

# Evolutionary Design of Complex Systems

## Open Technology for Software Evolution: Hyperware, Architecture, and Process

### Second Annual Technical Report

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## 1. Progress and Accomplishments

We are working on several technologies to aid in the effective evolution of complex software. In particular our research foci are:

- open, broad-based hyperprogram and active rationale support
- component-based architecture evolution technology, and
- multi-stakeholder process support

Open hyperware, software architecture, and workflow/process technologies are key enablers for supporting evolution of complex software systems. We are developing techniques, standards, and tools in each these areas and are distributing the results via the World-Wide Web (WWW). The technologies are being developed cooperatively, so that results in one area leverage the other two. The hyperware focus is on developing infrastructure to integrate open link server hypermedia systems with the WWW, while adding support for hyperweb configuration management, semantically-rich link generation, cooperation agents, and automatic rationale capture. The architecture research is directed at reducing the cost of application development by providing domain-informed, style-based design guidance, architecture design environments with analysis capabilities, implementation technologies, and support for dynamic change. The process work is designed to improve coordination and managerial control of teams by allowing flexible definition, modeling, and execution of typical workflow and process applications over the Internet.

Highlights of our progress and accomplishments for this reporting period include:

- The Internet Engineering Task Force (IETF) approved both the WebDAV (RFC 2518) and URI (RFC 2396) specifications as proposed standards. This indicates that both standards are stable, of high technical quality, and have undergone significant community review.
- Northrop-Grumman Military Aircraft Systems Division successfully used Chimera for the creation of a hyperweb of software development artifacts containing hundreds of thousands of hypermedia entities. They also successfully used the C2-style and implementation framework for the modeling and implementation of a B-2 avionics simulation environment.
- UCI organized the first Workshop on Internet-Scale Event Notification (WISSEN). Attendees included The Aerospace Corp, Microsoft, Tibco, BLIP, Lotus, Oracle, Sun Microsystems, Netscape, Activerse, Novel, and Hewlett Packard, Raytheon, GTE, Lucent, IBM Research, FileNet, and Tandem.
- Endeavors research was licensed to an internet start-up company, Endeavors Technology, Inc. Founder, Gregory Bolcer is a former UCI researcher.
- Several new systems have been developed during this reporting period, including:
  - Argo/UML*, a software architecture design environment based on the UML (Unified Modeling Language) meta-model.
  - DRADEL*, an component-based environment for architecture evolution. *DRADEL* enables modeling, analysis, and evolution of architectures expressed in a formalized architecture description language (ADL), as well as mapping of the architectural models to the C2 implementation infrastructure.
  - WebDAV Explorer*, a prototype WebDAV client application which is being used by multiple WebDAV developers to test interoperability of WebDAV server implementations.
- Research this period has resulted in 8 technical journal publications and over 30 conference/workshop publications.

## 1.1. Hyperware

The first beta for Chimera 2.0 released in early February. This release featured an improved user-interface to all Chimera servers, support for XML import and export of Chimera's hypermedia databases, and integration with Rivendell. The release was accompanied by a redesigned website that now includes better documentation and a Chimera tutorial.

Chimera was used successfully by two aerospace companies, Northrop-Grumman Military Aircraft Systems Division and Raytheon. Northrop Grumman was able to take advantage of Chimera's XML import feature to automatically process large documents into Chimera databases and generate hyperwebs containing hundreds of thousands of hypermedia entities. A Chimera installation was achieved at Raytheon for a EDSC2 grant proposal feasibility study. Raytheon is using Chimera to access various artifacts used on the F-15 project.

Scalability issues arose in supporting the large number of hypermedia entries generated by Northrop-Grumman. In response, we have improved Chimera's support for scalability on data intensive operations by two orders of magnitude, from thousands to hundreds of thousands of entities handled. This was accomplished by adopting the use of a freeware relational database (MYSQL) and developing the capability to use filtering mechanisms over a large scale hyperweb. The use of MYSQL enabled us to respond to Northrop-Grumman's demands in a rapid fashion (the increase of Chimera's scalability occurred in less than four weeks). In order to further improve scalability, work has begun on evaluating COTS relational and object-oriented databases in order to meet Northrop's future demands.

