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Thinking Big: Large Media, Creativity, and Collaboration

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ABSTRACT My subject is the relationship between space and media. I focus on the role space and media play in supporting collaborative work and the opportunities that emerging technologies present to reshape collaborative-intensive endeavors for the space/media relationship. We normally treat spaces and media as different things, but our interaction with such communicative media as newspapers, paintings, books, and maps has an important embodied, physical dimension to it.

To understand these space and media interactions I examine how large-scale media, such as wall-sized maps and floor-to-ceiling whiteboards, have a role in supporting collaboration. I have considered three examples of paper spaces: Buckminster Fuller's World Game, emergency tabletop exercises, and expert workshops conducted by futurists. I note that these schematic visualizations invite participation, annotation, and reinterpretation by users as opposed to passive consumption. I also highlight the importance that physically navigating paper spaces supports the communication of what Sandy Pentland calls "honest signals," rapid negotiation, and thus the generation of common knowledge. Finally, I show how in the near-future we will be able to design digital tools that better support collaboration. The falling cost of large-scale displays, including OLEDs (Organic LEDs), e-paper, and large LED displays, suggest that the day will soon arrive when relationships between interface design and interior design, as well as computer architecture and traditional architecture, overlap and merge. Our growing familiarity with tools such as smartphones, iPads, and haptic interfaces all suggest that we will soon be able to create electronic spaces that preserve the affordances of physical media while adding flexibility to digital media. As a consequence, it will be possible to create large-scale digital media—not paper spaces, but electronic spaces—that are physically engaging, support rich social interactions and tacit knowledge, and can handle a truly three-dimensional vision of collaboration.

INTRODUCTION While we recognize that physical spaces, such as an office interior, can affect the success of collaborative work, we do not give as much credit to the role that large-scale media—examples being wall-sized maps and floor-to-ceiling whiteboards (what in an earlier essay I called paper spaces)—can play in supporting collaboration.[1] To better understand the spatial and architectural quality of media, and the way that quality outcomes when working with this media can be manipulated, I have examined several examples of paper spaces designed to support collaborative work among diverse groups. Paper spaces can be compared to physical work environments, such as offices and conference rooms, in the way that a Claes Oldenburg sculpture of a giant clothespin or eraser be compared to the real thing: a vastly larger object that highlights properties that under normal circumstances can be easily overlooked.

Recognizing that thinking and working with ideas is shaped by the properties of spaces and media—the package of properties that Abigail Sellen and Richard Harper call the "affordances"[2] of physical media—has implications for the design of digital tools for supporting collaboration. The first generation of computer-supported collaborative work systems saw group-work as essentially an exchange of formal information; the limited opportunities to design beyond the teletype or computer monitor reinforced a vision of collaboration that pushed its physical and tactile qualities to the margins. This was a vision that was less than three dimensional, both literally and figuratively.[3] But, as stated, the falling cost of large-scale displays—including OLEDs, e-paper, and large LED displays—suggest that the day will soon arrive when relationships between interface design and interior design, as well as computer architecture and traditional architecture, overlap and merge. Our growing familiarity with tools like smartphones, iPads, and haptic interfaces suggest that we will soon be able to create electronic spaces that preserve the affordances of physical media while adding the flexibility of digital media. As a consequence it will be possible to create large-scale digital media—not paper spaces, but electronic spaces—that are physically engaging, support rich social interactions and tacit knowledge, and can handle a truly three-dimensional vision of collaboration.

In this paper I begin by drawing on scholarly literature to better understand the relationships between media, space, and knowledge-production. I examine some historical aspects of reading and writing, as well as the organization of what we read (an example being office design), and the emerging literature on the cognitive impact of reading to make the case for recognizing the spatial and architec-

tural dimensions of media. Next, I look more closely at a few recent examples: the practice of analog circuit design reviews; Buckminster Fuller's World Game; emergency tabletop exercises; and expert workshops conducted by futurists. Finally, I survey emerging information technologies, and describe how they could be used to create systems that combine the flexibility of digital media and the affordances of physical media.

