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Emerging Methodologies for Interdisciplinary Research Practice

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by

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January 2014

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For my mother, Margaret Joy McKenzie Forbes (1947-2009)

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Curriculum Vitæ
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Education

2006 - 2009	Master of Arts in Media Arts & Technology, University of California, Santa Barbara. Master's Thesis: *A Framework for Dynamic Information Visualization*
1990 - 1992	Bachelor of Arts in British and American Literature, New College of Florida. Bachelor's Thesis: *Babbling on the Threshold: Duality, Myth, and Resistance in James Merrill's "The Changing Light at Sandover"*
1988 - 1990	Associate of Arts, Bard College at Simon's Rock

Experience

2013 - present	Assistant Professor, School of Information: Science, Technology, and Arts, University of Arizona, Tucson
2013 - present	Director, Creative Coding Lab, University of Arizona, Tucson
2012	Assistant Research Professor, School of Information: Science, Technology, and Arts, University of Arizona, Tucson
2012	Researcher, Allosphere Research Facility, California NanoSystems Institute, University of California, Santa Barbara
2011	Researcher, Four-Eyes Lab, Computer Science Department, University of California, Santa Barbara
2009 - 2011	Lecturer, Media Arts and Technology Program, University of California, Santa Barbara
2009	Researcher, Experimental Visualization Lab, Media Arts and Technology Program, University of California, Santa Barbara
2006–2008	Researcher, NSF IGERT Trainee in Interactive Digital Media, University of California, Santa Barbara

Selected Recent Publications

2014	A. G. Forbes. Interactive cellular automata systems for creative projects. In P. Rosin, A. Adamatzky, and X. Sun, editors, *Cellular Automata for Image Processing, Computer Graphics & Computational Geometry*. Springer, 2014. To appear.

2014	S. Savage, A. G. Forbes, C. Toxtli, and S. M. Desai. Visual analysis of online audiences. In *Proceedings of the International Conference on the Design of Cooperative Systems (COOP)*, Nice, France, May 2014. In submission.
2014	A. G. Forbes and J. Villegas. Creative applications of microvideos. In *Proceedings of the the Sixth International Conferences on Advances in Multimedia (MMEDIA)*, Nice, France, February 2014, To appear.
2014	A. G. Forbes, J. Villegas, K. Almryde, and E. Plante. A stereoscopic system for viewing the temporal evolution of brain activity clusters in response to linguistic stimuli. In *Proceedings of IS&T/SPIE Electronic Imaging, Stereoscopic Displays and Applications XXV*, February 2014. To appear.
2014	J. Villegas and A. G. Forbes. Interactive non-photorealistic video synthesis for artistic user experience on mobile devices. In *Proceedings of the International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM)*, Scottsdale, Arizona, January 2014. To appear.
2014	A. G. Forbes, C. Jette, and A. Predoehl. Analyzing intrinsic motion textures created from naturalistic video captures. In *Proceedings of the International Conference on Information Visualization Theory and Applications (IVAPP)*, Lisbon, Portugal, January 2014. To appear.
2013	A. G. Forbes and L. Thorson. Art+experiment. In *Proceedings of the IEEE VIS Arts Program (VISAP)*, Atlanta, Georgia, October 2013.
2013	A. G. Forbes, M. Surdeanu, P. Jansen, and J. Carrington. Transmitting narrative: An interactive shift-summarization tool for improving nurse communication. In *Proceedings of the IEEE Workshop on Interactive Visual Text Analytics*, Atlanta, Georgia, October 2013.
2013	A. G. Forbes, T. Fast, and T. Höllerer. The natural materials browser: Using a tablet interface for exploring volumetric materials science datasets. In *Proceedings of IEEE Visualization (VIS)*, Atlanta, Georgia, October 2013.
2013	A. G. Forbes and L. Thorson, editors. *The IEEE VIS 2013 Art Show Catalog.* IEEE, 2013.

2013 A. G. Forbes. Media arts roles in art-science collaborations. In *Proceedings of the Re-new Digital Arts Festival*, pages 276–282, Copenhagen, Denmark, October-November 2013.

2013 J. Villegas and A. G. Forbes. Double-meaning: Interactive animations with simultaneous global and local narrative. In *Proceedings of the Re-new Digital Arts Festival*, pages 300–304, Copenhagen, Denmark, October-November 2013.

2013 A. G. Forbes, T. Höllerer, and G. Legrady. Generative fluid profiles for interactive media arts projects. In *Proceedings of the International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging (CAe)*, pages 123–129, Anaheim, California, July 2013.

2013 J. Villegas and A. G. Forbes. Real-time ambiguous animations. In *Proceedings of the International Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging (CAe)*, Anaheim, California, July 2013.

2013 C. Roberts, A. G. Forbes, and T. Höllerer. Enabling multimodal mobile interfaces for musical performance. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, Daejeon, Korea, May 2013.

2013 S. Savage, A. G. Forbes, and T. Höllerer. Utilizing crowdsourced databases for social media question asking. In *ACM CSCW Workshop on Social Media Question Asking*, San Antonio, Texas, Februrary 2013.

2012 A. G. Forbes, S. Savage, and T. Höllerer. Visualizing and verifying directed social queries. In *IEEE Workshop on Interactive Visual Text Analytics*, Seattle, Washington, October 2012.

2012 A. Burbano, D. Bazo, S. DiCicco, and A. G. Forbes. The new dunites. In *Proceedings of the ACM International Conference on Multimedia (MM)*, pages 1501–1502, Nara, Japan, 2012.

2012 S. Savage, A. G. Forbes, R. Savage, T. Höllerer, and N. E. Chavez. Directed social queries with transparent user models. In *Adjunct Proceedings of the ACM symposium on User Interface Software and Technology (UIST)*, pages 59–60, Cambridge, Massachusetts, October 2012.

2012 A. G. Forbes, T. Höllerer, and G. Legrady. Expressive energy: The fluid automata project. In *Proceedings of the International Symposium on Electronic Art (ISEA)*, pages 65–70, Albuquerque, New Mexico, September 2012.

2012	A. G. Forbes and K. Odai. Iterative synaesthetic composing with multimedia signals. In *Proceedings of the International Computer Music Conference (ICMC)*, pages 573–578, Ljubjiana, Slovenia, September 2012.
2011	A. G. Forbes, B. Alper, T. Höllerer, and G. Legrady. Interactive folksonomic analytics with the tag river visualization. In *IEEE Workshop on Interactive Visual Text Analytics*, Providence, Rhode Island, October 2011.
2011	B. Alper, T. Höllerer, J. Kuchera-Morin, and A. G. Forbes. Stereoscopic highlighting: 2d graph visualization on stereo displays. *IEEE Transactions on Visualization and Computer Graphics*, 17(12): 2325–2333, November-December 2011.
2011	A. G. Forbes and G. Legrady. Cell tango: An evolving interactive archive of cellphone photography. In *Proceedings of the International Symposium on Electronic Art (ISEA)*, Istanbul, Turkey, September 2011.
2010	A. G. Forbes, T. Höllerer, and G. Legrady. Behaviorism: A framework for dynamic data visualization. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1164–1171, November-December 2010.

Selected Recent Exhibitions and Performances

2013	Sound-Worlds, at *Exploded View Microcinema*, Tucson, Arizona, 2013. With Christopher Jette, Kelland Thomas, and Javier Villegas. Organized by Angus Forbes, Rebecca Barton, and David Sherman.
2013	Turbulent World, in Brave New World, *Spare Change Artist Space*, San Francisco, California, 2013. Curated by OFF Space (Kathrine Worel and Emmanuelle Namont-Kouznetsov).
2013	Generative Fluid Profiles, at *Expressive 2013, Visual Showcase*, Anaheim, California, 2013. Chaired by T. Metin Sezgin.
2013	Multiple Water, in Form, Content, & Computation, *The Student Union Gallery,* Tucson, Arizona, 2013. Curated by Kelland Thomas.
2012	New Dunites, in Eternal/Moment, *ACM Multimedia Interactive Arts Program, Todaiji Cultural Center*, Nara, Japan, 2012. With Danny Bazo, Andres Burbano, and Solen Kiratli DiCicco.

2012	Annular Genealogy, presented at *AlloSphere Research Facility*, Santa Barbara, California, 2012. With Kiyomitsu Odai.
2012	Annular Genealogy, in Standard Deviation, *Old Peace Store*, Santa Barbara, California, 2012. With Kiyomitsu Odai. Curated by Marco Pinter and Ted Mills.
2011	Fluid Automata, in IEEE VisWeek 2011 Art Show, *Convention Center Rotunda*, Providence, Rhode Island, 2011. Curated by Dan Keefe and Bruce Campbell.
2011	Cell Tango, in Rethinking Art & Machine, *The Museum*, Kitchener, Ontario, 2011. With George Legrady. Curated by Marla Wasser.
2011	Incompressible, in Keeping an Eye on Surveillance, *The Performance Art Institute*, San Francisco, California, 2011. Curated by Hanna Regev.
2011	Study on Brownian (*F) Motion in Questionable Utility, *Media Arts & Technology Art Show*, University of California, Santa Barbara, June 9, 2011. With Kiyomitsu Odai.
2011	Infrequent Crimes, in Spread: California Conceptualism, Then and Now, *SOMArts Gallery*, San Francisco, California, 2011. Curated by OFF Space (Kathrine Worel, Elyse Hochstadt, and Emmanuelle Namont-Kouznetsov).
2011	Information Poems, in Super Santa Barbara, *Contemporary Arts Forum*, Santa Barbara, California, 2011. Curated by Warren Schultheis.
2010	Cell Tango, in Beyond Mediations, *Poznan Biennale*, Poznan, Poland, 2010. With George Legrady. Curated by Tsutomu Mizusawa and Ryszard Kluszczynski.
2010	Cell Tango and Coil Maps, presented at Gala Event, *Lawrence Hall of Science*, Berkeley, California, 2010. With George Legrady. Coordinated by Marjorie Randell-Silver.
2010	Amazing Stories, presented at Bradbury Media Arts Festival, *The Children's Library*, Palo Alto, California, 2010. Festival organized by Christopher Jette.
2009	Data Flow, installed at *Corporate Executive Board corporate headquarters*, Arlington, Virginia, 2009. With George Legrady. Commissioned by Gensler Design.

Abstract

Emerging Methodologies for Interdisciplinary Research Practice

Angus Graeme Forbes

Media arts practice often includes activities that may be at odds with the goals of empirically-oriented research, such as experimenting with representation, challenging cultural assumptions, and questioning the meaning and impacts of technology and innovation. This dissertation investigates the following question: what methodologies effectively enable media artists to operate both pragmatically and creatively within interdisciplinary research projects? To answer this question, I propose framing media arts activities in terms of the following methodological themes: *generation, augmentation, provocation*, and *mediation*. I present a series of collaborative art works and research projects— including *Data Flow*, *Fluid Automata*, *Information Poems*, *Annular Genealogy*, *Natural Material Browser*, and *Augmented Communication Tools*, among others— as case studies that elucidate these overlapping themes. I contend that they more accurately describe the creative activities of media artists, and moreover that they provide an effective way for explaining the emerging roles of the media artist when integrating creative arts practices into interdisciplinary research projects.

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Chapter 1

Media Arts Roles and Methodologies

> *If the fruits of hybrid research are not strictly science, or engineering, or art, then one must wonder about the epistemological and ontological status of these hybrid forms: What exactly are they? What new knowledge do they produce or enable? What is their function in the world?* – Edward Shanken

1.1 Introduction

Media arts practitioners are positioned at the crossroads of technology and culture, with hybrid expertise in art production and the creation of new technologies. Many academic, scientific, and governmental organizations recognize the importance of interdisciplinary collaborations that include experts from a variety of disciplines, including engineers, designers, scientists, as well as media artists. These collaborations, often referred to as "art-science" projects, are important because of their potential to provide new perspectives and new possibilities to the collaborators. For media artists, these include: opportunities to work with emerging media that might not otherwise be directly available; access to resources and funding not normally as readily available to art practitioners; and a greater influence in affecting projects that may have far-reaching effects on research practice and policy. Art-science collaborations often make use of some of the skills of the media arts practitioner, such as knowledge of multimedia technologies and design methodologies. But at the same time either de-value or de-emphasize other aspects, such as the use of aesthetic production as a vehicle to tease out cultural issues and mediate between disciplines. Thinking of the media artist largely, for instance, as a software engineer, or expecting the media artist to be primarily involved with secondary aspects of the project, such as public outreach, limits the possibilities for the media artist to have a more integrated role. Enabling each team member to achieve to their fullest potential will result in stronger work from all disciplinary perspectives. On the other hand, media arts practitioners who see their role primarily as challengers, provokers, and questioners risk positioning themselves as outsiders not directly influencing research agendas and activities.

In this dissertation I introduce a methodological framework that encourages a more integrated role of the media arts practitioner; a role that includes valuable creative components of artistic activities. Many of the actual, day-to-day contributions of media arts are not accurately characterized by the current literature, and indeed are not generally well articulated by media artists themselves. This hinders the ability of the media artist to make useful contributions in collaborative projects, as it is often difficult for the media artist to explain their role in these projects, either to themselves, to collaborators, or to external agencies such as grant foundations or galleries. In particular, the value of the art-producing aspect of media arts is often misunderstood, simplified, and marginalized, even, ironically, while it is simultaneously celebrated.

This dissertation proposes the framing of media arts activities in terms of the following "methodological themes": *generation, augmentation, provocation*, and *mediation*. I contend that these overlapping themes more accurately describe the creative activities of media artists, and that they provide a more effective way for explaining the emerging roles of the media artist. I present a series of my own collaborative projects as case studies that elucidate aspects of these themes and which inspire a general framework for integrating creative arts practice into interdisciplinary research and engineering projects. Along the way to presenting these projects and these themes, I explore the motivations, roles, and methodologies discussed by a variety of media artists, multimedia researchers, and media arts theorists. Many of these perspectives are contradictory to each other, and, even within the scope of a single article, demonstrate overt or unarticulated tensions. Some unifying threads that tie much of the literature together are an aim toward a "meta" awareness, an insistence that process is as important as results, and a desire to make progress, not only in research, but also in the way research is carried out. Phrases like "meta-design," "meta-critical," and "meta-knowledge" occur in much of the writing by and about media artists. While these phrases have precise definitions in the contexts in which they are introduced, they more generally refer to the need for new thinking about how research is conducted and about the importance of exploring the meaning and effectiveness of design and evaluation in collaborative situations.

Roger Malina, in his 2010 essay, "What are the Different Types of Art-Science Collaboration?," considers a taxonomy of art-science objectives that include: aiding in community outreach or pedagogy; creating hybrid artists/scientists with dual careers that inform each other; utilizing scientific research to understand creative activities; and producing outputs that are scientific, artistic, or both simultaneously [141]. Many media artists, as discussed below, find that working within art-science contexts can be, for various reasons, problematic. But at the same time these situations present interesting opportunities to work with technologies that would otherwise remain inaccessible. While new ways of practicing in these contexts are already occurring, relatively little has been written regarding these practices, and certainly there is no consensus about appropriate methods and tasks in the different approaches. This means that media arts practitioners often re-invent methodologies or take on roles that are not ideal. Articulating appropriate methodologies for effective art-science collaboration is difficult, as the methodologies are not simple heuristics, but rather require flexibility, since they are highly project-specific and involve multiple domains of inquiry. And thus the contribution of media arts in art-science projects can be hard to evaluate. A central goal of this dissertation is to shed light on effective methodological approaches to media arts practice in art-science and interdisciplinary collaborative contexts.

1.2 Problem Statement

In comparison to empirical methodologies used to conduct scientific research, the activities of media arts practitioners are less clearly, and sometimes contradictorily, defined. Media artists function in a range of roles. In addition to producing art, building multimedia tools, critically evaluating culture and technology, and speculating about the future, media artists– perhaps because of this array of activities– are increasingly becoming involved in or are leading collaborative projects involving interdisciplinary teams. Media arts often inhabit these roles simultaneously, and are forced to reconcile the tensions in these perspectives, or to try to ignore them altogether. On the one hand, the history that media arts shares with conceptual arts implies a critical role, one where the media artist thinks about the ramifications of technology, using art as a space for exploring cultural, political, or ethical issues. On the other hand, the engineering aspects of media arts projects steers artists to focus on making or applying technology, seeking novel configurations in order to find new creative possibilities. Of course, this duality is not insurmountable, and many media artists do manage to negotiate these opposing perspectives. However, this ontological tension is more apparent in collaborative projects. Media arts projects are often complex, requiring coordination between people with different perspectives. Moreover, media artists are increasingly becoming involved in interdisciplinary "art-science" projects that include a range of expertise in order to discover innovative solutions to complex problems beyond the scope of a single discipline. In order to participate more effectively in art-science collaborations, media artists require a clear set of methods, tasks, and terminology that will guide their activities within these types of projects.

1.3 Contributions

By thinking of the "space" of media arts through using the methodological themes that I introduce, it is easier for media artist practitioners to focus on foundational aspects of media arts. These aspects have a different focus and use different methods than either fine arts or of engineering, the two fields that media arts is usually seen as being closest to. Although media arts is practiced using a mixture of artistic and engineering methodologies, I show that it is more fruitful to think of media arts methodologies as being different in nature than either arts or engineering methodologies. In the following sections I describe the space of media arts practice (as it is useful to interdisciplinary art-science research projects) both in terms of the potential *roles* of media artists and of their *goals*. I use a series of projects that I am familiar with, either as the main author or as a collaborator, in order to examine in detail the various aspects of these methodological themes, and as a first step to evaluating the effectiveness in thinking about these themes. It is my hope that other will also find division of the media arts space into activities centered around these themes as a useful way to become more effective in interdisciplinary research projects.

In this chapter, I also show that the current ways in which many media artists define the space of media artists may not be ideal for collaborative research projects. This is not to say that there is anything inherently problematic with existing categorizations and methodological approaches, or to say that media arts does not have important foci outside of interdisciplinary collaborations. However, as I show in this chapter, without any methodological foundations, media artists are often relegated to less integral positions in art-science projects, such as public outreach, or arts focused projects that are more-or-less ornamental. With these methodologies, media arts practitioners are able to clearly define their role and intentions within these projects.

The contributions of this dissertation are as follows: 1) To introduce new methodological approaches to help frame media arts practice; 2) To define and explain roles of the media artist in collaborative "art-science"/interdisciplinary projects; 3) To present case studies as examples for thinking about these integrated methodological approaches and roles; 4) To provide a comprehensive literature review of media arts roles, methodological approaches and specific research methods; and 5) To suggest and articulate new lines of media arts research based upon these methodological approaches. Chapter 1 contextualizes the methodological themes and artworks in terms of both the current and historical literature on media arts production and art-science collaboration. Chapter 2 presents some of my interactive data visualization projects, including the "Cell Tango" and "Data Flow" projects and examines their possible research contributions, examining in particular issues in conducting data visualization research and creating data art visualizations. Chapter 3 describes two projects, "Fluid Automata" and "Annular Genealogy," and discusses how artworks can function to generate novel research topics. Chapter 4 describes an ongoing project, "Augmented Communication Tools," as well as the "Natural Materials Browser" [70], a project that evolved out of an artistic contribution to the "New Dunites" art project to effectively augment domain-specific volumetric data [20]. Both of these projects are examples of how these methodological themes are effective within interdisciplinary research projects. I conclude by discussing how these methodologies can help to explain and to promote emerging roles of media arts practitioners in interdisciplinary collaborations, and by providing an overview of the IEEE VIS Arts Program. This workshop, which I co-chaired in October 2013, brings together visualization researchers, artists, and designers to explore potential benefits of collaborative methodological approaches to research.

1.4 Background

Over the last few years, my work as a media arts practitioner has included creating multimedia art installations, designing novel visualization algorithms, creating software frameworks to make it easier to visualize dynamic data, and researching techniques for interacting with scientific data. Although I work both as an artist and as a researcher, and I believe that both of these roles inform each other, I have found myself increasingly engaged with research questions but that in some ways my art production has had a less primary focus. Another way of looking at this might be to say that the way I *think* about media arts has evolved. Rather than seeing artworks as personal investigations and expressions, I more often prefer to see a more expansive role for the media arts, one that incorporates multiple perspectives and many sources of data, that invites participation and collaboration, and that contributes to interdisciplinary projects. However, there is a definite difference between creating media arts projects that have a specific artistic agenda and those that might lead to publications in computer science conference proceedings. As many authors have noted, and as I discuss later in this chapter, the methodologies of art and science are fundamentally different in nature. Art projects tend to be more exploratory, coming to a final incarnation through many twists and turns; creating an object or an installation that fulfills a range of constraints simultaneously, not all of them necessarily clearly or specifically articulated, and thus not easily repeatable. Empirically-oriented projects require clearer goals, appropriate hypotheses, and well-articulated evaluation methods. I believe that the flexibility inherent in the process of creating art projects can be combined with the rigors of empirical projects. This is not to say that research is not creative, or that art is not rigorous, but rather that a clearer methodology is needed to clarify how this flexibility and rigor can be combined in the media arts.

Part of the reason I have been more interested in collaborative projects is due to the type of research that occurs at UC Santa Barbara within the Media Arts and Technology program. Projects led by the MAT faculty have a large technical component, and developing the skills to manage systems involving advanced, complex technologies is explicitly encouraged. It is exciting to be on the cutting edge of thinking about novel applications of new technology; on the other hand, the time and effort that is required to learn these skills attenuates the ability to think more expansively about the *meaning* of these applications of technology. This is especially ironic because often the goal of these collaborative projects is in large part to facilitate new ways of thinking about and representing technology and data collected via these technologies. Art historians Kristine Stiles and Edward Shanken, in their insightful essay discussing the use of technology in media arts, "Missing in Action: Agency and Meaning in Interactive Art," warn about this problem, inherent in art that engages with implementing new technology. If the only meaning of the art is the fact that it, however adroitly, makes use of new hardware or software, then it suffers as art; it becomes outdated quickly, is seen as trivial, or worse, as being in some sense compromised. Stiles and Shanken describe how media arts projects might unwittingly serve the "interests of industry" through popularizing commercial products and technologies and endorsing a "co-opted" ideology of interactivity and agency [204]. Elsewhere, Shanken notes that even at the "dawn" of art and technology there is a tension between art and technology that continues today [191]. He explores the early conflict between media arts and conceptual art– still ongoing– where the output of media arts projects is not considered to be actually artistic or truly meaningful, but rather is tainted with, as explained by Jack Burnham, the "chic superficiality" of "the uptown discotheque" [21]. More recent gripes about media arts attack its triviality when used to create generative art [7], mathematical art [104], animated films [18], video games [53], festival installations and VJ performances [37], and, most relevant to this dissertation, art-science collaborations [104, 140, 234].

Along with many others who write about the politics of new media, such as Rita Raley and Pamela Jennings, Edward Shanken claims that a primary agenda of the media artist is to be conceptually focused and politically aware. And, while this belief is not necessarily shared by all media artists, it indicates some tensions that are commonly discussed within the media arts community. What is the role of the media artist? What agendas are they fulfilling? Is it the media artists' responsibility to raise ethical concerns? Is a purely aesthetic impulse a form of decadence? How do media artists negotiate this tension between using technology and questioning technology? One common perception of the media artist's role is that he or she provokes, problematizes, challenges– embodying the quintessential role of the outsider. On the other hand, media artists are increasingly becoming insiders, and are considered instrumental in successful interdisciplinary projects. But why exactly? As I discuss later in this chapter, the reasons range from their general creativity to their specific ability to think through issues of representation, translation, and interpretation. Most of these tensions arises out of a concern that the media artist, as someone who *uses* technology, may also be *used* by technology. For a number of reasons, I think that this is an oversimplified dichotomy, and that it is indeed possible and worthwhile for media artists to become insiders (that is, involved in empirically-focused projects) while still maintaining artistic agendas, without being solely responsible for community outreach, ethical determinations, and public mediation.

Although Shanken articulates a concern about the potential misuses of technology for artistic and entertainment purposes, other media artists describe themselves explicitly as makers of new technology, or active researchers into scientific projects. Many media artists are deeply involved in the process of building tools to support their own art projects, or to aid other artists in their work. These tools generally involve the writing their own software libraries or frameworks, or contributing patches or example code to existing ones. As tool-builders, media artists have more control over their artistic output, but may then spend large swathes of time in making these tools. Artists have always been involved in making or modifying their tools; but while, to take just one example, the 15th century painter Jan van Eyck may have pioneered methods for developing oil paints, these enabling technological innovations are secondary to his artistic output [96]. In my own work, I often find myself drawn into developing software frameworks for particular projects. For instance, after working on a variety of projects involving the dynamic streams of heterogenous data for media arts installations (discussed in chapter 2), I created a framework called *Behaviorism* that codified some of the patterns for managing data and animation that I found myself reusing. A newer project, *Aluminum*, is a lightweight C++ framework that supports current graphics libraries and was created originally to enable projects to be used in the AlloSphere Research Facility [2], but also to allow them to be easily ported to mobile devices. I have also created software tools for video manipulation and stereographic rendering (the latter in collaboration with Charlie Roberts) solely for the purpose of learning a new technology. That is, software tools are sometimes created out of a need, and sometimes created before there is even a need. Tool-building requires its own form of creativity, but, as interdisciplinary researcher Kaley Middlebrooks explains in her article, "New Media Art: A New Frontier or a Continued Tradition?," it is of a different nature [150]. Creativity in tool-building is at once more focused and more expansive. More focused, because the main innovations that are solved are micro-level– finding robust and elegant ways to solve coding problems– and more expansive because the goal is to enable other people to be be creative through using your tools. Although not always completely straightforward, there are much clearer evaluation methods for software development that there are for artistic production. Every compilation evaluates the success of your code; and it is easy to distribute and gather feedback for software tools. On the other hand, tool-building is a more abstract form of media artist practice. While it promotes and enables creative projects that may perform explicit cultural and aesthetic engagement, this function is not intrinsic to the task of tool-building.

Many media artists have used scientific investigation and scientific materials as a basis for their artwork. Historically, a number of research labs fostered creativity and innovation by inviting artists to work alongside scientists [97]. For instance, John Whitney, a pioneer in computer animation, was a resident at IBM [90]. The experimental filmmaker Stan Vanderbeek worked for a time at Bell Labs [184]. And artists, musicians, and composers, including Laurie Anderson, Terry Riley and the Kronos Quartet have had work commissioned by NASA [134]. SymbioticA, at the University of Western Australia, is an artistic laboratory that over the last decade has been dedicated "to the research, learning, critique and hands-on engagement with the life sciences" [30]. The artist, maker, and builder Garnet Hertz has investigated the use of circuits and circuit bending as an art form [100]. Collaborations by Victoria Vesna and James Gimzewski utilize nanotechnology to "blur fact and fiction" in order to create hybrid artistic-scientific installations [88]. And artists such as Chris Woebken and Natalie Jeremijenko, who was also an artist-in-residence at Xerox PARC, have created installations based on ecological sciences [50].

Media artists are increasingly interested in conducting or enabling scientific research. Artists and researchers, such as Stephen Wilson [230], Roger Malina [138], Christa Sommerer and Laurent Mignonneau [198], Jill Scott [187], John Maeda [136, 137], and many others, have begun to position themselves as interdisciplinary investigators that work on and promote the importance of art-science projects. Prevalent examples of what also might reasonably be considered art-science at UC Santa Barbara include: the AlloSphere Research Facility led by JoAnn Kuchera-Morin, investigating interaction, sonification, and visualization in a virtual reality environment; George Legrady's work in computational photography and culturally-contextualized information visualization; Marcos Novak's explorations of morphogenesis; Curtis Roads' compositionally-focused analysis and application of matching pursuit algorithms; Marko Peljhan's MakroLab; and Ted Kim's development of physical simulation algorithms for use in entertainment. While these projects maintain an artistic focus, and are sometime criticized for it (see, for example, [164]), they often strive to move into a more integrated role, and argue for the importance of new kinds of creative thinking in scientific research. Projects of this scope require multiple people with different skills, or even large teams to function successfully. Regardless of the size of the projects, art-science research is inherently collaborative.

My own collaborative work in research-oriented projects has fallen into different areas, including user interface design, knowledge representation, visualization, interaction, and software development or database design. For instance, I worked with the computational linguist, Stefan Gries, to build the *Corpus Browser*, a tool that allows linguistic researchers to quickly test hypothesis about language using a large corpus of written text [71]. I have also worked on several projects related to social network visualization and analysis with Saiph Savage [77, 185]. I am also continuing to collaborate with Tony Fast, a materials scientist at the Georgia Institute of Technology, on a system to share and annotate volumetric materials science samples [70] (described in Chapter 4). More recently, I have begun working with members of Elena Plante's Speech and Hearing lab at University of Arizona on a project to visualize and interact with temporal clusters of brain activity that change over time during language acquisition tasks [79]. I am also a co-PI on a grant to study cyberinfrastructure for a comparative genomics tool, led by Eric Lyons at University of Arizona. Most recently, I am a co-PI on a pending grant with the health informatics researcher, Jane Carrington, to explore the use of new visualization and interaction techniques to improve nurse communication via augmenting electronic health records [78] (also introduced in Chapter 4). In fact, the majority of work I do, whether they are part of art or research projects, are intrinsically collaborative, as is true for most media artists. Media artists are thus in a good position to leverage their skills and interests to make important contributions to these projects and to wrestle with many of the issues that arise at this intersection between art and research. Throughout all these collaborations with domain-experts, and whether or not my role was more or less technical or creative, various dichotomies arose again and again. Some of these tension that I had to wrestle with included: an expectation to focus on public outreach while at the same time contributing academically; having an empirical outlook but also an interpretive one; having technical, engineering skills at the same time as artistic goals; being an insider to the main concerns of the project but also being aware of cultural outputs.

While these tensions may be overly simplistic, they nonetheless indicate a prevailing mindset about the proper role of media artists for particular activities. It is these experiences of needing to articulate my "hybridity" that has led me to this study of media arts methodologies. In the following sections, I will survey how other media artists in art-science collaborations have resolved or at least come to terms with these tensions, exploring how they work and how they present themselves to the world.

1.4.1 Terminology

Media arts is at the center of various discourses; this section clarifies some common terminology in order to focus the following discussion about the roles and methods of media artists.

Disciplinarity In an often-cited article, the public-health scholar Patricia Rosenfield describes "a simple taxonomy" of cross-disciplinary research: *multidisciplinary* work involves researchers working independently, but to address a common issue shared by multiple disciplines; *interdisciplinary* work involves researchers from different fields working together, but from different perspectives; and *transdisciplinary* work involves a "shared conceptual framework" where researchers collaborate together to merge disciplinary-specific theories, concepts, and approaches [178]. For the purposes of this thesis, the terms interdisciplinary and transdisciplinary will be used more-or-less interchangeably, with complete transdisciplinarity seen primarily as a potentiality that rarely exists in working groups due the time and effort it takes to merge disparate perspectives and methodologies. Rosenfield writes that transdisciplinary research "has the potential to move [...] to a stage where disciplines can build on their distinct traditions and coalesce to become a new field of research, such as has happened in molecular biology." Media arts is an example of a field that emerged in part out of distinct traditions of art (e.g.. conceptual art, art-and-technology, composition, film) and technology (e.g., computer science, electrical engineering).

Media Arts Practitioners who identify themselves as being involved in media arts, or some closely-related title, such as “intermedia” “new media arts,” “interactive art,” “digital art,” may perform quite different functions. This dissertation explores the various roles the media artist inhabits, the communities he or she belongs to, and, in part, seeks to investigate what a useful definition of the media artist might be for successfully participating in interdisciplinary projects. Part of what I will be arguing is that the role of the media artist is precisely that of mediating between disciplines to help makes projects more transdisciplinary in nature. Since the phrase media artist refers to both artists who use technology as well as to researchers who explore multimedia technologies (or to both simultaneously), I use the phrase “media arts practitioner” to broadly indicate this range of roles, unless otherwise specified. One definition that I do not discuss is media arts as purely visual or aural production and/or effects. While these activities are interesting and complex, in general they are used to serve entirely different forms, such as video games or animated films.

