Exploring the Design of Clinical Information Systems

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1. Introduction

The initial forays into the use of information technology in hospitals go as far back as the 1960's. During the following three decades a few process specific systems were slowly refined and expanded at hospitals like Harvard, Duke, and Intermountain Healthcare in Utah. However it wasn't until the 1990's, on the heels of major advancements in computing technology, that full fledged clinical informations systems became a viable option for a significant number of healthcare providers. Since then a number of vendors have entered the picture and developed sophisticated electronic medical records hoping to capitalize on what is seen as a growth market. However up until this point adoption has remained slow and at the turn of the century it was estimated that less than 10% of hospitals had any health information technology.[1]

Obama's election and the subsequent stimulus bill will vastly change things. The bill contains an "unprecedented $19 billion program to promote the adoption and use of health information technology (HIT) and especially electronic health records (EHRs)."[2] It is believed by the administration that the adoption of clinical information systems will greatly improve the health and healthcare of Americans. The task is not as simple as many believe. There are major social and organization barriers to deployment of EHRs. Research has shown that "these socio-technical issues dominate the success or failure of medical information systems."[3] In fact Anderson et al. (1994) estimate that more than half of medical information systems fail because of user and staff resistance.

This paper seeks to explore some of the social issues impeding the development and successful deployment/adoption of clinical information systems. It specifically looks at the socio-technical gap as it relates to the provision of healthcare. After a brief review of the literature I will present findings showing that clinical information systems, and more specifically electronic health records, are highly distributed cooperative work platforms that are especially vulnerable to the socio-technical gap. I will then argue that a proper understanding of this gap should inform the fundamental architecture and design of these systems.

2. The Socio-Technical Gap Paradigm

The socio-technical gap derives from the inability of current technologies and systems to completely reflect the nuanced, tacit, and contextualized nature of human activity and interaction (Ackerman, 2000). It is an acknowledgement of the paradigm upon which Herbert Simon's "Sciences of the Artificial" are premised (Simon, 1981), an exploration of the implicit differences between the natural and the artificial, a study of mechanistic limitations.

The conceptual tenets of the socio-technical gap percolate through the social and artificial sciences, manifesting themselves to varying degrees in the research of those studying technology and society.

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[1] Ringold, D., Santell, J. P., Schneider, P. J. "ASHP national survey of pharmacy practice in acute care settings: dispensing and administration—1999".

[2] Blumenthal, D. "Stimulating the Adoption of Health Information Technology." p. 1.

[3] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. "Incorporating Ideas From Computer-Supported Cooperative Work." p. 129.

While a complete survey of the relevant literature is beyond the scope of this paper, I'll reference a few pertinent papers to highlight the socio-technical gap paradigm and explore its important themes. These themes will then be used to develop a framework for thinking about the design and implementation of clinical information systems.

There exists ample future opportunity for social scientists and others to explore in depth how broad social theories such as Determinism and Social Constructivism might interpret the socio-technical gap. Readers familiar with these theories will probably recognize such opportunities and my allusions to them. However this discussion will be limited to a brief review of what I see as the more pragmatic manifestations of the gap including its importance in computer supported cooperative work (CSCW) and its relationship to studies of tacit knowledge and heterogeneous networks.

2.1. Computer Supported Cooperative Work

A developing field of research collectively known as Computer Supported Cooperative Work has emerged over the last two decades in response to, and in conjunction with the ever expanding use of information technology, and more specifically groupware,[4] in work environments. As of yet the field seems to lack a generally accepted definition (Bannon, 1993), however Schmidt and Bannon (1992) suggest that the field be seen as "an endeavor to understand the nature and requirements of cooperative work with the objective of designing computer-based technologies for cooperative work arrangements."[5] As such, much of the research centers around analyzing the potential for computer systems to support and coordinate collaborative activities (Carstensen & Schmidt, 1999).

