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Envisioning the Future of Computational Media: The Final Report of the Media Systems Project

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Envisioning the Future of Computational Media

The Final Report of the Media Systems Project

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Executive Summary

This is the final report of the Media Systems project, held at University of California, Santa Cruz in 2012. This gathering brought together field-leading participants from media-focused computer science, digital art, and digital humanities — located in and across universities, industry, federal agencies, publishers, and other stakeholders in the future of media. Different participants focused on diverse aspects of how new media forms are impacting culture, education, the economy, and other areas of national importance, using examples ranging from the World Wide Web to computer animation, and from video games to social media. Surprisingly — despite this diversity of background and focus — rather than struggling to explain our different fields to each other, we found ourselves engaged in deep conversation focused on a coherent set of shared activities. For the purposes of this report, the authors have chosen to name these activities *computational media*.

Computational media involves four types of work and develops four types of knowledge and skills — generally combining two or more of these categories simultaneously:

- **Technical** — computational media work requires and develops deep technical engagement, from the invention of new algorithms to the use of specialized tools for purposes such as 3D animation or examining code archives.
- **Creative** — computational media practitioners must exercise creative skills, from the creation of new genres of digital art and scholarship to the imagining and prototyping of new technology and tool possibilities for media.
- **Interpretive** — the creation and understanding of computational media requires being able to interpret particular examples and place them in broader contexts, from situating media forms historically to interpreting new kinds of human learning behavior enabled by computational artifacts.
- **Collaborative** — computational media work is most often carried out by interdisciplinary groups, exercising and developing 21st Century skills in communication, teamwork, and problem solving.

Looking at the same activities through a different lens, we could say that computational media work produces four kinds of outcomes — often with outcomes in multiple categories from the same project:

- **Artifacts** — the outcome of making novel computationally-driven media.
- **Capabilities** — the outcome of developing computational, representational, and design approaches that enable new forms of media.
- **Insights** — the outcome of studying the technical, historical, and cultural creation and function of computationally-driven forms of media, both old and new.
- **Educated Practitioners** — the outcome of interdisciplinary education and training in computational media.

During the discussions at the three-day Media Systems gathering (together with more than a year of followup conversation and writing) we identified a core set of opportunities and challenges facing computational media work. Examining these resulted in the development of 12 recommendations for specific constituencies, which are summarized here and discussed in greater detail at the end of this report.

Summary of Opportunities

The major opportunities can be organized into three groups. First, opportunities for economic and cultural impact. These are already significant, though computational media are among the youngest forms of media. On a cultural level, innovations in computational media shape the expression of ideas and modes of communication in a wide variety of contexts. For example, video games are becoming culturally pervasive: played in 67% of U.S. households, with 70% of U.S. companies using games to train their employees — as well as becoming recognized for their unique expressive powers (and now exhibited by venues such as the Smithsonian and the Museum of Modern Art). Economically, the video game business is now estimated at $66 billion a year and the even-younger mobile app business is estimated at $25 billion. Other forms of computational media — from computer animated films to World Wide Web pages — are at least as economically significant and culturally widespread. Computational media have reached this level of impact through innovation in new forms, providing new experiences to broadening audiences. A major focus of our recommendations is creating the conditions needed for continuing this kind of trajectory in innovation and impact.

Another area of opportunity is in addressing national priorities. President Obama's Strategy for American Innovation identifies a number of national priorities, ranging from broad-based emphases on fundamental research and 21st Century skills to highlighting very specific Grand Challenges. Computational media have important roles to play in a number of these areas. For example, they can be highly intrinsically motivating, as recognized by the administration's ARPA-ED initiative, which includes as a key goal making "Educational software as compelling as the best videogame." They can also be deeply customized, as seen in cutting edge work on intelligent educational media. They have demonstrated potential in areas ranging from health interventions to formal software verification. They are also particularly powerful for representing how systems shape our world — from civic engagement to climate change. And their creation has proven a successful focus for interdisciplinary education efforts. The powerful cultural and economic effects of the development of fundamental technologies and approaches for representing three-dimensional spaces and objects on a screen serves as

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Computational media have reached this level of impact through innovation in new forms, providing new experiences to broadening audiences.

an exemplar of the dividends that computational media research can pay. Significant research will be required to deliver on the promise of the many other areas of computational representation that are currently underdeveloped or unexplored.

Finally, the growing importance of computational media has led to another opportunity — in education and research. Many colleges and universities have now founded one or more programs or centers in areas connected to computational media — often under umbrellas such as digital arts, video games, new media, or digital humanities. For example, nearly 300 colleges and universities are members of the New Media Consortium. Some of these are already deeply interdisciplinary centers for computational media research and/or education. Many more of them have the potential to fulfill this role, helping address the significant challenges that face the field, if the right conditions for this growth can be established.

Summary of Challenges

A key challenge facing the field is the need for sustained basic and applied computational media research. Currently, computational media work in industry is often highly interdisciplinary, but the work is generally focused on the results needed for a specific product. Teams dedicated to basic research — tackling the high-risk, high-payoff questions — are rare. On the other hand, organizations in which basic research is the norm, such as research universities, have a hard time assembling and maintaining interdisciplinary teams. This is for a variety of reasons, including: their institutions and institutional success criteria are often strongly disciplinary, their funding sources may provide no appropriate programs or mechanisms for such work, and their opportunities for publication and other research impact are generally determined by peer reviewers who may apply inappropriate metrics to judging their success.

This is related to another challenge facing the field — a lack of balance between basic and applied research. For example, in games research by far the largest investments are in applied research: games for training, games for health, games for education, games for crowdsourcing knowledge, and so on. Applied research helps define questions and creates impact, but basic research provides the foundational understandings and capabilities that allow applied research to make major strides. While it is appropriate to make these investments, applied research needs to be in better balance with basic research for the field to move forward. Media Systems participants particularly

Organizations in which basic research is the norm, such as research universities, have a hard time assembling and maintaining interdisciplinary teams,

Summary of Challenges

discussed the need for basic research in enabling new forms of media (e.g., deeply interactive narrative, radically adaptive and generative games) and in improving research and dissemination (e.g., innovative approaches to evaluation, new forms and genres for scholarly communication, education, and cultural heritage).

Further, computational media production (in industry and non-profits), research, and education are all made significantly more challenging by a lack of computational media practitioners with deeply interdisciplinary training. Industry has created special job categories for such individuals, such as “technical artist” (connecting visual art and computer science) and “gameplay programmer” (connecting experience design and computer science). But these jobs are exceptionally difficult to fill. Universities have run into the same issues when attempting to hire interdisciplinary faculty to lead computational media research and education initiatives. It is not only necessary to begin training many more truly interdisciplinary computational media practitioners, but also necessary to focus on increasing the diversity of enrolled students, the diversity of faculty, and the diversity of the fields in which students are eventually hired.

Finally, computational media lacks many of the pieces of infrastructure that help fields continue to grow and innovate. The lack of sophisticated tools and platforms in many areas of the field raises costs for all creators and results in high barriers to entry, reducing diversity in both what is created and who creates it. A lack of accessible collections of computational media works means that designers, artists, scholars, and technologists cannot gain insights from experience of the field’s history. The application of innapropriate evaluation criteria — and the lack of established, more appropriate alternatives — makes cutting edge work hard to fund and publish. And a lack of well-documented models for successful interdisciplinary work creates challenges in everything from organizing small project teams to developing major educational initiatives.

Summary of Recommendations

1 Support the Creation of New Works and Design Approaches

ADDRESSED TO: Industry; independent and non-profit creators; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support interdisciplinary design research that results in high-risk computational media creation efforts — integrating arts, humanities, and computer science — on three scales: demonstration, project, and product.

EXAMPLE: Computational media works that attempt to translate knowledge from the history of rhetoric into new interactive forms.

2 Invest in Developing New Computational Models and Genres

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support interdisciplinary basic research toward developing new technological possibilities for computational media, integrating efforts across multiple areas of computer science, the arts, and the humanities.

EXAMPLE: New technology and design approaches to enable compelling, highly-interactive dramatic characters.

3 Encourage New Forms of Scholarship

ADDRESSED TO: Publishers; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Invest in new publishing venues that will provide a high-quality outlet for experimentation with new forms of scholarship; revise funding programs and review procedures to support these new forms; and seek ways to recognize a broader range of scholarly activity in computational media.

EXAMPLE: Prototyping new scholarly forms that require computational media for their argument structure.

4 Cultivate Rigorous Dissemination Venues and Evaluation Approaches

ADDRESSED TO: Professional societies; publishers; conference organizers; journal and series editors; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support computational media communities in: identifying exemplars of strong projects and research contributions; describing current best practices in computational media evaluation; developing new interdisciplinary evaluation approaches, which may combine methods formerly seen as in tension with or in contradiction with one another; and disseminating these for use in existing field-defining contexts (from journal review to tenure evaluation) and in the establishment of new dissemination venues.

EXAMPLE: A computational media track of a rigorous, high-impact conference, with distinct, publicized evaluation criteria and knowledgeable peer reviewers.

5 Build Interdisciplinary Education and Student Diversity

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Design degrees and student support programs to enable student-led interdisciplinary pathways; create degrees (and modify existing degrees) with interdisciplinary cores (and foundation courses) engaging the methods, languages, and problems of more than one discipline; hold workshops and summer institutes for working computational media practitioners (and those looking to transition into computational media); and use resources to recruit and support diverse faculty and students.

EXAMPLE: Transitioning a relatively disciplinary “game engineering” degree into a deeply interdisciplinary computational media degree.

6 Foster the Next Generation of Leaders

ADDRESSED TO: Industry; professional societies; conference organizers; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Develop appropriate tenure and promotion guidelines; mentoring and career development workshops; support for post-doctoral researchers (and potentially early-stage faculty) to be embedded in successful interdisciplinary computational media contexts; and support for cross-training of disciplinary researchers seeking to move into computational media.

EXAMPLE: “Hydra” post-doctoral grants, bringing together early-stage researchers from multiple disciplinary perspectives to create a multi-year computational media project under the guidance of a researcher experienced in organizing, supporting, and communicating the value of such work.

7 Support for Tool and Platform Development

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Provide support for tools and platforms that address needs already demonstrated by patterns of media making practice; strongly consider open source strategies, especially before putting more resources into a tool project that has thus far failed to find or create a community.

EXAMPLE: Tools that represent and can reason about the system components and play aesthetics of simulation and strategy games, enabling a dramatic broadening of creators and applications.

8 Support for Collections and Archives

ADDRESSED TO: Industry; independent and non-profit creators; libraries, archives, and museums; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Industry, independent and non-profit creators, collecting organizations, and research organizations collaborate to develop strategies for collecting and making accessible final works, the resources from which these works were created, records of the development process of works, records of reaction and contribution by audiences, and records of marketing and reception. Supporting basic and applied research in fundamental questions ranging from information organization (e.g., ontologies and metadata) to preservation and access (e.g., emulation and migration).

EXAMPLE: Developing industry best practices around archiving current “closing kit” materials with third parties, expanding to include records of the development process.

9 Promote Collaboration

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Supporting co-teaching and other interdisciplinary education efforts; hiring individuals who can translate across research and media-creation groups within an organization; promoting organizational structures and best practices for collaborations between computational media researchers and media creators who are in different organizations; experimenting with artist/humanist/computer scientist-in-residence programs and decentralized, partially-volunteer efforts (including with open source developers); and not assuming members of collaborations will be drawn from disciplinary backgrounds (computational media collaborations are strongest between interdisciplinary practitioners).

EXAMPLE: Create best practice intellectual property and collaboration models for computational media projects spanning industry and universities, based on studies of successful partnerships; incentivize their adoption through startup funding for centers that use them.

10 Develop Better Field Understanding

ADDRESSED TO: Professional societies; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Resources for both broad and detailed studies of computational media, resulting in specific, strongly-supported recommendations and rich, particular case studies.

EXAMPLE: An extensive research and writing project on computational media, in the vein of *Beyond Productivity* or *Our Cultural Commonwealth*, including public information gathering meetings, testimony from field experts, and analysis of available empirical data.

11 Build on Existing, Local Strengths

ADDRESSED TO: Industry; universities and colleges.

IMPLEMENTATION: Identifying nascent computational media strengths and differentiators (which may already be organized in development groups, research centers, and/or educational programs) as starting points for building computational media focus areas.

EXAMPLE: Building on local strengths in software studies, natural language processing, and human-computer interaction to develop a computational media focus area around tools for analyzing computational media authoring strategies and artifacts.

12 Establish National Centers of Excellence

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Found centers that engage in fundamental field-development work (from developing best practice recommendations to hosting mentoring workshops); provide loci of expertise for particular research and/or application areas; and build the national research and education infrastructure for computational media.

EXAMPLE: A center linking three North Carolina universities, and local computational media industry partners, with a research focus on operationalizing interdisciplinary models (working with experts in cognitive science, psychology, design studies, creative writing, and narrative theory) to enable new kinds of interactive media and media design tools for learning and entertainment.

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Preface

The Media Systems convening was made possible by an unprecedented group of partners: the National Science Foundation, the National Endowment for the Arts, the National Endowment for the Humanities, Microsoft Studios, and Microsoft Research. Our hope is that this kind of interdisciplinary partnership is a harbinger of things to come. The convening was brought to fruition through the organizational work of two UC Santa Cruz institutions: the Center for Games and Playable Media and the Institute for Humanities Research. We owe them great thanks.

This document, the final report from Media Systems, is intended for a diverse group of audiences. But in particular, it is intended as a tool for two groups. The first are those who wish to support the ongoing growth and impact of computational media in industry, universities and colleges, professional organizations and publishers, public and private funding, and other contexts. We hope that it provides a useful guide to what might be important to do, and why. The second are those who, in a variety of fields, consider computational media work to be an important part of what they do. We hope that this document provides them a way of clarifying this work to a variety of audiences — something to point to and say, "This is a description of the type of work I'm proposing."

We — Noah Wardrip-Fruin and Michael Mateas — are the authors of this document. We have done our best to capture the sense of the Media Systems convening and follow up conversations. But it is likely that this document contains statements that not all participants or computational media practitioners would agree with (in fact, one of our hopes is to spark debate) and we are certainly responsible for any errors. Also, while we have done our best to attribute ideas to individuals, or to particular parts of the gathering (such as breakout discussions), many ideas that come from the participants are simply worked into the flow of the text. In other words, to the extent the ideas here are valuable, we must share credit with all those who participated in Media Systems and all those who have taken part in conversations with us on these topics since.

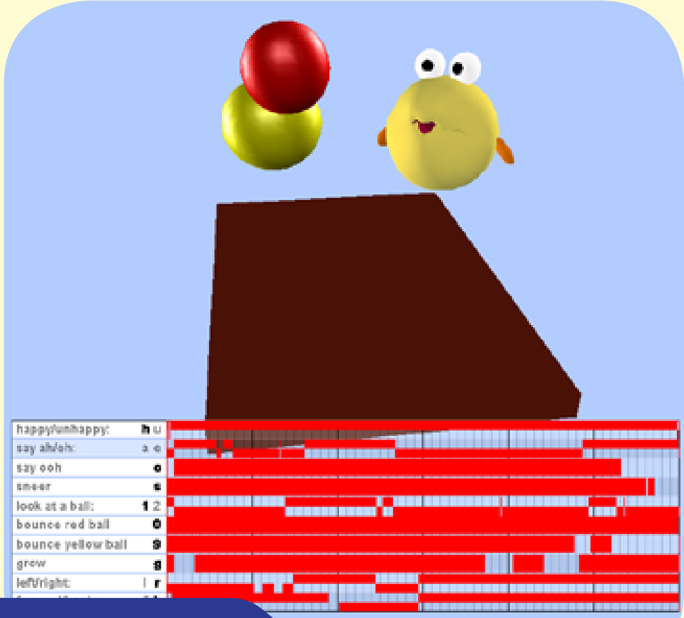
Humanities I Building, UC Santa Cruz © UC Regents

Sidebar One: New Media Forms & Methods

Computational media have transformed how we develop and communicate our ideas, knowledge, and values — and are continuing to do so. From the World Wide Web to computer animation, from video games to social media, computation now defines much of our experience and creation of media.

As a society, we are now exploring the possibilities of new media forms in a wide variety of contexts, such as smartphone apps and public interactive displays. We are reinventing long-standing media forms in many parts of our lives, such as family albums and scholarly monographs. We are inventing new tools, and new ways of working, that are transforming practices such as film production and book publishing. This comes as a result of research and experimentation across universities and industry — at the Media Systems convening participants demonstrated and discussed work that will help us produce and understand future transformations in this area.

For example, Chad Greene from Microsoft Studios discussed how the common basis of computation is leading to transformations in film and games — and further, is enabling borrowing between the two, as well as both borrowing from academic research. Increasingly, previsualization is a major component of film directing, borrowing real-time, reduced-detail techniques invented for games. Artists working on computer animated characters and objects for film are able, using game-derived techniques, to see their work rendered as they craft it (rather than working on abstract representations and only occasionally rendering an image more like what the audience will see) making faster iteration and more refinement possible. In the other direction, games are now borrowing many computational techniques from film, as well as emulating both the language of film and the look of particular technical artifacts of film (from lens flare to depth of field). This combination of greater visual detail and building on well-understood filmic forms is allowing games to create more immersive-feeling worlds, but it is also producing a new set of challenges. Greene particularly drew attention to the challenge of avoiding the pitfalls that computer-animated film and robotics have experienced with the "uncanny valley" (discussed further in "Need to Develop and Adopt New Evaluations" below) creating characters for interactive media that feel engaging and alive.



Ken Perlin's research combining procedural computer graphics with the arts, particularly animation and puppetry, enables believable characters that can respond in real time — a key capability for future highly interactive, engaging experiences.

This report grows out of a convening, focused on the future of media, that brought together representatives from three different fields: media-focused computer science, digital arts, and digital humanities. The participants were drawn from universities, industry, and field-defining groups (involved in activities such as granting and publishing). With such a diverse group, conventional wisdom would suggest that much of our time would be dedicated to trying to overcome disciplinary and organizational divides.

In fact, just the opposite happened. There was the immediate sense, starting with a "lessons learned" session the evening before the main workshop, that the participants were actually involved in the *same* activity — one that was simply awaiting being identified and named. After three days of in-person presentation and conversation (and significant follow-up discussion and analysis) identifying and describing this activity, for which we suggest the name *computational media,* has become a major purpose of this report. Below we describe the questions and activities pursued in computational media, outline the major opportunities it offers, challenges it faces, and recommendations we have for stakeholders who can help unlock its potential.

What is Computational Media?

Consider a field such as bioinformatics. A naive conception might think of it as the "application" of computer science techniques to "problems" from biology. But in fact bioinformatics pursues questions that could only arise, and could only be answered, in an interdisciplinary field containing people knowledgeable in both biology and computer science. It is this kind of thinking that led to the sequencing of the human genome, unlocking huge potential for medical research and health care.

Computational media is a similar field. It is not the application of computer science techniques to problems from the arts and humanities. Rather, it brings together people knowledgeable about the arts, the humanities, and the sciences — particularly computer science, but also the social sciences — to pursue questions that could only arise, and only be answered, in an interdisciplinary field.