Chimera research at the University of Colorado at Boulder has identified efficient restructuring of the hyper-base through changes in the structure of the back-end database. During this investigation, other back-end databases (i.e. relational, object-relational, etc.) were examined for viability. Chimera will integrate these changes into future releases of Chimera 2 beta.

Seven Chimera 2 beta releases were produced this year. In addition to the scalability enhancements described above, other new features include:

- improved XML support
- A selectable traversal algorithm function which will allow client applications and users to select the traversal behaviors for Chimera. This allows the user to apply rules to traversals across the n-ary links Chimera supports, such as a rule to traverse to documents ordered with the newest linked document appearing first
- a new enhancement known as anchor and link filtering, which allows users to restrict links made visible on the Chimera Server's display to those of a specific type
- A Chimera COM API on the Win32 platform. Chimera's API is now available as a COM object that can be used to integrate Win32 applications. These integrations involve an application using a DDE interface to the COM API which then accesses Chimera
- A client integration of Adobe's Frame Maker using the COM API
- A port of the Chimera to the NT platform

The integration of Chimera with the Rivendell Tool Server, developed by Gail Kaiser's group at Columbia University, was successfully completed. Further refinement of the integration was achieved with feedback provided for future versions of Rivendell. Columbia University replaced Xanth with Chimera as the underlying hypermedia infrastructure on Oz web.

Research on the Chimera hyperware project is currently focused in the areas of interoperability and back-end optimizations. The COM API which allows for Win32 Applications to access Chimera services are being used by graduate students at the University of Colorado at Boulder in an effort to integrate Windows based applications as Chimera clients. UCI ported the Chimera servers onto Linux as well as the Xemacs and jimage clients.

Current development to enhance Chimera user support includes a utility program which configures the XML preference files for the servers and a Adobe Acrobat client integration. Both will be released next quarter.

The World Wide Web was originally conceived as an interactive, read/write medium, and it is only the early dominance of the Mosaic browser which cast the Web into its current publish/browse paradigm. While the HyperText Transfer Protocol (HTTP/1.1) contains limited support for remote authoring in addition to remote browsing of content, this support is not sufficient for collaborative authoring of web content. Jim Whitehead is the Chair of the Internet Engineering Task Force World Wide Web Distributed Authoring and Versioning (WEBDAV) Working Group, which is developing interoperability specifications for how to extend HTTP to perform remote authoring and versioning of web content. WebDAV provides a network protocol for creating interoperable, collaborative applications. Major features of the protocol include locking (concurrency control), XML properties, and namespace manipulation.

The WebDAV Working Group, led by Jim Whitehead, achieved a major milestone during the reporting period with the approval by the Internet Engineering Task Force (IETF) of the WebDAV Distributed Authoring Protocol as a Proposed Standard (RFC 2518, [GWF+98]). This indicates the WebDAV standard is stable and of high technical quality, has undergone significant community review, and is generally believed to have resolved known design choices. Approval by the IETF also acts as a signal for corporations and other organizations to begin adopting the protocol in their products. The Microsoft Corporation announced that they will be providing broad WebDAV support in their Internet Information Services (IIS) web server product, in their Internet Explorer web browser, and in Office 2000 applications. Novell also announced that WebDAV will be a significant part of their future product plans. Two independent software developers working on open source projects also announced WebDAV support: Greg Stein began work on a WebDAV module (mod\_dav) for the popular Apache web server, and Joe Orton developed a tool called site-copy which synchronizes a local directory with a remote WebDAV server. Together, these developments show the benefits of EDCS involvement in network protocol standardization, since once the standard has been approved, significant development coalesces around the standard, leveraging DARPA investments.

The WebDAV working group began work on functionality enhancements in the areas of advanced collections, access control, and versioning. Advanced collections functionality encompasses referential members of collections, and ordering of collections, and is described by a requirements document and a protocol document. Requirements for access control were submitted during the reporting period, as was a versioning protocol draft. Work on these drafts will continue in the WebDAV working group.

UCI/EDCS was instrumental in helping form a follow-on effort to WebDAV called DASL, DAV Searching and Locating. The DASL effort, currently in-process of becoming an IETF working group, will address issues of how to remotely search a repository which contains a set of Web

DAV resources. Alex Hopmann, Microsoft, is chair of the DASL group.