One of the problems in the CSCW field is in identifying what exactly is meant by cooperative work. An expansive interpretation might include any set of result oriented activities requiring input from multiple people. This would imply that cooperative work is inherently distributed, an axiom that I will borrow from Carstensen & Schmidt (1999). Let's assume then that the degree of distribution in a given cooperative work environment is directly dependent on the number of actors, the breadth and depth of their specialization, and the interdependency of the work activities (Carstensen & Schmidt, 1999). This suggests that distribution is an alias for complexity which leads us to a second axiom: the more distributed a cooperative work environment is the harder it becomes to accurately articulate its activities. Or to put it more succinctly, its hard to model complex cooperative work environments.

Ackerman (2000) proclaims that we don't know how to build systems that fully support the complexity of social activity. Through an extensive survey of CSCW research he concludes that "human activity is highly flexible, nuanced, and contextualized," and that the inability of computational entities to be "similarly flexible, nuanced, and contextualized"[6] is due to a socio-technical gap. This conclusion is supported by numerous findings, including extensive analysis of social interaction. In particular, Ackerman highlights research showing that the details of interaction play a considerable role in people's decisions and reactions, and that the specific details they consider or act upon differ according to the situation. The gap arises when "rigid and brittle"[7] technical systems fail to adequately handle this detail and flexibility.

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[4] Groupware is the term for the technology analyzed by this field of research

[5] Schmidt, Kjeld, and Liam Bannon: "Taking CSCW Seriously: Supporting Articulation Work," CSCW, vol. 1, no. 1-2, 1992, p. 11.

[6] Ackerman, Mark S. 2000. "The Intellectual Challenge of CSCW: The gap between social requirements and technical feasibility". *Human-Computer Interaction* **15**: p. 180.

[7] Ackerman, Mark S. 2000. "The Intellectual Challenge of CSCW: The gap between social requirements and technical feasibility". *Human-Computer Interaction* **15**: p. 180.

Flexibility is especially important in handling workflow exceptions and conflicts. Klein and Dellarocas (2000) define exceptions as “any deviation from an ‘ideal’ collaborative process that uses the available resources to achieve the task requirements in an optimal way.”[8] Exceptions appear frequently in cooperative work environments, and handling these exceptions makes up a significant portion of office work (Suchman, & Wynn, 1984). Conflicts are also common when the people within a group or organization do not share the same goals, knowledge, or meaning. While people tend to be good at dealing with conflicts and exceptions (Suchman, 1987), often by changing or adapting their roles (Strauss, 1993), systems have a much harder time. Considerable research has gone into designing workflow systems that can fluidly deal with conflict, role changing, and exception handling (Klein and Dellarocas, 2000), however current systems still remain ill-suited to address this aspect of the socio-technical gap.

Many researchers in AI, computer science, and related fields will argue that the gap is simply the product of current technological limitations, and that completion of a bridge remains imminent. Weak determinists might argue that this is simply a ripple in the coevolution of society and technology, and that people will eventually adapt to the gap. Neither of these arguments are immediately disprovable and both are worth considering, if for no other reason than to expand on existing research. In my discussion of Actor Network Theory I will return to the more deterministic argument, but the take away here is that there is strong evidence suggesting that the gap exists and will continue to exist for the foreseeable future.

2.2. Tacit Knowledge

Studies of tacit knowledge also imply the existence of a socio-technical gap. Most people are familiar with the concept of tacit knowledge, but for the purposes of this discussion I’ll borrow the following definition from Mackenzie and Spinardi (1995):

> “Tacit knowledge is knowledge that has not been (and perhaps cannot be) formulated completely explicitly and therefore cannot effectively be stored or transferred entirely by impersonal means.”[9]

While this definition is somewhat abstract, it successfully avoids being recursive. The important thing is that tacit knowledge can’t be transferred by impersonal means. In other words, it can’t be codified or captured by a computer system.

In their study of nuclear weapons designers Mackenzie and Spinardi (1995) point to the use of judgement as bridging the gap between model and reality. They state that “judgement is the ‘feel’ that experienced designers have for what will work and what won’t.”[10] But how does this tacit knowledge develop? Hutchins (1995b) points to situated learning in a community of practice. The visibility of the information being communicated, in this case between weapons designers, facilitates learning. Over time the designers develop a feel for the subtleties and nuances of their craft which can’t be explicitly formulated. Their use of judgement is a manifestation of tacit knowledge that enables them to bridge the gap.

