Immersive Empathic Design for Interdisciplinary Collaborations

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LIST OF ABBREVIATIONS

ANDRILL	Antarctica geological Drilling
BRG	Borehole Research Group
DIS	Drilling Information System
DPI	Dots per inch
EOL	End of life
EVL	Electronic Visualization Laboratory
GUI	Graphical User Interface
HANDS	Hands-on Automated Nursing Data System
ICDP	International Continental Drilling Program
IODP	Integrated Ocean Drilling Program
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
JR	JOIDES Resolution
LacCore	National Lacustrine Core Facility, University of Minnesota
LCD	Liquid Crystal Display
LDEO	Lamont-Doherty Earth Observatory, Columbia University
LIMS	Laboratory Information Management System
LOD	Level of Detail
NANDA	North American Nursing Diagnosis Association
NIC	Nursing Intervention Classification
NOC	Nursing Outcomes Classification
SAFOD	San Andreas Fault Observatory at Depth
VCD	Visual Core Description

SUMMARY

In this dissertation I propose the ‘immersive empathic design’ approach for interdisciplinary collaborations. It is hard to design a useful system and it is even harder to design a system for people who are working in a different knowledge domain. The high domain knowledge barrier can make it difficult for a person who is outside of a given domain to imagine the experience of a user within that domain. This can lead to systems that are designed, implemented, and deployed without sufficient knowledge of the domain they will be used in, leading to a low willingness of users to adopt the new system. Globally distributed collaboration is becoming more common in the modern world, and modern science discovery requires interdisciplinary collaboration. This imposes even more spatial and temporal constraints in designing an interactive system. The goal is to move beyond collaborative technology showcases in the laboratory to workplace deployments that solve real-world problems.

The proposed “immersive empathic design” approach attempts to reach across the discipline boundary. In the exploratory case study in geological core drilling, computer scientists were embedded in the core drilling workplace setting. On-site hands-on “experiential learning” and off-site reflection analysis inspired innovations in the workplace setting while still maintaining their domain-specific perspective. This approach helped to overcome the initial high domain knowledge barrier. It also established trust with domain users and encouraged system adoption.

The proposed approach helps computer scientists to overcome the initial domain barrier efficiently in interdisciplinary collaborations. The domain knowledge obtained in the immersive experience forms a sustainable common ground between the collaborating parties. It affords authentic user experience and more context-sensitive inquires in later design and development activities. The process encourages computer scientists to design an innovative system that will be used by domain users to solve real-world problems.

SUMMARY (continued)

Modern science discovery requires interdisciplinary collaboration. The proposed method suggests system developers to step out of the laboratory environment and be empathic with their new system's potential users through immersive hands-on experience, so the system being designed will better fit the users' needs and expectations. The trust established through this process should encourage the users' adoption of the new system. It provides a general guideline to "co-evolution on a human scale" in interdisciplinary collaborations. The method and lessons learned will be beneficial to future human computer interface practitioners when the potential users of the system are within domains sharing similar qualities such as scale, a high knowledge domain barrier, and geographically distributed collaborations.

1. INTRODUCTION

It is hard to design a useful system. It is even harder to design a system for people who are in a different knowledge domain. In the software engineering world, researchers are seeking, categorizing, and mapping [Glass04][Segal08] the right software development model for scientific collaborations. Most of the effort has taken place in domains where a “computational” component has emerged close to one of the principal components of the domain, such as high-energy physics, astronomy, computational fluid dynamics, and bioinformatics. There are more domains and different phases in science workflows [Bose05] where scientists still work the way they did decades ago with paper and pencil. Unlike the nature of computational science striving for optimization and robustness, these phases require more attention to support interactions between scientists and their tools to empower them to achieve their research goals.

Human-computer interaction research has proposed user-centered design practices [Vredenburg02] and participatory design [Michael93] to include potential users in the design process. Cognitive scientists embedded themselves in real-world working environments to study “distributed cognition” [Hutchins96][Hollan00]. However real-world users such as scientists may lack the motivation to bring in an outsider from another domain to tell them how to improve their workflows.

On the other hand, researchers without prior domain knowledge may have difficulty understanding the context. Empathic design [Leonard97] has been used in industry for commodity product design. Designers use activities such as biographies, scenarios, simulations, role-playing, and social probes [Mattelmaki02][Wright08] to step into their users' shoes. While these practices are useful in designing commodity products, some of them may not be useful, or even practical, for scientific users, especially in the early stage of the design cycle. For example, the lack of background context might prevent the designer from fully understanding why a clastologist needs to count the number of rocks in a sediment core as soon as possible. The lack of mutual trust becomes another barrier during the design cycle. A software developer should be embedded and immersed in the early stage of the development timeline. We believe this is more beneficial than holding joint meetings, collecting observations, and recording dialogue activities from a third person perspective.

I propose the immersive empathic design methodology for interdisciplinary collaborations. A high domain knowledge barrier can make it very difficult for a person who is outside of a domain to imagine the user experience of someone within that domain. This reduces the domain users' willingness to adopt the new system. Because of the mismatch between the user's experience and his/her expectations, scientists will drop the new system entirely or use it in unexpected ways as workarounds. There are also culture differences. In [Finholt08], Thomas Finholt described the domain scientists as "fundamentally hierarchical, uncertainty avoidance, highly skeptical of new technologies and extremely risk averse." Computer scientists are described as "egalitarian, bias toward talent, extremely open to new technologies and extremely risk seeking." If such cultural differences are not valued starting from the initial design phase, even a new innovative useful system will have adoption issues. Modern science's geographically distributed collaboration imposes even more spatial and temporal constraints in designing effective interactive systems.

This issue is important because modern scientific discovery requires interdisciplinary collaborations. For example, studying the reasons and impact of global warming requires climatologists, biologists, ecologists and oceanographers. To collect and process the data in such a global scale, computer scientists will be needed to design and develop next generation systems and infrastructure to monitor, acquire, process and visualize the vast amounts of data. Expertise from different domains must all contribute to achieve co-adaption [MacKay08] in order to solve modern real-world problems. If innovation put into computer systems stops as technology showcases in laboratories instead of being put into workplaces to solve real-world problems, resources are wasted, and scientific opportunities are lost.

The proposed immersive empathic design approach for interdisciplinary collaborations attempts to reach over the discipline boundary from computer science. The method advocates that the computer scientist can take the initiative and be an active participant in the other domain. Computer scientists should leave their laboratory office and join the daily life of the potential users of the new system he/she is helping to build. These computer scientists are embedded within the workplace with domain scientists to experience their regular activities within context. On-site hands-on "experiential learning" [Kolb94] and off-site reflection analysis can inspire innovations in the workplace setting while still maintaining their domain-specific perspective. The blueprint of the proposed approach is stated as follows.

1. Identify initial problems
2. Gain situated hands-on experience to establish knowledge model and vocabulary
3. Rapid prototype on the spot
4. Pitch and reflect off-site
5. Generalize workflow to identify processes and practices
6. Uncover constraints and prior assumptions
7. Validate and improve iteratively
8. Always learn about the domain

This approach helps to overcome the initial high domain knowledge barrier. It also potentially establishes a trust bond with the domain scientists and encourages later system adoption. The domain knowledge learned in hands-on activities will continue to be valuable as the collaboration proceeds. It forms a substantial foundation for the computer scientist and domain scientists to build on for more in-depth and context-sensitive inquires in the following design cycles. We believe this approach is more beneficial than merely conducting observation and dialogue activities from a third person perspective. This approach can be useful to future human computer interaction practitioners who work with potential users or communities that share similar properties.

In the following chapters, I will first review related work in chapter 2 and then describe case studies of two different knowledge domains using the immersive empathic design methodology in chapter 3. In chapter 4, I will document implementation details in the described settings, and provide the reasoning between findings and implementation designs. Finally in chapter 6, through a series of in-situ deployments, verifications and evaluations, I will show the impact of the systems designed using proposed immersive empathic design methodology, and discuss lessons and experiences learned that could be beneficial to future designers and developers working on innovating in interdisciplinary collaboration settings.

2. RELATED WORK

This chapter discusses prior work and practices related to designing and developing systems for scientific users in an interdisciplinary collaborative team.

In software engineering, researchers are seeking, categorizing, and mapping [Glass04][Segal08] appropriate software development models for different domains. Most of the study efforts have focused on domains in which a "computational" component has emerged as one of the principal components of the domain, such as in high-energy physics, astronomy, computational fluid dynamics, and bioinformatics. There are still more domains and phases in science workflows [Springmeyer92][Bose05] that hands-on activities and highly valued and scientists still work the way they did ten years ago with paper and pencil. Unlike the nature of computational science striving for optimization, performance, and robustness, these phases require more attention to support interactions between scientists and their tools to empower them to achieve their research goals.

2.1 User-centered design

User-centered design is a design philosophy that advocates focusing on users to design everyday things [Norman88]. Designers and developers use practices such as persona, scenario, and use case [Nardi92][Vredenburg02]. Field studies were generally considered highly valuable but seldom used because they were costly. Sometimes, shortcuts such as paper prototyping will be used because it is cheaper and can be easily disposed if it does not work. The design comes from observations from the users' point of view. This concept worked when designing everyday products for regular people because the designers could be empathic with the potential users easily because he or she was potentially one of them. As a matter of fact, many innovative products and pieces of software were originally designed to solve the designer's or developer's own problem. If the users' workplace context is beyond observer's study domain, it is difficult to imagine the user experience, and simply utilizing observation from an outsiders' perspective might not be enough.

2.2 Participatory design

Participatory Design [Greenbaum91][Muller93][Irestig04] invites users into the design cycles. In some interpretations it suggests that everyone is a designer. Various practices have been demonstrated over the years. T. Mattelmaki et al. used "Empathy Probes" [Mattelmaki02] in order to be empathic with users. Probes kits containing disposal cameras with photography assignments, diary booklets, and illustrated cards with open questions, were given out to participants. Participants were required to use these tools to record their everyday life and send them back. Researchers then used the collected data along with interviewing some selected participants so researchers could be empathic with the users. The practical issue of applying this to a scientist is that scientists think they have "real work" to do. They might be reluctant to participate in design meetings in the early stages. The geographically distributed nature of modern collaboration might even lower their motivation. An additional issue is that most of the time users who are fine with the way they work right now might not exactly know what they really need or want in a new improved system.

P. Dourish created an overview of the evolution of perspective in human-computer interaction (HCI) and computer-supported cooperative work (CSCW) from one of viewing interaction design as an algorithmic step-by-step process in human psychology and cognition reasoning as one of embodiments of the related people [Dourish04]. Beside traditional human factor studies in psychology and cognition, concepts from sociology and anthropology started to be being utilized by HCI and CSCW researchers to develop theories including “Distributed Cognition” [Hutchins96] and “Activity Theory” [Nardi96] to move beyond human-defined processes and explain people’s actual practices in workplaces, and hence to suggest implications for design. E. Hutchins’ work pointed out that the knowledge of navigating a military vessel resided not just in either single person’s (commander officer) brain (as a view from traditional cognition) but actually existed in the interactions of on-board instruments and all personnel involved. In B. Nardi’s work, she applied the work of Lev Vygotsky in the 20s and argued: “consciousness is shaped by practice, that people and artifacts mediate our relationship with reality… and it can be scaled to collaborative settings without losing sight of individual participants in an activity.”

2.3 Ethnographic studies

Ethnographic study originated from ethnography and typically involves sociologists from anthropology and ethnography backgrounds in the design process as ethnographers. Ethnographers went in the field and immersed themselves with the users. They collect photos, videos, and field notes to describe and study real-world settings and practices as foreign social phenomena. Ethnography field reports will often provide design implications to the development team to focus their work on developing systems. A representative example of using ethnographic study is the study of air traffic control system [Bentley92] [Hughes92a] [Hughes92b] [Hollan00]. J. Hughes et al. formed a team with ethnographers and system developers to modernize technology in the air traffic control room. Ethnographers situated themselves in the air traffic control environment and conducted ethnographic studies. They found that the flight (paper) strips were an essential part of the whole air traffic control activity and practice. With paper flight strips controllers might still be able to direct flights without a modern electronic air traffic control display, but it would be problematic if it were the other way around. In this kind of methodology ethnographers became proxies between the actual users and the system developers [Bentley92]. The end users do not interact directly with people who actually build the final system so there might be discontinuity between the expectations of both ends and each prototype cycle might take longer. It would be restrictive and not agile enough in scientific collaboration settings. In E. Evans et al. software pattern work [Evans03] he even advocated that design is implementation. If the developer received the domain knowledge second-hand, there might exist a huge gap between actual settings, jargon, and practices and the terminologies and concepts in the implementations.

Additionally, as information technology evolves faster and faster, it is hard to keep up with it for domain scientists. A. Zimmerman and B. Nardi reported that traditional methods including User-Centered Design and Participatory Design could not be used to plan and design modern Cyberinfrastructure because of uncertainty, heterogeneity and the rapid rate of change [Zimmerman06]. Because 1) You do not really know who are going to be the users in the next few years. 2) The users might be diverse and perform many different types of work in different environments. 3) Because of the rapid change in technology, there is no time for lengthy requirements analysis, prototype development and user feedback in classic iterative design iterations. Plans designed few months or years ago might already be outdated when the system is built.

The proposed immersive empathic design for interdisciplinary collaboration wants to absorb the benefits of these prior methods and practices. It should focus on people, location, artifacts, and activities. Unlike having a separate ethnographer or designer, it also advocates the developer's commitments to dive into the potential users' knowledge domain and become involved in the users' workflow. The developer experiences first hand authentic user activities and interacts with the system's future users directly. With the support of "experiential learning" [Kolb94], the developer can overcome the initial high knowledge barrier. Since modern collaboration is global in scale, a co-located hands-on experience could benefit even more if language and culture pose an issue. Socially, an invisible trust bond could be formed as users begin to treat the developer as "one of them."

Just like ethnographers, the immersed developer collects valuable visual and audible field notes along with his/her hands-on experience. When the developer goes back to the computer science laboratory, he could use these assets to reflect on the domain context, to go through experiences with colleagues in the computer science laboratory in pitching and brainstorming sessions. This helps the immersed personnel re-gain perspective and to abstract and generalize the domain users' workflow and identify practices which may not be so obvious when he/she is situated within the setting. Using these steps, software developers could identify blind spots such as assumptions and constraints inherited from practices that domain users might not be aware of and find opportunities where technology could help domain users in solving their real-world problems. The knowledge model the software designer gained from the immersive hands-on experience co-constructed with his/her "domain colleagues" also serves as a great discussion platform for further communication. The systems developed should also then utilize the same vocabulary that is based on the same knowledge model, which both developers and domain users understand.

The general comparison of these related researches is summarized in the following table.

Table 1. Comparison of related work used in interdisciplinary scientific collaborations.

	Immersive Empathic Design	**User-Centered Design**	**Participatory Design**	**Ethnography Study**
Knowledge of domain activities	✓			*
Users' trust	✓			✓
Motivation to involve in system design	✓	✓		✓
Direct user interaction	✓	✓	✓	
Rapid prototyping	✓		✓	

* In best case scenario

2.4 Domain backgrounds of case studies

In the chapter 3, I will describe case studies of applying the proposed immersive empathic design methodology. Before that, domain backgrounds of these two settings, geological core drilling expedition and medical hand-offs, are described below.

2.4.1 Geological core drilling

Geological cores are cylindrical bodies containing natural materials and sediments. They are recovered from the surface or the crust of the Earth. Just like tree rings, the composition and deposition layers of cores contain detailed records of the climatological and ecological changes on the Earth dating back millions of years

[Cohen03]. The length of cores could range from tens to more than a thousand meters depending on how far geologists would like to look back in time.

Cores can be retrieved from different locations including lakes, ocean floors, continents, and ice sheets. Each has different properties and each allows geologists to look into different time periods and different aspects of past climate or environment. For example, the lake cores retrieved from Lake Tanganyika in Africa date back to 10 million years and show evidence of environmental changes [Cohen03]. Oldest seafloor age is about 150 million years. According to the Ocean Drilling Program leg 207 preliminary report, some ocean cores extend back 65 million years to the Cretaceous-Tertiary boundary (K-T boundary) as shown in Figure 1, and were used to support one of the dinosaur extinction theories. Sediment cores recovered in Antarctica are expected to date back to 40 million years ago. They are the most un-disrupted records of the ancient climate and environment on Earth. These cores provide geoscientists with the most extensive and accurate picture of the Earth's past. By studying our past, theories and models can be formulated to predict what our future is likely to be.

In the past, scientists studied these cores with physical core observations on hand-drawn notes called "barrel sheets" as shown in Figure 2 (left). The workflow varied among communities due to cultural and expeditions setup differences, however the simplified scenario was as follows. Once the cores were recovered they would be sliced into roughly 1.5-meter sections for easy processing and transportation. Sections of cores would be scanned through "Multi-Sensor Core Loggers" to measure physical properties including porosity, density, electrical resistivity, and magnetic susceptibility. The cores would be split into halves. One half would be put into a “D-tube” and stored in air-conditioned storage in the core repository as archival half. The surface image of the other half (working half) would be taken with a high-resolution image line scanner at more than 254 dpi (dots per inch) as the digital archive. A core technician would examine the working half and write down his/her interpretation on the barrel sheet. These barrel sheets served as the initial visual core description record. They would later be used as the basis of further processing requests. After the core expedition, these records would be packaged into core boxes and stored in a core repository. A core repository would use an either co-located or remote climate-controlled storage space to preserve these core samples in conditions similar to where they were recovered. Core repositories are located around the world hosting cores recovered from different regions. For example, in the Integrated Ocean Drilling Program, the Center for Marine Environmental Sciences (MARUM) Bremen Core Repository at the Bremen University, Germany hosts cores recovered from the Atlantic Ocean, the Mediterranean and Black Sea, and the Arctic Ocean. The Kochi Core Center (KCC) at Kochi University, Kochi, Japan houses cores from the Pacific Ocean (west of western boundary of Pacific plate), the Indian Ocean (north of 60°), all of the Kerguelen Plateau, and the Bering Sea.

Several systems have been developed for these geologists. The Japan arm of Integrated Ocean Drilling Program (IODP), the Center for Deep Earth Exploration (CDEX) developed J-CORES [Jcores08] in-house. This software system was tightly coupled with a backend Oracle database. It was used extensively in CDEX expeditions as a part of enforced standardized operation process on the Chikyu ocean-drilling vessel. The tight backend and embedded logic dependency made it difficult for other geologists to adopt the software. Mike Ranger developed the proprietary AppleCORE program for the Ocean Drilling Program (ODP) in the 90's. It was a classic Mac OS 9 program for describing cores. One of the main purposes of the program was to generate diagrams for publishing and it is not currently being updated or maintained. The latest "Paleontological Stratigraphic Interval Construction and Analysis Tool" (PSICAT) is a Java based standalone graphical editing tool for creating and viewing core description diagrams for publication, similar to AppleCORE. None of these tools can handle the core imagery data in its native resolution. Even using practices of user-centered design and participatory design, the way these systems were designed was either that a domain scientist developed the system, or that scientists told a developer or a group of developers what system to build.

Figure 1. (Above) Cores (replica) recovered from the New Jersey coast show K-T boundary impact evidence. (Below) Just like tree rings, a sediment lake core shows the history of geological changes.

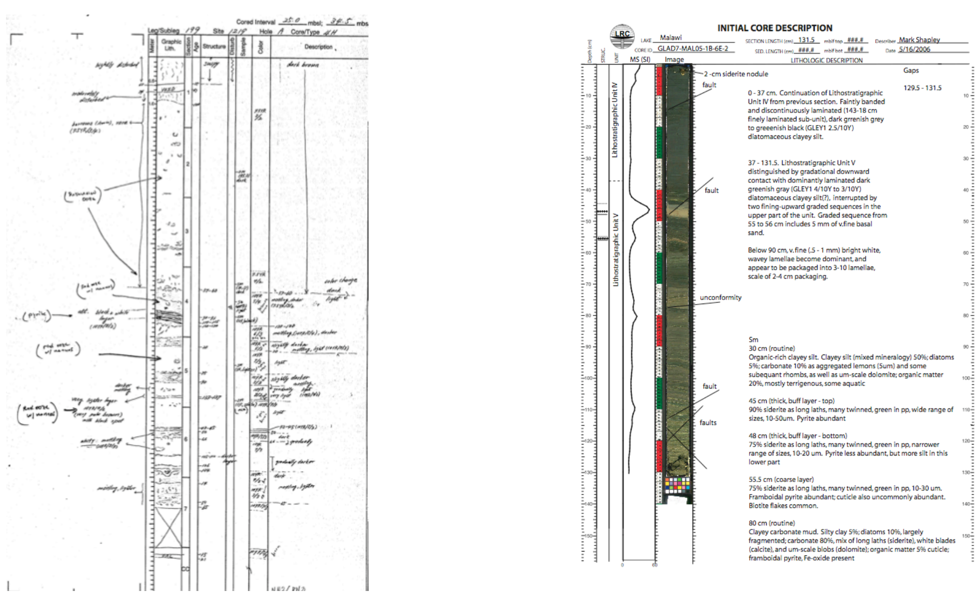


Figure 2. "Barrel sheets" are a researcher's interpretation records from the initial visual core description.
Left: A hand-drawn barrel sheet from the Ocean Drilling Program leg 199, site 1219.
Right: An electronic barrel sheet generated in the Lake Malawi in the Global Lake Drilling (GLAD) project.

2.4.2 Medical hand-off

Hand-off is a collaborative process involving passing task information and knowledge during shift change from one person or group to another. It is also an opportunity to introduce error and decrease efficiency. Depending on the context, the cost to errors made during hand-off could be disastrous and a matter of life and death. Medical hand-off guidelines and policies were developed as standardized protocols to avoid common mistakes that a human might make. Computer systems have also been designed to support human's external memory, up-to-date documentation sharing, and to improve awareness and efficiency. The Hands-on Automated Nursing Data System (HANDS) framework was developed to address these issues with 1) Standardized nursing terminologies and 2) A web-based computerized system to capture the change of care plans in shift hand-offs. With the first iteration of the HANDS system in place and deployed to multiple healthcare institutes in the last few years HANDS healthcare researchers are now moving the research focus from the data collection phase to the data analysis and visualization phase to further support on-the-spot decision support during hand-off activities.

In the medical literature researchers suggested using an interdisciplinary approach to manage medical care information system projects in 1982 [Kaplan82]. Interdisciplinary collaboration was considered necessary for developing medical information systems because while most system vendors might be able to provide the technological capability, when it came to the users' needs and reaction healthcare administrator would just assume the system designers understood this or that they would just ask. In 2009, the American

Medical Informatics Association workshop report found that most medical information systems failed to achieve their goals [Kaplan09]. The joint report also called for further studying processes throughout their life cycle and interfaces appropriate for clinical settings. Medical hand-off tools including UWCores [Eaton04], Patient Handoff Tool [Flanagan09] were developed using user-centered design and participatory design methodologies [Eaton05], however almost all of these systems were initiated and developed within medical settings by medical researchers if not outsourced the actual development to an external vendor. Systems developed this way often worked like a typical office automation systems, which collected verbose textual data blocks. There was not much innovation in representing the data to the real users. When considering benefits and efficiency, they were always only compared with “verbal” or “workaround” ways (using copy and paste in multiple software) [Bhabra07].

3. IMMERSIVE EMPATHIC DESIGN CASE STUDY

In this chapter, I will use case study examples in two different knowledge domains to identify the development workflow and project traits to properly tailor methodology in order to create useful system for real-world domain scientists.

