centre's office, but also the relations which occur within, and between, the virtual spaces in which these actors store, organize and project their work.

Problems within a site-specific society (such as the one in which researchers at the genomics research facility work within) deal not only with the physical limits of space, but with data collection, classification and calculation. The problem "is that of knowing what relations of propinquity, what type of storage, circulation, marking, and classification of human elements should be adopted in a given situation in order to achieve a given end" (2004, p. 230). The problem lies in knowing what to order and how to order it within specific sites and with the hope of achieving specific goals. The epoch of space, in this account, represents "the epoch of simultaneity... the epoch of juxtaposition, the epoch of the near and far, of the side-by-side, of the dispersed" (Foucault, 2004, p. 230). Contemporary space is marked by a series of lateral relations between sites (Hetherington, 1997).[25] In "Of Other Spaces", Foucault lists six principles of heterotopic spaces:

1. There is not a culture in the world that fails to constitute heterotopias (Foucault, 2004, p. 232). While no universal form exists Foucault argues that most, if not all, heterotopias can be reduced to either heterotopias of crisis or heterotopias of deviation. Crisis heterotopias represent "privileged, forbidden or sacred places,

[25] In "Of Other Spaces" Foucault is particularly interested in those spaces which "suspect, neutralize, or invert the set of relations that they happen to designate, mirror or reflect" (2004, p. 231). Heterotopias are heterogeneous collections of things unified, not by their resemblance or coherence, but through a process of similitude (Hetherington, 1997). This process of similitude "produces, in an almost magical, uncertain space, monstrous combinations that unsettle the flow of discourse" (Hetherington, 1997, p. 43). For more on similitude see the first chapter of *The Order of Things*.

reserved for individuals who are…in a state of crisis" (2004, p. 232). Heterotopias of deviation are those in which individuals who behave against the norm reside. How a culture defines "crisis" and "deviation" varies depending on the age and geography in which that culture is situated.

2. Societies can make heterotopias function in different ways as their histories unfold. Each heterotopia, Foucault argues, "has a precise and determined function within a society and the same heterotopia can, according to the synchrony of the culture in which it occurs, have one function or another" (2004, p. 233). Heterotopias, like actor-networks and multiform narratives, are dynamic, open to change, variation and improvisation.

3. Heterotopias are capable of juxtaposing in a single real place several sites that are in themselves incompatible. To highlight this principle Foucault offers the example of the cinema: "[t]hus it is that the theatre brings onto the rectangle of the stage, one after the other, a whole series of places that are foreign to one another" (2004, p. 233). This principle will be particularly helpful in describing genomics research facility employees' use of the space of the computer to store and classify raw data obtained from the space of the biological laboratory.

4. Heterotopias are linked to slices in time, what Foucault refers to, for the sake of symmetry, as 'heterochronies'. Some heterotopias, like libraries, are of indefinitely accumulating time. This principle will be used to highlight the importance employees at the genomics research facility place on documentation, data storage, and their

desire to map a four-dimensional model of the human body in order to simulate the processes of genetic diseases.

5. Heterotopias are sites among others, but also presuppose a "system of opening and closing that both isolates them and makes them penetrable" (2004, p. 235). Entry to these spaces is either compulsory (like a prison) or else requires one to submit to rights of purification in order to enter. In the case of the genomics research facility, these permissions and gestures might refer to recognized medical credentials, such as degrees, as well as positions held at respected hospitals and research universities.

6. Heterotopias have a relation to remaining space. This relation occurs along one of two poles. At one pole heterotopias function to "create a space of illusion that exposes every real space, all the sites inside of which human life is partitioned, as still more illusory (Foucault, 2004, p. 235). At the other pole a heterotopia represents an enclosed space which forms "another real space, as perfect, meticulous and well-arranged as ours is disordered, ill-conceived and in a sketchy state. This heterotopia is not one of illusion but of compensation" (2004, p.235). I will use this principle to describe how the genomics research facility's virtual models compensate for the limitations of genetic disease research conducted on material bodies. In what ways, for instance, does the virtual CAVEman function in relation (to use Foucault's term) to the real space of the human body?

Like Latour's (2005) actor-networks, heterotopias are constantly shifting in meaning and practice, depending on who is occupying them at a given time. Also like Latour's actor-networks, Foucault's heterotopias can be made up of monstrous combinations of humans and nonhumans, animals and machines, that work together with varying degrees of influence to achieve a common goal.

No one has used the heterotopic imperative in an ethnographic study of a technoscientific research centre. This is troubling given the emphasis science studies scholars place on the variability of nature (Law, 1991), the social construction of scientific knowledge (Latour & Woolgar, 1979), the interaction between humans and nonhumans (Latour, 2005; Callon, 1986; Law, 1991) and, perhaps most importantly, the social, economic and political complexity of technoscientific investigations (Haraway, 1997). As Timothy Lenoir puts it, "matters of distinction, prestige, recognition, and struggle over economic and technical resources have become inseparable from the production of scientific knowledge" (1997, p. 7).

Both ANT and Foucault's concept of heterotopic sites provide ethnographers with tools to account for the complexity and contingency of the contemporary world. These theories can work together because they each enrich a different element of an ethnographic narrative. ANT, on the one hand, allows one to describe the complex and contingent socio-technical characters which occupy the spaces and places of technoscientific explorations, such as laboratories and research facilities. Its weakness, however, lies in the fact that its developers and practitioners often have difficulty describing how to make these analyses more manageable. Networks, if one is not careful, follow seemingly infinite courses. In technoscience you can follow networks from finite locations, like laboratories, into board meetings, marketing departments, funding agencies and any number of other sites. It is up to the researcher to determine where to draw the line, when and where to stop collecting data (Latour, 2005). Foucault's description of heterotopic sites, on the other hand, allows scholars to theorize the specific places and virtual spaces occupied by socio-technical actants at a specific moment in time. It provides a tool for limiting the scope of one's analysis. The two theories, therefore, can work together to afford a rich and diverse perspective on a given site of technoscientific innovation.

The Cultural Production of Anatomical Fictions

So far I have suggested that technoscience is produced by loose, changing and contingent assemblages of humans and nonhumans, who work within heterotopic sites of improvisation and uncertainty. So, what do they produce, and how do they produce it? In this thesis I argue that the models produced by the genomics research facility are built out of a combination of "instrumentation, skill, practice, and the material embodiment of dispositions, taste and other cultural forms that do crucial mediating work between disparate domains of experience" (Lenoir, 1997, p. 8). This thesis, therefore, sees "the cognitive and social as mutually implicated in one another" (Lenoir, 1997, p. 8) in the production of the genomics research facility's models. From this perspective I have situated the work done at the genomics research facility as a form of cultural practice, or cultural production (Lenoir, 1997, p. 8).

Broadly speaking, this constitutes a cognitive definition of culture, most clearly articulated by Clifford Geertz. For Geertz, culture was "an historically transmitted pattern of meanings embodied in symbols, a system of inherited conceptions expressed in symbolic forms by means of which men communicate, perpetuate, and develop their knowledge about and attitudes toward life" (1973, p.89). I view the models being built at the genomics research facility as symbols that communicate a twenty-first century understanding of biological life as information to be abstracted, stored and manipulated. The biologists and computer scientists implicated in the genomics research facility's network, for instance, must find ways to negotiate, or communicate, both their goals and their tastes to one another. These producers don't make decisions that are motivated simply by the instrumental and technical needs of the four-dimensional modeling project; they make aesthetic decisions as well. The models they build are, therefore, cultural products, linked to culturally specific methods of abstracting information and culturally specific expectations for what constitutes art and knowledge.

Anatomical Art

Representations of human and animal anatomy are simultaneously indebted to the pursuit of scientific knowledge, the passions of visual artists, and the cultural production of new media technologies for displaying or projecting these representations:

> From the early wall paintings of ancient Egyptians to the recent advent of computer graphics, medical illustrators have employed a variety of techniques and materials to enrich the art of medicine. Over the centuries, medical illustrators have captured the variety of physical findings observed in the clinical, surgical, or postmortem settings and transferred them to a permanent medium. (Calkins, Franciosi & Kolesari,1999, p. 120).[26]

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[26] According to Calkins, Franciosi and Kolesari, "[t]he illustration of medical subjects took place before the advent of papyrus, paper, and similar materials" (1999, p. 120). Prior to 1500 B.C., Egyptian, Babylonian, Chinese, and Indian civilizations "were some of the first to provide medically related illustrations recorded on nontraditional media such as stone, bamboo, silk and metal" (Calkins, et al. 1999, p. 120). These studies, however, are often regarded as "examples of art in medicine that did not serve to elucidate scientific text associated with the advancement of anatomical study" (Calkins et al., 1999, p. 120). Scientific anatomical inquiry owes its origins to the Greeks. According to von Staden, "[i]n the first half of the third century B.C, two Greeks, Herophilus of Chalcedon and his younger contemporary Erasistratus of Ceos, became the first and last ancient scientists to perform systematic dissections of human cadavers" (1992, p. 223). Herophilus, however, did not illustrate his dissections, choosing instead to simply describe human anatomy in his *On Anatomy.* Although Aristotle's most famous anatomical text, *Historia Animalism*, is based on dissections of nonhuman animals he was "the first individual of record to illustrate human anatomy based on legitimate scientific study" (Calkins et al., 1999, p. 120).

With the rise in popularity of the computer have emerged new means, modes and methods for developing complex, and dynamic representations of human anatomy and biomedical data. As Catherine Waldby argues, "[t]he computerisation of medicine...has transformed that field of knowledge in dramatic ways. Computerisation has touched most pedagogical, clinical and research practices" (1997, p.84). In genomics and biomedical research, the computer has become an integral part of research and training. The CAVEman is just one of many recent examples of this trend. This increased computerization has further blurred the distinction between what constitutes fact and fiction in contemporary technoscience.

As noted earlier, the word "fiction" comes up again and again in technoscience studies. The word is used to highlight the constructed nature of technoscientific innovations, as well as the social and cultural reality within which those innovations are produced. For instance, this is how Donna Haraway described cyborgs in her *Cyborg Manifesto*:

> The cyborg is a matter of fiction and lived experience that changes what counts as women's experience in the late twentieth century. This is a struggle over life and death, but the boundary between science fiction and social reality is an optical illusion. (1991, p. 150).

Cyborgs are presented as a bridge between science fiction and the facts of lived experience, providing evidence that the two realms are often needlessly separated. "Contemporary science fiction is full of cyborgs", Haraway continues, "creatures simultaneously animal and machine, who populate worlds ambiguously natural and crafted. Modern medicine is also full of cyborgs, of couplings between organism and machine, each conceived as coded devices, in an intimacy and with a power that was not generated in the history of sexuality" (Haraway, 1991, p. 150). This point of view sees technoscience in terms of its ability to constantly marry the imagination with the real world. This is, at least partially, a result of an understanding of human biology as information, not materiality: "[u]nlike the body of Frankenstein, constructed out of recycled parts which never add up to a seamless whole, the new regime inaugurated by molecular biology conceives of the body in bits, as an archive of interconnected codes to be deciphered" (Marchessault, 2000, p. 39). Nothing in technoscience, in this account "simply or passively is" (Hayles, 1999, p. 157). This, I think, is a crucial point.

As Ira Livingston has noted, "fact and fiction both derive from Latin words that mean nearly the same thing: to do or to make" (2006, p.43). While fiction has always been understood as something "fashioned or feigned", Livingston argues that it took until the early nineteenth century for a "sense of fact as something actively done or made to be completely driven out by the sense of something that simply and passively is" (2006, p.43). In his 2006 book, *Between Science and Literature,* Livingston describes how the rivalry between fact and fiction "is a long story, culminating in the invention and polarization of science and literature—two more words that acquired their modern currency only in the nineteenth century (2006, p.44). "Not surprisingly", Livingston continues, "science fiction is a genre in which questions of the borders between fact and fiction are commonly and obsessively thematized and theorized" (2006, p. 45). Once one realizes that nature, society and culture are not mutually exclusive, but mutually constitutive, Livingston argues, we can begin to comfortably walk the fine line between science and literature (or any form of artistic expression). It then becomes possible, for instance, to use cultural texts, such as science and speculative fiction, to describe technoscientific products and practices, and vice versa. The CAVE environment in which the CAVEman was built and projected is, for instance, described by employees of the genomics research facility, with whom I interacted, as a "theatre" and a "research Holodeck" (McCarl, 2007). This suggests not only a connection to the history of medical research and representations of human anatomy. It also suggests an explicit connection to virtual narrative environments found in real world research centres, as well as popular science and speculative fiction, such as the *Star Trek* franchise and Richard Powers' novel *Plowing the Dark* (not to mention the fact that a number of genomics research centre employees are former video game developers and art school students).

Multiform Narratives

My focus is on the four-dimensional modeling project's development of a specific kind of fiction. I am interested in how the models being built at the genomics research facility might facilitate the construction of what Janet H. Murray (1997) refers to as "multiform narratives". What makes the four-dimensional project so compelling is that it represents not only a fiction, but a dynamic, narrative fiction. These four-dimensional models, and the virtual environments in which they are project, can be regarded as complex storytelling machines.

To refer to the stories being developed by the four-dimensional modeling project as fictions is not to diminish the potential for the project to serve as a powerful resource for the production of scientific facts. Such a distinction is unnecessary, and contradicts even a literary understanding of narrative fiction. In a literary sense, all narratives, whether imagined, or based on supposedly true events, are fabricated. As Richard Walsh has argued:

> The significance of narrative is not latent in the data of experience, or of imagination, but fabricated in the process of subjecting the data to the elemental rhetoric of the narrative form itself. The categorical difference between real and imagined events is overwhelmed by the artificiality of narrative representation in either case: all narrativity, from this point of view, shares in the properties of fictionality (2003, p. 111).

It is the inherent artificiality of technoscience that affords its products their status as fictions. The models being developed by the four-dimensional modeling project are fictional because they are built from data abstracted from a variety of data sources; not because they produce something inferior to scientific facts. As a generic model, the CAVEman is not based on any one specific human cadaver. It can, therefore, be remade to look like any body. The stories the CAVEman can tell are, therefore, numerous.

In her book, *Hamlet on the Holodeck*, Janet H. Murray discusses the narrative potential of computer-generated environments. She argues that, "although we may talk of an information highway and of billboards in cyberspace, in fact the computer is not fundamentally a wire or a pathway but an engine" (1997, p. 72). For Murray the potential for computers to facilitate the construction of powerful fictional narratives is the result of four properties of digital environments. Digital environments, in Murray's account, are procedural, participatory, spatial and encyclopaedic. Computers are important not because of their increasing ability to make realistic representations of worlds and bodies, but because of the ways in which they follow sets of complex procedures. These procedures can be improved over time. Procedural environments, however, are appealing not "just because they exhibit rule-generated behaviour but because we can induce the behaviour. They are responsive to our input" (Murray, 1997, p. 74). In this sense, digital environments are both participatory and interactive. Part of the joy of working within interactive computer-generated environments is that researchers can play with their code. Researchers can "[test] the limits of what the program will respond to" (Murray, 1997, p. 77). Furthermore, when it comes to information visualization, like the building of virtual models from biomedical data, a key concern is how "human beings interact with data, and therefore how best to encode and present data graphically" (Spence, 2007, p. 10). Murray refers to the complex and interactive narratives that can be developed in these environments as multiform narratives.

Multiform narratives do not represent black boxes, nor do they come to definitive conclusions. Multiform narratives are open to variation and allow multiple users to generate multiple interpretations. These narratives can be viewed from multiple angles, slowed down or sped up, and they are open to the addition of new information. Multiform narratives, like actor-networks and heterotopic spaces, are complex and contingent, with actors and actions changing overtime.

Multiform narratives are quite distinct from a traditional understanding of narrative structure. Traditional narratives feature three key elements: exposition, rising action and resolution (Cody & Sprinchorn, 2007). The action in a traditional linear narrative leads to a climax, "a moment of intense feeling", and then a conclusion (Cody & Sprinchorn, 2007, p. 365). For Arthur Hopkins, a theatre critic, the three parts of a traditional narrative were reducible to three punctuation marks—a question mark, an exclamation point, and a period. Cody & Sprinchorn summarize Hopkins argument like this: "The first part raises the question, 'What is going to happen?' The second produces a surprise: 'I didn't expect that!' The third part brings a resolution: 'Everything is settled'" (2007, p. 365). Multiform narratives, on the other hand, withhold climax (Murray, 1997, p. 174). They are open to the constant addition of new information, new questions, new suspense. It is almost as if multiform narratives are stuck in a state of rising action. As a result, these narratives can not be adequately transmitted through uni-directional media. They require interactive and malleable virtual environments. The CAVE in which the genomics research facility's models are developed and projected can be described as such an environment.