Art-Science The interdisciplinary projects I discuss all involve in some way the participation of a media arts practitioners in interdisciplinary research collaborations that include a significant scientific and/or engineering focus. There are of course many examples of media artists working with engineers to craft components of artworks. Similarly, media artists often appropriate scientific material for artistic projects in various ways. However, here I specifically refer to projects in which the output of the collaboration is neither purely artistic nor traditionally scientific, but rather have some kind of hybrid result that has a broader result of interest to both artists and scientists. These types collaborations are called by various names, such as “art-science” project, “transdisciplinary” research, “STEM” or “STEAM” initiatives, all of which indicate a particular type of research that require the expertise of multiple disciplines and aim to broaden the scope of how certain problems are solved or research tasks are thought of. I use all of these terminologies– usually “interdisciplinary” or “art-science” collaboration– and point out particular nuances as needed.

1.5 Motivation

In this section, I draw a trajectory from general to specific reasons for the importance of media arts practice, especially as it relates to interdisciplinary collaboration. Works of media art tend to be evaluated either in terms of cultural or pragmatic utility. Media arts is often regarded in generalist terms that describe its societal contribution in creating products of cultural enrichment, tools for promoting innovation, or providing the means by which to think critically about the ethical ramifications of technology. Media arts is also characterized as having the potential ability to aid in the solving of specific scientific and engineering problems, especially those having to do with creative representations of, interacting with, and reasoning about data. At all levels of this trajectory, there is a struggle to articulate concerns regarding the tension between artistic outlooks and technical engagement, as well as to define the role and methods of the media artist within both art and research contexts.

The importance of media arts as an art form is often explained in a similar manner as other arts– they imbue society with vibrancy and culture. Jennifer Craik, a researcher who explores comparative cultural policy, for instance, addresses this in Re-Visioning Arts and Cultural Policy [40], exploring the reference to "cultural vitality" as a prevalent justification for the governmental funding of media arts. More specifically, Martha Nussbaum, the American philosopher and ethicist, in her book, "Not for Profit: Why Democracy Needs the Humanities," sees a correlation between creativity and democratic principles, exploring how necessary ingredients for a robust society, such as the ability to empathize with others, to see problems from multiple perspectives, and to think critically and ask questions, are effectively learned through a strong arts curriculum [161]. The artist and researcher Pamela Jennings also describes the societal benefits of media arts: "The new media arts express a risk-taking and subversive attitude, ultimately seeking cultural acts through which to provide society with entry points for change" [106]. Seen in these ways, media arts practice as a whole is a humanistic endeavor that makes science more accessible and increases public engagement with issues surrounding technological innovation.

At the same time, many research initiatives point to changes in the landscape of STEM (science, technology, engineering, and mathematics) research that indicate that new ways of thinking creatively and collaboratively are becoming increasingly important for various practical reasons. A study released by The Conference Board in 2008, "Ready to Innovate," explores the relationship between creativity and innovation, and argues for the importance of instilling creativity via education in order to foster a globally-competitive workforce [130]. A recent report released by The President's Committee on Arts and Humanities specifically outlines recommendations to facilitate the promotion of arts education, including an emphasis on integrating art practice with other subjects, which seems to improve overall academic involvement and to encourage innovative thinking [171]. John Maeda also describes the need for integrating the arts into government-backed STEM initiatives so that they are recognized as being "part of the same pool of knowledge." More hyperbolically, he explains that because art is needed to help foster innovation it is therefore is "vital to national security"[1]. Specifically, the STEM to STEAM Initiative (championed by Maeda) presents a series of case studies involving experiments in early education and corporate collaborations in creating and packaging "design-centered and human-focused products"[2].

Other authors more concretely examine contemporary needs that require creativity and innovation and explore how the media arts (or creative aspects of computer engineering) specifically can be effective. For instance, Roger Malina outlines increasingly problematic issues in contemporary scientific practice and hopes that art-science collaboration may lead new techniques and methodologies for approaching them. In a book review published in Leonardo, he explains that a primary motivation for the "art-science movement" is the "epistemological inversion" that has occurred due the exponential increase in data that is available whereby the sciences have become "data rich and meaning poor" [140]. Moreover, the type of data has changed– Instead of having "snapshots" of data, there are temporal "streams," or complex "data systems." This leads to a "crisis in representation." Science is largely conducted through data analysis and not through empirically sensing the world, and, because there are no obvious ways to represent probabilistic, fleeting, or otherwise unintuitive data, this necessitates the attention of the artistic sensibility that is skilled at thinking about issues of representation, or what he calls "re-sensing": "use of visualization and sonification technologies from computer science are a rich terrain of art-science practice and should be viewed as projects in translation" [139]. Moreover, this "deluge" of data creates potential "blind spots"– areas and interpretations that are ignored because the amount of data exceeds our ability to analyze it. Finally, he advocates for the importance of art-science collaboration because the solutions to complex, global issues require diverse skill sets and the involvement of experts from multiple disciplines. Interestingly, Malina disagrees with the idea of a transdisciplinary merging of art and science, but instead imagines a "shared language" that "entails shared ontologies and eventually connected epistemologies" that "contribute to creativity and innovation." However, the process of building this shared language involves

[1] http://www.newscientist.com/blogs/culturelab/2012/08/john-maeda-steam.html
[2] http://www.stemtosteam.org

a perpetual negotiation between different perspectives, a process of "trade and barter and not assimilation" [139].

Another motivating factor for this dissertation is the continued participation of media artists in developing tools and platforms that foster creative ways of representing and interacting with data. In a 2007 essay, Ben Shneiderman, a pioneer in the field of information visualization, describes the need for tools that enable researchers to come to new understanding or to make discoveries. These tools involve the various stages of research, from the "early stages of gathering information, hypothesis generations, and initial production through the later stages of refinement, validation, and dissemination" [195]. Specific examples of tasks that creativity support tools facilitate include: the rapid generation of multiple alternatives, the freedom to explore implications of alternatives, and the option to revert to earlier stages. Linda Candy, co-founder of the ACM SIGCHI Creativity and Cognition conference series, sees the media artist as especially well situated to develop new creativity support tools. She explains that media arts projects present a way to "harness" the various "complex social, organizational, and cultural factors" that are required for innovation. Candy thinks of the artist as a "power user" that pushes the boundary existing frameworks and tools in order to discover new forms of expression [23]. Zafer Bilda, an Australian researcher in design cognition, also examines media arts installations as proving grounds for techniques that are helpful for understanding how different forms of interaction promote increased engagement and creativity [13]. Pamela Jennings further extends the idea of creativity support tool as a framework for pervasive computing. She explores ways in which media artists more expansively consider creativity support tools to be "distributed structures that mutually reinforce both individual and social creativity." She recognizes that any tool is part of "a socio-technical architecture deeply interwoven with the physical environment and social fabric of local communities" and calls for a more "pervasive" outlook on creativity when "investigating and promoting situated and distributed aspects of creativity, particularly in relation to temporal, spatial and conceptual distribution across multiple interaction spaces" [106].

Edward Shanken, in "Artists in Industry and the Academy: Collaborative Research, Interdisciplinary Scholarship and the Creation and Interpretation of Hybrid Forms," explores the gap between the perceived importance of media arts engagement with science and technology and lack of clear methodologies for conducting interdisciplinary projects [192]. He writes that "despite the general recognition that there are substantial challenges to collaboration across disciplines, there is scant metacritical research that studies best practices, working methods, and contextual supports and hinderances." Moreover, there is confusion about the end goals of interdisciplinary projects, especially when it does not lead to a typical artistic or scientific outcome: "one must wonder about the epistemological and ontological status of these hybrid forms. What exactly are they? What new knowledge do they produce or enable? What is their function in the world?" Shanken is concerned that if there are no clear practices or results to evaluate, then artists and researchers will not have the incentive to "facilitate the creation of new forms of invention, knowledge and meaning." On the other hand, there are exemplary projects that might serve as case studies, and certain individual artists are successful at functioning within interdisciplinary contexts. But it is less clear exactly how and why they are are able to function as "catalysts." That is, it is not always clear what specific methods were used in these projects and what specific roles media artists take on in order to help make them successful.

Media arts practice, with its hybrid focus on art (thinking about, extending, and challenging representation) and engineering (creating new systems, making use of new technologies) is in an appropriate space to begin to think about the cultural and technological concerns and opportunities inherent in shaping technology for new research methodologies. In the next section, I explore a sampling of the various roles that media arts have defined for themselves, especially in relation to interdisciplinary collaboration.

1.6 Media Arts Roles

As described above, the discipline of media arts includes a wide range of practices, with a wide variety of roles available to different media artists. Nonetheless, in the literature describing the roles of media arts practitioners a few general categories emerge, especially in the context of participating in interdisciplinary projects. These roles include diverse activities such as: managing public outreach, leading interdisciplinary teams, organizing politically-charged events, building software tools, as well as making art objects or installations. In this section I look at some representative examples of these roles drawn from ethnographic studies of art-science collaborations, essays on pedagogical approaches, and theoretical idealizations of the media artist. Different methodologies follow from these different roles, and I argue that all of these conceptions indicate an evolution of the activities of the media artist, and that, taken as a whole, they indicate interesting tensions in the perspectives and goals of the media artist.

1.6.1 Art-Science Collaboration

In the essay, "Art and Science Research: Active Contexts and Discourses," the Switzerland-based artists Jill Scott and Daniel Bisig describe their experiences during recent collaborative interdisciplinary projects and raise questions regarding the effective role of the media artist. They conclude that media artists who work in collaborative contexts with scientists are provided with the materials to conduct "critical analysis in the public realm" and believe that through these collaborations media artists can "perhaps even conduct social change." For Scott and Bisig, the primary motivation for bringing together media artists and scientists or engineers is so that the activities of researchers can be better explained and presented to the public. That is, the skill set of media artists positions them to be effective mediators between the academy and the public, and to construct effective, educational public outreach campaigns. Internally to the collaborative project, the media artist, as an artist and simply as an enthusiastic outsider, is also able to: challenge disciplinary hierarchies to promote new insights, to critically examine the prevailing tacit methodologies, to point out that knowledge is situated in culture and socially constructed, and to raise ethical considerations [188].

These examinations also discuss how artistic methodologies may promote creative thinking and how creating non-hierarchical research centers may help foster sharing and communication. However, the authors think that it is the media artist's general outlook that is useful to the collaboration, rather than a particular set of skills. Because artists have skills at finding unique visual metaphors, are not afraid to say what they think, and because are concerned with artistry of communication, they envision media artists as the "main players for interpreting scientific research" to a general public who find science "ethically suspect." They introduce the idea of the media artist as an activist who is able to mediate between the world of research and various public works: "some artists can assist local communities in a move toward sustainable developments, others can look for ways to raise public awareness" [188]. Though many aspects of their account are intriguing, in my experience media artists do not position themselves in terms of public outreach and activism when participating in collaborative research environments. For instance, one assumption that the article makes is that scientists and engineers do not consider ethical issues, but they provide no evidence that media artists would for some reason have enhanced ethical sensibilities. Although media artists often present their work to the public in gallery and museum settings, they generally do not act as spokespeople either for the public or for scientists– a role that seems perhaps a more appropriate for a journalist, whose job it is to report information to the public. While there is a rich history of the use of art as a form of activism in media arts (and conceptual art in general), this role tends to imply an outsider's perspective, and this kind of provoking and/or community involvement does not necessarily lend itself to successful collaboration. On other hand, it does partially capture the spirit of *why* collaboration is considered important. Both scientists and artists are in some sense public figures, working in public institutions, tasked with contributing to society. In some projects it may make sense to utilize the skills of the media artist to mediate between the public and the researcher, but in general, it is not characteristic of the ideals and the day-to-day practice of most media artists.

Media artists often choose to be insiders, or even leaders, with a role that is more fundamentally integrated with the scientists and engineers. The artist George Legrady presents a series of articles that examine his own work both as the leader of a team of interdisciplinary researchers and also as an educator investigating methods for fostering creativity in interdisciplinary projects. An article co-authored with Brigitte Steinheider, "Interdisciplinary Collaboration in Digital Media Arts: A Psychological Perspective on the Production Process," contextualizes the process of creating a complex multimedia installation both in terms of the final artistic output and in terms of the collaborative work needed to create the installation [202]. The piece, Pockets Full of Memories, applies information technologies and self-organizing algorithms in order to conduct a public cultural exploration of everyday objects [128]. In particular, Steinheider and Legrady examine some of the practical considerations of working with a diverse team of computer scientists, designers, and artists. While the project resulted in a series of successful installations, various problems arouse during both the design and installation phases of creating the piece. They explore the tension between production and experimentation; getting things done versus remaining open to new possibilities. From the artist's perspective, flexibility is necessary in order to maintain creativity and to make sure that the final project has aesthetic integrity, despite the potential to cause some amount of disappointment (if plans need to change or people need to leave or work on different tasks) and inefficiency (as work that does not end up fitting the final project must be re-done). However, identifying issues with "communication, coordination, and knowledge-sharing" may make it easier to collaborate. In particular, they emphasize the importance of knowledge-sharing. All participants in the project need to have a "meta-knowledge" that allows them to connect "the different areas of needed expertise as they relate to the project that has brought them together."

Another article by George Legrady explores difficulties that arise when media artists and engineers attempt to collaborate in a more integrated manner, sharing in leadership of a project. In "Perspectives on Collaborative Research and

Education in Media Arts," Legrady describes co-leading an innovative graduate-level course with an engineering professor. The course included students from different fields who were tasked with working together on conceiving and creating novel interdisciplinary projects. In observing the development of these interdisciplinary projects, the course leaders noticed different roles that tend to be played by the artist and engineering members of the projects. For instance, artists focus on "cultural aspects of media," look for various kinds of "subtext," and are comfortable with noisy data while, on the other hand, engineers are interested in "problem-solving opportunities," are more comfortable with "purer signals," and seek reliable, measurable collections of data. Artists are by nature "generalists" who incorporate a "wide spectrum of sources" to come up with a unique approach that cannot be reduced or replicated without dissolving "essential qualities." Ultimately, Legrady concludes that these differences in approach are somewhat detrimental to engineering goals and that there is not necessarily an immediate benefit when including artists in specific, existing research problems. However, he also believes that the artist's insight may "have an impact down the road by opening up new vistas" [126]. In his article, "Expectations of Scientists Towards Interdisciplinary and Transdisciplinary Research," geographer Marc Antrop also explores some complications inherent in finding a joint language between participants from different domains working on solving interdisciplinary problems. He believes that interdisciplinarity is actually "an attempt to re-introduce lost skills" that disappeared due to the narrowing of disciplinary focus. In particular, he finds that communication with quantitative scientists is difficult because they do not always understand that research can be "holistic, dynamic, and multi-scale" [5]. He envisions a "global theoretical basis" for "a common language understandable and meaningful" to a participants in interdisciplinary projects.

These sample case studies present four different perspectives characteristic of recent writings describing roles of media artists, as artists, when working in collaborative projects. There are a variety of different configurations of collaborations and different tactics for operating in these configurations are still being explored. Although a goal may be to have integrated teams of artists and researchers, no "best practices" have been identified that are completely effective. However, some important issues are acknowledged, such as the need for clearer communication and knowledge-sharing. The concept of "meta-knowledge" is especially interesting, as it encapsulates the importance of having each participant be aware of the roles of the other participants as well as the overall methods and goals of the project. Since the media artist is positioned in between art and technology, their role in facilitating this meta-knowledge may be important for successful interdisciplinary projects involving multiple participants.

1.6.2 Aesthetic Computing

A different role for the media artist is described in Paul Fishwick's "Aesthetic Computing" [64]. He eschews the dichotomies of the artist and scientist roles and does not explore ways for artists and scientists to create common a language. On the contrary, he believes that media artists should not aim merely to interact with scientists and engineers, but instead think of themselves as scientists and/or engineers themselves. In particular, he imagines media artists as engaged in thinking about the aesthetics of computational representation as it applies to data structures, algorithms, as well as user interfaces. His main contention is that there is already an embedded sense of aesthetics in mathematics and computer science that involves invariance, parsimony, minimalism, proportion, and symmetry but that framing research in terms of other kinds of aesthetic modalities, such as pliability, fluency, and seductiveness could lead to new breakthroughs and also help the research to find a wider audience. He finds that the increasing power and ubiquity of computers introduces new aesthetic possibilities that can take advantage of customization and personalization and engage with issues of modality, quality, and culture. Media artists are well situated to think about cultural issues, and they also can think about new metaphors with which to frame "notational spaces."

Fishwick describes activities of the computationally and aesthetically engaged media artist that includes "representing programs and data structures with customized, culturally specific notations," "incorporating artistic methods in typically computing-intensive activities," and "improving the emotional and cultural level of interaction with the computer." That is, the media artist is first and foremost a computer scientist, but with a background in aesthetics and cultural mediation. Additionally, Fishwick does see a role for the media artist in "non-utilitarian" roles. A project that is wholly aesthetic, and not directly research-oriented or product-oriented, can still influence utility by wrestling with issues of aesthetics, modality, metaphor, and culture. These art projects can have both a inspirational and pedagogical function.

Other researchers similarly see their aesthetic work as a catalyst for advances in the development of computer programming techniques and frameworks. For example, the algorithmic composers Alex McLean and Geraint Wiggins discuss the idea of "bricolage" programming as an approach whereby the constraints and opportunities of a particular computational artwork can lead to novel programming methods. Bricolage implies a more iterative way of thinking, of creating through crafting, of experimentation based on limited resources. In the article, "Bricolage Programming in the Creative Arts" they make a case for thinking more metaphorically about programming in order to foster both artistic creativity and computational flexibility. While "shallow" ideas that introduce spurious concepts, techniques and systems can be problematic to computer scientists (cf. Dijkstra's screed against "inflicting" misguided "radical novelties" [49]), creative experts working on specific artistic projects are able test out new ways of thinking about metaphors, workflow, and design patterns that are actually effective at promoting efficient programming techniques [147]. That is, by using an aesthetic focus as a springboard for programming innovation, creative practitioners are able to introduce not only new ideas and new techniques, but also new ways of thinking about the research methods themselves. For example, in "Metaphors We Program By," Alan Blackwell examines a series of social, physical, and conceptual metaphors [14] underpinning the structure of the Java programming language that may influence the mental models of programmers. One role of the media artist is to introduce new metaphors and to expose the metaphors that are already being utilized. That is, the aesthetic computer scientist, or the computational media artist can have a dual role, creating new ideas and problematizing existing ones.

JoAnn Kuchera-Morin also sees a role for aesthetics in computer science research. In "Using the Creative Process to Map N Dimensions: Quantum Information at Your Fingertips," she envisions the role of the computer scientist as similar to that of a composer. In particular, she cites the compositional process as being an appropriate methodological system for thinking about how to move between and integrate processes occurring at different hierarchical levels. This aesthetic process works whether it begins from a "microstructure" or at the "macro-level" – with the right tools, a researcher can "unfold" a complex process, creating a "navigable immersive context" that can benefit scientific research [119]. The media artist is thus a composer of data, and uses technology as a "large, multi-user instrument" that creates outputs that are simultaneously immersive research environments and "abstract art forms and visual/sonic installations."

1.6.3 Post-Media Aesthetics

In opposition to the more utilitarian agendas prescribed by the above roles in which the media artist develops or assists practical research agendas, some writers imagine a more inspirational role. For example, in "Liquid Architecture in Cyberspace," Marcos Novak describes the media artist as a visionary architect of a digital environment that is defined by a constantly metamorphosizing poetics where data can be mapped to form in an infinite variety of ways [160]. Novak advocates a methodology that encourages "minimal restriction" and "maximal binding" so that new representational schemas can allow different "correlations" to appear within the same data. As Randall Packer and Ken Jordan explain, this visionary outlook implies "a commitment to forms of media and communications that are non-hierarchical, open, collaborative, and reflective of the free movement of the mind at play" [163]. Deleuze and Guattari's influential concept of the *rhizome* as a decentralized organizational structure is apparent in the much of the writing about multimedia technology. They conceive of the rhizome as a kind of "abstract machine" that "ceaselessly establishes connections between semiotic chains, organizations of power, and circumstances relative to the arts, sciences, and social struggles" [46].

Lev Manovich, in his article, "Post-Media Aesthetics" also envisions a new role for media arts as creators of "information interfaces" that influence societal "information behaviors." This concept of media arts subsumes both traditional and digital media by reframing artwork in terms of its "operations." For instance, he likens the films of Eisenstein to Tim Berners-Lee's invention of linked multimedia pages in that they both challenge the way information is experienced. He theorizes that post-media categories can help us think about dimensions of cultural communication that might otherwise be hidden. In his conception, the role of the media artist then is to invent new experiences– to find new ways of encoding information– and in so doing shape new behaviors [143]. Manovich also discusses the fact that existing categories of media arts do not represent the actual function of media art, and that the emphasis on the new forms of media as *material* is misplaced. In fact, media arts either uses material in "arbitrary combinations" or in fact aims to "dematerialize the art object." Edward Shanken also explores this tension between the media artist's use of new materials and the their use of concepts that do not rely on any materials at all. In *Art in the Information Age*, Shanken explores how "cybernetics, information theory and systems theory [are] foundational intellectual models" that have shaped culture in a significant way, alongside "the advent of digital computing and telecommunications." In particular, he explores the close ties between media art involving technology and conceptual art [191]. In so doing, he teases out interesting issues inherent to the media arts, both in relation to aesthetics and technology. He looks at some of the earliest successful art exhibitions that involved software and information technologies and finds that they involve "meta-critical" practices which privilege a certain type of thinking that "challenges modernist aesthetics and technocracy." He makes a distinction between art that uses technology as a spectacle, emphasizing its materiality, from art that proposes that require viewers "to investigate the cognitive functioning of their own minds with respect to the processing of information and the creation of meaning." That is, although media arts projects make use of technology, one goal of media art is to cause the viewer to think about the nature of certain aspects of technology itself and its relationship to the individual and to culture.

1.6.4 Tactical Media

Another article by Shanken explores a less idealistic aspect of media arts. In *Missing in Action: Agency and Meaning in Interactive Art*, he describes how media arts (and specifically interactive digital art) can serve the "interests of industry" through popularizing commercial products and technologies and endorsing a "coopted" ideology of interactivity and agency. By offering "imagined personal control to consumers" artists simplify the complex discussions of agency and meaning, reducing participation to a simple choices constrained by a "hegemonic" aesthetic [204]. In some sense, he is directly critiquing the involvement of artists with research into the areas Fishwick wants to claim as aesthetic (e.g., HCI, scientific visualization, VR). Shanken suggests that instead of "earnestly pursuing technological enhancements of agency" artists could take an ethical stance and "focus attention on deconstructing the vast ideological apparatus that enlists individuals in their own subjugation." Art that utilizes technology in a non-critical way, i.e., that blindly accepts the benefits of technology, is in some sense being *used* by the technology, or is fulfilling some other, non-art function. While the language of subjugation and hegemony indicate the need for successful technological and interactive art to involve some level of activism, this can take the form of creating interactive works that promote awareness and encourage thinking and reflection: "the interactive features of multimedia become meaningful when they engage and activate complex emotional and decision-making responses" that reinforce "transformative effects" and play "a constructive role in creative change and exchange."

In "Art, Technology, and Institutional Discourse," contemporary artist Jill Fantauzzacoffin notes that art necessarily has a "destabilizing" role, and that "incorporating art and technological innovation practices means admitting the dynamics of stabilization and destabilization within the discourse of innovation" [63]. Rita Raley's "Tactical Media" explores how one role of media artists is to find provocative ways to promote changes in thinking. Effective works of surveillance art, bio art, performance art, and hacktivism can function to expose corporate/capitalistic structures, and to make a space for citizens to think clearly, politically, and humanistically. She discusses media arts as *disturbance*: "tactical media signifies the intervention and disruption of a dominant semiotic regime, the temporary creation of a situation in which signs, messages, and narratives are set into play and critical thinking becomes possible" [173].

1.7 Methodological Themes

While aspects of the above conceptions of roles are compelling, they do not fully characterize all aspects of the media artist. And in fact, they contradict each other in some fundamental ways. Of course everyone has multiple roles, and some contradiction provides necessary tension. How then can the media artist be characterized, what practical methodologies could embrace these tensions?

A host of artists and researchers have attempted to offer methodologies that incorporate arts practice and research. Many of these attempts are directed to media artists that have a studio-based practice, or that attempt to work with technologists. That is, their methodology follows from the role they imagine for the media artist. These methodologies are largely geared toward art production. Some attempt to frame research methodologies in terms of theory related to cultural practice and art history. However, the methodology of media arts (as I am describing it) is increasingly drawn from pragmatic concerns. Practice-based research can be defined simply as "a research methodology in which an artifact is created by the researcher." Mick Winter, an English composer, explains its differences from ordinary research methodologies, noting that it does not "analyze artifacts or texts created by someone else" or "directly study an individual or group of people." Rather, practice-based research has the interesting property where the thing that is studied "does not exist until the research project begins to create it" [231].

Ernest Edmonds and Linda Candy, through a series of case studies with practicing artists, examine the "research trajectory" of media artists. They observe that practice-based artists generally do focus on theory and evaluation, but that these "research elements" are often done in a non-linear way. Media artists are concerned with creating artifacts, installations, or performance; the process of creating and exhibiting is both an expression of a "conceptual structure" and also a mechanism that can lead the artist to formulate or reformulate theories about the content and meaning of his or her work. They find that artists do not normally rigorously evaluate their work in a formal way, but rather critique it intermittently during the creation process [55].

Estelle Barrett, an Australian proponent of practice-based methodologies, lists a series of foundational questions that need to be asked when explaining creative research: "What is it? Why do we need it? What can it do within the context of a knowledge economy? How do we judge its success and value?" In particular, she questions how artistic production could be "validated" as a useful research mechanism: "What did the studio process reveal that could not have been revealed by any other mode of enquiry?" She offers the idea of critical interpretation, or "exigesis" as a way to think about artworks, and in particular in using creative arts as a way to demonstrate processes rather than results [10]. The importance of creative research stems from the "growing recognition of the limits of traditional ways of representing the world" [59] and the awareness that it can lead to “new ways of representing ideas and of illuminating the world and domains of knowledge.”

These methodological approaches aim to articulate and codify some of the common mechanisms artists use to produce a stronger and more meaningful body of work. However, they are largely focused on the creation of the artwork, and not integration with other forms of research. Other artists and scholars have more specifically examined methods that artists use to further research that is not necessarily solely directed toward the goal of creating an artifact or installation. For instance, the media artist Eleanor Gates-Stuart, in her essay, “Art and Science as Creative Catalysts,” discusses her experience with creative research in an art-science context, and offers a conceptual model of “constructive connection and interplay” that enables her to work effectively with scientific researchers in a series of projects. She writes: “In isolation, scientific and artistic processes pursue orthogonal ‘directions’ of creativity, but, in combination, they allow their participant to access new areas of ideas, imagination, and innovation” [86]. Similarly, Andrew Brown and Andrew Sorensen, live coders who perform in the duo, *aa-cell*, examine their process of developing algorithmic multimedia art to explore “the role of aesthetics in research” and to demonstrate a methodology whereby “knowledge is created and expressed through a conversation between research and practice.” They find that their practice-based research draws on experimental and conceptual traditions of theory. They use their art practice as a system for making hypotheses and empirically judging outcomes; but they also, in part, see their work as logical, non-empirical research that relies on “measures of internal consistency.” At the same time, they emphasize the importance of turning this personally consistent knowledge into shared knowledge, transforming the knowledge of their craft through its expression “as a method, process or theory.” In particular, they note the symbiotic relationship between creating art and creating software. In addition to using software to make their art, their art inspires how they structure their software. Both processes are iterative and involve many “refactoring” steps. They liken their art performances to the release of a new version of software. They consider their research contribution to be in the field of applied computer science; their practice contributes to discover or create the best algorithms or coding techniques for particular effects [17].

Another attempt to codify a methodological system is described by the interaction designers and researchers, Elisa Giccardi and Gerhard Fischer. In their article “Creativity and Design: A Meta-design Perspective” [87]. A key component of their system is that it incorporates the idea of systems that change over time, evolving as problems and needs change. Although they discuss in particular the design methodology for creating new artworks and new software tools, some of their ideas are applicable to collaborative research in general. In particular, they note that the involvement of multiple perspectives, the need for iterative development, and, in particular, the fact that many problems are "ill-posed" require flexible new ways of working and thinking about work. For them, "improvisation and evolution are more than a luxury: they are a necessity." That is, when solutions cannot be specified in advance and when there may not even be a clear way to frame these problem, it may not be possible to delineate an end goal for the collaborative project. Instead, they provide some ideas about how to take advantage of a collaborative design process that necessarily needs to evolve over time. The reformulated goal is not to create a specific outcome, but rather to define and create "social and technical infrastructures in which new forms of collaborative design take place." In some sense, the goal of the collaborative design is to design good collaborative design systems! In other words, there is an element of community building or organizational psychology in their work. They also describe specific methods that encourage effective collaboration. For instance, they discuss the idea of "externalization," which means the creation of a tool or system that encourages or forces participants to externalize their understanding of the project and each other's roles. By so doing, participants are forced to explain their understanding of the material and the research process in general. If it becomes clear that there are misunderstandings or differing perspectives, then this process exposes it, ideally leading to more effective communication. Another idea they discuss is the introduction of "mediators" as a component of the open system. Mediators are emergent languages that emerge through the process of collaboration. Because problems may not be well-defined and may evolve over time, it may be difficult to describe them at the outset of the project. Similar to the concept of externalization, they discuss how tools could be built to encourages the participants to share their knowledge and to create language or codes that describe their new ideas.

In large part, these practice-based methodologies are aimed at introducing empirical research concepts, such as formal evaluation mechanisms, into art practice, both in order to validate the intellectual contribution of the artwork and also to help the artist describe and clarify their aesthetic concepts. A secondary aspect of this work is to think about how iterative, production-oriented, and "bricolage" techniques might be useful addition to interdisciplinary research projects.

1.7.1 Emerging Methodologies

Based upon the survey of roles and methodological approaches described above, I present four methodological themes can be used to more accurately be used to define and guide the activities of media artists in art-science contexts. These

Theme	**Source**
Augmentation	Shneiderman, *Creativity Support Tools* [195]
	Card, *Sensemaking / Information Foraging* [26]
	Kramer, *Auditory Displays* [118]
	Jennings, *Narrative Structures for New Media* [105]
	Kuchera-Morin and Peliti, *Hydrogen Atom Project* [177]
	Sutherland, *Sketchpad* [205]
	Wattenberg, *Shape of Song* [226]
	Electronic Visualization Laboratory, CAVE [43]
Provocation	Kac, *Alba* [108]
	Raley, *Tactical Media* [173]
	Critical Art Ensemble, *Free Range Grain* [42]
	Cox, *Coding as Aesthetic and Political Expression* [39]
	Harris, *We Feel Fine* [110]
	Shanken, *Art in the Information Age* [191]
Mediation	Lovejoy, et al., *Context Providers* [135]
	Legrady, *Collaborative Research and Education* [126]
	Vesna, *Toward a Third Culture* [217]
	Scott, *Artists in Labs* [187]
	Victor, *Media for Thinking the Unthinkable* [220]
Generation	Fishwick, *Aesthetic Computing* [64]
	Interval Research Corporation [131]
	Turkle, *Bricolage Programming* [212]
	Plautz, *New ideas emerge when collaboration occurs* [170]
	McLean, *Live Coding Programming* [147]
	Wilson, *Elaboration on the Approach of Art as Research*, [229]
	Xerox PARC, *PARC Artist-in-Residence* [97]
	Bell Labs/Explorations in Art and Technology [24]

Table 1.1: Example texts and artworks associated with the different methodological themes.

themes will be used to ground the contributions of the projects I describe in later chapters. Table 1.1 catalogs which texts and artworks are most related to these themes, providing a link between various media arts activities and my methodological themes. Although, as I have discussed, there is a wide range of thinking about these activities and various, sometimes conflicting terminologies to describe them, these themes synthesize important aspects of these activities. Table 1.2 lists tasks associated with each of these themes.

1.7.2 Augmentation

The theme of *augmentation* is centered around the idea that certain media arts projects are effective at enhancing important aspects of research in order to make more accessible and more effective, both for outsiders and to domain-experts. That is, a media arts project is a methodological approach to understanding data. A fundamental activity of art is thinking about representation. Research into visualization and sonification are obvious areas in which media artists can make contributions. Similarly, thinking about immersion and interactivity as ways to augment research are also highly active research areas that make sense for media artists to explore. The creation of artworks, whether static or interactive, involves issues of engagement and how to use the “language of art” to tell stories and provide context and narrative, and media artists could apply this know-how to make research both more accessible and more meaningful. Additionally, the tool-building interests of media artists can also serve to augment research, as media artists apply their creativity to novel ways of working with data representation and interaction. Ben Shneiderman’s interest in “creativity support tools”, as discussed above, clearly fits into this theme. Media arts projects, even if they have personal or cultural outputs, are already interested in augmenting research. Media arts projects will find interesting opportunities to augment existing research and also to provide interactions and representations that help researchers make insightful connections. Media artists can work in art-science contexts simply by recognizing that their work can function as augmentation. Some potential activities include: iterating over a specific, manageable data set rather than developing a universal technique; using media arts projects to explore research narratives, to help users turn raw data into a story; or analyzing the existing representation techniques (if any) to see what can be augmented or improved.

