CLINICAL AND TRANSLATIONAL SCIENCE INFORMATICS

Translating Information to Transform Health Care

Arkalgud Ramaprasad, Annette L. Valenta
University of Illinois at Chicago, Chicago, IL 60607, U.S.A.

Ian Brooks
National Center for Supercomputing Applications,Urbana, IL 61801, U.S.A.

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Abstract: Clinical and Translational Science (CTS) is a new and emerging academic discipline which seeks to reduce (a) the time-to-application of research to, and (b) the time-to-research of, health care problems. Translating information within and between the research and practice silos is central to CTS. The role of CTS Informatics (CTSI) can be stated as 'translating information to transform health care'. We present an ontological analysis of the transformation of health care by CTSI. The five dimensions of the ontology are derived by parsing the above definition of CTSI. They are: (a) information, (b) semiotic translation, (c) spatial translation, (d) temporal translation, and (e) health care. Each dimension is defined by a taxonomy. Each sentence, formed by concatenating categories across the five dimensions using appropriate prefixes and conjunctive words and phrases, is a natural language descriptor of CTSI. The set of all such sentences is a closed description of CTSI.

1 INTRODUCTION

Clinical and Translational Science, at its core, is information intensive. The guiding mission of CTS Informatics (CTSI) is to develop, support, and continuously improve the research workflow to reduce the time-to-application of basic research and the time-to-research of clinical and community health problems. CTS' success will depend upon the "bi-directional information flow between basic and translational scientists…." (Zerhouni 2005, p. 1621) It is expected that the "CTSA [CTS Awards] institutions will work as part of a national effort to expand and improve clinical research informatics to share data across disciplines and across institutions….New and expanded IT will help to solve issues related to workflow, usability, and interoperability with collaborating organizations, along with the need to ensure privacy and confidentiality of human subjects." (Zerhouni 2007, p. 127) The informatics infrastructure will be essential "[t]o develop the preemptive, predictive medicine of the 21st century." (Zerhouni 2005, p. 1355) Overall "the NIH aims to develop a national system of interconnected clinical research networks capable of more quickly and efficiently mounting large-scale clinical studies. As currently conceived, this system of networks will integrate and expand extant research networks using common or interoperable infrastructure, including harmonized informatics, governance, terminology, and training." (Zerhouni 2005, p. 1356)

Thus, we can succinctly encapsulate the above visions and objectives of CTSI in the statement 'translating information to transform health care.' Using this statement we will deconstruct the complexity of CTSI.

The following ontological analysis (Ladkin 2005) of the transformation is a step to capture CTSI's complexity with natural language descriptions using a structured terminology. We address the complexity using an ontology derived by parsing the above stated definition of CTSI. We synthesize the extant literature on CTSI using the ontology. The analysis is used to develop a strategy for CTSI. At a time when CTS is still developing a CTSI strategy will be critical to its wellbeing.

This method of logical analysis, synthesis of the literature, interpretation, and application is systematic, repeatable, and extensible. It is also novel. In the following we will first present the ontology derived by parsing our definition of CTSI. Then, we will discuss the topics corresponding to the

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ontology in the following sequence: (a) ontological analysis, (b) CTSI ontology, (c) translating information between research and practice; (d) translating information semiotically, spatially, and temporally; and (e) translating information to transform health care.

2 ONTOLOGICAL ANALYSIS

Ontologies are used in informatics systems design to standardize terminologies, map requirements, organize them systematically, facilitate integration of systems, promote information exchange between systems, etc. (Gruber 1995; Gruber 2008) Ontologies are related to but different from taxonomies, typologies, concept hierarchies, thesauri, and dictionaries. (Gilchrist 2003) They are tools for systematizing the description of complex systems (Cimino 2006); a way of deconstructing the architecture of complexity (Simon 1962). Such systematization, in turn, facilitates analysis and design of these systems.