Computational media involves four types of work, and develops four types of knowledge and skills — generally combining two or more of these categories simultaneously:

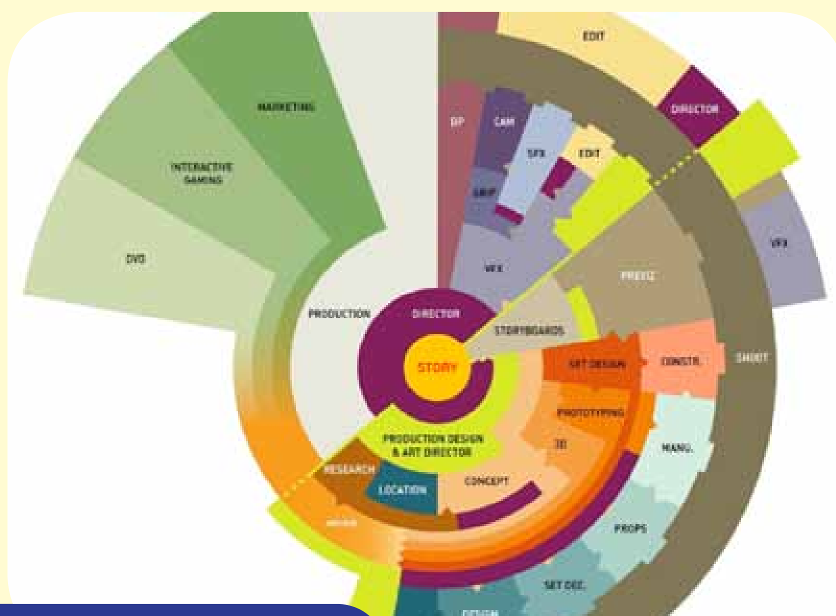
Computational media brings together people knowledgeable about the arts, the humanities, and the sciences – particularly computer science, but also the social sciences – to pursue questions that could only arise, and only be answered, in an interdisciplinary field.

Sidebar One: New Media Forms & Methods

Making progress on enabling believable interactive characters will require significant research. At Media Systems one of the leaders in this research, Ken Perlin from New York University, argued that the key is characters who can carry out intelligent performances of their roles, based on the kinds of high-level direction that can be provided by an AI system or by audience interaction (e.g., with a game controller). He showed two prototypes of characters like this, able to give engaging, coherent, grounded performances in real time. These simple characters arose from research deeply combining procedural computer graphics with the arts, particularly animation and puppetry (Perlin regularly collaborates with puppeteers). Addressing the challenges of creating believable interactive characters will require additional disciplinary perspectives, such as artificial intelligence and humanistic performance studies. This is a hallmark of computational media research that develops new media capabilities — a driving problem from media making requires the creation of new technical, creative, and interpretative knowledge.

These kinds of knowledge also come together in the emerging media-making practice of "world building" — as discussed at Media Systems by leading film industry designer Alex McDowell, who has recently established a world building laboratory at the University of Southern California. McDowell described how the world building process was pursued in parallel with scriptwriting for the 2002 film *Minority Report*, investigating potential impacts of the film's premise from perspectives such as urban planning, social relations, and transportation design. Computational media tools then allowed this world building work to integrate with the filmmaking process, from directing in pre-visualization to rapid prototyping of 3D-modeled props. In the time since *Minority Report* it has become clear that world building is moving increasingly away from the linear process of film production (followed by the production of spin-off interactive experiences) into one in which computational media provides a unified framework for the creation of worlds in which multiple types of media and storytelling are developed simultaneously.

Of course, changes in what is on the screen and how it is produced are only part of the transformations currently occurring through computational media.



In Alex McDowell's "world building" approach, computational media provides a unified framework for the creation of worlds in which multiple types of media and storytelling are developed simultaneously. This framework also enables a distributed, increasingly real-time, and integrated environment for simultaneous collaboration among authors/creators.

By permission Alex McDowell.

- *Technical* — computational media work requires and develops deep technical engagement, from the invention of new algorithms to the use of specialized tools for purposes such as 3D animation or examining code archives.
- *Creative* — computational media practitioners must exercise creative skills, from the creation of new genres of digital art and scholarship to the imagining and prototyping of new technology and tool possibilities for media.
- *Interpretive* — the creation and understanding of computational media requires being able to interpret particular examples and place them in broader contexts, from situating media forms historically to interpreting new kinds of human learning behavior enabled by computational artifacts.
- *Collaborative* — computational media work is most often carried out by interdisciplinary teams, exercising and developing 21st Century skills in communication, teamwork, and problem solving.

Or, looking at the same activities through a different lens, we could say that computational media work produces four kinds of outcomes (often with outcomes in multiple categories from the same project):

- *Artifacts* — the outcome of making novel computationally-driven media.
- *Capabilities* — the outcome of developing computational and design approaches that enable new forms of media.
- *Insights* — the outcome of studying the technical, historical, and cultural creation and function of computationally-driven forms of media, both old and new.
- *Educated Practitioners* — the outcome of interdisciplinary education and training in computational media.

We use the term “computational media” to label this set of practices, bringing it into focus in order to discuss its importance for economic development; for education, health care, and other vital tasks; and for developing deeper cultural expression in, and understanding of, what are becoming dominant media forms (as discussed in later sections of this report). Additionally, the term computational media has the advantage of helping clarify the areas of overlap and differentiation of computational media research with three closely-related research fields: digital humanities, digital arts, and human-computer interaction (HCI).

Digital humanities. A significant number of activities often included in the digital humanities research are also key parts of computational media research. This includes the creation of novel media guided by humanities insights, as discussed

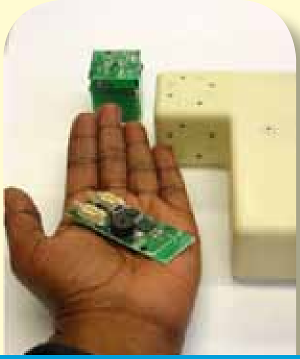
Sidebar One: New Media Forms & Methods

Greene also discussed Microsoft's Kinect sensor, sold as a way for audiences to control games and other Xbox experiences with their bodies and voices. Selling more than eight million units in its first two months of release (making it the fastest-selling consumer electronics device on record) the Kinect was a huge success for Microsoft. But Greene also described the significant mistake Microsoft made in trying to close the device off from the exploration of other uses by the open-source community. Luckily, through the efforts of hobbyist tinkerers an unofficial open-source driver for Kinect was available within days after launch, resulting in projects showing its potential for computational media applications in areas ranging from medicine to education.

The potential for new hardware to enable new kinds of open-source computational media creativity was also a focus of the presentation from Pamela Jennings, a former NSF program officer who is now CEO of the startup company CONSTRUKTS. She discussed her CONSTRUKTS Toolkit (seen below), a wireless sensor mesh network system for new mixed-reality (virtual and physical) applications in education, gaming, and design prototyping. Providing new hardware/software possibilities such as these can help in engaging diverse groups, spark new kinds of speculations, and make possible the construction of new demonstrations and prototypes that could lead to new insights and products. This in turn, is one strategy for creating the kinds of "digital sandboxes" that aid field building by providing opportunities for those from different disciplines to engage, communicate, collaborate, and play.

The untapped potential of widespread hardware, such as the smartphones that many of us carry each day, was a focus of another Media Systems presentation — that from Brenda Laurel, whose writings and projects were influential in founding the computational media area. She emphasized the role such devices could play in grounding conversations about issues such as climate change by layering augmented reality visualizations of possibilities and processes onto views of the immediate world around us. She also discussed how this could combine with citizen science practices such as widespread community sensing projects, framed as computational media experiences, in which members of the public collect data on a scale impossible with more centralized means. Such possibilities have significant implications for fields ranging from the natural sciences (with the availability of data that is significantly larger and more fine-grained than before) to national politics (with a larger number of citizens whose opinions are shaped by direct participation in data gathering and by experiencing visualizations grounded in their own contexts).

The desire to seize and build upon developments and concepts such as these shapes the recommendations of this report.



The CONSTRUKTS Toolkit prototype consists of fourteen tangible blocks — two each of seven unique 2D and 3D pentomino shapes. The pentomino shape supports three-dimensional cantilevered constructions. The Interchangeable Magnetic Sensor Connector supports gender-neutral block connections.

at Media Systems in examples ranging from the 1980s work of Brenda Laurel at Atari and Apple to the contemporary work of Tara McPherson (*Vectors*, USC) and Geoffrey Long (Microsoft Studios). It also includes interpretive work focused on computational media, especially that which engages its computational specifics, as found in areas such as software studies and platform studies. It further includes work that we would classify as digital humanities, but which is invisible in many surveys of the field, such as building humanistic models of media genres and tropes that are specific enough for computational implementation — or even building computational models that are themselves generative interpretations (see the “Need for New Computational Models and Genres” section). However, there are also major areas of digital humanities research that are often disconnected from computational media research, because they are not focused on understanding or creating computational media, such as the curation of digital data collections or the building of tools for traditional corpus analysis.

Digital arts. Just as with the digital humanities, a significant number of activities often included in digital arts research are also key parts of computational media research. In a wide range of sub-fields, from computer music to video games, computation is used as an artistic material. The computation may be used to generate artifacts (e.g., images or sounds) or to create an interactive situation in which audience members may produce one of many possible performances together with the work. However, the digital arts also often include many arts in which artists work with digital tools, but don’t use computation itself as a medium. For example, many works created with photo editing or digital video software packages might be considered digital art, but artists are often entirely operating within the metaphors of the tool, which do not require or permit any *computational thinking* (e.g., model building or abstraction and reuse). Of course, such work may still be an important step toward the creation of a novel work of computational media research, and all software tools that embody artistic techniques and modes of work — past and future — are themselves products of computational media research and development.

Human-computer interaction. Given that a major focus of computational media research is the development and understanding of interactive media, there are clearly important overlaps with HCI research. At the same time, there are also wide areas of divergence. In particular, HCI has included a range of topics that aren’t primarily concerned with media, from workspace ergonomics to control systems. More subtly, while HCI has included insights and practitioners from media arts, media design, and humanities media studies throughout its history, these have generally been in the minority. Instead, by far the most strongly-represented practices and evaluation metrics are those from computer science, quantitative social science, and psychology. As discussed in the two evaluation sections below, such approaches must be complemented or replaced by approaches such as expert interpretation and critique, grounded in the arts and humanities, for evaluating and guiding work in computational media.

Background

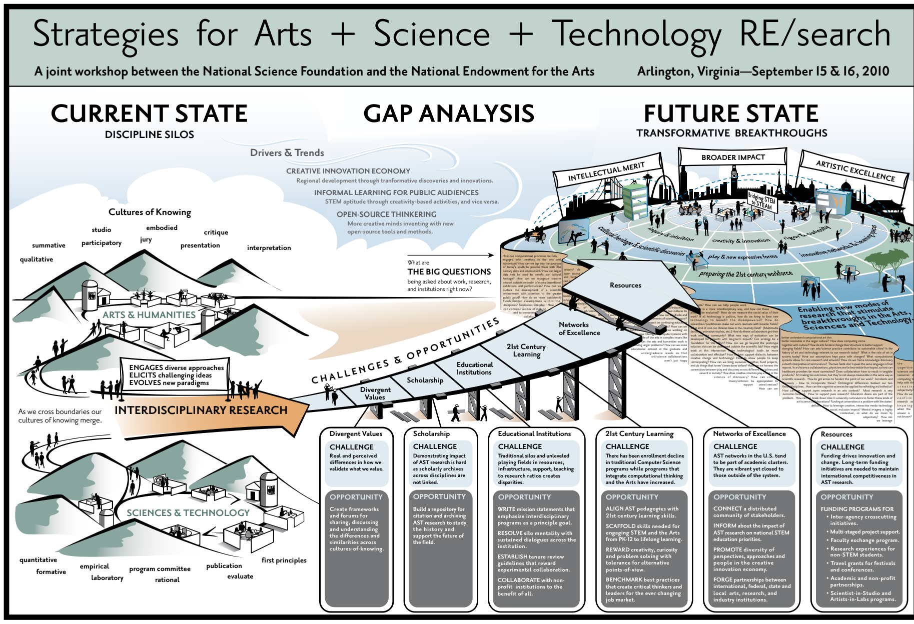
We have had computational media since the advent of modern computers. Christopher Strachey wrote a poetry generator and a checkers-playing program for the Manchester Mark I, one of the first stored-program digital computers, in the early 1950s. These were arguably the first piece of digital art and the first video game, respectively.

As computers became more widespread, institutions developed that were devoted to computational media research and commercialization. MIT's Architecture Machine Group, which would later become the Media Lab, was founded in 1968. Atari Incorporated, which began by creating commercial versions of early video games from research universities and national labs, was founded in 1972. Lucasfilm's Graphics Group, which built upon early university research in computer graphics and would later become the research-heavy Pixar, was founded in 1979. The combined cultural, technical, and economic impact of institutions such as these, together with individuals and small groups following in Strachey's footsteps, is enormous.

However, recognition of computational media as a research area — by any name — was slow to develop. Instead, computational media work was largely funded, made public, and discussed as something else: media art, computer science, video games, computer graphics, multimedia education, human-computer interaction, and so on.[1] An important shift in the landscape came with the National Academy of Sciences' publication of the *Beyond Productivity* report in 2003. As that report describes, it had its genesis when "the Computer Science and Telecommunications Board (CSTB) began in the mid-1990s to examine opportunities at the intersection of computing and the humanities and the arts.

Beyond Productivity, *published by the National Academy of Sciences in 2003, is a key landmark on the road to understanding and support of computational media.*

1. In some cases this work was undertaken by practitioners who pursued the interdisciplinary, media-oriented approach of computational media. In other cases, practitioners saw themselves as making contributions to a narrower area, but their results could be integrated into a computational media framework by others. For example, practitioners in computer animated film and video games have been able to create computational media institutions that build on research results from computer graphics — even from research that was focused on narrower questions, and success metrics, such as the optimization of existing techniques.



A storymap from the Re/Search gathering powerfully summarized the new context of interdisciplinary possibility in which the Media Systems project, and related efforts, have taken place.

Storymap designed by Pamela L. Jennings, former NSF Program Officer, in collaboration with Laurie Durnell of The Grove Consultants International and in consultation with her workshop committee colleagues Joan Shigekawa and Bill O'Brien from the National Endowment of the Arts.

In 1997, it organized a workshop that illuminated the potential, as well as the practical challenges, of mining those opportunities and that led, eventually, to the project described in this report."[2]

While the field-defining term used in *Beyond Productivity* was not to last ("information technology and creative practices") the report became a touchstone for practitioners in a variety of fields — especially the digital arts, digital humanities, and media-focused computer science. We see it as a clear harbinger of computational media. At the Media Systems convening, it was one of the shared references for many present.[3]

A next major step came with the engagement of the Federal government, as seen in the 2010 "Re/Search" gathering, the first official collaboration between the National Science Foundation and the National Endowment for the Arts. While this had a mandate much broader than computational media — embracing the entire art/science agenda, as exemplified by organizations such as Leonardo — it was a strong current in the discussions. The success of this gathering led to a series

2. National Research Council, *Beyond Productivity: Information, Technology, Innovation, and Creativity* (Washington, DC: The National Academies Press, 2003).

3. *Beyond Productivity* was supported by the Rockefeller Foundation, and foundation support has been important to a number of significant computational media projects. Notably, the interdisciplinary HASTAC organization (Humanities, Arts, Science, and Technology Alliance and Collaboratory, founded in 2002) has been supported by the MacArthur Foundation — and has administered MacArthur's yearly Digital Media and Learning Competition.

of NSF-sponsored workshops that gave birth to a number of initiatives and collaborations. Among these are the twin "SEAD" efforts. NSEAD is an advocacy-focused network for "Science, Engineering, Art, and Design" while XSEAD is a novel platform for communication, curation, and publishing aimed at the SEAD community.[4]

Noah Wardrip-Fruin and Michael Mateas — the authors of this report and principal investigators of Media Systems — both took part in briefings for *Beyond Productivity* and participated in the Re/Search convening. Wardrip-Fruin also took part in NSEAD workshops and follow-on activities. The initial goal of Media Systems, as a convening and planned report, was to build on the momentum of Re/Search and SEAD while (1) focusing the conversation more specifically on issues of interdisciplinary research in computational media and (2) drawing more representatives from the digital humanities and from industry into the conversation.

Media Systems was made possible by a historic group: the National Science Foundation, the National Endowment for the Arts, the National Endowment for the Humanities, Microsoft Studios, and Microsoft Research. It is the first activity ever jointly supported by the NSF, NEA, and NEH. It was facilitated by two organizations at UC Santa Cruz: the Center for Games and Playable Media and the Institute for Humanities Research.

Some topics in this report overlap those discussed in *Beyond Productivity,* in *Strategies for Arts + Science + Technology Research* (the final report from Re/Search), in *Steps to an Ecology of Networked Knowledge and Innovation* (the report from the SEAD white papers process of 2012–13), in *The Future of Research in Computer Games and Virtual Worlds* (the report from an NSF workshop on this topic), and in reports from a number of other convenings and organizations.[5] But the main focus of this report is on new contributions arising from the Media Systems gathering and the discussions and analysis that followed. In particular, we focus on the emerging understanding of computational media as a coherent set of practices (as discussed in this introduction), opportunities identified and lessons learned from computational media work to date, intellectual and structural challenges facing the field, and recommendations for future actions by particular stakeholders.

Our hope is that this report will help spark debate within and outside the field; inform decisions by leaders in universities, industry, and government; and also — perhaps most importantly — provide others the opportunity to experience what many participants in the Media Systems gathering described so strongly: the shift from feeling at the periphery of another field to feeling at the center of something newly-defined.

4. "SEAD – About," Network for Sciences, Engineering, Arts & Design, accessed February 28, 2014, http://sead.viz.tamu.edu/about/index.html. "Welcome to XSEAD – A home for cross-discplinary exploration," Virtual eXchange to Support Networks of Creativity and Innovation amongst Science, Engineering, Arts and Design, accessed February 20, 2014, http://xsead.cmu.edu/.

5. D. Fox Harrell and Sneha Veeragoudar Harrell, *Strategies for Arts + Science + Technology Research: Executive Report on a Joint Meeting of the National Science Foundation and the National Endowment for the Arts* (2011). Roger Malina et al., *Steps to an Ecology of Networked Knowledge and Innovation: Enabling new forms of collaboration among sciences, engineering, arts, and design* (2013). Walt Scacchi, ed., *The Future of Research in Computer Games and Virtual Worlds: Workshop Report*, Technical Report UCI-ISR-12-8, Institute for Software Research, University of California, Irvine, Irvine, CA (2012). National Research Council. *Beyond Productivity: Information, Technology, Innovation, and Creativity*.

We are entering a period of great opportunity for computational media. This is in part due to changes in infrastructure. Even two decades ago, production and public experience of computational media often required expensive workstations, clusters of compute and rendering machines, and even supercomputers. Powerful personal computers were rare and often custom-built, and the only way to reach broad audiences with computational media was through major distributors who were able to make temporary claims on retail shelf space.

Today, mid-range laptops can perform many of the required production tasks, everyday computing appliances (from game consoles to smartphones) provide a powerful platform for individual experiences, and low-barrier distribution methods have emerged (from app stores to web pages that now operate like programs). In other words, the technical barriers to entry, growth, and diversity have fallen dramatically.