3.1 CoreWall

3.1.1 Initial Problem

For decades, stratigraphic records have been locked in core repositories around the world. Now, aided by advanced equipment like high-resolution color line-scanners and multi-sensor data loggers, core data can be digitized to create large amounts of high-precision digital images and numerical data. However the size of the data becomes an issue. The amount of data can be estimated from the numerical sensor dataset and image sizes. For 1000 meters of core, the digitized images take up much more space than the sensor data. A digital line-scan camera can produce images from 254 to 1000 dots-per-inch (DPI). Consider 1000 meters of split cores using a 254 DPI configuration. The total image size can be calculated to be 10,000,000 x 900 pixels in RGB color space, which is about 27GB of raw image data. There are about 10km of cores archived in the National Lacustrine Core (LacCore) Facility in the University of Minnesota, Twin Cities, which is about 270GB of imagery. The Antarctica geological Drilling (ANDRILL) McMurdo Ice Shelf expedition in 2006 to 2007 drilled one hole and recovered more than 1,500 meters of cores, whose digital data took up roughly 30GB of storage. The digitalized ocean drilling core data including data from Deep Sea Drilling Project (DSDP) since 1968 takes nearly 9 TB. Scientists cannot examine this data easily using existing tools. Often times due to the frustration, they will fall back to the old hand-drawn barrel sheets.

Figure 3. Inside the core repository storage of the National Lacustrine Core (LacCore) Facility at the University of Minnesota, Twin Cities. The storage is located about 2.1 miles from the core laboratory. It provides refrigerated (4°C), frozen (-20°C) and dry/ambient (20°C) environments. The LacCore facility houses more than 10km of cores recovered from lakes around the world.

Scientists have tried to utilize these digitized assets, but they did not make the best use of the digital images' unique affordances, which include feature-preserving representation in high-resolution and easy access. Scientists used these digital assets to print out paper-based "barrel sheets" as shown in Figure 2 (right) through tedious steps as workarounds.

In order to generate a barrel sheet, they had to:

1. Use image-processing software to scale down the raw image because the original image file is too large.

2. Use a spreadsheet and plotting program to generate numerical data plots.

3. Copy and paste these pieces into a desktop publishing program to generate a barrel sheet page.

Commodity photo editing software does not allow them to continuously navigate and visualize this huge amount of image data without interfering with their daily science workflow. Additionally, geologists want to have a way to digitally input and keep track of the derived numeric data (porosity, density, electrical resistivity, and magnetic susceptibility) related to the recovered records, and most importantly present this numeric data along side the digital imagery.

Prior collaboration on the GeoWall project [Johnson06] and the need for modern visualization expertise brought geologists from the National Lacustrine Core Repository (LacCore) at the University of Minnesota to the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago in 2004. In order to design a system that geologists can use in their daily work solving problems, it is important for the computer scientists involved to understand the core-drilling workflow and how potential users might use the system. Through discussions with the geologists about their existing software systems, we found that these systems are either technology-wise incapable of processing a large amount of imagery data (those that were developed within the domain) or there is a user-experience mismatch (those that were developed outside of the domain).

3.1.2 Method

To overcome the initial high domain knowledge barrier and to better understand the working context of potential users, starting from summer 2004 one of the computer science students in the development team joined expeditions in ocean and lake drillings. The student received training as a junior core technician from an early stage of the design cycle. The work led to innovations in the CoreWall system that is now used in the LacCore, Antarctica Drilling, and on the Integrated Ocean Drilling Program's JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) Resolution scientific drilling vessel.

3.1.2.1 Situated in a scientific workflow

Just like any other scientific discipline, a core-drilling expedition involves: 1) Designing the experiments, 2) Conducting the experiments, 3) Analyzing the results and 4) Publishing the results [Bose05]. For modern expeditions and research, it is even more complex. The experiment may involve researchers distributed around the world, and the logistical cost for the drilling vessel and personnel is enormous. Moreover, as data generated from modern experiments grows, data management and sharing become even more crucial to the success of globally distributed collaborations. There is a need to store core data in an easily retrievable form for geologists to make use of it. The computer scientists in the project immersed themselves with the geologists and evolved with the workflow to discover more details as the process continued, and attempted to afford the users' needs in different phases.

In the "first contact" meetings, we realized that core drilling involves a lot of hands-on work and geologists like having people from the 'other side' become involved in their daily work. They can efficiently introduce a new person to their domain knowledge on the spot with context and hands-on experience. Sharing the hands-on experience and lingo breaks down the initial social barriers which later shows benefits when introducing the newly developed system to other individuals and communities. We think this is especially important and useful for building interactive systems involving data collection and experiment stages of scientific workflows. It is because these systems interface directly among scientists, activities and data within domain settings. It is important, as a system developer to be empathic with actual users since this will be the main thing the designed system has to offer. If it took too long to understand the essence of domain knowledge in early stages of collaborations, it might show less commitment. Patience and incentives could be lost.

In the summer of 2004, one of our computer science students in the development team joined expeditions in ocean and lake drilling. Because of the geographically distributed potential users, the student worked with specific coring communities and received training as a junior core technician from an early stage. In 2006, during a two-week training both in the field and in the laboratory, the student assisted in using piston tools to retrieve more than 10 meters of core samples from three locations in Lake Pepin, Minnesota. In the indoor laboratory work, he went through the core preparation processes including splitting the cores into “archive” and “working” halves, carefully smoothing the split core surface, and operating the high-resolution image scanning and multi-sensor core logging equipment to acquire digitized core data. He also attempted to do the initial visual core description as a real geologist. During the training period, he had to constantly make field notes along with pictures and videos of the artifacts and activities of throughout the workflow. This way so he could remember and reflect the experience once he was absent from the users’ context.

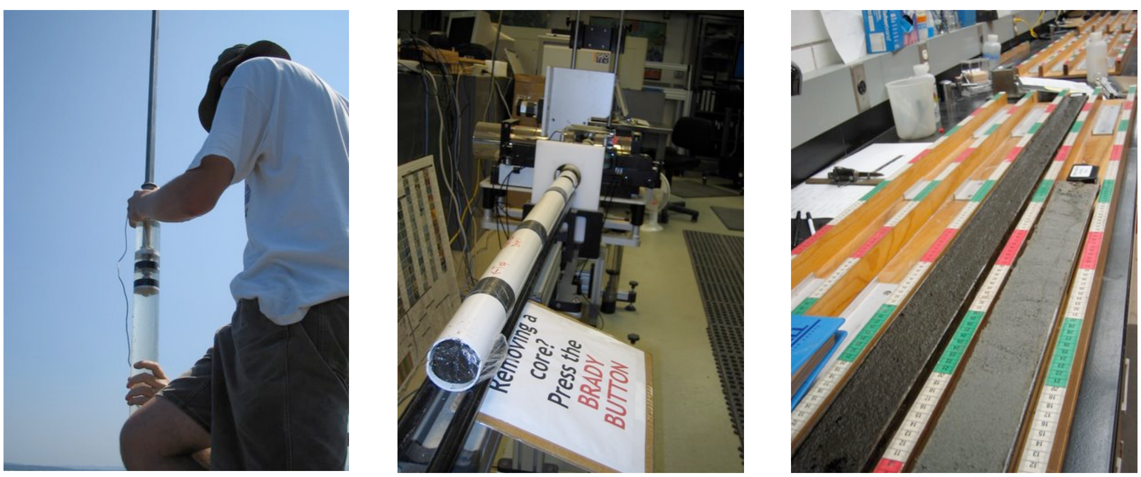


Figure 4. Immersive hands-on training. The developer received junior core technician training and assisted the LacCore curator using piston tools recovering more than 10 meters of sediment cores in the Lake Pepin, Minnesota in the summer of 2006. He also operated the multi-sensor core logger to measure cores’ physical properties, split the core and learned how to do initial visual core description.

When solving someone else's problem you can spend a lot of time guessing about the other person's particular needs. Having the software developer trained as a junior core technician allowed him to walk through the workflow tasks needed for initial visual core description starting from hands-on logistic planning, on-site core recovery, packaging, sampling and then data acquisition, quality assurance, and quality control in the laboratory. This immersive experience transformed ownership of the domain problem from the domain scientists into the software designer/developer's mental model so he could think about issues and problems that he could improve using his prior computer science training.

Additionally, [Evan04] suggests that design should not be separated from the actual implementation as a lot of methodologies suggest having separate design and engineering teams. "At the core of design is the idea that immersion begets empathy, and empathy begets the best solutions," said Kate Canales. The hands-on process was a constant uninterrupted collaboration between the domain scientist and the developer to establish a mutual agreed domain model and vocabulary that goes with it. This way, the developer does not sit in his/her laboratory reading domain textbooks to learn the domain jargon and trying to understand workplace activities. Some people might say you can also ask users about the work they do. But "you don't ask fish about water". Scientists live and breathe within their work settings. They knew everything about their work, they just couldn't tell you, even if you asked.

The developer put together the first concept system right in the core lab during his hands-on internship. The system was computer and monitor setup right in the center of the core lab next to the core description table. It was a “chop suey” mixed with monitors borrowed from other labs and slow rendering software, but it gave the geologists a tangible artifact that encouraged discussion and brainstorming. We thought one of the advantages of having the developer immersed within the domain context was that instead of simple “paper prototyping” techniques commonly used in the designer community, a developer could create a live working prototype on the spot. The prototype was not just sketches on paper. It contained most essential components of the final system that was going to be developed. It gave the domain users more confidence in what the final system was going to look like and made possible concrete system suggestions and recommendations. That might cost more time and effort, but it assures that down the road scientists are having the authenticate user experience of the final system.

3.1.2.2 Generalized Workflow

Through the immersive hands-on experience and understanding, we further generalized the detailed core expedition workflow for different drilling communities. Once the cores are recovered they are spliced into roughly 1.5-meter sections for easy processing and transportation. Sections of cores are scanned through “multi-sensor core loggers” to measure physical properties including porosity, density, electrical resistivity and magnetic susceptibility. The cores are split into halves. In the past, scientists would study these split cores surfaces, make observations, draw features, and write comments on “barrel sheets” as shown in Figure 2. Currently digital images of the split core surface will be taken under fixed lighting conditions and the sensor data will be plotted and printed on barrel sheets in the tedious preprocessing steps described in the previous section. The core technician observes the physical core sections laid out on the examination table. She draws and writes down her interpretation on the barrel sheets. These paper assets serve as the initial visual core description records. They will later be used as the basis of further processing requests. After a core expedition finishes, the records will be stored with the physical core boxes in core repositories.

Figure 5. Fast prototyping in the same media form during training in the LacCore core laboratory. Photos by Arun Rao [Rao06].

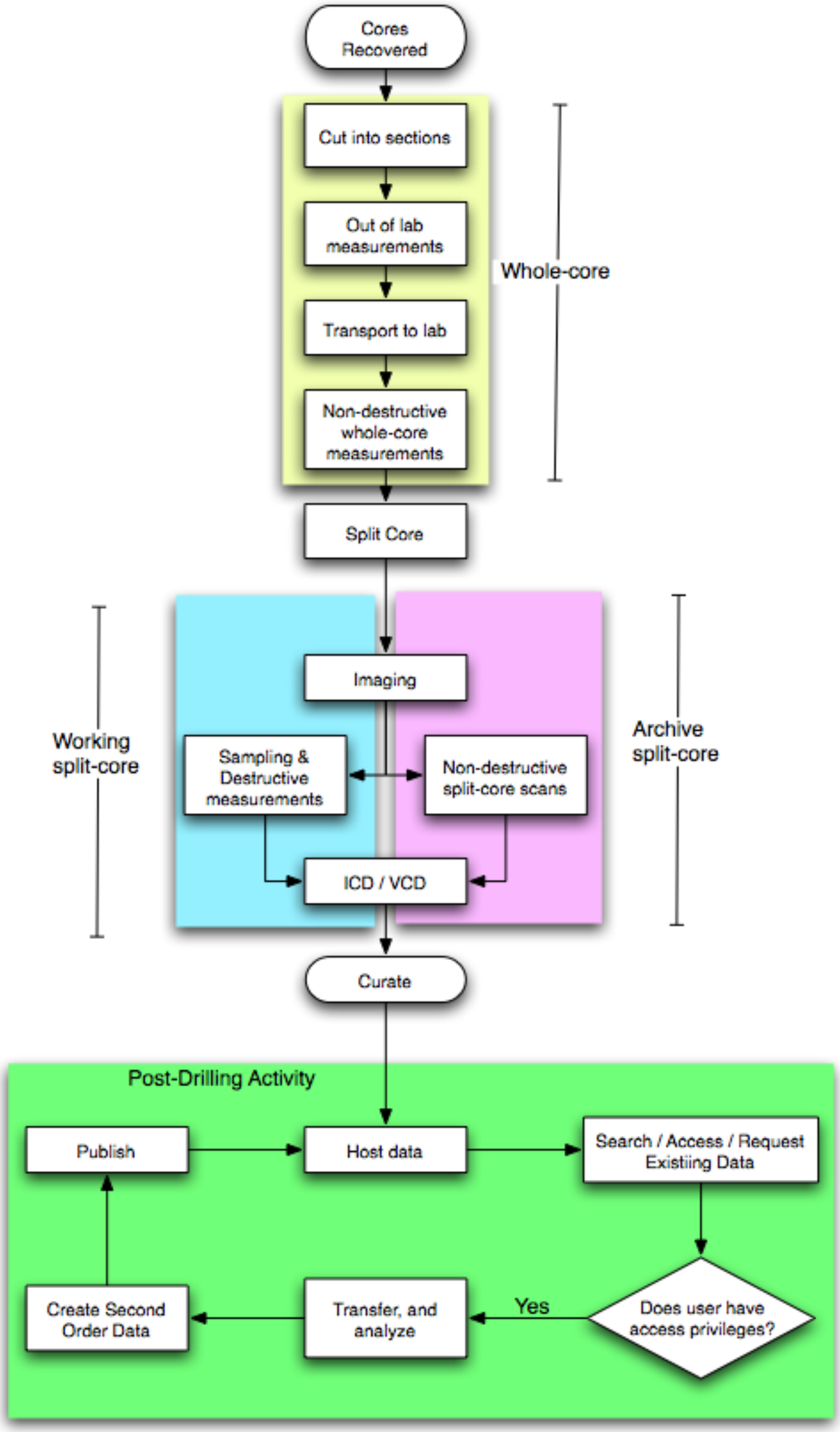


Figure 6. Workflow generalization [Rao06]. The first CoreWall developer, Arun Rao modeled the generalized core drilling workflow from different core drilling communities (LacCore, the Antarctica geological Drilling project and the Ocean Drilling Program).

3.1.2.3 Collaborative analysis and reflection through pitching

After the hands-on training, the developers were asked to prepare an experience reflection presentation. They were encouraged to use all field notes, audio, pictures, and videos they captured during training to “show and tell” and to make the presentation more like a brainstorming meeting than a formal presentation. They could put all pictures and videos on a large display wall and “pitched” the story of being trained as a core technician from the first person point of view to other members of the development team. Other team members could use this process to peek into the domain user’s life even though they were not there. Reasoning and answering questions from those who did not received training helped the developers who received immersive training to re-gain perspective away from the users and suggested further inquiries to the domain users to clarify certain points. Through this process we found that there were additional issues in the workflow besides the functional issues described in the previous section.

Figure 7. Pitching in the large-scale high-resolution display. Photo provided by Electronic Visualization Laboratory.

3.1.3 Initial findings

3.1.3.1 Assumptions from prior legacy practices

Geologists may be unconsciously keeping in mind the final stage of their workflow where they need to publish expedition reports and papers. Geologists make heavy use of paper assets in the description process and also during shift changes. By participating in the handoff process, we discovered that geologists print out core descriptions on pages of paper then place these paper assets on the wall and make comments during the handoff to keep track of research progress. The printed representation of the cores is an invaluable piece in the whole workflow. In attending geological conferences like the annual American Geophysical Union Fall Meeting we found that the printed poster is the major representation of geological research results.

Most existing tools and practices were designed toward this kind of “final product”. Bearing such assumptions in mind, the unique affordances of the digital data could be easily neglected. Even though scientists tried to utilize the digital assets, they did not make the best use of their affordances, which include feature-preserving representation in high-resolution and easy remote access.

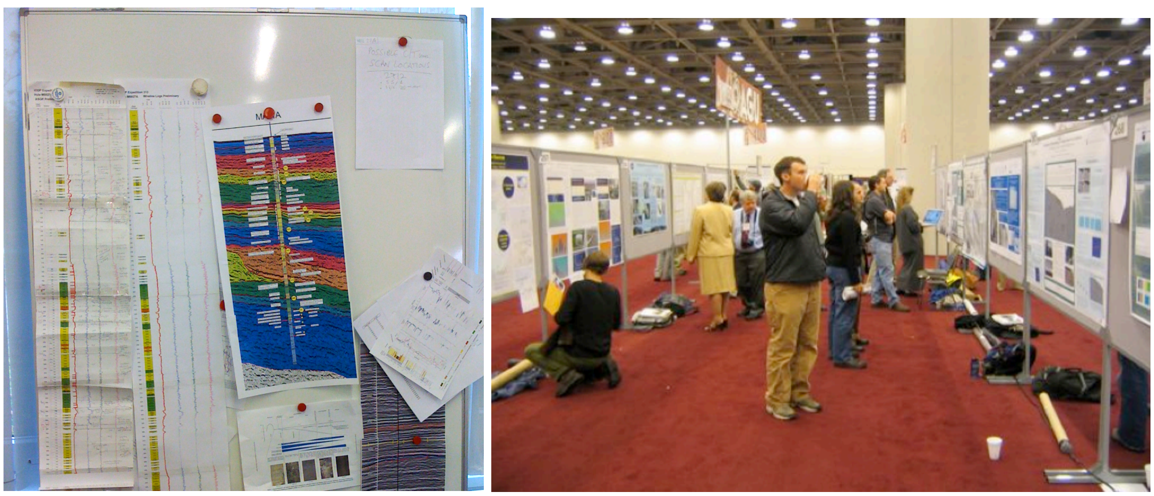


Figure 8. Left: Numerous paper printouts used for shift handoffs. Right: Hundreds of printed posters in the poster session in the American Geophysical Union Fall Meeting in San Francisco, CA.

3.1.3.2 Observational constraints

Some geologists use Munsell color cards to standardize color categorizations during interpretation, but lighting conditions (amount of light, the color of the light) could affect physical core observation and interpretation. For example, core description might be done right on the expedition site or drilling vessel. If different kinds of light sources (for example incandescent light vs. fluorescent light) were used, it might result in differences in interpretation. Additionally, the only way to integrate the various types of data including core imagery, multiple sensor logs, and historical interpretation, together for initial visual core description was to print everything out on sheets of paper and carefully lay them out in a long hallway for "physical juxtaposition" similar to Figure 9. However a large amount of the high-resolution detail was lost in converting to the printed form, which making it less valuable as an observable artifact for scientific research.

3.1.3.3 Spatial and temporal constraints

The availability of physical cores could vary. In lake drilling, the cores will often arrive at the core laboratory weeks before the investigator can travel to "meet them". A similar and more extreme case was later found in the Antarctica drilling community where the cores are boxed for shipping back to the repository once the expedition season is ended. The time to ship the cores could take another season. During the shipping period, scientists have no access to the physical cores.

Figure 9. Physical juxposition using recovered cores and paper printouts in the hallway.

3.1.3.4 Computing capability constraints

Information technology (IT) resource support for mid-size to individual scientists is limited. Geologists coming to use the LacCore facility usually do not have the luxury of having a dedicated IT department supporting their computing needs. Almost all of the scientists' software tools needed to fit inside one self-contained computer system without network connectivity when they were out in the field and the computer system had to be able to process and present data in the resolution and size described in section 3.1.2 "Initial Problem". The data size is still growing as new data is acquired in new expeditions. Scientists desperately need a way to manage and discover related core data from their own project, legacy, and on-going expeditions.

3.1.4 System Design

Aside from the requirements to solve these issues, there are constraints that the developer found in interfacing with scientists during the training period.

Geologists emphasize working with physical cores. Similar to domains like biology and medicine, core-drilling geologists rely heavily on physical interactions with the recovered samples, especially in the initial core description phase. Out in the field you can see geologists getting their hands dirty in the mud to take samples. In the laboratory, they will lay all the recovered core sections on an already crowded examination table and use a magnifying glass to look at the details of the split core surfaces.

Because of the physical space constraints, geologists must mentally keep track of the spatial relationship of core sections for visual core description. For example, 30 meters of cores might be recovered in different drill sites during one expedition. After splitting it into 1-meter sections, the worktable is not big enough to hold all of the sections arranged in their original spatial relationship. Geologists can only work on few sections at a time and constantly have to mentally keep track of which section is on the table.

We proposed the CoreWall system, which includes a single workstation with multiple large LCD displays as shown in Figure 10. The system supports configurable multiple LCD visualization output to overcome the observational constraints. The displays can be arranged horizontally just like how the physical cores are laid out on the table in the LacCore core lab, which provides a familiar experience, as if geologists are examining physical cores. The LCD displays allow for easy color calibration to provide a unified environment for core interpretation in different locations. As shown in Figure 5, a 1.5 meters long core section was about as long as three 20” 1280 by 1024 monitors laying on the core table. For larger amount of data, the system can scale up to higher resolution LCD monitors or having more cascading LCD monitors installed in the hallway like in Figure 9. The use of a single machine eases the maintenance burden on the core drilling workflow that already suffers from a lack of IT support while still giving enough screen space for individual work and small group discussions. Because of the unique affordances of digitalized imagery, the spatial relationship of sections of cores can be maintained in the CoreWall visualization output. This not only eases the extra mental load but also stimulates more research ideas, said scientists in interviews.

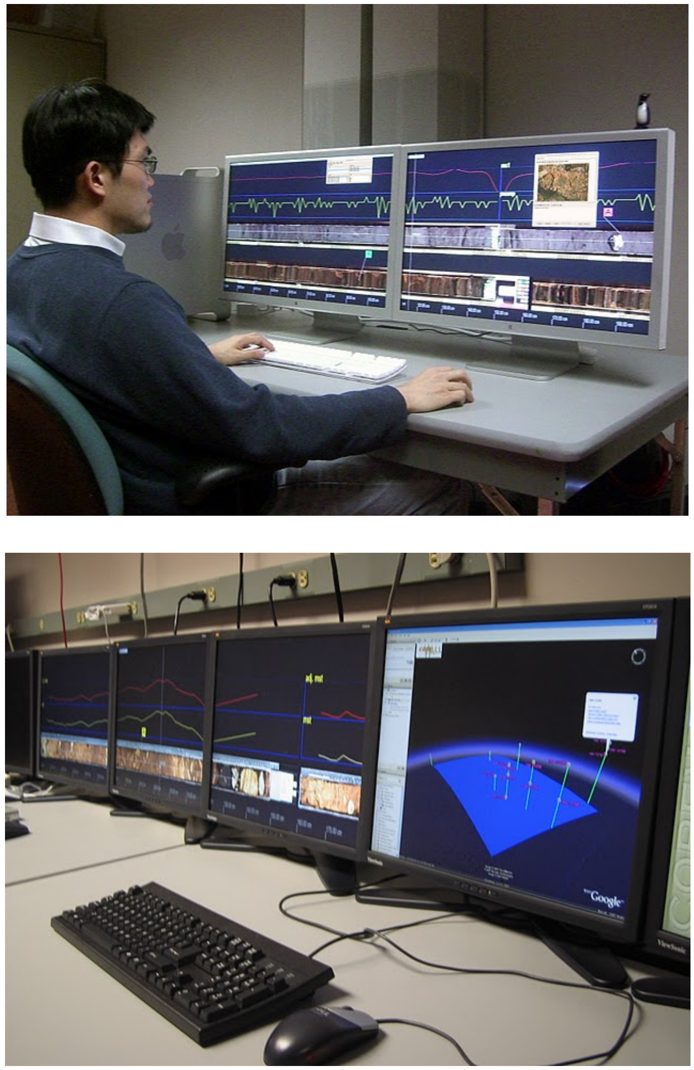


Figure 10. Typical CoreWall hardware setups

One of the system's software design goals was to bridge the gap between geologists and the huge amount of digital core data. It should allow scientists browsing and manipulating of thousands of meters of geological cores from macro-scale overview to micro-scale details while maintaining fluid interactivity. Scientists should be able to easily pan the core images with familiar gestures in a modern computer system with a keyboard and a mouse. It should also be able to present all the related data like high-resolution core images, sensor data plots, smear slide images, lithological diagrams and description texts co-registered with physical depth information. The resulting juxtaposed digital “mashup” should be able to be shared among colleagues for further collaboration.