It’s very hard to prove that tacit knowledge does in fact exist. It’s easy to think that, given enough time, people could capture and codify every variable used to make a decision or reach a conclusion and that through proper analysis a different person or group of people could use this information to reach the same end result. The knowledge that this train of thought is unrealistic and not possible may itself be tacit, hence the recursiveness of the problem. In either case, even if complete codification were possible, the economic feasibility of it would approach zero which is sufficient reason to acknowledge the existence of

[8] Klein, M., Dellarocas, C., (2000). A Knowledge-based Approach to Handling Exceptions in Workflow Systems. Computer Supported Cooperative Work, vol. 9, p. 400.

[9] Mackenzie, D., Spinardi, G., “Tacit Knowledge and the Uninvention of Nuclear Weapons.” p. 215

[10] Mackenzie and Spinardi, “Tacit Knowledge and the Uninvention of Nuclear Weapons.” p. 230

tacit knowledge. This supports Ackerman's (2000) theory that the socio-technical gap will remain for the foreseeable future.

2.3. Actor Network Theory

While a full exploration of ANT is beyond the scope of this paper, a brief review of some of its concepts will help in thinking about the socio-technical gap, and also in the development of our framework. At its core ANT assumes the existence of heterogeneous networks made up of both human and non-human actors. These actors are characterized by their ability to act and interact, and by the influence they exert on other actors in the network (Esnault, Zeiliger & Vermeulin, 2006). John Law suggests that "society, organizations, agents, and machines are all effects generated in patterned networks of diverse (not simply human) materials."[11] One of the logical extensions that ANT draws from this is that non-human actors possess agency.

Translation is also a core concept in ANT and it "implies transformation and the possibility of equivalence, the possibility that one thing (for example an actor) may stand for another (for instance a network)."[12] The idea is that when all of the various actors in a network become aligned or ordered then the network, at a more abstract level, takes on the role of an actor. This abstract actor could be a device, institution, organization, or some other node in a higher level network. Put another way, the "actor is a patterned network of heterogeneous relation, or an effect produced by some network."[13]

Actor Network Theory is important to the socio-technical gap paradigm because it forces us to consider the gap from both sides. As I mentioned previously, a more deterministic view would say that humans simply need to adapt to the gap. Without going that far, it's still important for us to consider the influence that systems have on the people that use them and the possibility for translation. Akrich has said that "a large part of the work of innovators is that of inscribing their vision of the world in the technical content of a new object."[14] ANT suggests that this inscription process can align the interests of all of the actors in the network, and that "a translation process supposes a medium or a material in which it is inscribed."[15] An understanding of how this translation and abstraction works can be useful building major information systems.

3. Clinical Information Systems Case Study

In order to illustrate the concepts discussed above I will outline how they might influence and inform the design and development of clinical information systems, or more specifically, electronic medical records (EMRs). EMRs, also called electronic health records (EHRs) and patient records (PRs), are digital documents that are meant to replace the paper records currently used by most hospitals. The systems used to generate these documents are included in this analysis. I'll begin by showing why electronic health records present such a rich opportunity to address the socio-technical gap and Actor Network Theory. I'll then present a possible system architecture based on these findings, and finally I'll recommend a design approach.

3.1. Hospitals as Heterogeneous Networks

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[11] Law, J. 1992. "Notes on the Theory of the Actor Network: Ordering, Strategy and Heterogeneity." p. 2.

[12] Law, J. "Notes on the Theory of the Actor Network: Ordering, Strategy and Heterogeneity." pp. 5-6.

[13] Law, J. "Notes on the Theory of the Actor Network: Ordering, Strategy and Heterogeneity." p. 4.

[14] Akrich, M. "The Description of Technical Objects."

[15] Esnault, L., Zeiliger, R., Vermeulin, F. "On the user of Actor-Network Theory for Developing Web Services Dedicated to Communities of Practice." p. 301.