We focus on three areas of opportunity: increasing economic and cultural impact, addressing national priorities, and developing widespread centers for education and research.

In this environment, a set of key opportunities present themselves. Here we focus on three areas of opportunity: increasing economic and cultural impact, addressing national priorities, and developing widespread centers for education and research. These opportunities can only be grasped by addressing key challenges outlined later in this report.

Economic and Cultural Impact

The importance of computational media has grown not simply through the ongoing development of early forms, but through the continual invention of new categories, outreach to new audiences, and development of new approaches and understandings. We have the opportunity, now, to take steps to expand and shape this growth.

We see computational media's impact in part through the creation of new sectors of economic activity. For example, the video game business, which hardly existed four decades ago, is now estimated by DFC Intelligence at $66 billion.[9]

9. "FACTBOX – a look at the $66 billion video-games industry | Reuters," Reuters, last modified June 10, 2013, accessed February 20, 2014, http://in.reuters.com/article/2013/06/10/gameshow-e-idINDEE9590DW20130610.

Sidebar Two: New Forms of Scholarship and Cultural Heritage

Computational media are fundamentally shifting how scholarship and cultural heritage are experienced, the potentials for how they can be experienced, and the objects of study themselves.

Academic articles are increasingly read electronically (rather than on paper) and monographs are moving in the same direction. This presents the potential for moving away from "paper emulation" (as in common uses of PDF) and toward computational media's possibilities for audience interaction, expression through systems, and community engagement. We can already see this happening in cultural heritage, and related areas. An example is the Cleveland Museum of Art's Gallery One — where visitors engage in activities ranging from using a 40 foot touch screen to explore and learn about the context of works in the collection to playful experiences such as using their bodies to match the poses of figurative sculptures or making facial expressions as a way of browsing artworks.[6]

At the Media Systems gathering, Janet Murray of the Georgia Institute of Technology argued that one of the great opportunities presented by computational media is the development of new approaches to scholarly editions and archives — potentially radically reconfiguring the work and the discourse around the work. As an example, she shared her work on the *Casablanca* digital edition, created together with the American Film Institute. This project required rethinking the segmentation of cinematic works, with the elements that scholars and fans wish to refer to (portions of the film, outtakes, script, and more) not neatly corresponding with standard segmentation into acts, scenes, and takes. New types of segmentation allow addressability, which allows juxtaposition, enabling scholarly activities such as comparison to take place in powerful new ways — as well as allowing film scholars the kind of fine-grained citation (and quotation) employed by scholars of traditional literature. This project was significantly more successful than other projects Murray helped create that focused on remediating legacy forms (such as the textbook). Instead, it focused on doing as much as possible to support core humanistic activities, by scholars and students, with the goal of gaining long-term design insights (and leaving aside issues raised by barriers to short-term distribution, such as proprietary rights).

Anne Balsamo, from The New School for Public Engagement, described a new approach to another scholarly form: the monograph. Her *Designing Culture* project is published as a traditional print book, but the chapters engage concepts that Balsamo has also taken on as a computational media designer.[7] The book includes a

6. "About Gallery One | Cleveland Museum of Art," Cleveland Museum of Art, accessed February 20, 2014, http://www.clevelandart.org/gallery-one/about.
7. Anne Balsamo, *Designing culture: The technological imagination at work* (Durham, NC: Duke University Press, 2011).

Computer animated feature-length film, which was still nearing birth two decades ago, is now a major part of the film industry. The mobile app business, which is roughly a half decade old, in recent projections (final numbers are not available at the time of writing) is expected to have reached $25 billion in 2013.[10] Simultaneously, computational media has played a major role in the growth of some of the largest information technology companies, including Microsoft, Apple, Google, and Facebook.

The interdisciplinary nature of much computational media economic impact is not always discussed. One exception can be found in the public explanations from Steve Jobs (which received further attention after his death) as to why Apple achieved success in tablet computing, though other companies had struggled to find a foothold earlier. In 2010 Jobs argued that the "reason that Apple is able to create products like the iPad is because we've always tried to be at the intersection of technology and the liberal arts."[11] And, of course, another company Jobs led — Pixar — is also famous for its integration of disciplines and its economic success. Educating more practitioners who are capable of such interdisciplinary work, and supporting projects and organizations that combine the insights and modes of multiple disciplines, is strongly in our economic interests. But as this report discusses below, our fields are organized in ways that discourage such interdisciplinary undertakings, from the foci of education and funding programs through the department structures of universities and companies.

The video game business, which hardly existed four decades ago, is now estimated by DFC Intelligence at $66 billion

Beyond purely economic considerations, computational media are increasingly integrated into our lives. For example, 67% of U.S. households play computer games, while 70% of U.S. companies use games to train their employees (according to the Entertainment Software Association).[12] In addition to introducing such compelling new forms, the rise of computational media also presents opportunities for reinventing existing forms. We see this in the case of books, with the rapid rise of electronic books (often read on platforms with significant computational power, such as smartphones) producing a steady growth in experiments that

10. "Apps Rocket Toward $25 Billion in Sales," The Wall Street Journal, last modified March 4, 2013, accessed February 28, 2014, http://online.wsj.com/article/SB10001424127887323293704578334401534217878.html.
11. "Why Did Apple Lose Its Humanities? | Fast Company | Business + Innovation," Fast Company, last modified October 25, 2013, accessed February 20, 2014, http://www.fastcompany.com/3020609/leadership-now/why-did-apple-lose-its-humanities.
12. Entertainment Software Association, *Essential Facts About the Computer and Video Game Industry* (2010).

disk with the 1995 *Women of the World Talk Back* interactive documentary that Balsamo created with Mary Hocks, as well as archives and applications from projects such as the Experiments in the Future of Reading exhibit Balsamo created with the RED group at PARC.

Balsamo's talk also discussed an ambitious cultural heritage undertaking — digital projects engaging the AIDS Memorial Quilt — that later formed a major topic of the Media Systems talk from Microsoft Research's Donald Brinkman. These projects explore the potential of digital memorials in an era when, as Balsamo references in Wendy Chun's work, "we must be reminded that memory and storage are not the same thing." Balsamo and collaborators began exploring the concept of creating a digital version of the quilt, allowing one to see and move across its massive surface, in 2001. With the emergence of national support for the digital humanities, a 2010 NEH Digital Humanities Startup Grant allowed them to begin work on the project — and

As an example of the use of computational media, Anne Balsamo and her collaborators created several interactive digital experiences to complement viewing of the physical AIDS Memorial Quilt. The AIDS Quilt Touch Timeline *was installed on the National Mall in Washington D.C. during the Quilt in the Capital 2012 events organized by the NAMES projection Foundation.*

Photography by Sherry Moore, 2012. Used with Permission.

employ computational media approaches within the ebook context. Media Systems participants discussed a number of opportunities arising from this, from engaging interactive narratives to educational texts that enable experimentation (e.g., with simulations, with interpretive visualizations) *in situ.* However, many of the ebook experiments released thus far reflect the incremental work that is possible in low-risk industry contexts or by minimally-funded individual artists, and are often unknowing reinventions of work previously explored during the CD-ROM era or by the electronic literature community (prior work that is unfortunately often unavailable, due to the lack of accessible computational media collections and supported platforms). The transformative leaps envisioned by Media Systems participants will require dedicated research, informed by the field's past. If this is made possible, we will enable high-impact transformations of the communicative and idea generating potential of a wide range of media, both familiar and new.

Further, as computational media plays a larger role, and a longer-term role, in how we understand the world and ourselves, additional opportunities are arising from new historical, critical, and design-oriented interpretive approaches. Such approaches are helping us more deeply understand these media, their impacts, and their potentials. For example, just as the interpretive approaches of dramaturgy help make fictional performances and media more compelling, the newly-arising practices of "software studies" hold the potential to help us understand issues such as how the concepts driving a media work are (or are not) supported by the underlying computational system architecture. This not only presents important information for system designers (which is unavailable using the tools of disciplines such as computer science) but also promises a deeper understanding of how computational media shapes our lives and world views, as we increasingly engage in activities such as social networking and video game playing. Further, the understandings of computational systems that can be developed by students through such interpretation provide invaluable context for interpreting — and acting as informed citizens within — our increasingly computationally-driven culture. However, despite these exciting possibilities, the development of interpretive and educational approaches such as software studies faces significant challenges in areas ranging from disciplinary structure to funding and publication mechanisms.

Finally, computational media is also beginning to better reflect our diversity of cultures and experiences and include a broader range of artistic excellence. This is in part because lowered barriers make creation possible for

The MIT Press has initiated a "software studies" book series, demonstrating how humanistic methods can engage the specifics of software's operations — and offer insights unavailable through computer science methods.

led to an invitation to include their digital version in the physical display of the AIDS Quilt on the National Mall being organized by the NAMES Project Foundation for 2012.

From here a level of complexity in collaboration began to take shape that testifies to the many potential ways that computational media can engage memorialization and memory, as well as to the range of organizations enthusiastic to contribute to this work. The University of Iowa's Digital Studio for Public Humanities began working with Balsamo and her team at USC on a mobile web app, allowing people to find their way to desired panels on the Mall and also experience the quilt remotely. Brinkman became involved, bringing both Microsoft Research's expertise as well as the software and groups of two of their collaborations: the ChronoZoom team (at UC Berkeley and Moscow State University) and the LADS team (at Brown University). This made it possible to pursue both an interactive timeline and a table-sized zooming display of the quilt itself, but there weren't enough development resources to complete all three projects before the quilt was due to be installed on the Mall. By tapping into the Garage program, which encourages Microsoft employees to dedicate time to charitable causes, all three projects were brought to fruition in time. Together they helped demonstrate that computational media experiences can not only provide access to works that are otherwise unavailable, but they can powerfully complement the experience of works that are physically present, contributing to the occasioning of remembering and testifying — as well as to education and critical reflection.

Memorialization is also an important theme for a quite different prototype cultural heritage project, presented at Media Systems by D. Fox Harrell from the Massachusetts Institute of Technology. His *Living Liberia Fabric* is an interactive narrative peace memorial initiated in affiliation with the Liberian Truth and Reconciliation Commission and Michael Best at Georgia Tech. It was created together with Harrell's students, building on his operationalization of "conceptual blending" in the GRIOT research system. It presents itself as an interactive

D. Fox Harrell's Living Liberia Fabric *is the result of combined artificial intelligence, storytelling, and cultural research — creating a new kind of interactive narrative peace memorial. This screenshot shows dynamically placed clickable images representing themes and stakeholders that aid in determining the narrative theme.*

Image courtesy of D. Fox Harrell and his research group, the Imagination, Computation, and Expression Laboratory.

more people, with wider possibilities of team size and budget. But it is also because audiences are coming to expect a wider range of aesthetics and cultural venues for computational media, as smartphones play host to experimental artworks and the Museum of Modern Art collects its first mass-market games.

Addressing National Priorities

President Obama's Strategy for American Innovation[13] identifies a number of national priorities, ranging from broad-based emphases on fundamental research and 21st Century skills to highlighting very specific Grand Challenges: "ambitious but achievable goals that harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination."[14] Computational media has the potential to help address such national priorities in a wide range of areas. In some cases, decades of creation and research (e.g., in computer graphics and spatially-oriented interaction) have developed mature techniques that knowledgeable computational media practitioners can apply in new areas. In other cases, major impact will require design, technology, and interpretive research.

For example, interactive forms of computational media can be highly *intrinsically motivating* — a type of motivation associated with quality learning and creativity — and it would be powerful if we could harness this source of motivation for ends beyond entertainment. This is recognized by the administration's ARPA-ED initiative, which includes as a key goal making "Educational software as compelling as the best videogame."[15] Fully grasping this opportunity would integrate what is understood about engagement, motivation, and communication in domains like the learning sciences with what is known in the arts (including game design), rhetoric, and media studies.

Computational media also has the strong potential to be *customized,* for individuals and groups, both automatically and with human expertise in the loop. It is the nature of computational media that anything explicitly modeled within it can be algorithmically manipulated. For example, in games this is used for "dynamic difficulty adjustment," keeping players in an experience that is appropriately challenging — never becoming boring nor impossible. In intelligent tutoring systems it is used to introduce concepts and their application in the right order and combination for an individual based on their work

13. "A Strategy for American Innovation: Securing Our Economic Growth and Prosperity | The White House," The White House, accessed February 20, 2014, http://www.whitehouse.gov/innovation/strategy.
14. "21st Century Grand Challenges | The White House," The White House, accessed February 20, 2014, http://www.whitehouse.gov/administration/eop/ostp/grand-challenges.
15. The Department of Education, *Winning the Education Future: The Role of ARPA-ED* (2011).

digital cloth, telling stories of post-conflict Liberia from multiple identity perspectives. The metaphor of fabric is drawn from Liberian models of mourning and memorialization and is an instance of Harrell's wider strategy of "cultural computing" — grounding computational media elements (from interface metaphors to system designs) in diverse cultural perspectives appropriate to the audience and subject of the work. The resulting project is a deeply interactive exploration of the diverse stakeholders and themes represented in a large body of video interviews with postwar Liberians, combining the power of traditional and computational media.

Harrell is also one of a number of Media Systems participants engaging in new forms of scholarly inquiry that focus on computational media objects of study, such as software studies, platform studies, and digital game studies. Such work is a promising alternative to viewing computational media solely through the methods developed for previous media. Researchers in this area are focusing on key questions for both understanding past computational media and designing future media, such as the impact of interaction structures, how tools and platforms shape expression, and how meaning is embedded in and expressed through computational processes. At the same time, these researchers remain connected to key insights from the history of the humanities. As Simon Penny, from UC Irvine, memorably put it during the Media Systems opening gathering, software studies is "reading software as if somebody wrote it" — interpreting computational media works in context, from the history of ideas to the history of technical development.

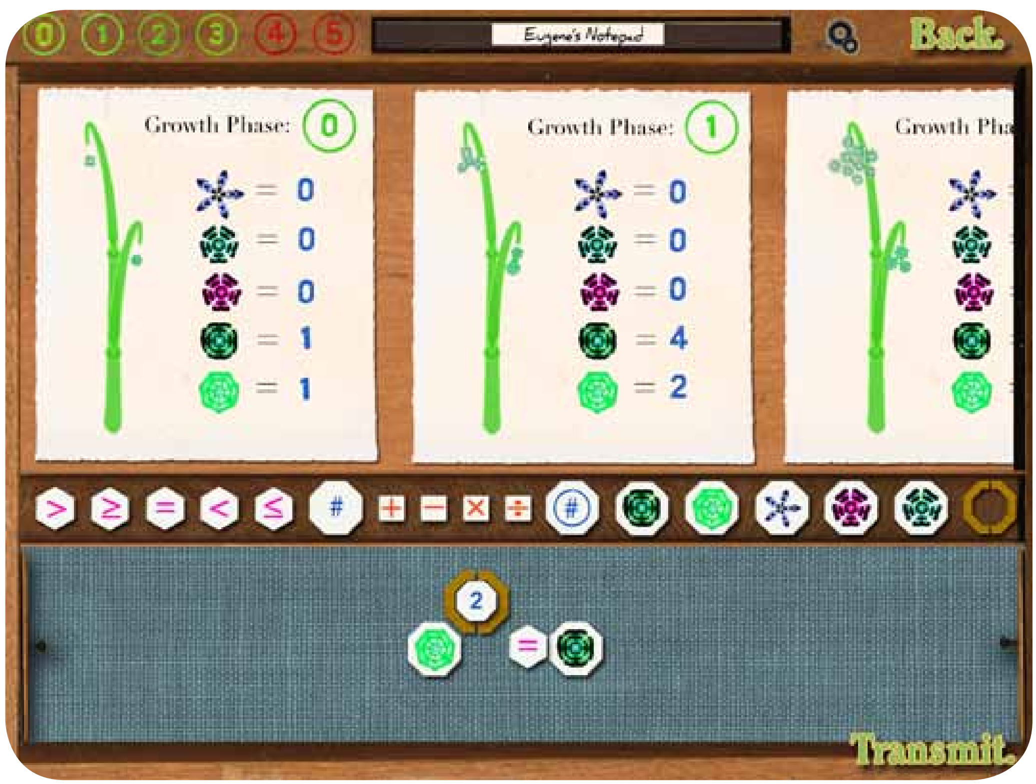
In a related vein, in her Media Systems presentation Pamela Jennings touched on the XSEAD effort and its work toward creating a platform and archive "for those working across disciplines: design, the arts, engineering and science."[8] Using computational media to create, manage, and provide access to archives and documentation of interdisciplinary works (some of which are themselves computational media) is a promising strategy. And in the case of XSEAD it also holds the potential to provide a view of the field's present within the same context.

8. "XSEAD," Virtual eXchange to Support Networks of Creativity and Innovation amongst Science, Engineering, Arts and Design, accessed February 20, 2014, http://xsead.cmu.edu/about.

so far, an exciting potential recognized by the President's grand challenge in this area.[16] Fully grasping this opportunity requires developing models, and modeling tools, for many more domains, so that models of compelling aspects of media experiences (from narrative progression to image composition) can be combined with models of learning and behavior.

These potentials in motivation and customization could be transformational in traditional and informal education, in training for a wide variety of contexts and areas, and also in areas such as health education and health intervention. Many public health issues require large scale behavior changes, which can come about through a combination of education and motivational aids for changing habits. Computational media have a powerful role to play here, as shown in the national Games for Health conference.[17] This role also extends to national goals in areas such as development, where grand challenges include reducing complications and mortality in childbirth. Computational media research is already showing promise for purposes such as providing engaging, cellphone-based education for childbirth assistants.[18]

Combining human insights, through interactive computational media, with the best results from purely algorithmic approaches holds great promise in many areas. The game Xylem *is an example of research into doing this for creating more reliable and secure software.*



16. "21st Century Grand Challenges | The White House."

17. "Games for Health," Games for Health, accessed February 20, 2014, http://gamesforhealth.org/.

18. Holloway, Alexandra, and Sri Kurniawan, "System design evolution of The Prepared Partner: How a labor and childbirth game came to term," *Meaningful Play* (October 2010).

Opportunities and Current Context

Computational media also represent a powerful tool for developing new knowledge. The intrinsic motivation provided by social interaction and puzzle solving in computational media has already been harnessed for such tasks as producing protein-folding solutions and image processing datasets that would be otherwise intractable to create.[19] There is great potential not only in these kinds of computational media-driven harnessings of human perception and creativity, but also in exploring novel combinations of these with best-of-breed autonomous computations. This approach is already being used in areas such as formal software verification (which could make software used in mission critical contexts much more reliable) and could be applied in contexts such as the administration's BRAIN Initiative.[20] As with education and health, fully seizing opportunities in this area requires harnessing motivation and developing deeper customization, so that media can be automatically generated for exploring and verifying areas of knowledge.

Computational media are also particularly powerful for representing how systems shape our world — from civic engagement to climate change. This is a dynamic way of reaching the public, particularly generations that have grown up with computational media. For example, at the Media Systems convening Ian Bogost discussed how traditional media coverage of the proposed 2007 merit-based green card system in the U.S. Congress merely cut and pasted examples of how the system would function from press releases. On the other hand, his game, *Points of Entry: An Immigration Challenge* (published by *The*

Computational media can make public policy issues experiential — with implications and alternatives easier for the public and students to understand. Points of Entry, *a game created by Persuasive Games and published by The New York Times, does this for a proposed merit-based green card system.*

Screenshot courtesy of Persuasive Games.