The CoreWall system should become a piece of equipment for initial core description in the core laboratory. It allows geologists and even drillers to get immediate feedback from the data to make on-the-spot sampling or drilling decisions during a coring expedition. This is something that they could not do before with their traditional tools. The next chapter will describe implementation details and how design consideration affects the actual implementation.

3.2 Hands-on Automated Nursing Data System (HANDS)

The Hands-on Automated Nursing Data System (HANDS) is a standardized plan of care method in which the patient's plan is updated at every nurse hand-off allowing the interdisciplinary team to track the story about care and progress toward desired outcomes in a standardized format across time and units. From [Keenan07], “The HANDS method is an intervention currently being refined to bring a strong patient focus to the medical record by replacing current forms of care plans with a single, standardized plan and related plan of care processes. The method addresses the needs … for summary patient care information that is standardized, meaningful, accurate, and readily available to all clinicians involved in a patient’s care across time and space. The HANDS method embodies the concepts and characteristics of high reliability organizations and as such is fixated on ensuring the continuity, quality, and safety of patient care."

3.2.1 Previous work in medical hand-off systems

In 1982, a panel of researchers suggested using an interdisciplinary approach to successfully manage medical care information system projects [Kaplan82]. In 2009, the American Medical Informatics Association workshop report still claimed that most medical information systems failed to achieve their goals [Kaplan09].

Additionally, recent systematic literature surveys [Riesenberg09][Riesenberg10] concluded that 1) "There is a great need for high-quality handoff outcomes studies focused on systems factors, human performance, and the effectiveness of structured protocols and interventions." 2) More research is needed to identify best practices. We found several patient hand-off systems published in the recent literature [Flanagan09] [Eaton04] [Frazer88] [Reider98], for example, UWCores [Eaton04] published in 2004 and Patient Handoff Tool [Flanagan09] published in 2009. These systems mostly collected raw text-based data, as their main goal was to duplicate the original paper assets in the healthcare process. One main contribution for these systems was identifying "what" data fields are essential to be included in the final paper printouts for handoffs. A system would be considered successful if it shortened the data collection time [Eaton05]. When considering efficiency, it was always compared with "verbal" or "workaround" ways (like software copy and paste) of doing the same task [Bhabra07]. More evidence is needed to show the improvement of patient care quality and efficiency.

3.2.2 Interdisciplinary Collaboration Team

Interdisciplinary collaborations of statistics, data mining, visualization, and user interface experts outside the medical knowledge domain are needed to realize the additional functions requested by medical practitioners. For example, in the semi-structured user interviews in [Eaton05][Flanagan09], healthcare researchers found practitioners suggesting medical hand-off systems providing functionalities like “if-else” suggestions based on either the previous shift’s note or previous collected data in the medical information system. Advanced functionalities like this are inherently difficult to implement into systems with just plain raw text data; secondary or derived data will be required. Once we have so much more data, “how” to present that data becomes another issue to support on-the-spot medical care decisions.

3.2.2.1 Domain background

Inside HANDS, real patient care plans are defined with the hieratically structured North American Nursing Diagnosis Association International (NANDA-I) classification, Nursing Outcomes Classification (NOC) and Nursing Intervention Classification (NIC) terminologies. Nurses would document (add, delete or modify) a patient’s status change based on these three classifications to form a patient’s care plan during shift changes.

Because of this “discretization” of the conventional natural language textual data, statistics and data mining techniques could be used to view the problem from an abstract perspective and use a computational methodology to analyze and utilize not only the raw data but also generate secondary derived data from it. The types of data to be presented in a hand-off support system become even more complex. Additional expertise from data visualization and user interface design may also be required to advance the research from identifying “what data to collect” to “how to present related and useful data”. This might allow HANDS to move from the “data collection phase” to the “data analysis and visualization phase” and further afford decision support during medical hand-off and improve the quality of patient care.

3.2.2.2 Initial Plan and Assumptions

We formed an interdisciplinary group including experts in nursing, statistics, data mining and visualization at the end of 2009. The goal was to look at the collected care plan data in the HANDS database in order to better understand the data from different perspectives, and to find a way to utilize the data to support clinical decision-making. The on-going collaboration wanted to focus on statistics, data mining, and visualization of the HANDS system data. The visualization goals included: 1) Improving the original HANDS user interface beyond the existing nurse users to potential users such as doctors and therapists. 2) Adding visualization to HANDS existing reports in an effort to empower current and future users to do more data exploration and visual analytics.

We assumed that nursing hand-offs shared several similarities with the core description workflows from the high level point of view. Geologists used large amount of printed (paper) artifacts along with physical core observation in the visual core description process. They used specialized tools like AppleCORE, PSICAT and multiple pieces of commodity software as workarounds, mainly for generating print quality paper artifacts before having modern systems like CoreWall. On the other hand, there might be required hand-off processes using the original HANDS defined and forced by clinic administrators. We imagined that healthcare practitioners (nurses and physicians) in clinics or hospitals might still use random pieces of paper and personal notebooks as their way of remembering patients' status during hand-offs. We would like to use the immersive empathic design method to understand not only the defined medical hand-off processes but also actual practices and to propose user interface changes and visualization presentations to assist hand-off and healthcare administrators' policy and decision-making.

3.2.2.3 Constraints and Issues

We initially intended to apply the immersive empathic design method similar to the CoreWall setting described in section 3.1. We would like to have been immersed in the clinical hand-off setting where the system was used, but there were additional constraints compared to the CoreWall setting.

The medical environment in the clinics and hospitals was more hierarchical and rigid. Unlike the academic environment of geological core drilling, the medical setting treated patients' safety and quality the first priority. It was more challenging to being an "outsider" into such a setting. Instead, we gained most of our knowledge about HANDS from:

1) HANDS on-line training “screencast” material for new nurses.

2) Access to a test HANDS instance, so we could actually try and see how the system worked.

3) Regular meetings and interviews with healthcare (nursing and physician) researchers.

This seemed to correspond with findings in the literature [Kaplan82] that most modern medical information systems were developed by a vendor and the healthcare administrations of a system would assume the vendor knew what real users responses would be or they could just ask them.

3.2.2.4 System design

Based on the “indirect” data we collected, we used digital screen mockups to add requested features based on literature survey findings and physician interviews. Additionally, we also did fast exploratory prototyping of several different visualizations and presented these results to healthcare researchers for feedback and correctness verification. These prototypes might not be used in the final system, but through these activities, the developer could establish the domain vocabulary while understanding the HANDS system. The prototypes could also provide a way for healthcare researchers to verify whether the developer understands the domain correctly and to see possibilities that the new technologies could offer. In the next chapter, I will show several proposed user interface enhancements and visualization prototypes.

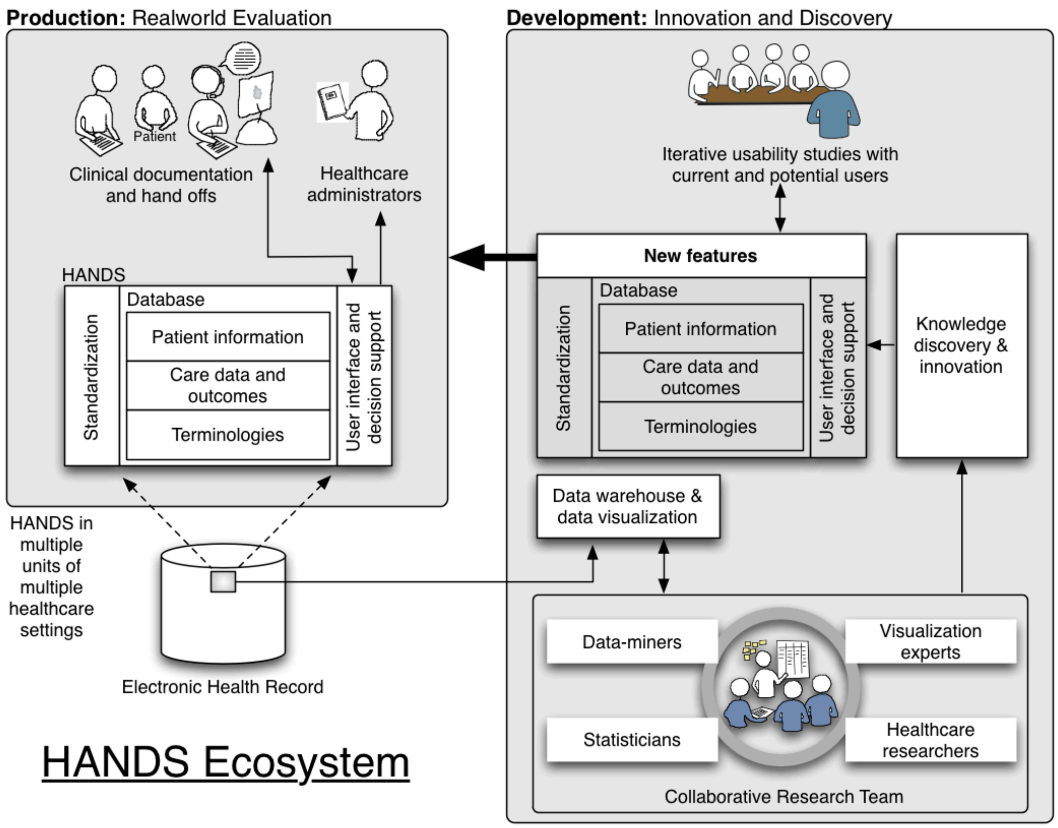


Figure 11. Planned HANDS Ecosystem. The collaboration team would build and prototype HANDS data mining, statistics, and visualization enhancements on a development environment with a duplicate snapshot of the production HANDS databases. The new user interface and visualization features in the development environment would undergo iterative usability studies with current and potential user and be verified with healthcare researchers before being deployed to the production setting. Copyrighted 2011 HANDS Research Team

4. IMPLEMENTATION

This chapter will describe implementation details of the CoreWall system and enhancement mockup screens and prototype visualizations of the Hands-on Automated Nursing Data System (HANDS).

4.1 The CoreWall System

The CoreWall system consists of a customizable hardware setup and a software suite. A typical CoreWall hardware setup includes a single computer with a single or multiple LCD displays. Several different CoreWall hardware setups are shown in Figure 12. The software suite includes two major pieces of software: 1) Corelyzer: a scalable high-resolution core visualization tool for initial visual core description and 2) Correlator: a visual stratigraphic correlation tool for reconstructing a complete stratigraphic record from sensor data extracts from multiple-hole cores. Section 4.1.1 to 4.1.3 will mainly be used to describe the implementation of the Corelyzer software. Section 4.1.4,will describe the implementation of integrating the Correlator software with the Corelyzer software in order to support visual stratigraphic correlation in the National Lacustrine Core Facility at the University of Minnesota and on the U.S. JOIDES Resolution scientific drilling vessel.

4.1.1 The Corelyzer User Interface Design

Corelyzer is the main software application of the CoreWall software suite. Its implementation focused on the design of bridging the gap between geologists and the huge amount of their digital core data. It was implemented with a multi-level image texture paging system [Rao06] that allowed scientists to navigate thousands of meters of high-resolution core images and sensor data plots while maintaining smooth interactivity.

The hardware design also affected the design of software user interface. (Figure 13)
1) Since the tiled-display is used for presenting high-resolution visualization, the display bezels were taken into account when generating visualization output in order to reduce the interpretation interference [Mackinlay04].

2) Because the physical visualization was large, the system should keep track of the user's current attention point. Often used user interface elements should be easily accessed. The most common toolbox will follow mouse cursor from one display to another. User interface elements like dialogs and status notifications should popup close to attention focus area. This is absent in most of modern operating systems' user interface design for the multi-monitors setups [Czerwinski06].

3) Scientists could easily navigate through all core data with familiar dragging mouse gestures and smoothly switching from an overview scale to micron level details with mouse scroll wheel.

During the immersive training, we noticed that geologists often had to reference other types of data or samples in order to write down their interpretation. Additionally, the curator of a core laboratory had the responsibility to take sample requests from geologists. It was always tedious for him to keep track of samples like smear slides and thin sections that he already collected. One good way to do that was to align the samples taken with split cores co-registered in depth. Now the software's built-in multi-level high-resolution image system could display a large amount of imagery data and still maintain fluid interactivity. We designed a track-based abstraction organization scheme to house different high-resolution images in the Corelyzer software. This meant that the images could be split-core surface scans, smear slide samples or even lithological diagrams. They could all be put into the visualization output in separate tracks and could be aligned side-by-side as shown in Figure 14. If the system was designed just as the geologists asked for, it might not be realized such requirements were needed. We found that a system designed using participatory design presented similar functionality as a database table linking to images files in multiple scattering windows as the user interface.

During core technician training, we learned that geologists would put little flags (Figure 15) on the split core surface to denote spots that he/she would like to request samples from. We further extended the idea and implemented a customizable annotation module to further support adding user-generated data to the juxtaposed "mash-ups". Scientists could circle an area right on top of the high-resolution core images and input structured and freeform annotations with related images and document attachments. Since all the operations and data were digital, the "mash-up" can be packaged and shared online with the curator and colleagues to support synchronous and asynchronous remote collaborations such as sample requests and notes sharing. If using other design methods, scientists might not even mention actual domain practices in an interview session in computer science laboratory. One of prior practices involved sending reduced core images to all scientists and asked them to circle sample regions in presentation slide tools and send the slide stack back to the curator. And because prior systems and assumptions, systems designed using other approaches could always tend to very data entry oriented. Little attention was paid to creating an easy to use and manage user interface for scientists and curators.

The system had to be customizable to fit into different expeditions and workflows. The Corelyzer software included a plug-in architecture that allows enhancements from 3rd party developers. Examples of this include the Paleontological-Stratigraphic Interval Construction and Analysis Tool (PSICAT) plugin, which allows the display of lithological diagrams alongside high-resolution core images in custom drawings; the ANDRILL Southern McMurdo Sound (SMS) expedition manager plugin, which automated data retrieval for ANDRILL SMS on-ice users. As pointed out in [Zimmerman06], using user-centered design and participatory design practices might be limited to a specific user group because of uncertainty, heterogeneity and rapid changing. The initial domain-centric immersion built a sustainable knowledge foundation that was transferrable from one user community to another. And it also allowed us to know what and where to build in customizability within the system based on the identified generalized workflow.

As we continued carrying the often-referenced hands-on experience in the LacCore and introduced the system to other coring communities, we also learned that we had to make the Corelyzer's input and output system flexible with reusable customizable templates for accessing web-services and creating user-generated annotations. This would allow the system to provide similar functionalities in similar user interfaces and avoid confusion. And most importantly, through the process of talking to different data providers, we could influence how the data were served and discovered. That was not seriously considered by legacy core data management systems before. Oftentimes systems designed using other approaches within the domain remained database-centric, rigid and inflexible when the need to connect with data sources in other communities.

Figure 12. CoreWall setups in different hardware configurations. Above: Dr. Tomas P. Wagner using the CoreWall during ANDRILL 2006 season in the Crary Laboratory at the McMurdo station, Antarctica. Photo by Joshua Reed. Below: The multi-panel CoreWall system on IODP U.S. JOIDES Resolution scientific drilling vessel.

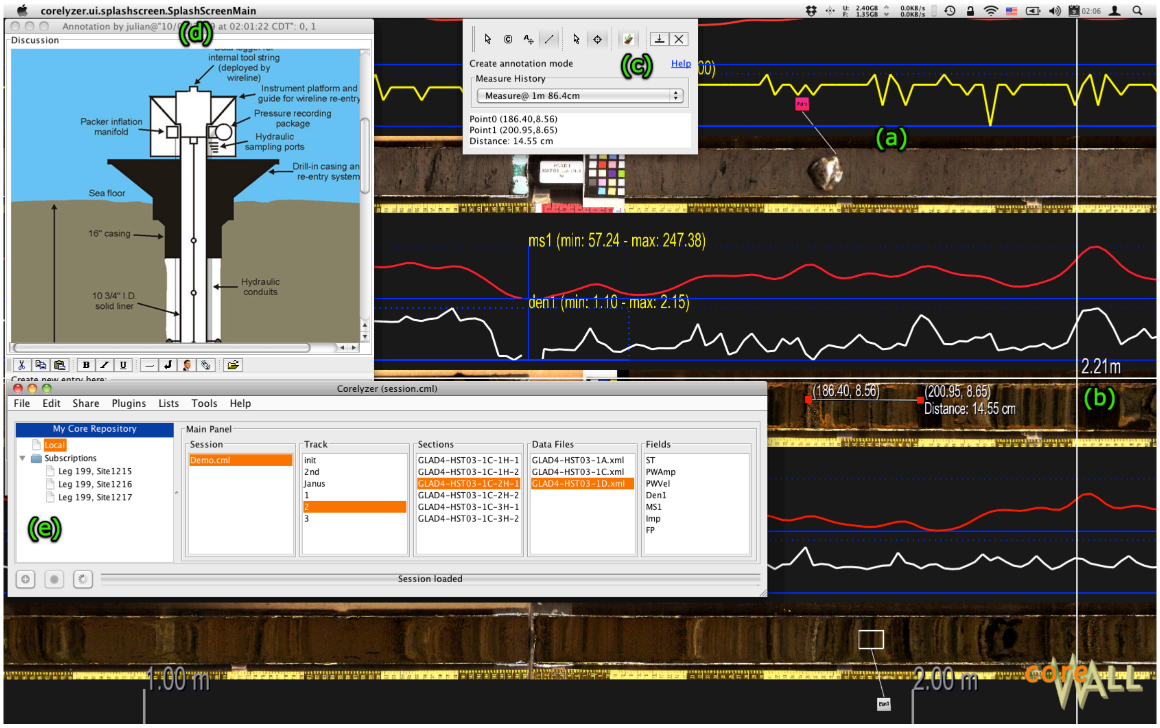


Figure 13. Above: User interface screenshot. (a) The main core data context will be shown in the backdrop co-registered in depth. (b) A crosshair with current depth information is shown, which lets users easily identify the location of the cursor. (c) Common toolbox will float from one display to another (in the upper center of the display) with the crosshair. (d) User interface elements like popup dialog and window will be positioned close to the crosshair cursor when it first appears on the screen. (e) The iTunes-like interface allows the users to subscribe to “Corecasts” and retrieve core data from different sources.

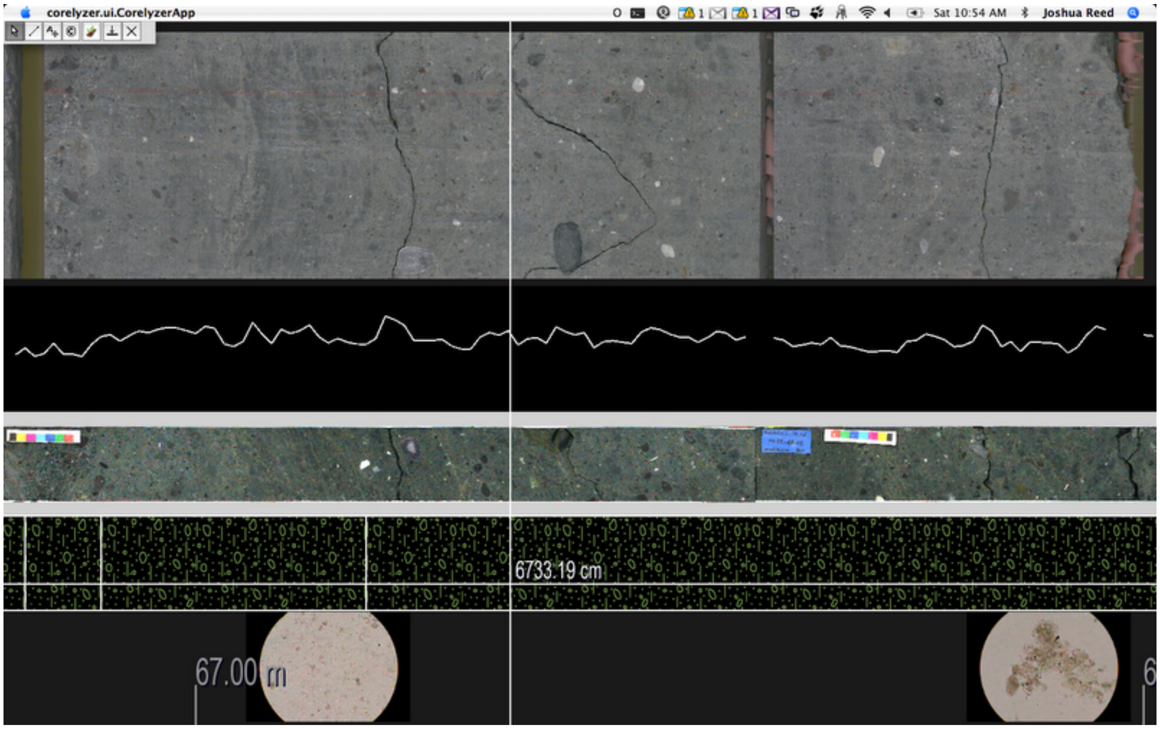


Figure 14. A Corelyzer screenshot by Josh Reed during ANDRILL 2007 season. It contained split-core, whole-round core, smear slide sample images and sensor data plots.

Figure 15. It was a common practice that scientists put little flags on physical core samples to indicate sample requests for curators [ANDRILL08].

4.1.2 <u>Input/output mechanism improvements</u>

Data input and output options are one of the most important things that the geologists care about. In the first iteration of design and implementation, the Corelyzer software in the CoreWall software suite supported data input from local files for individual geologists and a remote centralized collaboration server developed for the Antarctica Geological Drilling project [Rao06].

During the hands-on training in the immersive empathic design methodology, we realized that the data collected throughout the generalized workflow was actually a large number of individual files generated by different instruments even though these pieces of data were correlated. Geologists had to manually copy these files and put them together using file name convention and directory structure. For example, for each 1.5m section of core, the MSCL would generate a plain text file containing depth and sensor measurement pairs stored on the MSCL instrumentation computer. The split-core surface high-resolution scan images would be generated in a separate computer that controlled the line scanner. Oftentimes in order to look at a set of data from one expedition, a scientist had to manually go through a batch of individual files, which was time-consuming and inefficient. If a scientist decided to share a set of data with his or her colleague, it often involved uploading the whole directory to a FTP site, even though parts of the data set might have been accessible via online legacy databases.