A hospital is made up of an extremely heterogenous group of actors performing a wide variety of functions. The human actors include physicians, patients, nurses, technicians, administrators, and others. These actors "are heterogeneous in respect to their disciplines, preoccupations and interests."[16] Non human actors range from simple surgical tools, to powerful imaging devices, to complex clinical information systems. These machines are heterogeneous with respect to their functions. The hospital as a whole is an extremely heterogeneous network. Berg writes that "approaching health care practices as heterogeneous networks (...) is a crucial first step towards systems that will articulate more powerfully and more artfully with their surrounding networks."[17]

3.2. Healthcare as Cooperative Work

Healthcare quite literally is a field that is designed to provide care for people with health related problems. Providing care is an inherently collaborative process, requiring cooperation from a variety of actors. For example, a patient might visit their primary care doctor at a local clinic, then get referred to a hospital where they are seen by multiple nurses, one or more specialized doctors, a lab technician to run tests, and in the case of surgery, an anesthesiologist. The patient then might visit a pharmacist to pick up medication, schedule a session with a physical therapist, and see their primary care doctor again for a follow up visit. On top of that the payer or insurance provider has to be in contact with everybody. In order to provide a high level of care an amazing amount of cooperative work must take place.

In order to limit the scope we will only look at the cooperative work within a single hospital which is where most of the interaction with the electronic medical record system will take place. Even with this limitation we still find that the "working practices in hospitals require strict coordination between different physicians, nurses and other personnel as well as within and between departments."[18] All of these actors "use the EMR in different ways to accomplish the shared goal of effective and efficient patient care."[19] It is this interaction with the EMR that we will concern ourselves with.

3.3. Interaction with an Electronic Medical Record

An electronic medical record is defined as "any system that supports an electronic collection of an individual's health information that is used to care for that individual."[20] The EMR of a single patient would include a history of their care including what they've told their physician, the diagnoses they've received including prescriptions, lab results, and any other information related to the patients interaction with the care providers. The EMR is also used to plan patient care so it would include records of communications between primary care physicians and specialized physicians, as well as nurses and lab technicians.

Because neither diagnoses nor treatment are an exact science, the EMR becomes somewhat of a living, collaborative document. It is a digital representation of "ongoing negotiations about the nature of the

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[16] Esnault, L., Zeiliger, R., Vermeulin, F. "On the user of Actor-Network Theory for Developing Web Services Dedicated to Communities of Practice." p. 300.

[17] Berg, M. "Patient care information systems and health care work: a sociotechnical approach." p. 98.

[18] Tjora, A., Scambler, G. "Square Pegs in Round Holes: Information Systems, Hospitals and the Significance of Contextual Awareness." p. 2.

[19] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. "Incorporating Ideas From Computer-Supported Cooperative Work." p. 131.

[20] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. "Incorporating Ideas From Computer-Supported Cooperative Work." p. 129.

tasks and the relationship between those who execute the tasks."[21] The document is constructed by a highly distributed network of collaborators, each providing their own unique input in the hopes of coming to a unified conclusion that maximizes the quality of care for the patient. However, "the never fully predictable nature of patients' reactions to interventions results in an ongoing stream of sudden events"[22] which must be supported and mediated by a fluid documentation process. As we showed earlier it is extremely hard, if not impossible to accurately articulate all of the activities in a highly distributed collaborative work environment. This is where an understanding of the socio-technical gap becomes most important.

3.4. Identifying the Socio-Technical Gap

In order to identify the socio-technical gap relating to EMRs I will summarize a number of findings from clinical informatics and social science research. We've already established that EMRs are collaborative work tools that function in highly distributed heterogeneous networks which is heavily indicative that the gap will exist. Let's now pinpoint some of the specific areas where these EMR solutions fail to support the flexible, nuanced, and contextualized nature of the users.