Concerns for WebDAV's use of the Extensible Markup Language's (XML) MIME media type "text/xml" were addressed. This has led to work on *XML Media Types* [WM98], a document which registers the "text/xml" and "application/xml" media types. During the reporting period, this document went through 6 major revisions, and received significant review from the World Wide Web Consortium's XML Special Interest Group and the IETF Media Types community. This document was submitted to the IESG and is currently awaiting approval.

UCI has developed WebDAV Explorer, a prototype WebDAV client application which is being used by multiple WebDAV developers to test interoperability of WebDAV server implementations.

Students at UCI have maintained the Columbia WebDAV server, keeping it compliant with the latest revisions of the WebDAV distributed authoring protocol specification. This server was instrumental for testing the WebDAV Explorer client.

Rohit Khare has focused on tracking development of HTTP-NG and researching the potential for third-party extensibility using Web proxy servers, Extensible Markup Language, and the current generation of HTTP. He is also writing *Seventh Heaven*, a bimonthly column on application-layer protocol design in IEEE Internet Computing [Kha 98, Kha98-2, Kha98-3]. Topics covered include the contributions of Jon Postel to protocol specification, and histories of Network News Transfer Protocol (NNTP), Gopher, and Hypertext Transfer Protocol (HTTP).

Roy Fielding is working on a survey of software architectural styles that will characterize styles in terms of their impact on system communication across a network. The goal of this research is to provide a design framework to help software architects and application-level protocol designers choose an appropriate architectural style for the particular communications characteristics of their application.

He is also working with the Apache Group to assist with the transfer of HTTP/1.1 and WebDAV protocol enhancements to the Apache HTTP server technology, used by over 54% of all public Internet websites.

Roy Fielding's specification of Uniform Resource Identifiers (URI) [BFM98], the technology for identifying resources on the Internet, was accepted by the Internet Engineering Steering Group (IESG) for publication as Draft Standard RFC 2396.

## 1.2. Software Architecture

Software architectures have the potential to substantially improve the development and evolution of large, complex, multi-lingual, multi-platform, long-running systems. However, in order to achieve this potential, specific architecture-based modeling, analysis, and evolution techniques must be provided. One aspect of our current research in software architectures focuses on a type theory for software architectures, which allows flexible, controlled evolution of software components in a manner that preserves the desired architectural relationships and properties. Critical to the type theory is a taxonomy that divides the space of subtyping relationships into a small set of well defined categories. In the context of this work, we are investigating the effects of large-scale development and off-the-shelf reuse on establishing type conformance between interoperating

components in an architecture [MRT98]. Furthermore, one cannot fully benefit from such techniques unless support for mapping an architecture to an implementation also exists [MRT99].

One aspect of the research conducted this reporting period is the construction of an architecture-based modeling, development, and evolution toolsuite, called DRADEL. DRADEL is an outgrowth of our experience with systems developed and evolved according to the C2 architectural style. We formalized the syntax and semantics of an architecture description language (ADL) specifically designed to support architecture-based evolution and enumerated the kinds of evolution the language supports. We used the ADL as the basis of DRADEL, a component-based environment that enables modeling, analysis, and evolution of architectures expressed in the ADL, as well as mapping of architectural models to our implementation infrastructure (the C2 class framework). The architecture of the DRADEL environment itself can be evolved easily to support multiple ADLs, kinds of analyses, architectural styles, and implementation platforms. Our approach is fully reflexive: DRADEL can be used to describe, analyze, evolve, and (partially) implement itself, using the very ADL it supports [MRT99].

Another aspect of our architectural research deals with implementing complex software connectors. Since architecture-level components often contain complex functionality, it is reasonable to expect that their interactions will also be complex. Modeling and implementing software connectors thus becomes a key aspect of architecture-based development. Software interconnection and middleware technologies such as RMI, CORBA, ILU, and ActiveX provide a valuable service in building applications from components. The relation of such services to software connectors in the context of software architectures, however, is not well understood. To understand the trade-offs among these technologies with respect to architectures, we have evaluated several off-the-shelf middleware technologies and identified key techniques for utilizing them in implementing software connectors. We have integrated four such technologies with the C2 implementation infrastructure: University of Colorado's Q system, Sun's Java RMI facility, University of Maryland's Polyolith software bus, and Xerox PARC's ILU distributed object system. Our platform for investigation was the C2 style. By encapsulating middleware functionality within software connectors, we have enabled the coupling of C2's existing benefits such as component interchangeability, substrate independence and structural guidance with new capabilities of multi-lingual, multi-process and distributed application development in a manner that is transparent to architects [MDT98, DMT99].