In Corelyzer, users could load imagery and sensor data files from local hard drives. The on-screen working status could be saved as a session file that kept track of metadata like depths and storage locations of individual files. The session file format supported both local and remote files using URL addresses. The session file was good because:

1) An individual scientist could save a snapshot of her work in very small file without re-saving multi-gigabytes of all imagery data.

2) Because of the small size of session file, it could be shared easily with collaborators if related imagery could be served from remote web or storage servers. The receiver of the

session file could use their local copy of the imagery or Corelyzer would start downloading the necessary imagery from remote servers when opening the session file.

There were still issues with imagery and sensor measurement files that only existed in one scientist's local machine and an additional need to package all core data with attached annotations into a self-contained media like DVDs that could be used in a classroom and museum environments where stable and constant network connectivity could be an issue. We added additional output options that would package all the required material including imagery, sensor data, and annotations, along with the session file into a self-contained "core archive". After rolling out this function to the users, we found that it was a good way to take a snapshot of work session and share it remotely for debugging and discussion. The solution to problems discussed above using other methodologies tended to design a centralized database hosting service for storing all related data. It could work if the expedition was well supported to afford a dedicated IT department, but was less feasible for small scale and agile individuals and groups.

For remote files, the collaboration server plugin designed in [Rao06] worked for moderate size expeditions. Data management and ownership policies are always issues in different drilling communities, and especially for organizational expeditions in larger scales. A centralized collaboration server worked for a moderate size expedition like ANDRILL, but as the scale of an expedition grows, an additional service implemented by 3rd party will be less welcomed. Instead, a data management infrastructure would be preferred for hosting and sharing related drilling data artifacts along with other cooperative systems installed in a specialized environment like a scientific drilling ship or platform. For example in the Integrated Ocean Drilling Program (IODP), a data management system based on the Laboratory Information Management System (LIMS) was developed to service all measurements acquired during the expedition. In the International Continental Drilling Program (ICDP), different versions of Drilling Information System (DIS) were developed to fulfill needs of different stages. These hosting systems often have different storage architectures and sharing policies, making it cumbersome and difficult to fight through all the obstacles of installing a foreign collaboration server on each individual system. Instead, we took two different approaches to integrate the Corelyzer system in different settings. One is collaborating on an interoperable exchange file format; the other is using a one-way open standard protocol.

4.1.2.1 An interoperable exchange file format (for Drilling Information System integration)

In the effort to expand outside the LacCore user community and bring the CoreWall system to the International Continental Drilling Program (ICDP), an integration plan allowing Corelyzer, Drilling Information System (DIS), and Paleontological Stratigraphic Interval Construction and Analysis Tool (PSICAT) to work together was proposed. The differences between these three systems are shown in the table below. Each piece had its merits and weakness, and we needed to combine them while preserving and using most of their synergy without losing integrity and discreteness.

The idea was proposed and discussed via email communication for a few months, but as G. Olson et al. pointed out, “distance matters” [Olson00]. It showed in this case that not much progress was moved forward until we utilized the proposed immersive empathic method and had developers worked with scientists in person for few weeks in order to identify the actual practices and workflow on site. It also showed advantages over other prior methods. We constructed user case scenarios that were further described below.

Table 2. Comparison table of Corelyzer, PSICAT and DIS

Feature	**Corelyzer**	**PSICAT**	**DIS**
Project Level	Expedition-Site-Hole-Core-Section	Expedition-Site-Hole	Expedition-Site-Hole-Core-Section
Recovery Data	Required	Not required	Required
Data Acquisition	Low	High	Very high
Data Visualization	Very High	High	Low
Main Purposes	Visualization, Collaboration, Interpretation	Data Acquisition, Visualization	Data Acquisition of Primary Data
GUI	Graphical interactive images, image annotations	Graphical interactive forms	Text-based interactive forms, image annotations
Data Sources	Files, Plugins	Files, Plugins	Database (MS SQL Server 2000), Files
Export	Corelyzer XML Session File (cml), Corelyzer Archive File (car)	Images, PSICAT Data (XML), Subversion, Presentation, Summary Sheet (XLS), Transformation, Data Set Lithology Correlation	Tab delimited ASCII Files, Corelyzer XML Session Files (cml)
Import	Corelyzer XML Session Files (cml), Images, Annotations, Tab delimited ASCII Files, CSV Files	PSICAT Data (XML), Subversion, Corelyzer Clast Data, Dataset, Lithology CSV, Geotek (tab delimited text files)	Tab delimited ASCII Files, CSV Files, Images (jpg, bmp, tif)

We referred back to the generalized workflow derived in the immersive empathic design methodology described in the last chapter. We used the generalized workflow as a foundation to understand the terminologies of the DIS and how DIS was used in expeditions it supported. Then we identified the commons and where modifications and enhancements were required in the Corelyzer software to integrate with the DIS.

In a general DIS use scenario, it would call raw collected data as “recovery data”. They were the mandatory data required before moving onto next workflow stages like initial visual core description. Recovery data would include 1. The location of the core data, which used the expedition, site, hole, core and section convention. 2. The data model for the lithological description. 3. The necessary libraries for the lithology and their classifications. All scientists were required to use pre-defined structural input forms to document observation and measurements into the DIS, which was different from LacCore users ad-hoc individual data management strategy. In practice, a scientist might either input data directly on a computer or wrote on printed forms and then copied his or her writing from paper to the electronic input form. There was also a limitation of at most 255 characters in a free text field. It was due to the policy of the archival system PANGAEA information system hosted in the University of Bremen’s Center for Marine Environment Sciences (MARUM), where the DIS would be archived in the long term.

The proposed idea was to integrate the best features of the individual tools into an interoperable configuration without tightly coupling pieces together. We designed a common drilling data exchange Extensible Markup Language (XML) format based on the user workflows to make Corelyzer, DIS and PSICAT work together in different phases of a drilling expedition by users with different roles. DIS will be used as a central data management repository for all drilling data. It could export “recovery data” description metadata in the defined common format based on user-selected leg, site or hole. That file could be imported into either Corelyzer or PSICAT for visual core observation and lithological description. Data generated in Corelyzer and PSICAT could also be added to the common exchange XML file, which would be used to notify DIS to update the drilling data repository.

The conceptual steps of activities were:

1. DIS exported user-selected recovery data in the common exchange format, which would include core imagery, data plots and their metadata.
2. PSICAT could generate a visual core description (VCD) form for each core section from the common exchange file exported from DIS. Existing VCD data can be modified and new data can be added using the graphical functionality of PSICAT. Modifications can also feed back to DIS.
3. Corelyzer could load all core images and corresponding logging data by importing the common exchange format. The PSICAT Corelyzer plug-in could also be used to render lithological diagrams along with high-resolution core images. The user could add annotations attached to the core images, which would be added to the common exchange format and updated back to DIS and then can be used by other tools.
4. DIS could import, store, and keep track of all modified and new lithological data from common exchange files from Corelyzer and PSICAT.
5. Additionally, we started testing using the Corelyzer software and the Correlator software (4.1) together to conduct finer-scale stratigraphic correlation using data logs and high-resolution images. More details will be discussed later in this chapter.

Because the DIS used during expedition mode only supports local files, we had to additionally adopt a set of conventions, which were customizable in the Corelyzer software to access core data exposed from the common exchange format. This meant commonly agreed data structure, format, and location from the users' point of view and minimized the user interaction required to bring drilling data assets from one system to another. The integration efforts and tool advancement was published in Scientific Drilling Journal in 2010 [Conze10]

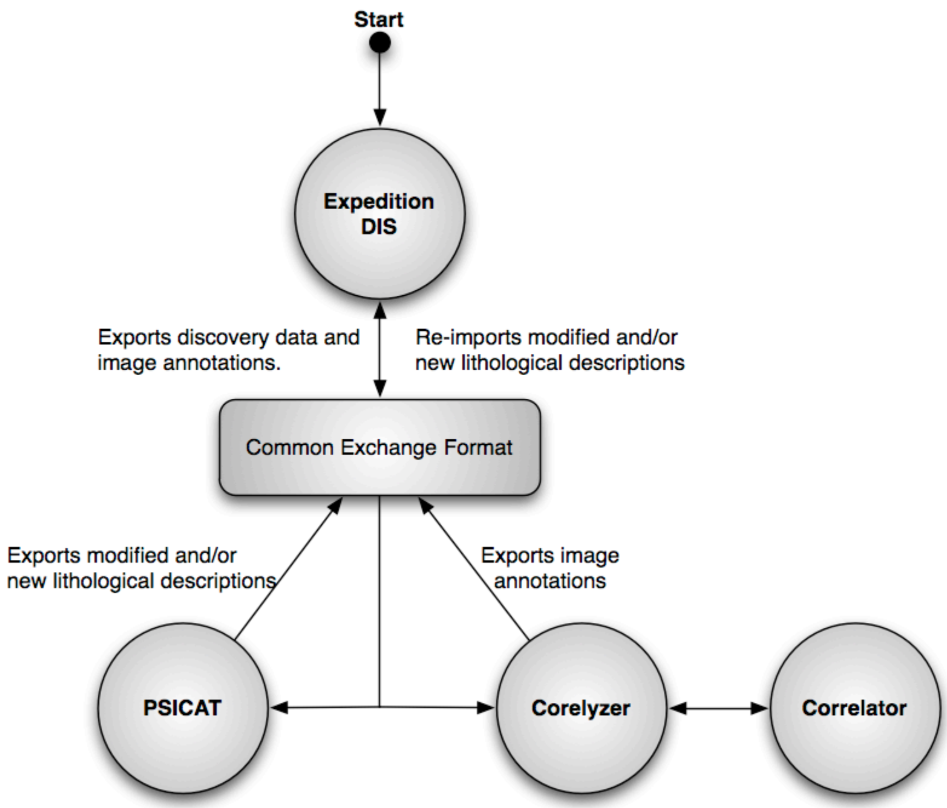
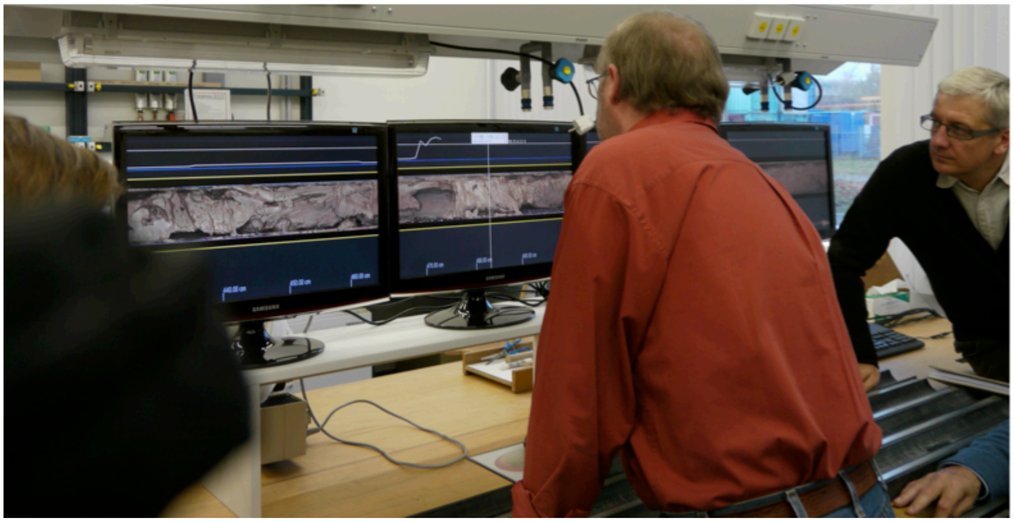


Figure 16. Corelyzer, DIS and PSICAT integration. The DIS exposed recovery data in the common exchange format file. Corelyzer and PSICAT could load the exposed data using the file and do visual core observation and/or lithological diagram creating. The user-generated content could be also exported from Corelyzer and PSICAT and re-imported back to DIS. A small group of scientists also started testing Corelyzer and Correlator software together to do finer-scale visual stratigraphic correlation. [Conze10]



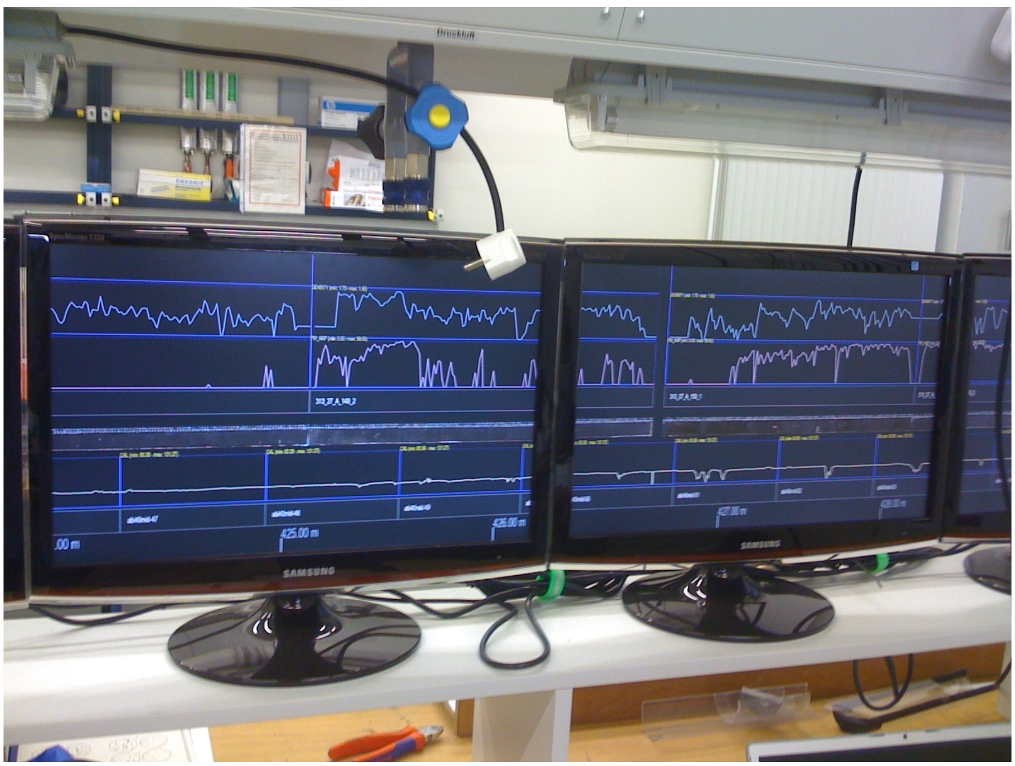


Figure 17. Above: Corelyzer station at the IODP Exp. 313 New Jersey Shallow Shelf onshore science party at the Center for Marine Environmental Sciences (MARUM), University of Bremen. The station was fed continuously with scanned images and MSCL data of new core sections as they were added to the ExpeditionDIS. In conjunction with Correlator, this station was used for correlation between sites using lithological features and logging data. Photo by H. Ando, Ibaraki University. Below: Multi-Sensor Core Log (MSCL) physical property data alongside core image data on Corelyzer.

4.1.2.2 One-way open standard protocol for legacy data (for IODP integration)

For legacy data repositories, we designed a one-way sharing protocol to expose these assets, since they are more stable and underwent fewer modifications over time. We designed a data sharing protocol based on the Atom syndication format. Similar to DIS integration, we modeled the recovery data structure in core drilling with few customized tags to form a core data syndication protocol that could be used in a publish-subscriber model.

On the server side, publisher feed generation can be easily realized with a site or hole based core section traversal program. For example, for generating the Ocean Drilling Program (ODP)'s Janus database feeds (www-odp.tamu.edu/database/), we could use the search and list service provided by the Iowa State University's Chronos portal (www.chronos.org). It would return a list of available core data in the comma separate format, which could be easily re-formatted to the proposed syndication feed format. Feeds for a drilling site can be easily generated in minutes with the program we developed and released in open source for further modification if necessary. An example feed file content is shown in the Table 3.