1.7.3 Generation

The theme of *generation* involves the idea that media arts projects can generate research topics. Simply by following an artistic inclination, a media artist will

Theme	Task
Generation	Implement ideas without clear hypotheses about outcomes Clarify limitations/boundaries of knowledge and expertise Bring existing ideas into new contexts
Augmentation	Enhance data representation Enhance interaction with data Make data more accessible to domain experts Make data accessible to non-experts Show provenance of data
Provocation	Question assumptions Point out biases and blind spots Indicate cultural implications Expand audiences
Mediation	Create tools that make it is easy to represent concepts Create projects that facilitate communication Support knowledge-sharing

Table 1.2: Potential tasks associated with the different methodological themes.

quickly run up against personal and disciplinary limitations. Many times what the artist wants to do is not possible, or not accessible. Through a bottom-up approach, media arts projects can generate valid, interesting research questions. Moreover, the exploration of a particular area of interest can serve as a way to explicitly trace the contours and boundaries of the research, of precisely what is not known or is not easily accessible. In addition to surveying the research topic, media artists, who are often experts at particular engineering tasks or generating creativity support tools, can "switch hats" and turn from idea generation to actual research, whether it be in the area of augmentation, or other research. Of course, it is impossible to be an expert in everything, and this may be a point where the media artists now has a precise enough understanding of what they *don't* know in order to seek out appropriate collaborators. Media arts projects will naturally come across interesting research topics and run into technical, representational, and even fundamental issues that can be explored. Some potential activities that can purposefully leveraged in art-science contexts include: defining a project or series of projects purposefully to explore a particular area; keeping track of where creative exploration becomes research, and being able to switch from exploratory to methodical approach; and actively looking for these boundaries instead of skirting around them.

1.7.4 Provocation

The theme of *provocation* involves the idea of challenges to the status quo, of introducing alternative perspectives and interpretations. Media arts activities have originality as a goal, and new thinking can arise by questioning assumptions from different points of view: Why are the stated goals of a project important? Are there are other more interesting or useful goals? Are the methods being used to achieve these goals ideal? While there is a critical aspect to provocation, it also has a generative function. The conceptualist artist and interdisciplinary researcher Roland Jones writes, “If artists and designers want to participate in reshaping the political, social, economic and cultural agendas, they will have to begin to think beyond the exhausted forms of critical belligerence and mere consciousness-raising” [107]. This generative function is of a different nature than the theme described above. It is questioning and experimenting goals and methods; in the previous we are trusting the goals of the project in order to find new avenues of research. Through provocation, media artists can introduce an interpretive element to research and can provide new formulations through exploring cultural implications embedded in research questions. Some potential activities include: pointing out areas that are underrepresented in research and exploring ways of including those areas; exploring meaning and implications, not just functionality; and explicitly discovering guiding metaphors and aesthetic modalities in order try to frame research using other metaphors and modalities. In other words, the goal of provocation leads initially to complication, but ultimately opens up dialog for more interesting and meaningful research.

1.7.5 Mediation

The theme of *mediation* involves the idea that media arts projects can function to build a shared language. Media arts projects often consider, or are often explicitly examining, mediations between different realms, bridging between different worlds that may not always come together, or exposing how they do come together. This includes starting or forcing a conversation between the everyday and the rarefied, the natural and the unreal, the public and the private. Interesting projects, almost by definition, are making new knowledge through combining different areas of experience and expertise, by presenting new perspectives and interpretations that are informed by multiple disciplines or ways of thinking. Thus it is important to create processes and strategies that support effective knowledge-sharing. What if this were an explicit goal of a project, rather than a side effect? In order to function in collaborative contexts, Victoria Vesna writes, media artists “must learn the etiquette and language of various disciplines [...] Negotiating the gap between the canon of rationality and the fluid poetic is ultimately the goal of artists who work with communication technologies [...] Bridging and synthesizing becomes the art." Media arts projects already engage in this kind of negotiating, bridging, and synthesizing – an important yet often unarticulated focus of media arts – but this might be a valuable way for media artists to explicitly position themselves as builders of "mediation support tools," tools that can help mediate between different research communities in art-science collaborations. Some potential media arts activities include: creating projects to represent or externalize thinking and understanding; exploring ways to translate concepts from one domain to another; and creating projects that facilitate communication.

1.8 Research Outline

As a step toward defining a practical methodology, the following chapters will explore some of my own interdisciplinary projects that have helped me to think about the nature of media arts in relationship to art production and art-science collaboration. Chapter 2 looks at the *Cell Tango* [75] and *Data Flow* [127] projects, along with a series of smaller projects called *Information Poems*, and examines the possible research contributions of these media arts pieces, examining in particular the role of data visualization research and data art visualization. Chapter 3 describes the *Fluid Automata* [73] and *Annular Genealogy* [76] artworks and discusses how artworks can generate research topics. Chapter 4 describes recent interdisciplinary collaborations with domain scientists, the *Natural Materials Browser* [70] and *Augmented Communication Tools* [78], two interactive visualization projects explicitly drew upon these methodological themes in order to more effectively promote research. Finally, in Chapter 5, I summarize the contributions of this dissertation and discuss a new conference session, the IEEE VIS Arts Program, within the larger IEEE VIS conference that facilitates discussion about the role of art in visualization research.

Chapter 2

Emergent Organization: Aesthetic Data Visualization in the *Cell Tango*, *Data Flow*, & *Information Poems* Projects

> *Modern media is the new battlefield for the competition between database and narrative.*
>
> – *from* "Database as Symbolic Form," Lev Manovich [142]

2.1 Overview

The previous chapter surveys roles of media artists in collaborative projects and presents four clusters of approaches– what I am calling methodological themes– that could aid artists when formulating, creating, contextualizing, or explaining their work, especially if they are explicitly concerned with working in art-science collaborations. In this chapter I examine art projects that, while not involved directly in an art-science collaboration, nonetheless also engage with the methodological practices described by these themes. That is, although they have a solely artistic output, they present activities that are useful in the context of interdisciplinary research. Moreover, I highlight central tenets of the scientific method (as it has become loosely codified in the mid-20th century and beyond). In so doing, I look at ways in which media arts methodologies could facilitate aspects of empirical science – a goal of art-science projects and a rational for the inclusion of arts in STEM curriculum. I specifically delineate a series of useful media arts activities and further suggest how such projects could make explicit contributions to various research pursuits.

2.2 Collaborative Data Art Installations

2.2.1 Info-aesthetics Methodologies

Andrea Lau and Andrew Vande Moere, in their article, "Towards a Model of Information Aesthetics in Information Visualization," introduce a domain model that positions visualization projects on along continuums of focus: data, interaction, and aesthetics [124]. In their view, work that emphasizes aesthetics has an "interpretive," rather than a "direct" purpose. However, they believe that successful data visualization projects could incorporate both of these outlooks simultaneously. They stress that it could be more useful to think about the term "aesthetics" as involving reasoning about *context* instead of limited to the realm of representation (as often happens in the visualization research literature). Though they discuss the different focus of art projects and research project, noting that art visualizations engage with culture, they do not explore specifically how these projects may be useful beyond the scope of media arts. In fact, while it may be true that the art projects on Lau and Moere's spectrum of visualizations are not directly engaged in information visualization research agendas, I contend that data art projects nonetheless do have the potential to contribute to research, in addition to their cultural contributions.

In the sections below, I examine two collaborative artworks that I helped to create while working with George Legrady Studio. These installations, *Cell Tango* and *Data Flow*, are projects that are based upon the interactive visualization of specific data sets. Specifically, I examine how these artworks are perceived and utilized in order to discuss some of the methodological themes described in the previous chapter. Although the projects are not art-science projects, per se, they are nonetheless of an interdisciplinary nature, and involve elements that are usually not incorporated into art projects. I show that, in various ways, these artworks can be usefully explored in terms of the methodological themes, *augmentation*, *mediation*, and *generation*. These themes can be used to frame the potential contribution of media arts projects and to characterize a possible methodology for the creation of projects that seek to have a cultural impact and to engage with research agendas.

2.2.2 Cell Tango

Cell Tango is an interactive installation that has been presented in fine arts museums, in galleries, and at special events.[1] The public visiting the exhibition is invited to interactively contribute to the project through submitting personal cellphone images to the installation [75]. These images become the primary content source of the Cell Tango artwork, and are stored online at the Flickr photo management and hosting website[2]. The gallery display consists of a large cinematic projection that presents the contributed cell phone images in four animation configurations – 'Cell_Bin,' 'Cell_Clusters', 'Cell_Burst,' and 'Cell_Finale.' The public is asked to add descriptive tags in the subject heading along with each submitted image. These descriptive tags function as search queries for retrieving other images from the larger Flickr database of public photography and also as organizational devices to create thematic clusters of images. The intent is to explore the potential of unexpected juxtapositions where common semantic labels can generate interesting visual relationships.

The animation 'Cell_Bin' consists of visualizing the most recent images in the database on the screen. We developed a custom bin-packing algorithm that selectively places large images first and then gradually fills in blank spaces with gradually smaller images until all of the empty screen spaces are filled. 'Cell_Clusters' consists of thematic clusters of found images that are related to an image submitted by a participant. The photos in the thematic clusters themselves are generated by an analysis of the contributors' tags, and are placed around the contributed image (which is differentiated by being given a yellow frame). The 'Cell_Burst' animation throws images on the screen that then open like bursting fireworks, placing the tags once the image appears, followed by the found Flickr images associated with each tag. 'Cell_Finale' concludes the visualization sequence by rapidly placing on screen all of the contributed images in the database one af-

[1] *Cell Tango* premiered at the International Society of Electronic Arts (ISEA 2006) annual conference exhibition in San Jose, California in June 2006 under the title "Global Collaborative Visual Mapping Archive." Since then, iterations of the projects have been included at many venues, including: George Legrady's solo exhibition at the Pari Nadimi Gallery, Toronto (2006); "Speculative Data and the Creative Imaginary," curated by Pamela Jennings, National Academy of Sciences Rotunda Gallery, Washington, DC, (2007); Inauguration of the National Theatre Poitiers, organized by Hubertus von Amelunxen, Poitiers, France (2008); "Cell Tango," curated by Sarah Smarch, Ford Gallery, Eastern Michigan University, Ypsilanti (2008-2009); "Scalable Relations," at the Beall Center for Art & Technology, UC Irvine (2009), curated by Christiane Paul; and "Cell Tango," at Davis Museum and Cultural Center, Wellesley College, Wellesley (2009), curated by Jim Olson. Sonification was added and premiered at the Lawrence Hall of Science, UC Berkeley (May 2010) and then showcased at the Poznan Biennale, Poland (Fall 2010).

[2] http://www.flickr.com

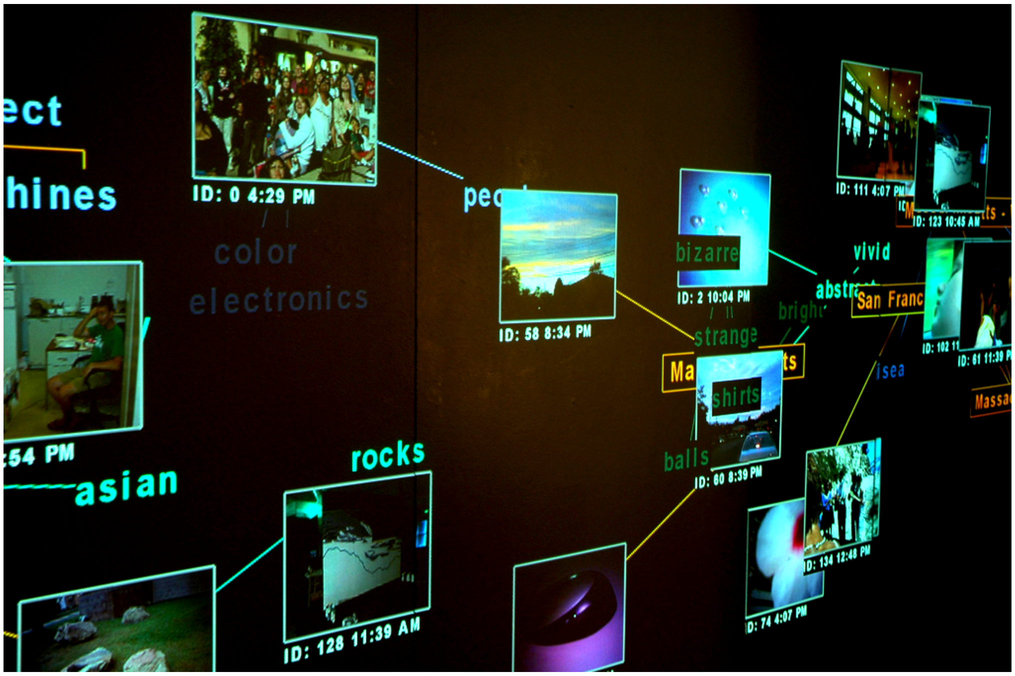

Figure 2.1: A photo of an earlier iteration of one of the *Cell Tango* visualizations.

ter the other in the spectacle action of fireworks exploding in the sky. Figure 2.1 shows an early iteration of the Cell Tango project, Figure 2.2 shows an example of the 'Cell_Burst' visualization, and Figure 2.3 shows an example of the 'Cell_Finale' visualization.

The artwork is dynamic; the arrangement of featured photographs is continuously being generated in real-time according to the rule-sets defined by the custom software. The software development involves significant engineering and problem solving, but it is driven by cultural concepts and aesthetics. In other words, it was designed with a "creative pull" as opposed to "technological push." Works of art tend to coalesce concerns, goals, and meaning, all of which evolve at multiple stages in the work's evolution. These stages include the initial planning and design phase and the continued iterations of transforming the design during production. Cell Tango addresses a variety of concerns. It is an artwork that is about the creation of an archive of images, in this case limited to cell phone images. The project is based on the participatory, public contribution of data. Each exhibition represents a collection that is the sum of all contributions made by the public during the length of the exhibition. So at the start of an exhibition, the collection is empty; and at the end, the collection is closed. Each time the project is exhibited, the sum of all images collected during the exhibition's lifetime becomes the embodied visual archive specific to that event.[3]

Relevant research literature related to Cell Tango's foci of interests includes Tim Kindberg's discussion on the ubiquitous transformative role of cell phone camera usage [114]. Kirsti Lehtimaki and Taina Rajanti discuss the increased use of picture taking from specialized occasions to the documentation of ordinary life [129]. Andrew Miller and Keith Edwards address the social network aspect of image storage sites, including Flickr [151]. Nancy Van House articulates a prioritization for image sharing as story telling, self-representation, self-expression, and documenting of everyday life over the long-term archival, collection opportunities that the photo management site offers [214]. The artist Golan Levin has assembled a useful reference page of cell phone art projects[4], however most projects use the cell phone as a sound instrument in group performance, or else as control devices by which to activate events in site-specific locations, for example by turning on architectural façades with embedded LEDs [102]. The media artist Jonah Bruckner created an early cell phone image-based work titled "Phonetic Faces" that consists of a mixed collage of images and portraits on a display contributed by the public present at the exhibition. This work used the cell phone to activate and control an onsite video camera that did the visual recording to a computer that assembled the images[5].

The Cell Tango project may be understood as an exploration of the process of constructing and conveying meaning through the organization of visual elements (the images) according to a set of rules or conventions defined in the algorithms (the syntax) used to create the visualization. This positions the project within the context of a structuralist, cinematic tradition, as defined by the French film theorist Christian Metz in his analysis of semiotics and film [149]. Cell Tango follows the structuralist film theory model of constructing meaning through juxtaposition, adding an uncertainty component as the aleatory selection of accompanying images are delivered according to common tag labels. The outcome of the selection covers a continuum from a pure literal, analogous matching visual content to visual content that may be totally unrelated at the literal, similarity level, but which may have implicit metaphoric or associative relevance. For instance, a tag that says "circular" might result in an analogous image of a tire, whereas

[3] *Cell Tango* has a prior history that extends back to its initial development by George Legrady via a 2004 Canada Council grant. The intent of Cell Tango was to create follow up to the *Pockets Full of Memories* project. Pockets Full of Memories involved a heavy and cumbersome data entry station, and a main goal of Cell Tango was to make the data input station more portable and to give global rather than only gallery-specific local input access.

[4] http://www.flong.com/texts/lists/mobile_phone

[5] http://www.coin-operated.com/coinop29/2010/05/01/phonetic-faces-2003/

another image which is tagged less literally with words like "yummy" or "sweet" might result in images of cell phones, cupcakes, chocolate drippings, images of a mug, a doodle, et cetera. One of Structuralism's fundamental principles is that underlying structures lie beneath the surface or the appearance of things [8]. In Cell Tango, the algorithmic processes express the projects' structure through its programmatic rules, and this functions as the binding by which the juxtaposed images in Cell Tango are organized. When the meanings between juxtaposed images are evident, the viewers' experience in fact becomes less interesting than when the meanings are harder to interpret. Humans naturally attempt to create and interpret meanings out of any information coming their way, and the less evident pairings turn out to be the most stimulating in the viewing experience.

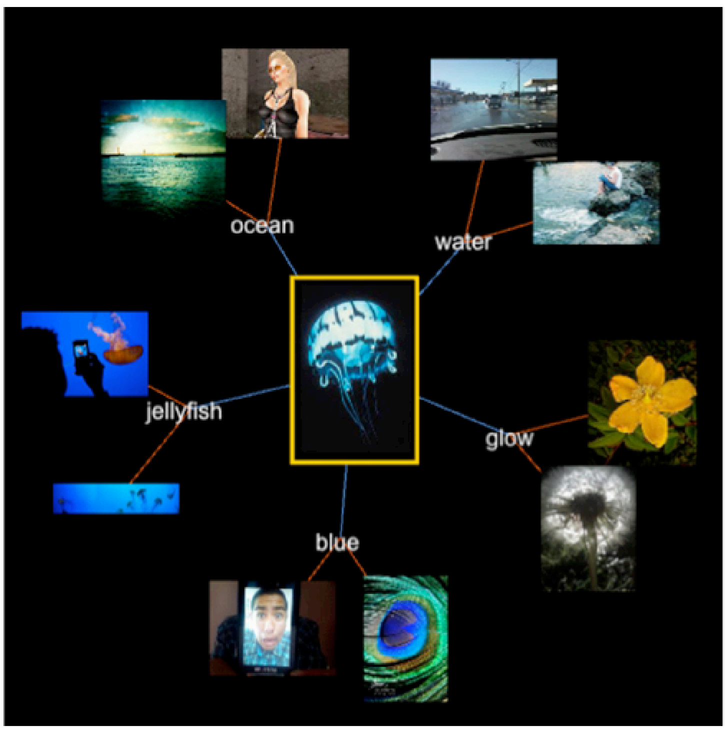

Figure 2.2: A detail from the 'Cell_Burst' visualization.

Cell Tango features the interplay between two image sets: the "known" system of the visiting public's cell phone contributions; and the "unknown" open system of tag retrieved associative images from the larger Flickr archive. At the start of the exhibition, the collection is limited to a few seed images, but then builds up throughout the length of the exhibition. When the exhibition is completed, the collection culminates into the unique record representative of that installation's specific set of conditions, visitors, and cultural and temporal contexts. Following the 2006 premier at the International Society of Electronic Arts in San Jose (under a different title, "Global Collaborative Visual Mapping Archive"), Cell Tango has been featured in a variety of venues that include: an opening event at a national theater in France; a month in a commercial gallery; a long-running media arts exhibition at a West Coast research university gallery; a two month exhibition at a public Midwestern university; and a four month exhibition at an East Coast private university. While Cell Tango functions primarily as an artwork, it is also an investigation in the study of how the functionality of photographic image-making is changing through cell phones. Each exhibition is a data collection environment as the public submits images, which are then stored for later analysis. Each venue has its own socio-economic/cultural context with some noticeable differences. User responses revealed that images were expressive of local community interests, social perspectives, and varying degrees of implementation of the functionality of photographing, from recording special events, to recording phenomena, or idiosyncratic expressions. Additionally, there is interplay between the collection of submissions through the artwork's context and the public images retrieved from Flickr through the associated tags submitted by users.

The artistic requirements of Cell Tango necessitated the creation of a robust software implementation that allowed effective user interaction via the cell phone, animation of the visual elements within the different scenes, and the extensibility and adaptability to add new scenes and to easily relocate the project in different environments. Cell Tango visualizes an evolving database of cell phone photography and it is itself an evolving project that changes according to the venue, but also in order to explore new ideas and representations. The system is separated into four processes that run simultaneously: the data gatherer, the visualization modules, the local network management component, and the graphics renderer. Communication between these processes occurs through writing and reading from concurrent data structures, which efficiently and safely allow multiple threads to access and update the same information asynchronously. Because the main user interaction with the system is done via the submission of cell phone photography, a primary technical goal of the system is to retrieve new photos as soon as they are available. Another goal of the project is to explore the relationship between the user-submitted photos and the related public photos. In order to facilitate the rapid retrieval of new photos and the exploration of related photos, a data-gathering component is placed in a background thread that continually checks the Flickr database. The process gathers both user-submitted photos and tags, as well as related photos from the public Flickr photo pool that are related to the user-submitted photos via their folksonomic tags. A local data store is kept in memory that holds the most recent user-submitted photos and well as selection of photos selected from the pool of other, less recent, user photos. Other important aspects of the software design included: the development of a real-time bin-packing algorithm that worked with streaming data; concurrent data structures that could rapidly store and retrieve large collections of user photos, tags, and related photos; and general robustness that allowed the project to be run for the duration of the installation (in some instances up to six months) without human intervention.

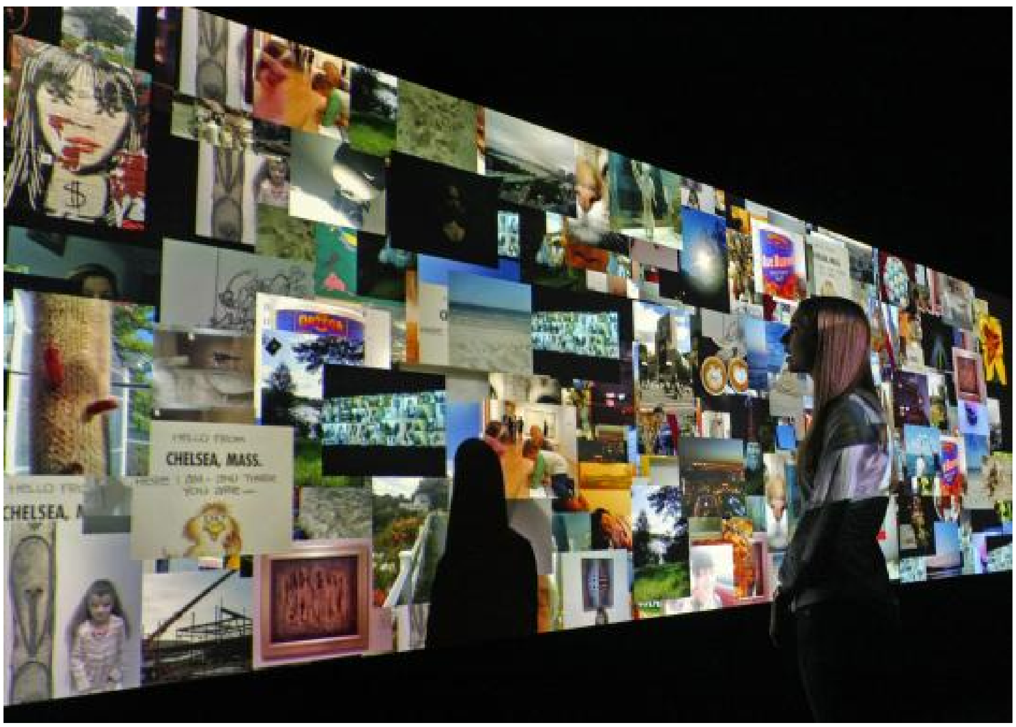

Figure 2.3: A participant standing in front of the *Cell Tango* installation.

The system uses a custom 3D graphics framework called "Behaviorism" [72] which loads each of the photos on to hardware-accelerated textures and also provides a scene graph and various animation and timing techniques that control the layout and narrative of the different visualization modules. Each of the visualization modules processes the data that has been placed within the local data store by the data gatherer. Visual elements based on this data are placed on the scene graph, and then rendered via a dedicated rendering thread at sixty frames per second. Animations of the movement, size, color and structure of visual elements, as well as the movement of the camera view, can be programmatically defined by adding behaviors to the timing graph. These behaviors update the objects in the scene graph at the start of each loop of the rendering thread. In addition to using hardware-accelerated textures for rendering the photos and text, each visualization module is able to use OpenGL for advanced graphics techniques, including binding to custom GLSL shader programs. Because the Cell Tango project has had to evolve and adapt to new environments, the software system is designed to make it easy to add new visualization modules that transform and visualize the photographs and tags in novel ways. Additionally, some iterations of Cell Tango experimented with the sonification of the visualizations, and included a networking component for propagating visual or data events to another computer that then transforms these events into algorithmically generated composition.

The preceding description indicates an interesting dynamic: software engineering enables artistic goals, but at the same time the artistic goals require the development of new engineering methods. Media arts projects have research possibilities beyond the cultural goals and the software engineering aspects. These possibilities are especially interesting as they emerge unexpectedly out of the project itself, and simultaneously involve creative and technical thinking. These ideas can be grouped under the themes of generation, augmentation, and mediation. While not fully explored in this project, I contend that media arts projects could be reframed to highlight these potential research avenues. That is, the creation of the media arts project is in and of itself a methodological tool for creating and conducting research.

2.2.2.1 *Generation* in Cell Tango

Some components of Cell Tango only emerged through the process of trying out many iterations of different ideas related to the main theme of interacting with cell phone photography. These components required further study, and presented interesting avenues of research beyond the installation itself. That is, the project itself was a *generator* for potential future research in unexpected domains. For example, a main aspect of the project involves searching an image database using an image and its associated folksonomic tags. The idea for searching databases using images was introduced at least as early as 1980 [32]. Since then, much research has been done to improve the results of using images to find similar images. For example, in 1989 a technique was developed to encode only the most relevant aspects of an image for faster an more accurate image retrieval [125]. A similar technique is described in [58], except a sketch is used rather than an image to retrieve images. More recent work focuses on combining image analysis techniques and feature detections with contextual clues and image metadata in order to produce more results more relevant to a particular query [239]. In 2013, Google Images introduced the ability to drag and drop an image and include semantic tags and nearly instantly retrieve accurate results [91]. Although at the time the project was not informed by the literature in this research area, we nonetheless explored interesting approaches to image retrieval. Some of our ideas included: culling the results from Flickr by identifying simple features and comparing them to our input image; using features from connected photos in order to find images relevant to not only the original image, but all of the *neighbor* images in the installation; making use of multiple tags to whittle down results into a manageable number.

Another emergent idea from Cell Tango is the concept of presenting search results in a non-linear manner. Nearly all search interfaces impose an order on their results and visualize them in a list. In one sense, all the visualizations of Cell Tango operate to present search results in ways that challenge this representation. Moreover, each visualization tries to contextualize the results in terms of the other images, in terms of previous or concurrent searches, an in terms of the installation as a whole. The cycling quality of our system brings in new results and new rankings. In so doing, Cell Tango provides interesting juxtapositions that forces viewers to think about the narrative implications of search, something which is explicitly hidden in most search applications, or is governed by less meaningful metrics, such as popularity or relevance to advertising interests. Again, there is much research about these topics that we did not investigate at the time, but that the project could potentially have been used to explore. For example, [95] examines the complex dynamics of collaborative tagging, and [243] discusses methods to improve search results through topics diversification.

It would be interesting to create an installation with the intention of pursuing researching the questions the research questions that emerge from the installation. Although this project did not directly engage with these research questions in a formal sense, it is clear that the project delineates their contours. Moreover, the artwork functioned not only as an aesthetic experience, but, in a sense, also as a data gathering system for conducting empirically-based experiments towards these topics. In Chapter 3, I discuss projects that switched between an artistic and a research focus, purposefully using the media arts project as a methodology for generating research topics.

2.2.2.2 *Mediation* in Cell Tango

In Chapter 1 I introduced the theme of *mediation* as a primary methodological focus for media artists. Cell Tango is explicitly engaged with thinking about how individuals mediate between the public and private. Additionally, simply by virtue of the fact that it is both an art project and a complicated engineering undertaking, its creation involved the continual mediation between the creative and the technical. While these mediations are not specifically applied to larger research endeavors, they serve as examples of the type of focus that media arts projects could offer art-science discourse as well as interdisciplinary research in general. Mediation involves understanding and communicating fundamental differences in interpretation and perspective. Media arts projects are able to practically engage in this type of mediation, and at the same time, comment on them, experiment with them.

Victoria Vesna's book, "Database Aesthetics," brings together various perspectives regarding the cultural implications of quantifying and storing large amounts of data [218]. Christiane Paul, in her essay in that collection, "The Database as System and Cultural Form: Anatomies of Cultural Narratives," explains that "database aesthetics" projects explore ways of "revealing (visual) patterns of knowledge, beliefs, and social behavior." She further explains that novel characteristics inherent in works of database aesthetics include the concept of multiplicity, that is, enabling opportunities to view data from many perspectives and narratives. Paul explains that these types of projects are by nature provocative because they offer alternatives to normal or expected narrative structures. She cites the early net art project, Carnivore, (an open source packet sniffer created by Radical Software Group) as an example in which an artwork can, simply by exposing the normally hidden protocols and processes of sending information, make a "political statement about access and its control." In so doing, it constitutes a shift toward a "networked approach to gathering and creating knowledge about cultural specifics" [165].

The Cell Tango project explicitly investigates the cultural meaning and narrative effects of translating personal photographs into the various visual representations of the database of the installation. This is similar to an earlier project by Legrady, *Pockets Full Of Memories*, in which "the function of semantic interpretation" related to private objects scanned into a public installation [128]. A relevant recent essay by media theorist Nick Couldry talks about the difference between "mediation" and "mediatization," where mediatization indicates a transfer of an item of personal or cultural significance into a publicly visible social network [38]. Another way to think about the Cell Tango project is that it provides a space for participants to reflect upon the relationship between their private images and the public interpretation of the image as it becomes mediatized. Issues between public and private are perennial, especially involving digital communications industry [89], and much research investigates some of the potential negative issues associated with the loss of privacy associated with mediatization. Less polemically, Leah Lievrouw, a communication theorist, writes about the importance of "resituating mediation at the center of communication" in order to "help us conceive of communicative action, social context, and material resources as inextricable, co-determining aspects of sociality, interaction, expression, meaning, and culture" [132]. In her article, "Between Archive and Participation: Public Memory in a Digital Age," The rhetorics scholar Ekaterina Haskins looks at the September 11 Digital Archive to explore the nature of dynamic archives in the age of social networks [98]. Although she notes the tension between storage/ordering functionality and presence/interactivity functionality, she proposes shared, dynamic archives as an effective way to store personal meanings, and superior in some respects to the "hegemonic official memory" of closed archives.

2.2.3 Data Flow

The *Data Flow* project is a site-specific installation commissioned by Gensler Design for the Corporate Executive Board Headquarters. Corporate Executive Board (CEB) provides research and analysis of various business sectors to over 16,000 paying members (mostly business executives) throughout the world[6]. Data Flow consists of three visualizations that map the members' daily interactions with the CEB web portal. These visualizations are situated on the "Feature Wall," a three-story installation space adjoining an open staircase on the top floors of the CEB headquarter offices in Arlington, Virginia. Each of the three visualizations of Data Flow consists of three horizontally-linked screens displaying hi-resolution animations. A main server retrieves and analyzes a constant flow of user data, including search terms that are used to find documents, information related to the webpages the user visits, and geospatial data indicates where and when the user logs in to the CEB web portal. Data relevant to each visualization is then forwarded to a separate computer that handles the layout and animation of a particular visual representation of the data. One visualization displays statistics about which webpages are most active at a given time. A second visualization displays real-time information regarding the location where members are logging in from. The final visualization displays an animated record of the search terms used to access business documents. Figure 2.4 shows two of the Data Flow visualizations over two floors of the CEB headquarters. Figure 2.5 shows a detail from one panel of the GeoMap visualization.