SPACES AND MEDIA

Space and media are deeply intertwined at many levels, this merger is so familiar that it is not initially obvious. It's apparent even at that most cerebral of activities, reading. Reading happens in space, and reading creates space. We think of "reading" as primarily visual and cognitive—something that happens between words, eyes, and brains—but it has an important spatial and physical dimension.[4] Readers behave as if books themselves are spaces: as Rory Ewins puts it, "reading takes us into an imaginative state, a state shaped by the author of the words we read, and by ourselves as readers."[5] Reading is made intimate and private by the simple fact that books are held and brought within the reader's own personal space. Even when spreading books out on a table or desk reading materials are rarely more than an arm's length away—any further and they become increasingly illegible. Readers also treat books and manuscripts as spaces in which they can construct meaning: witness the practice of marginal annotation, which is nearly as old as the book itself, and which some readers treat as a martial art.[6] Charles Darwin, for example, "had 'no respect' for books but 'merely considered them tools to be worked on,' reading them to pieces or tearing them in half as necessary."[7] As Sellen and Harper succinctly put it, "When we read, we work our way through a text using both our hands and our eyes."[8]

Private reading jumbles together space and books, and actively reconstitutes the relationship between minds, bodies, and texts. Likewise, our built environments mix spaces, images, and texts in ways that blur the functional boundaries between them. Examples of such spaces can be found in the ancient world—ranging from the carved inscriptions of ancient cities to the crowded habitus of the Renaissance scholar—but the world of ubiquitous, rapidly-changing images is a nineteenth-century invention.[9] The era saw the emergence of visual spectaculars such as: dioramas, panoramas, and lantern slides that entertained urban audiences in Europe and America. Concurrently, the proliferation of billboards and commercial lithographs from the 1870s transformed public spaces into advertising venues.[10] Out of this mix emerged spaces to support increasingly complex industrial and commercial activities. Stock exchanges and commodities markets broadcast information via large boards (the New York Stock Exchange is still called "the Big Board.")[11] The spread of the blackboard in the early nineteenth century was part of the modernization of both teaching and classroom design.[12]

The modern paper space is a descendent of these visually rich spaces, and they generally exist alongside each other; it is telling that some of the most alienating modern spaces have little signage: consider an empty parking garage, for example. Sometimes this mixture is more indiscriminate—the room I'm writing in has Wii video games, books, registration forms, illustrated drink cans, and DVDs—but many organize the relationship between space and media more systematically. Sometimes one is clearly subordinate to the other. For example, a highway is a space in which speed-limit signs, distances, road markers, and other media serve to help users navigate a space as they travel from one place to another. At the other extreme, art museums are designed to facilitate interaction with paintings, sculptures, videos, and the like; in the museum environment the physical movement is placed at the service of visual contemplation.

Media also affects cognitive practices. Consider the following two examples: the impact of the introduction of paper on medieval scholarship, and the introduction of the Blackberry on modern reading practices. Until the thirteenth century, many monastic authors dictated to secretaries who wrote in shorthand on wax tablets, summarizing rather than transcribing, and then later recreated final documents. As a consequence, Paul Saenger argues, "composition was… clearly a group activity… and a very prolific writer might well publish works which he had never seen or heard in final written or edited form." Composition involved less consultation of primary texts and fewer revisions, and the finals works were "more repetitive and less tightly reasoned than those composed in later centuries in written form, when authors consulted reference works and exercised direct visual control over their work." Finally, wax tablets "limited the scope of written composition," so "glosses were phrase-by-phrase explications of the text without cross-references or discussions of problems pertaining to the work as a whole." Albertus Magnus and Thomas Aquinas, in contrast, were able to work directly on quires and parchment, and so "could revise and rearrange their texts while composing them." The greater availability of parchment and paper allowed "thirteenth-century scholastic writers to prepare texts rich in cross-references," creating the complex body of philosophical work remembered as Scholasticism.[13]