On the client-side, we implemented an "iCores" Corelyzer plug-in interface shown in Figure 18 to allow users subscribing to data feeds as "Corecasts". The user interface is similar to the modern "Podcast" or feed aggregation clients. It provided a central place to collect all core data references instead of scattering files and links, as we identified as one of the constraints in the actual setting during the hands-on training.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<feed xmlns="http://www.w3.org/2005/Atom"
xmlns:image="http://www.corewall.org/image"
xmlns:taxo="http://purl.org/rss/1.0/modules/taxonomy/"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:core="http://www.corewall.org/core"
xmlns:sy="http://purl.org/rss/1.0/modules/syndication/"
xmlns:dc="http://purl.org/dc/elements/1.1/">
  <title>Leg 199, Site1215</title>
  <link rel="self" href="http://corewalldb.evl.uic.edu:8081/cache/iodp/1215.xml" />
  <subtitle>Generated from ChronosJanus Service by iCores</subtitle>
  <id>tag:corewall.org,2007-10-12:/1215.xml</id>
  <updated>2007-10-12T16:57:27Z</updated>
  <dc:creator>iCores@CoreWall.org</dc:creator>
  <dc:date>2007-10-12T16:57:27Z</dc:date>
  <entry>
    <title>1215a_001h_01.jpg split-core image</title>
    <link rel="alternate"
href="http://www.iodp.tamu.edu/publications/199_IR/VOLUME/CORES/JPEG/1215a/1
215a_001h_01.jpg" />
    <category term="split core image" />
    <author>
      <name>IODP</name>
    </author>
    <id>tag:corewall.org,2007-10-12:/iodp/1215/1215a_001h_01.jpg</id>
    <updated>2007-10-12T16:57:27Z</updated>
    <published>2007-10-12T16:57:27Z</published>
    <summary>IODP split core image of leg 199, site 1215,
1215a_001h_01.jpg</summary>
    <dc:creator>IODP</dc:creator>
    <dc:date>2007-10-12T16:57:27Z</dc:date>
    <core:depth>0.0</core:depth>
    <core:length>0.9800000190734863</core:length>
    <image:thumbnail>http://corewalldb.evl.uic.edu:8081/cache/iodp/1215/thm-
1215a_001h_01.jpg</image:thumbnail>
    <image:orientation>vertical</image:orientation>
    <image:dpiX>254.0</image:dpiX>
    <image:dpiY>254.0</image:dpiY>
  </entry>
</feed>
```

Table 3. A “Corecast” feed example to access IODP Janus database archive. It was reformatted from the CSV (comma separated values) list returned by the Iowa State University’s Chronos portal (www.chronos.org). The feed format was based on the Atom standard (en.wikipedia.org/wiki/Atom_(standard)) with additional namespaces like “core” and “image” to embedding additional metadata (like core section’s depth, length and image’s DPIs) for core data.

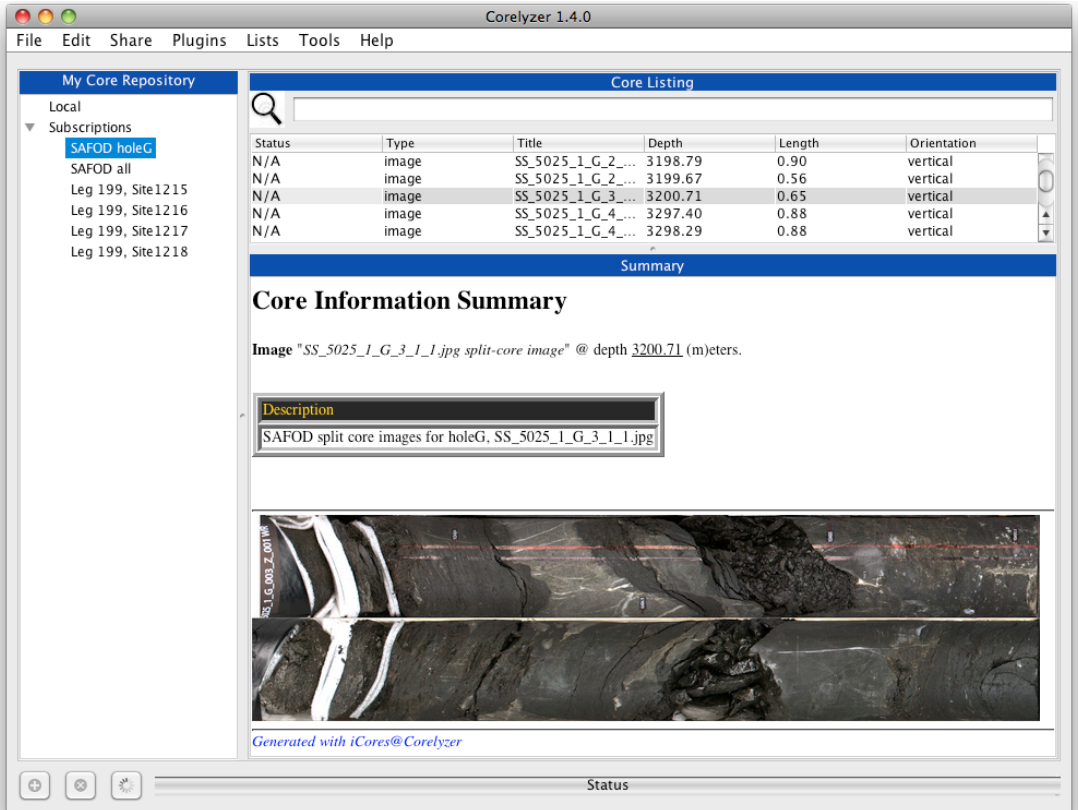


Figure 18. Corelyzer Corecast client interface. The use could use the interface to add Corecast feeds into his or her own subscription list on the left hand side. Each feed provided core images or data files in the interested location. Individual core section list could easily be searched and sorted in title, depth or length as shown in right above section. The highlighted core section in the list would bring up more detailed information about the core section with lower resolution thumbnail for a quick preview of the actual high-resolution core data.

4.1.2.3 Web-services accessing user interface templates

There are numerous databases with different architectures and formats in different geological core drilling communities. Even within the ocean drilling community, different types of data might be hosted in different repositories and managed by different affiliations. Developing the input modules for all these different sources one by one could result in heterogeneous user interfaces and is scalable. The user experience would also be poor, since the user will see different ways to access data even through fundamentally all the data are related.

For example, in a larger organizational expedition like those undertaken on the Integrated Ocean Drilling Program (IODP) scientific drilling vessel JOIDES Resolution, a centralized data input based on the Laboratory Information Management System (LIMS) is required by the standard operation procedure policy. A two-way integration described in the DIS integration section might be less feasible due to such policy. Additionally, related drilling data might exist in different systems even on the same vessel and be managed by different parties. The logging database that hosts all borehole logs and Formation Micro Scanner (FMS) images was managed by the Borehole research group (BRG) at the Lamont-Doherty Earth Observatory (LDEO) in Columbia University. The core imagery, on the other hand, was hosted in LIMS managed by the IODP at Texas A&M University (TAMU).

For most scientists onboard the drilling vessel, the CoreWall system's ability of pulling various pieces of data from the data management repository and integrating them in a comprehensive representation is still indispensable. To solve the problems described above, we designed a set of templates including data access and user interface paradigms.

On the service side, we worked with both BRG at LDEO and IODP at TAMU to serve in the "Representational State Transfer (REST)" based services. The service can be easily accessed with an HTTP request attaching interested core data like operator, time and/or location. Two types of fundamental request interfaces needed to be implemented. One is a directory lookup listing and the other is returning the list of actual data available. On the client side, a multi-threaded remote lookup requesting module and a generic user interface form were designed. The interactions to access remote services became simple.

1. A user selects to access a service. The service returns what data are available grouped by drilling sites.
2. The user chooses which hole to query. The service returns available data listed in the result table grouped with types.
3. The user chooses to load interested logging, FMS and/or high-resolution imagery data into the Corelyzer.

As we identified that scientists did not always want to adapt to a new user interface modal using the proposed methodology, other approaches might introduce new interfaces and interacting modal for different instruments and storage systems. A similar and family interaction modal for all similar data sources could lower the initial learning curve and encourage system adoption.

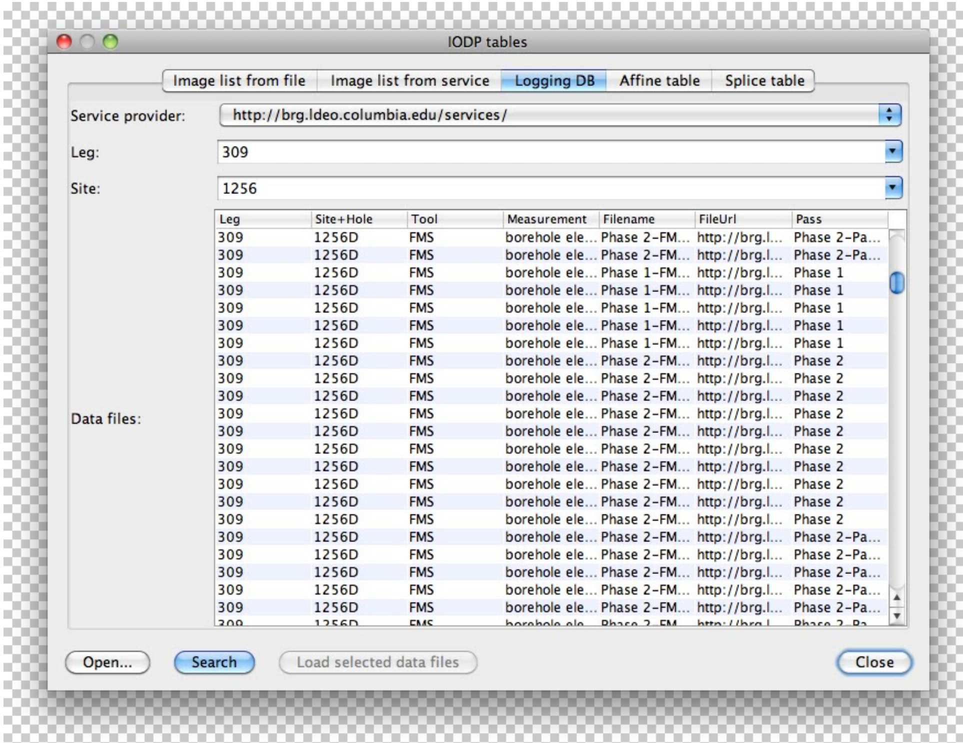


Figure 19. Lamont-Doherty Earth Observatory Logging database access module. The user could basically follow interface elements from top to bottom using service provider, expedition (leg) and site to filter and find the core data available in the remote logging database. Double clicking on the found entries would notify the background downloader to retrieve selected data from the remote server and load them in the right depth position provided by the metadata from the remote service.

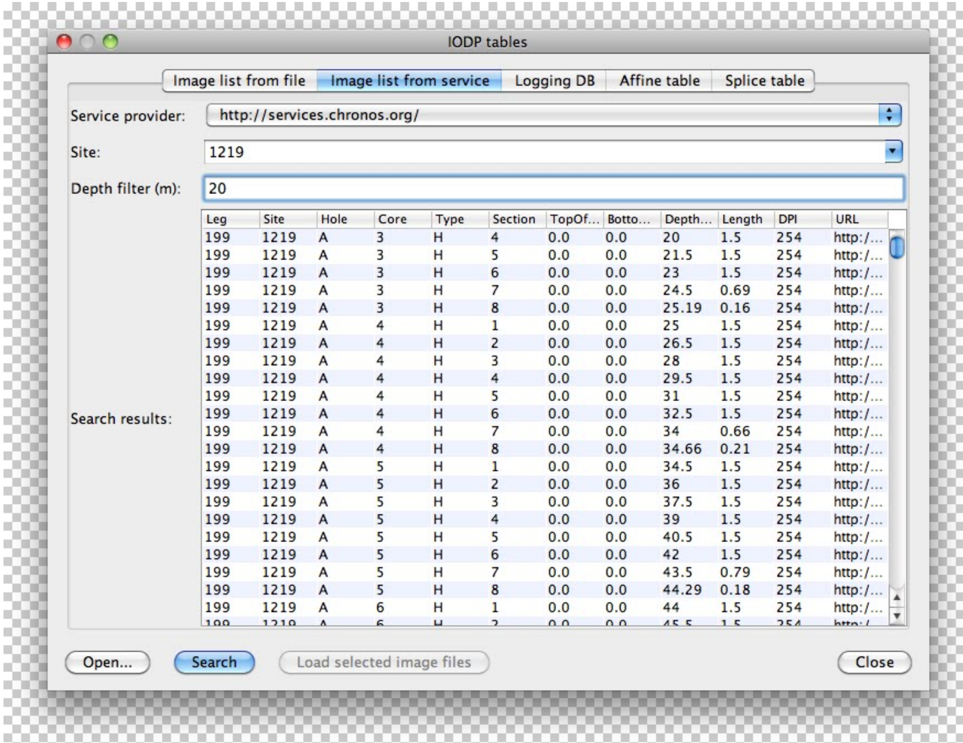


Figure 20. Imagery service access module. The imagery service access module user interface resembled that of the logging database access module. The user could use the same logic to find core sections by selecting service provider, site and depth (range) of core section interested. Double clicking selected rows from the search results would download the high-resolution core section images, generate multiple resolution image textures and visualize them in depth-registered position in the Corelyzer visualization output.

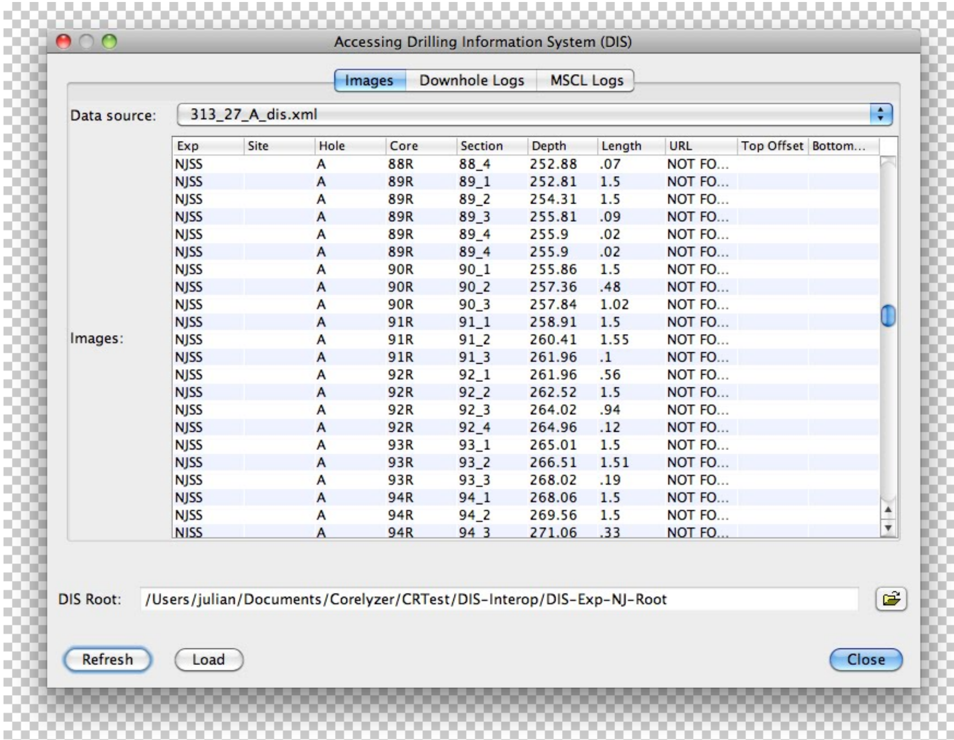


Figure 21. Corelyzer connecting to ExpeditionDIS database system supported by IODP-ESO and ICDP projects.

The similar user interface and interaction paradigm was also re-used in the DIS integration in IODP Exp. 313 New Jersey Shallow Shelf onshore science party at Center for Marine Environmental Sciences (MARUM), University of Bremen. This is good to users of the system because we established single or similar modality of accessing various remote data sources hosted by different drilling communities. Users do not have to learn different ways loading remote core data just because they were provided by different online databases. Additionally, it allows developers creating flexible and customizable data access, transformation and user interface templates that can be re-used when adding access to a new data management system is requested.

In Figure 22, it summarizes the evolution of the Corelyzer data input mechanism. The motivation started with solving individual scientist data management need in mind as experienced in the immersive training of the proposed methodology. It moved from local file access, customized web services plugin, and centralized collaboration server, to standardized data feed protocols commonly agreed upon by major community data repositories like IODP and ICDP. Such an application side evolution also encouraged the movement of service providers to make their services REST-based and furthered long-term developments in Scientific Earth Drilling Information Service (SEDIS).

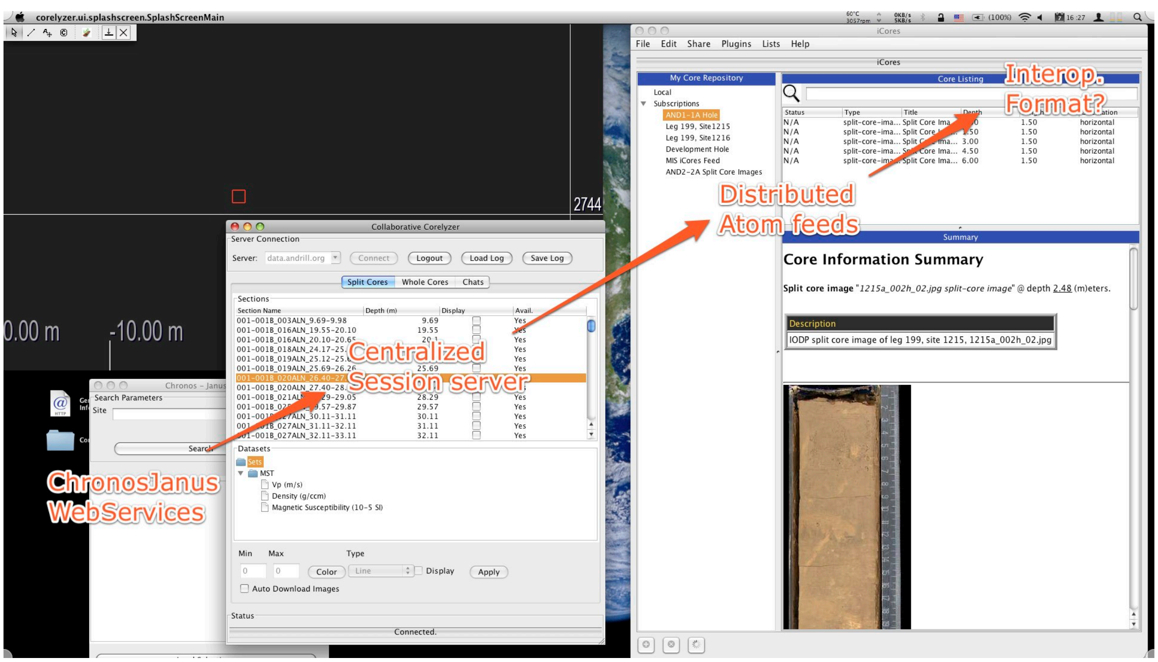


Figure 22. The evolution of inputs supported by Corelyzer. The data input support was designed with individual scientist's data management need in mind. It ranged from local files, customized service access plugins to a community-supported open standard format.

4.1.2.4 Barrel sheets output

The CoreWall system supports multiple ways of bringing core data into the electronic form. For output, scientists need a way to bring information with them when they are out in the field with no electricity. Barrel sheets also still serve as a standard way of communication and as official records among field geologists. Barrel sheets could also be used as a form of documentation that is ready for publication. Such discovery came from the early immersive training realization. Additionally, an identified common potential fear of geologists was that the proposed system would be a one-way black box system that could not get their data out as a familiar barrel sheet form. Such findings could be easily overlooked if just using other methods.

In the CoreWall system we designed a barrel sheet output option that will transform all activities including core section adjustment, logging data plot and user-generated annotations into a ready to print barrel sheet. The barrel sheet output uses a standardized HTML file format with adjustable Cascading Style Sheets (CSS) templates that can be customized to conform different expedition requirements. The core image along with sensor log data are formatted into the Scalable Vector Graphics (SVG) format that most modern HTML browsers support. The output file can be easily printed out as a PDF file ready for further editing or publication. An example barrel sheet output is shown in Figure 23.

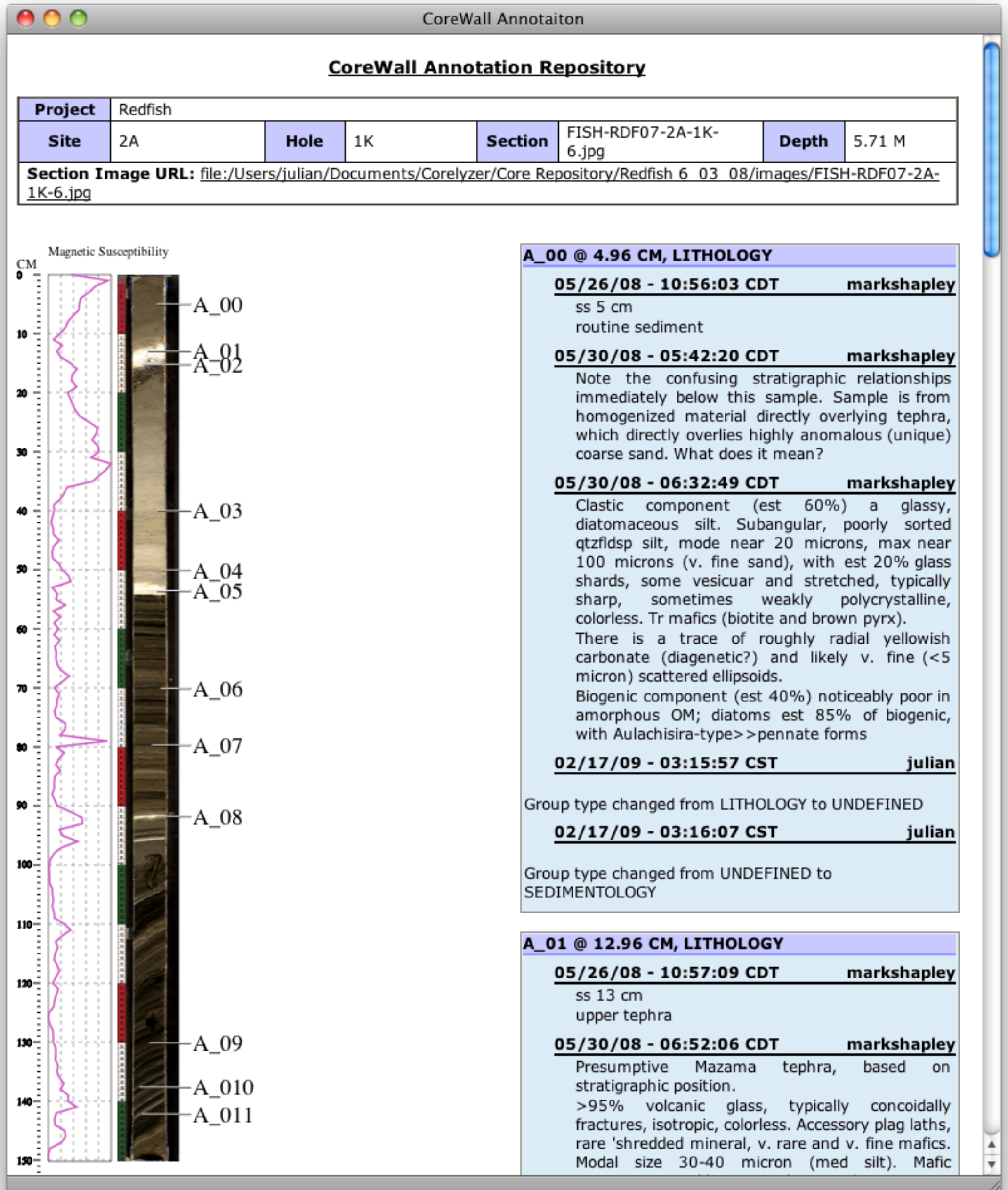


Figure 23. A barrel sheet output example. This is an example of a scientist using the CoreWall as a research note-taking tool. Top part of the sheet contains metadata about where the core section is from. On the left hand side, core section image and magnetic susceptibility plot are co-registered in depth with annotations highlighted. On the right hand side, it shows freeform notes threaded in time.

4.1.3 Customizable annotation framework

In the first design and implementation iteration, we built an annotation system [Rao06]. The annotation system allowed users to highlight features and jot down comments and ideas with the high-resolution core imagery as the context. The annotations were saved in HTML format in the file system. Because of the HTML format, an annotation can easily include hyperlinks to attachments such as images, videos, PDF documents, and even other documents of customized software tools in the local file system or on remote servers. With the collaborative server plugin, users located in different geographical locations could even share comments and discuss ideas asynchronously within the Corelyzer platform [Rao06]. Coupled with the “core archive” whole session export function, a self-contained research archive with multiple types of media content can be easily put together for remote scientific collaborations and classroom education material.

Individual researchers often used the annotations as a note-taking tool. They would select visual features on the image and write down research ideas just for his or her later review. The notes were just for him or her. In the Antarctica geological Drilling (ANDRILL) expedition in 2006, we learned that while individual researchers used “freeform” annotations frequently, not all expedition participants used it as a collaboration tool like we expected. Among several potential reasons, we focused on contrasting one heavy user’s use case with others’. The heavy use researcher’s main responsibility in the sediment core description was identifying clast sizes and distribution across all recovered split cores. It was a very specific task-oriented usage, unlike the more casual discussion threads that we imagined before the expedition. We later concluded that in expeditions like ANDRILL, each geologist had a very specific task during his or her shift. For casual activities, they would just use the most comfortable tool like E-mail instead of a then newly introduced and optional system (more deployment detail will be described in the next chapter). We needed to re-design the annotation system around supporting these different tasks.

We think that the methodology used played an important factor here. Before the first ANDRILL season, we did not know who were real users of the system because scientists and educators had not formed and worked together yet. We could only immersive within scientists in meetings and interviews. Additionally we used simulations to identify potential group interactions with the system. Retrospectively, it was a sign to inform the system developer to provide framework customizability and extensibility. With the rapid change in technology and uncertain future users, it could remedy some limitations of applying proposed methodology.

Several requirements had to be taken into consideration when we designed the new annotation framework. For tasks like clast analysis and sample requests, freeform text based input would increase the complexity of further analysis. Additionally, we identified that these goal-oriented tasks usually contain inherited structure and terminologies. We could increase the input efficiency and reduce data analysis complexity by harnessing such structures into the user interfaces. For data stores, we generalized the types of data that sample request and clast classification were required to collect and found they could be stored in the generalized “property-value” pairs easily. The new annotation framework contained three components:

1. A configuration file describing supported types of annotations, as shown in Table 4.
2. A customization dictionary file to define property-values pairs to be collected in each supported type of annotation, as shown in Table 5.
3. Optionally, a Java class (path) to provide customized annotation user interface, as a customized clast annotation interface shown in Figure 24.

Types of annotations could be turned on and off easily using the configuration files during release cycles and the Corelyzer system could be adapted for use in a more special purpose setting to support specific tasks. It could also be further extended to support customized annotation glyphs and maybe an automatically generated user interface skeleton based on a set of commonly used properties.

The re-designed annotation system with customized “Clast annotation” was used in the second ANDRILL season in Antarctica. It provided a customized input form user interface to easily capture clast observation and generated the same spreadsheet output for continuing the scientific analysis workflow. Using the proposed methodology with an immersive proxy, we could quickly re-position a special purpose functionality to satisfy a missed user requirement in a short turn around time. And lessons learned in the process inspired us to provide a more flexible framework to support similar future enhancements satisfying more potential users doing diverse tasks.

Table 4. Annotation framework configuration proper list file.


```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple//DTD PLIST 1.0//EN"
"http://www.apple.com/DTDs/PropertyList-1.0.dtd">
<plist version="1.0">
<dict>
	<key>name0</key>
	<string>Clast</string>
	<key>form0</key>
	<string>corelyzer.ui.annotation.clast.ClastInfoDialog</string>
	<key>desc0</key>
	<string>Clastology collection analysis</string>
	<key>dict0</key>
	<string>clast.plist</string>
	<key>name1</key>
	<string>Sample</string>
	<key>form1</key>
	<string>corelyzer.ui.annotation.sampling.SampleRequestDialog</string>
	<key>desc1</key>
	<string>Sample request information</string>
	<key>dict1</key>
	<string>sample.plist</string>
</dict>
</plist>
```

Table 5. An example clast annotation property list storage format.