In *Computers as Theatre*, Brenda Laurel called for a non-classic theatrical approach to graphical computer interface design. Her goal was to explain that computers and CAVE environments offer seemingly limitless potential for artistic representation, much like dramatic productions:

> In a theatrical view of human-computer activity, the stage is a virtual world. It is populated by agents, both human and computer-generated, and other elements of the representational context (windows, teacups, desktops, or what-have-you). The technical magic that supports the representation, as in the theatre, is behind the scenes. Whether the magic is created by hardware, software, or wetware is of no consequence; its only value is in what it produces on the 'stage'. (Laurel, 1993, p. 17).

Laurel's statement is very useful when thinking about the application of virtual models in biomedical science. Thinking about computers and CAVE environments as 'stages' reminds us that computer programming and graphic design are modes of cultural production, regardless of whether they are applied to technoscientific work or the development of a video game. Computers are not uniquely designed to be used only for calculations, data management, scientific visualizations, etc. Computers can be very playful and, as a result, can be of great value to their users. In genomics research the computer is important not only because it is capable of storing and organizing such large quantities of data, but because it allows users the ability to play with this data, to come up with unique, improvised and innovative ways of working with those data, without major consequences (destroying a cadaver, decay, making irreversible errors).

Laurel makes it clear that the desire "to create interactive representations, as exemplified by human-computer activities, is only the most recent manifestation of the age-old desire to make what we imagine palpable" (1993, p. 30). This desire feeds into "our insatiable need to exercise our intellect, judgment, and spirit in contexts, situations, and even personae that are different from those of our everyday lives" (1993, p. 30; my emphasis). In this way, the computer is conceptually similar to the dramatic stage, the filmic screen and the literary page. In Laurel's argument, each of these media environments constitutes a space of cultural production that facilitates both work and play.

It is interesting to note that both Laurel and Murray fail to see another field in which the narrative potential of the virtual worlds is used in technoscience. It seems odd that neither theorist would make this leap, given the increasing body of literature describing the collapse of the modern perception that nature, society and culture are mutually exclusive realms. It is not too big a leap to include the building of virtual models to study genetic diseases within the same theoretical framework as video games and interactive virtual theatres. I argue that the virtual models built by the genomics research facility add an important component to both Laurel and Murray's arguments about the narrative potential of virtual environments.

Just as computers and virtual worlds have opened up the future of film, literature and video game narratives they also open up the artistic and narrative potential of technoscience. As Hayles argues, "[c]ulture circulates through science no less than science circulates through culture. The heart that keeps this circulatory system flowing is narrative—narratives about culture, narratives within culture, narratives about science, narratives within science" (1999, p. 22). This is because so much of contemporary technoscience is the result of complex assemblages of humans and nonhumans, scientists and artists.

As a form of cultural practice, the work of genomics and bioinformatics researchers—and the limitations of working on material bodies—necessitates the use of these storytelling apparatuses. In genomics and bioinformatics research, it is often difficult to visualize the processes of genetic diseases, particularly at the molecular level. Many details and patterns are impossible to account for in flesh and blood human and animal bodies. It becomes necessary to use complex imaging technologies, and visual models, in order to aggregate, combine and project diverse quantities of biomedical data. As N. Katherine Hayles argues, this framework views information as "more mobile, more important, more essential than material forms. When this impression becomes part of your cultural mindset, you have entered the condition of virtuality" (1999, p. 19). Information is not only stored, but combined in complex ways, in order to make patterns invisible to the human eye accessible to a diverse range of researchers conducting a range of biomedical case studies. The models built by the Western Canadian genomics research facility, for instance, are designed to serve as both complex digital databases *and* virtual research subjects. As research subjects these models are less like human cadavers and more like characters in video games and other virtual narrative environments. They are dynamic, multiform narrative fictions, which researchers hope will contain enough variable information to aid in the construction of scientific facts.

What better area of research is there to engage in the development of loose and contingent multiform narratives than fields such as genomics and bioinformatics research? These fields, as I have argued, are constantly changing, constantly in need of new ways to deal with the constant addition of new data and new means, modes and methods for abstracting, organizing and visualizing those data.

Chapter 2
Introducing the Main Characters: Actor-Network Theory as a Theoretical and Methodological Foundation

As noted earlier, ANT literature provides both the theoretical and methodological foundation for this thesis. Remember, my overall goal was to study the practices used by employees in the genomics research facility. As Latour puts it:

> [w]e will enter facts and machines while they are in the making; we will carry with us no preconceptions of what constitutes knowledge; we will watch the closure of the black boxes and be careful to distinguish between two contradictory explanations of this closure, one uttered when it is finished, the other while is being attempted" (Latour, 1987, p. 15).

With ANT as its foundation, this thesis unfolds as a critical instance case study of the Western Canadian genomics research facility. The critical instance case study applies various methods in the examination of "one, or very few, sites" (Stake, 1995). The value of this case study approach is that it allows a diverse range of methods to be used to describe a specific site of technoscientific development. Case studies, as Marshall & Rossman argue, "may entail multiple methods—interviews, observations, document analysis, even surveys" (2006, p.56). My critical instance case study involves three key sources of data. First, I developed a constructionist ethnography of employees working at the genomics research facility. Second, I conducted semi-structured interviews with each of the participants. These interviews were conducted on-site at the genomics research facility (See Appendices for a general interview guideline, as well as the letter of information participants were provided). Third, I developed a textual analysis of relevant literature pertaining to the development of the four-dimensional modeling project.

More on Constructionist Ethnography

A large portion of my work is based on a four-week participant observation of, and interaction wit, the actants that comprise the genomics research facility. This approach is best defined as an "*in situ* monitoring" of technoscientists in a particular setting (Latour & Woolgar, 1979, p.27). The difference between constructionist and what Holstein & Gubrium call 'naturalistic' ethnography lies in the formulation of *what* and *how* questions. Whereas the naturalistic impulse is typically to ask "'what is going on?' with and within social reality, constructionist sensibilities provoke questions about how social realities are produced, assembled, and maintained" (Holstein & Gubrium, 2008, p.374). The focus for my research narrowed more towards the constructionist impulse. I incorporated "an analytic orientation that centre[d] on...reality-constituting practices more than on the realities themselves" (2008, p. 375). At the heart of the ethnographic component of my inquiry was an exploration of the ways in which the interaction between humans and nonhumans was productive of the genomics research facility's socio-technical reality. It was my job to have an "abiding concern for the ordinary, everyday procedures that society's members use to make their experiences sensible, understandable and orderly" (Holstein & Gubrium, 2008, p. 375). Furthermore, a constructionist ethnographer is willing to acknowledge the limits of his/her analysis and is sensitive to his/her own influence on the "everyday procedures" of those they observe. Such ethnographers are aware of their 'partial perspective' (Haraway, 1991, p. 583).[27] I kept detailed notes of all conversations and observations made on-site, many of which will feature prominently in subsequent chapters.

[27] According to Haraway, a partial perspective promises a very specific version of *feminist* objectivity. On her account "feminist objectivity is about limited location and situated knowledge, not about transcendence and splitting of subject and object" (1991, p. 583).

Because I was studying the construction of a technoscientific innovation, I had the unique opportunity to observe employees who were themselves observing various phenomena, trying themselves to make sense of various data sources and methods for constructing their virtual models. I conducted what Paul Rabinow calls second-order observations. I was, as Rabinow so aptly describes it, "observing observers observing" (2008, p.64). As a second-order observer I took the "system (observer-environment) established by the first-order observations" as my referent (Rabinow, 2008, p. 64). The benefits of this type of analysis are numerous. As Niklas Luhmann states: "Second order observations offer a choice whether certain designations are to be attributed to the observed observer...or seen as characteristics of what he observes" (1993, p.47).

Inscriptions and Textual Analysis

Broadly defined, textual analysis is "a methodology—a data-gathering process—for those researchers who want to understand the ways in which members of various cultures and subcultures make sense of who they are, and how they fit into the world in which they live" (Mckee, 2003, p. 1). ANT considers a wide range of texts, or 'inscriptions', which may prove useful in defining key actors and establishing key moments in the development of a technoscientific project. Inscriptions, according to Latour (1987), refer to all documents and communications which may be relevant to the assemblage of a given network. Inscriptions can be as diverse as conference papers, journal articles, internal memos, patents, training videos, etc. In ANT, a researcher follows human and nonhuman actants in the field, but it is also important that they study "inscriptions" (Randall, 2007, p. 108). This is because inscriptions are the means by which human actants attempt to gain credibility during the process of translation (Callon, 1986). The inscriptions I have included range from journal articles written by the director and post-doctoral students at the genomics research facility, to the director's appearance on *Daily Planet* (a science news program which airs on the Discovery Channel), and various press releases, as well as internal memos, diagrams, and textbooks I found on-site. These inscriptions serve as source material for subsequent chapters. They are, for instance, used to support many of my key arguments. They also helped me determine who/what were the key actors in the building of the four-dimensional modeling project.

Interviews

An unstructured interview is a spontaneous conversation which occurs between researchers and participants (Cresswell, 2003, p.186). These interviews were conducted throughout my visit at the genomics research facility. These one-on-one interviews made me more familiar with both the individual researchers and the technological design of the four-dimensional modeling project. This helped me to define key actors, and make sure I did not miss key details due to my ignorance of the design and significance of potential nonhuman actors. These interviews were also useful for better understanding the reasons and motivations human actors cited for being involved in the four-dimensional modeling project.

Most of the interviews were conducted on-site, in a boardroom located at the genomics research facility. These conversations lasted anywhere between fifteen minutes and one hour. I kept detailed notes during the interviews (an unstructured interview guide can be found in Appendix). Some of these conversations also took place on bus rides home at the end of the work day. In one instance an interview was conducted over lunch at a coffee shop down the road from the genomics research facility.

Storytelling

By incorporating all of these data sources, this thesis constructs a loose narrative about the genomics research facility. I begin by describing the main characters (made up of human and nonhuman actors). I then describe the setting (the heterotopic site of cultural production), the rising action (a set of conflicts the human and nonhuman actors must overcome within their heterotopia), and the genomics research facility's desired conclusion: the construction of multiform narrative fictions, which researchers hope will facilitate the future construction of scientific knowledge about genetic diseases.[28]

My story is, however, just as loose, contingent and interpretative as its characters and settings. By acknowledging the interpretative nature of my story, I am trying to combat the myth of positivism. I recognize that "there is neither a single, absolute truth in human reality nor one correct reading or interpretation of a text" (Lieblich et al., 1998, p.2). Observers of technoscientific practice are in a position very similar to the technoscientists they observe in that they "are also confronted with the task of constructing an ordered account out of a disordered array of observations" (Latour & Woolgar, 1979, p.34). My observations are conducted on admittedly shifting, dynamic, ever-changing ground. Technocience is not static, and I do not intend for my analysis to refer to the genomics research facility as a fixed site. Instead, I offer insights into the

[28] It would, however, be incorrect to refer to this work as narrative research. Narrative research is perhaps most easily defined as "a form of inquiry in which the researcher studies the lives of individuals and asks one or more individuals to provide stories about their lives. This information is then retold or restoried by the researcher into a narrative chronology" (Cresswell, 2003, p. 15).

ways in which the genomics research facility's actors communicate and interact with one another in the settling of controversies, and the achievement of a common set of goals. Any knowledge obtained from my little narrative will be situated, partial, based on a very elaborate and detailed collection of contextual information.[29]

Part of the job of an ANT practitioner is to enter a case study with no preconceived notions about who or what the relevant actants might be, or how they will work to assemble the socio-technical network: "[s]uch local explanations can only emerge in the description of the networks, but it has to be a description (or more accurately, a narration) that does not a priori disqualify certain actors and intermediaries from the list of dramatis personae" (Michael, 1996, p. 57). It is therefore important to take on an 'ethnographic attitude'. As Haraway argues, "[n]ot limited to a specific discipline, an ethnographic attitude is a mode of practical and theoretical attention, a way of remaining mindful and accountable" (1997, 191). This attitude helps science and technology scholars collect, organize and juxtapose detailed descriptions of a wide range of data sources. All of these sources can be combined into a story, the star of which is the technoscientific innovation, the literary subject Latour wants to hold onto.

Introducing the Main Characters

Because this research is site specific, my sample population is quite narrowly defined. The genomics research facility had sixteen staff members whose work was directly related to the four-dimensional modeling project. This included researchers, the director,

[29] Researchers must be willing to ask themselves detailed questions about the interaction between persons and technology: "How to see? Where to see from? What limits to vision? What to see for? Who gets to have more than one point of view? Who gets blinkered? Who wears blinkers? Who interprets the visual field? What other sensory powers do we wish to cultivate besides the visual field?" (Haraway, 1991, p.194).

secretaries and maintenance staff, all of which proved to be relevant actants in the human component of the genomics research facility's network.

The employees at the genomics research facility were very gracious during my four week stay. I was granted my own access card to enter the building as well as my own workstation. My workstation was fully equipped with my own desk, computer and telephone. I was situated amongst the employees. I was also granted unlimited access to the virtual CAVE environment. Most of my time was spent sitting at my own workstation observing the interactions between the various employees working at the facility. I often took part in the conversations, and actively presented myself as a member of the group. I conducted my observations and interactions between 10:00am and 4:00pm, or what the employees referred to as "core hours". Some of my observations and discussions were conducted during lunch breaks, and on two occasions on bus rides home with employees. This gave me a diverse and rich perspective, and allowed me to spend a lot of time simply "hanging out" with the genomics research facility's employees.

I am, for the most part, ignorant of the scientific work incorporated by genomics research facility employees in the building of their virtual models. My goal is not to "reveal hitherto undiscovered facts about the details of scientific work to the subjects of my study" (Latour & Woolgar, 1979, p.30). My goal is to shed some light on the "soft underbelly of science" (Edge, 1976). I focus on the work done by and the interactions between the human and nonhuman actors that occupy the genomics research facility.

The following is a list of the human and nonhuman actors which comprise the genomics research facility. While I observed and interviewed all sixteen of the employees who were working at the facility during my visit, this list is made up of only those actors who were directly involved in work related to the four-dimensional modeling project. While the genomics research facility had employees working on a number of other genomics research projects, many of them were not relevant to my particular research questions. Think of this list as a cast of characters:

The Director: also considered the genomics research facility's primary investigator. He is a biologist by training. He does very little of the day to day work at the genomics research facility. He does however write lots of papers and attends most of the conferences and media interviews related to the four-dimensional project.

Danielle: the administrative coordinator. She operates as both the director's secretary and as the genomics research facility's administrative liaison. She is on the lower rung of the genomics research facility's ladder of importance. She says this is because she is not involved with the technical component of the genomics research facility's work. She instead operates as an administrator and personal assistant to the director. Her job is to schedule meetings for the director and conduct performance reviews of all of the genomics research facility's employees. She also acts as a mediator between employees if personal or professional problems arise.

Frank: Frank is the head post-doctoral researcher. His background is strictly in computer science. He runs the genomics research facility's four-dimensional modeling project.

Julie: an undergraduate from a Canadian bioinformatics program. She is working at the genomics research facility on her summer work term.

Nick: another summer student, taking a break from his undergraduate studies at a Canadian university's faculty of computer science.

Douglas: a graphics artist working under a biology professor. Douglas works for an undergraduate medical education program through the genomics research facility. The program is dedicated to the development of teaching aids for undergraduate students working in anatomy and biology. Specifically Douglas is focused on anatomy and anatomical modeling.

Maxine: one of the other post-doctoral Fellowes. She got her PhD. in computer science. She works principally on the 4D project and is currently working with Nick on the development of a generic anatomical model of a mouse.

Devon: received a Master's degree in bioinformatics. He is currently working on modeling the interaction between cell types.

The Guru: has degrees in both biology and computer science. He is currently working on his dissertation. He works very closely with the genomics research facility's director.

Alex: is one of the post-doctoral Fellows. Alex received his PhD. in computer science. He works very closely with the director and Julie on the four-dimensional modeling project.[30]

SAM-QFS Data Storage System: consists of a Storage Archival Manager (SAM) and the Quick File System (QFS) which together provide data management and high performance. SAM is a hierarchical storage manager which means it stores data in different media (disk, tape) based on policy. QFS is a shared file system which supports up to 256 nodes and access to data at device-rated speeds.

The CAVE Automatic Virtual Environment: Built by Fakespace, this is an immersive virtual reality environment comprised of four projection walls, a tracking system and hand wand. It enables scientists to interact and view three-dimensional models of biological systems, including cells, tissues and entire organisms.