There is no standard definition of ontology of an informatics system. We will define it as a logically constructed n-dimensional natural language description of the system. The dimensions are derived from the problem statement, system's definition, or objectives. Each dimension is independent of the other and is a taxonomy of discrete categories. Each taxonomy may be flat or hierarchical. Further, the order of categories in a particular dimension at a particular level of the taxonomy may be nominal (no particular order) or ordinal (based on some parameter). The stages of progression along the dimension, the sequence of evolution, the progressive part-whole relationships, the scale, etc. are some bases for ordering the categories. Last, a dimension may have sub-dimensions with their own taxonomies. That is, a dimension itself may be hierarchical.

A combination of categories across all the dimensions, with appropriate conjunctive words, is a natural language descriptor of the system in the form of a sentence – albeit a little awkward grammatically sometimes. The set of all combinations across all categories – that is all possible sentences – is a closed description of the system. The full set can have a very large number of descriptors (individual combinations). However, many of the combinations may be uninterpretable or empirically unviable – they may be discarded from further analysis. At the same time some combinations may be novel and creative, providing valuable insights into the properties and possibilities of the system.

3 CTSI ONTOLOGY

The ontology we use for the analysis of CTSI has five dimensions, namely: (a) information, (b) semiotic translation, (c) spatial translation, (d) temporal transportation, and (e) health care. The logic of the derivation of the dimensions from the definition of 'translating information to transform health care' should be intuitively clear. We have deconstructed translation into three dimensions: (a) semiotic translation, (b) spatial translation, and (c) temporal transportation. Information and health care have been retained as such.

The five dimensions and their corresponding taxonomies are shown in Figure 1 and discussed below. The conjunctive prefixes, words, and phrases to concatenate the columns are shown before and between the columns. They make the concatenations across dimensions natural and understandable. Five illustrative combinations are shown at the bottom of the figure. The ontology as presented can be expanded into 7*6*4*6*7 = 7,056 combinations. The above representation is a concise way of representing them and analyzing them systematically. A listing of all the combinations would likely take about 100 pages.

4 TRANSLATING INFORMATION BETWEEN RESEARCH AND PRACTICE

This section focuses on the first and the last dimensions of the ontology. They mirror each other with the order reversed – the first dimension is focused on information and the last on health care. In a sense they can be seen as the input and the output of CTSI, cross-linking research to practice and practice to research, with the translation process in between.

The dichotomy of research and practice in health care (and other disciplines) is historical and persistent. While there is some overlap between the two, they are often seen as polar opposites. CTS seeks to transform the relationship between the two into a seamless continuum. Ideally perhaps they should be like the Yin and the Yang, separate but simultaneously containing the other – research

	Translation			
[Translating] **Information**	[+] **Semiotic**	[in] **Spatial**	[space in] **Temporal**	[to transform] **Health Care**
Research	Observation	Physical	Minutes	Practice
Basic	Data	Internal	Hours	Clinical
Animal	Analysis	External	Days	Public health
Clinical	Interpretation	Virtual	Weeks	Community health
Public health	Conclusion	Internal	Months	Research
Practice	Recommendation	External	Years	Basic
Clinical				Animal
Public health				Clinical
Community health				Public health

Illustrative combinations

Translating basic research conclusion in external virtual space in months to transform clinical practice.

Translating clinical practice observation in external physical space in months to transform basic research.

Translating public health research data in external virtual space in days to transform public health practice.

Translating clinical practice recommendation in external virtual space in months to transform community health research.

Figure 1: CTSI Ontology.

embedding practice and practice embedding research.

We will use the research-practice dichotomy for the taxonomy of information and of health care in the ontology. There are many other taxonomies; any one of them could be used in the ontology. A different taxonomy would naturally yield a different perspective on the issue. Our choice would be in keeping with the actuality (Cicmil, Williams et al. 2006) of CTSI. Research information and health care research are further categorized as basic, animal, clinical, or public health; practice information and health care practice as clinical, public health, or community health. The four categories of research have been construed to connote two stages – from basic research to clinical trials, and from clinical trials to clinical practice (Sung, Crowley et al. 2003). The two-level taxonomy shown in Figure 1 is adequate for the present discussion. It can be extended or refined subsequently if necessary.