In contrast, reading on small screens makes it harder to follow complex arguments. User interface designers have written at length on the difficulty of designing displays for showing text on mobile phone screens. In fact, the reading experience on small screens is different enough to force researchers to explore systems designed around very different reading interactions than paper — ones in which words flash on the screen for a fraction of a section, for example, or scroll across the screen like a news crawl.[14] This helps explain business author John Hagel's experience that essays are hard to interpret when read in Blackberry screen-sized increments. As Hagel writes,

> *The Blackberry or Treo is not conducive to a careful read—it encourages skimming. It also encourages people to find a quick way to capture what is in the document and then move on to the next message. As a result, people tend to try to fit these documents into familiar categories based on some key words rather than thinking deeply about the topic and absorbing new perspectives.*[15]

He adds, "It also doesn't help that documents on these devices are typically accessed in environments with lots of distractions—meeting rooms, airports, automobiles, etc.—making it difficult to concentrate on the message at hand." Indeed, the belief that such devices distract people from other tasks, but tend to be used in environments that keep users from concentrating on complex messages, has led some organizations to ban Blackberries and iPhones.[16]

All this argues against seeing reading as a disembodied interaction with content rather than with things. Ann Blair and others remind us, Renaissance readers "were distinctly aware of reading as a physical activity," and saw reading as a visceral, emotional undertaking that involved—and could even threaten—mind, body and soul.[17] This sense of reading as transformative and potentially dangerous is an ancient version of a very modern insight, that reading illustrates our ability to merge with technologies—to become cyborgs, as Andy Clark would argue.[18] Recent neuroscientific research on reading has emphasized the degree to which it succeeds because of the plasticity of the brain, and the mutual influence brains and books have on each other. Stanislas Dehaene argued that "learning to read, and other forms of cultural learning, are only possible if… [the brain's] built-in flexibility can be used to divert brain circuits from their previous uses. The brain is predisposed to develop only in certain ways. We are able to learn to read only because the primate visual system, originally evolved to perform a different job, was sufficiently flexible to allow it to be "recycled" into a reading machine."[19] More recently, Maryanne Wolf's *Proust and the Squid* argues that brains and books have a symbiotic relationship: the "brain's design made reading possible, and reading's design changed the brain in multiple, critical, still evolving ways."[20]

PAPER SPACES IN ACTION

Paper spaces allow several people to simultaneously read, annotate (or extend ideas), and to interact with each other. Their relationship to more familiar working media—notebooks, desktops, computer screens—is akin to the relationship between television or traditional film, and to large-scale projection systems like Imax through which viewers have the experience of being immersed in a visually complete alternate reality—a "frameless" experience in which the distinction between image and room disappears.[21] As Ben Shedd, one of the pioneers of Imax, put it,

> *[Imagine a] cardboard box over your head with a rectangular shaped hole cut out from its bottom. Look through that rectangle. That is the view of the movies, of TV, of small screen cinema as we have come to know it. Then take the box off your head. That's the gigantic screen view. Unframed cinematic visual space.*

Imax is not just a bigger movie screen; the immersive, frameless quality of the viewers' experience opens new opportunities and challenges for film-making. As Shedd writes,

> *The filmic experience has moved from passive, from being held in a frame, to active, to becoming the engulfing reality with the audience present within the filmic events. In frameless film the audience becomes the main character in the film.*[22]

Groups use these functionalities to share or make tacit knowledge, create novel views of the world, generate situated action, or build a sense of collective identity. The practice of analog circuit design review is a rich example of sharing craft knowledge, illustrating judgment, and building tacit knowledge. The World Game combined an unusual space—a giant version of Buckminster Fuller's Dymaxion map—with a novel process to rewire players' relationships with the world along with their views of how the world can be improved. Tabletop exercises support sensemaking by providing a space where organizations

and emergency responders can create and work through collective models of worlds in crisis.[23] Finally, futures workshops are designed to support strategic planners and executives working to create a shared vision of the future. Let's look more closely at each.