19. Firas Khatib et al., "Algorithm discovery by protein folding game players," *Proceedings of the National Academy of Sciences* 108, no. 47 (2011). Von Ahn, Luis, and Laura Dabbish, "Labeling images with a computer game," *Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 319-326. ACM, (2004).

20. Heather Logas, Jim Whitehead, Michael Mateas, Richard Vallejos, Lauren Scott, John Murray, Kate Compton, Joseph Osborn, Orlando Salvatore, Dan Shapiro, Zhongpeng Lin, Huascar Sanchez, Michael Shavlovsky, Daniel Cetina, Shayne Clementi and Chris Lewis. "Software Verification Games: Designing Xylem, The Code of Plants." (Paper presented at the 9th International Conference on the Foundations of Digital Games.) Forthcoming. "Brain Initiative | The White House," The White House, last updated April 2, 2013, accessed February 20, 2014, http://www.whitehouse.gov/share/brain-initiative.

New York Times) made a game system of the proposed rules, giving the public a place to experiment with (and develop a deeper understanding of) the way such an approach would work in practice.[21]

Further, crafting such representations can be a powerful educational experience, combining thinking about system modeling, developing media engagement and rhetoric, and practicing team collaboration skills. Fully seizing this opportunity also requires overcoming a variety of challenges, from the need for educating more deeply interdisciplinary practitioners to supporting the experimental media creation that will help develop new design and technology vocabularies (as discussed in the Challenges section, these are necessary because simply “re-skinning” an experience of spatial navigation or combat with images of social or scientific issues will not be effective).

Centers for Education and Research

The growing cultural and economic importance of computational media has led to another opportunity — in education and research. New generations of students, having grown up with computational media as central to their lives, and having witnessed its rapid evolution, are hungry to create and innovate in computational media forms. This has the potential to attract more students to educational experiences that will help them learn technical skills (helping address the serious shortfall the U.S. faces in this area) together with the creative, interpretive, and collaboration skills necessary for computational media. There is also some evidence that such programs may attract a more diverse population than some other educational programs teaching comparable skills.

As an example, consider the Computer Science: Game Design B.S. launched at UC Santa Cruz in 2006. This degree includes all the major elements of a computer science degree, from exposure to a variety of areas of CS to a grounding in mathematics. It also requires courses in the arts, as well as at least five courses specific to game design and development (which use media/technology design to integrate 21st Century skills around creativity, problem solving, and critical thinking with those around communication and teamwork), making it one of the most demanding and interdisciplinary degrees on campus. Despite these high demands, it quickly grew larger than the traditional CS degree — and was soon the largest degree in the School of Engineering, enrolling roughly 400 students. Further, it did not accomplish this by diminishing the traditional CS degree, but rather seems to have helped draw more people to that degree, as some students expressed interest in coming to the department to work on games but preferred a more traditional degree. Finally, over the first five years of the degree, among undergraduate students who had declared or proposed the games major, 19% were from

21. “Persuasive Games – Points of Entry,” Persuasive Games, accessed February 20, 2014, http://www.persuasivegames.com/games/game.aspx?game=nyt_immigration.

underrepresented ethnic groups, a significant improvement over the traditional CS degree.

Over the last two decades, the potential for such interdisciplinary degrees has grown considerably, due to the fact that many colleges and universities have now founded one or more programs or centers in areas connected to computational media — often under umbrellas such as digital arts, video games, new media, or digital humanities. For example, nearly 300 colleges and universities are members of the New Media Consortium. The Princeton Review considered 150 programs in its most recent rankings of undergraduate video game degrees.

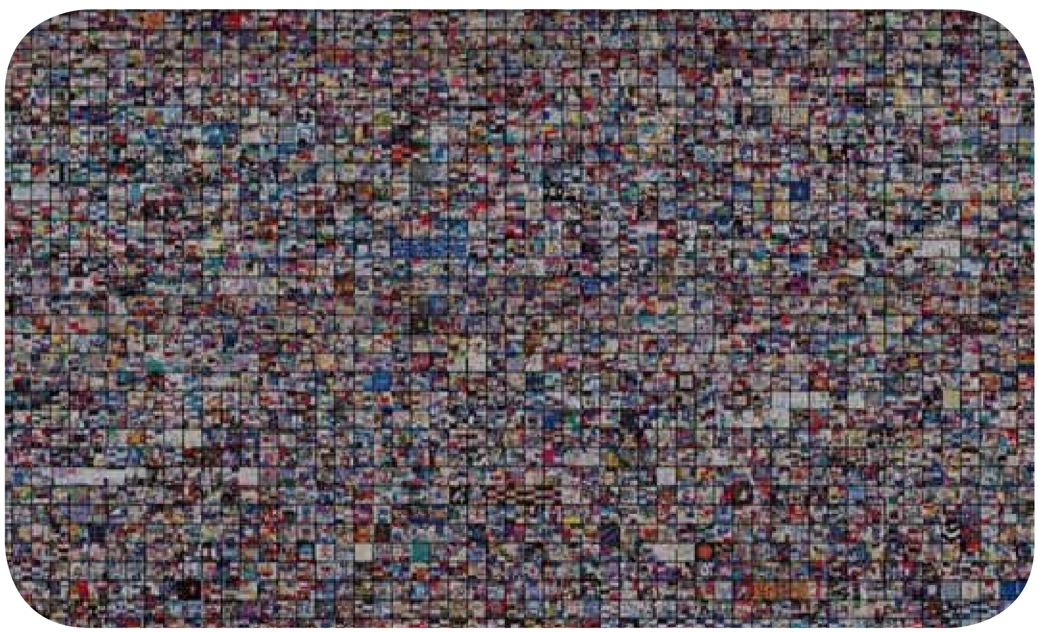
Such programs have the potential to become homes for interdisciplinary teaching and research. They often already affiliate faculty from multiple departments and disciplines and attract students with a passion for genuinely interdisciplinary work. With greater support for overcoming the challenges such programs face, as discussed below, they could become the seeds from which the next stage of computational media could flourish.

A strong example of such a center in a university context is the New York University MAGNET ("Media and Games

The New York University MAGNET ("Media and Games Network") Center is an example of a new generation of centers for computational media research and education. It physically brings together faculty and students from computer science, game design, engineering, learning sciences, digital media, and other disciplines — for the first time in NYU's history.

Network") Center, which arose from faculty collaboration in computational media across NYU's Polytechnic Institute; Steinhardt School of Culture, Education, and Human Development; Tisch School of the Arts; and Courant Institute of Mathematical Sciences.[22] The NYU Provost's office invested in shared physical space for faculty, graduate students, laboratories, production facilities, a game library, and classrooms. This facility, of nearly 40,000 square feet, brings together activities and people that would otherwise have been located in dispersed areas of Brooklyn and Manhattan — creating the opportunity for types of interdisciplinary research and education collaboration that would have otherwise faced high barriers. This interdisciplinary computational media co-location is the first collaboration of its kind between NYU's schools and institutes.

Another potential site for successful research centers is industry. Computational media work in industry is often highly interdisciplinary, with organizations like Pixar and Microsoft Studios routinely assembling teams of innovative technical, artistic, and even interpretive thinkers. Here, again, challenges would need to be addressed for a significant number of these interdisciplinary teams to engage basic computational media research, but if this occurred they would become an important force for addressing priorities such as those discussed above.



Creation of the zooming version of the AIDS Quilt involved collaboration between two funders (NEH and Microsoft Research), four universities (in three time zones), and the Garage program through which Microsoft employees can volunteer time.

Screen shot of Interactive Tangible Browser for the AIDS Memorial Quilt *interactive experience; image of array of 48,000 panels of the AIDS Memorial Quilt.*

Used with Permission.

22. "NYU to Open Media and Games Network in Brooklyn," New York University, last updated March 19, 2013, accessed February 20, 2014, http://www.nyu.edu/about/news-publications/news/2013/03/19/nyu-to-open-media-and-games-network-in-brooklyn.html.

Sidebar Three: Learning with Computational Media

One of the most promising application areas of computational media is in learning, including formal education and training as well as informal, sometimes playful learning — and in a wide variety of domains. There are already exciting learning applications of computational media, and much basic research in computational media has potential benefits in this area. Media Systems participants addressed this from a variety of directions.

Janet Kolodner — from Georgia Tech, but currently program officer for Cyberlearning at the NSF — discussed the way computational media is positioned in the cyberlearning frame. Interactive media and experience design are discussed as part of *learning technologies*, with the focus on the socio-technical systems and ecologies of use. Seen this way, some of the most important potentials for computational media are: enabling learners to experience things that simply aren't possible without technology (e.g., getting inside a cell, seeing the development of the cosmos); connecting with communities it would otherwise be impossible to be in dialogue and shared learning with; providing learning scaffolding that helps people do things they couldn't otherwise, and grow in their capabilities through it; and rich, timely, personalized feedback during the learning process. The cyberlearning research direction attempts to make progress in areas such as these by integrating advances in computational media with advances in what is understood about how people learn.

Janet Murray, in her talk, addressed lessons learned from working with educators in both language learning (at MIT) and engineering (at Georgia Tech). Murray talked about how great teachers, who often hate computers, have insights into student learning that range from the explicit and systematic (e.g., common

The NSF-funded Interactive Toolkit for Engineering Learning (InTEL) project is aimed at motivating underrepresented minorities and women to become engineers by creating entry-level exercises based on real world situations, like the New Orleans levee problem shown above. Creating abstract representations of real situations helps all students learn the abstraction processes recognized as "thinking like an engineer," but it remains challenging to integrate computer-based learning environments into the text-book and lecture-based culture of introductory engineering courses.

Copyright Georgia Institute of Technology.

While computational media work already has significant impact, and presents great opportunities for future contributions, it also faces a significant range of challenges.

Need for Basic and Applied Interdisciplinary Research

At the Media Systems convening, Janet Murray declared:

"There has to be someplace where you say, 'How do we reconfigure knowledge?' Because that is what happens when you have a new medium of representation, as with the printing press. And we're not making fast enough progress there, because nobody's getting rewarded for it, nobody's being paid to do it."

Murray's call points to significant structural challenges facing the computational media field — challenges that make significant research progress difficult to achieve. Currently, computational media work in industry is often highly interdisciplinary, as noted above. But the work is generally focused on the results needed for a specific product. Teams dedicated to basic research — tackling the high-risk, high-payoff questions — are rare. Further, the processes of product creation and basic research are in tension. Commercial media products, after an initial period of "pre-production," generally need to minimize risks and unanswered questions, instead working relatively predictably toward an end goal. True research, on the other hand, includes the risk of failure, the pursuit of potentially unanswerable questions, and the potential to change direction as more is learned. This tension is often particularly pronounced for small computational media companies, where the success of near-term products may be necessary for survival.

On the other hand, organizations in which basic research is the norm, such as research universities, have a hard time assembling and maintaining interdisciplinary teams. This is for a variety of reasons explored further in this section, including: their institutions and institutional success criteria are often strongly disciplinary, their funding sources may provide no appropriate programs or mechanisms for such work, and their opportunities for publication and other research impact are determined by peer reviewers who may apply inappropriate metrics to judging their success. As a result, most progress in computational media research is made, and justified, in the context of something other than its contributions to computational media.

This is related to another challenge facing the field — a lack of balance between basic and applied research. For example, in games research, by far the largest investments are in applied research: games for training, games for health, games for education, games for crowdsourcing knowledge, and so on. It is appropriate to make these investments, seeking to build on the opportunities outlined above, but applied research needs to be in better balance with basic research for the field to "cognitive glitches" students experience with the material) to the unspoken and perhaps unreflected-upon (e.g., the "embodied knowledge" shown in how teachers use gestures and draw diagrams when explaining concepts). But at the same time, as computational media systems and simulations are brought to bear for learning, issues arise that disrupt field epistemologies, which can cause problems for work with educators. For example, the Georgia Tech engineering team was creating computational media for learning that was based on real-world problems, rather than abstractions, in part to see if this would appeal more to women and minority groups.[23] However, while some members of the team had imagined creating physics "sandboxes" in which things could be constructed and then potentially collapse, this ran strongly against the established pedagogy of the department, which teaches "statics" separately from "dynamics." And in the end, it was very difficult to get established educators to adopt new computational media learning materials, even when they did stick to the established category of "statics" topics. Murray identified experiments with radically reorganizing curricula around the possibilities offered by computational media as a key place where field funders could make a difference.

Ken Perlin, in his talk, offered a vision of how computational media can become integrated throughout the curriculum, as something both written and read. This began with a split-screen interface that allows both reading of a particular section of a book and a view of the entire manuscript. Using *Pride and Prejudice* as an example, Perlin showed how simple buttons could be used to let students ask "distant reading" questions of the sort popularized by digital humanities, such as looking at the patterns of mention (and collocation) for key terms such as the names of major characters and locations. He showed how the code could easily be exposed and modified for creating new buttons, and how doing this in a live, shared document could enable new kinds of classroom conversation. Such capabilities are the foundation of his approach.

Next Perlin demonstrated the same kinds of connections between code and media views for three-dimensional objects. The first version of an object can be created with a gesture — a mouse gesture, or an embodied gesture detected by a Kinect-style sensor — and this object can then be viewed both as an object and as code, with bridges back and forth. These bridges include code changes making live updates to the visual representation of objects, with widgets showing up on the visual representation of the object one is editing in code, and with changes made using these widgets producing live updates in the code. This extends not only to objects but to animation, with the ability to change shapes and blending operations while

23. Sue V. Rosser, "Keys to the Engineering Gateway: Using Creative Technology to Retain Women and Underrepresented Students," *On Campus With Women* 37, no. 2 (2008), accessed February 28, 2014, http://www.aacu.org/ocww/volume37_2/feature.cfm?section=1.

move forward. Applied research helps define questions and creates impact, but basic research provides the foundational understandings and capabilities that allow applied research to make major strides.

At UC Santa Cruz we saw this point illustrated in an unexpected collaboration with the University of Washington. We were engaged in basic game research, inspired by humanistic game studies and the practices of game designers, looking at ways to computationally model game rules. As part of this research, one of our graduate students was using these representations to create an art game — a game that changed its rules every time it was played — discovering ways this work could be used generatively. Simultaneously, UW had a major research project in educational gaming, with one of the goals being the generation of customized levels for individual learners, reflecting the understandings players had demonstrated (and failed to demonstrate) in their play thus far. But this turned out to be impossible when approached as applied research. Standard techniques, such as depth-first search, either took too long or failed at the task completely. Luckily, our PhD student Adam Smith was personal friends with a PhD student at UW, and arranged to spend the summer working there with her. And it turned out that the techniques developed in our basic research at UCSC enabled fast generation of levels for the UW game that were guaranteed to be solvable by players, that matched player progress (demonstrated mathematical and spatial skills) to that point, with prescribed visual aesthetics in element placement, and with guarantees that they could not be solved without students employing the intended concepts. This combination of

Generating customized levels for players of the educational game Refraction *proved impossible when approached as applied research. The problem was addressed by using techniques of game representation and generation drawn from basic research combining computer science, game design, and humanistic game studies. Unfortunately, such basic research in computational media is currently difficult to initiate and sustain.*

animations are happening, giving the impression that the model is being updated every animation cycle. This not only invites experimentation and refinement using both code and visual modes, but builds deeper understanding of the connection between the two. It makes code a powerful path for media creation — enabling iteration, scaffolding, and incremental movement to deeper engagements with the code level.

Returning to Perlin's foundations in the extended book, he showed how these connected visual/code objects could be embedded within it. The reading and writing of visual/code objects — from smart, engaging characters to revealing visualizations — can take place in the same context as, and interact with, bodies of text. In short, Perlin showed a working demonstration of a platform for collaborative reading and writing of this new sort, defining a potential future in which we stop asking how students will learn programming and the vocabularies of computational media, and instead make these an embedded part of learning every subject.

One UC Santa Cruz project (mentioned by both Michael Mateas and Noah Wardrip-Fruin) shows the unexpected ways that research projects can contribute to learning. This project, *Prom Week,* was the guiding application for basic research on how to make a model of social interaction *playable,* just as past research has made models of space and economics playable.[24] This required developing novel computer science social simulation techniques, guided by arts storytelling and humanities media studies approaches. This work was so successful that it began almost immediately to have applications in learning contexts. First, its AI system became a major component of the European Union FP7 project SIREN, aimed at creating games to help children learn strategies for addressing cross-cultural conflict. This new use required further interdisciplinary connections, especially being informed by social sciences (e.g., ethnographies of playground bullying).[25]

The next use, now underway, stems from combining the results of the *Prom Week* research with another interdisciplinary effort in computational media research. Mateas and Andrew Stern are the creators of the first interactive drama, *Façade,* which required developing novel computer science reactive planning and multi-agent coordination techniques guided by humanities and arts theories of dramatic writing and action.[26] These are now being brought together with *Prom Week*'s social simulation to create a project for DARPA's Strategic Social Interaction Modules program, aimed at helping soldiers learn embodied approaches for de-escalating conflicts in the field.[27] This project requires further computer science advances, guided by the non-verbal

24. Josh McCoy et al., "Social Story Worlds with Comme il Faut," *Transactions on Computational Intelligence and AI in Games special issue on Narrative* (forthcoming).
25. Georgios N. Yannakakis et. al, "Siren: Towards adaptive serious games for teaching conflict resolution," *Proceedings of ECGBL* (2010): 412-417.
26. Michael Mateas and Andrew Stern, "Façade: An experiment in building a fully-realized interactive drama," in *Game Developers Conference* (2003): 4-8.
27. Daniel Shapiro et al., "Creating Playable Social Experiences through Whole-Body Interaction with Virtual Characters." (Paper presented at the Ninth Artificial Intelligence and Interactive Digital Entertainment Conference, Boston, Massachusetts, October 14-18, 2013.)

applied and basic research was so successful that we published a joint paper about it.[29]

But in many cases, when applied computational media research runs into trouble, there is no such fruitful connection made with basic research — because so much less basic research is supported. And this, combined with the structural issues noted above (and with the exception of notable bright spots), has the result that both industry and universities have difficulty making sustained progress on the most high impact computational media questions. Finding ways to change this situation is one of the most pressing challenges facing computational media, if the opportunities outlined above are to be seized. Potential strategies are discussed in the Recommendations section.

Need for More Interdisciplinary Practitioners and Greater Diversity

The work of computational media requires interdisciplinary teams — often including experience and system designers, programmers, visual artists, writers, musicians, subject matter experts, and more. The work of such teams is made slower and harder when the participants have primarily disciplinary training, and some kinds of goals are simply unreachable without team members and managers who can think and communicate in terms of the capabilities, methods, and vocabularies of multiple disciplines.

The computer game industry has created special job categories for certain types of interdisciplinary team members, such as “technical artist” (connecting visual art and computer science) and “gameplay programmer” (connecting experience design and computer science). But these jobs are exceptionally difficult to fill, because very few are prepared for this work by their educations, and developing this kind of expertise “on the job” requires taking highly-skilled workers and encouraging them to begin spending a significant amount of their time learning about domains in which they are effectively novices.