```xml
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE plist PUBLIC "-//Apple Computer//DTD PLIST 1.0//EN"
"http://www.apple.com/DTDs/PropertyList-1.0.dtd" >
<plist version="1.0">
<dict>
        <key>grainsize</key>
        <string>fg</string>
        <key>trackname</key>
        <string>1</string>
        <key>shape</key>
        <string>sub-angular</string>
        <key>corename</key>
        <string>GLAD4-HST03-1A-3H-1</string>
        <key>quartzCount</key>
        <string></string>
        <key>pebbleCount</key>
        <string></string>
        <key>roundedCount</key>
        <string></string>
        <key>angularCount</key>
        <string></string>
        <key>intraclastCount</key>
        <string></string>
        <key>metamorphicCount</key>
        <string></string>
        <key>cobbleCount</key>
        <string></string>
        <key>texture</key>
        <string></string>
        <key>doleriteCount</key>
        <string></string>
        <key>lithology</key>
        <string>Quartz</string>
        <key>height</key>
        <string>2.1665645</string>
        <key>size</key>
        <string>boulder</string>
        <key>width</key>
        <string>4.6471634</string>
        <key>volcanicCount</key>
        <string></string>
</dict>
</plist>
```

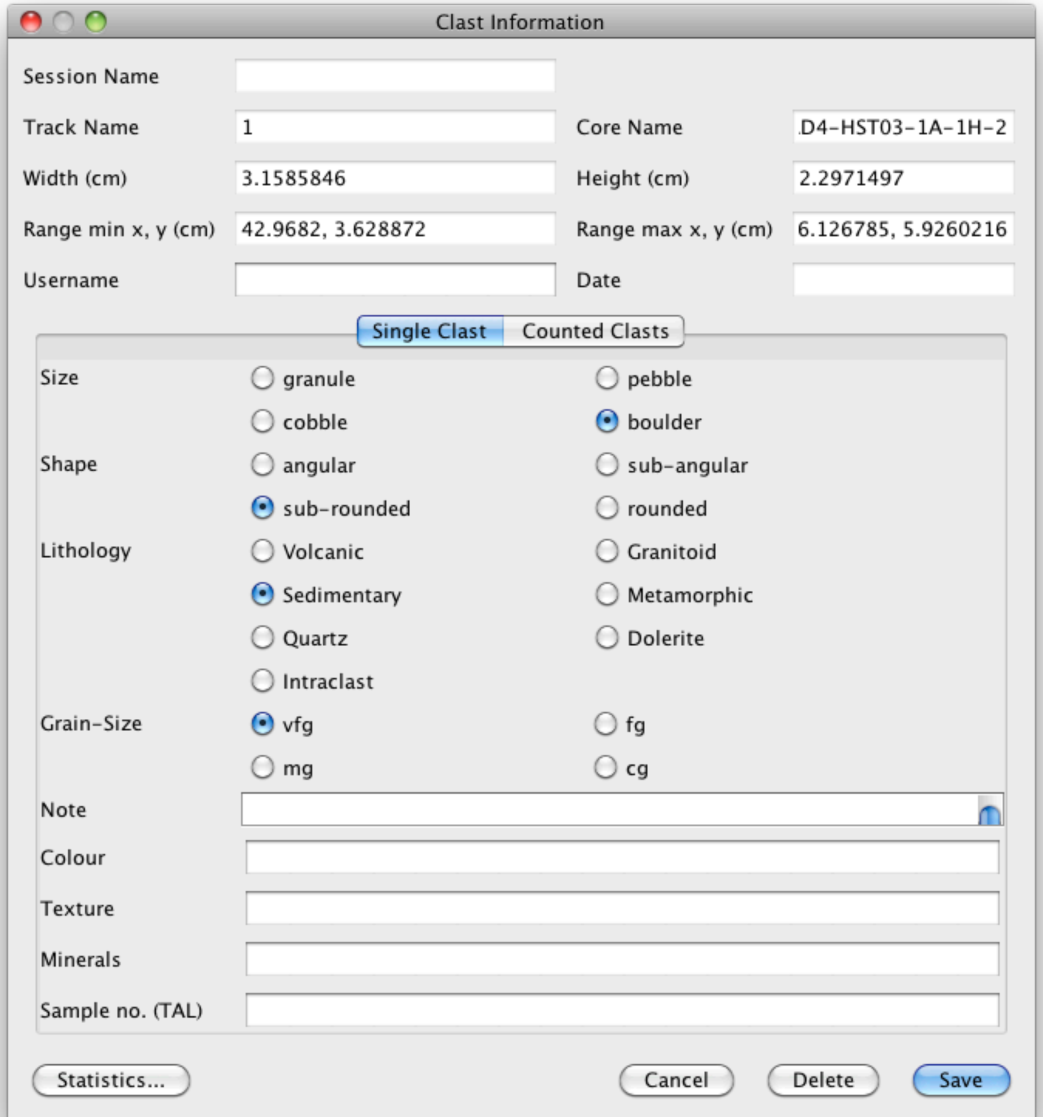


Figure 24. A customized user interface for clast annotation input.

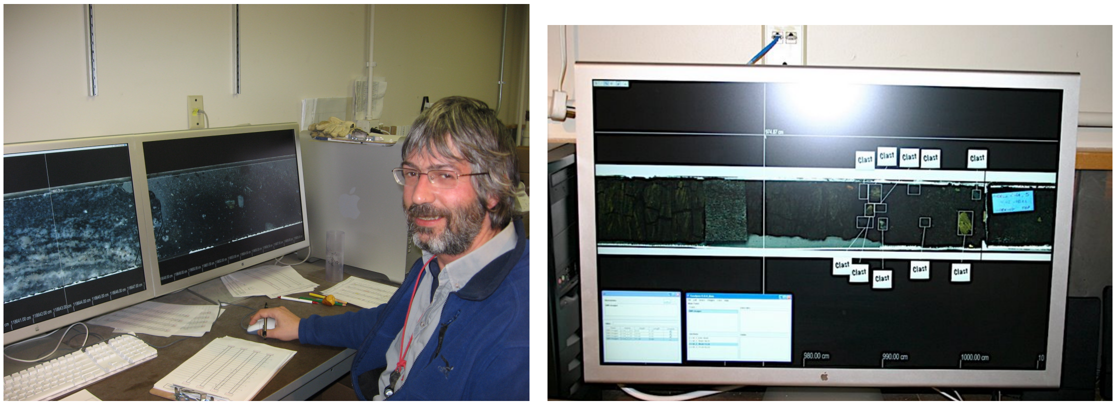


Figure 25. Re-designed annotation framework used in the field. Photo by Betty Trummel (left) and Ken Manhoff (right).

4.1.4 <u>Visual stratigraphic correlation using Corelyzer and Correlator</u>

As described in section 4.1, the CoreWall system consists of a customizable hardware setup and a software suite. The software suite includes two major pieces of software: 1. Corelyzer: a scalable high-resolution core visualization tool for initial visual core description and 2. Correlator: a visual stratigraphic correlation tool for reconstructing a complete stratigraphic record from sensor data extracts from multiple-hole cores.

In a typical drilling expedition, multiple core samples are recovered from a drilling site. Recovered cores are cut into sections and are run through an automatic multi-sensor track system to capture physical properties like P-wave velocity, magnetic susceptibility, density, and natural gamma-ray activity before they are imaged in high resolution. The data from these various sections must be composited and spliced together to reconstruct the complete stratigraphic record. Correlator, another CoreWall software tool, allows users to digitally correlate multiple-hole cores and restore any compression or stretching of the sediment core that may have occurred during the recovery process. Correlator works on numerical sensor data only and can be used to analyze petro-physical and paleo-magnetic sensor data in order to correlate adjacent holes and construct a composite depth scale for each drilling site. Before using the CoreWall suite, drilling sites and core labs relied primarily on numerical data and a photo editing tool to correlate and composite the cores. A typical simplified Correlator working style is, from top to bottom depths, identifying the same feature (a peak or valley) in two sensor plots and telling the software tool that these 2 features should actually be in the same depth. An example Correlator working session is shown in Figure 26.

One thing the old workflow could not do is using both the numerical data and the high-resolution core imagery together to construct the whole stratigraphic record. There are advantages to using not only the numerical data but also the imagery. One of the most significant advantages is resolution. Intuitively you may think that the numerical data is more precise and accurate, but there is actually more information contained in the high-resolution image in terms of samples per centimeter. A state-of-the-art high-resolution multi-sensor core logger (MSCL) will produce samples at the millimeter scale. Researchers rarely used them until recently. A common 254-dpi (dots per inch) high-resolution image scanner from three years ago can already easily produce 10 times the number of samples of sensor data. Also, identifying a visual feature in the split core images is much easier than identifying the plotting structure in different peaks and valley using human visual perception. The idea of combining two types of data for stratigraphic correlation sounded straightforward at the beginning. It took us few months discussing the idea with remote scientists. There were a lot of workflow details not just about the data itself, but also how the data were acquired, what kind of tools was used and how the data were named. Additionally, the user interaction of using two pieces of software together became crucial. We did not make much progress until sitting with a real "stratigraphic correlator" in one of the U.S. JOIDES Resolution scientific vessel port calls. The proposed methodology let us be empathic with real users in an authentic work setting doing real task to identify users' real needs and design a system that could help users do their research.

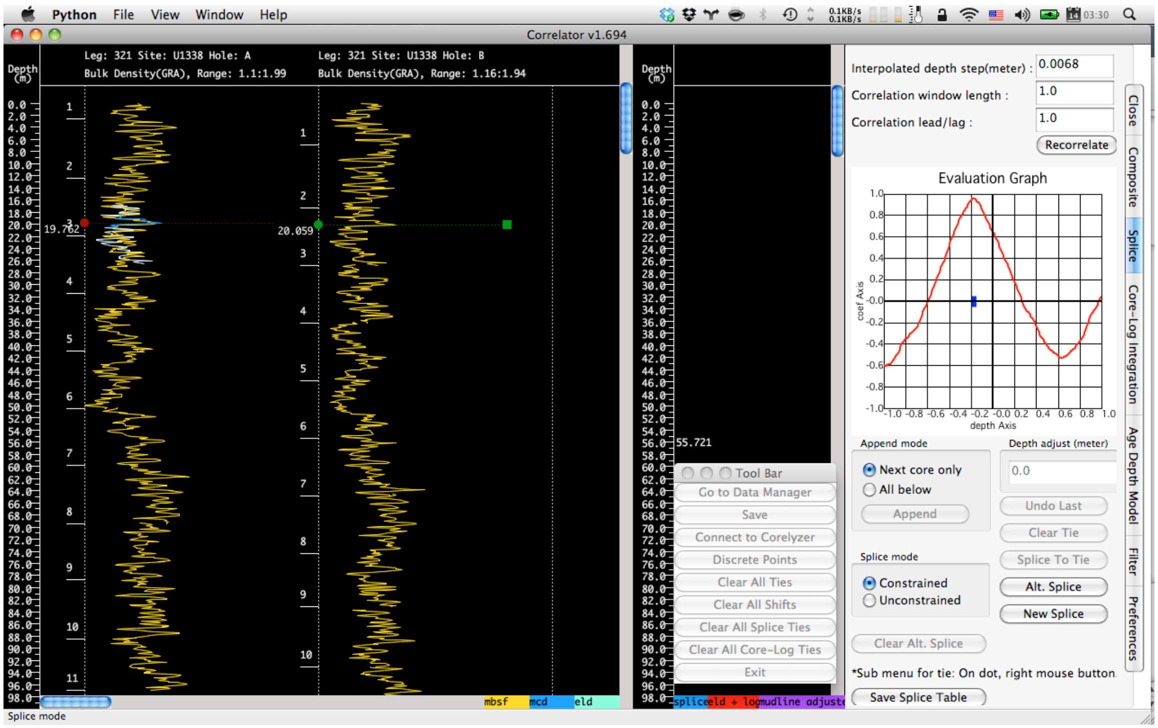


Figure 26. A Correlator session screenshot. Two gamma ray attenuation (GRA) data plots from two different holes were loaded in the left-hand-side. The user could pick feature corresponding points from each of the plot denoting that they were the same feature. The right-hand-side similarity graph could be used to evaluate how good the correspondence is as moving these two points' positions along the depth.

To make Corelator and Correlyzer work together a remote control architecture was designed and integrated into Corelyzer. Corelyzer exposed a subset of its functionalities with a stateful TCP socket connection server. The remote control server used the "Thread Pool" design pattern. In its implementation there are multiple thread pools in place and each incoming action command submitted from the client would be wrapped into a thread pool worker and committed for execution. The worker wrapper object would also be tagged in different types depending on the types of action to perform. This separated input/out-bounded actions from view oriented actions to avoid input/output actions blocking user interactions with the system. During a Correlator-

Corelyzer collaboration session, the user can choose to connect to the running Corelyzer instance from the Correlator. Then the moment on, each proper user actions in the Correlator will send corresponding action messages to the running Corelyzer instance. For example, when the user changed the viewing range in Correlator, Corelyzer will change its viewing range correspondingly and put the data of interest in the central location of the screen. When the user make a correlation tie between two cores in different holes, Corelyzer will cut at corresponding points of the core images and put the composite core into a separate track showing where the core segments came from using an arrow segment from parent to child core sections. A screenshot of an IODP JOIDES Resolution researcher using Correlator with Corelyzer is shown in Figure 29.

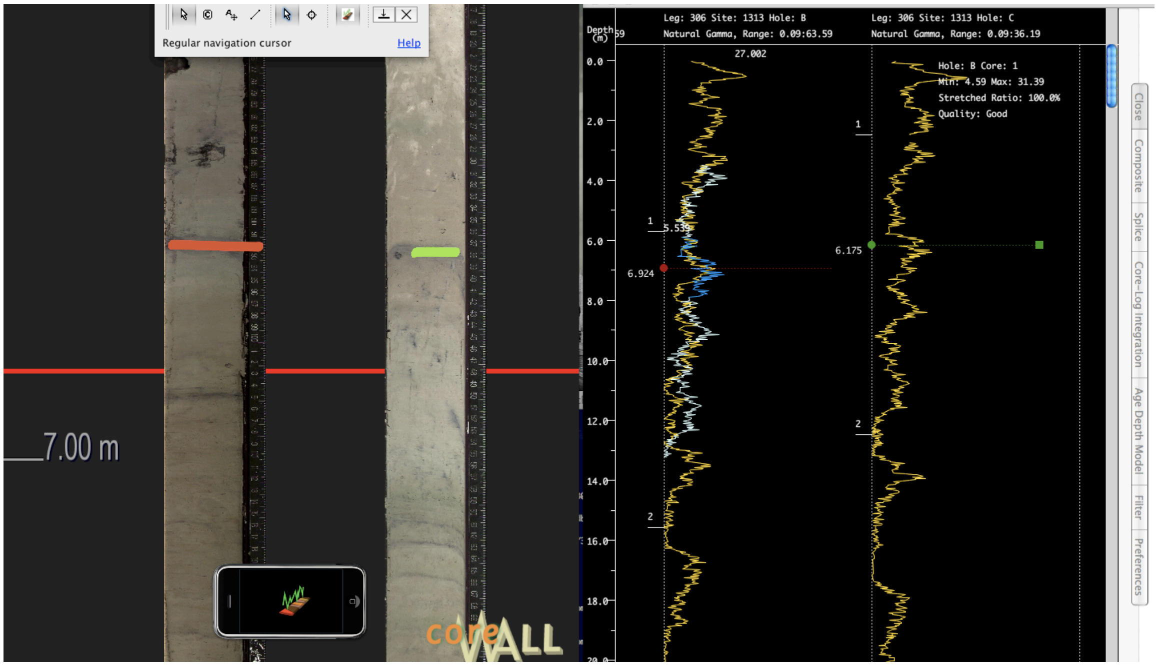


Figure 27. Using Corelyzer (left) with Correlator (right) to do visual stratigraphic correlation. A scientist could initiate the connection to Corelyzer from Correlator. Correlator would pass core data information to Corelyzer so high-resolution core images could be loaded inside Corelyzer. The scientist could then use visual features of core images to assist tie points correlations in the Correlator.

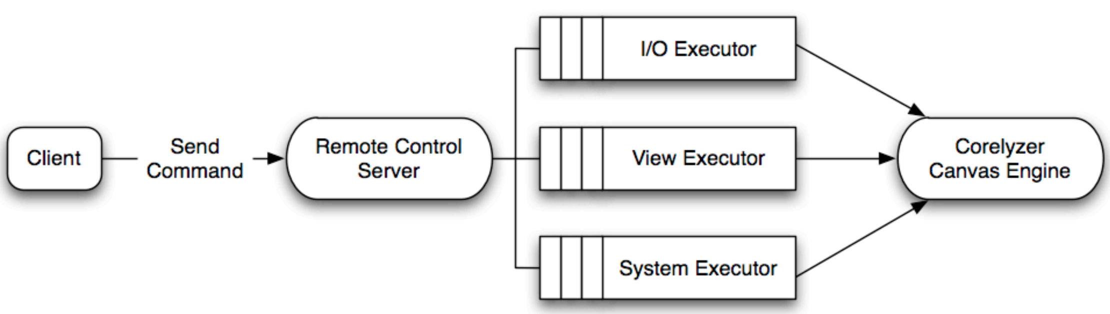


Figure 28. Corelyzer remote control server thread pool architecture

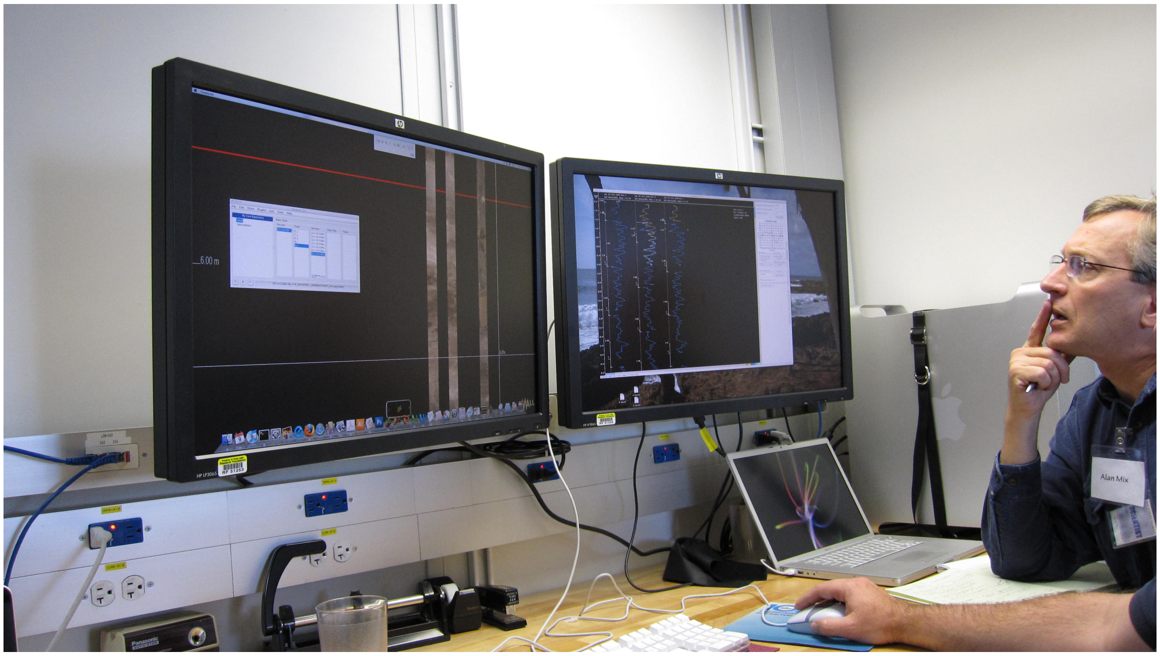


Figure 29. Researchers used the CoreWall for visual stratigraphic correlation on US. Scientific Drilling Vessel JOIDES Resolution.

4.2 Hands-on Automated Nursing Data System (HANDS)

The standardization of HANDS affords more possibilities than other prior handoff support systems mentioned in the last chapter. It has been used to collect multi-year and multi-institute care plans that consist of more than just verbose texts. With help from statistics and data mining experts in the collaboration team, we have the capability to provide "on the spot" decision support using historical care plans. Statistics and data mining experts can view the problem from a computational perspective and employ multiple methodologies to analyze and generate secondary derived data results. The medical researchers use their knowledge to interpret and verify the real meaning of those results. User interface and visualization researchers will also be needed to design ways to present verified information to real users in medical hand-off settings with iterative usability studies. Here we present the preliminary design and prototype implementation of the enhancements to the original HANDS to afford medical hand-offs and administrative decision support for the on-going collaboration project.

4.2.1 Intervention and diagnostics suggestion alert

If we treat a patient's care plan as a structured NANDA / NOC / NIC (Diagnostics / Outcomes / Interventions) combination, we can use it as an instance template to find care plans with the same NANDA and NOC combinations from the HANDS database historical records. Applying statistical analysis methods with matched care plans could be used as the basis for providing future intervention suggestions during hand-offs. Using such strategy, the data mining team looked specifically at end-of-life (EOL) patients' visiting episodes in the historical dataset. The statistical results shown in Figure 30 would allow us to evaluate the pain management performance of this unit and also benchmark an end-of-life patient.

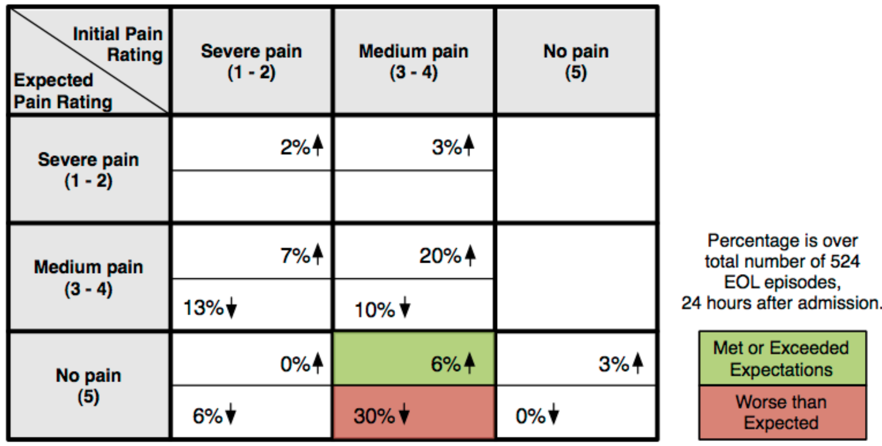


Figure 30. A snapshot of percentages of EOL patients' pain level outcomes based on the initial and expected pain ratings 24 hours after admission [Khokhar11]. For example, if the patient's initial pain rating was medium (3-4) and was expected to be no pain (5), 6% (31.44) of the total population (524) had met or exceeded expectations and 30% (157.2) turned out having worse than expected outcome.

In Figure 31, the current patient's care plan was compared with historical care plans and the system found that in a significant number of matched cases, adding "NIC: Positioning" intervention tend to yield better "NOC: Pain level" outcome. The receiver in the hand-off could consider suggested interventions to provide better quality of care. This would be very difficult for conventional pure text-based systems to implement.

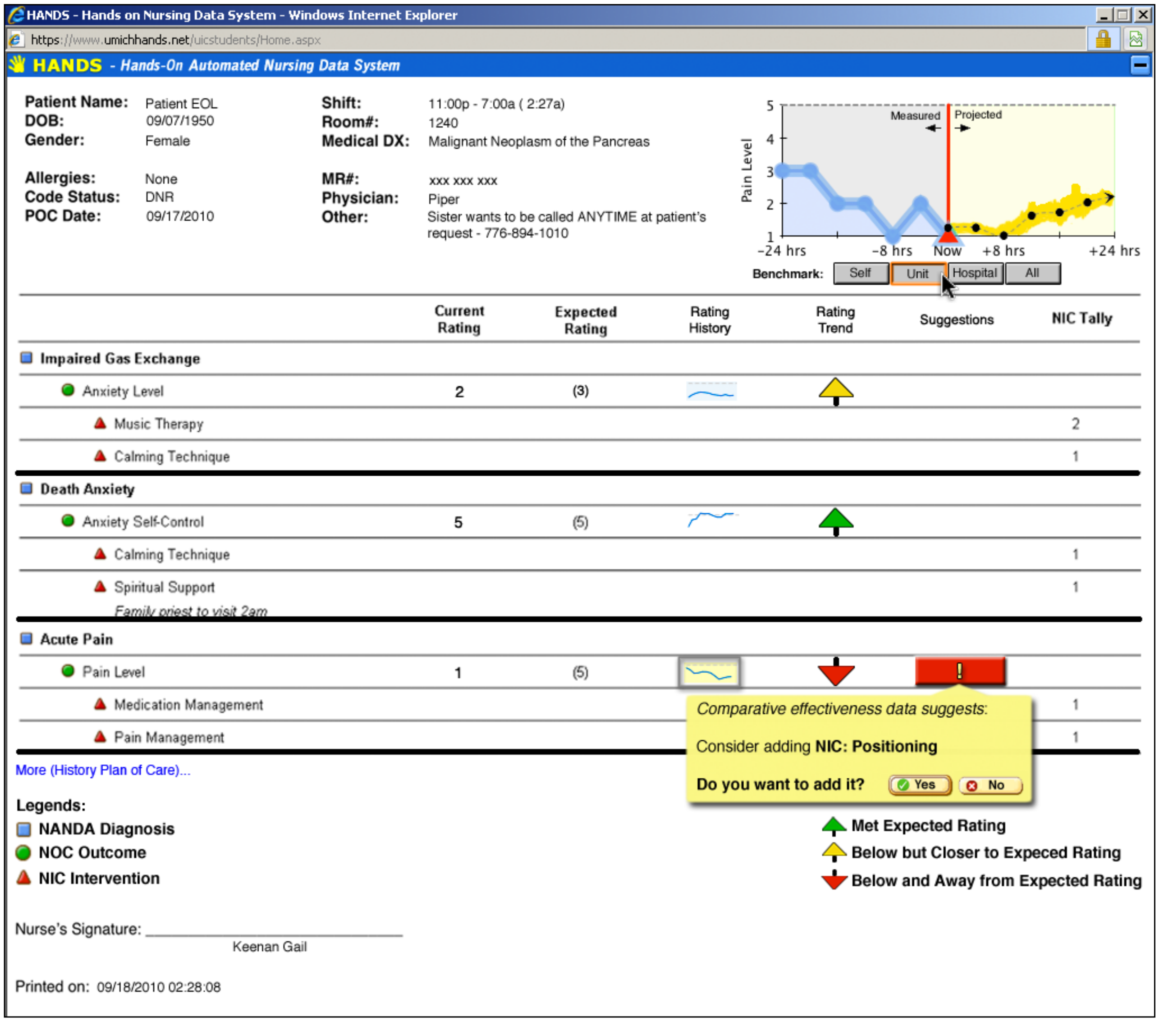


Figure 31. Intervention suggestion alert

Similarly, we can modify the matching criteria to support different suggestion scenarios. Figure 32 is another example for care plan suggestions. In this example, the matching criteria are present diagnostics (NANDAs) in a patient's care plan. A pre-processed rule concluded from the collaboration of statisticians and data miners could generate the suggestion that the patient's pain (NOC outcome) was not treated effectively.

These recommendation rules could be further weighted and filtered based on whether they were really selected by the hand-off personnel. This would be as another mechanism to provide the users with potential mitigation plans for “what-if” scenarios.

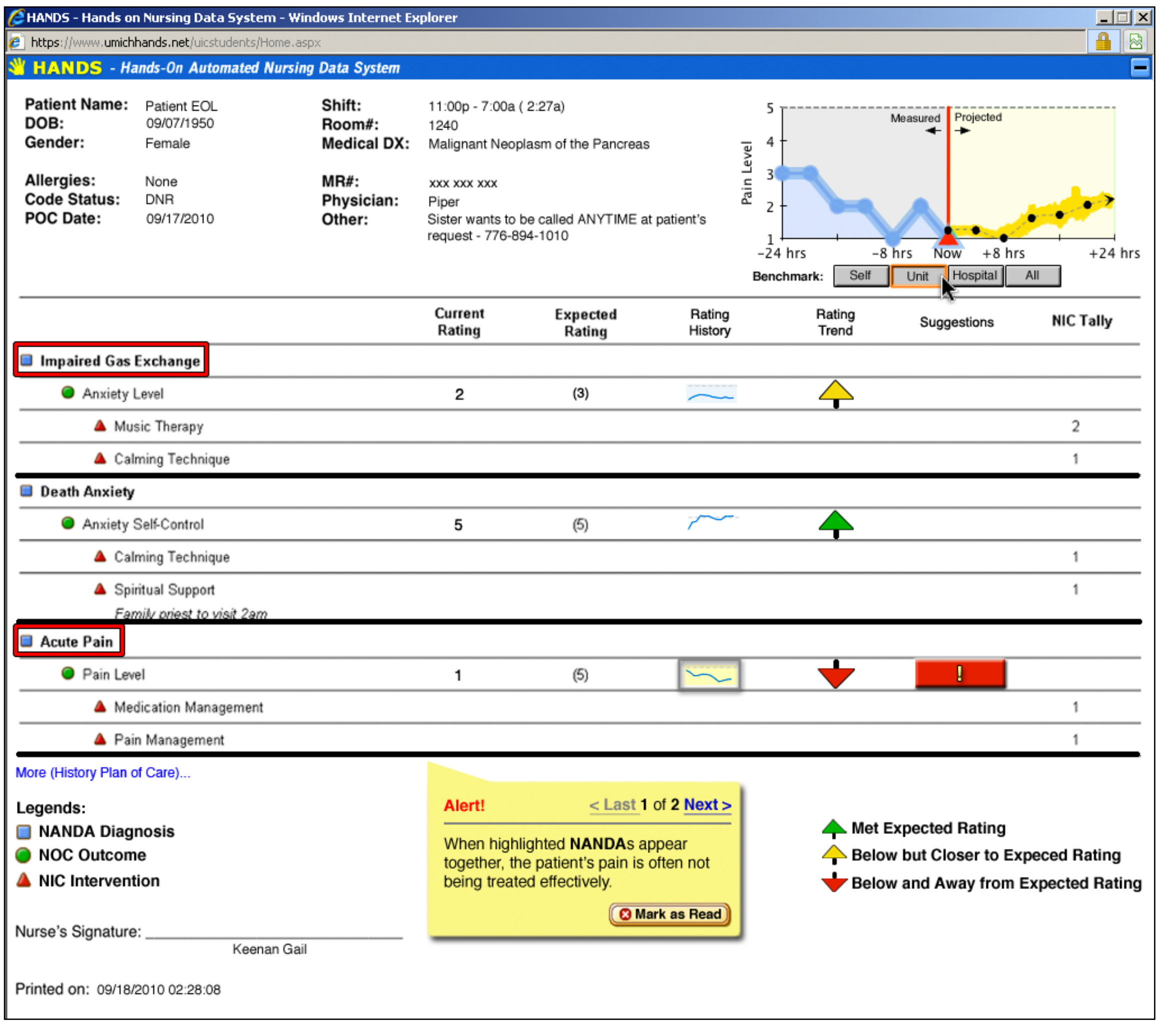


Figure 32. NANDA combination alert and suggestions

These mockups were created using partial immersive empathic methodology because of several constraints in the actual settings. First, the original HANDS were developed by an outsourced vendor. It became difficult to modify and add enhancements onto the system directly. Secondly, patients' safety and quality of care in the actual medical handoff setting in clinics were considered top priority. It was inherently difficult for healthcare administrations allowing outsiders without substantial healthcare training participating and immersing themselves in the settings. This showed some limitations of fully practicing the proposed methodology in certain domains like healthcare medical settings. On the other hand, we still worked closely with healthcare researchers including medical doctors and registered nurses to design and develop static mockups and interactive prototypes during each group meetings. This ensured we could still receive representative users' feedback and had the improved prototype system ready for future user studies within clinic settings when the moment comes.

4.2.2 To-do note and multiple patient list view

The original HANDS were developed with nursing hand-off in mind. To support more diverse hand-off practices, we interviewed physicians and compared other interview results from the literature [Eaton04][Flanagan09]. We took the common requests that physicians and residents thought would be helpful for their hand-offs and added two additional user interface enhancements to the original HANDS design. As described in the last chapter 3.2.3.3, the modifications suggested here are based on prior literature review and interviews with nursing and physician researchers in the university instead of the proposed immersive empathic design method. The indirect data and information collected are not from real users within domain settings.

Proposed enhancements to current HANDS include: 1. Multiple ways of listing those patients those need the physician or resident's attention in this shift. A physician can view the list as two groups: his or her own patients, and patients that he or she needs to cover in his shift. Furthermore, the list can also be sorted by geographic location in the hospital so the physician can attend to his/her patients' needs more efficiently. 2. A short to-do note attached to the care plan at each shift hand-off. The short note would contain reminders from previous shifts and also include report links (for example lab testing results) that would be available during this shift. From interviews and literature surveys we believed that these would be indispensible to extend HANDS to a broader user base.

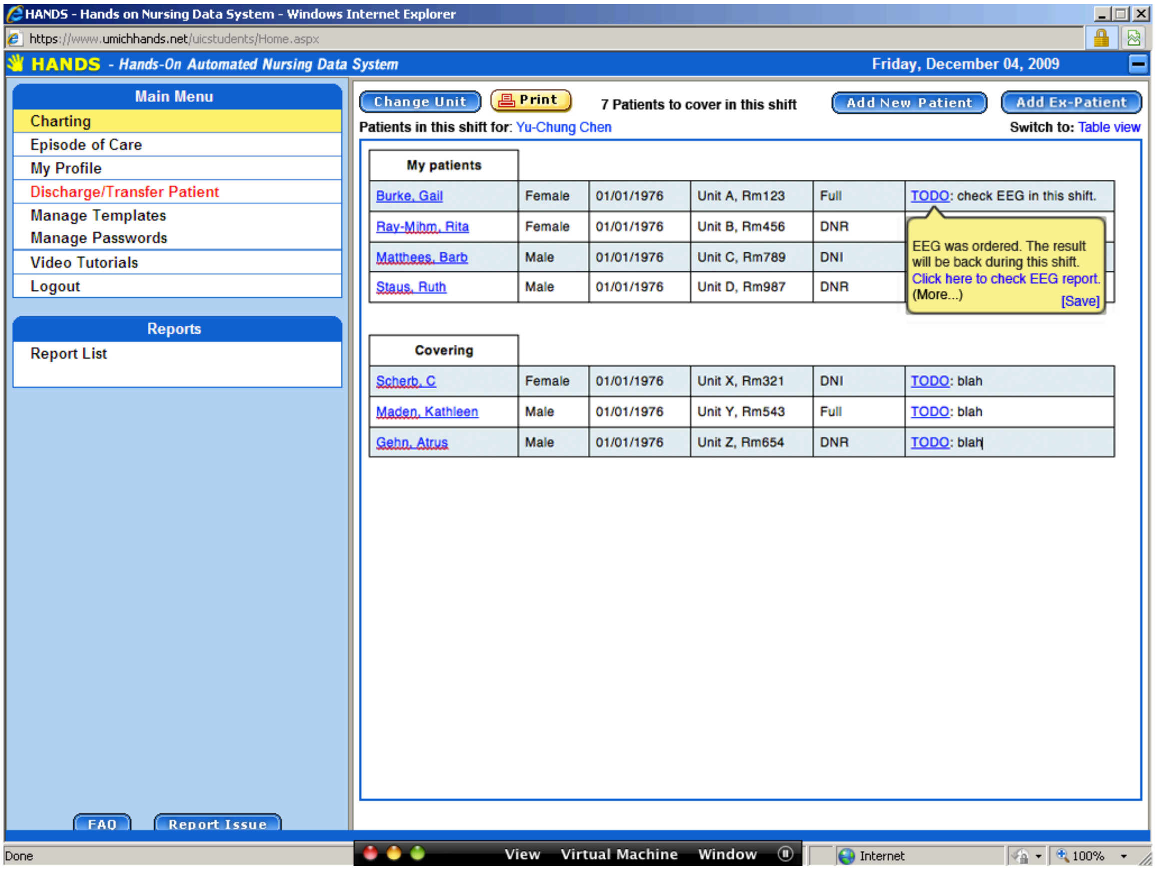


Figure 33. Different patient listings to satisfy physician and resident's rounding preferences

4.2.3 Administrative and policy decision support

Aside from enhanced hand-off support, the collected data and analysis results could also be useful for medical administration and policy makers. In Figure 35, all care plans in medical unit over a year long time were shown in NOC-NIC (outcome vs. intervention) 2D scatter plot. The size of the dot shows the number of care plans with a given NOC-NIC combination. The color of the dot was mapped to the degree of how well the intervention improved the outcome. Interactive parameter controls would allow policy administration personnel to get an overview from the high-level big picture to specific categories of NOC-NIC distributions. The prototype web-based visualization service was implemented using modern Web 2.0 technology including AJAX, JSON and generic Java application server model (so it can be deployed to a standard JSP container server and Google App Engine), in order to be portable and securely delivered statistics information over the network.

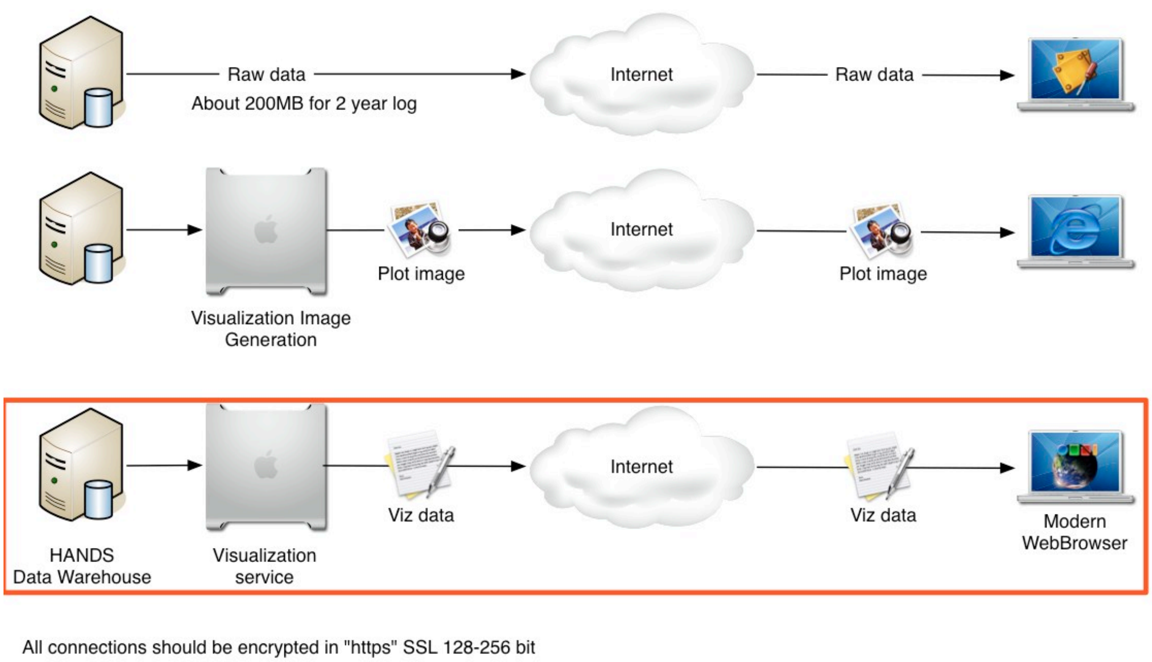


Figure 34. The architecture of a secured web-based visualization service for medical decision support.

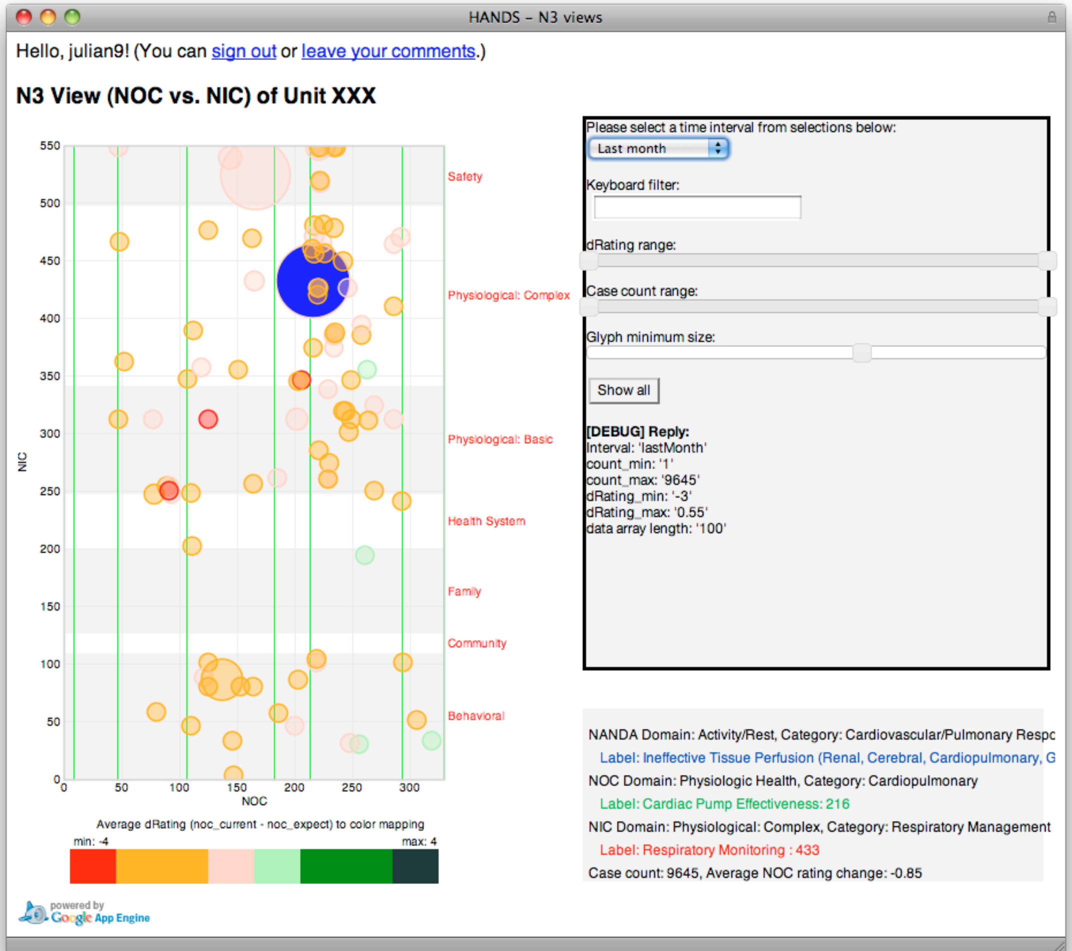


Figure 35. The overall NOC-NIC distribution scatter plot over secure web service. This visualization shows the number of times an Outcome (NOC) vs. Intervention (NIC) used (as dot size) in a unit over a selected period of time. Colors are used to show whether an intervention makes the outcome improving or becoming worst.

All results and visualizations from the described abstract model and computational methodology will need additional close collaboration and iterative evaluations involving front line users, domain experts and computer scientists. Medical domain experts will need to interpret and review the correctness and the true semantic meaning of numerical outcomes and suggestions before putting them into the automatic production process as shown in Figure 11.

5. DEPLOYMENT EVALUATION

Chapter 5 will describe multiple deployments of the CoreWall system and using user feedback and adoption to evaluate whether the system designed with the proposed immersive empathic method met the users' need. Figure 36 below shows the overall timeline of expedition activities and the different methods used.

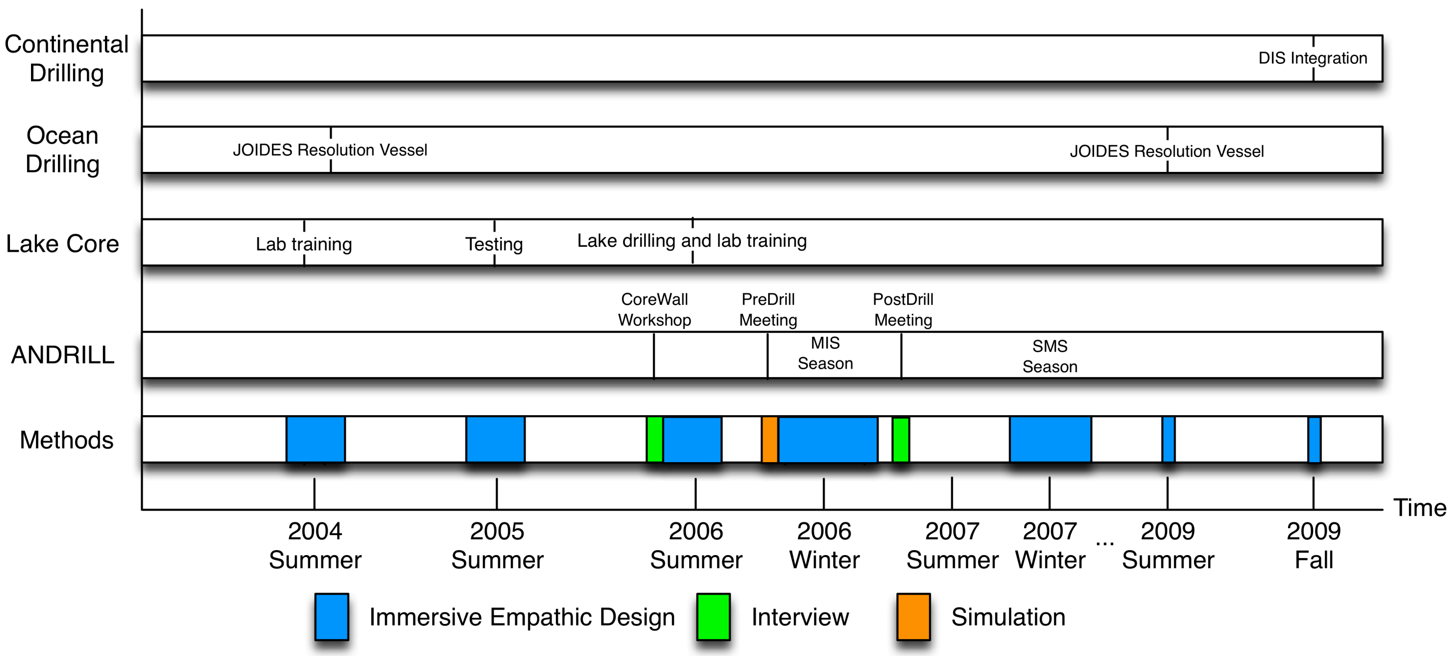


Figure 36. Development and expedition activity timeline

5.1 Polar Drilling Deployment