David Rosenblum and his students Rema Natarajan and Doris Tonne have been investigating techniques for supporting architectural concerns in the use of component interoperability standards. Rema Natarajan has developed an enhancement to Sun's Beans Development Kit, called *Arabica*, to support composition of components or "beans" according to the rules of the C2 architectural style. The enhancements include (1) checking C2 design rules as beans are graphically composed; (2) encapsulating elements of the C2 class framework as beans, including explicit architectural connectors; and (3) providing interactive wrapping of off-the-shelf beans, whereby the architect provides a mapping from bean events to C2 request and notification messages. This work resulted in a publication for ISAW-3 [NR98]. Doris Tonne has developed an enhancement to the Beans Development Kit and the definition of the JavaBeans "design pattern", called *Robusta*, which supports the evaluation of methods that incorporate bean invariants and bean method pre- and post-conditions.

David Rosenblum and Elisabetta Di Nitto (CEFRIEL/Politecnico di Milano) began investigating

the problem of reconciling middleware constraints with architectural modeling, with a focus on middleware infrastructures for event-based architectures. Middleware infrastructures are becoming a significant component of large-scale software systems. Traditional software process models encourage postponement of implementation decisions as late in the lifecycle as possible, but this is no longer possible for middleware-based architectures and systems. Architectural models can severely restrict the choice of middleware infrastructures, and middleware infrastructures can impose strong constraints on architectural models. Therefore, languages and environments for architectural modeling must account for the constraints imposed by middleware infrastructures. As a first step in studying this issue, existing ADLs were evaluated as to their suitability for expressing and capturing constraints of event-based styles and event-based infrastructures. This work resulted in a publication for ISAW-3 [CDRW98] and a paper accepted to ICSE'99 [DR99].

Notable progress was made on understanding how software architectures could be used as a basis for runtime software evolution. The contribution of architectural style and software connectors was explored and described in a paper presented at the International Conference on Configurable Distributed Systems [OT98]. We have been studying the role of connectors in supporting the modeling, analysis, and execution of software systems. In particular, the beneficial role of connectors in flexibility, heterogeneity, code mobility, and distribution are described in [ORT98].

We have also begun to investigate different approaches for evolving software in-the-field (i.e., after it has been deployed). Many commercial systems employ such techniques as a means of providing end-user customizability and behavior extension by third-party developers. These techniques include application programming interfaces (APIs), scripting languages, software plug-ins, etc. Early results based on this work were submitted and accepted for publication at the International Workshop of the Principles of Software Evolution [Ore98].

Peyman Oreizy completed a survey that compares different approaches to Decentralized Software Evolution (DSE). DSE enables third-parties to evolve a software application independent of the organization that originally developed it. Application vendors employ DSE as a means of attracting additional users to their applications - and, consequentially, increasing their market share. This benefits everyone involved: the original application vendor sells more product since customization constitutes use; third-party developers deliver a product in less time and with lower cost by reusing software as opposed to building it from scratch; and customers receive a higher quality product, customized to suit their needs, in less time and with lower cost. While there are a variety of approaches to DSE, there were no clear characterizations of their differences or of their relative benefits and shortcoming. The survey covers different approaches to DSE and helps answer the following questions: What is decentralized software evolution and why is it important? What are the characteristic approaches to DSE? What are the important issues to consider when evaluating different DSE approaches? How do different approaches compare and what are their benefits and shortcomings? Where do current approaches fall short? What are some open areas for further research and development? The results of this survey can be found in [Ore98-3].