VRCO Full Circle Portable Display Unit: "The VRCO Full Circle portable display unit is a front projected, passive stereo visualization environment. It consists of two projectors, a portable screen, workstation and passive stereo glasses - which we use for demonstrating and sharing our research with others. Most notably, the VRCO Full Circle portable display unit has been used to showcase CAVEman at the Telus World of Science" (Visualization).

Personal Computers: Each employee's computer was equipped with its own computer. Much of what I observed took place by individual employees at their assigned work station.

Open GL: One of the major programming languages used by Sun Centre employees.

C++ : One of the most popular computer programming languages. Used by all of the Sun Centre's programmers.

Medical imaging data: such as those derived from functional Medical Resonance Imaging (fMRI), Computed Tomography (CT), Positron Emission Tomography (PET), and microscopy.

Anatomical organ reconstructions: in the form of 3D surface-based models and digital atlases of the organism's anatomy.

Time-varying biochemical concentration data: such as those from gene expression microarrays, proteomic studies, pharmaco-kinetic studies, and metabolomic experiments.

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[30] All names of human actors are pseudonyms.

In what follows, I argue that these actors work within a heterotopic site of cultural production, and are working towards the construction of complex multiform narrative fictions about the processes of genetic diseases. I begin by describing the places, and virtual spaces, occupied by the actors which comprise the genomics research facility.

Chapter Three:
The Heterotopic Space of the Genomics Research Facility

My version of Borge's list from the fictional Chinese encyclopedia, noted in my literature review, might look something like this:

> actors are divided into: (a) computer scientists, (b) biologists, (c) graphics designers, (d) virtual CAVE environments, (e) Mouse embryos, (f) plastinated human kidneys, (g) MRI scans, (h) C++ programming language, (i) Open GL programming language, (j) Genome Canada, (k) information technicians, (l) Sun Microsystems, (m) Fakespace Inc., (n) VTK virtual cutting tool, (o) VRCO portable CAVE, (p) Breve programming language (q) office gossip (r) facebook, (s) coffee makers

This chapter unfolds as a doubled heterotopic story. Not only do I describe the genomics research facility itself as a heterotopia, but also the virtual spaces within which employees combine, organize and project their work. Remember, the use of the concept of heterotopic sites is not meant to simply describe finite places, but also the relationship between various sites, real or virtual. As Foucault argues, "the heterotopia is capable of juxtaposing in a single real place several spaces, several sites that are in themselves incompatible" (2004, p. 233). Foucault uses the example of the theatre because it brings "onto the rectangle of the stage, one after the other, a whole series of places that are foreign to one another" (2004, p. 233). Even more interesting, however, is Foucault's example of the cinema. "[T]he cinema", Foucault argues, "is a very odd rectangular room, at the end of which, on a two-dimensional screen, one sees the projection of a three-dimensional space" (2004, p. 233). Similarly, the genomics research facility is a finite location which features a number of virtual spaces, such as personal computers and the CAVE, in which employees juxtapose, organize and project a number of seemingly incompatible data sources.

The Setting

Since the previous chapter introduced the reader to my main characters, this chapter will establish both the setting and the rising action of my story. Based on field notes collected over a four-week period in August of 2008, this chapter analyzes the ways in which the actors, both human and nonhuman, that occupy the genomics research facility interact with one another. My goal is to highlight the contingency and complexity of the work done at the genomics research facility. Specifically, this chapter deals with the difficulty computer scientists and biologists, as well as various nonhuman actors, had finding common ground on which to effectively build the four-dimensional modeling project`s complex models of the human body.

The following is an excerpt from field notes compiled on my first full day at the genomics research facility:

> I should note that the office sort of feels like a government land registry office. It is a typical office space with lots of cubicles. Every desk has a computer. The office walls are painted various shades of gray. There is some dull green trim around the wooden office doors. The office is very small, containing about 20-30 cubicles, a small lunch room, and a boardroom. Higher up staff members have personal offices. These include Denise's office, which acts as a gateway to the director's office, an office for the IT specialist, personal offices for Frank, the director's right hand man, and The Guru, who works with Andrea, the director's wife. There is also a special room in which the Cave Automatic Virtual Environment resides and, perhaps the most interesting surprise, a state of the art biology lab. It is a shockingly common office environment. (From field notes, August, 7, 2007).

Each of the separate rooms listed are places, which have a distinct purpose (meaning in space). The main office, for instance, was where much of the work I observed was conducted. Individual employees worked at their assigned cubicles. I also observed these employees engaging in conversations, both work related and non-work related in this space. The boardroom was where I conducted most of my interviews with individual employees. The boardroom was also where most of the genomics research facility's meetings took place. Many of these meetings involved computer scientists and biologists discussing the progression of the four-dimensional modeling project. The lunch room served as another room where I conducted a couple of my interviews, but it also served as a social site, a place where employees could get together to discuss work, and non-work related topics. The room in which the CAVE resided was where employees of the genomics research facility would test the models and demonstrations they had been building at their individual workstations.

The office, though typical in appearance, was a site that juxtaposed biologists, raw biological data, computer scientists, various programming languages, administrators, CAVE environments, modeling tools, coffee makers, office gossip, and graphics designers.[31]

[31] Although not directly related to my present project, while at the genomics research facility there was a lot of gossip going around about a woman who had mysteriously stopped coming to work. Denise, the administrative assistant to the director, also told me that there were a lot of problems with various employees not taking seriously enough the hours they were supposed to be working.

Fig. 3.1 The Main Office.

Fig. 3.2 The Boardroom

Fig. 3.3 The Lunch Room.

Figure 3.4 Outside the CAVE

ACT I – Humans vs. Humans: Problems and Limitations

At the genomics research facility the juxtaposition of biologists, computer scientists and graphics designers generated a major problem. The problem, in practical terms, was that often it was very difficult for various employees to communicate their goals, their progress towards those goals, and the limitations or obstacles which got in the way of their achievement of those goals. For instance, all sixteen of the genomics researchers, graphic designers and bioinformaticians I interacted with claimed that one of the biggest hurdles they had to overcome was figuring out what exactly biologists wanted from them. As noted earlier, scientific knowledge and technological innovations are constructed through a process in which controversies are resolved, comprises are made, and conclusions are agreed upon. When you juxtapose a number of researchers from seemingly incompatible fields in one location, it becomes increasingly difficult to settle controversies and create the 'black boxes' of technoscience. At the genomics research facility, the problem of translating goals came up again and again. If place is "space infused with meaning" then it was up to employees of the genomics research facility to find ways of meaningfully engaging with biologists in order to achieve their common goals. Again, their goal was, and continues to be, to build functional and scalable models of the human body to aid in the study of diseases with a genetic component.

Frank: Frank had focused on nothing but computer science in his post-secondary education. He had very little understanding of biology. He said that he hadn't taken any biology since high school:

> He is willing, however, to learn basic biology when it is to his benefit. He sees himself as a dabbler, trying to understand what he can in order to keep up in his

> conversations with biologists. One of the problems Frank faces is an assumption on the part of many biologists that he knows the basic foundations of their work. They take for granted his limited understanding of biological processes. Often he just lets them speak, as it is often very difficult to cut them off. If, however, the talk relates specifically to the work he is doing he will speak up and ask them to explain it to him in simpler terms. Frank thinks it is important to recognize that biology is a massive area of study; it is almost impossible to know even the basics without a lot of studying. He often ends up studying on his own in order to make sure he understands the basics, especially for concepts related to his work. The problem is further accented, Frank argues, because biomedical research, especially those projects related to the work he does, is often at the experimental level. (From field notes, August 19, 2008).

Frank argued that problems which arose were both "technical and biomedical"(From field notes, August 19, 2008). Often these biomedical challenges were not fully understood by Frank or the other computer scientists. For instance, at one point the biologists claimed that it took six months or more to produce data which Frank said amounted to little more than a small text document. These biological researchers could be a bit defensive, especially if Frank tried to get more data from them (From field notes, August 19, 2008).

This issue came up quite often in my discussions with genomics research facility employees. One of the biggest issues for the computer scientists and bioinformaticians was communicating problems and goals with the director of the genomics research facility. All of the undergraduate computer science students and post-doctoral fellows, graphic designers, and bioinformaticians saw communicating with the genomics research facility's director and principal investigator to be one of the greatest impediments to the achievement of their goals.

Julie: Julie saw the problem being the director's general lack of computer literacy. Julie cited issues with translating the director's wishes into programming code in the virtual space of the computer.

Nick: At one point Nick laughed and said that it had always surprised him that the facility's director was a biologist with no computer programming knowledge. Sometimes this caused him to request things that Nick and the other programmers deemed either impossible or at least very difficult to accomplish in the short time frame provided. "The problem", Nick argued, "is that they [biologists] seem to think that computers can do anything" (From field notes, August 9, 2008). There were, however, real limitations that biologists were not always capable of recognizing. These limitations were linked to computer power, storage space, and sometimes the limitations of the programming languages. These are problems that could only be understood with at least a foundational understanding of computer science. As a way of getting genomics research facility employees to think about this problem, I asked them a fundamental question: Do you see yourself as more of an expert in biology or do you see yourself as strictly a computer scientist?

Julie: She started out as a biology student but she doesn't think she has progressed too far beyond her first couple of years of work in biology (From field notes, August 12, 2008).

Douglas: Douglas said his work consisted of a lot of programming. Douglas studied at a fine arts college, and received his diploma in digital art. He was thinking about getting a Master`s degree in computer science sometime in the near future. Douglas claimed that prior to getting this job, he had almost no knowledge of human biology.

Devon: When asked where his expertise lay, Devon stated that although he studied bioinformatics he believed that his knowledge was split: "30% biological knowledge and 70% computer science" (From field notes, August 7, 2008).

The problem seemed to lie in knowing how much information computer scientists could comfortably communicate with biologists (and vice versa) and how much knowledge each party could assume the other had of their area of research. This issue is very similar to what sociologists of science have described as difficulty scientists have communicating their important findings to the general public. Ravetz (1973) suggested that the activities of scientists are often misrepresented by the very methods they use to present their findings. Similarly, Catherine Waldby has argued that there is always a "dynamic tension between the humanism of medicine's rhetoric and the technically driven nature of its practices" (2000, p. 82). Latour and Woolgar argued that "not only do scientists' statements create problems for historical elucidation; they also systematically conceal the nature of the activity which typically gives rise to their research reports" (1979, p. 28). In this context, the public incorrectly perceives scientific facts to be objective discoveries of the processes of the natural world (Callon, 1986). I argue, however, that a very similar problem arose when the genomics research facility's computer scientists and biologists attempted to communicate their goals with one another. Each would wind up either misleading (whether intentionally or unintentionally) the other, by leaving out vital technical information or, as in Frank's case, incorrectly assuming the other's technical knowledge of a given field. The biologists' rudimentary understanding of the activities of computer scientists, and vice versa, had a negative impact on the ability for researchers to achieve their goals.

One of the reasons these problems are so pervasive is that genomics and bioinformatics research have "married the two most powerful technologies of the 20th century—computer science and molecular biology" (DeLisi, p. 28). These two fields are combined in a number of different ways, for a number of different projects, each with a distinct set of goals.[32] The problem, as Frank suggested, was that molecular biology, computer science and genomics research are massive fields. By combining the work of biology and computer science, bioinformatics reveals to us the complexity of both fields, and the difficulty one has describing what each of these separate fields produce, let alone what they produce when combined under the umbrella of a genomics research venture. The genomics research facility's bioinformaticians, for instance, had a hard time describing what exactly they do and what constitutes the common ground on which all bioinformaticians find themselves:

> I asked Julie to define bioinformatics. She says that until only recently, even though she has been studying the field for more than three years, she wasn't too sure what exactly the term meant. She has settled on a rather simple, but telling,

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[32] Both computer science and genomics research are broad fields, made of many small-scale research projects. Karin Knorr-Cetina, for instance, has argued that genomics research follows a "small-science" style, conducted "through multiple, decentralized, small-scale efforts" (1999, p. 83). Genomics research is a wide open, emergent field of study, one that "includes agriculture, bioinformatics, environment, fisheries, forestry, health and technology (Graham & Bibeau, 2007). For instance, while my work is focused on the four-dimensional modeling project, the genomics research facility is involved in a wide range of research projects. These projects include the Jabiru project which the genomics research facility describes in the following terms: "Jabiru is a set of object behaviors that are controlled by a virtual wand. This wand can be manipulated through any suitable input device. Current input device implementations as part of Jabiru include either a mouse + keyboard combination or a 6DOF Joystick (CAVE) device + head tracking glasses"(visualgenomics.ca). Milner, one of the genomics research facility's bioinformaticians, works for the Designing Oil Seeds for Tomorrow's Market (DOTM) project. The DOTM project is being used to make mustard seeds more efficient and more productive. They are trying to produce more oil, but also to change the genetic make-up of the seeds so that they can use the remains of seeds which have had oil removed from them for things like animal feed. It is all about efficiency and wasting as little of the mustard seed as possible.

> definition: "Computer science applied to biology" which means that it can be a number of different things, applied to a number different areas of technoscientific inquiry (From field Notes, August 18, 2008).

Similarly, Maxine saw bioinformatics as a new and potentially confusing field. She said that when she first arrived here the director made it clear that science and biology were focusing more and more on the use of computers. She offered that since technology has become more advanced there has been more and more interest in being able to visualize, in the space of the computer, the data obtained from real bodies.

The problem is that the emergence, dynamism and complexity of these fields make it difficult for practitioners to be provided with specific guidelines for effective and productive practices. Genomics and bioinformatics research facilities are heterotopic precisely because individual projects feature new assemblages of biologists, computer scientists, and programming languages, who come together to achieve a unique set of localized goals. As a result, the genomics research facility provides a site "for the presence of constant change and improvisation" (Reed-Pharr, 1994, p. 348). In this sense the genomics research facility is liberating because it is site which opens up the "possibility of possibilities", but debilitating because of the constant struggle between computer scientists and biologists to work together to efficiently and effectively develop complex models of human and animal anatomy.

In order to create the 'black boxes' of accepted technoscientific practice, genomics research facility employees were responsible for developing new modes of ordering what is important to biologists. The problem, generally speaking, was "that of knowing what relations of propinquity, what type of storage, circulation, marking, and classification" (Foucault, 2004, p. 230) would sufficiently tell computer scientists what biologists wanted from them.

Improvised Resolutions

A resolution to this problem might be for the computer scientists to become biological experts, and for biologists to become computer scientists. This is, of course, a laughably unrealistic proposition.

Julie agrees that, ideally, people working in bioinformatics would be experts in both raw human biology *and* computer science. This, however, seems like an impossible ambition, except for a select few employees. She is trying, however, to become as well versed in both as possible (from field notes, August 18, 2008).

Nick saw his job to be one of problem solving. It was not necessary for him to "know how everything works [concerning the human body]" (from field notes, August 12, 2008). His job, rather, was to solve any problems which arose from trying to translate data obtained from real human bodies into a virtual model. An understanding of human biology was not, according to Nick, absolutely necessary. It was important, however, to recognize that which is most important to the biologists.

Devon saw a problem with being a "generalist" across the two fields; but he believed that the more one knew about both fields the easier it would be to make real contributions to bioinformatics research.

Frank found it useful to figure out ways of studying on his own in order to abstract the important elements from his conversations with biologists. It was not important to know everything about biological processes, but Frank thought that one should be well-equipped to understand exactly what biologists want in their anatomical models.

The Guru

There was one other resource these computer scientists had at their disposal. While it is not reasonable to request that all biologists become computer scientists and that computer scientists become experts in molecular biology, the genomics research facility does have one employee, who the other employees referred to as The Guru, who does bridge this gap. He was, perhaps, the most important resource other genomics research facility employees had for creating meaningful exchanges with biologists, and for classifying and ordering important biological data. With the help of The Guru, computer scientists could understand, and, finally, translate biological data into functional virtual models.

The Guru was equally comfortable speaking with biologists and computer scientists. When one of the summer students was confused about something a biological researcher had said, they could often get The Guru to clarify the confusing statements. The Guru was often willing to make recommendations about possible solutions to any emerging problems. As noted above, the problem for biologists and computer scientists alike was that of knowing what information was important, what information would be instrumental to the achievement of the goals of the project. The Guru helped this process by being able to filter out unnecessary information. He could also translate the language of biologists into the language of computer scientists, thus making it easier for work to continue and progress.