After we designed the CoreWall system for LacCore scientists, we wanted to see if such a setup developed through an "immersive empathic design" approach could also be beneficial and sustainable in a different core drilling community.

"Antarctic geological drilling (ANDRILL) is a multinational collaboration comprised of more than 200 scientists, students and educators from Germany, Italy, New Zealand the United Kingdom and the United States to recover stratigraphic records from the Antarctic margin" [ANDRILL08]. In the Antarctic summers of 2006 and 2007 (also see the overall deployments timeline in Figure 36), ANDRILL drilled in the McMurdo Ice Shelf (MIS) and Southern McMurdo Sound (SMS). Each season ANDRILL planned to recover more than 1,000 meters of cores that can be dated back to 40 million year ago. Scientists are interested in cores from Antarctica because all of Antarctica has long been covered with ice, and the continent below the ice could be one of the most un-disrupted areas that contain answers to questions about environmental changes, paleo-glacial activity and paleo-climatology.

In May 2006, around two years since the first developer immersed in LacCore receiving core technician training, we presented the CoreWall system to core drilling communities including LacCore, the Antarctica geological Drilling project, the International Continental Scientific Drilling Program, the Integrated Ocean Drilling Program operators from Japan and Texas A&M University at the CoreWall Workshop held at the Joint Oceanographic Institute (JOI) office in Washington D.C. in order to get community feedback and potential feature requests for the first public released CoreWall system release. Even though the majority of the workshop participants were geologists, the CoreWall system developers could easily immerse themselves and join the discussion. Having shared the hands-on coring experience from the proposed methodology was one major reason for this. That experience was constantly referenced, as context for the discussion, multiple times during the introduction among communities in the workshop.

The workshop took place only a few months before the ANDRILL expedition began. We conducted interviews with the staff scientist during the meeting in order to understand the specific user needs and the workplace scenario in order to seamlessly integrate the system into their workflow in Antarctica. The method proposed in this dissertation was not directly used here because this was the first time the ANDRILL management office was planning a real expedition involving more than a hundred technicians, geologists and educators coming from multiple nations around the world. They did not yet have an established "ANDRILL core drilling workflow". Prior LacCore training experience and established domain knowledge and vocabulary really helped the developers be empathic with the researchers about the challenges in the upcoming first ever ANDRILL MIS expedition. One advantage of being a system developer with deeper domain knowledge was that we could be involved in ANDRILL's workflow planning and we had the ability to show what was possible and could be done in time to afford potential unknown needs of the first ever ANDRILL expedition.

We demonstrated the existing CoreWall system and discussed the planned ANDRILL workflow. One of the conclusions was that the CoreWall system should minimally interfere with the other existing scientific activities and practices. We agreed that CoreWall could be used in several places without causing too many adverse impacts.

1. In the core description team: A CoreWall workstation would be used in the core description process (mostly night shift) to assist the investigation of specific sections of the core acting as a digital microscope.

2. In the morning progress meeting and public discussion area: During the morning meeting, a large tiled display CoreWall system would be placed in a common area to encourage and facilitate group discussions.

3. In each member's laptop: Project members who are interested in the digitized dataset could access the data freely via wireless network with around 12 hours delay after the cores were recovered and shipped back to the Crary Laboratory in the McMurdo station. They could download the dataset to their personal laptop and were encouraged but not forced to install the Corelyzer software for their own offline individual research.

Based on the staff scientist's interview suggestions, we further enhanced the annotation functionality and persistent data and knowledge distribution system [Rao06]. The system was verified in the pre-drilling meeting held in the ANDRILL management office in Lincoln, Nebraska in September 2006, just weeks before the real deployment.

During this meeting we used the "simulation" technique along with sedimentologists to simulate the workflow as if they were in the Antarctica. The main purpose for the simulation before the first deployment was that this group of scientists was going to be the major users of the system. We wanted to make sure they would share a similar user experience as the LacCore scientists on the task of visual core description. We conjectured that once we provided easy access to high-resolution datasets, the members in the ANDRILL expedition team might want to utilize the annotation feature to share their ideas and comments right on top of the context of core imagery.

In order to properly support the expedition under that extreme spatial constraint (geologists in the Antarctica), we adapted the "embedded proxy" approach. While the CoreWall development team remained in North America, there was a computer scientist working with ANDRILL scientists down in Antarctica during the expedition season. He worked with the scientists in the same location and he acted as communication proxy for immediate support. The whole McMurdo station shared one single Internet connection with bandwidth about 1.5Mbits link. It was often busy during its daytime because more people were using it. The proxy worked and the sedimentology core description team mainly worked night shifts in the Crary Laboratory at the McMurdo station, which overlapped morning in the central time zone. The CoreWall developers could have a synchronized online text chat with the proxy about issues and potential features the geologists desired. Two CoreWall systems were constantly used throughout the four-months season.

Figure 37. ANDRILL sediment description team simulated the description workflow in the ANDRILL pre-drill meeting held in the ANDRILL management office in Lincoln, Nebraska in September 2006.

5.2 User Feedback

Two multi-displays workstations and several laptop-based CoreWall systems were used during the three months duration of the first ANDRILL expedition in late 2006 to early 2007. During this period, we received the following messages (among others) sent from McMurdo station in Antarctica.

"... Corelyzer gets quite a bit of use especially during the night. The sedimentoligists and the clastologist use it a lot when they are logging the core. It also gets a fair amount of use during the morning when people come in and want to see the upcoming core." Josh Reed, ANDRILL IT Manager, November 15, 2006

"... FYI Corelyzer is being utilized extensively. People are very impressed with both Corelyzer and PSICAT. All is working rather well." Dr. Richard Levy, ANDRILL Staff Scientist, November 22, 2006

"... Corelyzer is awesome. Only rave reviews from users down here. Some suggestions to improve (added capabilities) but it really has been used a lot on a daily basis. ... People are very happy with Corelyzer." Dr. Richard Levy, ANDRILL Staff Scientist, December 12, 2006

The CoreWall developer participated the ANDRILL post-drilling meeting held at the Florida State University, Tallahassee Florida, whose core repository housed the ANDRILL cores, in April 2007. Even though we did not require or force ANDRILL users to use the CoreWall software to access ANDRILL data, there were still more than 25 participants indicating that they were still using the software on their laptops and were considering building a desktop CoreWall hardware with multiple display outputs.

While the feedback from users was positive throughout the season, we found that the annotation function was not fully utilized as we expected. After further investigation, we found that we overlooked two important factors. The first reason was that there were other systems that users used during the expedition sharing similar annotation functions, and scientists still tended to exchange ideas either with face-to-face conversation or through emails. The second reason was more related to the organizational composition of the expedition team and "information distribution pattern". The project included not only core geologist but also schoolteachers. During the expedition period, only small portions of the members are data “publishers”. Most of the members in the team are data “subscribers”. Major data propagation mostly happened in one direction.

This might be due to: 1) This is the first of its kind expedition for ANDRILL. There was little prior reference experience. As described earlier, the ANDRILL management office could define workflow processes based on their previous expedition experiences in different settings. People might develop different “practices” as the expedition proceeded. Without the system developer there as such practices were forming, we lost the opportunity of changing the system to afford such practices on the spot. The proxy could communicate some observations but it was more indirect and tedious to update the system remotely. 2) Different methods were used to design different parts of the CoreWall system. The original CoreWall system developed using the immersive empathic design method was mainly to be used by users doing the initial visual core description task. It worked well in the sediment description team. Instead of immersive empathic design method, we gained our big picture and detailed workflow knowledge about ANDRILL solely based on interview and simulation observations right before the actual deployment. One fundamental difference was that we had the actual description team as our target users doing tasks very similar to LacCore users, but it was more conjecture-based for the potential use case of the annotation system. The intended collective usage model was not based on a concrete context. This could indicate one potential benefit of having the system developer immersed within the domain setting, he might be able to change the implementation on the spot to afford the newly formed practices.

However, one specific usage of CoreWall caught our attention. We found that Dr. Franco Talarico from the University of Siena, Italy used the system extensively. He is the clastologist in the ANDRILL project. Clasts are rock fragments or grains resulting from the breakdown of larger rocks. A clast can scale from 2-4 mm to more than 256 mm. They are both time and labor intensive to identify from a core's physical scale. “In all sediments clasts are essential tool to reconstruct the provenance of debris supplied to a subsiding basin through erosion and transport processes in nearby topographic heights”, said Dr. Talarico. In the past, in order to calculate the clasts distribution, Dr. Talarico had to look at the physical cores and then hand-draw them on pieces of paper meter by meter in order to properly classify and count them in terms of size, shape, and lithology. In the 2006 ANDRILL season Dr. Talarico used CoreWall to zoom in and draw the same diagrams on paper from the core images as soon as they were available. When the actual core was in the laboratory for description, he verified what he had drawn with it. The capabilities of the CoreWall allowed him to scale high-resolution core images to fill the display space with full details. That made his work easier. At the end of the 2006 expedition, more than 1,200 meters of cores were recovered. Laid end-to-end, Dr. Talarico's hand drawings stretch out of his office and down the hallway as shown in Figure 38.

Figure 38. Dr. Franco Talarico and his clast drawing sheets. Photo taken by Joshua Reed, ANDRILL

We took the idea back to the generalized workflow context we learned in the immersive hands-on experience and realized that there might be other specific tasks similar to the use case of Dr. Franco. We refactored the static freeform annotations into a customizable annotation framework that supports multiple types including freeform, clast, sample request and generic property-value pairs. This way the CoreWall system could be customized to meet users need depending on what task they would like to complete.

In the 2007 ANDRILL season, we enhanced the CoreWall for Dr. Franco based on the customizable annotation system. Instead of a “freeform” annotation provided for idea exchange and discussion, we proposed a "structured" annotation so users could easily input property values pairs based on a pre-defined dictionary. The CoreWall allowed him to examine and circle clasts on the high-resolution core images directly as annotations. The system would mark, record and generate a quality spreadsheet report, which saved not only Dr. Franco's time, mental loading, and space. The structured style annotation system could be potentially a preferable interface to provide quality control over user-generated contents in scientific applications.

Because of this usefulness, in the second season, ANDRILL increased the number of CoreWall workstations from two to six. Dr. Franco received a dedicated CoreWall workstation for his research and there was even one CoreWall system setup at the drill site to support on-the-spot drilling decisions.

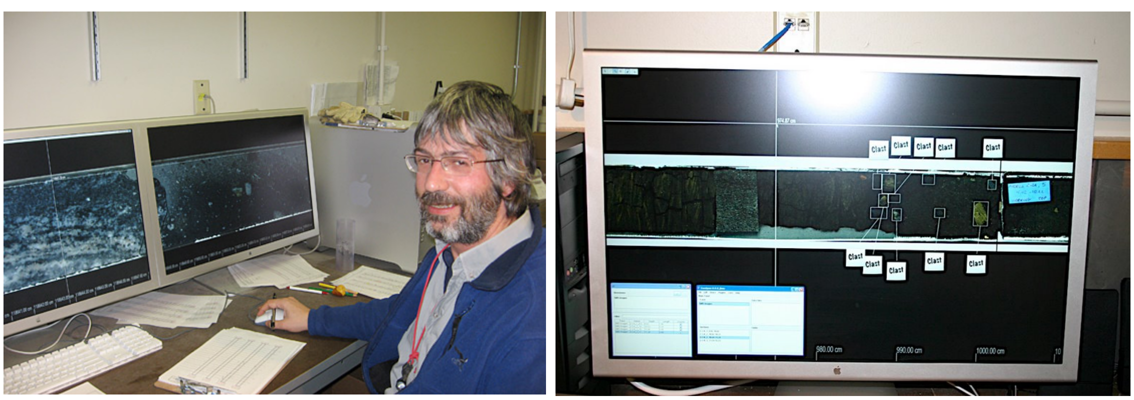


Figure 39. Dr. Franco Talarico in front of the CoreWall setup in Crary Lab in the U.S. McMurdo station, Antarctica. Photo taken by Ken Manhoff (right) and Betty Trummel (left).

5.3 IODP US JOIDES Resolution scientific drilling vessel

In 2009, the system was further connected with Correlator, the stratigraphy correlation tool, and integrated with the on-ship data management system LIMS as described in the last chapter. The integrated system was deployed on the renovated U.S. JOIDES Resolution scientific drilling vessel to support on-ship scientists' visual core description and stratigraphic correlation requirements. The vessel was where the first CoreWall developer used the immersive empathic design method to learn about geological core drilling while transiting from Panama to Canada five years ago. The renovated core description area in core laboratory on the vessel was almost designed around the CoreWall system's multi-display hardware for high-resolution core data visualization. The system could make use of not only numerical sensing data but also the high-resolution images. It allowed geologists intuitively analyzing and correlating adjacent holes and constructing a composite depth scale for each drilling site.

Figure 40. CoreWall systems used in the next generation U.S. JOIDES Resolution scientific drilling vessel.

If we combined evaluation expedition deployments described above with CoreWall system's implementation evolution discussed in chapter 4, the summary and timeline are shown in the Table 6 and Figure 36.

Table 6. CoreWall major functionalities developed corresponding with user expedition events.

Function	Usage	Importance	Application
Tiled-screen setup	Side-by-side as the core table	Similar core description setup	Initial LacCore adoption
Level-of-Detail, out-of-core image rendering	Scale to massive datasets	Smooth user interactions	LacCore and ANDRILL prototype
Annotation system	Distributed rich media core annotations	Distributed core annotation and sharing	ANDRILL 2006
Customizable annotations	Task-specific annotations	Assist users accomplish tasks easily	ANDRILL 2007
Corecast feed management	Data source connectivity and management	More flexibility and reaching for more communities	ANDRILL 2007 & accessing IODP legacy data
Visual core correlation	Core segment correlation	Restore more precise depth/age scale	IODP JOIDES Resolution expeditions

5.4 Evidence

In this section, we will present several pieces of evidence we observed showing the wide acceptance and success of the system designed using the proposed immersive empathic design practices.

1. Scientists want to use it.

Aside from the feedback such as those from ANDRILL users described above, the ANDRILL staff scientist also said that he felt proud that each of the participating countries left Antarctica with a detailed copy of all digitized core data and the CoreWall software in both seasons. Without utilizing these high-resolution digital core data, scientists would have to wait for another four months waiting for the shipping of physical cores from Antarctica to the core repository in the Florida State University, Tallahassee, Florida. This allowed them to carry on their work right after leaving the McMurdo station. That was never done before. In the first post-drilling meeting held in Florida State University, more than 25 members were still using the CoreWall software on their laptops and wanted to setup CoreWall stations in their home institutions.