CIRCUIT GROUP DESIGN REVIEWS

Another example of a paper space that supports social interaction and knowledge-sharing is the analog circuit group design review. Analog circuit design is regarded as something of a black art among electrical engineers: analog circuits have a very wide variety of uses, which means that their designs are highly varied. This puts a premium on craft knowledge. The community uses large-scale documents to encourage communication and sharing of craft knowledge among young designers and their peers. The field "is highly collaborative -- passed down from generation to generation, like artisans learning from master tradesmen." The group design review is one ritual for sharing that information.[24] As one journalist described it,

> *More than a dozen semiconductor engineers stood around a large conference table, scrutinizing a massive sheet of paper with the layout of a chip being developed for LCD TVs—a bit like artists looking at a canvas.*
>
> *The brightly colored design showing circuitry grids and their connections took up the entire table. As they walked around it, some made notations on the paper with black markers. The discussion was animated, with ideas, suggestions and debates going back and forth…. The interaction between the more experienced and the less experienced is key in developing analog design skills. "That room is where the real magic happens," [design manager Bryan] Legates said.*[25]

The large format of the design meant that several participants could study and interact with the design simultaneously, but also easily converse with each other: the design drawing serves both as a medium for capturing ideas, and a medium for stimulating discussion.

THE WORLD GAME: CREATING NOVEL GLOBAL VIEWS

Buckminster Fuller's World Game was developed in the 1960s, and first played in New York and Southern Illinois University. The World Game was a global simulation in which players, representing countries, worked together to create a future world that provided a basic standard of living for everyone on earth. As Fuller put it, players were answering a simple question: "How do we make the world work for one hundred percent of humanity in the shortest possible time through spontaneous cooperation without ecological damage or disadvantage to anyone?" Fuller's SIU program conducted in the summer of 1970 formulated much of the research that went into the World Game. The program attracted a talented, eclectic group, all who went on to have notable careers in a variety of areas. Medard Gabel continued developing the World Game; Gil Friend founded Natural Capital, a consulting and design group in Berkeley; Edwin Schlossberg founded EIS Design, a New York-based architecture and design firm; Mark Victor Hansen co-authored the *Chicken Soup for the Soul* series; Ed Hauben became an author and facilitator; and Dewayne Hendricks pioneered wireless Internet systems.

A group with such a diversity of talents would be interesting no matter what. But the experience of working with Fuller and developing the World Game was intensified by the space they all worked in. As Dewayne Hendricks recalled, there were about fifty people working in Carbondale that summer, and they were all in a thirty-foot geodesic dome on campus:

> *We had a big Dymaxion map of the world in the center. You had to take your shoes off before you walked on it.*
>
> *We would have certain teams assigned to different parts of the dome, and we'd put our stuff there and it would be our (sic). The map was common space, and you'd have people meeting on it. There were things representing oil, coffee, water, energy, and other resources on the map. You'd walk the planet with other people and say, "what if you did this?" and move the tokens around. That's where all the collaboration would happen. People would meet there, would move resources around the planet. There was a great kinesthetic element to it.*
>
> *There were people who didn't know Fuller or his work in detail, but what grounded us was being in the dome, and the Dymaxion map. It was a transformative environment, one that opened you up to thinking in new ways. You would look at a Mercator projection of the world, and the Dymaxion map, and it would be like "Wow! The fog is raised from my eyes."*[26]

The geodesic dome and Dymaxion map combined architecture and media into a space that supported the game and inspired researchers. As another participant put it, at the end of the game, "We stood in the future in success and looked back at how we did it. We came away with a profound sense of power and possibility and responsibility."[27] Hendricks' recollections suggest that while it was designed to inspire, the group treated the space in ways that reinforced its imaginative and collaborative qualities. The group worked together on a giant map of the earth to share ideas, collaborate, and imaging the future of mankind. Even the practice of removing one's shoes before walking on the map is a telling sign: joining the game and walking the earth required an act that is common before entering temples and homes (and suggests humility and lightness rather than world-striding power). Through the dome and map, they turned the planet into their workspace; in turn, Hendricks said, workspace "put in an exploratory frame of mind, because something you'd seen all your life was transformed. You could really see the world in a different way."[28]