2.2.3.1 Bigram Visualization

The "Bigram Visualization" animation displays a constant stream of the most common keywords culled from members' web queries over the last hour. Each keyword is presented in tandem with their most popular associated words, forming a series of bigrams. Colored lines show the relationship between the bigrams and

[6]http://www.executiveboard.com/exbd/about

what type of page (which "sector") within the CEB portal the user ended up at via the search terms, as well other information about the member's level of access (their "program"). This visualization makes visible the members' search interests as they investigate various sectors in the web portal. The animation begins by grabbing the most recent 20000 events within the last hour and analyzes them for the most popular 12 keywords (stems). Each stem is linked with its with four most commonly associated words to create bigrams. The bigrams are then placed on screen, moving from right to left. Bigrams appear on screen and travel diagonally upwards or downwards, exiting at their opposite corner. Each bigram is linked to its various sectors, appearing above it, and its program, appearing below. Bigrams accelerate as they move across the screen, and the text boxes shrink as they move from right to left. A vertical line moves across the screen separating stem groups.

Figure 2.4: The Bigram visualization and the GeoMap visualization of the *Data Flow* installation.

While bigrams are often used as a way to conduct certain types of linguistic analyses, they, at the time, were not usually used for providing insight into more focused data sets. Over the last few years, and especially with the introduction of the Google Books Ngram Viewer [167] it has become more common to use bigrams to analyze various types of text. For instance, in NGram Viewer, users can search for particular terms over specific types of texts or time periods. Data Flow uses bigrams to provide a window into the main interests of users of the CEB website. Moreover, because the installation perpetually analyzes new, incoming streams of data, it serves as a way to track how these interests change over time.

2.2.3.2 GeoMap Visualization & Coil Map Algorithm

The "GeoMap Visualization" shows temporal changes within a geographical representation. Data representing the number of elements related to user interaction on the CEB website is stored within the data graph, such as the geographical location of the user, information about the type of account they have, the search terms that were used to find particular documents, and what section of the CEB website they are searching. New data is retrieved every 5 minutes from a centralized SQL database and outdated data is purged once it is an hour old. At the start of each iteration of the geographical visualization a sample of the searches from the last hour is collected. The visualization begins with a map of the world broken into 2048 * 3 cells. Each of the search samples are processed in order and the cell containing the location expands distorting the world map slightly. After a number of samples has have been processed it is easy to tell which parts of the world have active users. After all the samples are processed, each of the behaviors used to change the visual appearance are "rewound" at a faster rate, and the map "unwinds" back to its original state. Because each of the visual behaviors runs asynchronously and because the speed of the cell expansion animation may be slower than the rate of processing new samples, the overall effect is that the map changes in a fluid manner.

The visualization uses an information visualization method called "Coil Maps," an animated treemap algorithm created for this project, to display a dynamic overview of geographic data [68, 72]. A world map is initially recursively subdivided to a specified depth. The final subdivision constitutes the leaf tiles, which cover the entire map. As new events are attached to a leaf tile, the tile increases in size, which causes its parent tile to increase in size, which in turn causes its parent tile to increase in size, and so on up until the root subdivision. This causes a change to be very apparent on the local level, but also to more subtly show changes on a global scale. For example, if initial tiling covered a map of the world, and an event arrives on, say, New York City, then that tile would immediately greatly increase in comparison to its neighboring tile, but also lesser changes would affect all of the parent tiles, up to and including a minor increase in size of the northern hemisphere and a related minor decrease in the size of the southern hemisphere.

Figure 2.5: A detail of the GeoMap visualization of the *Data Flow* installation.

This distortion allows a viewer to see at a glance the most active regions of a map over time while retaining the perceptual grounding of the map itself.

The use of cartograms that distort geographical features in order to emphasize particular data relevant to a visual presentation is a much studied and ongoing topic. The cartographer Waldo Tobler has examined the history of digital cartograms beginning in the 1960s [208]. Advances in methods for generating cartograms continue to be developed. Recent work by a number of different researchers explored various tradeoffs between different aspects of cartogram algorithms, including issues related to readability, optimal layouts, and flexibility [60, 215, 235]. An article by Marc Van Kreveld and Bettina Speckmann looks specifically at ways to animate rectangular cartograms (using a different method than the Coil Maps algorithm) [60], and a recent survey of geovisual analytics by Gennady Andrienko, et al., notes that the simultaneous representation of temporal and spatial aspects of data continues to be an important area of research [4]. Daniel Keim, et al., has also cataloged the current scope and challenges in the field of visual analytics, identifying the representation of dynamic, temporal, geographically-situated data as one contemporary issue that requires further research.

2.3 Information Poems

Here I introduce a series of smaller data visualization projects I call "Information Poems." These smaller, individually produced, artworks use raw data in a very different way, and are example illustrations of the theme of *provocation*. Although not a direct collaboration with a single person, these projects are unwittingly collaborative in a sense since they rely on data generated by others. I call these pieces "poems" since they are lightweight pieces: they take less time to create, they make a smaller statement, and they are less substantial in many ways than full art installations. Moreover, they have a "lyric" sensibility – They are evocative and provocative, but do not attempt to engage with the complete, or even the main, ramifications of the data sets they utilize.

2.3.1 Infrequent Crimes

Figure 2.6: A screenshot showing one of the crimes from *Infrequent Crimes*.

Infrequent Crimes is a data visualization art piece that was shown originally in Santa Barbara and then again in San Francisco.[7] In both cases, the main medium

[7] *Infrequent Crimes* was presented in "Spread: California Conceptualism, Then and Now," at SOMArts Gallery, San Francisco, California, 2011. Curated by OFF Space (Kathrine Worel,

of the piece was a dataset of crimes reported to the police and kept in a large database. In addition to the type of crime that was reported, information about the location of the crime was kept as well, recorded in longitude and latitude. While data visualizations incorporating crime data are popular (see for instance the New York Times' *Homicide Map*[8] and Stamen Design's *Crimespotting*[9]), it is less common to visualize unusual minor crimes within neighborhoods. While there might be, say, an average of twenty crimes involving cars being broken into per night, other crimes are less frequent. For instance, the crime labelled as "defrauded innkeeper" was reported only nineteen times in a single year in San Francisco in 2011. Similarly, a crime labelled as "cruel children" was only reported four times. Giving a representation to these infrequent crimes provided an alternative perspective on the life of a city, as seen through the lens of police activity. The crimes were visualized in an easy to read manner. The name of the crime would pop up, along with the number of times the crime occurred in the last year. Then a number of tiles would appear, counting out the total number of crimes, where each tile represented one crime. Each tile contained either a) a map indicated where the crime occurred, or b) a photo taken from Google Maps Street View at that location. The result was a strange mix of the eerie and the humorous, where odd-sounding crimes, like "gunshot fired indoors," or "bus mischief," were placed against unpopulated views of street corners, houses, and parks, providing an oddly unsettling tour through locations of the city via the location of infrequent crimes. By so doing, I focused less on the crimes themselves, and more instead on the way the crimes are classified. That is, it serves to expose the arbitrary parceling of deviant behavior and the Byzantine penal structures that regulate it. Figure 2.6 shows a screenshot from Infrequent Crimes.

2.3.2 Turbulent World

Turbulent World displays an animated atlas that changes in response to the increased deviation in world temperature over the next century.[10] The changes are represented by visual eddies, vortices, and quakes that distort the original map. Additionally, the projected temperatures are themselves shown across the world,

Elyse Hochstadt, and Emmanuelle Namont-Kouznetsov), and also in "Super Santa Barbara," a group show at the Contemporary Arts Forum in Santa Barbara, California, 2011, curated by Warren Schultheis.

[8] http://projects.nytimes.com/crime/homicides/map

[9] http://stamen.com/projects/crimespotting

[10] *Turbulent World* was shown as part of "Brave New World," at the Spare Change Artist Space, San Francisco, California, 2013. Curated by OFF Space (Kathrine Worel and Emmanuelle Namont-Kouznetsov).

increasing or decreasing in size to indicate the severity of the change. The data was generated by a sophisticated climate model that predicts the monthly variation in surface air temperature across different regions of the world from 2013 through 2099 [47]. The dataset is available at the National Climactic Data Center (NCDC), run by the National Oceanic and Atmospheric Administration (NOAA). More detailed information about CM2 Global Coupled Climate Models (and the data itself) can be found at the Geophysical Fluid Dynamics Laboratory (GFDL) website[11].

The goal of Turbulent World is to provide a window into projected data representing current thinking by leading scientists about climate change. Scientific visualization often focuses on individual data samples. Visualizations that effectively capture large-scale systems are more difficult to represent. Additionally, climate change represents multiple, intertwined systems and necessitates new thinking about economics, policy-making, urban development, and other activities. Since modeling, representing, and explaining climate change is so challenging, Turbulent World doesn't attempt to be a comprehensive visualization, but rather presents one aspect (the projected temperature) in order to provide a window into this complex system. An additional issue in representing climate change is that it exists at a scale that is hard to reason about, and thus, despite the major implications to our civilization, it is not something that people think about very often. A recent article by Adam Corner argues that, by inventing new ways of representation, artistic projects keep environmental issues "in the public eye"[12]. Turbulent World has been shown at the Spare Change Artist Space in San Francisco, curated by OFF Space. It will also be shown in a planned exhibition in the Biosphere2, as part of the Climate, Adaptation, Science, & Art initiative. Figure 2.7 shows a detail from Turbulent World.

2.3.3 Poetry Chains & Collocation Nets

In their article "Deformance and Interpretation," Lisa Samuels and Jerome McGann examine a seemingly whimsical fragment written by Emily Dickinson: "Did you ever read one of her Poems backward, because the plunge from the front overturned you?" [48]. They choose to interpret it literally, asking how a reader could "release or expose the poem's possibilities of meaning" in order to explore the ways in which language is "an interactive medium." Poems, they claim, citing Shelley, lose their "vital force when they succumb to familiarization." They imagine instead unfamiliar deformations of literature that offer "a highly regulated

[11] http://nomads.gfdl.noaa.gov
[12] http://www.theguardian.com/sustainable-business/art-climate-change-communication

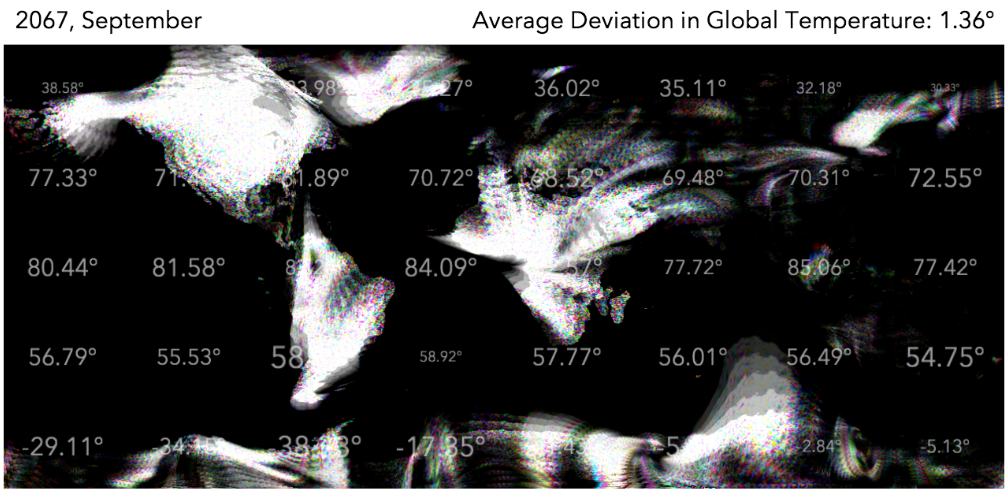

Figure 2.7: Screenshot of *Turbulent World* displaying the projected surface-air temperature throughout the world for September, 2067.

method for disordering the sense of a text." In so doing, they posit that *performative* critical models provide an important "anti-theoretical" interpretation not available to traditional interpretative criticism [146].

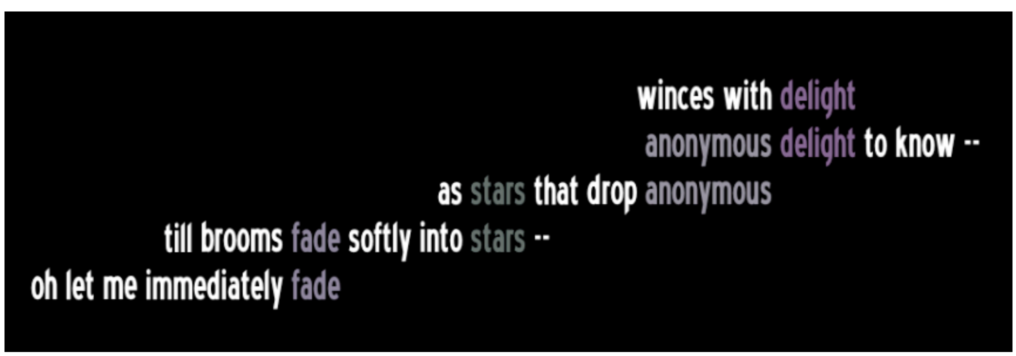

Figure 2.8: An example of a *Poetry Chain*. When one poem is finished, a new one will start, using the last line of the finished poem as the first line of the next one.

Two projects, *Poetry Chains* and *Collocation Nets* investigate the 1955 edition of Emily Dickinson's complete poems through various interactive animated navigations of collocated words. As such, they perform what Samuels and McGann term "experimental analyses." Each of the visualizations displays a different presentation of her work. Poetry Chains begins with two words and attempts to find a chain of words in a specified number of lines that connects them together, displaying them as it succeeds. Collocation Nets begins with a single word centered in the middle of the screen. When the user selects the word, a random selection of its collocations pops out in a surrounding ring. Any of those words can be selected, which results in collocations of that word appearing. A user can toggle into an ambient mode of this visualization, which begins automatically cycling through all of the words, forever.

These visualizations offer a continuously dynamic remapping of Dickinson's work. The deformations present new opportunities for interpretation, some of which may lend themselves to successful insights, and others which might be ludicrous, or merely bland. Each of the visualizations performs this remapping in different ways. The Poetry Chain effectively runs a kind of smoothing operation, an averaging filter, by treating her entire corpus as a single poem. Additionally, it uses a depth-search algorithm to get between two points within the corpus, performing a non-linear "hopscotch" (with a poetic rather than narrative destabilization). The Collocation Net completely disassembles the corpus into individual words and links them together, not grammatically, but instead by a frequency metric that correlates words by the likelihood of their appearing together within the same line. While it is unclear what exactly the interpretive value of these remapping offers, it is interesting to think of them in relation to, or perhaps as a differentiation from, visualization projects utilizing the methods of information visualization or visual analytics. In those fields, it is assumed that the raw data is inherently atomic, and that the goal of the project is to enable users to recombine the data in different ways in order to facilitate new revealing and new interpretation, or what Peter Pirolli and Stuart Card term "knowledge crystallization" [168]. That is, they allow the user to create models by the synthesis and analysis of data, through which hypotheses may be generated and then either validated or falsified. A recent article by Ben Shneiderman reframes the products of information visualization projects as creativity support tools, where the goal of such a tool is to facilitate creativity: novel ideas and new perspectives. Poems however, as noted in Samuels and McGann's article, are not simply composed of irreducible raw data. Instead, the meaning in some sense *is* the raw data. But this meaning lives in the interaction between the text and the reader, and can not be extracted, simplified, summarized, or evaluated in any direct way.

A primary task in traditional information visualization projects is to provide different kinds of overviews so that the user can, at a glance, get a general sense of the data before investigating aspects of the data in more detail. For textual data, which is unstructured, and which has more nuanced, complex meaning, it may be too reductive to attempt to provide this kind of overview. Instead, overviews of textual works are provided in different ways: through biographical information, through a delineation of themes or topics, through summarization, or, most generally, by having the reader skim through the text. In lyric poetry however, where the themes are not easily explicable and no obvious narrative lends itself to summarization, overviews are necessarily interpretive acts. Through a series of ambient and interactive visual sketches, these two projects aim to provide the user with a loose overview of the language using a "skimming" metaphor, providing perhaps ad-hoc interpretations, and allowing the user to investigate further. A second primary task of information visualization projects is to allow user the opportunity to find more detail about a particular element or set of elements. A future task of these visualizations would be to allow users to the ability to view the poems themselves when desired, and to bring up further information about a particular word as desired. That is, it is important for a user to be able to contextualize the investigations offered by the visualizations, and to have more control over the interpretive process.

In developing these sketches, the first step common to all of them was to parse the data into a format that enabled the visualizations. Each line of each poem is connected to all of the words in the line, and vice versa. And all of the words have a pointer to each word that it is collocated with, as well as how many times it is collocated with that word. Additionally, the total frequency of each word is recorded, as well the rank of the commonness of the word. Using only these data structures, stored in memory, was sufficient for the Collocation Nets visualization. The Poetry Chain visualization required slightly more involved processing. In order to find a connection between two words, the software performs a depth-first search, recursively scanning lines connected by collocations until a line containing the target word is found. Because this can be a time-consuming process, I limited the number search by removing every word and every line that the search encountered in order to dwindle the possible pathways it searched, and also to prevent infinite loops during the search. Because of this fairly crude filtering process, it is possible that a path will not be found. In this case I simply re-run the search. In general, a full path between the source word and the target word is found relatively quickly, usually on the first attempt. I also improve the chances of generating a successful path by reversing the source and target words if the target occurs less frequently than the source (and reverse the path when it is complete). Occasionally, when both the source word and target word are infrequent it may take more than fifty attempts to find a path, in which case the search simply gives up and the user is asked to try a different source and target. Figure 2.8 shows a screenshot from a Poetry Chain. Figure 2.9 shows two example screenshots from Collocation Nets.

In a recent article, Johanna Drucker writes that a book is “a snapshot, a momentary slice through a complex stream of many networked conversations, versions, and fields of debate and reference across a wide variety of times and places. A book is a temporary intervention in a living field of language, images, and ideas” [51]. That is, while the layout of book implies linearity, the underlying connections are complex and multi-faceted. By presenting the text in a non-linear manner, these networked conversations become more apparent, and invite new readings based on the reconfiguration of words. In “Speculative Computing: Aesthetic Provocations in Humanities Computing,” Drucker writes that a goal of “humanities computing” is “to produce useful aesthetic provocations” that serve in part to emphasize that any data analysis is “constituted in an interpretation enacted by an interpreter” [52]. In both the *Poetry Chains* and *Collocation Nets* projects (as well as the other “Information Poems”), I was interested in unorthodox ways of representing the data in order to provoke a new attention to the meaning of the data, to highlight unusual or interesting components of the data, and to bring awareness to the structure of the raw data itself, whether it be crime data, environment modeling, or lines of poetry.

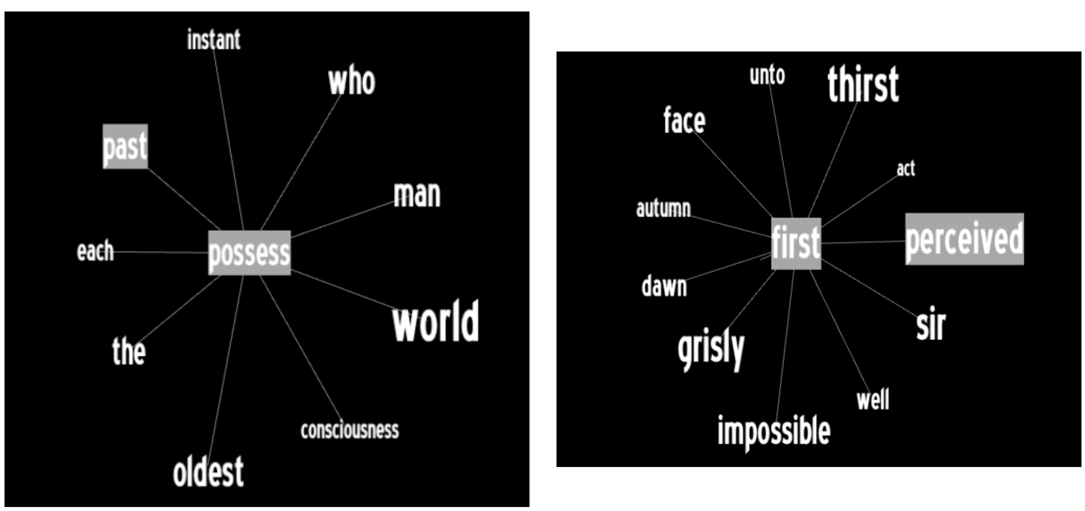

Figure 2.9: Two examples of *Collocation Nets*. Left alone, the system will cycle through the entire corpus of poems indefinitely.

2.4 Art as Research

In this chapter, I introduced a series of data visualization projects that I created or was involved with, including two larger endeavors involving multiple people working with George Legrady Studio, as well as three smaller projects that made use of culturally interesting data sets. In so doing so, I examined different aspects of particular art activities that share something in common with research practices and that moreover could be used to enable research practice in other domains.

In this concluding section, I draw parallels between artistic practice and scientific research. While there have been studies that have looked specifically at differences between practice-based and scientific research trajectories, for example, Mick Winter [231], and Ernest Edmonds and Linda Candy [55], I instead highlight the similarities, and show some opportunities for media art practice to enable scientific methodologies. Specifically, I look at at some of the different steps that have characterized the scientific method first delineated in Francis Bacon's 17th Century *Novum Organum* [9]. These steps include: observing and describing a phenomena; formulating a hypothesis; using the hypothesis to predict results; conducting experiments to test the results; and finally analyzing and interpreting the results [228].

2.4.1 Observing

Warren Sack writes, in "Aesthetics of Information Visualization" about how visualization can be considered either "sublime" or "anti-sublime." He takes issue with a statement by Lev Manovich, in which he discusses information visualization as a tool to translate phenomena into "the scales of human perception and cognition." However, Sack notes that information visualization methods, especially artworks that utilize the language of information visualization, in fact have the ability to allow viewers to observe things more accurately. That is, Sack shows that visualization can be used to see normal, expected things as unexpected; to increase our attention and focus, rather than dilute it. Specifically, he looks at projects that engage with infinite possibilities, that highlight the uncanny in normal interactions and behaviors, and that show the complexity and ideological structure of everyday activities [182]. Although focused on art of of a political nature, Rita Raley, notes something similar: that art be useful as a tactic to generate "the temporary creation of a situation" which allows users to observe "dominant narratives" clearly, and that "engage in a micropolitics of disruption, intervention, and education" [173]. It is hard not to see a parallel with Thomas Kuhn, who writes that "even when the apparatus exists, novelty ordinarily emerges only for the man who, knowing with precision what he should expect, is able to recognize that something has gone wrong." That is, Kuhn summarizes, expectations obscure the ability of a scientist to make new discoveries [120]. And media projects that engage in visualizing and unveiling may be effective tools that could be applied to making more accurate observations about the world.

2.4.2 Hypothesizing

Lev Manovich and others at the Software Studies Initiative at UC San Diego have written a series of articles and proposals describing their *cultural analytics* research program. Cultural analytics extends digital humanities analyses of texts by looking as well at visual new media artifacts such as video games, video clips, cinema, animation, and art, as well as by examining and analyzing data from human interaction with websites, software, and social media. Through using various data mining algorithms and image processing techniques, cultural analytics researchers transmute raw data into quantifiable representations of cultural phenomena. This increase in scope and interpretive techniques leads to useful visualizations of, for instance, of global flows of cultural change. It aims to create quantitative measures of cultural innovation. These measures can be used to create visual maps, for instance, of "global cultural production and consumption" which are sufficiently temporally discrete so that a representation of the flow of change in various cultural mediums– music, design, art, finance– could be presented. The goal of the research program, as defined in the white paper, "Cultural Analytics: Analytics and Visualization of Large Cultural Data Sets" [144] is to create detailed interactive visualizations of various cultural flows which provide "rich information" that can be presented in different formats. These cultural data sets are conceived of in the same scope as other global data sets such as those created by various scientific endeavors. For instance, Manovich compares forms of cultural data to real-time maps of global computer networks and also to real-time maps of the range and intensity of an earthquake. Manovich makes a point of differentiating these dynamic contemporary data sets with the historical data sets that are more often used in cultural analysis within the humanities. The interdisciplinary nature of this nascent field draws on digital humanities, social sciences, statistics, data mining, information visualization, and art.

A primary question is whether or not this project is actually possible– Can cultural data be meaningfully extrapolated at all? Manovich discusses the (mainly technical) reasons why current data projects fail to provide effective global cultural analyses and points to possible ways to provide these. Looking at current art or information visualization projects, Manovich notes that they use relatively small amounts of data (compared to what is available via Google, Amazon, or what is captured from scientific sensors.) That is, they are constrained by the data, or at least the form of the data, rather than motivated by the "more challenging" theoretical questions and agendas that the creator might desire. Moreover, these projects generally do not engage in any sophisticated data analysis and also do not effectively layer multiple sets of dynamic data. In particular, he points to the field of digital humanities and notes that the representations of textual data are not transformed into "compelling visualizations," and also that, inherently, the data sets are limited to texts (as opposed to images, statistical information, etc) and generally static, historical, canonical, "high-culture" texts at that.

Manovich summarizes the "new paradigm" of cultural analytics by outlining a series of steps that encapsulate its agenda, which include: a focus on visual data; using extremely large contemporary global data sets; the use of statistical analysis, feature-extraction, clustering; formatting output to work on very large, high-resolution displays; and a focus on non-corporate agendas. As a overarching goal, he wants to be able to track and visualize the flow of cultural ideas and influences to provide "the first ever data-driven detailed map of how cultural globalization actually works." A variety of other projects are featured on the cultural analytics website, such as a visualization of comments on a set of interconnected MySpace pages, visual analyses of cartoons, films, and music videos, and an examination of art history through the computational analysis of 20 million paintings.

The articles and white papers introducing cultural analytics tend to describe the research program in terms of "explorations" of data, presentations of an "overview" of information, finding cultural "trends" and "patterns." In other words, their work is in many ways analogous to the mathematician John Tukey's work in exploratory data analysis [211] and digital humanities researcher Franco Moretti's "distant reading" [153]. However, more recent work by So Yamaoka, et al., moves beyond the idea of simply gathering and visualizing cultural data sets. Instead, he discusses ways in which interactive visualizations could enable users to progressively develop and refine hypotheses to apply in gaining new insights into large collections of data [238]. Specifically, Yamaoka looks at analytic techniques that enable users to "gain new insights" into large databases of digital images, including "scatterplot multiples" that allow users to simultaneously view different dimensions of the dataset in order to facilitate reasoning about the meaning of the data.

2.4.3 Experimenting

In an article discussing what he calls the "transparency" experience, philosopher Alva Noë writes about the difficulties involved in "any attempt to make perceptual experience itself the object of investigation." For Noë, an contemporary goal of art is to encourage us to "catch ourselves in the act of perceiving" [159]. Edward Shanken similarly examines the early association of media arts and cybernetics, explaining that a main concern of media artists is "to investigate the cognitive functioning of their own minds with respect to the processing of information and the creation of meaning" [191]. The projects described earlier in this chapter are explicitly positioned as installations that operate as experiments, collecting data for later analysis. As I discuss in Chapter 5, an intriguing idea is to explicitly make use of a media arts project as a way to conduct rigorous, repeatable experiments in order to test specific hypotheses.

Of course many aspects of scientific methodology are not normally carried out in an arts context; research in the arts is not tantamount to scientific research, yet artistic methodologies can have a direct contribution to scientific methods. Clarifying what these artistic methodologies are and noting the points of contact with scientific methodology may be useful tool for mediation between participants with different research agendas within art-science projects.

2.5 Conclusion

In this chapter, I looked at a series of projects with clearly-defined artistic outputs. I showed that even though these projects were not intended to have any research outputs, they nonetheless incorporated current research topics in a variety of domains, including computer vision, information retrieval, and digital humanities computing. In particular, I reframed salient aspects of these projects in terms of the methodological themes defined in the previous chapter. Specifically, I looked at: the ways in which Cell Tango supports generation and mediation tasks; how Data Flow generated novel research into an animated layout algorithm; and how the series of smaller pieces, Information Poems, supported provocation tasks. Moreover, I explored how media arts project without an interdisciplinary research agenda can support art-science projects. I showed that, contrary to common thinking, media arts methods, even those geared toward an artistic output, share aspects with scientific methods, or at least could be seen as supportive of these methods. Specifically, I looked at ways in which media arts projects could enable the tasks of observing, hypothesizing, and experimenting. In the next chapter, I look at a project that was conceived as having both artistic and research outputs, and I discuss the role-switching that media artists perform in singly-authored and collaborative projects to generate new ideas.

Chapter 3

Fluid Research: *Annular Genealogy* and the *Fluid Automata* Project

3.1 Overview of Chapter

In the previous chapter I investigated some ways in which media arts projects may have overlapping concerns with research topics in other fields. Moreover, I contended that aspects of media arts projects have methodological components that could contribute to research methods in these other fields, and to empirical methodology in general. In this chapter I look more closely at an interactive generative artwork, *Fluid Automata*, that was initially formulated with hybrid intentions as a research project to create a fluid dynamics algorithm with particular properties and as an interactive media arts project that encouraged collaborative participation. I also discuss a subsequently developed audio-visual art piece called *Annular Genealogy*, based in part on the technologies invented for the Fluid Automata project. Although these works have been presented in art contexts, I explore them here as examples that utilize the methodologies outlined in Chapter 1. In particular, Fluid Automata is presented as an example of *generation*. That is, although the project had no specific research agenda to begin with, through the act of exploring aesthetic possibilities interesting areas of research were exposed. Moreover, through the artistic investigation, the contours of the boundaries of what was possible are defined. This chapter explores the process of identifying boundaries in order to define or help focus interesting or useful research questions. In the case of Fluid Automata, the research questions are in the areas of software engineering, visualization, interaction, and fluid simulation. For the Annular Genealogy installation, the research is related to collaboration of a synchronized process using feedback from multiple modalities of representation and interaction.

3.2 Introduction to the Fluid Automata Project

The Fluid Automata system explores the use of fluid simulation as an aesthetic component for interactive art. While fluid simulations are often used in scientific visualization applications in order to give researchers a practical understanding of a fluid system within a particular context, the use of fluid simulations to create realism and excitement in entertainment contexts is also a widely explored topic. Moreover, fluid systems have been used as a technique in generative media arts contexts, and a number of recent art projects utilize fluid simulation as a component of the work. A method created by computer graphics researcher Jos Stam in 1999 (and presented to the game developers community in 2003) to create a stable fluid system first made it possible to represent realistic looking fluids at real-time frame rates [200, 201]. Many interactive artworks have made use of this particular technique. For instance, the creative coder Memo Atken has created a series of demonstrations based upon Stam's method, showcasing them using mobile devices for interaction and making the code available for OpenFrameworks and Processing multimedia frameworks[1]. Another project that incorporates Stam's method is artists Graham Wakefield and Haru Ji's *Artficial Nature*. This project uses computer vision techniques to allow participants to interact with a 3D fluid representation through the movement of their bodies [222]. Other fluid simulation methods, such as [94], are optimized for real-time interaction in video games. Although simulation methods generally focus on producing accurate representations of natural systems, the Fluid Automata system demonstrates that aesthetically-interesting visuals with a wide variation of movement and color can be produced from a simple set of rules that do *not* attempt to exactly reproduce natural systems. In this sense, although influenced by physical simulation, Fluid Automata could be considered a "generative art" system [81, 15].