During this period, the C2 group, performed an integration of ArchStudio, a UCI architecture development environment, with the Armani constraint language from CMU (PI: David Garlan, contact: Robert Monroe). The integration enables architects to specify constraints on how a software architecture can evolve during runtime. As runtime software changes are requested, ArchStudio queries Armani to determine whether or not the change would leave the system in a consistent configuration. If the change violates a constraint, the change request is rejected; other-

wise the change is applied to the running system by ArchStudio. This capability provides additional assurances that runtime software upgrades do not violate application integrity. The integration also enables ArchStudio to generate ACME architectural descriptions.

During this reporting period we collaborated with Northrop Grumman (PI: Greg Johnson) on the use of a C2-style architecture in modeling and implementing the B-2 avionics simulation environment. Northrop Grumman successfully used ArchStudio/C2 as a tool integration framework for the B-2 test environment. This work was demonstrated at the EDCS Demo Days in Baltimore.

We are investigating the use of UML (the Unified Modeling Language) to represent software architectures. UML is a object-oriented design notation that has recently be standardized by the Object Management Group. UML has wide-spread industry interest and growing tool support. Unlike previous object-oriented design notations, UML is formally defined and provides a constraint language and extension mechanisms. We have been able to use the UML constraint language to express most of the guidelines of the C2 style and some aspects of the Wright architecture description language [RMRR98]. Expressing software architecture concepts in a standard design language is an important step toward wide-spread use of software architecture models.

We have revised the design and implementation of the Argo software architecture design environment to make it more efficient and flexible, and to ease integration with design tools implemented in Java. Specifically, we have implemented versions of the UML meta-model and associated visualizations in GEF and critics in Argo. Argo/UML is an object-oriented design tool that has cognitive support features as found in the existing Argo/C2 tool supporting C2-style software architectures. Like the previous Argo/C2 tool, Argo/UML has design critics and a dynamic “to do” list that together help designers resolve identified problems in a design. We have done a significant amount of development on Argo/UML resulting in several beta releases. Development progress includes:

- support for more of the standard UML (Unified Modeling Language) diagram types
- more critic implementations
- improved scalability in the critiquing system
- a new XML-based file format
- new design visualization features
- customizable navigational perspectives that structure the design around specific design tasks
- checklists which save time in later design reviews
- novel diagram editing tools
- support for attaching problem-fixing wizards to critics
- new support for UML activity diagrams
- table views of the design
- enhanced “clarifier” icons that visually highlight problems
- and a cooperative design query mechanism.

In addition, a survey of design critiquing systems is was completed [Rob98].

Two experiments were conducted with Argo/UML users. First, Argo/UML was used by undergraduate students as part of a software design project course. Second, we conducted a controlled

user study that evaluated the usability and effectiveness of Argo/UML's novel diagram editing capabilities. Specifically, we found that our "broom" alignment tool allowed users to organize design diagrams more easily than standard alignment commands. A CHI'99 submission describing this work is in progress.

Jaya Vaidyanathan and Jason Robbins conducted a trial of a new user interface prototyping method that uses off-the-shelf HTML editors to make early prototypes of complex user interfaces. This approach makes early prototypes available to more project stakeholders and is more convenient than previous paper-based approaches or the use of special-purpose prototyping languages. a CHI'99 submission describing this work is in progress.

Our Argo/UML web site had over 6000 visitors in the last quarter of 1998. Our Argo/UML mailing list currently has approximately 650 registered users, including employees of Aonix (a CASE tool vendor), ISX (a defense contractor), IBM, Oracle, Motorola, and many universities.

### 1.3. Process

We are exploring the issues of distributed processes through the creation of prototype systems. In order to validate portions of the technology and as part of a senior level project course in software engineering, one team of students created an Endeavors process to manage an on-line, distributed, travel expense reimbursement system. The process combines the core Endeavors technology and other web based tools such as JavaScript to provide an easy to use, customizable interface to the reimbursement process used in the ICS department. Another team of students began work on creating a process to provide control flow for the Endeavors bug tracking system. The process allows outside users to submit bug and suggestion reports through a web browser. The submission can then be verified, assigned to a developer, the bug fixed or suggestion implemented, and finally be approved for distribution.