TABLETOP EXERCISES: CREATING SPACES FOR SITUATED ACTION

Tabletop exercises present groups with scenarios of a crisis as well as a structure to act through their responses. They stand midway between written instructions describing first responders' roles and responsibilities in a crisis, and full-scale drills that unfold in real time with actors, network disruptions, and the like.[29]

Tabletop exercises are led by a facilitator or designer, and are conducted either around a large model of a school, airport, or other facility, or in a conference room. The Department of Homeland Security recommends layouts in which "all players can see all other players… [and] the facilitator," and see "the screen to visually process the discussion and validate notes the data collector takes on a shared display."[30] Most exercises unfold over the course of several hours, or over a full day. For example, ER doctors and nurses, public health officials, police, and paramedics might gather around a model of a hospital to work through a scenario that begins with a hurricane that knocks out local power failure and disrupts roads. In a second phase of the scenario they might have to deal with shortages of personnel and supplies and an outbreak of infectious disease. At each stage of the scenario, the group assesses the viability and likely success of different responses, tests their ability to communicate orders (sometimes using real equipment), and thinks through how best to divide responsibilities for different elements of a crisis.[31]

Tabletop exercises do three critical things, and the media they use play a role in supporting all three. First, tabletop exercises help responders visualize how emergencies might unfold and see their own actions as part of a whole. For example, participants in airport tabletop exercises work with a scale models that give

> *Emergency response units and Airport Staff [use] the opportunity to work together and practice response protocols to different emergency scenarios that could occur at the Airport….The realistic depiction included a layout of the Airport and surrounding areas on an 8' x 24' tabletop… allowed members to move appropriate vehicles in response to the described scenarios, as well as communicate with each other by radios…. [This] allowed all entities involved to role-play emergency scenarios and help them become more prepared should an actual emergency occur.*[32]

Second, tabletop exercises let participants rehearse their responses to scenarios in the company of other first responders. Unlike practices that focus on sharpening individual professional skills—putting out fires, for example, or setting up quarantine zones—tabletop exercises let groups of emergency responders to practice together. Gathering in a single space makes lets participants watch each other think through problems, and share common resources like maps and physical models. This is especially valuable knowledge for dealing with complex emergencies like oil spills, which require interagency mobilization and cooperation, are highly complex, and happen rarely.[33] Finally, tabletop exercises help participants create a space in which they can improvise to handle challenges. As John Carroll says, emergency responders quickly learn not to "expect to merely execute a plan; rather, they use plans as a basis for more effective improvisation as they respond to an emergency situation.... Tabletop exercises help emergency personnel to build a planning space for improvisation during actual crises."[34]

FUTURES WORKSHOPS: CREATING COLLECTIVE VISIONS OF THE FUTURE

Professional futurists use workshops to understand what trends are likely to shape the future; how trends may combine or build on each other; how wild cards or disruptions could affect the future; and how organizations can develop strategies and skills to respond to those trends and disruptions.[35]

Expert workshops bring together diverse groups ranging from academic scientists and engineers, to venture capitalists and entrepreneurs, to extreme athletes and online gamers, to think together about the future. Workshops begin with brainstorming sessions in which participants write down on large Post-it notes the factors that they see affecting the future.[36] The facilitator then asks one participant to contribute a note and briefly explain its importance; as they do so, the facilitator puts the note up on a large sheet of paper facing the group. If others have written about similar factors, those are placed on the board with the first note. Once discussion of the trend finishes, a second person offers up a new note, and similar notes are gathered and added. The process is repeated until all the notes are played.