Scientific visualization projects aim to help researchers identify and reason about salient aspects of their data. While an aesthetic sensibility may contribute to the success of a visualization technique, this is not normally the primary motivation for its creation. Media artists, on the other hand, generally place aesthetic considerations at the forefront of their concerns. Similarly, physical simulations are concerned with accuracy and realism rather than extensibility and interaction,

[1] http://www.memo.tv/ofxmsafluid/

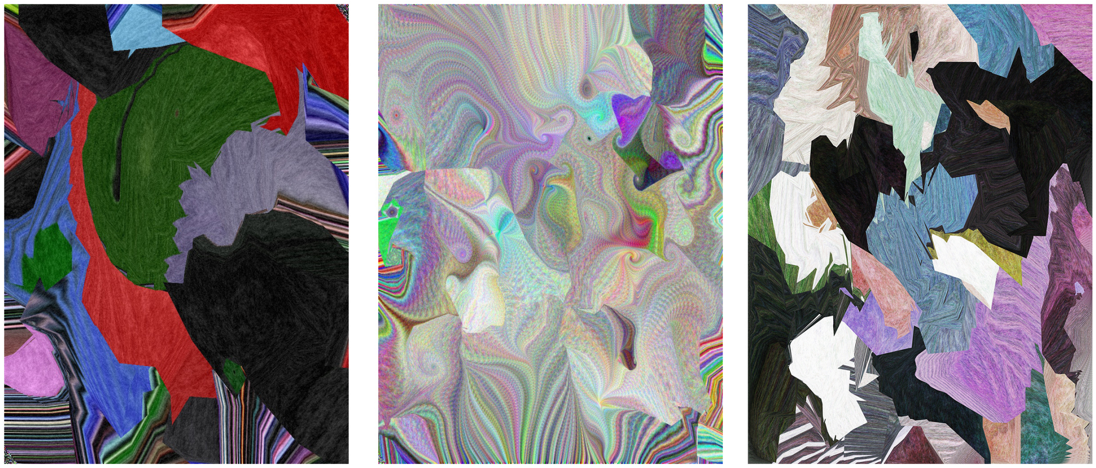

Figure 3.1: Examples of output from an iPad application utilizing the Fluid Automata system showing the wide range of aesthetic possibilities generated by the system when using different fluid profiles defined by customizing the fluid, visualization, and noise parameters.

which are central to media arts. However, media arts projects, due to time constraints or limitations in technical knowledge, often incorporate readily-available techniques not originally intended for artistic production, and thus that are not necessarily easily adaptable to artistic situations. A goal of Fluid Automata was to provide a system that provided more flexibility and that could be used in many situations, including on less powerful mobile devices, while retaining enough realism to be useful for simulations. Figure 3.1 shows examples of different outputs created with the Fluid Automata system.

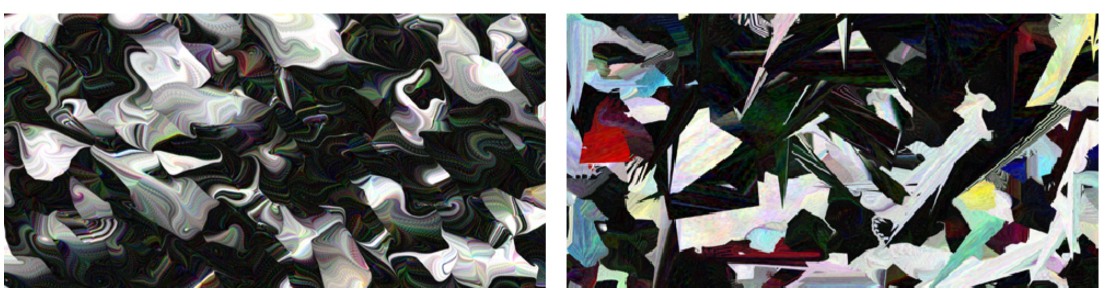

Figure 3.2: Details of high-resolution output demonstrating "unrealistic" fluid simulation. The left image shows the addition of a high amount of vorticity; the right image shows the "spikiness" associated with a high amount of energy.

3.3 Technical Details of *Fluid Automata*

The Fluid Automata system is composed of three integrated components: a fluid simulation engine; a flow visualization technique; and an interaction component that encourages interaction with the visualized fluid simulation [74]. Here I look at the technical details of the fluid simulation and flow visualization components that are shared across multiple deployments of the project.

3.3.1 Fluid Simulation

The fluid simulation is a novel technique inspired by cellular automata systems, in which discrete cells of information are updated by surrounding cells. As opposed to early cellular automata systems in which each cell contained only binary information, the Fluid Automata system contains $2^8 * 2^8$ states, where there are 256 values for the magnitude of a fluid vector and 256 states used to describe its direction. While the name of the system was inspired by the biologist Tibor Gánti's discussions of "chemotons" [83, 84], the initial kernel of insight for the Fluid Automata system arose while thinking about how to create a simple rule-based system to produce emergent behavior. Cellular automata systems, made popular through the introduction of John Conway's "Game of Life" [85], demonstrate complex behavior emerging through an iterative system that updates the state of each element (positioned in a uniform grid) based on a set of basic rules. These rules determine the next state of each element by querying each of its neighbors. In Conway's original automata system, each pixel has a binary state, and either "lives" (is set to 1) or "dies" (is set to 0) based upon the number of surrounding pixels that are on or off. In many implementations of the Game of Life, users interact with the system by using a mouse to turn pixels on or off. Other cellular automata systems, including many that are explored in Stephen Wolfram's "A New Kind of Science" [233], explore different rule sets and involve multiple states.

The current version of the Fluid Automata system effectively simulates the movement of fluid using an 8-bit cellular automata system that stores 256 states for orientation and 256 states for magnitude for each pixel. Retaining the discretization and simplicity central to cellular automata systems allows us to create a complex system that is linear and replicable. Unlike the majority of commonly-implemented fluid simulations which utilize the non-linear Navier-Stokes equations, our algorithm is always stable at any length of timestep. That is, our system is inherently non-realistic due to the fact that there is no mass conservation condition and because the fluid is compressible. Although our system is not physically accurate, it has the advantage of being easy to modify in real-time,

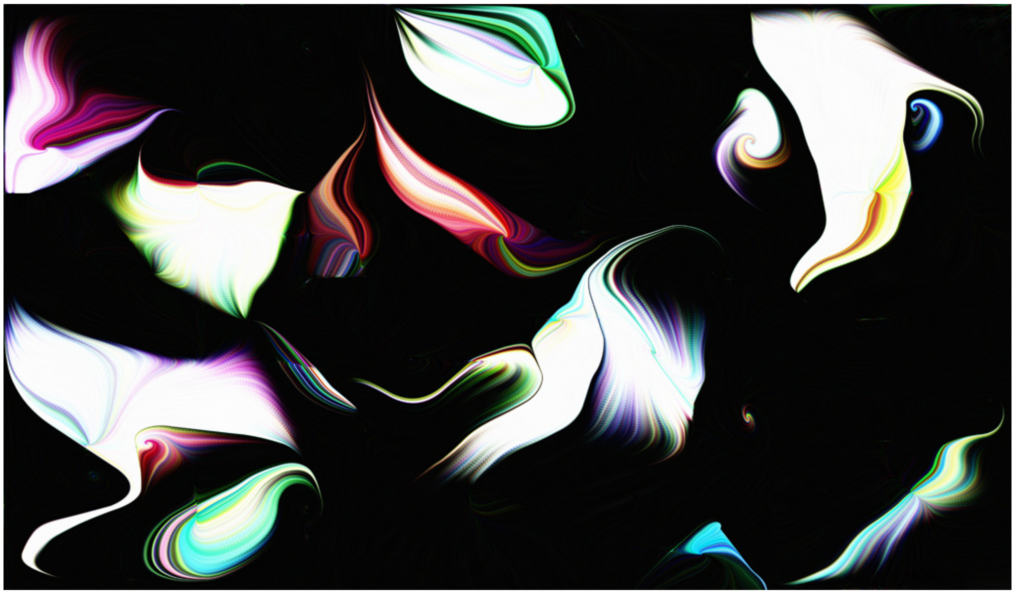

Figure 3.3: Example output using a custom color palette with high-contrast image processing variables.

and, more importantly, it is easy to comprehend and relatively straightforward to implement, leading to its incorporation in a range of projects.

Since one of the goals in the creation of the Fluid Automata system is to emphasize creativity and interactivity, it includes a robust simulation engine that allows a wide range of fluid-like behaviors to be explored. For instance, the system allows users to set parameters describing viscosity, rotational energy, and various momentum parameters. Various versions of this system have been implemented in the different projects that use the Fluid Automata system, taking advantage of available hardware on different devices. But, at its most basic, the system distributes a flow of energy throughout the system as follows:

1. The screen is divided into a grid of cells.

2. New energy is added into the grid by user interaction.

3. The energy at each cell is split into three streams, a forward stream and a left and a right stream.

4. In each of the defined directions for each stream defined in step 3, the energy of each cell is moved into the neighboring cell via the following process:

    (a) The cell is displaced along the vector describing the energy stream.

Figure 3.4: Photo of iPad application using the Fluid Automata system with a live video feed replacing the background noise texture.

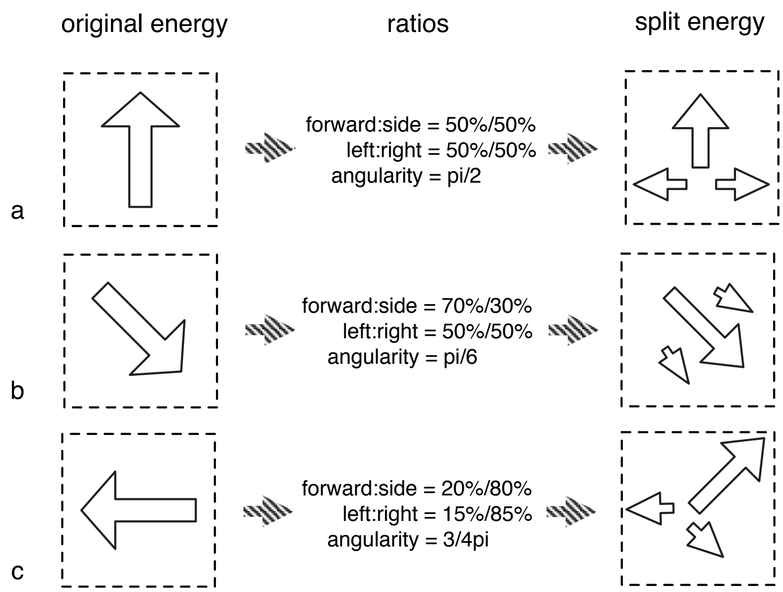

Figure 3.5: Examples of fluid systems with different characteristics, i.e., fluid profiles, based on different settings. The settings can be changed in real-time. The left side of the chart represents the energy in a single cell; the right side of the chart shows how the energy is split into different streams based upon the parameters defining the ratio between forward and orthogonal momentum; the ratio between left and right momentum; and the angularity of the orthogonal momentum. In the top row (a), energy with a magnitude of 255 and an orientation of pi/2 is split evenly between forward and orthogonal momentum. In the middle row (b), most of the energy in the cell remains moving in the original direction; the orthogonal energy is close to the forward orientation. In the bottom row (c), most of the energy is moving to the side, with a high angularity, and with an uneven distribution between the left and right sides. (Note, the arrows representing energy vectors are not drawn exactly to scale.)

   (b) For each neighboring cell the displaced cell intersects with, create a "partial" vector by scaling the original vector with the amount of intersection.
   (c) This partial is added to the cell it intersects with.

5. When this process is finished for the entire grid, the partials associated with each cell are combined, creating a new vector replaces the current vector in the cell.

6. Energy is removed from the system by scaling the energy in each cell by a dampening factor.

7. Steps 2 through 6 are iterated at each timestep until there is no energy left in the system.

More formally, the fluid system acts on a grid G of cells $C_{i,j}$ each containing an energy vector $\vec{E}_{i,j}$, with a particular magnitude m and orientation θ, and where $0 < i < columns$ and $0 < j < rows$. The resolution of the grid depends on the effectiveness of the hardware. On a third generation iPad, the maximum resolution at real-time frame rates is a 25x25 grid of cells; on a desktop computer with a modern graphics card, a 100x100 grid of cells or greater will run at interactive frame rates.

In order to define a fluid profile for the system, two ratios are introduced that regulate that behavior of energy as it moves through the cells. The first, the *momentum* ratio, or r_1, defines how much energy moves forward versus moving to the sides. The second, the *directionality* ratio, or r_2, defines how much energy moves to the left versus moving to the right. A parameter, *angularity*, is defined as $\angle\phi \in [0, \pi)$, describing a rotation offset from $\angle\theta$. Additional parameters influencing the fluid profile are the *viscosity* of the system, which acts as a dampening factor defining the rate at which energy is removed from the system, and the *sensitivity* which controls how much energy is added to the system through some form of user interaction. New energy is added into the cells in a particular direction using the multitouch capabilities of the tablet device. The amount of energy that is added in a particular touch depends upon the *sensitivity* parameter, which can be adjusted during runtime. The magnitude of energy is also determined by how far the current position of the touch is from its previous position. This difference also determines the direction of the added energy. If there is no change in position, then the energy is added in the last known direction. This vector of new energy is added with any existing energy at the currently touched cell to update $\vec{E}_{i,j}$.

At each timestep t during the operation of the fluid system, the energy $\vec{E}$ in $C_{i,j}$ is split into three separate streams: a forward stream, $\vec{F}$, and two "orthogonal"

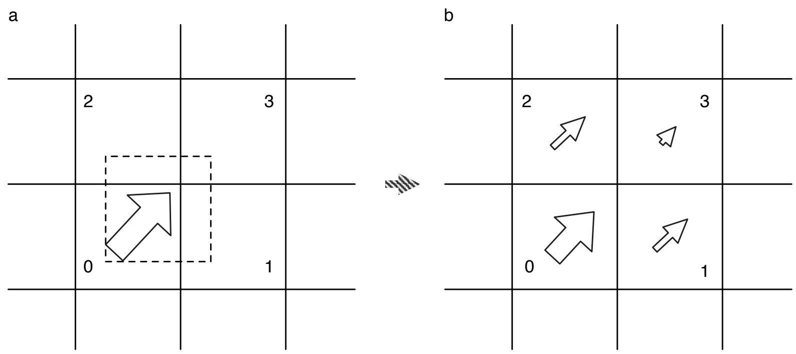

Figure 3.6: Example showing how a single stream of energy in a single cell is distributed to other cells. In this example, the left grid (a) shows that the energy in cell 0 is pointing in the direction pi/4 with a magnitude of 0.5. The dotted box shows where the "displaced" cell intersects with its neighbors. The largest intersection of energy stays within the original cell (cell 0); a tiny amount of energy is pushed into cell 3; and a small amount of energy is pushed into cells 1 and 2. The right grid (b) shows the distribution of energy from this single cell into its neighbor cells and back into itself.

streams, $\vec{L}$ and $\vec{R}$. Using the current fluid profile (the values for the parameters of *momentum, directionality*, and *angularity*), and the current magnitude and orientation for each cell, I define these three streams like so (in Equations 3.1 through 3.3):

$$\vec{F} = \begin{pmatrix} r_1 m \\ \theta \end{pmatrix} \tag{3.1}$$

$$\vec{L} = \begin{pmatrix} (1-r_2)(1-r_1)m \\ \theta + \phi \end{pmatrix} \tag{3.2}$$

$$\vec{R} = \begin{pmatrix} r_2(1-r_1)m \\ \theta - \phi \end{pmatrix} \tag{3.3}$$

Figure 3.5 shows examples of how the current total energy in a cell is split into three streams based on these parameters. Every cell in G thus contains three separate streams of energy, $\vec{F}$, $\vec{L}$, and $\vec{R}$. These streams are used to define the flux of energy moving from each cell into its neighboring cells.

A "displaced" cell $D(C, \vec{v})$ is a copy of a cell $C \in G$ that moves along a vector $\vec{v}$ positioned at the center of C. This displaced cell D intersects with between 1 and 4 cells (the original cell C itself and up to three neighboring cells). The

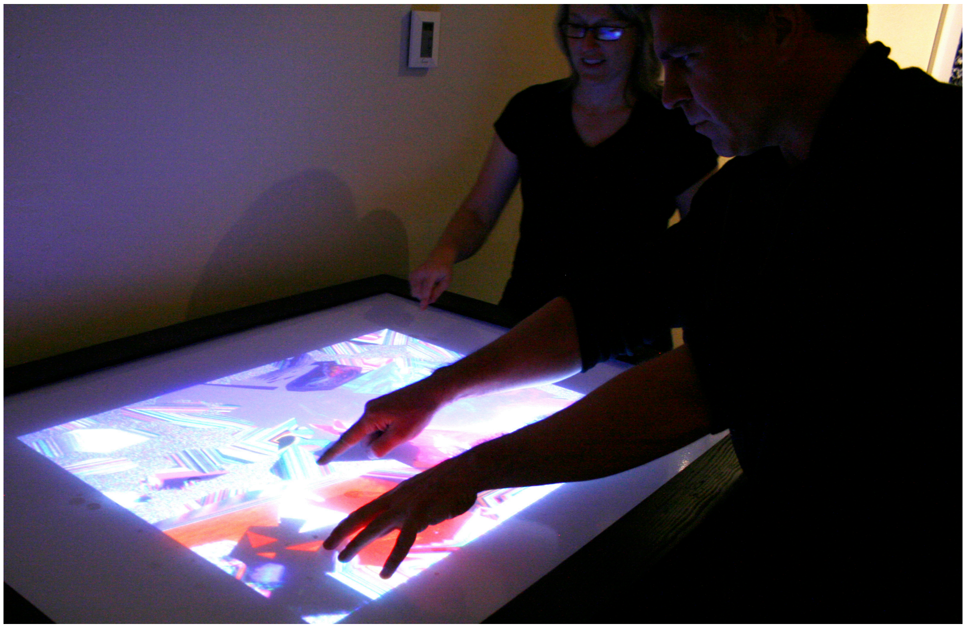

Figure 3.7: Users gathered around a multi-touch table running a project that uses the Fluid Automata system.

magnitude of any energy vector is constrained to range between 0 and 1. When displacing a cell, the magnitude is scaled by the length of a cell side. For instance, if the grid is divided into 10x10 cells, then each cell side is .1 in length. And so the magnitude in a cell is scaled by 1/10th before being displaced. This ensures that a displaced cell will only ever intersect a cell that is its immediate neighbor (although exceptions to this constraint may have interesting creative possibilities.) The amount of overlap between the displaced cell and the cell it intersects with determines how energy is placed into that cell. An intersection $I(D, C)$ is simply the amount of overlap between the displaced cell and another cell (Equation 4). The value of any intersection can range between 0.0 (no intersection) and 1.0 (full overlap).

$$I(D, C) = \Big(Area(D) \cap Area(C)\Big)/Area(C) \tag{3.4}$$

This value is used to create a "partial" vector $\vec{p}$ via a function $P(N, \vec{v}, C)$ for each energy stream. This partial is calculated simply by scaling the stream by the amount it overlaps with the current cell, as defined in Equation 5:

$$P(N, \vec{v}, C) = I(D(N, \vec{v}), C) * \vec{v} \tag{3.5}$$

In Equation 5, N refers to a neighbor cell of a cell $C \in G$ and $\vec{v}$ refers to one of the energy vectors ($\vec{F}$, $\vec{L}$, or $\vec{R}$) in that neighbor cell. Figure 3.6 depicts an example of this displacement and the subsequent generation of partials. For each cell $C_{i,j}$ in G, each neighbor is examined to determine how much each of its three streams overlap. The partials created by any intersection between the neighbor streams are summed to generate the new energy vector for the cell (Equations 6 through 9). It is important to note that a cell is considered to be a neighbor of itself. For instance, if a vector of magnitude 0.5 is pushed upwards at 90 degrees, it would intersect with both the current cell and the neighbor cell above it. Since the displaced cell would move a distance of 50% of its height from its current position, it would end up intersecting the current cell and the neighbor cell equally, and thus a copy of the vector, scaled by 50%, would be placed in each of the cells. Figure 3.6 shows a typical example of a single stream of energy in a single cell being distributed to its neighbors. Excluding any dampening factor or any new energy added from user interaction, the system will retain exactly the same amount of energy over each timestep.

$$\vec{F}_{i,j,t} = \sum_{p=i-1}^{i+1} \sum_{q=j-1}^{j+1} P(C_{p,q}, \vec{F}_{p,q,t-1}, C_{i,j}) \tag{3.6}$$

$$\vec{L}_{i,j,t} = \sum_{p=i-1}^{i+1} \sum_{q=j-1}^{j+1} P(C_{p,q}, \vec{L}_{p,q,t-1}, C_{i,j}) \tag{3.7}$$

$$\vec{R}_{i,j,t} = \sum_{p=i-1}^{i+1} \sum_{q=j-1}^{j+1} P(C_{p,q}, \vec{R}_{p,q,t-1}, C_{i,j}) \tag{3.8}$$

$$\vec{E}_{i,j,t} = \vec{F}_{i,j,t} + \vec{L}_{i,j,t} + \vec{R}_{i,j,t} \tag{3.9}$$

Other parameters can also be adjusted to create different characteristics for a particular fluid profile. These include: controlling the "jitter", or randomness of the system, and clamping the maximum outflow for the cells within the grid. I also experimented with a toroidal representation of the system where fluid energy wraps around the edges of the screen, instead of bouncing off the edges. Setting a maximum outflow parameter interestingly creates the sense of ice cracking and melting when a particular threshold is exceeded. And different settings of *viscosity* and *angularity* can create more or less turbulent behaviors. While it may be surprising that a simple heuristic could mimic the complexity of fluids, the iterative nature of the system does in fact create a wide variety of fluid-like structures, including the creation of eddies, vortices, and turbulence. Figure 3.1 and Figure 3.2 show examples of fluid systems with different fluid profiles defined by different settings for the *angularity* and *directionality* parameters.

Just as simulations for realistic films and video games do not feel constrained by a perfect representation of the physics of a visual effect, so to should media

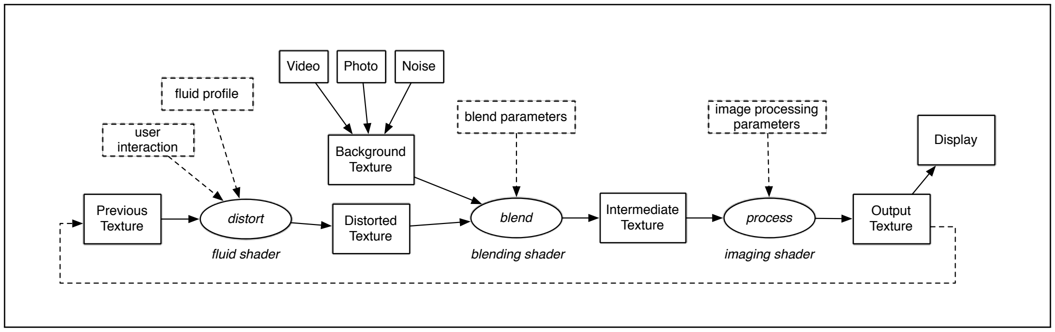

Figure 3.8: Schematic for the main functionality of the Fluid Automata system. The output texture after one timestep becomes the input for the next timestep.

artists not feel constrained by a perfect representation of existing algorithms and equations for a particular kind of effect. By creating a custom fluid system with a wide range of parameter adjustments I was able to extend the aesthetic applicability and variation of the fluid system to capture unusual behaviors not normally depicted with fluid representations. Although the system appears realistic, it in fact sacrifices physical accuracy in order to emphasize interactivity, expressivity, and experimentation.

The following code listing, UPDATECELLVECTOR, describes the fluid simulation, based on CA, as described in section 3.1. The *cell* parameter refers to a cell positioned in the CA grid (*pos*), with a particular state described by a vector (*vec*) that has a particular magnitude (*mag*) and orientation (*ang*). The *grid* has a pixel width of *width* and pixel height of *height*, and a particular number of columns (*cols*) and rows (*rows*), and contains a double array of cells. The variable m refers to the ratio that splits a cell vector into forward and "orthogonal" streams, the momentum parameter, or r_1. The variable ϕ refers to the angularity parameter. Other optional variables, such as the directionality and viscosity parameters, have been excluded for clarity. Note that the NEIGHBORCELLS procedure retrieving a cell's neighbors also includes the cell itself. Finally, the INTERSECTRECTS procedure (referred to but not shown) returns a value between 0.0 and 1.0 indicating the amount that two rectangles of the same size overlap.

Figure 3.9: Photograph of viewers wearing 3D active stereo glasses within an installation of *Annular Genealogy* inside the AlloSphere Research Facility at UC Santa Barbara.

Algorithm : UPDATECELLVECTOR($cell, grid, m, \phi$)

```
comment: Update vector vec in a Cell c by querying neighbors in Grid g

procedure NEIGHBORCELLS(c, g)
 neighborCells ← ARRAY(9)
 for i ← −1 to 1
   for j ← −1 to 1
        ⎧ nc ← c.col + i
        ⎪ nr ← c.row + j
        ⎪ if nc < 0,  nc ← grid.cols − 1
   do   ⎨ if nc > grid.cols − 1,  nc ← 0
        ⎪ if nr < 0,  nc ← grid.rows − 1
        ⎪ if nr > grid.rows − 1,  nr ← 0
        ⎩ neighborCells.push(grid[nc][nr])
 return (neighborCells)

procedure MAKERECT(p)
 w ← g.width/g.cols
 h ← g.height/g.rows
 pLL ← vec2(p.x − w/2.0, p.y − h/2.0)
 pUR ← vec2(p.x + w/2.0, p.y + h/2.0)
 return (RECT(pLL, pUR))

procedure PARTIAL(pos, nc, nv)
 p ← INTERSECTRECTS(MAKERECT(pos), MAKERECT(nc.pos + nv))
 return (nv ∗ p)
```

3.3.2 Flow Visualization

A perennial concern of scientific visualization is the effective visualization of salient features of a vector field, as indicated by the wide variety of approaches to their representation [148]. A popular technique introduced in 1993, called *Line Integral Convolution*, effectively identifies detailed curvature features of a vector field. In this technique each pixel of a background image is filtered along "streamlines" defined by the vector field [22]. Another early technique, *Choreographed Image Flow*, describes using image warping to generate animations for an animated representation of flow-fields [196]. A more recent technique, *Image Based Flow Visualization*, represents flow using the iterative deformation of a texture mesh along the directions of the vector fields. In this technique, an image is blended together with the distorted version of itself at each frame, causing pixels to "smear" and appear to leave streaks in the direction of the flow vectors [216]. While the creators of these techniques recognize and discuss applications outside of scientific visualization, more recent papers examine the relationship between aesthetics and visualization. For instance, [115] specifically looks at the various stylized qualities involved in painting and the possibility of brushstroke techniques for inspiring more effective scientific visualization methods. And [157] introduces a technique that allows artists to control small-scale animations on "advected" textures.

The main image processing scheme in the Fluid Automata system is based on a feedback loop whereby a high-resolution background image is perpetually blended together with a distorted version of itself. The characteristics of the distortion are based directly on the current state of the fluid system. This system is similar to van Wijk's *Image Based Flow Visualization*, which has been extended for use in a variety of scientific visualization applications, including animated and 3D flows [207, 216]. Since the focus of the application is aesthetic exploration, I provide the user with a variety of tools to alter aspects of these blending operations, and in addition introduce an image processing layer whereby the user can change a variety of parameters, including: the rate and amount of blending, the type and quality of the background texture, and the brightness, contrast, and saturation of the blended image. The default background texture is a grayscale noise texture at a resolution exactly matching the display size. However, I have experimented with various types of background textures, including lower resolution textures, static colored textures, static image textures, dynamic textures that are updated by noise functions, and dynamic textures that are updated by a live video feed. Figure 3.3 shows an image created using a static colored background texture with high contrast and high saturation image processing parameters. Figure 3.11 shows an image with no saturation and that uses a low resolution, black and white background texture to create an interesting "smearing" effect. And Figure

3.4 shows an image that is created using a live video feed as the background image, rather than an image populated with randomly-colored pixels.

Figure 3.8 provides an overview of the fluid visualization process over the course of a single frame. At t_i, the system: a) distorts the previous image texture (if $i > 0$, otherwise it uses a copy of the background texture) based on user interaction and the current fluid profile; b) blends the background texture in with the distorted texture based on a blending parameter (that can be updated in real-time by a user); and then c) applies image processing filters (based on the image processing parameters described above) to the image to create a final output texture for this frame at t_{i+1}. This output texture is then used as the input texture for the next frame.

3.4 Deployment

3.4.1 Fluid Automata, iOS Application

An initial iteration of the Fluid Automata system was implemented in a stand-alone version of Fluid Automata that could be run by a single user on an iPhone or iPad. Although other fluid simulation applications already existed for the iPad, ours offered a wide variety of customizability, including the ability to change image processing parameters and fluid profiles. Additionally, users were able to choose presets to quickly jump to interesting states and motions. Finally, the application included the ability for users to turn on the video camera to capture a live feed of themselves or their surroundings and to superimpose that into the fluid system. The application received positive reviews on blog sites, including CreativeApplications.net and OneAppOneDay.com. Within a few months it had a five-star rating and was downloaded thousands of times.

3.4.1.1 Interaction in the iOS application

The primary interaction component utilizes the multitouch capabilities of iOS devices, creating a believable representation of fluids being disrupted by human touch. Additionally, users are able to manipulate a wide number of parameters to control the fluid profile of the simulation as well as a number of image processing components. Much experimentation went into making the user interaction with the fluid system feel responsive and inviting: by tapping the screen the user adds energy to the system; moving a finger across the screen overrides the fluid dynamic system by forcing the vector to move in the indicated direction; and multiple fingers can be used to push energy around in a more complex way, possibly by more than one person. Other gestures can also be enabled to update fluid properties or image processing parameters. For instance, a pinching gesture using all five fingers simultaneously causes the entire background texture to scale up or scale down, creating a zooming effect. Similarly, a five-fingered panning gesture causes the entire background texture to be translated in the direction of the pan (as determined by the centroid of the five fingers), shifting all of the fluid vectors so that they point in that direction. In addition to being able to add energy to the system, users can update the fluid parameters and image processing parameters in real-time, or select a specified fluid profile defined at a previous time. In the iPad version of the project users can double-tap the screen to bring up a set of controllers that affect the various parameters of the system. Figures 3.10a and 3.10b show a detail of sliders affecting the image processing parameters and fluid parameters, respectively. Users can also save the current fluid profile at any time, allowing it to be quickly retrieved in future sessions.

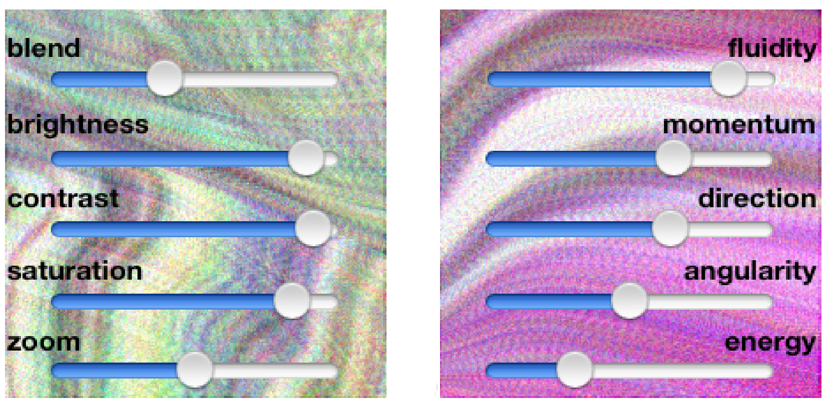

Figure 3.10: Details of the iPad controller. The sliders are used to update the image processing parameters (left) and the fluid profile parameters (right) in real-time.