Tjora and Scambler (2008) have suggested that "the oral, synchronous exchange of information is at the centre of many work tasks,"[23] and that we need technologies that "allow for efficient spontaneous communication in dynamic contexts."[24] Pratt et al. (2004) write that "the patient record is a form of asynchronous collaboration that provides a mechanism for information sharing between doctors."[25] But the methods for this information sharing are generally not flexible enough to fully capture the nuances of more traditional forms of communication, especially considering "the shifting dynamic character of work in a hospital department."[26]

Heath and Luff (1996) suggest that the "tacit and taken for granted practices on which doctors rely in reading and writing records are highly relevant."[27] They go on to say that "in writing an entry, practitioners are sensitive to the inferences that colleagues can draw from particular items."[28] The tacit knowledge that these physicians use can't be codified into the system. Berg writes that "any concrete work activity only unfolds 'in the doing', in constant interaction with the contingent circumstances that make up the situation in which it is located."[29]

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[21] Berg, M. "Patient care information systems and health care work: a sociotechnical approach." p. 91.

[22] Berg, M. "Patient care information systems and health care work: a sociotechnical approach." p. 90.

[23] Tjora, A., Scambler, G. "Square Pegs in Round Holes: Information Systems, Hospitals and the Significance of Contextual Awareness." p. 520.

[24] Tjora, A., Scambler, G. "Square Pegs in Round Holes: Information Systems, Hospitals and the Significance of Contextual Awareness." p. 520.

[25] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. "Incorporating Ideas From Computer-Supported Cooperative Work." p. 131.

[26] Tjora, A., Scambler, G. "Square Pegs in Round Holes: Information Systems, Hospitals and the Significance of Contextual Awareness." p. 520.

[27] Heath, C. and Luff, P. "Documents and professional practice: 'bad' organisational reasons for 'good' clinical records." p. 355.

[28] Heath, C. and Luff, P. "Documents and professional practice: 'bad' organisational reasons for 'good' clinical records." p. 356.

[29] Berg, M. "Patient care information systems and health care work: a sociotechnical approach." p. 92.

EMR systems also struggle to handle exceptions which are often the norm in clinical settings. Berg observes that physicians and nurses “often establish ‘workarounds’ to trick the system so that it keeps on functioning without interfering with the acute, practical situation at hand.”[30] These problems are generally due to failed attempts at articulating activities within the network, resulting in rigid systems with inflexible process flows that lack contingency plans.

3.5. A Communication Based Architecture

Every computer system designed to support cooperative work needs to facilitate interaction and communication between the actors in the network. In fact it has long been understood that the EMR “plays an important communication and workflow role.”[31] However it is the nature of this role and how it addresses the socio-technical gap that can lead to the success or failure of the system. Understanding the nature of the gap should inform the fundamental architecture of the electronic medical record.

Developing an EMR architecture that, at its core, supports an open, flexible dialogue between the actors in the network will best address the issues arising from the socio-technical gap. Simple communication protocols such as email and chat have enjoyed huge success in cooperative work environments for that very reason. More recently, web 2.0 applications such as Facebook (the Wall), Twitter, and Skype have developed other ways of facilitating communication. The flexibility of these systems allows them to better handle exceptions and the switching of roles. While they certainly can’t capture every detail of human interaction, they are designed to work through this problem by decreasing communication barriers.

On the other side of the gap we can see the influence that these non human actors have on the human actors. As Law suggests, “social relations may shape machines, or machine relations shape their social counterparts.”[32] The machines inscribe their particular innovations onto the users. Using Twitter as an example we see how quickly people have adopted the peculiar syntax they provide to interact with their service and with other users.[33] This coevolution eventually aligns all of the actors in the network allowing for translation and abstraction so that the network becomes an actor with its own metaphorical API. In the healthcare field this could allow individual healthcare providers to interface with each other, leading to a distributed heterogeneous network of providers.

Even with a flexible communication architecture that facilitates a nuanced dialogue between various human and non human actors, an EMR still must support more rigid processes. Things like filling out prescriptions and coding work for billing purposes should be attached to, and driven by, aggregated groups of select communications (similar to the way the “Wall” works on Facebook). The way these communications are aggregated to drive these processes, and the way these process flows are handled is beyond the scope of this paper, but as I hope to show, a socio-technical approach to their design would be best suited to soften the edges of the gap and increase the likelihood of adoption.