At the core of CTSI is the translation of research information into health care practice, and health care practice information into research (Sung, Crowley et al. 2003). The absence of these two types of translation results in the “knowledge to action gap” (Graham, Logan et al. 2006) or the “Evidence-to-Practice Gap” (Lang, Wyer et al. 2007, p. 355) and the “action to knowledge gap” – the last has not received as much attention as the first two in health care literature (Westfall, Mold et al. 2007). While there is a lot of concern about the accumulation of basic research that does not get translated into clinical trials and then to clinical practice (Sung, Crowley et al. 2003), there is some but not the same amount of concern about the accumulation of practice knowledge that does not get fed back to inform the basic research and be validated by it. For example, the “Institute of Medicine Strategies for Knowledge Translation Related to Health Care Quality” cited by Hedges (Hedges 2007) has no feedback loop from practice/outcomes to research/literature. Translation has to be “a 2-way connection between the interstates of academic scientific discoveries and the patients receiving care in the ambulatory practice.” (Westfall, Mold et al. 2007, p. 404) Interestingly, the CTSA programs are supposed to create “two-way synergies with local and regional communities by reaching out to underserved populations, community-based groups, and healthcare providers.” (Zerhouni 2007, p. 127) However their purpose is to help “deliver improved medical care to the entire population, helping to disseminate new technologies and new advances into clinical practice.” (Zerhouni 2007, p. 127) This could also take place by translating practice knowledge into research and back to practice – thus completing the feedback loop (Ramaprasad 1983).

There can be many barriers to and facilitators of translation of research information to practice and vice-versa (Sung, Crowley et al. 2003; Ghosh and Ghosh 2005; Gaughan 2006; Anderson, Lee et al. 2007; Westfall, Mold et al. 2007). We categorize them along the three dimensions of the ontology as semiotic, spatial, or temporal. In the next section, we discuss these three dimensions of translation and how they can inhibit or engender translation, starting with a lexical and linguistic discussion of translation itself.

5 TRANSLATING INFORMATION SEMIOTICALLY, SPATIALLY, AND TEMPORALLY

Translating information – we use information to generically connote data, information, and knowledge – is the key to CTS and hence to bringing about the transformation it seeks. We address the complexity of translation by breaking it down into three dimensions: (a) semiotic, (b) spatial, and (c) temporal translation. We discuss each of these three and their taxonomies below.

5.1 Semiotic Translation

The process of translating research information to practice and practice information to research to improve health care is semiotic. It is an ongoing series of iterative cycles of generation and dissipation cutting across the semiotic layers of morphology, syntax, semantics, and pragmatics (Ramaprasad and Rai 1996; Ramaprasad and Ambrose 1999; Ambrose, Ramaprasad et al. 2003; Payne, Mendonca et al. 2007). In lay terms, it is the process of moving from observation to data to analysis to interpretation to conclusion to recommendation, then feeding back into observation. These steps form the taxonomy of the semiotic dimension in the ontology (Figure 1).

The CTSI should support the semiotic translation of information (a) by researchers and practitioners, and (b) between and among researchers and practitioners. The traditional research process is one of semiotic translation by researchers; the semiotic translation by practitioners when it occurs is akin to the grounded research (Glaser and Strauss 1964) process. The exchange of information among and between researchers and practitioners may occur at a semiotic level or cut across many of them. Thus, for example, two researchers may simply exchange data or conclusions. Or, one researcher may send his data to another researcher who may analyze it and send her results back to the first researcher. The network of researchers and practitioners involved in CTS is likely to be far more complex than the above dyadic examples; correspondingly the semiotic translation entailed and hence CTSI has to support will be complex too.

The informatics tools and techniques required to move across the semiotic levels vary. For example, in some types of laboratory research all the steps up to and including analysis can be automated; on the other hand in some qualitative field research none of the steps can be automated. Similarly, a simple interpretation may be communicated succinctly without loss of fidelity, while communicating a complex interpretation may require a correspondingly complex explanation.