3.4.2 Fluid Automata Performer, iOS Application

The current iteration of Fluid Automata is a more full-featured version that is intended for performance situations, for example, by choreographers or VJs to augment a dance performance or musical event. In this version, the iPad is connected to a projector or monitor that displays the fluid simulation. The actual iPad screen then becomes a rich interface for controlling many aspects of the system. In addition to allowing for the control of fluid vectors, the user can incorporate video playback, a live video stream, or dynamic noise textures. The system also can be set up to receive or send OSC messages corresponding to different aspects of the Fluid Automata system so that it can be used as a more

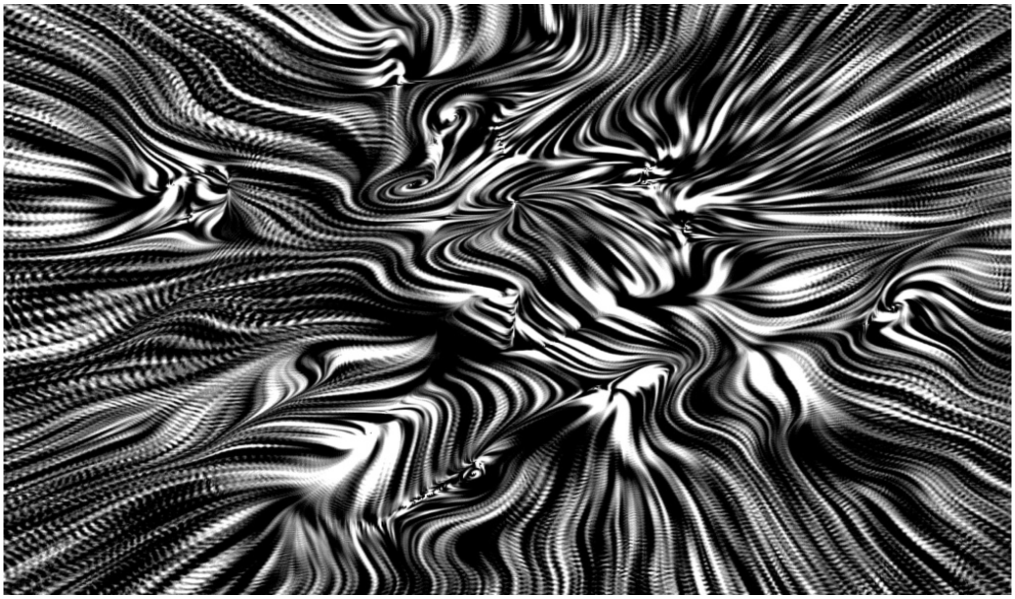

Figure 3.11: Example output of visualization using low-resolution binary background that creates a sharp, smearing effect.

general controller for other artistic outputs, or to be controlled by other external devices on the same network. This version also enables the ability to do real-time capture of a Fluid Automata session, which can then be shared or modified in video editing software. This version of Fluid Automata is available for the iPad and iPhone via the iTunes App Store[2].

3.4.3 Collaborative Installation

An iteration of the Fluid Automata project was showcased at the 2011 IEEE VisWeek Art Show, curated by Bruce Campbell and Daniel Keefe [69]. Research investigating interactive flow visualization indicates that novel interaction techniques can successfully enable collaboration and encourage exploration [103]. In order to investigate these aspects of fluid simulation, this version was presented as an interactive installation for multiple users. Each user was given an iPad and invited to interact with a single fluid system projected large-scale on a wall. On each iPad, users saw the current state of the fluid system's underlying vector representation (represented by rotating and scaling triangles) as well as an indication of the other user's interaction (represented by colored circles). This was done in order to see how users would interact together to manipulate the fluid system.

[2]http://www.fluidautomata.com

An interesting outcome of this presentation was the realization that many people were very interested in how others were interacting, and that allowing people to see each other's interactions increased engagement with the installation [73].

3.4.4 Multitouch Table

A more recent iteration of the Fluid Automata system was ported to a multi-touch table and shown in an art show at the University of Arizona called "Form, Content, and Computation." This installation made it easier for multiple people to interact with the system at the same time, and to explore specific gestures that were defined to allow users to alter the intensity of the turbulence of the system. In this installation, I used the TUIO protocol to map touches on the table as inputs that updated the Fluid Automata fluid vectors.[3] The table was built by the engineer Matt DePorter and uses a perimeter of LED light sources and light detection sensors to detect touches on the surface of the table. I created a timeline that cycled through different fluid profiles so that users could experience different aspects of the system without having to worry about any other interactions except multitouch to move fluids around. Figure 3.7 shows an image of people interacting with the Multitouch Table running an iteration of the Fluid Automata project.

3.4.5 Virtual Space Installation

Another iteration of the Fluid Automata system utilizes the gyroscope sensor built-in to the iPad in order to transform the tablet's screen into a "magic lens." In this version, the fluid system is placed on the six sides of a cube map (also known as a "skybox"), a technique often used in video games to display landscapes or distant horizons. The user is imagined to be inside a virtual fluid system that they can see by spinning in place while rotating the tablet. By touching the screen, a ray is sent to the cubemap texture, allowing the user to interact with the surrounding fluid system. Figure 3.12 shows a series of photos taken of a user interacting with the virtual fluid system.

3.4.6 Study in Brownian (F*) Motion

The Fluid Automata system has also been adapted for use as an instrument for controlling audio-visual compositions. In this configuration the output of the application is projected onto a large display. In addition to being controlled by multitouch, the system can respond to Open Sound Control (OSC) messages sent by another computer that are generated by musical events. Additionally, fluid

[3] http://www.tuio.org

Figure 3.12: A user interacting with the virtual Fluid Automata installation using the iPad as a magic lens.

vectors and various fluid parameters can be transmitted wirelessly via OSC to influence the composition. I have also experimented with attaching piezo sensors to the iPad itself in order to directly input data into an algorithmic composition engine. The first iteration of the Fluid Automata system was a collaboration with the composer, Kiyomitsu Odai, in the Spring of 2011 at the media arts showcase, "Questionable Utility," at University of California, Santa Barbara. In this improvised performance, Kiyomitsu Odai was responsible for creating live audio based on a generative system, while I used the multitouch capabilities of the iPad to push fluids around in response to the audio. Figure 3.13 show a photo of the performers interacting with the composition.

3.4.7 Annular Genealogy

Kiyomitsu Odai and I also collaborated on a more ambitious multimedia project involving generative music. We talked at length about the differences between this iteration and the previous, and decided that we wanted to create a piece where the sonification and the visualization were different representations of the *same system*, rather than two separate systems presented together. That is, we wanted to explore what would happen when the the data used to update the visualization system was the same data that updated the composition system. I defined a networked protocol based on OSC in order to transfer information back-and-forth between the different computers (one running Fluid Automata system, and the other the musical composition). Rather than having a centralized

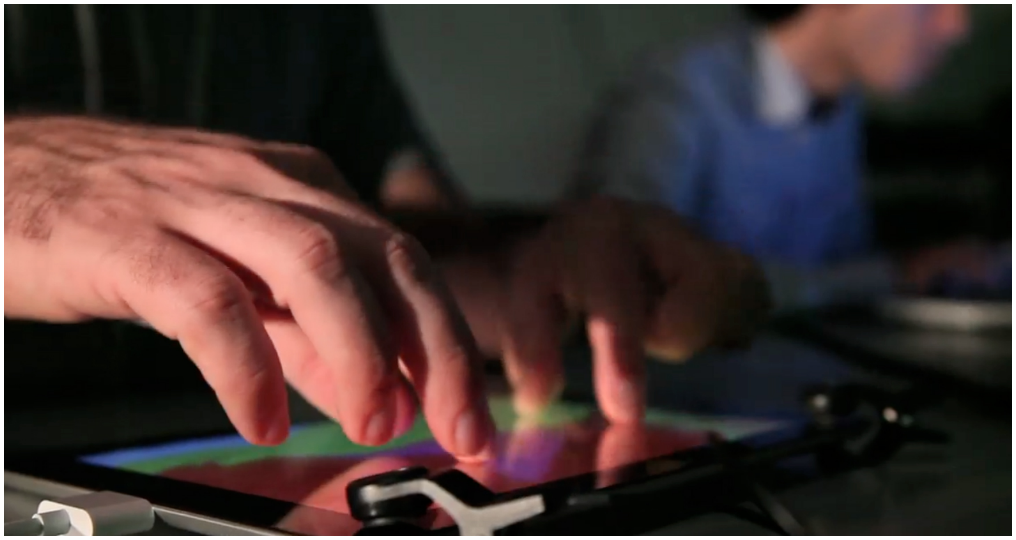

Figure 3.13: Photo from a live performance of *Study in Brownian (F*) Motion*.

platform for generating the data, the data was generated in a constant multi-modal feedback loop between the two computers. After being seeded with either an initial sounds or an initial fluid vector, the system could run on its own indefinitely. Additionally, we could use interaction to interfere with the endless chaotic looping of the system. We named the piece *Annular Genealogy*, highlighting the evolving "families" of feedback loops (annular means "ring-like" or "ring-shaped"). Some other additional components of Annular Genealogy that differentiated it from our previous work, *Study in Brownian (F*) Motion*, included the use of 3D space, the use of dynamic background textures based on Perlin noise functions, and the use of microphones to pick up ambient noise which were fed into the fluid system [76]. The piece has been presented as a live performance (it was performed it at the Bits & Pieces media arts festival in 2012) and also as a stand-alone fixed audio-visual piece that was shown in the Allosphere Research Facility in 2012 [2]. Figure 3.9 shows audience members inside the immersive Annular Genealogy installation.

3.5 Fluid Interaction and Visualization Research

In this section describe some of the research goals and design decisions involved in creating Fluid Automata. A main motivation for the project was the desire to better understand fluid dynamics, and in particular, to be able to create a custom fluid simulation that could be explored using mobile devices. Cellular automata approaches to fluid simulation have been explored. An early paper by Gerard

Vichniac describes discretized models for fluid simulation based of Cellular Automata, but indicates specific necessary parameters to avoid "divergences" [219]. Another paper surveys different cellular automata paradigms for fluid simulation, comparing lattice gas, digital fluid, and lattice-Boltzmann strategies [25]. A 1998 paper describes 3D fluids that can be represented with hexagonal and rhombododecahedron grids instead of uniform squares or cubes [16]. And Stephen Wolfram also explored general non-linear approximations of fluids via cellular automata [232]. More recent work examines cellular automata for a wide range of tasks beyond that of simulation, including, for example, image processing [179], urban design [209], and cognitive science [236].

Although a wide range of interactive cellular automata systems are available online, I was unable to find one that attempted to model fluid structures. After I developed the fluid simulation component that ran at real-time rates, I began to explore a variety of different interactive techniques. These included the use of the gyroscope within the iPad device, the attachment of piezo microphones, and the use of multitouch for the iPad version and the touch table version. While I did not investigate research into responsive or realistic touch interaction, I spent a lot of time testing a variety of parameters related to multitouch interaction with the fluid system, including how much energy a single touch added the system, how to control the direction of the energy, and how quickly the energy would be added to the system. While these explorations were not precisely measured, I included interactive sliders that let users change some of these variables, and this could be used as a springboard for future research into interaction.

Another goal of Fluid Automata was to make it easy to create different fluid profiles. In particular, I wanted the user to be able to add arbitrary amount of turbulence and vorticity into the fluid system. A recent paper describes a method to enhance fluid simulations with "intermittent turbulence" [241]. Recent research has investigated how to add pleasing effects to fluid simulation for use in animation and film. A 2009 paper introduces a to define "Eulerian vortex sheets" that make it possible to stretch and wiggle fluids using a "liquid-biased filter" [113]. And [242] looks at preserving vortical detail in smoothed-particle hydrodynamics techniques. By introducing the angularity, directionality, and momentum parameters, users could explore wide range of possibilities for creating turbulence and for introducing vorticity into the system. On the iPad version, I added presets that allowed the user to immediately jump to fluid profiles that had particular characteristics. For instance, the presets "Milky Way" and "Nebulae" create roving eddies that appear and dissipate repeatedly.

Finally, I wanted to make it easy to change the visual representation of the fluids in order to highlight particular aspects of the fluid dynamics via changes in, for example, color, saturation, and contrast. Research in the scientific visualization community has explored various techniques to visualize fluid flows. A survey of flow visualization techniques by Robert Laramee, et al. [123], includes dye-injection, texture advection, different kinds of arrows, pathlines, streaklines, as well as the streamlines introduced by Brian Cabral and Leith Leedom in their paper, "Imaging Vector Fields Using Line Integral Convolution" [22]. For this project, I decided to modify a texture advection technique called Image Based Flow Visualization, since it had the benefit of being relatively fast since it requires only a shift in texture coordinates, rather than needing to sample a large number of individual particles [216]. By creating a pipeline of programmable shaders, I made it easy to alter a wide range of parameters that lead to a wide range of visual effects.

As in the projects described in Chapter 2, this chapter shows that a media arts installation inherently engages with current topics in research. Differently from those projects, Fluid Automata more intentionally created the first deployment as a way to conduct research into fluid dynamics systems. This was partly as a learning experience for myself, as a way to explore existing techniques of modeling fluids in real-time. But once I realized that most fluid dynamics algorithms used in media arts projects were based off of the same algorithm and had some limitations as far as creative flexibility, it led me to conceive of my own potential research contributions. Some of the many related topics I was interested in when the initial exploration was initiated included: collaborative interaction; mobile devices; musical interfaces; interactive graphics; and live performance. While these may seem to form a disparate collection, they all relate to an interest in novel, easily-accessible forms of creative interaction. The Fluid Automata system functioned largely as a *generator* of multiple, simultaneous, integrated research ideas related to these areas; the exploration of which fed back into the design of the Fluid Automata system. Media arts projects, though their goal is oriented toward the creation of a project, a performance, or a tool, can inspire novel research development in the areas the art piece draws from. This switch from an art production-goal to a research-goal results in a fundamentally different orientation. Commonly in art production and design, a role of the creator is in part to figure out what is possible and to make do with the limitations and constraints of available resources and technology. A research agenda on the other hand involves exploring technologies with the goal of pushing beyond current limitations and constraints. This dichotomy between what I am calling a research-orientation versus a production-orientation is similar to the differences between science and engineering. And in fact, this mediation between research and engineering is exactly what a media arts project can, ideally, enable. This role switching between research and production is common in media arts projects, and can be explicitly directed to have outputs in both artistic and scientific realms. Indeed, this role-switching is powerful justification for the creation of media arts projects and their inclusion in art-science endeavors.

3.6 Collaborative Multimodal Composing

A secondary avenue of research that arose through the Fluid Automata project was about multimodal collaboration. As mentioned above, one of the more recent deployments of Fluid Automata is its integration in the Annular Genealogy project, created in collaboration with Kiyomitsu Odai. In this section, I describe the intriguing ramifications of thinking of the audio and visual components of the piece as different representations of a single multimodal source. Annular Genealogy is an interactive multimedia composition for two performers using multi-channel speakers, a projector, and a tablet computer. The performance is organized around a generative music composition and its visual analog. Both the audio and visual components are explorations of feedback processes that encourage the performers to interactively shape aleatory elements and transmute them into appealing, transient structures. The composition engine works with a stochastic sequencer that uses Brownian motion as a guiding metaphor. Similarly, the visualization engine depicts colored fluid energy as a representation of dynamic, ephemeral structures. In addition to exploring these feedback processes independently of each other, each engine also directly influences the other via networked communication: both the visual and audio processes broadcast data via OSC messages which then influence various parameters of the composition and/or visualization. Finally, even the physical interactions are fed into the generative system as contact microphones are used to pick up the tapping and other ambient sounds made during the interaction. The ultimate goal of the performance is to bring various layers of feedback into a cohesive compositional experience. These feedback layers are interconnected, but can be broadly categorized as physical feedback, internal or digital feedback, interconnected or networked feedback, and performative feedback. Specifically, these layers include: the generation of new musical motifs being created from the processing of the output sound; the generation of visual forms from the processing of the output graphics; the vector positions that govern the displacement of the visual forms used as inputs to control music parameters; and the sequencing parameters controlling the generation of the composition used as inputs to control image processing parameters.

In addition to having cybernetic properties of interlaced feedback systems, the piece can be characterized as being fundamentally synaesthetic. That is, the mix-

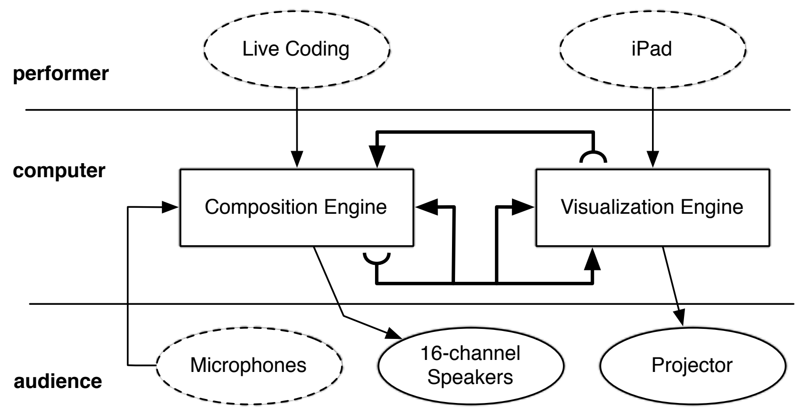

Figure 3.14: High-level overview of the Annular Genealogy project showing processes at three tiers: performer, computer, and audience member. The darker lines indicate the main feedback loops where the output of one process in piped in as the input to another.

ing of the mutual generative processes conflates the aural with the visual modality and vice versa [45]. Through the continuous interlinking of the two engines (via the performers and via the data sent over the network) a single interconnected multimodal signal is created. The output of this signal is represented simultaneously in multiple domains. Figure 3.14 shows a high-level chart of the relationship between the performers, the audience, and the visualization and composition engines. The performers input information to software in parallel using live coding and the multi-touch capabilities of the iPad. The outputs of each of the software engines then are fed back into themselves and into each other in various ways.

By supplying a multi-touch and live coding environment as an interface to and influencer of the generative processes the project includes another layer of feedback in which the performer is able to respond to and shape the multimedia output. That is, the performers are conceived of as participants in a compositional process rather than as on-the-fly creators of audio-visual output. The generative software serves to create some structures independently of the performers; it is the role of the performers to guide the generational processes toward more compositionally interesting output and away from output that is overly repetitive, monochromatic, garish, or otherwise less satisfactory. Likewise, the audio and visual engines, via the various feedback processes, continually push against the explicit control of the performers. Overall, the composition is defined by a network of nested feedback loops that link the performer and the algorithm to create an inherent aesthetic tension between the generative and the interactive, the performed and the composed, the random and the intended.

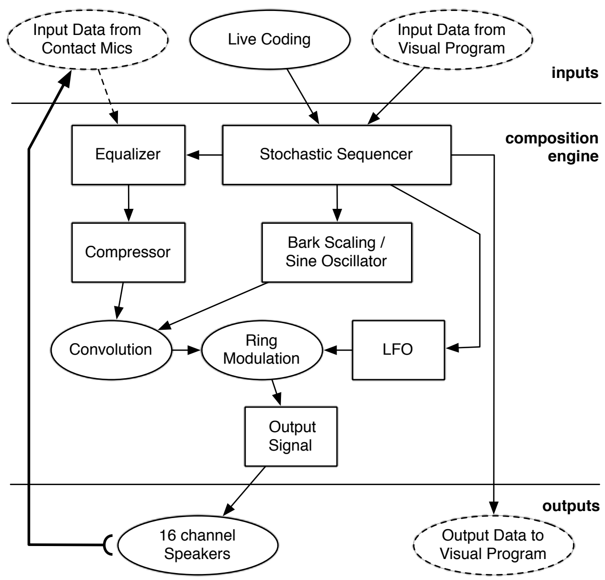

Figure 3.15: Overview of the interconnected components that comprise the composition engine. The darker line indicates the main feedback loop where the output audio signals are recapture by microphones to be used in the generation of sound.

Our composition refers directly or indirectly to a number of previous installations. Compositionally, we were inspired by composer David Tudor's Rainforest IV, an early sound-art installation featuring an entirely analog feedback system. Rainforest IV is "a collaborative environmental work, spatially mixing the live sounds of suspended sculptures and found objects, with their transformed reflections in an audio system" [101]. In particular, Annular Genealogy extends the concept of using loudspeakers as "an instrument unto itself" (rather than a tool of replication) and of using feedback as a compositional source. Another overt influence on Annular Genealogy is 20th-century composer Iannis Xenakis's concept of "Stochastic Music." As described below, our stochastic sequencer is an integral part of the generative composition. In particular, Xenakis draws a parallel between his compositional methodology and such natural phenomena as "the collision of hail or rain with hard surfaces, or the song of cicadas in a summer field" [237]. Similarly, we use a circular, stochastic timeline that is elasticized by Brownian randomness to create foreign sounds that nonetheless have the feel of natural phenomena. Xenakis, in describing his landmark orchestral composition, *Metastatis*, hypothesizes that by constructing acoustic spaces of constant expansion out of long passages of weaved glissandi “one can produce ruled surfaces by drawing the glissandi as straight lines” [237]. However Xenakis’ straightforward mapping of these glissandi sweeps to a chromatic scale is somewhat problematic as it imposes a non-linear relationship between the input and output frequencies. Our approach to this linearity problem, described below, involves replacing the chromatic scale with the Bark scale, which is at least psycho-acoustically linear, and thus more effectively captures the intended naturalistic feel. Other recent multimedia installations have also featured generative compositions that made use of feedback mechanisms between the audio and visual components. For instance, the New Zealand media artist Karen Curley created a work called *Licht und Klang*, an audio-visual installation that generates sounds via optical sensors that use the refractions of light through oil and water as inputs into sound generation software [44]. Various electro-acoustic ensembles have explored the use of networked feedback as a tool for improvised performance. Most famously, The Hub creates multimedia performances based on sets of rules that transform signals passed between performers and that are then presented in aural and visual domains [93]. A wide range of works have explicitly explored the notion of synaesthesia in installations. For instance, Jack Ox and David Britton’s *21st Century Virtual Reality Color Organ* uses visual representations of sound waves as an element in creating an interactive landscape [162]. More recently, Daniela Voto’s *Multisensory Interactive Installation* explores the interactive sonification of Kandinsky paintings [221]. Other works invoke Michel Chion’s concept of synchresis to describe the “welding together” of auditory and visual phenomena [33]. For instance, Niall Moody’s audiovisual instrument, *Ashitika*, generates simultaneous multimodal output from single gestures [152]. Our work similarly creates synaesthetic output based on a synchretic fusion of a mixed audio and visual feedback loop.

3.6.1 Compositional Details

Annular Genealogy is made up of two distinct software engines, one governing the aural domain and the other the visual. The visual and aural components are related by the structural mechanisms of generating and processing feedback and by the thematic focus on generating organic structures that continually devolve and transform into new structures. Both the aural and the visual engines represent the movement of energy through a system. These software engines are completely decoupled, but influence each other via the output of different multimedia data transmitted via OSC messages. In this way, each of the engines becomes part of a component of each other’s feedback loop. In this section, I describe the individual iterative feedback processing for the composition and the visualization engines, and also indicate where output is sent to and received by the engines.

The generative composition is largely generated through the receiving and processing of feedback from various sources: from the performer, from parameters received from the visualization engine, from the audience interaction, and via the piping of the composition data back into the composition engine itself. The external inputs are directly provided by the output of the visualization engine, performer interaction via live coding of a SuperCollider script, and contact microphone inputs that capture ambient sound. Moreover, the composition process is based on the continual recycling of audio data that is iteratively fed back into the microphones. Figure 3.15 shows a more detailed diagram outlining the main components of the composition engine.

The composition engine is written entirely in SuperCollider 3 and consists of various interrelated components, including: the interactive timbre generator, the stochastic sequencer unit, and the Bark scaling unit. The interactive timbre generator controls the overall quality of sounds by convolving the output of a compressor unit generator with a sine tone oscillator. In addition, a parametric equalizer and a ring modulator further ornament the signals before and after the convolution. The stochastic sequencer unit controls the timing and frequencies following a series of compositional heuristics. These frequency values are then piped into the Bark scaling unit, which defines the mapping of the frequency values according to the perceptual linearity of human ears (described below).

The main input signal is captured by a number of contact microphones, passing through a 6-band parametric equalizer that manipulates and enhances the timbral variety of the signal. This signal is then densely compressed, generating a thick feedback loop: the compressor amplifies the softer signals so that they are loud enough to be fed back to the loop, and at the same time, it squashes those above the set-up threshold in order to make the output sounds controllable. The feedback loop further functions as a distortion box by convolving sine tones with the output signal from the compressor. At the final stage of the system, the signal is ring-modulated with the low-frequency oscillator (LFO). The process is then iteratively repeated in real-time. The output through the speakers is again picked up by the contact microphones and becomes the main component of the input signal for the next pass of interactive timbre unit's feedback loop. Interactive control of this feedback loop is available through the live coding environment and, additionally, simply by making sounds that will be captured by the microphones. In our original performance, for instance, contact microphones were attached to the iPad controller to use the percussive tapping of the visual performer as another input into the composition.

The sequencer unit triggers the data for the following elements: the frequencies and durations for the enveloped sine tones, the six passing center frequencies and their bandwidth as Q values for the parametric equalization, LFO frequencies for the ring modulation, panning values for the spatialization, and the amplitude of the output sounds. All the values for those sequenced parameters are generated through stochastic processes that are based on four modes of increasing randomness. In *mode* 0, a sequence of values is created through a simple rising motion (which is not random). In *mode* 1, Brownian motion is used, where each following number is either incremented or decremented only slightly from the current number. In *mode* 2, *interpolated* randomness is used, where a random number is averaged with the current number, and thus more closely related to the current number than a purely random number. Finally, in *mode* 3, a non-interpolated, completely random number that is not related to the current value is used. Each parameter is then modified by the value resulting from the current mode. Both *mode* 0 and *mode* 1 are utilized to update the panning amongst the 16 speakers. *mode* 1 is used to update the amplitude, band-pass frequency, and EQ bandwidth. The LFO frequency is updated in *mode* 2. The sequencer runs indefinitely; the duration of the output frequencies are contoured proportionally using a meandering Fibonacci series that creates asymmetrical cycles. The duration of each note is also further adjusted using Brownian randomness (*mode* 1). In using this mode to update the majority of parameters serves to create the perception of naturalistic sounds. The output frequency is updated via a more complex amalgamation of the outputs of all modes, and then passed on to the Bark scaling unit.

The Bark scale is a non-linear frequency scale that was psycho-acoustically designed originally by the acoustics scientist Eberhard Zwicker in order to translate frequencies into values that sound perceptually linear (to human ears). The mapping from an input frequency to a corresponding output value in the Bark scale is governed by the following equation:

$$b = 12\ tan^{-1}(0.00076f) + 3.5\ tan^{-1}(f/7500)^2 \tag{3.10}$$

Here f is an input frequency value and b is the output Bark number. The non-linear frequency response of human ears is described by the concept of critical banding. The width of each of these critical bands remains more or less constant up to 500 Hz, and then jumps by approximately 20 percent thereafter [244]. The Bark scale is a sequence of these critical bands that are discretely enumerated. It is utilized as a compositional tool in order to generate a perceptually linear sweep of pitches and to define an evenly distributed pointillistic texture, and to create a solid mass of sounds.

3.6.2 Multi-modal collaboration research

Annular Genealogy is an innovative interactive composition that invokes a synaesthetic experience by emphasizing the use of synchretic feedback on multiple levels, the physical, the digital, the interconnected, and the human. Physical feedback occurs as multimedia information is put into the performance space and then recaptured by physical sensors. For instance, this happens continuously as the contact microphones reintroduce the output signal as an input signal into the composition engine. Digital feedback occurs internally in the software engines as output data is immediately used to update aspects of the digital heuristics. In the visualization engine, this occurs frame by frame as the previously generated texture is used as the new input texture to be distorted by the fluid vectors. Interconnected feedback occurs when the output data is sent over a wireless network to external software processes. This included the fluid vectors created on the iPad updating the stochastic sequencer running in SuperCollider on the laptop, and the sequencing data influencing the image processing parameters. Human feedback occurs as the performers use their instruments to influence the software, via multi-touch and live coding. The original interactive performance was shown at the *Bits & Pieces* media arts exhibition in Santa Barbara, California. The trickiest part in developing the original composition was to find an appropriate balance of automatically generated composition/visual via feedback and performers input. That is, it took time to find an aesthetic balance between the human and the computational. The iterative generative system can quickly fall into patterns that become either repetitive or overly chaotic. Finding the creative "cusps" teetering between these two extremes was the most rewarding aspect of the performance. While some of the results of interconnecting multiple feedback layers are unpredictable, the performers nonetheless begin to have an intuition as to how their actions will update the overall composition. For example, while there is no direct mapping of how the visualization data will update the compositional structures, after some experience using the iPad interface, it becomes clear that certain gestures during certain kinds of passages generate a particular shaping of the composition. We also found it interesting to re-conceive the performers role as a "guider" of aesthetics, rather than as a creator. A possible direction for future versions of the piece would be to more explicitly highlight the effect that an interaction has as it is transmuted from one medium to the other. Although the focus of the piece has been on interconnecting different feedback loops, one obvious feedback cycle that we did not attended to is the incorporation of the audience as a co-performer. Though adding extra elements to the piece increases the difficulty of maintaining aesthetic balances in the visual and aural domain, a careful integration of audience interaction in future versions of the piece will incorporate audience members as participants rather than as passive viewers.

3.7 Conclusion

In this chapter I explored the various iterations of an research project, *Fluid Automata*, that had both artistic and research outputs. This example was used to show how a single project can evolve through multiple implementations and through the reframing of the original intentions and ideas. These new ideas, I contend, would not have occurred without undertaking this process of implementation. That is, through implementation I was able to generate new research foci as well to see new ways to incorporate the core technology into new art installations.

Although the Fluid Automata Project is not an art-science project per se, the g*eneration* tasks I undertook I believe are useful for collaborative interdisciplinary projects. Ruth West, in her recent paper, "DataRemix: Designing The Datamade Through ArtScience Collaboration," explains her belief that media artists can develop approaches that "complement empirical methods being developed in visualization, information visualization, visual analytics, statistics and machine learning." Specifically, she posits three "meaningful" aspects of artistic practice: "the externalization of intuition"; "the creation and use of metaphor"; and the creative use of modalities that "make the abstract experiential" [227]. While it is clear that many types of art projects involve solving a host of technical and aesthetic problems, it is not as common to think of art projects as generators of worthwhile research questions outside the domain of media arts itself. But in fact art projects are precisely the appropriate location for both generating interesting research questions and exploring the boundaries of the questions, of finding out where known techniques are no longer sufficient and new research must be conducted. In fact, media artists often bounce back and forth between creative exploration and research. The exploration leads the artist to unsolved problems, at which point they must switch gears and solve those problems. Of course, this requires that artists have the knowledge/skills to make these leap. On the one hand, they are intimately engaged with what the issues are. On the other hand, the artist may not have the appropriate skill set or enough time to conduct the research on their own. In the next chapter, I discuss larger collaborative research projects involving myself and interdisciplinary teams of researchers with different expertise, and discuss how one role of media arts is to function as an explicit *mediation* between multiple perspectives and domains.

Chapter 4

Multiple Immersions: Collaborative Tools for Interdisciplinary Research Projects

Design with low thresholds, high ceilings, and wide walls...
– *from* "Creativity Support Tools," Ben Shneiderman [195]

4.1 Introduction

The previous chapters introduce art projects that have foci that parallels research in interaction and visualization, and also describe in detail a hybrid art and research project that explored aesthetic possibilities as well as questions of interaction, simulation, and collaboration. More recently, I have become more focused on working on a range of interdisciplinary projects that involve input from different domain experts and include a focus on design and usability as a component of facilitating research. These include projects with researchers in genetics, in cognitive science, in health informatics, in machine learning, and in natural language processing. In particular, I look in detail at two of these projects, *Natural Materials Browser* and *Augmented Communication Tools*. These two projects do not have a direct artistic focus, although they are still concerned with usability and design issues. In addition to showcasing these projects as examples which highlight the methodological approach of *augmentation* – of enabling research through novel interaction techniques and representational techniques – they also serve to introduce the idea of *mediation*. I believe that the success of these projects was due to having an interdisciplinary perspective that enabled effective communication and workflow. The media arts are advantageous to have in interdisciplinary collaborations because media artists already operate in a hybrid space between disciplines, and they are already adept at bridging different concepts and representations and mediating between different languages. In the sections below, I explore how the methodological themes introduced in this dissertation enable these projects to be more effective.

4.2 The *Natural Materials Browser*

The Natural Materials Browser is a project conceived in collaboration with the materials scientist, Tony Fast [70]. We wanted to find a way to support the Materials Genomic Initiative by making it easy to share volumetric data sets. In particular, we wanted to be able to load in multiple high-resolution material samples to support analysis and comparison tasks. In addition to being able to share data, we wanted to be able to enable materials scientists to conduct statistical analyses of their data. The project first was discussed after Tony Fast saw an installation called *New Dunites*, led by Andres Burbano and Danny Bazo, where I developed volume-rendering software to visualize data from ground-penetrating radar that explored the ruins of the Ten Commandments in dunes in central California [20].