Some goals are simply unreachable without team members and managers who can think and communicate in terms of the capabilities, methods, and vocabularies of multiple disciplines.

29. Adam M. Smith et al., “A case study of expressively constrainable level design automation tools for a puzzle game.” (Paper presented at the annual Foundations of Digital Games conference, Raleigh, North Carolina, May 30 – June 1, 2012.)

communication knowledge of both the arts (e.g., animation and theater) and the social sciences, as well as reasoning about participant experience guided by the learning sciences.

Projects such as these and Perlin's demonstrate how basic research in computational media, guided by the goal of enabling powerful new media forms, opens new doors for learning applications. They also show the range of interdisciplinary connections that are important for both basic and applied research in this area.

Of course, already-developed computational media technologies also have the potential for enabling new educational experiences, as seen particularly in a range of discussions about MOOCs (Massive Open Online Courses) at Media Systems. MOOCs represent one possibility for using the network communication modes of computational media (e.g., delivering live or pre-recorded video, engaging large numbers in online discussion forums) to create large learning communities. Kolodner discussed how MOOCs are of interest in a cyberlearning context. Murray warned against the premature monetization being attempted by many MOOC supporters, while the basic research on this and related forms of collaborative, online learning was still in early stages. Anne Balsamo presented an alternative formulation, the DOCC (Distributed Online Collaborative Course) or MDCLE (Massively Distributed Collaborative Learning Experiment).[28] The DOCC differs from the MOOC in a number of ways, perhaps most importantly in emphasizing that expertise is distributed throughout the online learning community, rather than flowing outward from a central source.

The Immerse project is an example of computational media research in training for "soft skills" — it is developing embodied approaches to social training (and conflict de-escalation in this instance). The work requires innovations in computer science and experience design that are driven by insights from the performing arts and social sciences.

28. "DOCC 2013: Dialogues on Feminism and Technology," FemTechNet Commons, accessed February 20, 2014, http://femtechnet.newschool.edu/docc2013/.

The same problems present themselves in universities, where attempts to hire deeply interdisciplinary faculty (e.g., bridging areas such as computer science and media arts or literary history) often fail. This may at times be because of institutional conservatism (as discussed in another section) but it is also because there are simply not enough individuals with appropriate interdisciplinary training. As a result, some of the initiatives needed to address the serious shortfall of interdisciplinarily-trained computational media practitioners never get off the ground — and a significant number of others end up being led by faculty who lack the kinds of interdisciplinary understandings that they are trying to help their students develop. We have also seen, as Ian Horswill pointed out at the Media Systems gathering, that training students in one traditionally-structured discipline and sending them to take a selection of courses in another traditional discipline mostly fails. Students generally take (and may be restricted to taking) the non-major courses in other disciplines, never really learning how those who practice those disciplines think and work.

Further, not only is there a need to educate many more interdisciplinary practitioners, at all levels, but it is also necessary to find ways to involve more diverse populations in computational media creation and education. For example, in 2005 the International Game Developers Association reported depressing statistics in the game industry: women made up only a little more than 10% of game developers, while black and hispanic participation were at roughly 2% each.[30] Diversity in the game industry has remained a significant problem, and more recently researchers have found that this lack of diversity is mirrored in the undergraduate populations of many game degree programs, making educational institutions sometimes a contributor to, rather than potential means of addressing, these diversity issues.[31] At the same time, other programs are much more successful at attracting diverse populations — and the fact that gender inequities in computational media can be addressed was an important "lesson learned" presented by both Brenda Laurel and Janet Murray at the Media Systems convening.[32] These issues are discussed further in the Recommendations section.

Institutional and Disciplinary Conservatism

Institutional and disciplinary conservatism has made the growth of many interdisciplinary fields challenging. For example, academic departments, journals, and funders all struggled during the rise of human-computer interaction to support work

30. Adam Gourdin, *Game Developer Demographics: An Exploration of Workforce Diversity* (IGDA, 2005).
31. Amber Settle, Monica M. McGill, and Adrienne Decker, "Diversity in the game industry: is outreach the solution?" (Paper presented at the 13th annual ACM SIGITE conference on information technology education, Orlando, Florida, October 10-12, 2013.)
32. Examples of interventions that have shown progress with gender inequities in computing fields include: Jane Margolis and Allan Fisher, *Unlocking the clubhouse: Women in computing*, (Cambridge, MA: MIT Press, 2003). Charlie McDowell, Linda Werner, Heather E. Bullock, and Julian Fernald. 2006. "Pair programming improves student retention, confidence, and program quality." *Communications of the ACM* 49, no. 8 (August 2006), 90-95. Christine Alvarado and Zachary Dodds. "Women in CS: an evaluation of three promising practices." (Paper presented at the 41st ACM technical symposium on Computer science education (SIGCSE '10). ACM, 2010, 57-61.)

that was, in many respects, obviously valuable — but also arguably not a good fit for mathematically-descended computer science (where many departments most highly prized questions about theory of computation) or for experimentally-oriented psychology (where timelines, funding models, and skillsets made building novel computational systems a challenge). HCI still faces some challenges in this regard, and the digital humanities and digital arts even more so.

One possible response is to retreat from interdisciplinarity, so that digital artists, for example, might focus on work that is possible with tried-and-true system designs (implemented in commercial, off-the-shelf technologies) and produce work designed to succeed according to traditional arts evaluation criteria. Obviously such work can make very strong contributions to its home discipline. But it cannot contribute to the deep interdisciplinary work that will move computational media forward — and that created the conditions of possibility for such new forms of disciplinary work to even exist. In the Recommendations section we discuss possible means of supporting deeply interdisciplinary computational media work.

In addition, at the Media Systems convening Janet Murray reminded us that similar conservatism creates challenges for adoption of computational media innovations — in her experience at MIT, she saw mathematics education held back by professors wanting to keep their students using slide rules, rather than experiment with new computer tools. Individuals, professions, and institutions may be concerned about objects (e.g., books) and rituals (e.g., exams) rather than focusing on core activities and goals, where computational media approaches might have powerful contributions to make.

Need for New Computational Models and Genres

Computational media grows in significance through the development of new computational models and genres. For example, the development of 3D computer graphics began by creating computational models of visual perspective and other knowledge from the visual arts. These models then enabled the creation of new media genres — from computer animated films to a wide range of video games, visualizations, and virtual reality applications. Similarly, the development of hypertext took place through attempts to model ways that knowledge is interconnected, building on humanities practices such as the footnote. This has enabled a range of new media genres, the most significant being the linked World Wide Web "page" — which has transformed knowledge dissemination over the last two decades.

Such already-established models and genres are powerful, but for many purposes they are inappropriate. A model of space (well established by computer graphics) generally can't be used as a model of specific knowledge, creative practices, belief structures, contingent behaviors, relationship networks, or storytelling traditions. And for computational media to deliver on its potential in areas such as learning, health, artistic expression, and economic development, it will be necessary to reach new audiences in new ways — through the kinds of genres that could be enabled by models in new areas. Unfortunately, in many such areas, not only have appropriate models and genres not yet been established, nor strong possibilities for them invented, but in some cases they have not ever been given significant research attention.

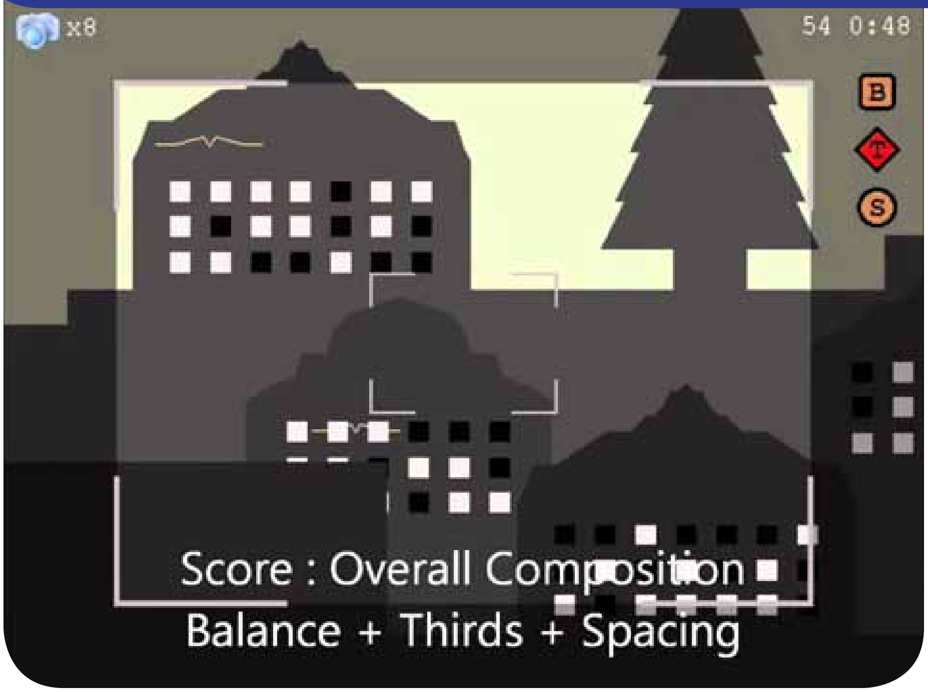
At the Media Systems convening, this key challenge was initially discussed in relation to the practice of "operationalization."[33] Nick Montfort, from the Massachusetts Institute of Technology, defined this practice as the formalization of theories from the humanities, arts, and social sciences and the implementation of these in a computational system, where they can be effective in new ways and "tested" in certain senses. Montfort demonstrated his work in operationalizing parts of formal narratology — which connected to an overall Media Systems theme, seeing the development of new models and genres of narrative as one of the most promising current fields of computational media research.[34] Mary Lou Maher, from the University of North Carolina at Charlotte, presented her work operationalizing models of creativity in different domains, including the ways that designers often operate in ways quite different from engineering culture, such as by changing the problem definition itself.[35] But such research is currently quite difficult to carry out, as Michael Young (from North Carolina State University) noted during Media Systems. The work of

Creating formal, computational models of new domains can enable new forms of media — and new tools for media making — by extending models from arts, humanities, and psychological work with media and creation. It can also provide new insights about the models themselves, as seen in Mary Lou Maher's research on curiousity, creativity, and the design processs.

33. The Media Systems organizers chose "operationalization" both because it is a term often used to describe work of this sort and because it is a somewhat provocative term. Its use in the Media Systems program and in this document is intended to call attention to two aspects. First, it references thoughtful practices of formalizing, further developing, and systematizing knowledge from other disciplines. Second, it highlights the related dangers of oversimplification, appropriation, and misapplication.

34. Nick Montfort, "Curveship: an interactive fiction system for interactive narrating." (Paper presented at the Workshop on Computational Approaches to Linguistic Creativity, Boulder, Colorado, 2009.)

35. Mary Lou Maher and Josiah Poon, "Modeling Design Exploration as Co-Evolution," *Computer-Aided Civil and Infrastructure Engineering* 11, no. 3 (1996): 195-209.



The Panorama *game developed by Arnav Jhala's Computational Cinematics Studio operationalizes traditional aesthetic rules often taught in beginning photography, such as compositional balance and the rule of thirds, to make a game about selecting photos to take in an endless landscape. Used this way it can provide an engaging way to learn foundational photographic skills — and in another mode it can be used as a data collection game to crowdsource public aesthetic judgements of image composition, which then themselves could be operationalized in other contexts.*

operationalization almost always involves novel scholarship both in computational systems and in the area being modeled, and (as outlined above) few individuals are prepared to do both types of research, while interdisciplinary teams are difficult to assemble and support.

Beyond operationalization, Media Systems participants discussed a number of other routes towards new models and genres (as discussed further in the "New Forms of Scholarship and Cultural Heritage" section). D. Fox Harrell presented the related practice of "cultural computing" — explicitly grounding computational work in diverse cultural perspectives, drawing models of both interface/ interaction and internal system operation from cultural practices that are not necessarily media-centric. Maher's work, as well as Harrell's, is also often situated within the realm of "computational creativity." This might be seen as a particularly developed sub-area of operationalization, in which a model or theory of creativity is at the center of most projects in the field, and which is characterized by the significance the community places on projects being able to produce *surprising* results.[36] Others, such as Anne Balsamo and Janet Murray, presented prototypes of new cultural heritage and scholarship genres. Though these are grounded in conceptual models and work practices of current research and dissemination, to call them "operationalizations" of such practices would be misleading. In these cases as well, the lack of appropriate, existing models and genres makes widespread adoption and experimentation with important approaches in computational media impossible.

36. Maher's talk outlined "novelty, value, and surprise" as important aspects of creative systems, and this is in line with much thinking in the computational creativity community. Anne Balsamo brought up the potential cultural specificity of these values, that not everyone sees these aspects as the hallmark of creativity. Maher responded that she had certainly encountered this: from another cultural perspective — not that of engineering, but perhaps that of arts and humanities — "intentionality, aesthetics, and emotional response" are associated with creative works. This was one of many moments at Media Systems that underlined the importance of describing what one means by key terms in interdisciplinary contexts, rather than assuming all involved understand concepts such as "creativity" in the same way.

Need for More Sophisticated Tools, Platforms, and Infrastructure

In areas where there have been significant investments in research and commercialization, such as 3D modeling and animation, robust creation tools exist. But even these are largely only usable by experts. And in other areas tools of any sort may simply be unavailable. As a result, the creation of computational media is restricted to those who can master the techniques, and take the time, to create anew what is needed for each piece of media. This is a challenge even for large companies, where the available talent can be difficult to recruit and combine into functioning teams. For others — such as educators, journalists, artists, non-profits, government agencies, and scholars — the creation of sophisticated computational media, capable of delivering the messages and experiences they wish to share, is often simply out of reach.

This is true even in areas with long histories and robust economic presences, such as game development. While a variety of “game engines” and game creation tools handle the physical world of games (spatial arrangement, physics), and “middleware” and “backend” tools may handle aspect such as path-planning or networking, the fundamental activities of game system and experience design are completely unsupported. Available tools don’t even provide a representation of game mechanics, resource management, challenge progression, game balance, and other relatively formal elements — much less areas like game feel or narrative experience.

Similarly, scholarly tools for doing research on computational media are almost completely non-existent. This is despite their demonstrated power for more traditional scholarship, for everything from textual analysis to citation management. Instead scholars who are trying to understand computational media, or designers who are trying to learn from it, must use tools created for tasks such as software development. And even this can only happen when the needed resources for this research are available (as discussed further below).

At the Media Systems convening there were discussions and demonstrations of a number of new approaches to tools for computational media. Ken Perlin’s tool demonstrations, which focus on a smooth connection between simple and code-level media authoring, are discussed further in the sections on new forms of media and on learning with computational media. A different approach to tool making was evident when Ian Bogost and Michael Mateas each discussed their joint work on an in-development tool called Game-o-Matic.[37] The goal of this project was to create a tool that would allow journalists and others to quickly create games about issues and ideas. The work began with careful humanistic and

37. Mike Treanor et al., “The micro-rhetorics of Game-o-Matic.” (Paper presented at the International Conference on the Foundations of Digital Games, Raleigh, North Carolina, May 30 – June 1, 2012.)

design studies of existing games on political issues as well as closely-related non-interactive forms, such as the political cartoon. The first version of the tool (as demonstrated at Media Systems) allows creators to work at the idea level: creating a concept graph illustrating their point of view on the topic. A complex artificial intelligence system then attempts to put together game elements that can represent different "micro-rhetorics" that are present in the concept graph, while also assembling a larger game structure with coherent rules, controls, and win conditions. A large number of candidate games are produced, which the human author can select from, playtest, and potentially "skin" with images and publish to the Web. In approaches such as this one, the future of computational media creation tools is envisioned as dialogue between human authors that have something to express and intelligent tools that can offer meaningful ranges of media choices in response.

Of course, even once new works of computational media are created, they must somehow be distributed and found by audiences. With media forms such as books, institutions such as libraries and specialty bookstores formed essential infrastructure that helped works reach appropriate audiences. The transition to computational media forms has undermined the economic models of much prior infrastructure (e.g., Amazon's web presence and the rise of ebooks have both undermined specialty bookstores) and even the best examples of computational media-specific infrastructure (e.g., Valve's Steam platform for games) lack much of what made prior forms of infrastructure valuable. Further, in some areas, such as academic publishing, almost no new infrastructure has arisen to take the place of what has been eroded. As a result, though near-instant access to a wide range of media possibilities provided by current computational media

Game-o-Matic is a collaboration between Digital Media at the Georgia Institute of Technology and the Expressive Intelligence Studio at UC Santa Cruz. Funded by the Knight News Challenge, it is a tool for generating journalistic games (or newsgames) through a simple "concept mapping" of relevant actors and their relationships. Game-o-Matic addresses a key problem facing the adoption of newsgames by traditional media sources: the expense, time, and expertise required to craft regular videogame content. Game-o-Matic relieves the burden of programming and design while encouraging journalists to think of news events as systems rather than as stories. Game-o-Matic can also be used as a general design tool for thinking about the relationship between things, the metaphorical potential of game mechanics, and procedural rhetoric. It is a demonstration of a highly-accessible direction for future computational media tools, enabled by combined technical, humanistic, and design research encompassing artificial intelligence and new forms of computational expression.

infrastructure is in many ways a great boon, the work of cultural institutions such as libraries must be reimagined and extended in this new era, as discussed further below.

Need for Deeper, More Accessible Collections

The computational media field is in danger of losing its history. While digital preservation projects are finally looking beyond preserving digital “documents” and moving toward preserving software, many computational media artifacts have never been collected (such as the majority of field-defining research projects) and others may still reside only on highly fallible media (such as floppy disks). There is some hope, given the work of everyone from hobbyists to professional archivists, but more needs to be done.

In addition, those collections that exist are difficult to access. In some cases they are impossible to access legally, because of copyright issues. In other cases they cannot be experienced on any current computing platforms, as seen with the many highly-significant works created with Apple’s Hypercard system, for which no known emulation solution exists. In all cases, such collections lack the scholarly infrastructure that is essential to work in other disciplines, ranging from discovery metadata standards to fine-grained citation practices.

Combined effort is needed from computer scientists, library scientists, media and technology historians, and others. Some of the effort required is at the level of understanding computational media and reifying these understandings into ontologies that can be used in scholarly work, libraries, and archives. (For example, how does one refer to, or catalog, particular elements of a computational media work, or documentation of that work, or a community-produced modification of the work?) Other effort will require developing and testing new computational approaches, in areas ranging from emulation and migration to overcoming legacy “digital rights management” technologies. All of these must be pursued in parallel with legal work, given that rights such as scholarly quotation and archival preservation are not as well established for computational media as for prior forms.

For all media forms, including computational media, understanding its history and development is essential to education, research, and design innovation. The fact that almost no one has easy access to a broad computational media collection presents a severe challenge to the field and its future.