These findings support a general understanding among scientists that the only way to deal with today's big questions is to have representatives from multiple fields working together:

> First of all, one could say that complexity seems to introduce the idea that knowledge is not simple any more. Different kinds of knowledge or different points of view are needed to describe a phenomenon. This is in accord with system theory and with the idea that different disciplines have to work together to describe and construct objects in a scientific way (Dijkum & DeTombe, 1992, p. 4).

The genomics research facility provides a great example of the changing face of biomedical research. The genomics research facility constitutes a heterotopia because it contests and inverts a traditional understanding of the fields of biology and computer science. The juxtaposition of these seemingly incommensurate fields generated a number of problems. This juxtaposition is, however, necessary for the genomics research facility to efficiently and effectively construct functional models of human anatomy.

Act II—Humans vs. Nonhumans: Problems and Limitations

So far I have dealt with the site itself, the office environment occupied by genomics research facility employees. The genomics research facility also featured a number of virtual spaces (or perhaps "cyberspaces"), which also fit with Foucault's description of heterotopias. The genomics research facility juxtaposed a number of nonhuman computer interfaces and virtual technologies which were used to build, store and project complex data sets and four-dimensional models of biomedical information.

The list of nonhuman actors from Chapter Two featured a wide range of very distinct technological components that helped facilitate and maintain the daily activities of the genomics research facility employees. As was the case with the interactions between the human actors, the problems that arose from the juxtaposition and eventual integration of all of these different technical components had to do with translating the goals of the project into new environments, through new modes of classification and communication. For genomics research facility employees, it was often very difficult to integrate information obtained from all of these different technical actors into unified models. There were issues with translating and transferring data between these various technologies. Furthermore, employees noted limitations, such as storage capacity and computer power, which often impeded their ability to build their four-dimensional models. These databases and models are intended to fulfill three primary functions: 1) Data organization and management, 2) visualization, 3) the illusion of coherence.

Data Organization and Management

It is always important to keep in mind that much of the work of bioinformaticians and genomics researchers deals simply with the organization and management of a diversity of data sources:

> At the beginning of the twenty-first century, biology may be said to have entered the era of 'Big Science'. Most notably, this is due to its increasing reliance upon immense computing power and technologies that allow the production and processing of large amounts of biological data. (Garlick, 2007, p. 258).

The computer's ability to organize and store complex and diverse data sets further supports my argument that the genomics research facility represents a heterotopic site.

Computers, in the digital era, provide an important resource for combining, and making sense of, large and diverse data sets. As Janet H. Murray argues:

> Starting in the 1970s, computers have become cheaper, faster, more capacious, and more connected to one another at exponential rates of improvement, merging previously disparate technologies of communication and representation into a single medium (1997, p. 27).

Even the Human Genome Project (HGP) is better characterized as a massive data collection program than as a scientific investigation. As Karin Knorr-Cetina observed, "[t]he knowledgeable members of the laboratories thought the genome project's work not particularly exciting, since knowing the genetic maps would not provide direct answers to any of today's burning questions. Nor did they think the work would yield more than systematically organized data banks" (1999, p. 82). Likewise, one of the most important elements of the four-dimensional modeling project is collecting and organizing a large amount of biomedical data. As noted in the prelude, the four-dimensional modeling project deals with three broadly defined sources of data:

1) Medical imaging data such as those derived from functional Medical Resonance Imaging (fMRI), Computed Tomography (CT), Positron Emission Tomography (PET), and microscopy.
2) Anatomical organ reconstructions in the form of 3D surface-based models and digital atlases of the organism's anatomy.
3) Time-varying biochemical concentration data such as those from gene expression microarrays, proteomic studies, pharmaco-kinetic studies, and metabolomic experiments.

Information is obtained from both natural specimens and artificial devices. In many cases, like the time-varying concentration data, natural specimens are altered in order to be suitable for data abstraction. The goal of the project is, again, to take all of these sources of data and create visually coherent models of human and animal anatomy, that may one day be used by researchers studying genetic diseases such as Alzheimer's and diabetes.

Visualization

The data provided to the four-dimensional modeling project was, at first, difficult to work with. In order to make the data usable genomics research facility employees were busy building virtual models of human and animal anatomy:

> The team is completing acquisition of Java 3D anatomical atlases for mapping genomics, proteomics, and imaging data from other subprojects. It will then create a tool kit for virtual reality-based exploration of genomic, proteomic, and metabolomic data on a molecular scale, and link this tool kit visually to the models on anatomical scale...Eventually, the efforts of the...team will culminate in a system that enables complex visual information-retrieval queries and biomedically relevant data mining strategies. (*4D Project Overview*)

The Cave Automatic Virtual Environment provides a virtual space in which the researchers can juxtapose a number of data sources into visually appealing, anatomically correct models of the human body. Remember, these data sets are, in many cases, abstracted from the cellular level. They are trying to visualize parts of the body which are invisible to the human eye.

Coherence

The overall goal of the four-dimensional modeling project is to create a system that can deal with the variability of a number of data sources, while creating the illusion that researchers are working on a unified model of a human or animal body or the individual parts of bodies. All of the various data sources need to work and blend together. Furthermore, the models need to be able to deal with the constant addition of new information, and must be capable of being displayed in a number of settings without affecting the illusion of the model's cohesion:

> For example, the Project requires implementation of portability features for the 4D software across a number of visualization environments including the CAVE, portable 3D visualization displays, and desktops to preserve maximum functionality. Advanced level of detail management features and data skeletonization will be developed to enable massive amounts of data to be loaded into the visual model on demand, in a scalable fashion (*4D Project Overview*).

According to genomics research facility employees, these new modes of display and new data would not be used to forever replace older data sets, but to build on them. Nick saw this as a crucial component of the four-dimensional modeling project. He argued that you could do a lot more with a computer and, as more information became available, computers allowed for the addition of that information without having to completely destroy older models, experiments or data sets (from field notes, August 11, 2008). The goal, again, was to make the system accessible to both the biologists who will use the virtual models and the computer scientists who will be building on these models. The employees at the genomics research facility never seemed to be working towards the completion of the project, but rather towards making the models and work routines accessible to new programmers, new designers, new biomedical data and new display environments.

"It is a Stupid Natural Problem!"

When building their models, there were a number of issues genomics research facility employees had to deal with. Here is an excerpt from my field notes:

> Devon and Alex conclude their chat. I ask Devon if he is having fun. He says "fun...umm...No! It is a STUPID NATURAL PROBLEM!" I then ask, ``oh like an actual problem with how cells work?`` Devon says that his problem is one of tedium and detail. He says that if a person observes a sphere of 10 billion cells and one cell in the middle of that sphere moves, then it affects all of the other cells. He now needs to calculate the movement of each and every cell in the space of the computer. He and Alex were looking for a faster way to do these calculations. I say,``yeah, like an easier way!``, but Devon cuts me off by saying ``Not easier, faster!`` Faster does not, necessarily, mean easier. (from field notes, August 7, 2008).

Devon was doing experimental research at the genomics research facility. He was trying to figure out efficient methods of programming and modeling the interactions between every cell and cell type in the human body. The details that Devon had to account for were staggering, such things as the elasticity of the skin, the health of the body, and whether or not the interior of the body was as sticky in certain spots as in others. For instance, the interior of the arm is not as sticky as the leg (from field notes, August, 7, 2008). The inability of a cell to hold on might mean a cell moves further through the body than it might otherwise. Devon also considered the possibility that two cells could get stuck together in an anomalous fashion. The goal was to see if there was any way to model, in four-dimensions (both space and time), the development of the human body from the first cell all the way to the body's deterioration in old age. Down the road Devon intended to add data obtained from genetic viruses to the simulation. This would allow them to visualize the dividing of cells in a diseased body. Devon was not, however, sure just how far he would be able to get with his project, due to a number of technical limitations.

``Bottlenecks in the System``

There were two major technical limitations that Devon and other genomics research facility employees discussed with me. One of them concerned the actual shape of cells. In bioinformatics programming the most commonly used shapes are spheres and cubes (from field notes, August 7, 2008). These are the closest in shape to what actual cells look like. This generated a number of problems when Devon tried to highlight how cells interact with one another. This was because the representations are not quite the right shape. This means that the ways in which the cells combine would not, necessarily, be duplicated in nature.

The other big problem Devon discussed was the speed of computer software he was using. This was a major problem because he needed to be able to account for potentially billions and billions of interacting cells. His computer dealt with a cluster of one hundred cells quite well, but when Devon increased the number of cells to one thousand the program slowed down considerably. Devon said that at its current level of performance there would have been almost no chance of the computer dealing with anywhere near the millions and billions of cell clusters contained within the human body. He seemed increasingly frustrated by this problem (from field notes, August 7, 2008).

A few days later, I asked Alex about the technological limitations he faced. He said that there were lots of "resources" but that there were 'bottlenecks in the system' (from field notes, August 19, 2008). For instance, they had a cluster of computers but that cluster couldn't render directly to the CAVE. In order to render to the CAVE he needed to do ``pre-computation`` (from field notes, August 19, 2008). A related problem Alex cited was the need for constant migration to new technological infrastructures. According to Alex, the genomics research facility always needed to be thinking about, or worried about, migrating to new systems (from field notes, August 19, 2008). The problem, however, was that new code and new products are often incompatible with the old. This issue actually contradicted one of the main selling points of the four-dimensional modeling project: the development of generic and extendible anatomical models, models which could be compatible with, and projected within virtually any computer system, from PCs and portable display units to massive CAVE environments.

Improvised Resolutions

Like they did with the human actors, genomics research facility employees had to come up with improvised resolutions to the problems which arose with nonhuman actors. Devon, for instance, simply tried to write a piece of code more capable of dealing with the increased number of cell clusters. In computer science, there is always the possibility that one might be able to write a piece of code which solves a lot of the problems a programmer runs into. Again, like the compromise that had to be reached between the human actors, Devon's interaction with his programming language, and with the biological data he was working with, had to do with deciding what information was the most important. His job was to determine what had to be accounted for in order for his models to help biologists study genetic diseases:

> Devon has been having a problem this morning getting his multithreading to work.In order for it to work he needs to start two new processes. One process

> does graphics rendering, the other is for the logic (movement of all cells and the collisions between those cells). He must also get the information on new positions for cells to transfer between the logic and the subsequent visualization. The problem is the connection between the two systems. He has to lock the whole thing to get the logic and then lock it to get visualizations. As I am writing this something has gone wrong. Devon looks agitated. I ask what the problem is. Devon says "don't worry, this is a typical problem" (From fields notes, August 22, 2008).

The problem, I later discovered, was that Devon was trying to account for the fact that all bodies are different. For instance, each body contains a slightly different protein system and a slightly different hormone system. If one thing changed then there would be a local effect. "It is incredibly difficult" Devon said, "to account for how everything will affect everything else" (from field notes, August 22, 2008). But there are, according to Devon, more important cells and more important cell types. As he put it:

> If you lose a finger it is not a huge deal, but if you lose your pituitary gland then you're really screwed. Think about it on the lowest level, what can one cell do,what can one cell type do? The system is built on different cell types. If you account for every cell and every cell type then you don't need to worry about the whole. You can just let the cell movement unfold in the computer. You don't need to keep intervening (from field notes, August 22, 2008).

Devon did not have to account for everything in the human body. He had to be able to model the various cell types, to give his models enough information for them to deal with as many of the various ways in which those cell types could be altered within the body. He did not, however, need to worry about "the whole" (from field notes, August 22, 2008). He did not need to worry about how to model every single human body, but had to provide a generic model which was capable of dealing with all of the variables that might influence the behaviour of cells in any human body. By allowing him to develop generic models, the genomics research facility's virtual infrastructure compensated for the limitations of static human bodies, and static models of human bodies.

Mouse Embryos

Just like research done on human bodies, researchers at the genomics research facility chose to begin many of their projects by working with anatomical images of mice. Together, Alex and Julie were developing a model of a mouse embryo for the purpose of studying particle expression. Specifically, they wanted to be able to look at specific cells in order to understand more about them. They also studied the proliferation of cells throughout the embryo. According to Alex, they were trying to measure certain patterns and the growth of cells in the embryo, specifically those which contribute to the definition of facial features. This includes a need to quantify, inside the embryo, those places where there is more cell growth.

The model was being developed from scanned images from a mouse embryo that was carefully sliced into 200 (give or take) separate pieces (From field notes, August 19, 2008). It was Julie's job to put the pieces back together into a four-dimensional model of the embryo. The lab used "biotechnology to take the image, which was then translated into a complex collection of images and data" (From field notes, August, 19, 2008). Then Julie took that information to build her model. To Julie the project sounded like it should work, at least on the surface (From field notes, August 19, 2008). She cited a number of problems which were both unavoidable and often very frustrating. For instance, it was hard for Julie to construct her model from the scanned images she received. She saw this as an unavoidably imperfect practice. These limitations, however, were nothing compared to the benefits she thought biologists received from being able to visualize bodies at this depth. “Of course”, Julie said, “it is going to be imperfect. You can always add more detail. Scientists don’t see a problem with this and neither should I” (From field notes, August 19, 2008). Among the imperfect practices Alex and Julie were faced with, the images they received were not aligned. Alex thought that a key to their job was something he referred to as “image alignment” (From field notes, August 20, 2008). The images they were working with had been sliced vertically. These images needed to be re-stacked vertically, with proper alignment in what Alex referred to as basically an exact replica of the material embryo.

Alex said that his work involved both automatic and manual tools. Again, the amount of detail he needed to account for was staggering. By the end of the alignment phase of the project, Alex and Julie expected to have anywhere between 20 and 30 embryos modeled. They were trying to get an average concentration in order to develop a generic model. They were very careful not to assume too much about the shape and concentration of cells in one sample. This, to Alex, was one of the most difficult things about their work. Sample size played a huge role. Again, the construction of the generic model was perceived to be superior than the production of a detailed model of one mouse.

Documentation

By building generic models, and by using improvised problem solving strategies, the genomics research facility employees tried very hard to leave their work open to the addition of new information, new code and new methods of abstracting and visualizing biomedical data. Although not perfect, the juxtaposition of such a wide range of human and nonhuman actors allows the models built by the genomics research facility to be open and extendible to new scenarios. The goal, again, is to make the system accessible to both the biologists who will use the virtual models and the computer scientists who will be building on these models. But because so much of the work done at the genomics research facility is improvisational in spirit they also have to make sure that future users and designers are made aware of how, why and with what resources these practices were employed. As a result genomics research facility employees are focused on documenting their own work routines just as much as they are focused on organizing and managing biomedical data.

I asked Nick what he thought was more important, documenting his work routines, or finishing the project. Nick explained the importance of documenting one's code as both a necessity and a common courtesy. It was absolutely crucial that incoming employees can make sense of the coding practices of another. Nick said that everyone had their own approach. Major problems could arise if one's own code had not been documented. Going back weeks or months after a piece of code has been written, with all the different variables and options involved can be very confusing. According to Nick, a person can get lost, even within their own code (from field notes, August 18, 2008).

The Value of Heterotopia to an Understanding of the Genomics Research Facility

The genomics research facility is heterotopic because of its dynamic nature. The employees who occupy the place and virtual spaces of the genomics research facility were trying to deal with the confusing and emergent nature of genomics research by making their models, databases and methods of programming malleable, mobile and accessible to future researchers, designers, visualization techniques and technologies. Each new piece of biomedical data, and each new piece of improvised code needed to be made accessible to both computer scientists and biologists. While it was very difficult to keep up with new information, technologies and infrastructures, these employees improvised, and they did so while accepting that "there can always be more detail added later" (from field notes, August 19, 2008).

The genomics research facility is a product of the age and geography of 21st century genomics research. Its employees develop culturally specific means, modes and methods for storing, organizing and projecting biomedical data. It is a heterotopia, a site of otherness, which facilitates the organization and juxtaposition of seemingly incommensurate humans and nonhumans, including researchers, virtual research and training environments, as well as various types of biomedical data.

The value of the concept of heterotopias is both theoretical and methodological. First, it allows me to justify studying a critical instance because, like ANT, it allows me to highlight the socio-technical complexity of a given site of technoscientific innovation. Technoscience is constantly changing, with individual research projects like the genomics research facility's four-dimensional modeling project, juxtaposing new assemblages of humans and nonhumans within finite places, and virtual spaces where various kinds of biomedical work is conducted, stored, organized and projected. It is important not only to limit analysis to individual projects, but to open up that analysis to include the sticky technical, social, political and economic fibers that facilitate their development, and the subsequent construction of new technologies and new knowledge.