By the end of the session, the board may have 75–100 notes on it, and look fairly chaotic. The next challenge is to give the board (and, though the board, their own ideas) some order, by organizing the notes into thematic clusters (to see which factors or trends are associated), placing them along a timeline (to clarify when different forces might come into play), or some other method. Participants then vote on the factors, identifying those that are most important, marginal, or wildcards—events with a low probability but high impact. The group is then guided through exercises to explore the implications of important trends. For example, they may divide into several small groups to create scenarios or maps that describe different potential futures made by combinations (or cross-impacts) of trends.[37]

These mapping processes serve to create a visible, collective vision of the future.[38] Just as powerfully, the process itself embodies ideas about how to approach the future. Workshops encourage participants to collaborate on common visions, to explore and expand the meaning of ideas contributed by others, to see various ways in which the future can be mapped, and to better understand how different possible combinations of trends can yield different futures. Processes and the affordances of paper conspire to reinforce a vision of the future as contingent, open-ended, subject to human agency, and collectively made. The paper space, in other words, becomes a representative microcosm of the future itself: the finished space contains a vision of the future, while the processes we use to help groups generate collective visions also produces intellectual tools that will help them better respond to the future.

HOW PAPER SPACES WORK

The World Game, emergency tabletop exercises, and futures workshops are very different kinds of events, but each share several features that account for their success. Their size allows them to serve as both workspaces and media. Because of this, they are able to serve as trading zones for sharing diverse ideas and skills. Finally, it allows paper spaces to support collaborative embodied cognition.

PAPER SPACES ARE BOTH WORKSPACES AND MEDIA.

Let's begin with something obvious but important: paper spaces are big—big enough to envelop a group and its conversation. Paper is usually something personal: we read books and magazines by ourselves, and the experience of having someone look over our shoulder as we read can be uncomfortable. But a large map or document reverses the normal relationship between users and information. A large map on a wall or floor requires you to approach it on its terms. The act of reading is not a private activity, but a public one: everyone can see you reading, and see what you're reading. Paper spaces can also comfortably support simultaneous reading or use by several people. The Dymaxion map was large enough to allow a group of researchers or players to work together at once without crowding; tabletop exercises give participants a common set of objects to work with and interact around.

Paper spaces are thus both workspaces and media: they support a group's work by recording its ideas, making them instantly available for reuse. Paper spaces begin as schematics, surfaces to work on, or explicitly incomplete visualizations, which are then completed by a group. As the World Game unfolds and players learn how to cooperate resources become more evenly distributed; over the summer of 1970, the SIU researchers filled their dome with books, maps, computer printouts, and the like. The paper space in a futures workshop starts as a tabula rasa; by the end of the workshop, every wall may be covered with maps and drawings. A prolific group will eventually be surrounded by its own work. The paper space serves as a memory palace.[39] Unlike official minutes of meetings, or private notes taken by individuals, a paper space is group property. A group shapes the space, and in turn the space can shape the group: the act of filling a paper space can help create a shared sense of identity among the participants. As sociologists of science might put it, the paper space, the knowledge within it, the social context necessary to interpret it, and a collective sense of ownership all become co-productions.[40]

Paper spaces also make complexity visible and manageable. Large sheets of paper provide room for every-

thing from big ideas to small details. They let users store and see a lot of information, and see it all at once. With conventional paper, paying attention to the "big picture" and small details at the same time is difficult: but in paper spaces, the big picture—the structures or abstractions that give context and meaning to the details—doesn't replace the details; it's built up from them. New ideas can emerge by literally moving the details from one place to another, embedding them in new contexts or creating new contexts around them.

PAPER SPACES ARE TRADING ZONES.