The study of the semiotics of translation is not new. “Medical semiotics in the 18th century was more than a premodern form of diagnosis. Its structure allowed for the combination of empirically proven rules of instruction with the theoretical knowledge of the new sciences, employing the relation between the sign and the signified.” (Hess 1998, p. 203) The semiotic dimension of translation, however, has received little explicit attention recently (seeGraham and Tetroe 2007, for example). As Scott et al. discuss “the challenge of translating evidence from SRs [systematic reviews], while maintaining a sufficient level of validity and relevance to satisfy both clinicians and researchers, is rarely discussed.” (Scott, Moga et al. 2007, p. 681) The complexity of the semiotics is indicated by their conclusion: “The key elements for creating clinically relevant knowledge from SRs are: a flexible, consistent and transparent methodology; credible research; involvement of renowned content experts to translate the evidence into clinically meaningful guidance; and an open, trusting relationship among all contributors.” (Scott, Moga et al. 2007, p. 681) The lack of attention to semiotics is particularly glaring at a time when the so called semantic web (perhaps better called the semiotic web (Ramaprasad and Kashyap 2008)) is under development and is likely to have a major impact on CTSI.

5.2 Spatial Translation

Researchers and practitioners who have to be networked for CTS are likely to be distributed internally within an organization, locally, regionally, nationally, and even globally. Among them, the silos of research and practice, and of the different categories of research and practice, may not just be artifacts of the mind fostered by specialized disciplines but also manifest in their physical location, their offices, and labs. The challenge for CTSI is to spatially translate the information (a) from research to practitioners, (b) from practice to researchers, (c) from research to researchers, and (d) from practice to practitioners, across the virtual and physical silos.

The broad presumption of spatial translation is to eliminate the physical location dependence of CTS (Ambrose, Ramaprasad et al. 2003). The NECTAR

Network (Zerhouni and Alving 2006), The Family Practice Inquiries Network and other practice-based research-networks (Westfall, Mold et al. 2007), the International Clinical Epidemiology Network, (Tugwell, Robinson et al. 2006), and the Oklahoma Physicians Resource/Research Network (OKPRN) (Nagykaldi and Mold 2007) are examples of systems set up for this purpose. In the same vein, the CTSA mandates that all the centers should be networked. Not only should any researcher or practitioner be able to access the information 'anywhere', but should be able to process it 'anywhere'. Today, with the internet, there is a rising expectation that information be available 'anytime, anywhere'.

Today's information and communication technologies – the internet is one of them – have not only altered the constraints of physical space but have also created an entirely new virtual space. The dynamics of the physical and virtual spaces affect and are affected by each other. The capabilities of the virtual space can be used to overcome the constraints of the physical space and vice-versa. Thus, CTSI can be used to create a virtual space that complements the capabilities and constraints of the physical space in which its users operate. It must be noted that the exchange of information in the virtual space has not obviated the need for exchange in the physical space – despite e-mails and webinars face-to-face conversations and meetings continue to be important. The barriers to and facilitators of spatial translation for CTS have to be understood in the context of the convergence of the physical and virtual space.

There is almost always a distinction between the 'internal' and the 'external' in discussing physical space and virtual space. The boundary between the two can be an important barrier to or filter of the information translated. The rules governing the translation internally – like security, privacy, and confidentiality rules – are different from those for translation externally. The boundary separating the two may itself be arbitrary or adaptive to the context. Thus for some information everybody in the organization may be internal, but for others only the members of the research group may be internal. Despite the fuzziness and variability of the boundary the internal-external distinction is an important consideration in the spatial translation in CTSI.

Thus, there are four categories of spatial translation in the ontology: (a) internal-physical, (b) external-physical, (c) internal-virtual, and (d) external-virtual. Each of these can play a different role in the translation of research to practice and practice to research. In a given context a mix of them may be used. The CTSI should facilitate and remove barrier to the use of all four.