Second, the genomics research facility provides a perfect example of the increasing power and influence nonhumans have on the work of technoscientific researchers. One of the major goals of this chapter has been to highlight the need for genomics researchers to adapt to and become comfortable with these unsettling juxtapositions of humans and nonhumans. Since the 1980s it has been accepted that humans are increasingly becoming cybernetic organisms (cyborgs). A cyborg is an amalgamation of both biological and technological components. As a hybrid identity the cyborg is self-aware, able to recognize his/her/its own malleability. Some have even suggested that this is the very nature of human beings; to build, adapt and absorb biological and cultural prostheses, in order to broaden their horizons and to eliminate the boundaries and limitations of space and time (Kurzweil, 1999). The genomics research facility does this by using virtual environments to build and project their complex models. As a heterotopic site, the genomics research facility opens up the 'possibility of possibilities' by using malleable, dynamic nonhuman actors such as CAVE environments. These technologies make the work of genomics research facility employees difficult and uncertain, but also provide them with a seemingly endless array of problem solving measures. This includes solving social problems which arise when biologists and computer scientists attempt to communicate their goals to one another. Also important, however, are the problem-solving measures provided by the nonhuman tools and virtual environments used by the genomics research facility's employees. While it is often the case that nonhuman actors generate many problems, their dynamic, malleable nature also allows them to remain open to a number of improvised problem solving strategies.

Segue

In order to bridge the gap between this chapter and the next, allow me to provide an excerpt from Samuel R. Delany's influential science fiction novel, *Trouble on Triton: an Ambiguous Heterotopia.*[33] The novel is about a 'happily reasonable male sex worker from mars' named Bron who immigrates to Triton, one of Neptune's thirteen moons.[34] On Triton Bron meets a brilliant artist—a "micro-theatre" performer—named The Spike. The two spend much of their time together engaging in complex philosophical arguments which often make little sense to the reader:

> **The Spike**: ...in the theatre, you have to learn a lot about what the body has to say concerning the movements of the emotions—
> **Bron**: Only I'm not into theatre. I'm into metalogics. What about those of us who don't know what the body has to say about the emotions? Or the paths of the comets? Put it in terms that I know!
> **The Spike**: Well, I'm not into metalogics. But you seem to be using some sort of logical system where, when you get near any explanation, you say: 'By definition my problem is insoluble. Now that explanation over there would solve it. But since I've defined my problem as insoluble, then by definition my problem is insoluble. Now that explanation over there would solve it. But since I've defined my problem as insoluble, then by definition that solution doesn't apply'. I mean, really, if you...No. Wait. You want me to say what happens in your terms? (Delany, 1976, p.103)

The problem, of course, is that Bron and The Spike are attempting to come to a common understanding of how Bron deals with human emotions, but both are approaching the

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[33] It should be noted that some editions feature the somewhat more confusing subtitle, "Some Informal Remarks Towards the Modular Calculus, Parts One and Two". "An Ambiguous Heterotopia" is the first and most well-known, subtitle of Delany's novel. The subtitle is a play on Ursula Le Guin's anarchist utopia, *The Dispossesed*, which features the subtitle, "An Ambiguous Utopia". Delany, however, did not write his novel as a response to Le Guin's; he added the subtitle to his completed draft only after reading *The Dispossessed.* Delany believed that if the two novels were placed in conversation with each other they could spark an interesting debate (Philmus, 1990, p. 301). In this way Delany follows Foucault by seeing an important connection, and contestation, between utopias and heterotopias.

[34] Triton is a place where unsettling juxtapositions abound. People are not bound by traditional means of social and bodily ordering, and there are no limits to the social and sexual identities one can embody. As Carl Freedman argues, heterotopia's core meaning, "the displacement of an internal organ or other body part to an abnormal location—is quite pertinent to Delany's invented society in which changes of sex and race are as common as tattoos or nose jobs in our own" (2006, p.22).

topic from a distinct perspective. The Spike is an artist, and approaches the discussion with an understanding of the contingency of human emotions. She recognizes the possibility of possibilities, noting that there is always an answer to one's questions, even if they are sometimes found in unusual locations or by unusual methods. Bron, on the other hand, takes a more literal approach, choosing to define his problems in terms of a set of logical statements leading to his inability to think outside of his predetermined box. Bron fails to see that explanations exist everywhere.

This excerpt provides a useful segue into the next chapter, which deals directly the blurred boundaries between what constitutes fact and fiction, nature and culture, art and science in twenty-first century technoscience. Technoscience, as I have demonstrated, is not simply the result of objective discoveries of the processes of the natural world. Instead, technoscientific innovations are the result of a number of complex and contingent factors, including social relationships, technological advances, and the cultural climate within which these innovations are developed. It is important, I think, for STS researchers to account for the cultural influences on technoscientific practice. In the next chapter, my goal is to theorize what the genomics research facility produces. Rather than scientific facts, in a traditional sense, the computer scientists, graphic designers and bioinformaticians that make up the genomics research facility are working towards building narrative environments, or virtual theatres which may, one day, facilitate the construction of scientific facts.

Like Foucault's description of the heterotopic cinema, the genomics research facility "is a very odd...room, at the end of which...one sees the projection of a three-dimensional space" (2004, p. 233). The difference, of course, that the CAVE environment allows researchers to be immersed in the illusion of three-dimensional space. The four-dimensional modeling project, because of its ability to project disease processes overtime is a powerful narrative environment. The CAVEman, genomics research facility`s four-dimensional model of the human body, could one day be capable of telling multiform narrative fictions of genetic diseases. These stories could be retold, revised, problematized and improved upon. As a result of the malleability, dynamism, emergence and fluidity of these models, they can help 21st century genomics researchers acknowledge the contingency of their research. Rather than hindering scientific progress, the humbling potential of these models could liberate scientific researchers.

Chapter Four
"Dealing Exclusively with Middles": Science Fact and Science Fiction at the Genomics Research Facility

> "The man's hands stopped and laced themselves behind his head. He snorted out the side of his mouth, as if flossing the idea from between his teeth. 'No finale. We deal exclusively with middles here.'"
>
> – Dr. Lentz, from Richard Powers' *Galatea 2.2*

My little narrative has been unfolding quite nicely up to this point. I have introduced the main characters—a clusterfuck of socio-technical actants—and established the setting—a grey and dreary Western Canadian heterotopia—in which these characters act. I have rising action through the establishment of a set of social and technical conflicts these characters must resolve in order to build complex databases and dynamic virtual models of the human body. I started, of course, from the assumption that technoscience was made up of what Bruno Latour refers to as a "proliferation of hybrids"; hybrids constructed by assemblages of humans and nonhumans. I then theorized the places and virtual spaces within which these humans and nonhumans interacted with each other in the construction of four-dimensional models of human and animal anatomy. My goal up to this point has been to highlight the complexity and contingency of the four-dimensional modeling project. But now it is time to say something about what this complex, "disturbing" juxtaposition of biologists, computer scientists, mouse embryos, and virtual CAVE environments is working towards. On the surface this seems like a simple task.

At their core, the models being built at the genomics research facility are biotechnologies. They are built using data abstracted from biological specimens, and are meant to be used for studying genetic diseases such as Alzheimer's, diabetes and various forms of cancer. While certainly a good start, this description doesn't tell me much about what exactly these virtual models are, how they are built, or what their potential implications might be.

Part of the problem is the slippery nature of descriptions of genomics and bioinformatics research. As I have shown, genomics research is constantly evolving and encompasses a wide range of disparate fields, making it hard to, among other things, "find one person who embodies the entire field of [genomics]" (DeSalle & Yudell, 2005, xix). Not surprisingly, it is also difficult to describe exactly what genomics researchers and bioinformaticians produce. As Sheryl Hamilton has argued:

> Biotechnologies can be described in Bruno Latour's language as emergent science- namely, a science whose "truth" has not yet been settled by consensus, either scientific or public. Therefore, what any given biotechnological practice—not to mention biotechnology as a whole—means is still unstable, still being negotiated in both the scientific and public domains. (2003, p. 269)

Just like actor-networks and heterotopic sites, biotechnologies are problematic because of their dynamic nature. I want so desperately to say what they are, but I only get these fleeting instances of understanding before a shift occurs. There is, for one thing, a constant and steady development of new biotechnologies. The problem that emerges is similar to the difficulty Latour has defining what constitutes 'the social'. Biotechnology "disappears because it flashes only briefly, just at [a] fleeting moment" (Latour, 2005, p. 159) and then gives way to new advances, new modes of production and design, new limits, new summits, new uses.

The findings in this chapter support the work of many STS and feminist science scholars who argue that there is no need to develop definitive, universal conclusions about the products and implications of fields like genomics and bioinformatics research. When trying to describe the fields of bioinformatics and genomics research, and the biotechnologies they produce, I have decided to take a cue from the wise, stubborn and eccentric Dr. Lentz from *Galatea 2.2.* Like the work described by Dr. Lentz, my narrative lacks the potential for a finale. I have humbly accepted that there will be no black box, no final resolution, and rightly so. In the field of genomics research there can only be rising action, and with rising action comes more questions, more details, more suspense, more concerns, and more minute discrepancies. But this does not mean that my inquiry into the construction of the four-dimensional modeling project has become a fruitless endeavour. I can still say something about the desired conclusions genomics research facility employees hope to come to. I can, for instance, provide some insights into how one might theorize the models and databases these employees are producing. And I can at least say something about the potential implications of these technoscientific products.

This chapter deals with the potential outcome of the practices described in the previous chapter. I view the genomics research facility as a site of cultural production where certain sets of practices and skills are applied to help researchers achieve sets of goals.[35] As Timothy Lenoir argues, "far from characterizing them by theoretical,

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[35] The work of researchers at the genomics research facility could also be described in terms of what Bourdieu calls 'symbolic capital' and fields of cultural production. Bourdieu's definition of cultural production is similarly broad, including science, law and religion as well as forms of expression such as art, literature, television and film. Bourdieu differentiates the field of cultural production from other fields, most notably the economic field. For instance, Bourdieu argues that the "literary field is the economic world reversed; that is, the fundamental law of this specific universe, that of which establishes a negative correlation between temporal (notably financial) success and properly artistic value, is the inverse of the law of economic exchange" (Bourdieu, 1993, p. 164). According to Timothy Lenoir:What distinguishes the fields of cultural production from the economic fields is that the logic of domination is reversed. In these social worlds the law of success is defined not in financial or economic terms but in terms of the creation of value the generation of belief in the value of art or science for its own sake and the recognition

disembodied abstraction, I view [laboratories] as sites for the coordination and embodiment of skill. Persons deficient in the requisite culture, lacking both explicit and tacit knowledge of how the institution works, run sprang into concrete walls" (Lenoir, 1997, p. 2). The genomics research facility can be similarly regarded as a site for the coordination and embodiment of skill.

According to Lenoir, "[a] related cluster of issues that an interpretation of science as a form of cultural production must address is the construction of meaning, the naturalization of representations, and the linkage between different domains in an economy of practices" (Lenoir, 1997, p. 18). The same can be said for a site of technoscientific production. The practices of genomics research facility employees, for instance, are interesting because of the ways in which they can be compared to other sites of cultural production. For example, I am intrigued by both the similarities and the differences between the facility's employees and video game developers. I am also interested in how I can use examples from other cultural products, such as video games, as well as science and speculative fiction, to help me describe the models these employees are producing, and the virtual environments within which these models are being displayed.

Here I argue that the genomics research facility's employees are attempting to produce fictions through, with and within the construction of scientific facts may one day be facilitated. I word my argument in this way because, like the incunabalas of the early

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of the legitimacy of the artist, writer and scientist as a creator of valued objects. There is, however, no such thing as pure field. For instance, there is always an overlap between the cultural and economic fields. As Lenoir argues, there is a battle between "forms that are culturally dominant and symbolically 'pure' though economically dominated versus those that are commercially oriented to the market" (Lenoir, 1997, p. 11). Similarly, genomics research facility employees are not creating a product which is free from economic considerations. Though they are creating something which they view as inherently beneficial for its own sake, they are still trying to turn their models into commercially viable training and research kits.

printing press, the models being developed by the four-dimensional modeling project are still in their infancy.[36] It is still not clear how, if at all, the virtual models produced by the genomics research facility's programmers and designers will help future biomedical researchers better understand the processes of genetic diseases in flesh and blood human bodies. I am, after all, dealing exclusively with middles here.

Within this framework I can highlight both the scientific and the artistic potential of the models being built by the genomics research facility. I can also account for the collapse of science fact and science fiction in 21st century technoscience. As Tamar Schlick has argued, it is important "to draw the sciences and the arts closer to one another, and to do so positively" (2005, p. 327). I will do this by describing the genomics research facility's models, and the CAVE within which they are projected, in terms of their narrative potential, their ability to operate not merely as forms of medical imaging, but as complex storytelling machines. These four-dimensional models, from this perspective, become complex forms of digital art, as well instrumental medical images.[37]

Using the work of Brenda Laurel and Janet H. Murray, I begin this chapter by describing the genomics research facility's CAVE as a fictional narrative environment. This includes a comparison between the CAVE and the Holodecks found in the popular *Star Trek* series, as well as the Cavern construct from Richard Powers' novel, *Plowing the Dark.* I will also introduce the malleable generic models that genomics research facility

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[36] According to Janet H. Murray, the word incunabala is derived "from the Latin for swaddling clothes and is used to indicate that these books are the work of a technology still in its infancy" (1997, p. 28).

[37] I view the work of the genomics research facility employees as the development of "a new art form, one largely immune to traditional tools developed for the analysis of literature and film", which "will challenge us to develop new analytical tools and will become a new type of 'equipment for living', to use Kenneth Burke's (1973) phrase for the role of literature" (Paul Gee, 2006, p. 58).

employees produce. By doing so I can more accurately describe the CAVEman as a fictional character.

At the heart of this chapter is a recognition that the work of genomics research facility employees necessitates the development of these complex storytelling machines. In order to deal with the complexity of genomics research, the constant development of new technologies, the constant addition of new information and new methods of abstracting and projecting biomedical data, these researchers *require* productive fictions. These fictions help them "make sense of their world". As Janet Murray argues:

> [W]e rely on works of fiction, in any medium, to help us understand the world and what it means to be human. Eventually all successful storytelling technologies become 'transparent': we lose consciousness of the medium and see neither print nor film but only the power of the story itself. If digital art reaches the same level of expressiveness as these older media, we will no longer concern ourselves with how we are receiving information. We will only think about what truth it has told us about our lives (1997, p. 26).

I want to bring virtual medicine into Janet Murray's framework. As a site of uncertainty and improvisation, the genomics research facility provides an excellent example of the liberating potential virtual reality research has for technoscience. It becomes important, however, to view these models and these virtual environments not in terms of their ability to provide us with objective discoveries of the processes of the natural world but in terms of their constructed nature. As noted earlier, such a framework reminds us of "the centrality of 'make-believe' in the conception and design of software" (Laurel, 1990, p. 29), regardless of whether the software being designed is intended for recreational use, or serious scientific investigations. The computer, as Brenda Laurel has argued, simultaneously facilitates both work and play. Colouring books, statues, science fiction films and literature, biomedical models and databases are culturally specific products of human imagination. Once again, as Donna Haraway argues: "[a]ll the trappings of universal science aside, amending a database is a pretty culturally specific thing to do" (1997, p. 268). Just because models and databases are built for technoscientific purposes does not make them immune to these sorts of descriptions.

I consider the uncertain, improvisational spirit I observed at the genomics research facility to be a liberating and humbling force. Computers offer researchers the unique ability to open up the possibility of possibilities. No longer do researchers need to concern themselves with making universal claims. Genomics research facility employees produce fictions which may one day facilitate the construction of localized scientific knowledge, but, as I have noted, they approach their work with a playful, improvisational spirit. They are the first ones, for instance, to tell you about the limitations of their work. They seem all too aware that they do not produce black boxes, but systems that can deal with the emergence, dynamism and fluidty (read: uncertainty) of contemporary genomics research.[38]

"And you are...?"

It was not just difficult to describe what genomics research facility employees produced, but also to describe the facility's various computer scientists and graphic designers. The following questions emerged: How do these employees fit within a technoscience studies framework? Are they mere laboratory technicians? Do they simply aid scientists or do they, along with scientists, produce their own facts, their own

[38] Though the work here could be used as a foundation for future research on other sites of technoscientific innovation, it should not been seen as a comment on technoscience in general.

knowledge? How can I account for the fact that these researchers blur the line between scientific and artistic production?

When asked about what exactly they produce, genomics research facility employees offered vague, yet telling answers:

> I ask Julie if she is producing knowledge, or simply a virtual space for knowledge to be produced. She is a little confused by this question, laughs and snorts. She says that although knowledge about biology is indirectly obtained, the purpose of her work is to provide an outlet for knowledge to be obtained. She is not, necessarily, responsible for the creation of new information. She is supposed to make data understandable and accessible in a virtual model which may be used to develop more profound knowledge about biological processes at the cellular level. (from field notes, August 19, 2008).