Paper spaces and the media they contain hold ideas or objects created by individuals, but they also allow groups to discuss, extend, and reinterpret those objects. Consider the Post-its used in futures workshops. Post-its notes are cheap, easy to use, and easy to handle. Participants write in large letters, which makes the cards legible at a distance, and forces the author to be brief. When making chronologies or idea maps, notes can be moved around easily, making them "mutable mobiles," in paraphrase Bruno Latour's phrase.[41] As participants move notes from one point on a timeline to another, or from one cluster of ideas to another, they acquire new neighbors and context, which subtly changes their meanings and importance. While talking about notes and the trends they describe, new meanings or implications may emerge. In short, notes are cheap, flexible, and eternally tentative.[42] They make ideas shareable, social things, both through the opportunities they create for group discussion and meaning-creation, and in the limits they impose on authors. The fact that notes cannot stand completely on their own—they're signs, not signifiers—means that the course of a day groups change notes' meaning, importance, and place in a larger network of ideas and associations.

Paper spaces thus operate as "trading zones," bringing together people from different disciplines and industries.[43] As historian of science Peter Galison describes it, a trading zone is a "region (conceptual and spatial) of partial coordination" between scientific and technical specialties or communities. One notable feature of trading zones is that even without "global agreement on the goals and ultimate principles…. there could still be a local coordination between actions in the laboratory and theories on paper."[44] Futures workshops often mix people with very different backgrounds and interests: academic scientists with little interest in corporate strategy, DIY tinkerers or amateur scientists unimpressed with academic credentials, industrial designers focused on the next product cycle, and corporate planners thinking about long-term strategic trends can come together to mapping the future. Tabletop exercises bring together city officials, public health and medical professionals, and emergency responders—groups with distinct skills, authority, and ideas about how to confront threats. Part of what makes the spaces valuable is that while paper spaces can encourage participants to work together, they do not *necessarily* become like-minded: their varied perspectives are a source of strength in seeing possible futures and anticipating problems.

PAPER SPACES SUPPORT COLLECTIVE EMBODIED COGNITION.

Philosophers and cognitive scientists recently have argued about the degree to which thinking and cognitive processes are embodied—that is, expressed and managed not just within the brain, but elsewhere in the body as well. The traditional view of the mind locates mental processes in the brain, but recent research suggests that memory and cognition are not computer-like operations that take place just inside our heads; they (as well as emotions, intuition, and instinct) involve our bodies too.[45] Just as the body supports individual cognition, I argue, paper spaces support collective embodied cognition: they provide a physical and material infrastructure that can improve the ability of groups to think and create together. How do they do that?

First, paper spaces give participants an opportunity to collaborate with one another in ways that build tacit knowledge, improve communication, and produce resources that can be used in more formal or real-world settings. In futures workshops, as many as twenty people can study, reorganize or annotate ideas in ways that would be impossible using regular pieces of paper. Several people can stand in front of an eight-foot long sheet, working together to arrange stickies in new combinations and patterns. Finally, the formal results of a futures workshop can be used in a company's strategic planning process, while the tacit knowledge it produces—the shared experience of thinking deeply about the future, the rich variety of meanings and discussion captured in the space and accessible only to its participants—can serve as a resource in implementing strategy. Tabletop exercises support collective embodied cognition by giving participants a chance to see how other first responders react to new situations, and to improve communications flows between responders. By helping groups create situated action—action about a situation, and action to help cope with a situation—tabletop exercises make it possible for groups of first responders to function more effectively as a group, and help individual responders better understand and anticipate the problems

or reactions others will have to novel problems. Analog circuit reviews provide a space in which participants can share craft knowledge, look together at an element of the design, and come to a collective understanding of why a solution makes sense or can be improved.