Sidebar Four: New Evaluation Approaches

The challenge of finding appropriate evaluation approaches was widely recognized at the Media Systems gathering. The methodologies used to guide projects while they are being undertaken, and determine their successes when they are completed, have a huge impact on any field — doing much to determine what work will be funded, how its trajectory will be shaped, what audience and influence it will have, and even whether its creators will get or keep jobs in the field. Unfortunately, for the field of computational media, the more interdisciplinary work — which is arguably the most important to the field's development — is also the work for which it would be least appropriate to directly import a single set of existing guidance and evaluation strategies from computer science, the arts, the humanities, or media industries. A number of Media Systems participants have proposed strategies to address this issue.

D. Fox Harrell argued in his talk that, rather than there being one answer to evaluating computational media research, part of the work is in identifying values and goals, which can then point to existing evaluation methods that might be appropriate. For example, he discussed *Mimesis,* a game exploring identity representation and prejudice.[38] One goal of such a project could be helping conceptual change happen for players. This kind of goal is a value in both computer-supported cooperative work/learning and activist contexts, which suggests that methods from these contexts might be appropriate for guiding and evaluating the work. For another of Harrell's projects, the *Living Liberia Fabric,* discussed in Sidebar Two, work began with guidance from both HCI and media approaches, ranging from scenario-based design and semi-structured interviews to iterative prototyping and stakeholder analyses. At the same time, the student team members were utterly daunted by the material, memorializing a war that only ended in 2003. They finally found entry through what Harrell calls "cultural computing," drawing on the models of mourning and memorialization in Liberian culture, and foregrounding the voices of different interviewees from Liberia. As a result, they created a design with the goal of *engineering for subjective experiences.* This then points to the appropriateness of using methods from both engineering and the arts to guide and evaluate the project.

The Media Systems talk of Bill Gaver — from Goldsmiths, University of London — instead focused on new methods that he and collaborators have introduced to the field, using examples from two phases of his studio's work.[39] The first phase, *context setting,* happens at the beginning of a project — while the second, *evaluation,* of course happens toward the end. Both phases are shaped by the still somewhat-unusual goal

38. D. Fox Harrell et al., "Exploring Everyday Creative Responses to Social Discrimination with the Mimesis System," *Computational Creativity* (2012): 223.

39. An overview of the Interaction Research Studio's methods is found in William W. Gaver, "Science and Design: The implications of different forms of accountability" in *Ways of Knowing in HCI*, ed. Judith S. Olson and Wendy A. Kellogg (Heidelberg: Springer-Verlag, 2014). An early discussion of cultural probes is found in William W. Gaver, Tony Dunne, and Elena Pacenti, "Design: Cultural Probes." *Interactions* 6, no. 1 (1999): 21–29.

Need to Develop and Adopt New Evaluations

Ian Horswill, at the Media Systems gathering, identified a priority for the computational media community: "protecting *making* as a mode of inquiry."

"Making" is, of course, the primary activity of most companies involved in computational media work. But as outlined above, such organizations rarely have the time and resources needed for true research during media production — such making is not fully a mode of inquiry. Within research organizations, on the other hand, the types of making required for computational media research are often at odds with prevailing norms guiding research progress and evaluating its results.

More specifically, to understand the power and potential of new genres and capabilities for computational media forms and tools, projects must both be judged by metrics and be taken to a level of completion that are unusual in Horswill's home discipline, Computer Science. At the same time, there must also be exploration of radical new technology/design approaches that are ill-matched with disciplinary expectations and funding levels in the arts and humanities.

One possible and partial way to address this is for new sub-communities to form within Computer Science, which have the funding levels necessary to support major new technology/design initiatives, while adopting new evaluation measures more appropriate for computational media work. ACM SIGGRAPH, the major community for computer graphics research, has to some extent achieved this, and provides an instructive example.

SIGGRAPH is a mature, rigorous research community in which the use of images and video are accepted as key elements of (a) rhetoric arguing in favor of the significance of results and (b) evaluation by reviewers of the significance of results. In both cases the key question might be phrased: "Does this look good?" (Or, comparatively, "Does this look better?") This is based on expert evaluation of members of the interdisciplinary research community and on shared understanding of the aesthetic effects and principles that guide the work as well as shared understanding of what is a novel result within that community. Crucially, it is not based on asking members of the general public (who may or may not understand these aesthetic effects and principles, and who

To understand the power and potential of new genres and capabilities for computational media forms and tools, projects must both be judged by metrics and be taken to a level of completion that are unusual in computer science.

Sidebar Four: New Evaluation Approaches

(a key one for the development of computational media) of creating finished, fully-functional projects that can be experienced by everyday people over extended periods. This is in sharp contrast to computational media work that focuses on momentary demonstrations or that creates systems that are theoretical "improvements" on elements of media technology, but that are not integrated with any audience experience.

Gaver is well known for having developed, together with collaborators, the concept of the "cultural probe" as part of guiding initial work. These probes present evocative tasks that can elicit inspiring information from people. Examples include partial storybooks to be completed with drawings and words, one-shot dream recorders, forms for listing house rules or relations, and cameras packaged with lists of images to take. The researchers get massive information back that is difficult to analyze and difficult to compare. It's hard to draw clear lessons — and according to Gaver that's the point. The point is to have one foot in empirically looking at people's lives while the other foot is in struggling to make sense of the mess in a way that, as Gaver puts it, "we're always sure that we're not sure." It is looking for inspiration, not information. Probes have been taken up in the research community, but often through their surface characteristics, rather than their deeper approach.

The approaches Gaver presented in the evaluation phase are focused on much longer-term engagements than in most "user studies" of fields like human-computer interaction. Such studies tend to be so short that they only capture the initial experience of novelty, which is not very informative for the design of objects or media intended for more prolonged experience. One technique that Gaver's group uses is simply looking at the trajectory of engagement over time. After the initial novelty wears off, do people keep interacting? If so, is it steady, or bursty, or in some other temporal pattern? Simply understanding whether something is compelling enough to produce a pattern of long-term interaction is a way of establishing if it is a successful project.

But to Gaver looking at these patterns is not as interesting as trying to get at deeper narratives of what his team's objects mean to people, understanding how people engage with them, what values are brought into

Bill Gaver's Interaction Research Studio uses "cultural probes" to elicit inspirational data about people's lives. Their approach to research on new technologies marries designers' abilities to work with ambiguity and uncertainty with the social-scientific empiricism of human-computer interaction.

almost certainly don't understand what is novel in the research community) whether an image looks good, or looks better, and then testing for statistical significance levels in their responses. Rather, it is fundamentally an issue of informed *interpretation* and *critique.*

As an alternative to interpretation and critique, one could attempt to frame progress in computer graphics in relatively pure engineering terms, defining a unitary goal (such as photorealism) and recognizing all movement toward that goal as progress, while sidelining work that moves in other directions. And this is an approach that has certainly proven tempting to some in computer graphics. But, as Chad Greene discussed at the Media Systems gathering, it is also well-known as an approach that can actually make media worse, rather than better: the "uncanny valley" describes how characters that approach realism can, as they move closer, become increasingly off-putting.[44] In creating new artifacts and capabilities for computational media, there is no substitute for informed interpretation and critique.[45]

Some members of the human-computer interaction community within ACM have attempted to move in this direction, with an increasing emphasis on end experience and aesthetics in a subset of papers in the field. There may be methods and language that can be brought to the computational media domain from this sub-area of the HCI field. HCI practitioners also suffer from questions of evaluation methodology in considering these new approaches. Media Systems participant Bill Gaver (whose work is discussed further in the New Evaluation Approaches section) is an early innovator within this community. Participant Katherine Isbister (whose work is also discussed in New Evaluation Approaches) has also done innovative work in this area, for example developing a set of handheld sculpted objects used to self-report one's emotional state after engaging a system (e.g., Sensual Evaluation Instrument).[46] The tool is meant to circumvent the need to fully resolve feelings and translate them into words as an experience unfolds. This part of the HCI community has also

44. Masahiro Mori, "The uncanny valley," *Energy* 7, no. 4 (1970): 33-35.

45. Understanding this is also important in areas such as interactive narrative. For example, "continuation desire" has been proposed as a means for evaluating interactive narrative, testing to see how much members of the public want to keep experiencing an interactive narrative, or how much they want to experience the next segment of one interactive narrative as compared with another. This kind of psychology-derived approach sounds scientific, and could be instructive when the research question is specifically about intrinsic motivation. But it has the problem that, when applied to narrative more generally, and drawing on members of the general public for the study, it would almost certainly favor a narrative such as Stephenie Meyer's *Twilight* over one such as Virginia Woolf's *To the Lighthouse,* even though the latter is understood by narrative experts to be a major contribution and the former is understood to be weak and derivative. Of course, if the goal is to develop a system that will encourage reading in middle school students, it would be appropriate for *Twilight* to be seen as more successful — underscoring the need for evaluation approaches to be selected in relation to project goals. A strong overview of past evaluation approaches in interactive narrative, and proposals for future directions, is found in Jichen Zhu's "Towards a Mixed Evaluation Approach for Computational Narrative Systems." (Jichen Zhu, "Towards a mixed evaluation approach for computational narrative systems." [Paper presented at the International Conference on Computational Creativity, Dublin, Ireland, May 30 – June 1.])

46. Katherine Isbister et al., "The sensual evaluation instrument: developing an affective evaluation tool." (Paper presented at the SIGCHI conference on Human Factors in computing systems, ACM, 2006.)

play in the interaction, and related issues. One way they conduct these investigations is through ethnography — and not simply through interviews, but by spending days at a time in the houses of people where their projects have been installed, without establishing the concerns and categories that will emerge from such ethnographies in advance. But they also feel it is important to move further from traditional evaluation approaches, in which there are always people in the room who know the agenda of the project, and in which there is always the danger that participants are performing for the researchers. Gaver's group has repeatedly used strategies like hiring documentary filmmakers to create films about the people and objects in their sites of deployment — or working with journalists, or even poets — with very little instruction from the research team. These provide important complements to the narratives and understandings built up by the research team through ethnographic methods.

Ian Horswill's talk at Media Systems also pointed to the importance of new evaluation approaches for evolution of the field, and the following year he published a short paper making a call for the field to begin engaging the case study as a form:

> [A]nyone who has taken a course in painting, writing, film making, musical composition, or any other art has probably noticed that they weren't trained to make art as if they were focus-grouping a new product. That's not because of an inherent bias against scientific methods, but simply because the design space is so impossibly large you couldn't possibly gather enough data to be able to know what the optimal haiku was, much less the optimal arc for a multi-decade soap opera. Plus, my optimal multi-decade soap opera would be different from your optimal multi-decade soap opera because different people value narratives differently.
>
> If you can't gather data across all possible designs and users, then the alternative is to look as deeply as possible at designs you do examine; to glean as much as possible from a specific encounter with a specific piece. So art training and theory are traditionally focused on examining specific pieces, specific cases. And as such, it is in some ways closer to the practice found in law and business than in engineering.[40]

40. Ian Horswill, "Science Considered Harmful." (Paper presented at the 6th Workshop on Interactive Narrative Technologies, Boston, Massachusetts, 2013.)

experimented with approaches specific to the evaluation of media art, such as Kristina Höök, Phoebe Sengers, and Gerd Andersson's approach to the *Influencing Machine*.[47]

The development of new evaluation measures, and shared understanding of their strengths and weaknesses, is one of the key challenges facing computational media. Evaluation measures based on expert aesthetic and critical understandings are one promising direction, and should be developed based on interdisciplinary dialogue (rather than in the ad-hoc manner of the early SIGGRAPH community). However, other areas do not have the advantage of results that can be experienced as quickly as the still images produced by the early SIGGRAPH community — and in fact often want to make innovations that can only be understood through sustained engagement.[48] Finally, Computer Science is only one area in which the issue of evaluation must be addressed. For these and other reasons, a diversity of approaches will be needed, supporting different types of teams, projects, and goals. Five proposals from Media Systems participants are described in the New Evaluation Approaches section. Potential ways to address this need are discussed in the Recommendations section.

Need for Models of Successful Interdisciplinary Work

In order to create the necessary conditions for computational media to flourish, the field needs well-documented, widely-available examples of successful interdisciplinary work in the area. As it currently stands, there is no strong source for this information — and, in fact, developing it would probably require a major effort of research, interpretation, and presentation.

Creating such detailed, available documentation would serve a wide variety of needs. For example, it would help clarify what those seeking to establish new computational media groups might require in terms of personnel, funding, facilities, and so forth — both in industry and in universities. It would help potential funders understand different models and timelines of work they might wish to support. It would help establish what differentiates successful interdisciplinary computational media projects, for those organizing and guiding them. It might also provide new information about the field,

47. Kristina Höök, Phoebe Sengers, and Gerd Andersson. "Sense and sensibility: evaluation and interactive art." (Paper presented at the SIGCHI Conference on Human Factors in Computing Systems.) ACM, 2003, 241-248.

48. We may need to develop a culture of "appendices" to publications, perhaps intended to be published electronically and simultaneously with the results themselves, in forms appropriate to showing the strengths of interactive works. These could include extended interaction transcripts or storyboards, videos of interactions, and/or prototype or full interactive experiences. Annotations and/or visualizations explaining the significance of what is shown, particularly connecting the experiential level to the computational level, may be necessary.

Sidebar Four: New Evaluation Approaches

Horswill argues that the value of a new computational media technology depends on the breadth and quality of the media works it enables, yet the quality of any one of those works is determined by the constellation of interlocking design decisions that allow that particular technology to interact successfully with the other aspects of that particular work. Those design decisions may well vary greatly from one work to another. And many otherwise promising technologies might be useless in practice because there is no good way of situating them within an overall system. Finding constellations of design decisions that allow a technology to be leveraged may often be a higher priority than improving the technology itself.[41]

The mismatch between the emphasis on generality in technology research and the grounding in specificity of aesthetic practices makes many of the traditional genres of CS research, such as the "paper on a new algorithm," problematic for computational media. Horswill argues that we need to expand the space of valued research genres to better support "in vivo" studies of technologies situated within full-blooded media works,

Yamove*, a dance battle game developed at NYU's Game Innovation Lab, which uses iOS devices worn on the wrist. In studying the game, researchers combine close, qualitative observation of game play with quantitative information about patterns of play to reveal more about the experience of movement-based games and potential design and technology interventions.*

Photo courtesy of World Science Festival 2012 and Getty.

41. In a 2013 email, Horswill gives the example of a natural language generation technology that might be seen as useless in practice for interactive narrative because current text-to-speech algorithms would deliver its output in a monotone. However, for particular niche genres (deadpan comedy, mumblecore) or characters (slackers, droning authority figures), such monotones might be appropriate. Finding a way to embed a technology in a specific genre, story, and characters, in a way that plays to the technology's strengths while minimizing its weakness or even making them into strengths, is a critical part of media systems practice.

such as organizing significant types of knowledge produced in such contexts that currently lack appropriate mechanisms for sharing with the community.

As it is, even the most famous examples of computational media organizations and projects are little-studied. We have no research-quality publications on the dramatic successes of the MIT Architecture Machine Group and Media Lab — and none on the less-successful attempts to expand its model beyond MIT (such as Media Lab Asia and Europe). The same is true of the successes and failures of the many other important computational media research organizations, such as the Electronic Visualization Lab at University of Illinois Chicago, the Studio for Creative Inquiry at Carnegie Mellon University, and the Institute for Multimedia Literacy and Institute for Creative Technologies at the University of Southern California. The same is true of Microsoft Studios, Electronic Arts, Pixar, Apple, Facebook, and so on. In fact, companies such as Microsoft and Apple are famously secretive, keeping the details of major computational media projects even from most of their own employees.

Finally, as was discussed repeatedly at the Media Systems gathering, we lack even a sense of how successful interdisciplinary computational media practitioners have forged paths to get them where they are. A few — such as Pamela Jennings, Brenda Laurel, and Janet Murray — made this a topic of their presentations at Media Systems. But a larger collection of such stories could provide more diverse inspiration, and hopefully even the opportunity to draw some wider lessons.

rather than "in vitro" studies in which the technology is deployed in the minimum possible media work that can be said to demonstrate the technology.

It is this that motivates Horswill's turn to the case study. The field needs papers that examine the deployment of technologies within particular computational media systems that draw out the technology's contribution to the overall aesthetics of the system, and the design decisions — such as the gameplay, the choice of genre, art style, and the choice of other technologies — that allowed the system to be successful or that hindered its success. Such papers are common within the game industry (for example, the postmortems in *Game Developer* magazine and on websites such as *Gamasutra*), but are rare in computer science research.

In a related vein, Media Systems participant Katherine Isbister argues that carefully conceived and executed interdisciplinary research can combine rigorous examination of a particular set of design choices, grounded in theory and evidence, with the creation of a fully resolved computational media artifact. In her work, Isbister explores the experiential impact of new interaction methods — such as full body movement sensors (e.g., *Yamove* dance battle game) and public surveillance cameras (e.g., *Pixel Motion* surveillance camera-enabled game) — by building research games robust enough to be deployed and observed "in the wild." Isbister combines close qualitative observation of play experiences with quantified information about patterns of play (through game logs and other sensor-based metrics) to get a rich picture of whether and how the design interventions "succeed" for those who experience the games. In the case of this sort of work, evaluation combines hypothesis testing to answer research questions with the external validation that comes through successful installation of these games at festivals, museums, and other non-research venues. *Yamove* is currently being finalized for release in the iOS App store, taking it all the way to a traditional software release.

Media Systems participants also discussed a number of further approaches to guiding and evaluating computational media projects, both in presentations and in breakout discussions. Ian Bogost, for example, called attention to David Williamson Shaffer's work on "epistemic games" — games intended to help students understand how socially-valued professions operate. One approach to evaluating these games shows potential promise for computational media projects that hope to help build understanding of complex domains.[42] Rather than give students standard assessments after playing games, or evaluate the quality of their work while playing the games, Shaffer has used interviews and concept maps completed before and after game play. Through these he has been able to show that students have changed the frames they use

42. David Williamson Shaffer, "When computer-supported collaboration means computer-supported competition: Professional mediation as a model for collaborative learning," *Journal of Interactive Learning Research* 15, no. 2 (2004): 101-115.

Given the background, opportunities, and challenges outlined above, we make the following recommendations.

1 Support the Creation of New Works and Design Approaches

ADDRESSED TO: Industry; independent and non-profit creators; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support interdisciplinary design research that results in high-risk computational media creation efforts — integrating arts, humanities, and computer science — on three scales: demonstration, project, and product.

EXAMPLE: Computational media works that attempt to translate knowledge from the history of rhetoric into new interactive forms.

It is through the creation of new works, and exploration of new design approaches, that new possibilities for computational media are identified. As articulated in a Media Systems breakout discussion, we need to celebrate and support "the creation of problems" — the creation of new goals, the identification of new possibilities. High-risk computational media projects not only help identify such new problems for research to address, but also explore in detail what is and is not possible given current technologies and design approaches.

One challenge is that these outcomes, which are often the most important from such projects, are also often a surprise to both investigators and funders. This is of course a hallmark of true research, but it presents challenges for proposal writing and project selection. One potential solution is to support projects that are explicitly framed as explorations, providing examples of how these can be presented for evaluation purposes.