5.3 Temporal Translation

The temporal dimension is intrinsic in the objectives of CTS to minimize the time-to-practice and the time-to-research. It is also implicit in the concept of preemptive and predictive medicine (Zerhouni 2005). The scale of these times varies by context. Bringing the current best research evidence to bear upon the diagnosis of a patient in the emergency room may have to be done in minutes (Holroyd, Bullard et al. 2007); research on and response to an epidemic such as SARS may spread over weeks and months; response to Avian Flu (Eysenbach 2003) can be planned months or years ahead and activated in hours or days; and taking a drug from discovery to clinical deployment may take over ten years. For example, "[i]n the first documented instance of bird-to human infection with the H5N1 flu virus in 1997, Hong Kong reacted by destroying its entire poultry population of 1.5 million birds within three days." (Webster and Hulse 2005, 415) For another example, in the case of SARS the first "[u]nusual atypical pneumonia was documented in Foshan, Guangdong Province, China" in November 2002; the virus was identified in March 21-27, 2003; and the full genome was mapped by April 12, 2003. (Peiris, Yuen et al. 2003, p. 2432)The total time was less than six months. The role of a CTIS in a SARS-like epidemic is highlighted by the recommendation for an "efficient information technology systems that provide a means to link clinical, epidemiological, and laboratory data on SARS cases and to disseminate this information locally, nationally, and globally, and systems that allow rapid identification, tracking, evaluation, and monitoring of contacts of SARS cases." (Parashar and Anderson 2004, p. 632)

Thus, in the temporal dimension of the ontology we categorize time by the common units of minutes, hours, days, weeks, months, and years. The categories are ordinal and the progression is not linear. To continuously improve the time-to-practice and time-to-research it will be necessary to map and measure the corresponding workflows. The workflows are likely to be complex, fragmented, and widely distributed in physical and virtual space. To date the whole process of translation has not been conceptualized as a system; it has been an agglomeration of a number of ad hoc systems. The CTSAs are compelling the (re)conceptualization of the entire system. In that context, the CTSI should reflect the requirements of these workflows and reengineer them to make them more efficient and effective.

6 TRANSLATING INFORMATION TO TRANSFORM HEALTH CARE

Consider the four illustrative combinations at the bottom of Figure 1. These four sentences are natural language descriptions of the functions of CTSI. They encapsulate the translation requirements in the context of the emergency medicine, SARS, and Avian Flu discussed earlier. Although a little awkward grammatically, they make sense and can be related to specific requirements of CTSI. There are 7,052 similar sentences that can be constructed from the ontology. Each of these sentences can connote a number of requirements. No one system is likely to fulfil all the requirements connoted by all the sentences. On the other hand, a selection of sentences can be a high level description of the requirements of a CTSI.

REFERENCES

Ambrose, P., A. Ramaprasad, et al. (2003). "Managing thin and thinly distributed knowledge in medical genetics using the Internet." Logistics Information Management 16(3/4): 207-214.

Anderson, N. R., E. S. Lee, et al. (2007). "Issues in Biomedical Research Data Management and Analysis: Needs and Barriers." Journal of the American Medical Informatics Association 14(4): 478-488.

Cicmil, S., T. Williams, et al. (2006). "Rethinking Project Management: Researching the actuality of projects." International Journal of Project Management 24(8): 675-686.

Cimino, J. J. (2006). "In defense of the Desiderata." Journal of Biomedical Informatics 39(3): 299-306.

Eysenbach, G. (2003). "SARS and Population Health Technology." Journal of Medical Internet Research 5(2).

Gaughan, A. (2006). "Bridging the divide: the need for translational informatics." Pharmacogenomics 7(1): 117.

Ghosh, A. K. and K. Ghosh (2005). "Translating evidence-based information into effective risk communication: Current challenges and opportunities." Journal of Laboratory and Clinical Medicine 145(4): 171-180.

Gilchrist, A. (2003). "Thesauri, taxonomies and ontologies -- an etymological note." Journal of Documentation 59(1): 7-18.

Glaser, B. G. and A. Strauss (1964). The discovery of grounded theory: Strategies for grounded research, New York: Aldine.

Graham, I. D., J. Logan, et al. (2006). "Lost in knowledge translation: time for a map." J Contin Educ Health Prof 26(1): 13-24.

Graham, I. D. and J. Tetroe (2007). "Some Theoretical Underpinnings of Knowledge Translation." Academic Emergency Medicine 14(11): 936-941.