The very act of moving in a paper space also has cognitive benefits. In futures workshops and analog reviews, participants are often standing and moving around, which keeps them more energetic and engaged: the ancient recommendation *solvitur ambulando* (it is solved by walking), which recognizes that motion—particularly walking or pacing—can help people be more creative. Paper spaces let participants see where others (literally) stand on an issue: what others are looking at, what their body language communicates, and what their movement through a paper space says about their interests or thinking.[46] Putting an idea on a map may look like a simple physical act, but it marks a person's contribution to a conversation; it locates that contribution in an emerging picture of the future; and it situates that contribution alongside (or against) others'.[47]

CONCLUSION: THE DIGITAL FUTURE OF PAPER SPACES

Throughout this article, I have argued that paper spaces have a critical material and physical dimension, and that attending to this dimension is critical to understanding how they support collaborative work and problem-solving, the revealing of tacit knowledge, and collective embodied cognition. It's illuminating to compare paper spaces to computerized collaborative systems. These systems allow individuals who are physically separated to communicate; they support asynchronous collaboration; they flatten social hierarchies and leapfrog prejudices by separating digital from real-world personas. In other words, their designers have assumed that these systems would succeed largely because they overcame the physical limitations of real-world collaboration. But as we have seen with paper spaces, what we thought of as bugs or limitations in the real world of collaboration are actually features: paper spaces succeed because they are physical places and material objects, that interact not just with disembodied individuals or minds, but engage multiple senses, facilitate multiple kinds of formal and informal communication, and support the creation, sharing, and use of both explicit and tacit knowledge.

To date, the affordances of paper have not been reproduced in digital hardware. Anyone who has spent time in a computer lab filled with desktop machines, or a meeting where participants have their laptops open, is familiar with a paradox: the same properties that allow computers to support collaboration between people thousands of miles away can disrupt collaboration between people in the same room. Because computers have been "personal," it has been hard for multiple users in the same space to share information with each other; this frustration has made it more inviting to retreat from group discussions into private spheres of connection and attention, to pay less attention to the meeting and more to Facebook and e-mail. More generally, computers have been hailed for their capacity to dematerialize knowledge, to set information free from physical or social boundaries. While in many contexts these are valuable, in intense collaborative work—the kind of highly-interactive, high-stakes work discussed here—those features are bugs, paper spaces succeed precisely because of their materiality, physicality, and sociability.

However, we are beginning to see trends that suggest that in the near future it will be possible to create new systems that break with the reigning paradigm of personal computing, and open the potential for creating technologies that combine the affordances of paper spaces with the advantages of digital media.

One trend is the growth of social software. In the Web 2.0 world, successful tools tend to be simple, social, and symbiotic. Simplicity makes them easy to learn, and easy to adapt to new use contexts. Sociability enables community development and the creation of communities of practice who share simple systems (rather than being divided by reliance on proprietary silos). Finally, powerful tools are symbiotic: they and their users co-evolve, each teaching the other new skills.[48] This more flexible and human approach to the design of knowledge management tools doesn't aim to replace existing work routines, or to create virtual worlds that simulate conventional offices and meeting spaces, but to augment existing practices and places. A second trend is the emergence of affordable large-scale projection screens and haptic devices that make it possible to create inexpensive, flexible digital versions of paper spaces.

For years, "data caves" were expensive, dedicated spaces used mainly for sophisticated scientific and technical research; with high-quality mobile projectors, interactive concept mapping tools like Ahead and Prezi, the growth and growing familiarity of haptic interfaces, and the proliferation of small Internet-enabled mobile devices like smart phones and tablets, it is becoming possible to create tools that project digital information in large physical spaces, and allow collaborators to read and work simultaneously on an electronic map or other file—all without disrupting the social exchanges and negotiations that

make traditional workshops, tabletop exercises, and other paper space activities valuable. It also becomes possible to do new things, such as linking together groups in different places to work simultaneously in parallel paper spaces, to create events that mix present and virtual participants, or to more intensively record the development of a concept map or timeline.

In short, this would be a space that preserved all of the virtues of physical media and space, but augmented them with the flexibility and contingency of digital media. Digital paper spaces would come even closer to the ideal of a "frameless" experience that immerses a group in a cloud or landscape of information, and invites them to extend, annotate, and generate new knowledge within it. Such spaces could combine the best of physical space and digital media and open new ways for designers and facilitators to create spaces that allow groups to create and share knowledge.

BIOGRAPHY

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