3.6. Participatory Design in EMRs

There is a wealth of research demonstrating the value of participatory design in electronic medical records. For example, it has been shown that “users play a large role in determining whether a software

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[30] Berg, M. “Patient care information systems and health care work: a sociotechnical approach.” p. 97.

[31] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. “Incorporating Ideas From Computer-Supported Cooperative Work.” p. 131.

[32] Law, J. “Notes on the Theory of the Actor Network: Ordering, Strategy and Heterogeneity.” p. 3.

[33] http://help.twitter.com/forums/10711/entries/14020

system will fail or succeed."[34] To put it another way, "it is believed that systems stand more chance of success when those who will use them have been able to have a stake in their development."[35] This is by no means counterintuitive. People have a harder time rejecting that which they've created, or at least helped to create.

Actor Network Theory also recognizes benefits to participatory design. Berg states that "in a well-guided development process, the application and the health care professionals 'enable each other to affect each other' in their mutual interactions."[36] This is a very important concept because it softens the existence of the socio-technical gap. As the users participate in the design process they are influenced by the software which can lead to acceptance of its limitations. This acceptance slowly works to align the interests of the actors in the network by encouraging the users to adapt.

Involving the users in the design process does not necessarily bridge the socio-technical gap. There are still significant limitations to what computer systems can achieve in a collaborative work environment. However it does help to highlight these limitations which leads to more informed decisions on how to work around them. And in addition, it enables the stakeholders to become "united by an ethos of empowerment and meaningful involvement."[37] This is especially important for electronic medical records because of the high distribution and heterogeneity of the networks they're meant to support, and the fluid, nuanced, and contextualized nature of the actors in the network.

4. Conclusion

Healthcare providers, and in particular hospitals, are extremely cooperative work environments that stand to benefit immensely from supportive technologies. However the socio-technical gap is a significant barrier to development of these technologies, and in particular, electronic medical records. The highly distributed network of actors makes accurately articulating activities a near impossible task. The dynamic environment is rife with nuanced and contextualized interactions, and the communication and interpretation of tacit knowledge. Exceptions to the 'rules' occur so frequently, and are so necessary, that they become normative. In this environment it is not uncommon for clinical systems to be rejected before they've even been deployed.

In spite of this, it is the goal of the current administration to implement an EMR in every hospital within the next four years. There is much to be gained from these systems beyond facilitating interactions within the hospital and improving patient care. Increased accuracy in drug prescriptions, improved relationships with payers, and the accumulation of higher quality research data have all been cited as benefits. It is expected that all of these things together will lead to improved, more affordable healthcare.

The fact remains that many of these systems fail, often because they are too rigid and process oriented. Improving these systems means allowing the existence of the socio-technical gap to inform every step of the development process. The nuances, subtleties, and tacit knowledge that exist in every interaction between actors in the network can't be denied or suppressed. The underlying architecture needs to be built with the flexible facilitation of communication and cooperation as its core value. This will not

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[34] Pratt, W., Reddy, M., McDonald, D., Tarczy-Hornoch, P., Gennari, J. "Incorporating Ideas From Computer-Supported Cooperative Work." p. 129.

[35] Martin, D., Mariani, J., Rouncefield, M. "Practicalities of Participation: Stakeholder involvement in an electronic health records (EHR) project." p. 2.

[36] Berg, M. "Patient care information systems and health care work: a sociotechnical approach." p. 97.

[37] Martin, D., Mariani, J., Rouncefield, M. "Practicalities of Participation: Stakeholder involvement in an electronic health records (EHR) project." p. 2.

bridge the gap but may provide a suitable work around and facilitate the coevolution of the systems and their users.

In addition to influencing the architecture, the socio-technical gap should play a pivotal role in the design of processes and interfaces. Participatory design is imperative to the success of electronic medical records, both because it increases the stake that the users have in the success of the project, and because it increases the transparency of the technological limitations. Rather than rejecting the systems for what they can't do, the users appreciate them for the benefits that they provide and adapt to the limitations that they create.

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