This connects to a related issue: the need to support projects of various sizes. A *product* that can be used widely can have broad impact (e.g., culturally, economically, educationally) and produce important knowledge. However, as Ken Perlin pointed out at Media Systems, it is an order of magnitude greater effort than creating a fully-functional *project* (which is perhaps not as general, complex, stable, or polished) that can prove the viability of to think about the professions, have learned material about the topics covered in the specific game scenario, and have developed skills that may transfer to other domains.[43]

Almost all of these methods require the creation of completed computational media works as a research activity — not the creation of initial concept demonstrations nor the initial implementation of potential technical approaches. Unfortunately, the creation of complete media projects as research is unusual for a number of reasons discussed in this report, though the emergence of stronger evaluation approaches for such projects could help change this. Nevertheless, the challenge of developing appropriate guidance and evaluation approaches for smaller projects, or the initial stages of large ones, remains a significant challenge for the field, in need of serious investigation. In these contexts there may be no alternative to developing methods based on expert evaluation and critique, potentially drawing on methods such as studio critique in the arts or close reading in the humanities, to replace or complement evaluation approaches that are now dominant.

Pixel Motion *is a game designed to be publicly deployed in locations with surveillance cameras, gathering information about the dynamics of interaction produced by novel technology and design combinations. The core game mechanic makes use of motion-flow software developed by Bell Labs, which looks for overall motion flow patterns and trends instead of trying to track individuals.* Pixel Motion *is simple to play, with short rounds that invite collaborative participation. In the version installed at the Liberty Science Center, when the game begins, anyone in the camera's field of view can join in 'wiping' pixels off the video feed by moving around within the play space. Players have 30 seconds to wipe off enough pixels to win the round.*

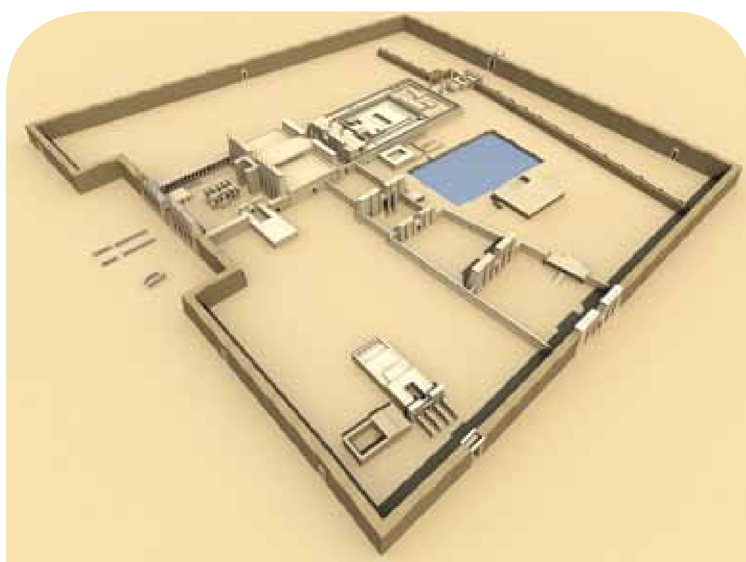
Photo courtesy of NYU Poly Game Innovation Lab.

43. David Williamson Shaffer, "Epistemic frames for epistemic games," *Computers and Education* 46, no. 3 (2006): 223-234.

new techniques and capabilities, yield valuable information about audience engagement and use patterns, and so on. And a project, in turn, is an order of magnitude more effort than a *demonstration,* which can also create valuable learning and serve quite powerfully in the identification of new problems (as discussed above). This may be why demonstration-scale computational media, as single objects or in related collections, has proven such an important genre in contexts ranging from "hackathons" and "game jams" to the MIT Media Lab and the SIGGRAPH Art Gallery and Emerging Technologies venues.

But demonstration-scale systems don't support a full and rich evaluation (as discussed in "New Evaluation Approaches"). It is thus important to support media and design research efforts with deliverables at all three scales, and for all of them to be genuinely investigating the boundaries of the possible in computational media. The smallest efforts — aimed at the exploration of new areas and identification of new problems — should focus on the production of small collections of demonstrations. The largest efforts should, instead, aim at taking highly-promising ideas previously explored in projects and turn them into high-impact products. The boundary between project and product is also a likely place for a productive collaboration between a research organization and a media-creating organization (as discussed below).

Supporting such work will require changes in the funding landscape. In industry, few computational media organizations dedicate significant resources to the creation of high-risk demonstrations or prototypes. Increasingly this is seen as the role of universities. But in a university context, media production grants are a primary source of support, and most media production grants try to minimize risk and uncertainty, instead backing exciting projects that are also highly likely to deliver expected results. Similarly, most media production grants could not support significant humanities analysis or computer science technology innovation, and either or both will be required for many innovative computational media research projects of the sort the field most needs supported.



A 3D visualization of an Egyptian temple from the Digital Karnak Project at UCLA. The model visualizes spatial and temporal changes at Karnak temple over 1500 years, allowing for user-controlled 360 degree movement within the reconstructed temple space. The project is one of a number of faculty research projects visualizing heritage sites, including Rome (Italy), Santiago de Compostela (Spain), Qumran (Israel), and Magnesia (Turkey).

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2 Invest in Developing New Computational Models and Genres

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support interdisciplinary basic research toward developing new technological possibilities for computational media, integrating efforts across multiple areas of computer science, the arts, and the humanities.

EXAMPLE: New technology and design approaches to enable compelling, highly-interactive dramatic characters.

While the creation of high-risk new works of computational media is essential for the identification of new possibilities and goals for the field, fundamental progress in the field also requires work that is led by technology research. This work must focus on questions and problems that are emerging at the boundaries of media creation, and must eventually connect back to media creation. But it also must move beyond the incremental, and without sustained efforts to create technology for types of media experiences that are not currently possible, only incremental progress can be made.

To make this kind of field-changing, non-incremental progress, radically interdisciplinary basic research will need to take place. For example, a project to fundamentally improve our ability to create dramatically compelling interactive characters would require a range of computer science knowledge that is beyond the bounds of what single funding programs generally support (e.g., computer graphics, artificial intelligence, and human-computer interaction) together with disciplines entirely outside the sciences, such as animation, puppetry, game design, and performance studies. For other computational media grand challenges discussed in this report (e.g., deeply interactive narrative) the research teams needed would be different, but equally diverse.

Unfortunately, there are few organizations in the world where collaborations between such different groups currently take place, due to disciplinary boundaries, funding structures, and evaluation models. Even when such groups do come together in industry, it is often in pursuit of particular products, operating on timetables too short for fundamental research. Outside industry, where such work would generally depend on grant funding, there are simply no mechanisms for supporting such work as a first-class objective. Addressing this will require new funding categories that are of sufficient scale for long-term technology research, while also being interdisciplinary enough to include research efforts in the humanities and arts.

3 Encourage New Forms of Scholarship

ADDRESSED TO: Publishers; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Invest in new publishing venues that will provide a high-quality outlet for experimentation with new forms of scholarship; revise funding programs and review procedures to support these new forms; and seek ways to recognize a broader range of scholarly activity in computational media.

EXAMPLE: Prototyping new scholarly forms that require computational media for their argument structure.

The digital humanities has done important work to support new forms of scholarship (e.g., those engaging with "distant reading" of large bodies of text). But much more needs to be done to support computational media scholarship, in three senses.

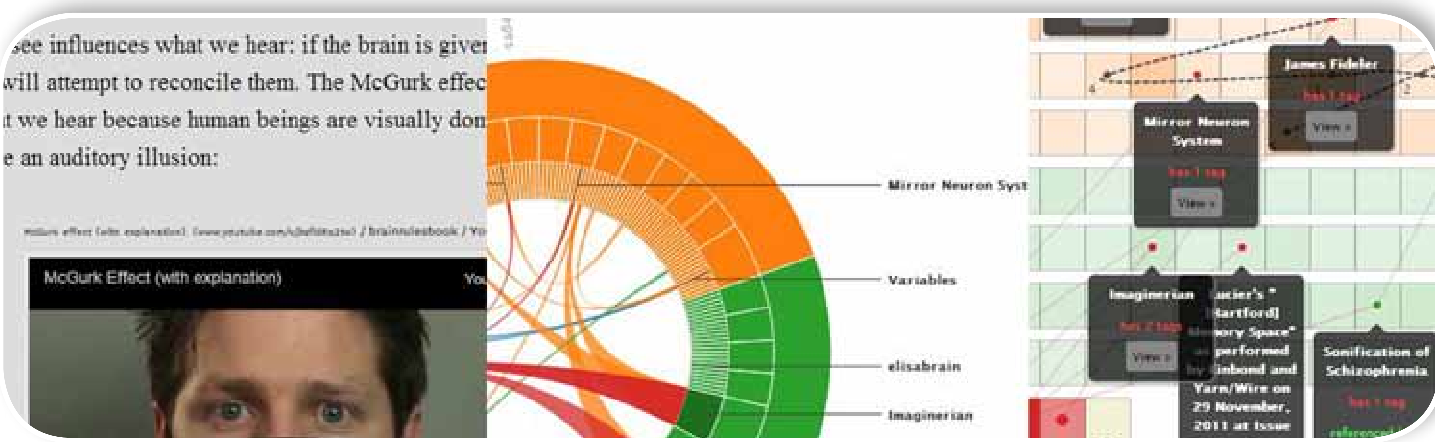
First, while there have been important experiments with the possibilities of computational media for new forms of scholarly argument and communication (as represented at Media Systems by work such as Tara McPherson's with the *Vectors* journal and Scalar authoring and publishing tools) there is still much to be explored in this area.[49] Computational media hold the possibility to transform many scholarly forms (e.g., critical "editions") and many scholarly practices (e.g., peer review). But research in these areas requires resources that are rarely supported by scholarly grants, from interaction design to technology development. Further, there is an ongoing push toward tools and platforms for computational media scholarship — that is, moving to the *product* stage — which might lead some to assume that the major discoveries of new possibilities for scholarship have already been made. On the contrary, while there is certainly a need for more sophisticated tools, at the Media Systems gathering there was wide agreement that we also need many more high-risk scholarly projects at the *demonstration* and *project* scales (as discussed above). We are only beginning to discover the new possibilities for scholarly communication and argument opened by computational media. Further, we are only beginning to understand the potential of new hybrid forms, such as Anne Balsamo's "transmedia book" *Designing Culture* (as discussed in Sidebar Two).

49. Tara McPherson, "Scaling Vectors: Thoughts on the Future of Scholarly Communication," *The Journal of Electronic Publishing* Volume 13, Issue 2 (2010), accessed February 20, 2014, doi: 10.3998/3336451.0013.208.

Second, while computational media is of increasing importance to our culture and economy, there is almost no dedicated support for scholarship that directly grapples with computational media. At the Media Systems gathering three important types of scholarly activity in this area — game studies, platform studies, and software studies — were represented in part by Doug Sery from MIT Press, which does significant publishing in each area. But we know of no grants, fellowships, or other financial support specifically for new forms of scholarship that attempt to grapple with the specifics of computational media. Further, even those more general programs that are open to such scholarship often are reviewed by panels that focus on how such work addresses the concerns of more traditional scholars, making work that has the greatest potential for contributions in this area some of the most difficult to fund.

Third, new forms of scholarship are emerging that are part of the practice of computational media research, but where the results are not visible or legible as traditional scholarly output. For example, the work on “operationalization” discussed above, in which theories and models from non-engineering disciplines are reified in computer programs, requires novel scholarship in the development and/or deeper specification of these theories and models. But it is difficult for some of the most qualified scholars to engage in this work, because often it is not itself seen as scholarship, and the results would likely be unpublishable in current scholarly venues.

As a result, we need to invest in new publishing venues that will provide a high-quality outlet for experimentation with new forms of scholarship, we need to revise funding programs and review procedures to support them, and we need to find ways to recognize a wider range of scholarly activities.



The Alliance for Networking Visual Culture, led by Tara McPherson, has released the platform Scalar, designed to support experimentation with new forms of scholarship and publishing. It supports a range of media types and models of community interaction. It includes an API as well as tools, such as those pictured here, to help authors create new kinds of information structures, understand them, visualize them, and expose them to readers. Source code is on GitHub.

Screengrabs from Erin Mee, “Hearing the Music of the Hemispheres,” TDR, http://scalar.usc.edu/anvc/music-of-the-hemispheres/index

4 Cultivate Rigorous Dissemination Venues and Evaluation Approaches

ADDRESSED TO: Professional societies; publishers; conference organizers; journal and series editors; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Support computational media communities in: identifying exemplars of strong projects and research contributions; describing current best practices in computational media evaluation; developing new interdisciplinary evaluation approaches, which may combine methods formerly seen as in tension with or in contradiction with one another; and disseminating these for use in existing field-defining contexts (from journal review to tenure evaluation) and in the establishment of new dissemination venues.

EXAMPLE: A computational media track of a rigorous, high-impact conference, with distinct, publicized evaluation criteria and knowledgeable peer reviewers.

A research area improves by sharing and building upon results. This is a major purpose of conferences, journals, and other modes of selecting and disseminating strong research results. The review process also can provide high-quality feedback to both experienced and new researchers, helping push and shape their work. But all of these are dependent on the communities they help create: there must be a group with shared beliefs about what constitutes high-quality work and appropriate evaluation.

The Media Systems gathering demonstrated that such groups do exist for multiple, overlapping sub-areas within computational media. But more work needs to be done in several directions. Work needs to be done to identify these communities and their exemplars of strong projects and research contributions. More needs to be done to identify current best practices in different forms of evaluation and to explore new interdisciplinary evaluation approaches. These need to be communicated to reviewers for conferences, journals, grant proposals, academic promotion, and other important field-defining mechanisms. And these need to be applied in the creation of new venues and strengthening of current venues for computational media work. In particular, evaluators may need to be recruited who have a breadth of knowledge in methodologies of development and evaluation that are not typically combined in today's reviewer pool. Such breadth is required to see the merits of new and unexpected methods and combinations of methods, instead of rejecting them as unorthodox or improperly mixed.

One question is how to incentivize and organize this activity. A recommendation emerging from Media Systems is for the creation of national centers of excellence in computational media, for which this work is a key activity. But individual computational media practitioners can also make important contributions — for example, by working with others toward establishing a track at a major yearly research conference, or toward editing a special issue of a major field journal, that seeks computational media contributions and is peer reviewed by those knowledgeable in the field. Further, in breakout groups Media Systems participants expressed the importance of busy members of the field making time to serve as peer reviewers, board members, editors, and organizers — as well as mentoring junior field members in how to carry out such work.

5 Build Interdisciplinary Education and Student Diversity

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Design degrees and student support programs to enable student-led interdisciplinary pathways; create degrees (and modify existing degrees) with interdisciplinary cores (and foundation courses) engaging the methods, languages, and problems of more than one discipline; hold workshops and summer institutes for working computational media practitioners (and those looking to transition into computational media); and use resources to recruit and support diverse faculty and students.

EXAMPLE: Transitioning a relatively disciplinary "game engineering" degree into a deeply interdisciplinary computational media degree.

Computational media education is greatly needed to address a dearth of truly interdisciplinary computational media practitioners. In general, interdisciplinary computational media education takes three forms. All three need greater support.

The first kind is student-driven. For example, students who get dual terminal degrees (e.g., an arts MFA and computer science PhD) or who get a single degree with substantial coursework (or a minor) in another area. As much as possible, educational institutions should work to support such students, for example by organizing degree requirements such that double majors are possible. The goal is for students to be able to truly immerse themselves in the methods, languages, and core problems of more than one discipline, rather than take a few courses aimed at non-majors. Unfortunately, in some cases this kind of student-driven pathway is becoming more difficult. For example, the NSF's Graduate Research Fellowship Program previously allowed applications from any student who had not completed more than a year of STEM graduate coursework. Recently the guidelines were revised to preclude applications from students who had completed more than a year of *any* graduate coursework, so that students who have previously completed graduate coursework in the arts or humanities and now seek interdisciplinary training in the sciences are unable to apply.

The second kind is program-driven. These are undergraduate and graduate degrees and certificates that are explicitly in interdisciplinary computational media. These are quite rare, because most degrees are offered by a single area of a college or university. As a result, it is much more common to see degrees that offer a disciplinary core (often overlapping significantly with the core of a disciplinary degree) and a smattering of courses elsewhere. A much more powerful design for addressing the lack of interdisciplinary computational media practitioners is a truly interdisciplinary core — and potentially also the introduction of new interdisciplinary foundation courses. For example, in a manner similar to the way many institutions now offer separate foundation courses in statistics for students in mathematics and social sciences (given the wide divergence in everything from motivating examples to eventual uses) so an increasing number of institutions may come to offer different introductory programming sequences for students in computer science and computational media. With the addition of such courses (either taught by interdisciplinary faculty or co-taught by disciplinary faculty) many current degrees in areas such as digital arts, computer games, and digital humanities could become more deeply interdisciplinary computational media programs, preparing much-needed interdisciplinary practitioners. At the same time, having multiple highly-connected degree programs from multiple disciplinary perspectives is probably a better strategy than having a single program answering to multiple academic deans (or none). Media Systems participants Ian Horswill and Simon Penny both warned about this issue, having helped create computational media programs that reported to multiple deans — Animate Arts at Northwestern University and Arts, Computation, and Engineering (ACE) at UC Irvine — which have since been discontinued.

The third kind is education for working practitioners — in industry, the academy, and a wide variety of other computational media contexts (e.g., cultural heritage). Computational media researchers need to take more advantage of possibilities such as workshop and summer institute funding to help educate each other and develop understanding of, and work in, the area. These structures may also provide important opportunities for those in disciplinary positions to transition to more fully interdisciplinary computational media work. Industry in some cases does versions of this, such as the Electronic Arts example of immersive workshops for employees seeking greater interaction design or production literacy.[50] At the same time, outside industry, few computational media practitioners have the appropriate infrastructure for hosting and organizing such gatherings. This is another important role that could be played by national centers of excellence.

In all three kinds of education it is important to make a priority of diversity. Many computational media contexts, from degree programs through jobs, share the poor diversity representations, cultures, and practices of computer science (and engineering generally). It is clear that successful diversity interventions are possible. Resources and case studies are available from organizations such as the the National Center for Women & Information Technology (NCWIT) and national Center for Minorities and People with Disabilities in Information Technology (CMD-IT).[51] However, it is essential that diversity efforts be approached as an ongoing investment in the health of a program and its contributions to the field, rather than as a short-term attempt to “fix” a departmental or disciplinary culture. Further, successful models of computational media education show that much better representation and more diversity-supporting cultures are not only possible, but perhaps given advantage by the interdisciplinary objects and methods of computational media.

6 Foster the Next Generation of Leaders

ADDRESSED TO: Industry; professional societies; conference organizers; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Develop appropriate tenure and promotion guidelines; mentoring and career development workshops; support for post-doctoral researchers (and potentially early-stage faculty) to be embedded in successful interdisciplinary computational media contexts; and support for cross-training of disciplinary researchers seeking to move into computational media.

50. Tracy Fullerton, *Game Design Workshop: a playcentric approach to creating innovative games* (Boca Raton, FL: CRC Press, 2008).

51. “National Center for Women & Information Technology,” The National Center for Women & Information Technology, accessed February 20, 2014, http://www.ncwit.org. “CMD-IT: The National Center for Minorities and People with Disabilities in Information Technology,” Center for Minorities and People with Disabilities in Information Technology, accessed February 20, 2014, http://www.cmd-it.org.