Endeavors developers completed a three tier database middle-ware module for the Endeavors system. This system consists of a programmer's interface for the client level (tier three), a middle tier web servlet module (tier two), and a RDBMS (tier one). The client connects to the middle tier using the provided API calls and utility functions from tier one. The middle tier module extends the Java HTTPServlet class and relies on a web server. The middle tier to tier one connection has currently been implemented using the JDBC which makes connections to the MYSQL RDBMS located at tier one. Communication between the tiers is via HTTP and will therefore be considered firewall friendly on many systems. The communication between the client and middle tier is based on ANSI SQL; this enables complex queries, joins, orderings and aggregations. The system supports prepared statements and multiple databases.

This new database middle-ware is compatible with the Endeavors user level Handler model. This feature provides a valuable tool for Endeavors users that require data storage into proprietary systems such as Oracle, MSSQL, and Sybase. In fact, handlers can be written to maintain user data into any DBMS that has an available JDBC driver. This model will enable Endeavors to interact with and maintain data and processes which rely on data from legacy data stores.

The new database middle-ware system has been incorporated with the Java Brain dynamic web content collection and presentation system, and is in the testing phase. The database system has enhanced Java Brain by providing optimized querying, data filtering, and relational data storage

of the user data. This implementation is providing a test environment for the MYSQL RDBMS as a data storage facility for Endeavors user data.

Endeavors has been connected to Oracle8 ORDBMS as a test-bed for transaction management within a database supported process environment. This will allow us to investigate the benefits of a transactional workflow system and to describe an optimal transaction manager model for the process environment.

An initial implementation of the Endeavors User and System levels as C2 components was completed this quarter. Using the C2-style allows the System and User levels bi-directional communication through any of the C2 Connector objects. The C2-style enables various Endeavors architectures to be constructed. For example, a server side architecture is created with a standard C2 connector welded to the System level component and the other end of the connector accessible by a servlet. The servlet is part of a C2 connector which uses a web server and a combination of Java's Socket, ServerSocket, and URL Connection classes to form the connector. This allows a User level component running as either an applet or as a stand alone application to connect to a remote System level component. Thus, multiple distributed User level clients can connect to the same System level component and receive updates when changes are made. Ninety-six of the messages have been implemented and we have validated the design. We are continuing to explore event based integration issues in Endeavors.

An installation manager called "Install Shield for Java" (ISJ) was used to facilitate installation of Endeavors. The installation management capabilities of ISJ include directory creation, file placement, configuration management, script creation, and environment modification. The incorporation of this system gives end-users "wizard" installation and de-installation facilities for Endeavors on Win95/NT and Solaris platforms. Installation executables were also developed that can be invoked by an Endeavors process network. This installation system allows the overall installation process to be managed as an advanced workflow, and thus allows for more sophisticated flow, decision, and event handling.

We have also continued to investigate transaction models for distributed workflow systems. Transaction management systems provide significant benefits to any computer operation that has components which are a long duration processes or set of related steps. Most of the systems looked at thus far support two phase commits. They use the XA/open standard. There are similar simple APIs to the functionality. The differences found lie in: platform dependence, footprint, cost, language, and completeness. A possible good fit system for the Endeavors project would be Java Enterprise Beans JTS. This is an architecture - not an implementation - and would require development of, or purchase of beans. Another good fit for Endeavors is Sybase Jaguar Component Transaction Server.

EDEM has been redesigned for compliance with the Java 1.1 event model. New features include more a flexible and efficient event dispatch mechanism, enhanced data collection and reporting options, an API to allow input and output of arbitrary events for monitoring, and default expectation agents with wizards to aid in expectation specification and agent parameterization. In addition, a survey of automated techniques for extracting usage/usability information from automatically captured user interaction events was completed [Hi198].

EDEM was successfully integrated by Lockheed Martin C2 Integration Systems into the Global Transportation Network (GTN) demonstration scenario for the Third Annual EDCS Demo Days

in Baltimore in July.

David Hilbert managed a development effort at Microsoft Corporation this summer in which an application (with over 1000 commands and 300 dialogs) was instrumented to collect usage data regarding the behavior of 500-1000 users using the application over a two month period. This industrial collaboration was initiated to allow the principles and techniques underlying UCI's EDEM research (in the area of large-scale collection of application usage data) to be evaluated within the context of a large-scale industrial project.