Alex offers a similarly interesting response:

> I then ask Alex whether or not he sees his work as producing new knowledge, or providing a space in which new knowledge of biological processes can be developed. Alex answers this question very carefully, much like Julie did. It is, for Alex, a little of both. He says this is because it is his job to model the things inside and the things around the organs and cells being modeled. If his job is to quantify cells in a slice of an embryo from a photograph he might indirectly create new knowledge, in the form of a method of programming or modeling in computer science, and in the process create a more efficient space for biologists to develop new knowledge about biological processes. (from field notes, August 20, 2008).

It is important to keep in mind that I am not dealing with natural scientists, but computer scientists and graphic designers. According to Peter Denning, "[t]oday, computing science, engineering, mathematics, art, and all their combinations are grouped under the heading 'computer science'" (2005, p. 28). Computer science is, like everything else comprising this thesis, an emergent, dynamic, fluid field. As Paul Graham argues, "[c]omputer science is a grab bag of tenuously related areas thrown together by an accident of history, like Yugoslavia" (p. 18). The bioinformaticians comprising the genomics research facility were, likewise, working with a grab bag of various biomedical data sources, and building models which could be used by a grab bag of various research projects, each with a distinct set of goals. Bioinformaticians "explain DNA as encoded biological information" (Denning, 2005, p. 28) but they do so using a wide range of sources, with a wide range of potential outcomes. The methods bioinformaticians and computer scientists use to explain DNA as biological information share important similarities with other forms of digital expression. As Janet Murray points out, "computer science itself is moving into domains that were previously the province of creative artists" (1997, p. 59). Genomics research facility employees walked a similarly fine line between scientists and artists.

Genomics research facility employees appeared to be fully aware of the relationship between their work and other modes of cultural production. For example, a number of these researchers had ties to art and video game communities.

Nick used to be a game programmer and sees very little difference between his work at the Sun Centre and his job developing video games. He feels this place provides a similar work environment. His role, he argues, is essentially the same. "The images", Nick says, "don't do anything without programming". (from field Notes August 11, 2008)

It did not seem to matter to Nick whether or not the images he is asked to program are for a game or a virtual model of human biology. Nick then laughed, and admitted that he did not necessarily intend on working in medical programming or bioinformatics. He simply applied late for different co-ops and this was the first one that responded. This is an important point because it highlights the fact that computer scientists and graphics designers approach their work in a playful, improvisational manner. They can adapt, quite easily at times, to a number of new and quite distinct research scenarios. This was perhaps the reason why the genomics research facility would want somebody with Nick's skill set. The ability to improvise problem-solving strategies seems very beneficial to the sort of work being done at the genomics research facility.

Douglas comes from a similar background. Douglas was trained at a Western Canadian art college. Like Nick, Douglas spent six months or so doing game development prior to working at the genomics research facility. He saw this as a hobby, but it seemed like he wanted to pursue game development as a career. He has independently developed his own games. According to Douglas, video gaming provided the foundation for his work at the genomics research facility. He suggested that all 3D modeling is based on the same basic principles. He even used the same software for creating kidney models as he did for developing video games. And while he admitted that it would be nice to have specialized medical modeling software, it was not necessary (from field notes, August 9, 2008).

Alex made a similar, if more nuanced, claim concerning the relationship between the work he does at the genomics research facility and video game development. Alex said that a key difference between biomedical computer modeling and video game development was the tools, goals and interests of the various research labs and companies. They all work in the same general field but something like video game development operates on different platforms, sometimes with different software, hardware and (obviously) goals for projects. Video game developers, for instance, want tight deadlines but research labs have softer deadlines, and are more willing to accept variables and problems which may arise. Video games and virtual genomics were like "cousins", according to Alex. In this way, video game development seems more rigid; they want, in the end, a final product. But, while the genomics research facility was interested in pursuits that were more exploratory, less goal-oriented, one cannot forget their mandate to develop a commercially viable virtual research and training toolkit. They are, in fact, attempting to build an aesthetically appealing piece of software (from field notes, August 20, 2008).

These responses provided some evidence that genomics research facility employees walked a fine line between those who create digital art and those who produce scientific knowledge. In fact, they seemed to bridge the gap, by working to build worlds structurally similar to the virtual narrative environments found in video games and other forms of virtual reality, but which could one day be used to produce functional knowledge of the processes of genetic diseases.

To put it more simply, genomics research facility employees produced ways of producing scientific knowledge. It is important to remember that software development, graphic design and computer science are malleable foundations for a number of intriguing scientific and artistic endeavours. Viewing the work of the genomics research facility's bioinformaticians and graphic designers as simultaneously artistic and scientific forms of expression reminds one of both the infinite possibilities virtual technologies afford, but also the constructed, aesthetic nature of the work they facilitate. As the narrator in Richard Powers' *Plowing the Dark* quips, "[w]hatever else they spoiled, graphics threw open portals all their own. The visual interface launched habitations faster than anyone could click through them. Any eleven-year-old who'd ever touched a video game was way out in front of the scientists on that score. Scientific visualization was born in the first wave of Space Invaders" (Powers, 2000, p. 110). My point is that the computer, even when used in genomics research, becomes a facilitator of both work and play, serving both the human need for scientific knowledge, and the need to visualize, in an aesthetically pleasing manner, the contents of human imagination.

Computers as Theatre

For genomics research facility employees the computer is important for a number of reasons. As has been noted, the computer is instrumental in allowing genomics researchers to organize large amounts of data. Data management, in bioinformatics, is impossible without the computer. But it is also important to think about what researchers do once they have compiled all of these seemingly disparate data sources. If properly managed, the wide range of data sources could help scientists discover biological patterns inaccessible to simple observations of live human subjects or cadavers. This claim suggests not only that the computer is an instrumental device, but one which is used as an aesthetic tool, in order to develop environments, models and simulations which are, in certain respects, better than the real thing. Those who develop informational images follow what James Elkins refers to as a "pre-Kantian sense of aesthetics as the 'perfecting of reality'" (1995, p. 558).

As I have stated throughout this thesis, the genomics research facility is a site of improvisation and uncertainty. Genomics research facility employees require playful environments which facilitate the juxtaposition of a number of unique sources of biomedical data. A computer "is potentially capable of supporting both serious and non-serious activities. Its evocative powers and even its ambiguities can be harnessed to enhance rather than to impede a person's serious goals, and to create the possibility of surprise and delight—things that are rarely produced by exhaustive responses to crystal-clear specifications" (Laurel, 1990, p. 27). This evocative power is helpful in a number of scenarios, not the least of which being the application of computers to research done at the molecular level. For genomics research facility designers, computer scientists, and biological researchers it is the *desire* to visualize—from multiple angles, and at multiple depths—and subsequently understand, the microscopic components of the human body that creates the *need* for complex virtual models. It is not simply the insatiable need, as described by Brenda Laurel, to exercise judgment, intellect and spirit in different contexts and situations, but to exercise intellect on what the human eye cannot see and to store and visualize information the human mind is not capable of organizing on its own.

The CAVE and Multiform Narrative Fiction

Perhaps it is useful to think about computer code as both a form of literary expression and technical communication. In Richard Powers' *Plowing the Dark,* two characters, a computer scientist named William Spiegel and a visual artist named Adie Klarpol have the following conversation:

> **Spiegel**: Code is everything I thought poetry was, back when we were in school. Clean, expressive, urgent, all-encompassing. Fourteen lines can open up to fill the available universe.
> **Adie**: Different kind of sonnet, though, right? Different rhyme scheme?
> **Spiegel**: I don't know, sometimes you gotta wonder (Powers, 2000, p.7).

Code, by this account, is as powerful a form of expression as a sonnet. Code, whether applied to video game development or technoscientific models is an aesthetic medium.

The virtual models built by genomics research facility employees have the potential to tell, what Janet Murray refers to as "multiform narratives". They can be told from a number of perspectives. For Janet Murray, the multiform story's importance is the result of "the dizzying physics of the twentieth century, which has told us that our common perceptions of time and space are not the absolute truths we had been assuming them to be" (1997, p. 34). She goes on to argue that "print and motion picture stories are pushing past linear formats in an effort to give expression to the characteristically twentieth-century perception of life as composed of parallel possibilities" (1997, p. 37). However, Murray sees print and film as limited media for the development of these multiform narratives. Describing a slew of self-reflexive films and novels, Murray comes to the conclusion that "[t]o capture such a constantly bifurcating plotline, however, one would need more than a thick labyrinthe novel or a sequence of films. To truly capture such cascading permutations, one would need a computer" (1997, p. 38).[39] The same can be said for the molecular biological research for which the genomics research facility's virtual models are being built. Multiform narratives are important because of their ability to tell complex, contingent and interactive narratives. Multiform narratives are not black boxes, but stories which are open to variation, open to multiple users coming to multiple conclusions. In order to tell stories which live up to the full potential of multiform narratives, one needs an interactive medium, like a computer or a virtual CAVE:

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[39] Murray references everything from *Back to the Future* and *It's a Wonderful Life* to Borge's "The Garden of Forking Paths". For more, consult pages 30-38 of *Hamlet on the Holodeck.*

> The complexity of pattern manipulation made possible by the computer seems to be pushing stories into the realm of higher degrees of abstraction and variation. But in pursuing complexity and abstraction, we run the risk of incoherence. Since the success of any abstract representation of plot will depend on how much control remains in the hands of the human author, we may find that less computational abstraction will produce more satisfying stories (Murray, 1997, p. 203).

Code is the script that helps those who will plot these complex narratives create aesthetically pleasing and seemingly coherent models and simulations within the CAVE environments. This is true at the genomics research facility, where one of the main goals of the project is to create a seemingly coherent model of the human body from a number of disparate, seemingly incompatible sources of biomedical data. In reality these data sources do very little for one another. In a coherent model of the human body, however, they work together to help researchers recognize patterns they otherwise would not have been able to observe. Code is crucial to the storytelling potential of genomics research, because without code, "you have a purely graphical environment. There is no movement" (from field notes, August 14, 2008).[40]

Genomics research facility employees display and test their models in digital narrative environments which share important similarities with other narrative environments, such as video games and examples from a number of science fiction texts. This is how the genomics research facility described its goals for the four-dimensional modeling project:

> Using an immersive virtual reality environment called the CAVE, the research team will integrate a high-resolution digital atlas of a human body with medical data related to specific diseases. The final result will be a next-generation 4D (space and time) visual system to "see" disease processes and the effects of interventions, such as drugs, on these processes (4D project overview).

[40] The employees at the genomics research facility use Breve and Open GL programming languages.

The genomics research facility's use of the CAVE, it should be noted, is just one of many contemporary examples of a shift towards the implementation of virtual reality research and training environments in the medical sciences.[41] Descriptions of the CAVEman and other virtual medical technologies have noted similarities between the virtual environments occupied by contemporary medical researchers and those represented in works of science fiction and video games. Some recent newspaper articles about the four-dimensional modeling project, for instance, include headlines like "Science Fiction a Virtual Reality" (Sinnema, 2007), "New Facility Unites Imagination of Science Fiction with Medicine" (Spencer, 2008), and "University of Calgary's Six Million Dollar CAVEman" (Lang, 2007). More relevant to my work, however, is the fact that researchers working on the CAVEman have referred to their CAVE as the "research holodeck" (Walton, 2007; Lang, 2007), a reference to simulators first found on the Starship Enterprise in *Star Trek: The Next Generation* (both the films and television series) and subsequently in *Star Trek: Voyager.*

In a press release the CAVEman was described as residing "in the CAVE, a cube-shaped virtual reality room, also known as the 'research Holodeck', in which the 4D human model floats in space, projected from three walls and the floor below" (McCarl, 2007). On a January 27, 2009 episode of *Daily Planet*, a popular television series about emerging science, Dr. Randall Johnson, a cancer researcher who is one of the first to use

[41] Among other recent examples are the use of Nintendo Wii gaming systems in surgical training (Nolan 2008) and the development of a virtual laboratory for cardiologists at the University of Alberta's Mazankowski Heart Institute where doctors can actually practice upcoming heart surgeries on a holographic model of the human body (Spencer 2008).

the genomics research facility's CAVE infrastructure, described his initial experiences in the CAVE:

> You know it's remarkable how this thing actually works. You put on these crazy glasses and you have these slippery shoes...and you walk into something that's kind of like the Holodeck in a way. You're surrounded on all sides by these screens which project images of whatever it is you happen to be studying. And you have this controller that is kind of like a controller on a video game. And you can sip and zoom and slide through the whole human body (Ingram, 2009).

Dr. Johnston made reference not only to the similarities between the genomics research facility's CAVE and the Holodeck, but also the ways in which interacting with the CAVE is a lot like playing a video game. This sort of self-awareness was also not uncommon among genomics research facility employees. They seemed to be aware of the similarities between their work and the work of other cultural producers and, as a result, were aware of the blurring relationship between science fact and science fiction in their work.

There are a number of interesting similarities between the Holodeck and the CAVE used by the genomics research facility. According to the *Star Trek: The Next Generation Technical Manual,* the Holodeck "generates remarkably lifelike recreations of humanoids and other lifeforms...The results are exceptionally realistic 'puppets', which exhibit behaviours almost exactly like those of living beings, depending on software limits" (Sternback & Okuda, 1991, p. 156). Similarly, the CAVE models built by genomics research facility employees are lifelike, and can behave in ways very similar to real world creatures, but are dependent on important software limits. Genomics research facility employees are, however, limited in ways that Starfleet officers are not. According to Sternback & Okuda, "under normal conditions a participant in a Holodeck simulation should not be able to detect differences between a real object and a simulated one" (1991, p. 156). At the genomics research facility there is a very clear difference between the virtual human and a real human subject. Regardless of the Holdeck's superiority in certain respects, it shares with the genomics research facility's CAVE a dynamic nature. Software limits are still an issue for this fictional environment and, even after centuries of development, the Holodeck is still being improved and built upon.[42]

Both the Holodeck and the CAVE open up the possibility of possibilities. They are both virtual environments which facilitate the construction of seemingly limitless multiform narrative fictions. The images they project can be viewed from multiple angles, can be stopped, fast-forwarded and re-wound, slowed down or sped up. As the Director of the genomics research facility told *Daily Planet*, "[w]e can actually put it so that you can study everything within five minutes. If it takes 90 years for it to progress, if you have Alzheimer's disease and you want to take time points from that over many many years, or, if you have a protein-protein interaction which happens in a few nanoseconds, or even faster than that, you can always time it so that you see it in there at the time that you need to really understand what the mechanism is" (Ingram, 2009). Similarly, the Holodeck, according to Janet Murray, is "an illusory world that can be stopped, started, or turned off at will but that looks and behaves like the actual world and includes parlor fires, drinkable tea, and characters, like Lord Burleigh..." (1997, p, 15). For Murray the

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[42] Here is what the *Star Trek: The Next Generation Technical Manual* has to say about the four hundred year history leading up to the development of the Holodeck: "the desire to experience images, sounds, and tactile stimuli not normally encountered on a space vessel has followed explorers across the galaxy for the last four hundred years. Computer-driven projection imagery has filled starship crews' needs for provocative spaces and, with the addition of certain sport and recreational gear, provided an enjoyable model of reality. Various holographic optical and acoustic techniques were applied through the years, finally giving way to a series of breakthroughs in small forcefield and imagining devices that not only seriously impact starship mass volume constraints, but actually nurtured hyperrealistic, flight-critical simulations. In the last thirty years, the starship Holodeck has come into its own" (Sternback & Okuda, 1991, p. 156).

value of the Holodeck lies in its power as "a universal fantasy machine: a vision of the computer as a kind of storytelling genie in the lamp" (1997, p. 15). Although it is a much more crude example, the CAVE used by genomics research facility can be similarly described as a storytelling machine.

Demos

While I was at the genomics research facility, I saw three demonstrations of the ways in which researchers are currently able to use the CAVE. One of the big demos the genomics research facility's employees showed me was a program for watching the concentration of painkillers (such as Tylenol or Aspirin) move through the human body over time:

> While an employee at the facility Nick has worked on two major projects. The first of these projects was to develop a metabolite map for the CAVEman. The metabolite map would be used for visualizing how pain killers are dispersed in the organs of the body. The team has only used data from aspirin and Tylenol so far, because, as Nick suggests, these are the two most common pain killers. Nick takes data concerning pain killer metabolite concentration and programs the CAVEman's virtual model to create visual representations of the concentration of those metabolites over time. He tries to make these images accessible to people who are not biology experts. (From field notes, August 7, 2008).