In materials science, the development of new materials with enhanced performance requires a detailed understanding of the internal structure of existing materials to connect the causal relationships between structure and property. Some researchers are interested in discovering how the organization of the internal structure, or microstructure, of natural materials lead to their enhanced structural properties and, subsequently, how to artificially recreate these same conditions. Materials have complex 3D structures and with emerging characterization techniques (e.g. atomic probe microstructure [190], micro-computed tomography [12], serial sectioning [54]) materials scientists are capable of producing detailed volumetric datasets from a breadth of materials systems. Visualizing the 3D structure of materials is complicated due to the wide array of material features (e.g. composition, orientation) whose 3D arrangement directly effects the materials performance. Even in the case of binary phase materials, the topology of the material is rich and complex, as indicated in the data used for this study. These example datasets are generated by micro-computed tomography (micro-CT) of various nutshells – pecan, hazelnut, coconut, and macadamia – with salient phases that are pore and solid. Micro-CT produces voxel-based 3D data with each voxel being described as phase zero or one, pore or solid, respectively. By visualizing the complex pore structure of natural materials, materials scientists hope to understand the source of their exceptional structural properties via both the raw data and subsequent statistical analysis.

The *Natural Materials Browser* is prototype tablet application that aids the materials scientist in the preliminary analysis of volumetric datasets and offers the following benefits: it is low-cost and easy to deploy; it allows the user to view the data from arbitrary angles and positions; it provides multiple visualizations of the volumetric samples; it couples real-time statistics with the visualizations; and it provides a sense of immersion within the data. The *Natural Materials Browser* aims to augment the existing workflow of the materials scientist by providing an easy way to discover structural and statistical properties of material samples. By integrating existing visualization and interaction techniques, our application effectively provides insight about volumetric datasets to materials scientists that would otherwise only be noticed through more extensive investigation.

The main viewport of the application acts as a window that displays a portion of the currently loaded sample. Rotating the tablet updates the view in real-time, and provides a new perspective of the data from a different angle, created via interpolating between the original 2D image slices of micro-CT data. Additional viewports simultaneously provide further information regarding the current view and the sample as a whole, including: a geometrical interpretation created using a mesh of an isosurface of the scalar data, a view of the data using a GPU raycasting technique, and a statistical representation of the data (using autocorrelation). An interactive legend situates the user by highlighting the user's location within the volumetric data. The user can swipe the screen to load in another microstructure dataset, encouraging the user to make comparisons between the different materials. Figure 4.1 shows a screen capture of the tablet application with the statistics viewport, the interactive legend, and the raycasting visualization visible along the bottom part the screen.

A host of visualization techniques exist to aid in reasoning about volumetric data. More general solutions for visualizing material data samples are discussed in [194]. Material science datasets can be visualized with high-end desktop software packages such as Avizo Fire[1] and the Accelrys Materials Studio[2], and with frameworks built using the VTK visualization toolkit [186]. For instance, [240] describes an "image-to-simulation" framework that makes use of multiple visualization techniques to enhance and validate models describing the structure of porous rock. However, in practice the most common methods of preliminary analysis usually involve viewing the raw data as a series of discrete image slices and generating statistical plots for each slice, often independently of each other. The

[1]http://www.vsg3d.com/avizo/fire
[2]http://accelrys.com

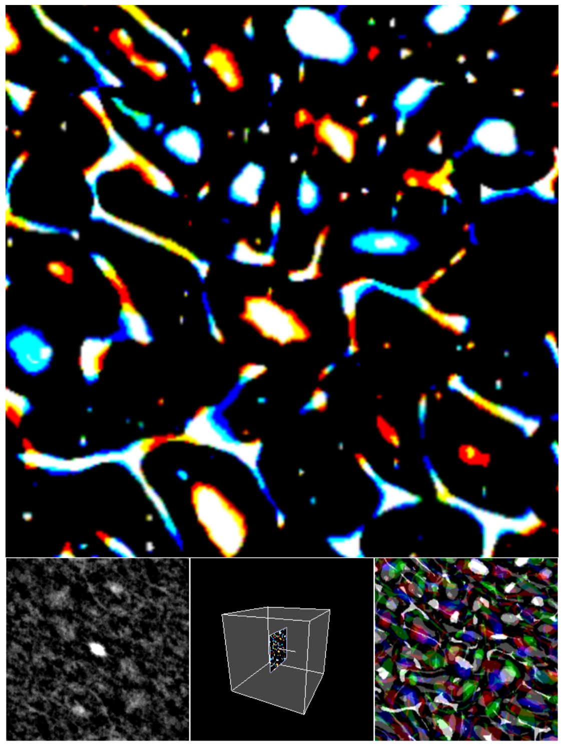

Figure 4.1: A screen capture of the Natural Materials Browser.

main issue with this approach is that the data sample is only viewed from a single direction and decontextualized from the full dataset. Furthermore, the visual inspection of the data is often decoupled from the statistical analysis of the data.

On the other end of spectrum, extensive work has been done on placing volumetric data in virtual reality (VR) environments in order to provide enhanced immersion and greater exploratory possibilities. An early report on the opportunities and challenges in using VR for scientific visualization purposes describes the importance of creating an immersive experience that lets the user to feel as if they are interacting with the data itself, rather than a picture of the data [19]. Another early study attempts to quantify the importance of immersion and concludes that users of VR applications have a better mental frame-of-reference of the data than they would using normal desktop applications [166]. More recently, [121] finds that there are significant benefits to analyzing volumetric data in immersive environments, and moreover concludes that the benefits exist for certain tasks even when only some aspects of immersion are present. [213] provides an overview of different uses of VR environments to aid in scientific understanding and emphasizes the possibilities available via immersive experiences, but also notes the disadvantages in cost and accessibility of using full-scale VR environments. For the basic needs of preliminary data analysis, full scale VR techniques may be impractical, requiring extensive preparations and expensive equipment. To that end, [35] describes a low-cost VR project that uses a multitouch table to interrogate volumetric data that is shown on a stereographic display.

The application forgoes some aspects of common VR elements, such as stereographic rendering and head tracking, but nonetheless aims to create a sense of immersion within a virtual environment. Using the gyroscope and multitouch sensors on the tablet computer, it simulates the movement of the user through the volumetric dataset. In some sense, our application is an untethered version of earlier projects that use a palmtop or mounted displays on a mechanical arm to navigate "3D-situated information space" [199, 65]. Although there is conflicting evidence in the literature regarding the importance of accurately tracking motion for effective immersion (cf. [180, 181]), a recent paper concludes that "allowing for full-body rotations without actual walking can provide considerable performance benefits, even for complex and cognitively demanding navigation tasks" [175]. Magic lens interfaces are frequently used in volume visualization tasks. For instance, [174] describes an application that uses a magic lens interface as a virtual "flashlight," highlighting fiber tracts in volumetric medical imagery. Another recent paper compares mouse interaction with gesture-based magic lens interaction and finds that magic lens interaction outperforms mouse interaction in time and accuracy for orientation matching tasks [116]. Our application provides a low-cost mechanism that helps users build an effective mental model of the 3D dataset through the use of a magic lens interface and full-body rotation gestures.

Figure 4.2: A user changes his vantage point of the currently loaded dataset by physically rotating inside the virtual space.

4.2.1 Elements of the *Natural Materials Browser*

The main interaction metaphor of the Natural Materials Browser involves placing the user within the meso-scale volumetric data sample and enabling the user to freely investigate qualities of the microstructure via physical rotation and multitouch gestures. Using the tablet device as a "magic lens," the user rotates within the surrounding data to change his or her perspective and uses a multitouch gesture (pinching) to move forward or backward along the current viewing angle. (Figure 4.2 shows an example of a user navigating the virtual volume using the iPad.) Other visualization modules are placed in additional viewports to display different interpretations of the data, including a spatial statistics analysis. These viewports are also updated in real-time, providing a synergistic experience of the virtualized data. The user can also quickly load in other datasets, which has the potential to aid comparative investigations of different materials (or different samples of the same material). The *Natural Materials Browser* was developed for a third-generation iPad device using a custom C++ framework and custom OpenGL ES 2.0 shader programs. The example datasets used for development and testing are each 512^3 voxels.

4.2.1.1 Interpolated Viewports

Despite the richness of 3D material science datasets, their visualization is often restricted to a single reference frame oriented in a single direction. That is, the material is primarily visualized as a collection of orthogonal 2D slices. This approach to visualization restricts the scope of the data that can be visualized while providing an incomplete engagement with the data. The main viewport of the *Natural Materials Browser* instead displays the interpolated slice across the 3D volume at a particular position and orientation, created in real-time as the user repositions and interacts with the tablet. The coloring of the main viewport is based on sampling the data at three points per pixel: the intersection of the viewing slice with the material (green), and two points orthogonal to the viewing slice, one slightly behind (red) and one slightly in front of (blue). This coloring gives an indication of the structure of the material at the current viewing slice, and also how particular fibers change (i.e., shrink, expand, and/or twist off in different angles) as the user moves forward and backward along the current direction (using the pinching gesture). Since the OpenGL ES 2.0 specifications does not enable the use of 3D textures, the application uses a custom GLSL shader program that stitches together a 3D volume out of a series of 2D images. A second viewport functions as a legend, orienting the user by indicating the current viewing slice within the bounding box of the full dataset. The user can rotate the legend independently, without changing the current view, in order to see their position more clearly (which might be necessary, for instance, when the current slice is nearly perpendicular to the viewer, and thus hard to see).

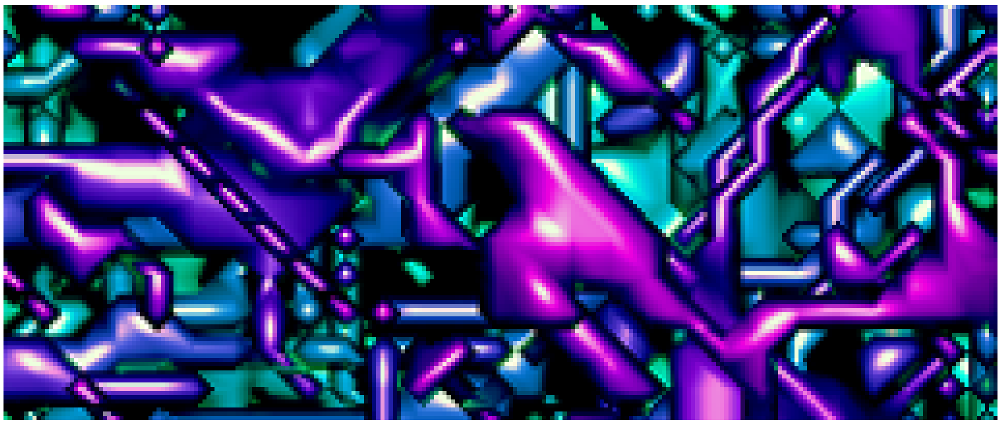

Figure 4.3: A detail of the isosurfaces viewport when the *hazelnut* sample is loaded.

The *Natural Materials Browser* has a modular design that allows for the inclusion of other visualizations created using the same interpolated data. In our prototype, the user can select either an isosurface visualization or a raycasting visualization (in the lower right hand viewport of the application). The former uses a geometric mesh created by generating an isosurface from the data. The application uses a simple Phong shading with multiple light sources and color interpolation (where each colored light is mapped to a particular corner of the volumetric cube) in order to accentuate depth cues and highlight structural density. Currently, different colored lights are placed surrounding the different corners of the “virtual specimen” with the assumption that the different colors will help orient the user as they rotate the interface. The latter uses a raycasting technique (similar to the volume rendering method described in [36]) in order to emphasize the structure of the material along a greater distance range. Volume rendering techniques generally use a transfer function to indicate the color of particular densities at different colors. However, since the micro-CT data for the nutshell microstructures sets have only binary density, a rainbow color map is used to indicate depth. In particular, structures that intersect the current viewing plane are given a white color, but structures that do not are instead given RGB coloring (where red indicates closeness and blue indicates distance). Opacity is used to indicate the density of structures along the viewing ray. Future versions will give users more control over lighting and coloring parameters. Figure 4.3 shows a detail of the isosurfaces viewport; Figure 4.4 and the lower right hand section of Figure 4.1 show the raycasting viewport.

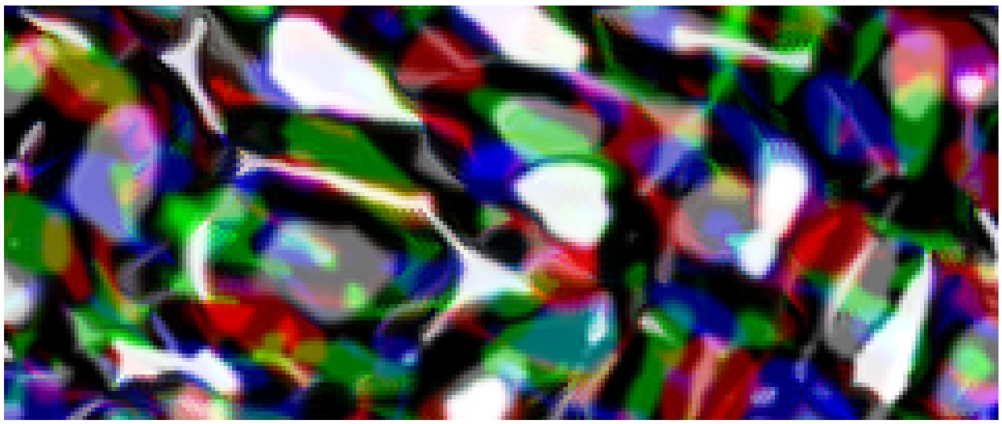

Figure 4.4: A detail of the raycasting render on a current viewing slice.

4.2.1.2 Statistical Interpretation

Effective statistical metrics (e.g., volume fraction, surface area) of the materials structure are the most prominent statistical descriptors used throughout the materials science community. However, these metrics fail to provide any information about the complex 3D topology of the material. In an effort to best leverage the information contained within rich, costly volumetric datasets, a growing portion of the materials science community is beginning to employ the use of cross-correlation statistics as material descriptors [80, 158, 109]. These metrics provide a statistical quantification of the material topology, and furthermore, they may encompass the more commonly used, effective statistical metrics (which are often a subset of the cross-correlation statistics).

The cross-correlation function quantifies the probability of certain material features existing at the head and tail of a vector within a particular realization of the volumetric data. As an example, the cross-correlation of pore voxels and void voxels for a given vector indicates the probability of finding a pore voxel at the head and a void voxel at the tail of said vector. A special case of the cross-correlation is the autocorrelation, which interrogates the probability of finding like phases at the head and the tail of vector (pore-pore correlations or void-void correlations). The autocorrelation function is the collection of all vectors possible in the volumetric domain; it is a convolution between two volumetric images that, with the assistance of the GPU, can be computed in real-time.

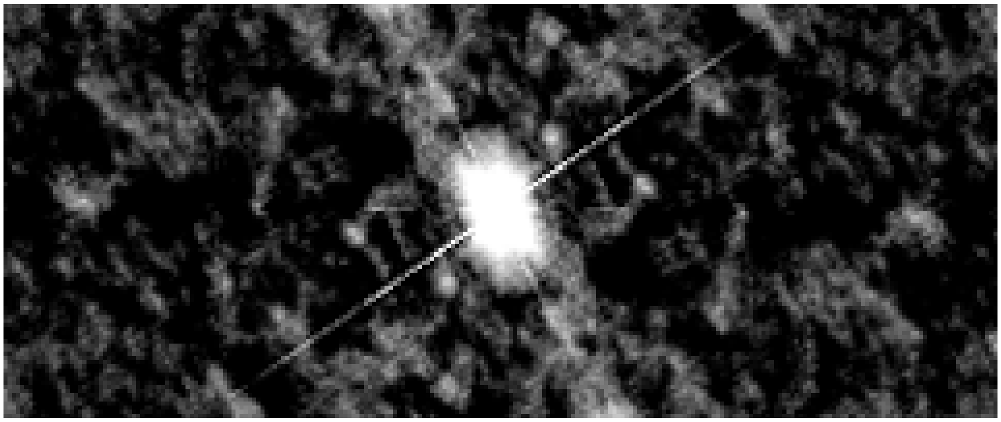

Figure 4.5: A detail of the statistics viewport showing a visualization of the autocorrelation function on a current viewing slice.

Correlation functions have proved valuable in a breadth of materials science problems, including image reconstruction [80], collation of datasets [109], and evaluating structure uncertainty [158]. Visualizing the statistics also allows one to readily notice anisotropic properties in the structure that may be missed if only viewing the image itself. Despite these efforts and benefits, the use of spatial statistics in materials science is still not commonplace, and providing a tool for real-time visualization of correlation functions will assist in its acceptance and application amongst the materials science community. Figure 4.5 shows a detail of the representation of the autocorrelation function.

4.2.2 Evaluation of the *Natural Materials Browser*

The prototype application was evaluated via running cognitive walkthroughs with ten domain scientists. These domain scientists included five professors at three different universities and five post-docs at two different universities. The easy-to-deploy nature of the browser greatly helped the evaluation process and accessibility across different institutions. Since these scientists regularly examine and conduct statistical analyses of volumetric data, it was important to solicit their feedback on the application while they performed various preliminary data analysis tasks, such as identifying interesting aspects of the materials and deciding whether or not the samples warranted more detailed investigation. Tony Fast and I were mainly interested in determining the potential value of introducing the application as another element within the workflow of a materials scientist, rather than in the detailed measuring of the individual effectiveness of particular techniques. That being said, we were also interested in observing the responses to various specific interaction and visualization aspects of the application, such as: whether or not the ability to navigate through an interpolated view of the data (via physical rotation and multitouch gestures) would be useful or distracting; if the real-time statistics viewport was a useful supplement for understanding cross-correlation functions; if the alternative views (raycasting and isosurfaces) provided any insights about the data; and if the simultaneous display of the the multiple viewports was beneficial. Our cognitive walkthroughs were led by one of the authors (who is himself a materials scientist) well-aware of the general strategies used by scientists to familiarize themselves with a material dataset. He began by giving a brief demonstration of the *Natural Material Browser*, and then allowing the subject to interact with the application on his or her own. This was followed by specific, neutrally-phrased questions about various aspects of the application as well as more open-ended questions that allowed the subject to comment on any aspect of the application or to discuss aspects of his or her current and/or ideal workflow when first encountering a new materials science dataset.

Each of the domain experts indicated that they found the *Natural Materials Browser* to be a promising tool for investigating materials data. They were particularly intrigued by the idea of easily viewing volumetric data at arbitrary viewing angles. Overall, they also found the simultaneous viewports to be valuable in communicating the idea of correlation when seen directly alongside the corresponding interpolated view of the raw data. Similarly, the users became clearly aware of some qualitative features of the data from the statistics, such as the preferential orientation of pores when the material is looked at in different viewing planes. That is, simply by rotating the iPad around the virtual specimen, properties of the data were displayed that otherwise would have only been noticed with more extensive analysis. Some subjects questioned the value of the raycasting and isosurfaces visualizations and were initially confused by the color mapping. At the same time, some of the subjects recognized the potential usefulness of incorporating additional viewport modules. Future version of the Natural Material Browser will provide alternate visualization and quantification tools. In our sessions with the materials scientists we also discussed issues of ergonomics, such as the potential for fatigue that might occur from full-body rotations during extended use of the application and whether or not it was awkward to use one hand to hold the tablet while the other hand was interacting with or pinching the tablet. Since the application is envisioned as a "browser" – a first pass that provides enhanced initial information about the statistics and anisotropy to indicate intriguing aspects of the materials data – materials scientists will not necessarily use the tablet for a long period of time, but rather take the information they have gathered from our application to conduct further analysis on a more powerful workstation. That is, the application will not replace any component of the materials scientist's workflow, but rather will augment the workflow by providing a helpful initial overview of the data.

The Natural Materials Browser is an immersive, interactive, real-time tablet application with multiple viewports for the simultaneous visualization and statistical analysis of a volumetric dataset that augments the workflow of the materials scientist. While the initial feedback from domain scientists is encouraging, further work on evaluating the efficacy of the immersive aspects of the application needs to be carried out. In particular, we plan to carry out a more rigorous comparison with an implementation that does not require physical rotation (e.g., rotating the data using a mouse or virtual trackball). Furthermore, we would like to extend the modularity of the application so that a wider range of visualization and analysis techniques could be selected as needed for particular datasets. One initial design goal of the application was to facilitate comparisons between datasets, and while the user currently is able to switch between the pre-loaded datasets, no direct methods for visualizing differences is available. In part, this is a limitation of the screen size of the iPad. A future goal is to investigate ways in which the *Natural Materials Browser* could be used to interact with a full-scale VR system featuring larger stereographic displays that could be more appropriate for comparative tasks. Finally, based on the feedback from our discussion with the expert users during our evaluation, we also plan to explore the effectiveness of different coloring schemes for the main viewport as well the visualization modules.

Materials science is a largely collaborative field that requires the varied skills of many experts to design and deploy new materials. These efforts often generate large collections of datasets. Facilitating the transfer of this data amongst collaborative materials science efforts stands at the forefront of national directorates, such as the Materials Genome Initiative [206], which aims to create the cyberinfrastructure capable of this data distribution. The *Natural Materials Browser* provides a low-cost, readily available tool for analyzing materials science data, and could be extended to enable end-users connected within a workgroup in the cyberinfrastructure to visualize, annotate, share, and discuss data in a progressive, collaborative manner.

The Natural Materials Browser is an example of a project that was created out of media arts focus on novelty of representation and interaction, but that was only able to be realized in collaboration with a domain expert in materials science. While the project clearly serves to augment the existing workflow of a material scientist, we hope that by making it easier to download and compare datasets, and then to statistically analyze them, that it will generate new research ideas for the materials scientist as well. Although I have not explored this in depth, I believe that the materials datasets could generate an artistic output as well, as they introduce a range of naturalistic, meso-scale patterns and structure not otherwise available to be observed or represented.

A first step in working with someone in a different field is understanding their language. To develop the Natural Materials Browser, I worked closely with Tony Fast, and had to learn basic tenets of materials science, as well as specific aspects of his current areas of research. Likewise, I had to explain some of the possibilities and limitations of the iPad platform that we were using to develop the application. The Natural Materials Browser is an example of an interdisciplinary project well served by the methodological themes and their associated tasks. However, both Tony Fast and I were computationally savvy and both interested in visualization. I believe that projects between participants who have less similar perspectives are a better case study for these methodological themes, especially the theme of mediation. When multiple people are involved, as in the Augmented Communication Tools project, described next, the issue of communication becomes even more important. In addition to having to learn enough about health informatics and natural language processing, I found that another skill that was helpful to the success of the project (and writing the grant) was being able to serve as a kind of *mediator*, or translator, between domain experts.

4.3 *Augmented Communication Tools*

Another ongoing project also involves collaboration with domain-experts from different fields. I am currently a co-PI on a grant with a data scientist focused on natural language processing (NLP) and a nursing professor concerned with issues in health informatics. Our project, *Augmented Communication Tools*, seeks to improve methods of communication between nurses. Specifically, we are developing a machine learning system for automatically identifying high-risk clinical events and presenting this information with novel visualization tools to more effectively transmit knowledge between the nurses [78].

The introduction and subsequent adoption of the Electronic Health Record (hereafter, EHR) is a step forward in automating data collection useful in the analysis of patient health and prevention of adverse health events [31]. However, unintended consequences mitigate the effectiveness of the EHR [29, 92, 203]. Most problematically, nurses alternately taking care of a patient are unable to effectively sift through the large amount of data available via the EHR in order to find pertinent information. Studies of nurse behavior has found that many nurses make an effort to talk to each other face-to-face as they change shifts [27]. Ideally, these face-to-face conversations provide a way for the *responding* nurse (leaving the current shift) to explain his or her interpretation of the patient's well being to the *receiving* nurse (starting the next shift). The absence of this dialog may account for an alarming number of miscommunications that have lead to catastrophic events in patient health [203]. For instance, a report by the Institute of Medicine [117] finds that up to 98,000 patients die per year as a result of complications of therapy due to ineffective communication and, moreover, that errors in communication cost US hospitals an estimated $12 billion annually [56]. Although providing verbal summarizations of patient health during in the hand-off between responding and receiving nurses can be helpful, these summarizations can themselves be misinterpreted or ignored [28].

The Augmented Communication Tools project involves the development of an interactive visualization system that augments EHRs to improve nurse-to-nurse communication. Our system uses a novel application of machine learning and natural language processing techniques to generate a series of potential *clinical events* [156] and, furthermore, can offer reasons why these events are plausible based on an analysis of: the vital signs recorded in the EHR; the verbal "hand-off" summary of patient health made by the responding nurse; and historical EHR data of patients that had unexpected adverse clinical events. In particular, we look at data related to six categories of clinical events that are most likely to be a precursor to unexpected patient death: uncontrolled pain, sudden fever, bleeding, changes in respiratory status, changes in level of consciousness, and changes in output. We further describe a novel, interactive shift-summarization visualization tool that provides: 1) the automatic proposal and notification of these potentially adverse clinical events; 2) a way for nurses to verify the likelihood of these events; 3) a mechanism for annotating the automatic proposals and for allowing the nurse to propose their own events; 4) and finally, an interactive tool that lets the responding nurse associate vital signs as they evolve over time with an overview narrative, making it easier to indicate highly pertinent data to the receiving nurse. In effect, our system aims to replicate, to some extent, aspects of face-to-face nurse communication that may have been lost through the introduction of EHRs, and to formalize the verbal summarization that some nurses have improvised. That is, our visualization system aims to make it easy for nurses to create, transmit, and verify narratives about patient health that augment their expert knowledge for improved decision making.

Both the development of a computational model to predict clinical events and the creation of interactive visualization tools based upon this model make use of data gathered from real-world scenarios where EHRs are used by nurses in making decisions regarding patient treatment. Currently, we have extensively annotated data generated through interviews with 37 nurses using EHRs who oversaw patients who died unexpectedly, and we are streamlining the interviewing process in order to gather 100 more samples of nurse (mis)communication [57]. Although this work is ongoing, it brings together interdisciplinary expertise in health informatics, machine learning, and text analytics with the aim of creating an effective interactive visualization tool with the potential to save lives.

4.3.1 Generating and Explaining Clinical Events

The computational modeling component of our visualization is divided into four interrelated modules, each making use of information available in the EHR and/or the transcriptions of verbal summarizations, or "hand-off" reports, created by the responding nurse. The first two models provide a detection facility for clinical events, as well as a probabilistic outcome prediction mechanism to determine the relative likelihood of an undesired outcome given the detection of a clinical event. To make certain that the hand-off report is properly connected with the EHR data, a third model grounds the narrative of the hand-off report with vital sign measurements in the EHR. These links between the two content modalities are further exploited in the fourth model, which generates an automated summary of the hand-off report, highlighting information that is predictive of a negative patient outcome.

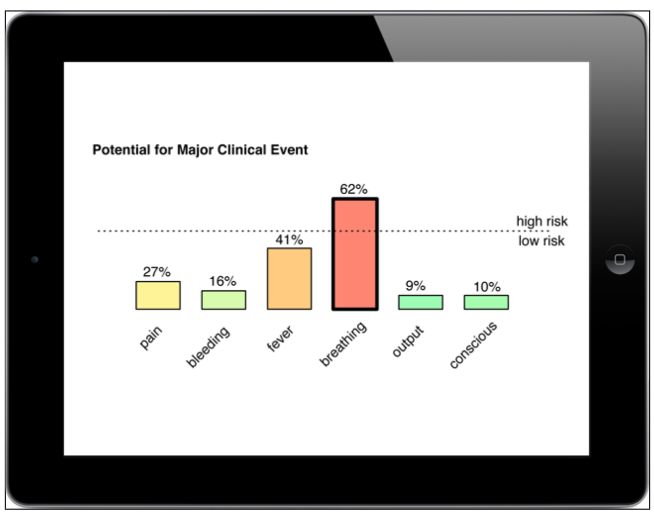

Figure 4.6: A prototype of the overview page of our shift-summarization tool. At the top we see a simple bar chart indicating high-risk clinical events (determined through an evaluation of historical EHR data). At the bottom we see a list of events generated by our system (based on expert rules), alongside related textual snippets from the nurse's "hand-off" report.

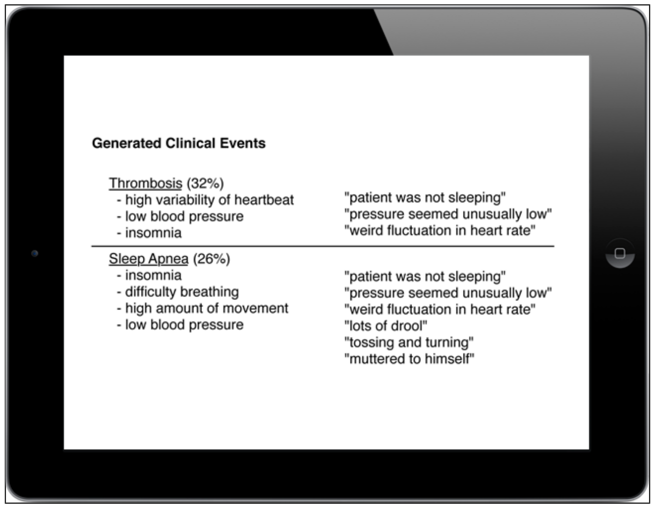

Figure 4.7: A prototype of the overview page of our shift-summarization tool. At the top we see a simple bar chart indicating high-risk clinical events (determined through an evaluation of historical EHR data). At the bottom we see a list of events generated by our system (based on expert rules), alongside related textual snippets from the nurse's "hand-off" report.

4.3.2 Visualization Tools for EHRs

The existing design of EHRs are graphically cluttered and parsing patient data can be cognitively-taxing, even for experts [224]. Moreover, in the attempt to provide information about all possible indicators of clinical events, ironically, the most relevant and potentially life-threatening of these can be obfuscated [28]. While previous work has explored different approaches to visualizing and managing the complexity of EHRs, for example [3, 169], our shift-summarization tool provides enhancements to EHRs to improve nurse comprehension of and communication about patient data that is related in particular to signals of a sudden and unexpected change in patient condition. The primary components of our visualization enhancements are based directly on the data generated by the computational models: the alignment between EHR data and the responding nurse's verbal summarization of the events during the shift; a series of generated explanations as to why these events happened; and an overview likelihood, based on historical data, of whether or not these generated events could lead to adverse changes in patient condition. Additionally, we incorporate temporal aspects of the EHR data in order to augment the receiving nurse's decision making when verifying the recommendations produced by the data analysis module.

Specifically, our visualization enhancements provide: a way to *notify* nurses about high-risk situations; detailed information that nurses can use to *verify* these notifications; a way for nurses to meaningfully *annotate* their interpretation of the patient health in relation to inferred clinical events; and finally, a system that encourages a nurse to link annotations to temporal data in order to *narrate* the overall story of how the patient's health evolved over the course of a shift. Each enhancement builds on the previous, adding functionality that increases the effective transfer of pertinent information between nurses when using EHRs. We are implementing the prototype of our shift summarization tool on an iPad tablet, but expect also to port it to desktop environments or other mobile devices.

4.3.2.1 Enhancement 1: Shift Summarization (Notify and verify)

Our primary enhancement clearly presents the results of our computational analysis. All six of the major clinical events are listed, and high-likelihood events (as determined via a historical analysis of the EHRs of patients who suffered these events) are highlighted. The receiving nurse is thus, at a glance, informed as to whether or not the patient is in imminent danger.

In addition to this high-level overview specific to the major clinical events, we also generate a list of other inferred clinical events that occurred during the shift and provide the evidence as to why they were inferred. That is, for each of the generated clinical events, we link to the EHR monitoring data or the transcription of the nurse's verbal summarization that led our system to conclude that the event occurred.

Explicitly presenting data that shows the logic behind the computational inference functions both as a way to create trust in the system, as has been shown in research on (or implemented in) recommendation systems, such as [34, 41, 77, 172, 197], and also provides a starting point for verifying or invalidating the automatic notifications, which could be especially important in the case of false alarms. A third component of this first enhancement is to provide an interface for browsing the alignment between EHR data and text. This enables the nurses to verify results of our automated system easily, and also to search freely for patient-specific information that could bolster or invalidate the automated recommendations. Figures 4.6 and 4.7 show a prototype of this enhancement. At the top we see a simple bar chart indicating high-risk clinical events. At the bottom we see a list of events generated by our system, alongside related textual snippets from the nurse's hand-off report. Figure 4.8 shows an example of how a nurse selecting a particular explanation for a generated clinical event can instantly see more detail about the aligned text and EHR vital signs that lead our system to present this explanation.

4.3.2.2 Enhancement 2: Issue Tracking the EHR (Annotate)

This enhancement aims to promote dialog between the nurses, to foster engagement with relevant information about patient health, and to provide accountability for the nurses caring for the patient.