EXAMPLE: “Hydra” post-doctoral grants, bringing together early-stage researchers from multiple disciplinary perspectives to create a multi-year computational media project under the guidance of a researcher experienced in organizing, supporting, and communicating the value of such work.

There is a great need for experienced computational media practitioners to lead efforts in industry, the academy, and in non-profits. But the potential paths from computational media education to becoming an established member of the community, and potential leader, are in need of broadening. Many early-stage researchers, even after completing a dissertation, have little knowledge of how to organize, support, and advocate for computational media activity.

As discussed above, one potential contribution in the university context would be to provide tenure and promotion guidelines — perhaps from multiple professional organizations — for interdisciplinary computational media practitioners, complementing guidelines for related areas from organizations such as the Computing Research Association,[52] Modern Language Association,[53] and College Art Association.[54] There is also a great need for junior faculty, early-stage industry researchers, and late-stage grad students to understand issues such as potential funding pathways, types of work and venues for dissemination, and different models of organizing computational media activity (and their tradeoffs). Mentoring and career development workshops would be a powerful tool for this, and another potential activity for national centers of excellence.

In addition, there is also the need to support early-stage practitioners, especially those who were trained in less interdisciplinary contexts, in how the work of computational media is done. At the Media Systems gathering Anne Balsamo proposed “hydra” post-docs, involving researchers trained in different disciplinary traditions that contribute to computational media, working together on a multi-year project under the mentorship of researchers with a successful track record of interdisciplinary computational media work. More generally, post-doctoral positions in computational media could provide even those trained in interdisciplinary labs with extremely valuable insights into how computational media work is managed, funded, and advocated for within university structures — information which is very difficult to broadly absorb while engaged in the highly-focused work of completing a dissertation.

52. Martha E. Pollack and Marc Snir, “Promotion and Tenure of Interdisciplinary Faculty” (Washington, DC: Computing Research Association, 2008).
53. “Guidelines for Evaluating Work in Digital Humanities and Digital Media,” Modern Language Association, accessed February 20, 2014, http://www.mla.org/resources/documents/rep_it/guidelines_evaluation_digital.
54. College Art Association, “Standards and Guidelines: Guidelines for Faculty Teaching in New-Media Arts” (New York, NY: College Art Association, 2007).

A similar mechanism could be a valuable tool for early-stage faculty, perhaps taking a year's leave to learn the strategies of a successful interdisciplinary computational media lab and/or educational program. Such a "visiting researcher" program would also be one strong approach to enabling disciplinary researchers seeking to move into computational media to immerse themselves in a new research culture. Support for other forms of cross-training, including release time to train in new skills and opportunities for disciplinary researchers to carry out multi-year research projects with computational media researchers, should also be considered in both industry and the academy.

7 Support for Tool and Platform Development

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Provide support for tools and platforms that address needs already demonstrated by patterns of media making practice; strongly consider open source strategies, especially before putting more resources into a tool project that has thus far failed to find or create a community.

EXAMPLE: Tools that represent and can reason about the system components and play aesthetics of simulation and strategy games, enabling a dramatic broadening of creators and applications.

As discussed above, one of the important needs of the computational media field is for better tools. While some parts of the field (e.g., the graphics and physics of games) have sophisticated tools, in many others the standard practice is to use spreadsheets and other tools from outside the field to create clumsy work-arounds for the lack of tools.

Tools can also be important for community development, pedagogy, and organizing collaborative efforts, as seen in tools such as Inform 7, Processing, and Arduino. In breakout sessions at the Media Systems gathering, participants discussed how disciplinary technologists and media makers can often use tools as boundary objects, each with their own area of concentration while communicating about the media possibilities that could be opened by expanding technical capabilities. One issue with this is that, even though it is possible for technologists to begin this work independently of artists (and generally not vice versa) the ideas that appeal to technologists may not address what artists see as exciting field possibilities. Tools that begin this way often fail to find or found a community of practice.

Support for tool development can avoid this with two strategies. First, tool efforts should arise from genuine issues identified in media-making. These can be seen in work elements media makers are building "by hand" that could be automated, in questions that are being asked through audience testing that could be answered automatically, in attempts to create experiences that provide the illusion of what is not possible with current technical tools, and a wide variety of other means. For example, a number of Media Systems participants described tool efforts in the area of interactive storytelling, an area that is promising for tool-oriented research, given the large amount of effort that media creators have invested in trying to create illusions and representations of types of interactive storytelling that are not possible with current tools.

Second, tool products that are not finding or creating communities of practice should, before significant further support is provided, seriously consider moving to an open source model, making it possible for the tools to be seized by passionate community members and moved toward a more productive role in the creative ecosystem. For example, a company that has created a piece of music-authoring software, with significant investment but little uptake, might find a greater audience for the tool if the next round of investment includes moving to an open-source model and encouraging direct contribution and guidance from the community. It may also be possible to transition the product directly to a core of open-source developers, rather than simply mothballing the tool (as was done successfully with the Blender 3D modeling tool).[55]

8 Support for Collections and Archives

ADDRESSED TO: Industry; independent and non-profit creators; libraries, archives, and museums; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Industry, independent and non-profit creators, collecting organizations, and research organizations collaborate to develop strategies for collecting and making accessible final works, the resources from which these works were created, records of the development process of works, records of reaction and contribution by audiences, and records of marketing and reception. Supporting basic and applied research in fundamental questions ranging from information organization (e.g., ontologies and metadata) to preservation and access (e.g., emulation and migration).

55. Roland Hess, *The essential Blender: guide to 3D creation with the open source suite Blender* (San Francisco, CA: No Starch Press, 2007).

EXAMPLE: Developing industry best practices around archiving current "closing kit" materials with third parties, expanding to include records of the development process.

As discussed in the Challenges section, current practices of collecting computational media are a significant field weakness. The resources used to create many landmark works are lost, and in some cases the works themselves are in significant danger of being lost (e.g., existing only on aged, volatile floppy disks). Some companies have maintained relatively good archives (at least of final products), important work has been done by amateur archivists, and some attention is now being paid by institutions that collect traditional media, but the field has much ground to make up.

One important area of work is the development of collections of computational media works, both in their final forms (as experienced by audiences) and in the forms used to create these (e.g., the source code and data files for software). It is also important to begin to collect deeper records of the design and development processes for computational media works — this is often the most telling material both for designers and scholars seeking to learn from past works. Developing stronger approaches to collection access is also necessary, ranging from legal issues of copyright to technical issues such as emulation/migration, digital rights management, and required connections to servers that are no longer online. The field must find ways to address often-ephemeral, but historically key, elements that exist "outside" computational media works, such as the work of fan and modification communities as well as marketing materials and critical reviews and responses. Finally, the field must address significant issues in the entire pipeline of cataloging and description of digital files, the creation of discovery metadata, the provision of access tools, and the development of a scholarly apparatus to deal with issues such as citation.

A number of these are issues where it is particularly important for industry and collecting institutions to work together. Without such collaboration the issues are simply intractable, and the computational media industry will be an active force in the destruction of its own historical record. On the other hand, if the work suggested in this recommendation is successfully pursued, we can imagine a future in which authors can make citations to specific states of computational media works and readers can "follow" those citations to versions of the work, in the same state, running in emulation. Though the research and legal challenges are great, the result could be a much richer discussion of computational media design and history than is currently possible.

9 Promote Collaboration

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Supporting co-teaching and other interdisciplinary education efforts; hiring individuals who can translate across research and media-creation groups within an organization; promoting organizational structures and best practices for collaborations between computational media researchers and media creators who are in different organizations; experimenting with artist/humanist/computer scientist-in-residence programs and decentralized, partially-volunteer efforts (including with open source developers); and not assuming members of collaborations will be drawn from disciplinary backgrounds (computational media collaborations are strongest between interdisciplinary practitioners).

EXAMPLE: Create best practice intellectual property and collaboration models for computational media projects spanning industry and universities, based on studies of successful partnerships; incentivize their adoption through startup funding for centers that use them.

Finding ways to encourage appropriate collaborations was a key theme at the Media Systems gathering. This can be particularly important when attempting to undertake interdisciplinary work (such as computational media research, media making, or teaching) using team members with largely disciplinary backgrounds. For example, Media Systems participants described very positive experiences with co-teaching across disciplines, both in student learning outcomes and impact on faculty interdisciplinary understanding, though this can be more expensive than university and college administrators are willing to support. That said, the most effective computational media collaborations are between individuals who themselves have interdisciplinary backgrounds, and attempts to promote collaboration should not begin from the assumption of disciplinary team members (e.g., specifying one participant should come from the humanities, another from engineering).

At an organizational level, finding ways to encourage collaborations between research and media-making organizations, and the accompanying transfer of technical and design knowledge, is an important goal. When these organizations are within the same company — such as the internal research organizations of Pixar and Microsoft — it is necessary to make sure that models provide incentives for all parts of the organization. Ideally, positions can also be created that span the two parts of the organization and help "translate" across boundaries of work methods, vocabularies, and goals. The recent experiments with shared post-doctoral researchers between

Microsoft Studios and Microsoft Research are one example of this. Studying current examples and releasing recommendations based on their successes and pitfalls could provide important service to the field.

In the more-common case in which the groups are not within the same organization, one possible model is to build on the NSF's sample intellectual property and collaboration models established for programs such as the Industry/University Cooperative Research Centers Program. However, these will likely require some significant revision, given issues such as the general secrecy prevalent within computational media industries (e.g., media products and their specifics are kept quite secret until their incremental announcements, which come as part of the product's marketing efforts rather than in the context of research dissemination). As discussed below, creating a small number of pilot centers, based on currently-strong collaborations between organizations, would be an effective way to build knowledge about these kinds of collaborations that could then be used as a model or starting place for future relationships.

Finally, certain kinds of collaborations that are relatively well-established in some areas should be explored further in others. For example, the concept of the "artist in residence" has been successful in computational media contexts such as Xerox PARC. But participants at Media Systems pointed out that almost no organizations have experimented with a "humanist in residence" or "computer scientist in residence," which hold the potential for similarly-exciting insights and collaborations to emerge. Donald Brinkman's talk also demonstrated how small amounts of funding (from the NEH and Microsoft Research) were able to combine with the expertise and existing software of five universities, together with the volunteer efforts of Microsoft employees (through the Garage program), to complete three linked computational media projects in a very compressed time period. Other companies with computational media expertise might consider options for letting employees volunteer efforts in similar ways, and further ways of linking universities, funders, and industry with other dispersed efforts (such as open source development groups) should be investigated.

10 Develop Better Field Understanding

ADDRESSED TO: Professional societies; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Resources for both broad and detailed studies of computational media, resulting in specific, strongly-supported recommendations and rich, particular case studies.

EXAMPLE: An extensive research and writing project on computational media, in the vein of *Beyond Productivity* or *Our Cultural Commonwealth*, including public information gathering meetings, testimony from field experts, and analysis of available empirical data.

The Media Systems gathering was a step toward better understanding computational media. By bringing together field leaders and synthesizing insights in this report, the stage is set for fuller investigations. These should be both at the broad and detailed level.

At the broad level, a more extensive research and writing project on computational media is needed, such as that undertaken by the National Academy of Sciences and Rockefeller Foundation for *Beyond Productivity* or by the American Council of Learned Societies and the Mellon Foundation for *Our Cultural Commonwealth.* While our three-day gathering (together with a discussion and writing process of more than a year) hopefully helps to provide some insights, a more accurate picture of the field could be developed through the processes of public information gathering meetings, testimony from field experts, analysis of available empirical data, and other work that goes into the preparation of such a report. In particular, this could result in more specific recommendations, aimed at more specific constituencies, and a larger collection of evidence to support them.

At the detailed level, there have been almost no research-quality studies of how computational media work is carried out successfully (and unsuccessfully). We need support for research on the detailed work of computational media, resulting in case studies in areas such as project creation, education, and basic research. As discussed above, we could benefit greatly from the creation of best practice models based on successful work in the field, from intellectual property agreements to promotion and tenure recommendations. Studies of individual career trajectories, in addition, were suggested at the Media Systems gathering, providing potential models for junior researchers looking to find their way.

11 Build on Existing, Local Strengths

ADDRESSED TO: Industry; universities and colleges.

IMPLEMENTATION: Identifying nascent computational media strengths and differentiators (which may already be organized in development groups, research centers, and/or educational programs) as starting points for building computational media focus areas.

EXAMPLE: Building on local strengths in software studies, natural language processing, and human-computer interaction to develop a computational media focus area around tools for analyzing computational media authoring strategies and artifacts.

Not all computational media activities should look the same. A university with strength in digital cultural heritage, or algorithmic music, or human-computer interaction should not ignore that strength and attempt to build a computational media research or education program based on the model of a very different university. Similarly, a company that has done strong research in the context of developing specific media titles should not immediately reorganize and split research from development. Instead, nascent computational media strengths and differentiators should help define the shape of investments in building capabilities and programs.

UCLA's Digital Humanities program, for example, grew out of existing strengths in digital mapping and 3D, based on the pre-existing "experiential technology center" (ETC) where faculty and staff worked on 3D cultural heritage projects. The resulting program is heavily grounded in spatial analysis and place-based studies, which both capitalizes on existing strengths and is broad enough to include faculty from 20 different departments and five schools within UCLA. The program has already launched a graduate certificate and an undergraduate minor, the latter including foundations, capstone courses, an internship, and work on ongoing collaborative digital humanities projects led by faculty or industry partners.[56]

12 Establish National Centers of Excellence

ADDRESSED TO: Industry; universities and colleges; federal and private funding agencies.

IMPLEMENTATION: Found centers that engage in fundamental field-development work (from developing best practice recommendations to hosting mentoring workshops); provide loci of expertise for particular research and/or application areas; and build the national research and education infrastructure for computational media.

EXAMPLE: A center linking three North Carolina universities, and local computational media industry partners, with a research focus on operationalizing interdisciplinary models (working with experts in cognitive science, psychology, design studies, creative writing, and narrative theory) to enable new kinds of interactive media and media design tools for learning and entertainment.

Addressing the challenges and taking up the recommendations outlined above will require the development of national centers of excellence, just as it has for many previous fields, from supercomputing to digital humanities.

56. "The Digital Humanities Minor," UCLA Digital Humanities, accessed February 20, 2014, http://www.cdh.ucla.edu/instruction/dhminor.html.

These centers should be founded based on existing computational media research strengths, and awarded either to single institutions or consortia. These centers should serve three primary purposes.

The first purpose is accelerating field development. Centers should hold workshops and summer institutes to address major issues in the field, mentor junior researchers, spread best practices in areas ranging from education programs to intellectual property, and provide opportunities for disciplinary researchers seeking to move into computational media. Centers should be tasked with producing detailed case studies of computational media practices in education, media projects, technology research, collaboration, scholarship, evaluation, intellectual property, mentoring, and other areas. The centers should produce best practice recommendations in a variety of areas based on these studies, from peer review to industry/university collaboration. Centers should work with professional societies, publishers, and conference organizers to provide support for special tracks at conferences, special issues of journals, and the establishment or strengthening of workshop series, conferences, and journals for specific areas of computational media. Centers should also work with funders, professional societies, and consortia to seek feedback on recommendations and spread best practices widely in each area. For example, in the area of education, these would include interdisciplinary computational media curriculum design and tenure review. Finally, centers should also assist in the establishment of further centers, as described below.

The second purpose is providing focused research expertise and resources. These might be organized by research areas (e.g., interactive narrative) or application areas (e.g., health applications). In each case, centers should provide a place for visiting researchers to learn about a particular topic; a place where promising demonstrations are regularly turned into releasable projects (and with active partnerships for transitioning to products); a place that can experiment with new evaluation and guidance methods for the area; a place that can provide yearly literature reviews of a topic; and a focal point (and gathering location) for collaborations involving universities, industry, funders, and other stakeholders. A single center might serve this purpose for more than one area, perhaps with different consortium members, or institution faculty, taking the lead in different areas.

The third purpose is expanding the computational media research and education infrastructure. After an initial phase of centers have done their first major round of field development work (and proposed, vetted, and disseminated their recommendations) a second phase of centers should begin. These centers will be incentivized to adopt the best practices identified in the first round of field development and should receive support in their establishment and work toward sustainability from both funders and established centers.

Conclusion

The expert conversations at the Media Systems gathering provided a vision of a future for computational media — one in which the challenges outlined above are overcome and the opportunities are seized. In this future, a broad understanding of computational media, and the contributions from different areas of human knowledge, emerges. The arts contribute processes and techniques for creating compelling audience experiences about issues and experiences that matter. The humanities interpret the structures of media and genre broadly (enabling practitioners to encode these in systems) as well as interpreting and evaluating the function and context of individual works, drawing historical and critical connections to the wider culture. The social sciences and education provide models of human behavior and learning, as well as models of their interpretation. Finally, computer science develops new computational approaches that make new modes of interactive media creation and experience possible, deeply connecting with the kinds of knowledge contributed by each of the other fields. The result is a set of inter-relations, in which computational media encompasses each type of contribution as a potential subject and/or practice for the others.

Within this context, existing and new university centers in areas such as new media, digital humanities, human-computer interaction, digital arts, and games come to identify computational media as part, perhaps even the center, of their research and teaching agenda. Companies with strong media creation and research groups deliberately bring them together in a computational media framework, and those with strength in one will expand to include new computational media activities. College and university departments in areas as diverse as Computer Science, Literature, and Art will hire computational media practitioners, feeling they understand how to integrate and evaluate their work, while new departments and degrees in computational media will continue to grow. New interdisciplinary grant programs will explicitly support computational media research, while existing programs will be expanded to include computational media topics, methods, and evaluation approaches. The combined impact of these changes will drive economic growth, produce powerful new media art experiences, help us understand our increasingly computationally-driven world more deeply, provide educational gains in both formal and informal settings, improve health care and health education, and provide a new dynamism to a wide range of experiences — from visiting museums to emergency preparedness training.

We hope that this report, by reflecting some of the conversations at the Media Systems gathering and those that flowed from it, makes a contribution to helping bring about this future.

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Online Talks

Introduction: Computation as Part of Culture
Noah Wardrip-Fruin

Theme 1: Lessons So Far

Crossing Boundaries
Brenda Laurel

Lessons Learned
Janet Murray

Interdisciplinarity is Hard: Who Knew
Ian Horswill

World Building
Alex McDowell

Theme 2: Operationalization & Beyond

The Art of Operationalization
Nick Montfort

Procedural Rhetoric
Ian Bogost

Curious Dances: Operationalizing Aspects of Creativity
Mary Lou Maher

Theme 3: Guiding & Evaluating

Designing Culture: The Technological Imagination at Work
Anne Balsamo

Matching Methods: Guiding and Evaluating Interdisciplinary Projects
D. Fox Harrell

Guidance and Evaluation Methods from Art, Design and the Humanities
Bill Gaver

Theme 4: Media Technology Innovation

Humanistic Media Computing
Michael Mateas

Interdisciplinary Media Technology Research
Ken Perlin

Creating Believable/Immersive Content: How Games and Film Imitate Life - and Each Other
Chad Greene

Theme 5: Field Building Models

Cyberlearning: Transforming Education
Janet Kolodner

Tin Cupping for Plutonium
Donald Brinkman

Field Building
Pamela Jennings

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