Here is how I described this demonstration:

> For this demo the skinless virtual model is whole. The entire body is visible and Alex can enlarge, shrink and spin the body in any way he sees fit. Alex then loads digital aspirin into the body. The model then shows the concentration of the aspirin in the body over time. At first the body is all white, showing that the drug is concentrated evenly through the body. As the aspirin becomes more concentrated in individual organs those organs will be highlighted with different colours. (From field notes August 7, 2008).

Unlike the Holodeck, the CAVE did not represent the metabolic concentration in real time. Its representations were based on intervals presented in the data. This is a major software constraint. And even though it was merely trying to show intervals, the CAVEman often ran very slowly. While trying to show me the demo, Nick's computer froze multiple times. These factors, however, should not diminish the narrative potential of the CAVE, nor the ability for the CAVEman demos to help researchers engage with virtual models of human anatomy with increasing detail and realism.

There were two other noteworthy demonstrations Alex loaded for me. The first was meant to highlight the CAVEman's capacity to abstract specific body parts, enlarge them, spin them and, perhaps the most interesting feature, place the viewer within the organ itself. The organ Alex demonstrated was the human heart. While everyone in the room could feel immersed within the heart, only Alex's glasses, which were connected to a remote, perceived the organ from the right perspective. This is interesting because the model actually accounted for people in the CAVE seeing the model from a different angle. The tracker on the glasses moved with Alex. So as Alex moved closer to the model of the human heart the model appeared larger and larger until he passed a threshold and actually appeared to enter the virtual organ. As he turned his head the angle from which one perceives the organ would change slightly. This demo highlighted one of the most important characteristics of Janet Murray's multiform narratives: "digital narratives add another powerful element...by offering us the opportunity to enact stories rather than to merely witness them". The CAVE's ability to alter the perspective from which Alex and others view the body or part of the body they are studying provides evidence that it "exceeds both narrated and conventionally dramatized events because we assimilate them as personal experiences" (Murray, 1997, p. 170). Although this experience is not seamless, like one which would take place in the Holodeck, it does provide a much more powerful way to interact with medical images.[43]

The third demonstration I was witness to highlighted another important component of the genomics research facility's project. According to Alex, this demo did not do much to benefit scientific investigations, it was "just for the sake of a demo" (from field notes, August 7, 2008). It was an interesting demo, because it had been designed to mimic how human beings see things in more detail as they get closer to an object. In this case the demo began with the model appearing far away. As Alex zoomed in, more and more body parts became visible and those parts became increasingly detailed in their design.

Within the multiform narrative environment provided by the genomics research facility 's CAVE, researchers project complex models of human and animal anatomy. These models are playful and malleable but also functional and adaptable to a variety of research scenarios. The CAVE environment allows researchers to develop increasingly realistic models which could one day be used to tell the story of genetic diseases in four-dimensions. Although the CAVE can at times be slow and although they are unable to provide seamless, real-time visualizations, the fact that genomics research facility researchers can display a dynamic image provides them with the potential to develop complex multiform narratives of disease processes and the effects of various drugs and treatments on genetic diseases. These models can be viewed from multiple angles, each angle providing researchers with a unique perspective and potentially a unique set of

[43] Based on this same understanding of the power of virtual reality, many psychologists and psychiatrists have implemented various forms of virtual therapy. This particularly true in cases when patients are haunted by debilitating phobias. As Murray argues, "the virtual world is more external than the hypnotic experience but artificial enough to make it possible for patients to approach it at a much earlier stage than they could if facing the actual situation. It is a threshold environment" (1997, p. 171).

findings and conclusions. The story they might tell will never come to a definite conclusion, but this does not mean that the work they facilitate would not be productive for genetic researchers. Allow me to provide one last example from a popular piece of speculative fiction.

In *Plowing the Dark*, a group of researchers at a "digital laboratory" work to build a CAVE, which they refer to as the Cavern. The Cavern can become anything from a jungle to a painting or a "vast Byzantine cathedral" (Powers, 2000, p. 158). William Spiegel, one of the main Cavern researchers, has this to say about the narrative potential of the virtual environment: "...the Cavern blows opera out of the box. We're not just passive recipients anymore. We'll become characters in our own living drama" (Powers, 2000, p. 160). The character in Spiegel's living drama is the human body. As he puts it, "The Cavern is the first art form to play directly to that body. We're on the verge of immediate, bodily knowledge" (Powers, 2000, p. 160). The main character in the narrative developed by genomics research facility is the human body. The models built at the genomics research facility are generic, allowing researchers to alter the design of the model to fit the needs of individual patients and research subjects. The CAVEman is therefore not simply the main character, but can be many characters in the biomedical narratives researchers hope to construct.

The CAVEman: A Generic and Extendable Piece of Digital Art

An important factor contributing to their functionality and adaptability is the generic nature of the genomics research facility's models As the host of *Daily Planet* puts it, "[h]e does have a name, but the CAVEman is not a real person. But that's a good thing because, in fact, he can be anyone" (Ingram, 2009). The genomics research facility's director puts it this way:

> CAVEman is actually a generic model, so it doesn't have any particular features of any person. But, of course, we can take objects and morph them, make them look like any person. If you have a scan of a broken knee of your own we can actually take that and convert it into you being able to work through your own knee (Ingram, 2009).

As noted in the last chapter, genomics research facility employees recognized that even though the building of generic models is not flawless they saw it as being superior to building a model based on one specimen. They wanted a "better approximation of things" (From field notes, August 11, 2008). The average may not work for everybody but it provides a better tool.

It was important for researchers to get their models to look as real as possible. This is just as much an instrumental choice as it is an aesthetic one. James Elkins has detailed the ways in which one could treat medical images and scientific simulations as pieces of art in their own right. Elkins argues that "[e]ven though the relative separation of art history and computer graphics may seem to indicate they have little in common, it is possible to demonstrate an ongoing dependence of computer graphics on the older history of art" (1995, p. 556). Furthermore, Elkins argues, the conventions of computer-generated "perspectival scenes in...scientific simulations, architecture, and commercial games appear 'natural' or mathematically driven to their designers, even though they can be shown to derive from Western landscape painting of the last two centuries" (1995, p. 556). These images constitute what Elkins refers to as "informational images".[44] Elkins

[44] Other informational images include maps, atlases, anatomical colouring books, anatomical dummies, dioramas and panoramas.

implores art historians and cultural critics to recognize the aesthetic qualities of informational images. He takes issue with art historical analyses which treat informational images as purely technical, "inherently informational and without aesthetic value" (1995, p. 557). In these instances the conclusion drawn is that informational images are merely "encased in the technical conventions of their fields" (1995, p. 557). Elkins wants to change this; he wants to bring informational images into art historical studies (1995, p. 557).

Those who develop informational images follow what Elkins refers to as a "pre-Kantian sense of aesthetics as the 'perfecting of reality'" (1995, p. 558). Similarly, Laurel argues that "[w]e often fail to see that these are representations of tools and activities and to notice how that makes them different from (and often better than) the real thing" (1993, p. 31). This 'perfecting' of reality often involves altering the images produced by scientists and medical technicians:

> Even when...astronomers use false colors for their scientific images, they do so in order to make natural forms clearer and more susceptible to quantitative measurement. Their images always aim to give what they consider to be the most rational version of phenomena (Elkins, 1995, p. 559).

The models built by the genomics research facility are useful for trying to visualize what is happening in the human body. They are based on aesthetic principles and are meant to make it easier for researchers to study elements of the human body which are inaccessible when studying either live human subjects or cadavers. In terms of being "better than the real thing" Maxine, for instance, suggested that part of the benefit of computer models is simply that there are some things "you just wouldn't do to a human being" (from field notes). For instance, researchers can either study the body as a whole, or abstract any part of the CAVEman's body. As the genomics research facility's director told *Daily Planet*, "we can actually go and see things that are behind other things. Of course, that's something that you cannot even do with a human cadaver, because you always have to cut through things" (Ingram, 2009). What is exciting for genomics research facility employees is the ability to move individual body parts without having to alter surrounding organs and tissues. Each body part is its own object, "so the teeth stay in place when I take the jawbone away" (Ingram, 2009). The body, or individual body parts, can be enlarged or shrunk, and displayed from every conceivable angle. Researchers can also enter individual organs, like the heart or the lungs.

Thanks to the CAVEman's malleability and functionality, researchers are able to "exponentially increase the amount of data that can be displayed" (Ingram, 2009). This is the result of what the director refers to as "acute display": "If you take acute display then you go from millions of pixels to billions of three-dimensional pixels, or voxels, and with this you have a much higher resolution and you can really show what actually happens in the body". All of these factors can be described as story elements which increase the narrative potential of the four-dimensional modeling project. These factors support my argument that virtual medical imaging technologies are facilitators of powerful forms of narratives art. As James Paul Gee has argued, virtual narratives:

> [M]arry an abstract rule system about shapes, movements, and combinations with story elements. By story elements, I mean actors (e.g., hunters and vampires), objects (e.g., chests and pools), actions (e.g., opening chests, killing monsters), states (e.g., being damaged), and events (e.g., dying). I call these story elements because after all, stories are composed of such things" (2006, p. 59).

Again, it is the interactivity of virtual spaces and video games that make them potentially potent forms of artistic expression. Speaking about video games, Paul Gee argues that, "by manipulating these shapes, movements, and combinations, the player produces and manipulates story elements. Thus, games like *Castlevania* and *Metroid* are story element generators" (2006, p. 59).

In chapter three I mentioned a problem Devon was having modeling the interaction between various cells and cell types in the human body. The story, at that point, was useful for describing the technical limitations of the genomics research facility's computational infrastructure. However, the story is important for another reason. Remember the problem for Devon was one of "tedium and detail". As described in my field notes:

> Devon says that if a person observes a sphere of 10 billion cells and one cell in the middle of that sphere moves then it affects all of the other cells. He no needs to calculate the movement of each and every cell. He and Alex were looking for a faster way to do these calculations. I say,``yeah, like an easier way...`` but Devon retorts with ``Not easier...FASTER``. Faster does not, necessarily, mean easier (from field notes).

For Devon the problem had to do with his ability to solve problems, to get the models to be more efficient and usable for biological research. For the biologists that might one day use these models the problem is significant for another reason. It is important, for one thing, that the computer be capable of representing the chaotic and variable ways in which cells interact with one another. This does not mean the models need to be able to do exactly what cells do in the human body, but that they can be modeled to create the illusion that they are doing what the cells in the body do. This was, among other things, an aesthetic choice. Like Murray's description of the effectiveness of the ELIZA project, the effectiveness of the four-dimensional models is the "cleverness of the rules" Devon and the other bioinformaticians give the virtual models. These rules must fit into a visually appealing, coherent model of the human body.

More specifically, these rules are meant to generate story elements. Similar to the development of contemporary video games, Devon was trying to "marry an abstract rule system about shapes, movements, and combinations with story elements" (Gee, 2006, p. 58). In this way the models being built by the genomics research facility were designed to set up possible interactions, but would allow each user to come to important conclusions in their own unique way. Devon's job, for instance, was to attribute meaning to symbols and shapes, even though the representational accuracy of these shapes could not be definitively verified. Remember, in bioinformatics programming the most commonly used shapes are spheres and cubes. This means that the ways in which the cells combine will not necessarily be duplicated naturally. But as long as users enter the CAVE with this understanding work could still be productive; they could still project productive virtual narratives about the processes of genetic diseases.

The models Devon is trying to build are interactive models which are accessible to a number of different researchers, with a number of distinct goals. Their power as story element generators lies in their adaptability to new research scenarios. In this way, they can be viewed as forms of interactive performance art. As Paul Gee concludes:

> This proactive production by players of story elements, a visual-motoric-auditory decision-making symphony, and a unique real-virtual story produces a new form of performance art coproduced by players and game designers. We have as yet no useful tools for analyzing the elements that make up this art form. But it is a form that has the potential to integrate pleasure, learning, reflection, and expanded living in ways that we expect from art (2006, p. 61).

Again, the dynamism, contingency, and interactivity of the four-dimensional models make them unique characters in the fictional narratives researchers hope will one day help them study genetic diseases. By providing researchers with such large quantities of data, which can be applied and manipulated within an interactive environment, the genomics research facility greatly increases its ability to tell complex multiform narratives. These data sources greatly increase the complexity of the CAVEman, the main character of the biomedical narratives these researchers hope to construct.

Rhetoric, Hyperbole and Real Limitations

It is important, however, to avoid making too much of the storytelling potential of the virtual models being produced by the genomics research facility. Too often those who study technoscience and twenty-first century biomedicine make needlessly bold claims about the potential for these posthuman, postbiological innovations to change the face of the political, social, medical and economic landscape of (at least Western) civilization. A great example of a thinker who uses rhetoric and hyperbole to make universalizing claims about technoscience is Ray Kurzweil. In his book, *The Age of Spiritual Machines*, Kurzweil makes a bold and unfounded claim concerning the impact of computer-human interfaces:

> There is growing prosperity, fueled not incidentally by information technology, but the human species is still challenged by issues and difficulties not altogether different than those with which it has struggled from the beginning of its recorded history. The twenty-first century will be different. The human species, along with the computational technology it created, will be able to solve age-old problems of need, if not desire, and will be in a position to change the nature of mortality in a postbiological future. Do we have the psychological capacity for all the good things that await us? Probably not. That, however, might change as well. Before the next-century is over, human beings will no longer be the most intelligent or capable type of entity" (1999, p. 2).

Such a bold statement is very difficult to support. While certainly these new postbiological, cybernetic technologies provide much in the way of hope for the future of the biomedical sciences, there is no certainty that these technologies will really live up to the hyperbolic potential thinkers such as Kurzweil proclaim. To compare these technologies to their counterparts in popular science fiction is not to make bold claims about their ability to develop new knowledge. Rather, the comparison is meant to highlight the increasingly blurry boundary between science fact and science fiction in twenty-first century technoscience. This does not mean that these technologies are not haunted by numerous limitations. In fact, the contingency and uncertainty of genomics research makes it quite likely that most of these technologies will do very little to increase knowledge about the processes of genomics diseases. One of the major problems with working in a heterotopic site of improvisation and uncertainty is that one must be inherently uncertain about the use value of his/her contributions to genomics research. Unfortunately, representatives for the genomics research facility tend to sound more like Ray Kurzweil when promoting the four-dimensional modeling project. This is surprising, giving the candid nature of the conversations I had with them.

As the preceding sections have suggested, the genomics research facility's virtual CAVE provides evidence that researchers are getting closer and closer to something which has only been represented in popular science fiction. For instance, as models become more realistic, and as processors become faster and more efficient, genomics research employees might be able to travel through the human body like the scientists in the film *Fantastic Voyage,* or perhaps even the germs in the film *Osmosis Jones*. Their goal is to be able to see and interact with that which is invisible to the human eye.

It is interesting to note similarities between the rhetoric used to describe the genomics research facility's CAVE, and promotional spots for these popular science fiction films. In a 1967 promotional spot for the motion picture *Fantastic Voyage*, the narrator exclaims, "[F]our men and a beautiful girl, off on a fantastic voyage. Actually entering inside the human body. Exploring an unknown universe, unknown dangers!". Later he remarks,"[i]f you thought it was too late to experience something entirely new on the screen, *Fantastic Voyage* will be a stunning experience. For you are going where no man, or camera, has ventured before!" In a spot for *Osmosis Jones* the announcer attempts to attract audiences by situating the narrative within the body of Frank, played by Bill Murray: "In the year 2001, witness this man, Frank, as he becomes the centre of the summer's greatest action/adventure, and the year's most intense, heart-pounding odyssey. The most amazing journey ever seen is about to take place...inside Frank's body."

Similarly, one of the main selling points for the CAVEman is the ability to 'walk' through his high-resolution digital body. Much like the previews for *Fantastic Voyage* and *Osmosis Jones*, the host of *Daily Planet* relies on rhetoric and hyperbole to make this point: "In the CAVEman, scientists can walk through right through their experiments and into the CAVEman's high res body" (Ingram, 2009). Later he proclaims that "[s]cientists can fly through the CAVEman's chest and gawk at his damaged heart" (Ingram, 2009). Like the announcers in the promotional advertisements, the *Daily Planet* clip describes the experience of being immersed in the CAVE as being an incredible journey through the human body.