The generated clinical events are essentially an *interpretation* of the raw data and the nurse's verbal summary of the shift. Moreover, the alignment process between the EHR data and the verbal summary is also based on encoded *assumptions*. We provide a system for the nurses to agree or disagree with the automatically generated clinical events and to annotate them with additional pertinent information. The annotations are in the form of a predefined comment– such as "agree", "disagree", or "inconclusive"– and, optionally, space is available for further detailed commentary. By providing a mechanism that operates, essentially, as an issue-tracker, nurses have an opportunity to create and respond to forums about particular events that may be important to the patient's health. In issue-tracking software or websites used for software projects (e.g., GitHub[3] or Google Code[4]), this type of commentary is used to build consensus on interpretation, to expedite decision making, and to facilitate conversation [11]. By requiring the nurses to annotate each of the generated events as well providing the ability to define their own, we instantly create a focused dialog about the relevant issues regarding the health of the patient. Furthermore, this mechanism creates a trail of accountability, as the nurse can explicitly explain their reasons for disregarding an event, or modify the reasoning behind why the event occurred.

The enhancement is split into two related components, one for the responding nurse and the other for the receiving nurse. First, we allow the responding nurse to evaluate the shift summarization created by Enhancement 1. In particular, we allow the nurse to annotate the generated events, either with predefined terms, or with a more detailed textual explanation. Thus the receiving nurse has more information regarding consensus between the automated interpretation and the nurse's interpretation of events in the shift. Second, we similarly provide a space to indicate agreement or disagreement with generated events and allow the receiving nurse to indicate that he or she has read and the responding nurse's annotations as well as space to provide additional commentary.

4.3.2.3 Enhancement 3: Telling a story via temporal data (Narrate)

This enhancement extends the annotation mechanisms described in Enhancement 2, allowing the responding nurse to link their interpretation of the patient's health

[3]https://github.com

[4]http://code.google.com

to particular events in time. That is, we allow the responding nurse to create a *curated timeline* of the patient's health as it evolved over the course of the previous shift. The receiving nurse can then use this temporally-contextualized data to augment his or her decision making process during the current shift. Previous research has investigated visual information seeking over temporal data across multiple EHRs [6, 176, 223, 224]. Our project emphasizes the temporal aspects of the patient data over the course of a single shift. This enhancement allows the responding nurse to browse the generated events and annotations along with the temporal EHR data (e.g. the "flow sheet") and then to create a visual narrative of how the nurse reasons about the possibility of clinical events. Narratives are made up of pertinent, sequential events, and providing a system that allows the nurse to explain the events of the shift in a narrative format attempts to replace an important aspect of face-to-face communication that is otherwise lost in the hand-off. Figure 4.9 shows a sketch of the proposed enhancement in which an annotated timeline is associated with potential clinical events. The circles indicate highlighted raw vital signs from an EHR flow sheet that led the responding nurse to make a comment.

4.3.3 Evaluation Methods and Considerations

Our shift-summarization tool aims to clearly represent the automated interpretation of patient data as well as the sentiment of the responding nurse and, second, to ensure that the receiving nurses trust the representation sufficiently to incorporate it into their decision making. Our system is meant to *augment* (and not replace) nurses' expert skills, and our evaluation is aimed not only at justifying appropriate visualization methods but also to measure the effectiveness of their integration into current practices.

The two main contributions throughout these enhancements are a) clearly representing the results generated by our computational models, and b) providing an interactive interface with which to support rapid exploration of EHR data. We hypothesize that each additional enhancement provides increasingly more effective communication leading to more accurate diagnoses of at-risk patients. We further hypothesize that our system increases the nurses' ability reason about salient information, while simultaneously reducing the amount of time they spend filtering out irrelevant data. To test these hypotheses we plan to run user-studies with nursing students and practicing nurses. These user studies will examine whether an expert using the proposed enhancements performs better than the automated system alone. We are also concerned about the level of trust an expert might have in the automated system and also with the amount of time it takes to use the enhancements. Obviously if there is no trust in the system or if it causes an undue

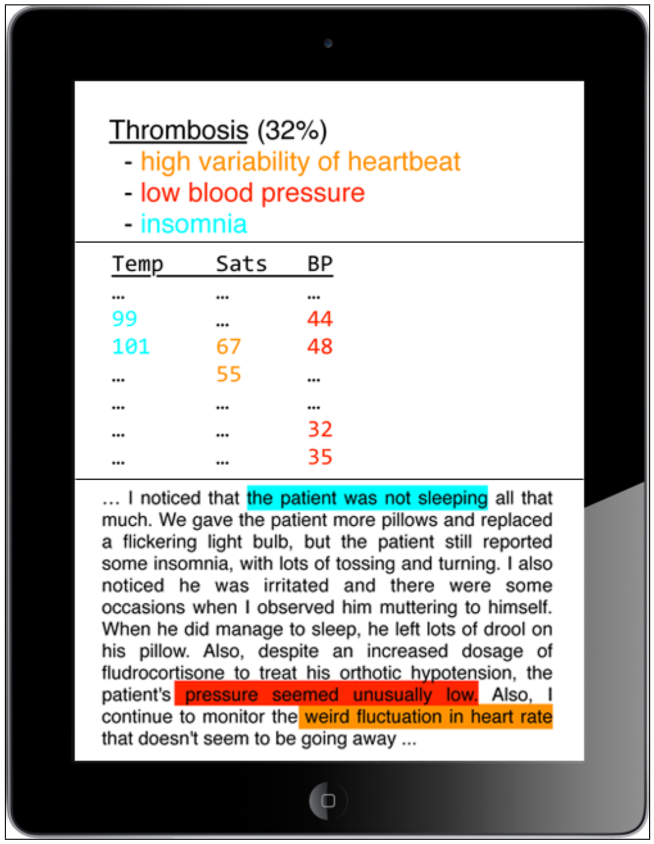

Figure 4.8: An example of how a nurse selecting a particular explanation for a generated clinical event can instantly see more detail about the aligned text and EHR vital signs that lead our system to present this explanation.

burden, then nurses will be less likely to use the visualization tools in real-world situations. Thus, in addition to the user-studies, we will also conduct cognitive walkthroughs in order ascertain the ease of use and potential rate of adoption of the tools. As discussed in [155] and [195], the iterative design of information visualization tools based on detailed feedback from cognitive walkthroughs with domain experts can be an effective way to create systems that will be useful in real-world environments.

While our initial results indicate the effectiveness of the relatively straightforward mapping of our automatically generated clinical events to visual alerts, we need to more thoroughly evaluate whether the additional enhancements are worthwhile. Our hope is that the integration of heterogenous patient data coupled with novel visualization tools will be an effective way to transmit a narrative of patient health. Indeed, whether or not this narrative is perfectly accurate, it

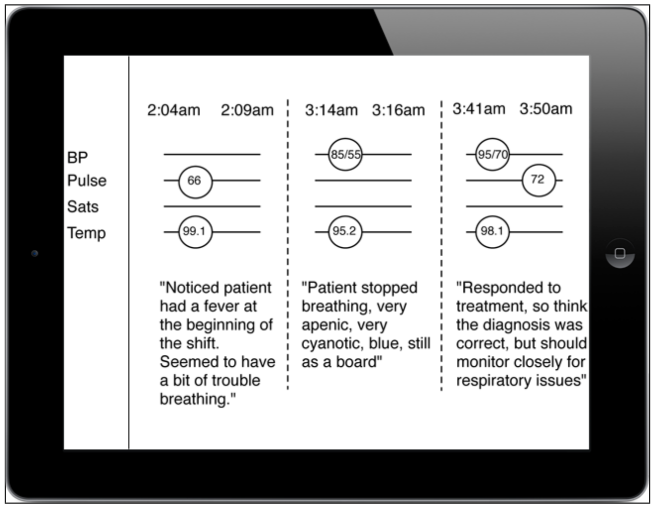

Figure 4.9: An annotated timeline that helps to *tell a story* by relating pertinent points of data on particular vital sign streams to nurse interpretation.

should adequately engage with and highlight the most relevant patient data so that another domain expert (i.e., the receiving nurse) can quickly validate (or invalidate) it and thereby become aware of potential patient risk. Finally, we hope that this additional level of annotation (via the creation of the narrative and its validation) itself becomes data that can be taken advantage of in future analyses that promote accurate interpretation of and communication about patient health.

4.3.4 Interdisciplinary Methodological Considerations

The Augmented Communication Tools project would not exist without interdisciplinary collaboration between researchers with expertise in the fields of health informatics, natural language processing, and interactive visualization. Although I was initially brought into the project to help design the interface– what possibly was considered a secondary concern of the project– through engaging with the methodological approaches outlined in Chapter 1, I was able to extend the aim of the project while enhancing the effectiveness of my participation in the project. Moreover, this project is allowing me to engage in fundamental research in information visualization, even as it serves as an application of existing design principles.

The initial reason I was brought into the project was to augment the design of tools to support effective integration of EHRs into nurse communication. I designed a straightforward visual system that would alert nurses as the results of the machine learning model which classifies patients according to their risk for certain outcomes. However, through a series of *provocations*, pointed questions aimed to tease out assumptions or flaws in reasoning, we realized that a straightforward representation of the machine learning recommendations would be problematic. Although we are convinced that the project, once complete, will be superior to current EHR tools, a central part of this project arose out of thinking about why previous attempts with automated systems have been less successful than expected. Through challenging some of our assumptions, we came to realize that we were making flawed assumptions regarding the ability of our system to fully automate the decision-making powers and expertise of nurses. Through asking a series of questions about real-world use cases, we recognized that a better approach would to create a system that allowed the nurses to guide the decision making process themselves. We also realized that if the nurses did not trust the system enough to incorporate it into their workflow then it would not matter how accurate our system was at predicting patient outcomes.

An upshot of changing this focus was that the interface design, rather than straightforwardly representing the results of the machine learning system, became an integral component of the system. Instead of visualizing results, the interactive system lets the nurse navigate the underlying *model* of the ML system and to understand why it offers particular suggestions. Ideally, since our system has access to a large amount of historical patient data and also transcripts of nurse communication, our system would normally make it clear to the nurse why a decision was made. However, in many cases, the classification model would not capture the reasoning of an experienced nurse, and in that case, the nurse would still learn *how* their opinion diverged from the expected conclusion. And, moreover, the nurse would be able to input that data back into the system, improving the underlying model for future use. This idea of using the information visualization system to visualize, explain, and enhance machine learning models for more effective communication and analytics is, I believe, an exciting area for future research, and one that only emerged, or was generated, through the process of designing the system. I expect that during the process of implementation and testing the system further research avenues will also arise.

In the case of this project, the interface itself serves as a kind of mediation both between the nurses and the automated system, and also between a nurse and the other nurses taking care of the same patient. On a more practical, day-to-day level, I often found myself working as a kind of a translator, summarizing the technical details of the machine learning system to the nursing professor who was less knowledgable about many aspects of computer science. I also was able to quickly understand what the nursing professor expected from the system, even when it was not initially clearly presented. I believe this ability to translate between different fields and to assist in the communication within a project stems directly from my experience as a media artist, used to working with novel, complex, or disparate information across disciplines on a regular basis. Two of the main tasks of mediation in collaborating include: summarization, or making sure that my understanding of the situation is accurate; and question asking, or asking questions that lead to simplifying a situation, rather than opening up the situation. This kind of question asking is of a different nature than the questioning task that is associated with provocation. Rather than using questions to expand the space of exploration, it instead served to focus our attention on particular issues and to prioritize the efforts of those involved in the project.

Chapter 5

Conclusion & Future Directions

5.1 Summary of Contributions

A primary motivation for this dissertation was the recognition that the roles of media artists need to be more clearly defined and recognized as important to effective interdisciplinary projects, including those that engage in foundational research. As explored in the preceding chapters, I believe that media arts implementations directly enable research in a variety of ways. Successful implementations are not just ornamental (although they can be); instead they promote new research. Furthermore, media arts activities can directly support (and are not antithetical to) scientific methodologies. I also believe that provocation has an important place even in non-arts focused projects. By pointing out blind spots and by questioning assumptions, media artists also help expand the range of effective research and help make connection foundational research to cultural considerations. Furthermore, I contend that *mediation* is an important component of media arts activities and that mediation tasks contributed to by media artists are integral to art-science projects involving domain experts from multiple disciplines. Below I recapitulate the main content of the preceding chapters and list how they support these points.

In Chapter 1, I explored the roles and methodological approaches of media arts practitioners as currently (and conflictingly) defined by a range of media artists and media arts engineers. I showed how much of the literature about the media arts presents approaches that are not always effective for media arts practitioners working in collaborative interdisciplinary research, or art-science, projects. I then presented a new methodological framework that included a range of tasks more effective for these kinds of collaborative research projects.

In Chapter 2, I examined a series of multimedia art installations that I helped to create, either as a collaborator or as the primary author, including Cell Tango, Data Flow, and Information Poems. I made the argument that media arts projects, even those with solely artistic outputs, are engaged, at least informally, with a range of research topics. Specifically, I looked at projects that explored research in computer vision, information retrieval, visualization, interaction, natural language processing, among other topics. A main point of this chapter was to show that media arts projects, although seen as taking from existing research, could easily be seen as producing research. In particular, I discussed tenets of scientific methodologies and showed that media arts methodologies are not, as is commonly thought, in opposition to scientific research, and pointed to ways in which media arts projects could support these methodologies.

In Chapter 3, I introduced the media arts projects, Fluid Automata and Annular Genealogy, that were intended to have both artistic and research outputs. I showed that, through a series of implementations and revisions, media arts project can function to generate new research questions, and similarly, that implementations of research can be used to generate new artistic concepts.

In Chapter 4, I introduced a series of ongoing interdisciplinary research projects, including the Natural Material Browser and Augmented Communication Tools, that involved domain experts from multiple disciplines. The methodological themes discovered through my own work (in Chapters 2 and 3) and coalesced via my research in Chapter 1 was shown to be useful in a wide variety of situations.

In this final chapter, I summarize the specific contributions of the dissertation, make recommendations for media arts practitioners interested in working in art-science collaborations, and point to future directions for research in effective methodologies for media arts practitioners. Finally, I discuss the IEEE VIS Arts Program that I co-chaired in 2013 (and will chair again in 2014) and introduce current areas of active research in the field of visualization that are related to the concerns of this dissertation.

This dissertation has presented the following main contributions: a comprehensive literature review of media arts roles, methodological approaches and specific research methods; a methodological framework and specific tasks associated with the framework that enable media arts practitioners to more effectively engage in interdisciplinary projects; description of the methodological themes, augmentation, generation, provocation, and mediation; examples of media arts projects whose artistic output is related to research in a variety of different areas; case studies where methodological approaches were instrumental in the development of effective interdisciplinary project; and the articulation of new areas of media

Main Contributions of the Dissertation
Chapter 1 1. Summarized methodological approaches in the literature of media arts. 2. Summarized roles of media artists from the literature of media arts. 3. Discussed how these themes and roles are incomplete, personal, and contradictory. 4. Synthesized new descriptions of media arts activities.
Chapter 2 1. Showed that arts projects share concerns of research projects. 2. Showed that arts projects can be more than ornamental, aesthetic, or conceptual. 3. Indicated that media artists could contextualize their work in terms of the research that they parallel. 4. Showed that media art-making can generate new areas of inquiry. 5. Showed how media arts methodologies can directly support scientific methodologies.
Chapter 3 1. Presented a media arts project that had outputs in arts and research. 2. Showed how media arts projects delineate new areas of research. 3. Explored how media arts projects offer new insight into collaboration.
Chapter 4 1. Presented examples of successful interdisciplinary research projects. 2. Showed how representation and interaction can augment interdisciplinary research. 3. Explored how mediation tasks can enable interdisciplinary research. 4. Introduced the idea of mediation tools as an area for further exploration.

Table 5.1: List of contributions per chapter.

arts research based upon these methodological themes. I explored and analyzed general themes in the literature of media arts about the role of media artists. I examined ways in which these themes are incomplete, personal, and contradictory. Then, from these themes, I synthesized what I find more accurate descriptions of media arts activities, especially as they relate to larger interdisciplinary projects. I showed that even media arts projects that do not have explicit research goals share many concerns of projects that are explicitly contextualized as having research outcomes. And I showed that media projects that create large scale artifacts (installations, software, etc) are rigorously engaged in implementations that are much more than ornamental, aesthetic, or conceptual. I also indicated that media artists could and perhaps should contextualize their work in terms of the research that they parallel. And I showed how media art-making is not simply "taking" from existing things (the bricolage model), but is also, potentially, generating new areas of inquiry. I also presented examples of media arts project that have multiple outputs in both the arts and in research. I explored how media arts methodologies can, potentially, directly support scientific methodologies. And I explored specifically how media arts projects engaged with new forms of visualization and interaction can offer new insight into collaboration. I also looked at examples of interdisciplinary research projects involving more than one person and showed how the media arts focus on representation and interaction can augment research projects in other domains. And I also discussed how media artists have an intrinsic awareness of how to bridge multiple fields, and thus can be effective mediators between multiple domain experts, even in areas not traditionally associated with media artists, that is, not representational or interactive. Table 5.1 lists the contributions that were made in each chapter.

5.2 Visualization Model

The field of information visualization is concerned with issues regarding visual representations that enable effective reasoning about abstract data [154, 225]. It is generally situated within the larger discipline of computer science, focusing on advancing scientific knowledge through empirical methodologies and the use of precise evaluation metrics. Information visualization is inherently interdisciplinary, and involves research in human-computer interaction, cognitive science, computational methods, and graphic design. Although many of the media arts projects I discuss in this dissertation are related to topics in a range of research areas, here I use information visualization as an example to demonstrate how media arts practitioners can serve as a bridge between the arts and research and to discuss the potential for enabling effective interdisciplinary collaboration.

The methodological themes I introduce in this dissertation in some ways parallel a model that has proved useful to the information visualization community. Tamara Munzner's widely cited "Nested Model for Visualization Design and Validation" arose out of a recognition that existing methodologies were not sufficiently accurate in characterizing visualization research, and thus less effective at "guiding" researchers in defining the scope of their investigations and in making decisions [155].

According to the tenets of the *Nested Model*, an effective visualization research project should: a) accurately describe the specific *domain* targeted and correctly characterize the problems and data associated with that domain; b) map the problems and data into appropriate tasks and data types (what she calls *operations*); c) design visual *encodings* and interaction *techniques* to support those operations; and d) create *algorithms* to make those encodings and techniques more efficient.

For Munzner, an issue is that visualization research doesn't always address each of these "levels" properly, or makes incorrect assumptions about how their research relates to them. Specifically, she identifies *threats* associated with each level, and also presents guidelines for handling these threats, and for providing *validations* for research activities. At the domain level, a potential threat is that the researcher mistakenly identifies a minor problem that is not necessary to solve, and ignores the major issues that actually are important to that community. A possible validation is to observe and interview domain experts who can give you insight into the problems in the domain. At the task level, one threat is poorly translating the problems into operations that might not effectively represent or address the domain problems. Here, a potential validation is to test the technique on target users and to conduct field studies to confirm that the tasks actually are useful for the particular problems. At the encoding and interaction level, a threat is that, even if the appropriate operations are identified correctly, the specific choices for visual representation or choice of interaction techniques may be ineffective. In order to validate these choices, the researcher needs to justify their design decisions and also to conduct quantitative and qualitative user studies. Finally, at the algorithms level, a threat might be a slow or otherwise ineffective implementation of even a successful interaction technique or visual encoding. A validation could be to investigate the computational complexity of the algorithm, or to quantitatively measure the method to evaluate its effectiveness.

Munzner recognizes that any visualization problem spans multiple levels. In her model, each of these levels are interconnected by "upstream" dependencies and "downstream" influences. For instance, it may not be possible to validate the appropriateness of a task until a visual encoding is chosen and evaluated. And then that visual encoding might not be able to be evaluated until an algorithm is designed that is fast enough to generate the visual encoding at interactive rates. Because each of these levels are interconnected, Munzner believes that it is import to iterate over prototypes that test assumptions at each level before committing to a decision about any one of the levels. Through analyzing the methodological requirements of a successful visualization project, Munzner provides effective guidelines for how to think about a problem and how to approach the creation of new projects. It may in fact be less important whether or not the levels accurately carve out the levels of abstraction related to visualization research with complete precision.

5.2.1 Interdisciplinary Threats and Validations

Although the "space" of interdisciplinary research is in many ways at once broader and less defined, and because media arts practitioners have a different set of priorities, it is not as straightforward to define specific levels for media arts practitioners that specifically enable pragmatic outcomes, maintain creative agendas, and allow all participants to be directly integrated with the primary goals of interdisciplinary research collaborations. However, I do believe that it can be useful to think in terms of threats to and validations of methodological themes and also to identify upstream dependencies and downstream implications of each of the themes. A difference however is that, unlike in the nested model, which is explicitly, if loosely, hierarchical, the guidelines offered by these methodological themes are more modular, and perhaps could be described as *rhizomatic* [46]. Nonetheless, I can present some initial, incomplete threats and validations for each of the themes, and indicate upstream and downstream connections to the other themes, meant to be helpful guidelines without being overly prescriptive.

5.2.1.1 Augmentation

The goal of augmentation is to develop or utilize techniques that enhance research goals. Its operations include: tasks relating to immersion, interaction, visualization, and sonification, or the creation of techniques or systems that assist scientific methodologies. Threats to the successful integration into an interdisciplinary collaboration include inadvertently working on tasks that are *interesting* rather than *useful*, and focusing on techniques that are *original* rather than *effective* (i.e., the "not invented here syndrome" [112]). Downstream implications arise from resulting new understandings of data that may necessitate the need to *generate* new research.

5.2.1.2 Generation

The goal of generation is to discover new lines of research and to clarify tasks needed to reach research goals. Its operations include conceiving of and developing artworks that investigate interesting or not well defined topics in order to discover and promote novel research. A main threat is that this process can be seen as risky, that it ends up being counter-productive, or that it takes too long and expends too much energy. Another threat to interdisciplinary research projects is that the team (or some of its members) become too focused on artistic outputs and neglect their relation to the research goals. One downstream implication is that the generation of new tasks and research ideas may necessitate critical discussion and further *provocation* about the research.

5.2.1.3 Provocation

The goal of provocation is to expose blind spots and to challenge assumptions in order to create new possibilities. Its operations include asking probing questions and thinking about "broader impacts" and cultural implications seriously. Threats to interdisciplinary collaboration might include asking questions that are antagonistic rather than helpful, that expand the scope of the project too far, that are too broad to be addressed effectively or within a suitable timeframe, or that are simply not applicable to a particular research agenda. A downstream implication of provocation is that it introduces new ideas and people that require new forms of *mediation*.

5.2.1.4 Mediation

Goals of mediation include effective knowledge sharing and the prioritizing of research goals. Its operations include developing mediation support tools, finding strategies to enable knowledge sharing, and exposing underlying models of users, systems, and disciplines. Threats include the unnecessarily complication of communication and being unaware of one's own biases and promoting specific models or agendas. Downstream implications include the need to generate new research in order to mediate effectively and to augment data and models relevant to the knowledge of different users.

5.3 IEEE VISAP: *Art+Experiment*

In this section I describe ongoing work to find connections between the methodological themes described in this dissertation and the visualization research communities, represented by the different conferences associated with IEEE VIS (Visual Analytics Science and Technology (**V**AST), Information Visualization (**I**nfoVis), and **S**cientific Visualization (SciVis)). I was, along with the designer Lauren Thorson, a chair of the IEEE VIS 2013 Arts Program. I had the opportunity to shape the program to focus not only on artworks that engaged topics in visualization, but also to introduce a forum for interdisciplinary researchers to present work or to introduce new thinking about the role of art and research. In the call for entries for the Arts Program, titled *Art+Experiment*, I asked artists and researchers to think about the potential of artworks to act, figuratively or literally, as research experiments:

> What could it mean for an art installation to produce experimental results? Can an artwork be expressive, challenging, and conceptual, yet simultaneously rigorous, practical, and empirical? We invite artists and researchers to think about the connections and chasms between art and research, and to explore the nature of experimental design and creative experimentation [67].

Discussions about the relation of art and visualization are often centered on the usefulness of aesthetics for functional purposes [122]. The influence of Edward Tufte's seminal work contributes to the awareness that design and aesthetics are primary components of effective visual communication [210]. On the other hand, some writers and artists resist a too-literal reading of that understanding. For instance, Warren Sack explores the aesthetic appropriation of visualization metaphors and methods for artistic, rather than purely functional, purposes [182]. He finds that many works of data visualization art are, in fact, relevant, challenging, and even sublime. Seeking to delineate the extent of what they call "information aesthetics," Andrea Lau and Andrew Vande Moere have designed a helpful domain model that positions visualization projects on along continuums of focus: data, interaction, and aesthetics [124]. In their view, work that emphasizes aesthetics has an "interpretive," rather than a "direct" purpose, yet, however, successful visualizations could incorporate both of these outlooks simultaneously. Intriguingly, they stress that it is more useful to think about the term *aesthetics* as involving reasoning about context instead of limited to the realm of representation.

Just as interaction, analytics, and evaluation are integral concerns of visualization research, similarly visual representation is only one of many possible components of works of new media art. As the art historian Edward Shanken discusses in his investigations into the beginnings of new media arts and conceptual art in the 1960s and 70s, media artists have always focused on systems and concepts more than on representations and technology, even as they make use of advances in representational technologies [193]. Although the phrase "experimental art" tends, popularly, to refer to art that is avant-garde or perhaps simply inscrutable, much of the art by early media artists consciously characterized itself as intentional, quasi-scientific experiments in creating "meta-critical" experiences, demanding "that the viewer examine the process of processing information, *while in the process of doing so*" [191].

Much recent visualization research is concerned with the creation, implementation, replication, and evaluation of user studies in order to increase knowledge in the fields of information and scientific visualization. While these studies are often meant to validate or reinforce the primary claims of novel visualization systems and methods, there is a growing awareness that creating empirical experiments that lead to new knowledge (or a validation of new knowledge) is not necessarily a straightforward task, and that the effective design of visualization experiments itself requires research. For instance, as described above, Tamara Munzner's "nested model" helps researchers untangle the many approaches toward validating visualization tasks [155]. Similarly, an article by visualization researcher Michael Sedlmair, et al., outlines the complexity of choosing appropriate design studies to convincingly evaluate visualization research [189]. And Ben Shneiderman calls into question the effectiveness of the "old strategies of controlled studies," preferring instead to make use of more flexible, iterative methods that "embrace ethnographic styles of observation" [195].

Despite perhaps some complexity and confusion regarding the meaning of the word "experiment" in different disciplines, it is clear that experiments function differently in artistic and research contexts. Nonetheless, the hope is to provide a creative forum to foster dialog about possible connections between artistic experiments and research experiments. Moreover, I believe that thinking more deeply about these connections could lead to novel creative works engaged in data and visualization, as well as to starting investigations into creative ways to design studies that validate research. In other words, I wanted to promote innovation in aesthetics and representation but that simultaneously have an analytic component; that ask meta-level questions about the way in which aesthetics and representation function. Artists and researchers were encouraged to submit work that offered novel explorations of what various modalities of art might have to say about the design and meaning of experiments. While the Arts Program submissions represent a wide range of perspectives and topics – and while they are certainly engaged in representational aesthetics and design considerations – the accepted works in the art show and art papers track are also concerned with the idea of art or artistic perspectives as *experiments* that contribute to thinking creatively about research, that are enablers of research, or that function as a form of research in and of itself.

5.3.1 The Arts Program Submissions

A number of themes were evident across the Art Show submissions, including a focus on real-time streams of data, the use of immersive, participatory environments, and an interest in presenting provocative, qualitative modalities of data representation [66]. Three pieces engaged with textual data arriving in real-time via Twitter feeds: Byungkyu Kang presented an ambient portal of currently trending topics using a “Tweet Probe” [111]; Ye Lin and Romain Vuillemont presented a novel creative ”spirograph” representation of the Twitter feed for the CHI2013 conference [133]; and a large, dynamic sculpture created by Hilary Harp and Barry Moon emits sounds based on a sentiment analysis of incoming tweets. Another piece that engages with a different type of temporal data was presented by the Los Angeles based artist, Xárene Eskander. Her piece, “Salton Sea Revisited,” presents her “realtime lapse” technique, concurrently presenting multiple slices of video taken at different times across a single landscape [61].

The exploration of data within immersive spaces was also a popular theme this year. Yuan-Yi Fan, F. Myles Sciotto, and JoAnn Kuchera-Morin demonstrated a version of their immersive installation, “Time Giver,” that measures and interprets EEG and PPG signals, visualizing and sonifying them within 3D space [62]. Qian Liu and Yoon Chung Han presented an interactive visualization using 3D arc diagrams to explore the borrowing patterns of library visitors checking books in and out over the course of a year. And Jeong Han Kim presented “Qualia Landscapes,” visualizations made by analyzing data associated with different cities using his “emotional search engines” to characterize the mood of a city. Chin-En Keith Soo was also interested in creative ways of transforming data. His work, “VICISS” is an interactive mirror than turns a user’s image and movements into melodic patterns. Many of the artists explicitly presented their work as an ongoing process of conducting artistic experiments. For instance, Yeohyun Ahn applied generative art to typography, using procedural texturing algorithms to evolve organic material into letters and words imbued with emotion and meaning [1]. And Philip Galanter, displaying excerpts from the latest incarnation of his project, “XEPA,” presented a series of intelligent sculptures that evaluate each other’s output, each making high level aesthetic decisions in dialog with its neighbors.

In addition to these artworks that incorporate various modalities of interacting with, representing, and transforming data, the Arts Program also provides a forum for artists and researchers to engage with the unifying theme, *Art+Experiment*, through presenting in the papers track. Three papers explicitly discuss the relationship of art to science, or what is often termed “art-science” or “Art-Sci”. In the paper, “Art and Science as Creative Catalysts,” Eleanor Gates-Stuart and her colleagues explore a group of projects involving scientists, engineers, and artists, and offer strategies for how to integrate the different modes of thinking related to their disciplines [86]. Similarly, Francesca Samsel provides an overview of what she defines as representative works that bridge art and science [183]. And Ruth West, in collaboration with Roger Malina and others, explores the “crisis in representation” stemming from the ever-increasing size and complexity of data; introducing the idea of “data remixing” as a potentially transformative approach to interdisciplinary collaboration that can include multiple inputs and objectives [227]. Francis Marchese takes an historical approach, analyzing early experiments by medieval scholars who operated in some way as proto-data visualization researchers, creating the first known examples of certain types of abstract data representations [145]. More contemporarily, Julian Heinrich and Daniel Weiskopf present a novel rendering technique for obtaining visually pleasing images from parallel-coordinate plots via “density footprints” [99]. Finally, Philip Galanter discusses the role of evaluation in computational aesthetics, and, using his art show submission as an example, explores evolving systems to mimic creative processes [82].

The goal of the conference is for a continued presence and greater integration of the Arts Program with other conferences, symposia, and workshops that make up IEEE VIS, and especially that the introduction of the VISAP papers track will be conducive to meaningful dialog about the role of art and creativity in scientific research, as well as the creative potentials of introducing empirical methodologies into artistic practices.

5.4 Future Directions

This dissertation presents many ways in which media arts projects could be beneficial to interdisciplinary research project, and looks at projects that have both artistic and research outputs. However, in the penultimate chapter, I describe research projects that have solely research outputs. In my most recent collaborative work, although I am utilizing the methodological themes I introduce, there have not been associated artistic outputs. That is, in one sense, I have the inverse of the problem I began with. A major future direction that follows from this dissertation is to continue to explore how to be simultaneously effective in *both* domains. In particular, I will pursue and evaluate media arts projects that can serve as generators that help find and focus interdisciplinary research topics.

Other future directions that follow directly from the work in this dissertation include the idea of mediation as a primary focus for media artists to contribute to and to think about. For instance, in the Augmented Communication Tools project I described the idea of using interactive visualization as a way to explain the model of *how* a computational system came to its results, rather than those results in and of themselves. I believe that thinking of media arts projects as explicitly engaged with transmitting models for reasoning about the world is a rich topic requiring further exploration. Moreover, similarly to the way in which Ben Shneiderman positions the idea of creativity support tools as a way to reframe the goals of information visualization, the idea of "mediation support tools" might be a useful way to think about creating projects that enable effective interdisciplinary research between domain experts in fields with widely divergent perspectives.

In sum, this dissertation clarifies some of the practical roles, agendas, and tasks that are important and effective for media artists working within interdisciplinary collaborative projects. I hope I have demonstrated how media arts practitioners can and do contribute to scientific endeavors and that I have provided a clear set of methodological themes with which media artists can draw from in order to guide and articulate their contributions in these areas.

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