Gruber, T. R. (1995). "Toward Principles for the Design of Ontologies Used for Knowledge Sharing." International Journal Human-Computer Studies 43(5-6): 907-928.

Gruber, T. R. (2008). Ontology. Encyclopedia of Database Systems. L. Liu and M. T. Ozsu, Springer-Verlag.

Hedges, J. R. (2007). "The Knowledge Translation Paradigm: Historical, Philosophical, and Practice Perspectives." Academic Emergency Medicine 14(11): 924-927.

Hess, V. (1998). "Medical semiotics in the 18th century: A theory of practice?" Theoretical Medicine and Bioethics 19(3): 203-213.

Holroyd, B. R., M. J. Bullard, et al. (2007). "Decision Support Technology in Knowledge Translation." Academic Emergency Medicine 14(11): 942-948.

Ladkin, P. B. (2005). "Ontological Analysis." Safety Systems 14(3): 1-7.

Lang, E. S., P. C. Wyer, et al. (2007). "Knowledge Translation: Closing the Evidence-to-Practice Gap." Annals of Emergency Medicine 49(3): 355-363.

Nagykaldi, Z. and J. W. Mold (2007). "The Role of Health Information Technology in the Translation of Research into Practice: An Oklahoma Physicians Resource/Research Network (OKPRN) Study." J Am Board Fam Med 20(2): 188-195.

Parashar, U. D. and L. J. Anderson (2004). "Severe acute respiratory syndrome: review and lessons of the 2003 outbreak." Int. J. Epidemiol. 33(4): 628-634.

Payne, P. R. O., E. A. Mendonca, et al. (2007). "Conceptual knowledge acquisition in biomedicine: A methodological review." Journal of Biomedical Informatics 40: 582-602.

Peiris, J. S. M., K. Y. Yuen, et al. (2003). "The Severe Acute Respiratory Syndrome." N Engl J Med 349(25): 2431-2441.

Ramaprasad, A. (1983). "On the Definition of Feedback." Behavioral Science 28(1): 4-13.

Ramaprasad, A. and P. J. Ambrose (1999). The Semiotics of Knowledge Management. Ninth Workshop on Information Technology and Systems, Charlotte, North Carolina.

Ramaprasad, A. and V. Kashyap (2008). Semiotic Web for Translational Medicine (Poster). AMIA 2008 Annual Symposium. Washington D.C.

Ramaprasad, A. and A. Rai (1996). "Envisioning management of information." Omega-International Journal of Management Science 24(2): 179-193.

Scott, N. A., C. Moga, et al. (2007). "Creating clinically relevant knowledge from systematic reviews: the challenges of knowledge translation." Journal of Evaluation in Clinical Practice 13(4): 681-688.

Simon, H. A. (1962). "The architecture of complexity." Proceedings of the American Philosophical Society 106(6): 467-482.

Sung, N. S., W. F. Crowley, Jr., et al. (2003). "Central Challenges Facing the National Clinical Research Enterprise." JAMA 289(10): 1278-1287.
Tugwell, P., V. Robinson, et al. (2006). "Systematic reviews and knowledge translation." Bulletin of the World Health Organization 84(8): 643-651.
Webster, R. and D. Hulse (2005). "Controlling avian flu at the source." Nature 435(7041): 415-416.
Westfall, J. M., J. Mold, et al. (2007). "Practice-Based Research--" Blue Highways" on the NIH Roadmap." JAMA: The Journal of the American Medical Association 297(4): 403.
Zerhouni, E. A. (2005). "Translational and clinical science—Time for a new vision." N Engl J Med 353(15): 1621-1623.
Zerhouni, E. A. (2005). US Biomedical Research Basic, Translational, and Clinical Sciences, Am Med Assoc. 294: 1352-1358.
Zerhouni, E. A. (2007). "Translational Research: Moving Discovery to Practice." CLINICAL PHARMACOLOGY & THERAPEUTICS 81(1): 126-128.
Zerhouni, E. A. and B. Alving (2006). "Clinical and Translational Science Awards: a framework for a national research agenda." Translational Research 148(1): 4-5.