It should be noted, however, that the CAVEman does not really function as well as the *Daily Planet* piece suggests.[45] It is incredibly slow, its demonstrations currently do

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[45] Similarly, neither *Fantastic Voyage* nor *Osmosis Jones* live up the hype of their promotional advertisements. Neither movie was the most "exciting adventure" I had ever experienced.

not unfold in real time, and it is still very difficult for researchers to model the human body at the molecular level. Researchers do walk in the CAVE, but no more than three or four steps in any direction. Walking too fast could slow down the demonstration. CAVEman researchers do not do anything resembling "flying", although the goal is to create an increasingly realistic illusion that users are effortlessly floating through the human body.

Although the *Daily Planet* clip suggests that the CAVEman is complete, the head researchers at the genomics research facility provided me with a much different and more nuanced response. One should not get bogged down in the rhetoric of technoscientific investigations. There are still major limitations which effect the use value of the CAVEman and the rest of the four-dimensional modeling project.

I spent a good deal of my time talking with Frank about some of the limitations of the four-dimensional project. These discussions helped highlight both the breakthroughs and limitations on the CAVEman's narrative potential. As Frank reiterated, specifically the four-dimensional modeling project is meant to provide a space for the visualization of data which changes over time. Ideally this would include data which develops or deteriorates over time:

> This, I tell Frank, was the reason why I became interested in the CAVEman project. I ask Frank to talk a bit about newspaper articles which have featured the CAVEman. Frank thinks there is a problem with the way the CAVEman has been presented in the media. He thinks the problem is that the media sensationalizes projects like this, in the interest of gaining popularity. The capabilities of the CAVEman have been exaggerated in many stories and the director himself has noted a distaste for a few articles. But, Frank says, there is little he or the director can do about it. He claims to not even really care what the media says, but it was obvious that he gets frustrated when truth is obscured or distorted in the interest of selling copy. (from field notes, August 19, 2008).

To avoid my own exaggerations, I asked Frank how well the project was coming along. He didn't think that the project was going as quickly as he had hoped. He cited issues with the speed and efficiency of the computers, but also the physical separation between the CAVEman and the separate biomedical case studies which provided the data used to build the CAVEman. Other problems that Frank cited are of a more ethical, or moral, nature.

Frank made a number of interesting claims concerning the use value of the work the genomics research facility does. He felt that researchers should always have a goal for visualizing data. He wondered if sometimes people are just asking for visual models of their data for the sake of "fun...for entertainment". Frank claimed that there are far better ways for people to be entertained. He found the CAVEman to be relatively useless, unless people came in with specific goals, especially goals geared towards human health. He found that a lot of biologists didn't come in with any goals. He encouraged bio-medical researchers to "really think about what you want to see". A mouse, for instance, is often used as a substitute for human beings. This means many mice get killed for data collection. Frank worried that sometimes research like this is conducted needlessly. They do it "just to see...with little meaning". He said that stuff like the bone demo and the Aspirin metabolite demo are two excellent examples of the proper use of four-dimensional visualization. "But sometimes", Frank said, people just throw data at you, "just to see". Frank said that these, and other issues, contribute to a personal feeling that the 4D aspect of his work is not as strong as it could be. People do not have a good enough idea about what they want to see over time. Having a goal in mind is even more important when one considers just how much time and effort is sometimes involved in the collection of data. Sometimes it takes months, years and longer to observe and collect molecular data.

No matter how powerful these multiform narrative fictions can be, there is still a general sense of uncertainty about how and why they may be useful to genomics researchers. This does not, however, change the desired conclusion for which genomics research facility employees are striving: to develop of powerful and productive fictions which will, they hope, facilitate the future production of scientific knowledge.

"Conclusions": Final Thoughts on/are Productive Fictions

As a heterotopic site of cultural production, the Western Canadian genomics research facility provides a useful example of twenty-first century technoscience. It constitutes a site of improvisation and uncertainty which blurs the boundaries between nature, society and culture, subject and object, science fact and science fiction.

I do not want to overstate the potential of the models being built at the genomics research facility. None of the employees I observed and interacted with were certain about whether the models would ever constitute effective virtual research subjects. This should not, however, prevent a consideration of what would happen if these models were to succeed in providing a fictional narrative space for the production of knowledge about genetic diseases. Too often STS scholars study technoscientific projects after they have been black boxed; after they have been either established or discredited. This thesis was meant to theorize a project in the making. While I cannot provide any definitive conclusion, I can speculate about the potential implications the four-dimensional modeling project might have for the future of genomics research.

According to Foucault, the more complex the social space within which a disease is situated the "more denatured" the disease "becomes...Like civilization, the hospital is an artificial locus in which the transplanted disease runs the risk of losing its essential identity" (Foucault, 1973, p.16-17). Diseases, in more refined and complex societies, are "variable, complex, intermingled, nervous ills" (Foucault, 1973, p.16). Like Foucault's description of site-specific societies in "Of Other Spaces", contemporary medicine has to find ways of solving problems of increased complexity and variability in diseases.

Foucault's description of allowing a disease to freely go through its processes without hospital interventions is, in many ways, precisely what CAVEman researchers claim their virtual model might one day be capable of reproducing. As noted earlier, it is the goal of CAVEman developers to create virtual maps of genetic diseases which they can watch unfold over time and within the space of the virtual body. The complexity and variability of these diseases could be monitored, and different parts of the body could be abstracted without affecting the flow of the disease over time. If researchers were working on a real human body they would not be able to witness these processes. Nor would they be able to save, let alone recreate, specific experiments over and over again. Perhaps it is not going too far to say that CAVEman researchers seek to let a genetic disease "be allowed, in the positive sense of the term, to 'vegetate' in its original soil" in a space, virtual in this case, "both enclosed upon itself and entirely transparent, where the illness is left to itself" (Foucault, 1973, p.18).

These various sites are defined by relations between social and technical actors, and provide 'perfected' and more 'meticulous' places and virtual spaces within which the study of genetic diseases may be advanced. Ira Livingston argues that "whereas classical medicine sought to *taxonimize* diseases exhaustively in their intricate interrelationship, modern medicine *anatomizes,* seeking the hidden structures and origins of diseases in the depths of the body and the germs they attack" (2006, p.17). Employees at the Western Canadian genomics research facility also hope to build a system which would enable other researchers to look for hidden structures and origins of genetic diseases, by creating a model of the entire human body that can be studied either as a whole, or from which specific virtual body parts can be abstracted, manipulated—re-sized, re-shaped, injected with 'digital' medicine—and returned to their original state. The data from these manipulations can be stored, allowing researchers to try countless new experiments and review old experiments.

The models being built at the genomics research facility constitute productive multiform narrative fictions, which researchers hope will one day tell the story of genetic diseases. These narratives, like the one I have constructed here, do not require definitive conclusions. This, I think, is what gives them such power.

It is impossible to describe technoscience in terms of objective knowledge and inevitability. As both culturally specific databases and virtual research subjects, the models built at the genomics research facility are inherently fictional in the sense that they are not the only nor necessarily the best means of obtaining knowledge about the processes of genetic diseases. Whereas one *may* be able to describe human research subjects as "natural phenomena" (Hayles, 1999, p.157), one cannot argue that the CAVEman, the genomics research facility's four-dimensional model of the human body, represents anything which "simply and passively is" (Hayles, 1999, p. 157). Rather, like the cyborgs described by N. Katherine Hayles and Donna Haraway, the CAVEman is "constructed; a technobiological object that confounds the dichotomy between natural and unnatural, made and born" (Hayles, 1999, p.157). In other words, these models are science fictions. As such they are easily revised and improved upon.

By describing these models as fictions I have highlighted the fact that they are the result of both scientific necessity and various modes of cultural production. They are built using data obtained from natural specimens, and for the purpose of studying natural phenomena. But at the same time they are cultural products, built using technologies and methods very similar to those used by video game developers, digital artists and other graphic designers. The researchers who build these models walk a fine line between science and art, with many of them having attended art schools, or worked in commercial video game development. It is important to understand that genomics research facility employees have opened up not only scientific, but the narrative and artistic potential of their virtual models. They can, with increasing detail and accuracy, project the story of genetic diseases within the virtual theatre of the Cave Automatic Virtual Environment.

The power of electronic narratives is precisely their ability to allow researchers to avoid coming to definitive conclusions, conclusions which are often unnecessary and which stand in the face of a generally accepted understanding of the natural variability of the outside world. Janet Murray argues that "in a shape-shifting world, stories often do not come to a clear end point. Electronic narrative teases us, holding back its gifts. The labyrinth is tricky, full of dead ends, uncertainties, questions that do not resolve" (1997, p. 173). When people play video games, or immerse themselves in virtual reality environments, they are liberated by a number of choices absent from uni-directional media like television, most films and novels, which follow traditional linear narratives. Computers afford us a seductive lack of closure. As Murray puts it, "[b]ecause of its ability to both offer and withhold, the computer is a seductive medium in which much of the pleasure lies in the sustained engagement, the refusal of climax" (1997, p. 174). The power of computers is their ability to provide an environment which is similar to, but in many ways better than the real world. According to Murray, "the never-ending, ever-morphing cyberspace narrative is a place to revel in a sense of endless transformations" (1997, p. 175). In terms of applications of CAVEs in technoscientific research, the seductive nature of this narrative potential lies in the computer's ability to resist climax and conclusions. As Murray argues, this should be considered a virtue: "to be always in search of secret information, in pursuit of refused reward can be...riveting" (1997, p. 173).

As generic, fictional characters, the models being built by genomics research facility employees could be used to meet both serious and non-serious ends. These models could allow researchers to cope, with more freedom and playfulness, with the natural variability of the human body. If they do become important tools for the study of genetic diseases, these models would allow researchers to deal with greater and greater detail. Past data will not be erased and researchers can continue to add new information without needing to completely replace older models, tests and methods for producing knowledge.

The potential of these models lies in their ability to remind us of the complexity of the natural world. Because designers can keep building faster, more efficient, more detailed models of biomedical data, scientific researchers could be made less concerned about disenchanting the natural world. Instead they could accept the constant evolution of technoscience, dealing with it by building complex databases and models which are adaptable to new research scenarios and technological infrastructures. This is, of course, one of the main tenets of Latour's nonmodern constititution:

> We never stop building our collectives with raw materials of poor humans and humble nonhumans. How could we be capable of disenchanting the world, when every day our laboratories and our factories populate the world with hundreds of hybrids stranger than those of the day before? (1993, p. 115).

Acknowledging the futility of a universal scientific paradigm could humble the researchers who use these models. They could store, retrieve and re-imagine without replacing; without, necessarily, constantly revolutionizing genomics research. As the protagonist in *Gallatea 2.2* puts it:

> When you see up close the countless subsystems it takes to place an image into the permanent buffer, when you measure the loop that image makes on its way to being retained, you temper yourself against the definitive. You go humble, understated, wry (Powers, 1995, p. 40).

It could no longer be about coming to final conclusions or developing black boxes, but about recognizing the contingency of fact production without limiting the productive potential of scientific facts. As the researchers at the genomics research facility kept telling me, "you can always add more detail" (from field notes, August 19, 2008)). With more details come more questions, more suspense, more perspectives and, hopefully, a humble appreciation of the variability of the natural world. All they can achieve is rising action, never a finale.

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Western
Faculty of
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Office of the Dean

Ethical Review of Research Involving Human Subjects

All non-medical research involving human subjects at the University of Western Ontario is carried out in compliance with the Social Sciences and Humanities Research Council Guidelines (2002). The Faculty of Information Media Studies (FIMS) Research Committee has the mandate to review FIMS student research proposals for adherence to these guidelines.

2008 – 2009 FIMS Research Committee Membership

1. T. Carmichael*, Dean and Chair
2. E. Comor*
3. N. Dyer-Witheford, Associate Dean
4. A. Quan-Haase*
5. D. Robinson (alternate)
6. L. Vaughan* (alternate)
7. N. Wathen

Research Committee members marked with * have examined the research project entitled:

Beyond the Cyborg: Science Fact and Science Fiction in the Virtual Space of Medical Research

as submitted by: Carole Farber (Principal Investigator/Supervisor)
Cameron Murray (Co-investigator/Student)

and consider it to be acceptable on ethical grounds for research involving human subjects under the conditions of the University's Policy on Research Involving Human Subjects.

Approval Date: June 25, 2008

Tom Carmichael,
Dean and Chair

Appendix B: Letter of Information

Beyond the Cyborg: Science Fact and Science Fiction in Virtual Medicine

INFORMATION FOR PROSPECTIVE PARTICIPANTS

Purpose:

This research project aims to examine the socio-technical construction of scientific knowledge about the processes of genetic disease at the Sun Centre for Excellence in Visual Genomics CAVEman. Participants will include any and all relevant employees working at the centre who may contribute to the socio-technical network of the CAVEman.

Procedure:

In addition to journal articles, visuals, newspaper articles, radio and television interviews, etc, this study will seek to develop a brief, four to eight week, ethnographic participant observation of CAVEman researchers at the Sun Centre for Excellence in Visual Genomics. Interviews will also be conducted in person, or by telephone, and will be tape-recorded. Follow-up interviews may be also conducted by email, as needed.

Risks and Benefits:

There are no physical or psychological risks associated with this study. This research aims to contribute a case study of medical researchers working to map out the processes of genetic disease on four-dimensional model of the human body located within a virtual research space. Participant observations are sought .

Voluntary Participation:

Participation in this study is voluntary. Participants should feel free to refuse participation or withdraw from participation for any reason. Although it will be difficult to avoid observing all relevant employees at the centre, given the nature of *site-specific* ethnographic research, participants should feel free to request the non-disclosure of information without fear of consequence.

Confidentiality:

The identity of all participants in the study will be kept confidential unless otherwise preferred by them. If a participant would like her/his identity to be revealed, that is fully acceptable. Unless otherwise preferred by participants, pseudonyms will be used in all reports and any publications that may result from the study. All transcripts, audiotapes, e-mail records, consent forms and any additional materials will be kept by the researcher in a locked cabinet and destroyed/deleted within 7 years after the completion of the study. The only exception will be in the event that a participant may request his or her own records.

Other Information:

Financial remuneration will not be offered for participation. The material will not be used for commercial purposes. This study has been reviewed and has received ethical clearance from the University of Western Ontario.

Further Inquiries:

If you require any further information or have any questions, please contact:
Cameron Michael Murray, Master's Candidate

Graduate Program in Media Studies
Faculty of Information and Media Studies, The University of Western Ontario
Phone:
Email:
Faculty Thesis Supervisor: Carole Farber

Appendix C: Consent Form

PARTICIPANT CONSENT FORM

Participant's Name: ____

In agreeing to be a participant in this study, "Beyond the Cyborg: Science Fact and Science Fiction in Virtual Medicine," I have read the letter of information and all questions have been answered to my satisfaction. I also understand the purpose, general nature and procedures of this study, as explained by the researcher.

I understand that unless I indicate otherwise, all identifying information resulting form my participation will be kept confidential.

I further understand that I may withdraw from this study for any reason without repercussions by notifying the researcher of my withdrawal at any time in the three months following the date of this consent.

I hereby give my permission:

1. to participate in the project as well as face to face taped interviews or interviews conducted via email; and
2. to allow the data, including interviews, field notes based on observations, and other information resulting from this research, for educational, research and publication purposes.

____________________________ ____________________________
Participant's Signature Researcher's Signature

____
Date

Appendix D: Unstructured and Open-ended Interview Guides

Unstructured Interviews

1. *Questions Regarding the Role of Each Employees*
   a. What motivated you to become a part of the CAVEman team?
   b. Did you apply? Were you appointed?
   c. Does this work fulfill a component of your graduate studies?
   d. What is your specific role here at the CAVEman project?
   e. What is your area of specialization?

2. *Questions Regarding Virtual Reality in Medical Research*

   a. What role do you think virtual reality should play in medical research?
   b. What are the limitations of virtual medical research environments?
   c. In what ways do you feel virtual training and research models, and environments, are superior to studying a real human cadaver?
   d. Why do you think so many medical schools and research facilities are implementing virtual reality technologies?

3. *Questions Regarding the CAVEman Project*

   a. Can research conducted on, and within, the CAVEman stand alone or should it be combined with studies of human cadavers as well?
   b. Can information obtained from CAVEman experiments translate into actual knowledge about real human bodies?
   c. Do you aspire to acquire specific knowledge about the human body? Is such knowledge even possible?
   d. What are the ethical considerations that need to be accounted for when studying virtual models of the human body?

Open-ended Interviews: *Questions for Researchers and Technicians.*

This section will involve casual questions and discussions pertaining to the specific technological components of the CAVEman project. Throughout my stay at the Sun Centre, and for some time after via email, I will engage in periodic conversations with researchers and other employees about how the CAVEman actually operates. These discussions will focus on developing a basic understanding of how the technology works. These interviews will also be used to gauge which components researchers believe to be most important to their experiments.