In August 2010, more than 20 active users around the world came to the CoreWall Users Workshop held in the LacCore, University of Minnesota. The CoreWall system has been used in core drilling expeditions including San Andreas Fault Observatory at Depth (SAFOD), ANDRILL, IODP, ICDP, LacCore and individual geologists working on smaller scale drilling projects around the world. If not for using the immersive empathic design method, the users' need might not be satisfied. You would have to use defined standard operation procedures and processes to force scientists using a system as required instead voluntarily.

2. Change of scientific workflow

Scientists started requesting more high-resolution data. Scientists started to scan their cores at the highest resolution possible. Before the CoreWall system was deployed they did not have a tool capable of visualizing all the expedition data at their native resolution. This meant they had to compromise and reduce the imagery to lower quality that limited the value of the data. Now with CoreWall they wanted to capture all the details. In the second season of ANDRILL expeditions, they even went to the manufacturer of the digital line scanner to make sure they squeezed out all the resolution from the equipment. As we identified in the immersive empathic design method's generalized workflow, high-resolution digital images were taken but rarely utilized before having the CoreWall system due to constraints described in 3.1.4. The Corelyzer software designed and implemented bridged the gap between geologists and all high-resolution core images. Users could now make full use of all the resolution they could get from the instruments including high-resolution line scanners and X-ray fluorescence (XRF) analyzers.

3. Even better than the real thing

At the beginning of the process, we computer scientists conjectured that it might be challenging to turn scientists' observation habits around from physical and tangible to digital. In ANDRILL, while scientists were still excited when seeing the physical cores just recovered from the drill site, during group activities the high-resolution large display actually attracted people leaning over and stimulated more discussion and idea exchanges. During the hands-on coring training in the LacCore facility, one scientist even reflected the high-resolution digital photos were actually better than the physical cores for certain work. The reason is that lake sediment cores contain more water, and the structure features might be oxidized and damaged over time once the cores were recovered. As described earlier, it might be weeks later when the investigator travels to meet the cores. By that time the structure features on the surface of the cores can be damaged forever. Being able to access the high-resolution imagery right after the cores are acquired allows the remote investigator to make immediate judgments early. The curator can also do meaningful sampling operations based on the remote investigator's request.

While the immersive empathic design approach was not employed extensively during the whole deployment period, the major functionality of CoreWall was designed using this approach in the earlier LacCore phrase. The foundation of the CoreWall work was sustained and generated positive responses in the ANDRILL deployment. These comments and feedback suggest that the system designed using this methodology was really utilized by the scientists. We found that the early immersive experience really brought the software designer into the domain community. This efficiently lowered the knowledge barrier in a relative short time. It also lowered the social barrier to enter the domain that was even more significant for introducing the system to other coring communities. Such an invisible trust relationship building is hard to achieve with other techniques.

However, this does not mean that scientists can do all their work with the digitized data. They still need to conduct physical smear slide sampling and chemical analysis etc. The CoreWall system acts as a piece of equipment in the laboratory just like an electronic microscope. It empowered the scientists utilizing the full affordances of digital assets. As a scientist pointed out, “it can do a lot of important components in the research workflows well.” With the easy distribution digital assets, scientists are now traveling less to distant core repositories.

5.5 Discussion

There are challenges designing and deploying an interactive system to a real-world working environment. We found that while different techniques were used in the design and development cycles due to spatial and temporal constraints, the “immersive empathic design” approach used at the early stage benefitted most in later adoptions among individuals and large expedition communities. Some evidence even showed changes in the scientists’ workflows.

As described in the reflection after immersive hands-on training section, users and designers might unconsciously make assumptions based on their prior legacy practices. Geologists need to publish expedition reports or papers eventually. You could find previous tools like AppleCore and PSICAT bearing similar design goals in their premises. Such design assumptions might in turn have limited the capabilities that those tools could provide and lost benefits of high-resolution data. The proposed approach sparks innovations within the workplace with emphasis the value of users and the artifacts.

How the core data were managed and distributed will affect how users adopt a new system. The data distribution pattern is different in different core drilling communities.

The LacCore structure is more bottom-up. Individual scientists work on their own expedition projects and ship the recovered cores to the LacCore laboratory to do digital acquisition and initial core description. These scientists do not have their own facilities to do all the laboratory work, but they are more agile and flexible and willing to experiment with new ideas and new tools. In contrast, the Integrated Ocean Drilling Program maintains a top-down hierarchy. All database models, workflows, and tools are designed and developed in-house. This provides well-defined processes for its users to follow, but at the same time it lacks flexibility and is more difficult to connect with external systems. The Antarctica drilling project lies somewhere in-between. As mentioned earlier, it is the first expedition of its kind in recent years. Workflows and practices are gradually being established as the project progresses. The low adoption rate of the original annotation sharing system during the ANDRILL 2006 expedition is one example that designers and developers could learn from, because 1. We were targeting a group of unknown users based on indirect information. 2. You might not be able to tell how the data were distributed among users because you did not really know who they were. 3. A group of unknown (future) users with different purposes were hard to predict [Zimmerman09].

Scientists want the freedom to choose what tools to use. Often they might not know of advances in other fields that could fundamentally change the way they work. When a tool does not fit their needs, they will create workarounds by mixing tools in a way that is not anticipated. We found that the shared hands-on experience in the early cycle not only helps early adoption but also the introduction to other communities. It was almost like a "ritual" of entering a new society. Passing the "ritual" created some invisible bond. The hands-on working experience was referred frequently during discussion in the workshops and conferences.

Different science domain users might have different degree of the acceptance to new technologies. For example, digital imaging analysis software tools are common in biology research. We found that in the early stage for each coring group, there were always geologists who were skeptical about the authenticity and usefulness of electronic core imagery. They would prefer to observe physical cores even though the digital image is perceptually better. A well-designed system that values users' needs could tackle such bias and utilize the system in proper process in the workflow.

5.6 CoreWall vs. HANDS

In section 3.2.3.2 "Initial Plan and Assumptions" of the HANDS project, I pointed out that we initially assumed the CoreWall project and the HANDS project should share some similar settings. Users in both settings were using prior systems and defined processes while they both used substantial amounts of paper artifacts in practices. That was part of the reason we would like to see whether the same immersive empathic design methodology successful in the CoreWall project could be repeated and generalizable to a different knowledge domain. In this section, I want to contrast and show some differences and commonalities between the two collaborations discussed. Through the process, it shall shed some lights on characteristic traits of the CoreWall collaboration project and the HANDS collaboration project. We could use these findings to recognize future subjects and can tailor generalized lessons and strategies learned in this work.

5.6.1 Differences

In the on-going medical hand-off system collaboration, we tried to follow the same methodology and hoped the lessons learned could also benefit the new collaboration. Soon enough we found that there were fundamental differences in these two settings.

The natural properties of the artifacts produced in each workflow are different. Geological artifacts are highly hands-on and visual. For example almost all data routed into the CoreWall system has real-world counterparts. High-resolution imagery came from the cores recovered from the drill site. They are tangible and after the hands-on experience of one drilling workflow, it can be generalized and adapted to other drilling communities. When the developer received training in the field, he found a lot of the artifacts could be easily mapped from physical objects to digital data and even to the abstract domain model and vocabulary. The proposed immersive empathic design methodology practices provided a perfect domain model construction situation.

On the other hand, medical data during shifts is artificial and abstract in HANDS. Much of the knowledge exists in man-made definitions and professional conventions. For example, nursing diagnostics, outcomes, and interventions were categorized into more than a thousand terminologies. A group of terms will typically be used to describe patients with a particular symptom. The terminology combination knowledge is often descriptive and existed in the user groups' experience. As outsiders, we needed constant explanations from domain experts, which took up to half of the meeting time in the first six months. In the early stages, more close face-to-face meetings and training are needed to clarify ambiguity and misunderstandings. And as prior literature [KAPLAN82][Kaplan09] pointed out, there are also other obstacles and constraints presented.

In 3.2.3.3 we described that we mainly establish own HANDS domain knowledge from:

1. HANDS on-line training “screencast” material.
2. Access to a test HANDS instance, so we could actually try and see how the system worked.
3. Regularly meeting and interview with healthcare (nursing and physician) researchers.

Knowledge and data collected from these approaches were indirect comparing to the immersive empathic design method. Additionally, we never had the opportunity to view authentic hand-off users within the context setting. It was more difficult to make concrete and goal-oriented prototypes because we could not be certain that an exploratory prototype could actually meet a real user’s need. This was like inviting a focus group of domain researchers into a conference room for participatory design brainstorm activity trying to add more features without user interface developers seeing or using the system within the busy medical hand-off setting.

5.6.2 Common Theme

One common theme emerged as we continued the collaboration in the HANDS project. It is that producing “observable artifacts” is crucial in both settings especially in early iterations. In the CoreWall project, the developer put together the first concept system right in the core lab during his hands-on internship. The system was setup right in the center of the core lab along with core description table. It was a “chop suey” mixed with monitors borrowed from other labs and slow rendering software, but it gave scientists a tangible artifact that encouraged discussion and brainstorming. An additional important lesson we learned was that the prototype should be created early in the same tangible form that it was supposed to be used instead of a paper prototype. That might cost more time and effort, but it assures that down the road, scientists are having the user experience closest to the final system.

In the HANDS setting, these artifacts became even more important. As discussed earlier, the medical data is comparably more abstract. We found that producing a tangible representation of such abstract data was invaluable in the following ways. For computer scientists who lack domain knowledge or experience, articulating these artifacts helps to develop meaningful test cases to verify the correctness of the system. It improved the mutual understanding of the domain science and also filled the gap between two different cultures while resolving misunderstandings. For domain researchers, it was a way to see if the developer understood the data and domain model. Domain scientists’ correction feedbacks tended to be the most valuable suggestions and verifiable test cases for the development of verifiable scientific systems [Howison10].

6. CONCLUSION AND FUTURE WORK

This dissertation described the proposed immersive empathic design for interdisciplinary collaboration. I presented real world case studies including building a scalable high-resolution visualization system for geological core drilling expeditions and creating enhancements to a medical hand-off system using the proposed method. The collaborative work in both settings involves domain users, their work and interfacing artifacts. I found that using the proposed method had the advantage of letting system developers gain an authentic user experience and uncover the user's true needs, compared with other methods of gaining understanding from indirect users, settings and practices. The domain knowledge construction is more efficient through immersive hands-on experiences. It could be propagated from one community to another within the same domain and encourage buy-in. As shown in the dissertation, the CoreWall system designed using this methodology has now been widely used in multiple core drilling communities. The development of the system itself even affected how international data management parties serve their data to users, with more focus on high-resolution visualization and some expeditions even changed their workflows.

In the summer of 2010, I found another potential setting for further investigation or borrowing experiences from [Weber00] and spent 2-months in an animation studio. Unlike computer scientist vs. scientist collaboration, the studio environment consists of computer scientists, artists and filmmakers. "Art challenges science, and science inspires art", as Pixar Chief Creative Officer John Lasseter said. I practiced the methodology described in this paper in this interdisciplinary collaboration setting and designed and implemented a patent-pending review system for film pre-production.

The work described in this paper is not an exclusive snapshot of the whole software development picture. There are still issues that need to be addressed in other phrases, for example maintenance. More future work of this paper could be following the framework practicing the methodology in different cross-domain collaboration settings. In analyzing and looking into the successes and failures, we could be able to identify and gain more insights of best practices in different representative collaboration domains. Additionally, with substantial and diverse instances, a more generalized domain knowledge model construction process could also be identified to help further scientific inquiries. Ultimately, such information should always feedback to the developers, informing them how to build software systems that will be utilized by domain users in work settings solving real-world problems.

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