Knowledge Depot is a tool for supporting Project Awareness. Originally it was a group memory used to store and automatically organize project related email and documents. It has evolved into a project awareness tool which allows geographically distributed project members to subscribe to specific categories of information in the group memory. These subscriptions cause the system to send users summaries of all new information to arrive in that subject, thus allowing people to remain aware of discussions and documents on project topics that affect them. A beta version of this tool is now being tested at UCI. This version is a redesign of the original Knowledge Depot to enhance speed, usability and accessibility.

There were three major activities related to research in Project Awareness and Knowledge Depot during this time period. First, we enhanced the Java Knowledge Depot's usability in response to initial user feedback. Second, we enhanced Bell Atlantic's Lotus Notes subscription feature to scale up to handling the thousands of people who use the Lotus Notes Knowledge Depots. This will help us gather usage data which will in turn enhance our understanding of the Java Knowledge Depot and how to improve it. Third, we processed survey and interview data from a prior study of the Lotus Notes subscription feature, and will be submitting a short paper to CHI'99 based on our results.

Shilpa Shukla wrapped up her work relating to a summer research internship with Hewlett Packard Labs, Palo Alto, California (Summer 1998). This research involved: 1. Conducting an ethnographic study on Hewlett Packard's customer support process of knowledge authoring. This study provided input to requirements for knowledge authoring technology. 2. Applying Activity Theory to analyze the data collected from the study of Hewlett Packard's customer support process. The Activity Theory framework provided the means to deliver various models of the artifacts involved in a diagnostic authoring process. 3. And helping improve Hewlett Packard's Research and Development's understanding of the Customer Support documentation process. She and David Redmiles are preparing a paper on this data which will appear in a Special Issue of CSCW Journal (Co-edited by Bonnie Nardi and David Redmiles). They are also writing up data results from a similar study at Apple Computer which they plan to submit to the ITP (Information Technology and People) journal.

## 2. Professional Personnel

### *Faculty:*

David Redmiles  
David S. Rosenblum  
Richard N. Taylor

### *Research Specialist:*

Kenneth M. Anderson, (*now at University of Colorado, Boulder*)

### *Research Assistants:*

Gregory Bolcer  
Roy Fielding  
David Hilbert  
Peter Kammer  
Michael Kantor  
Rohit Khare  
Neno Medvidovic  
Rema Natarajan  
Peyman Oreizy  
Jason Robbins  
Shilpa Shukla  
James Whitehead

### *Research Programmers:*

Clay Cover  
Arthur Hitomi  
Yuzo Kanomata  
Edwin Kraemer  
Kari Nies

### *Visiting Scholars:*

Elisabetta Di Nitto, *Politecnico di Milano, Italy*  
Alfonso Fuggetta, *Politecnico di Milano, Italy*

### *Degrees Awarded:*

Gregory Alan Bolcer, Ph.D. Computer Science  
Awarded November 1998  
Dissertation: “*Flexible and Customizable Workflow Execution on the WWW*” [Bol98]

Nenad Medvidovic, Ph.D. Computer Science  
Awarded December 1998  
Dissertation: “*Architecture-based Specification-time Software Evolution*” [Med98]

### 3. Publications in Technical Journals

Gregory Alan Bolcer and Richard N. Taylor. *Advanced Workflow Management Technologies*. To appear in the Journal of Software Process Improvement and Practice. [BT98]

Roy Fielding, E. James Whitehead, Jr., Kenneth Anderson, Peyman Oreizy, Gregory Bolcer, and Richard Taylor. *Web-based Development of Complex Information Products*. Communications of the ACM, vol. 41, no. 8, pp. 84-92. August 1998. [FWA+98]

Peter Kammer, Greg Bolcer, Richard N. Taylor, and Mark Bergman. *Techniques for Supporting Dynamic and Adaptive Workflow*. To appear in the Journal of Computer Supported Cooperative Work. [KBTB98]

Nenad Medvidovic and Richard N. Taylor. *A Classification and Comparison Framework for Software Architecture Description Languages*. To appear in IEEE Transactions on Software Engineering. [MT98-2]

Peyman Oreizy, Richard N. Taylor. *On the Role of Software Architectures in Runtime System Reconfiguration*. IEE Transactions Software Engineering, vol. 145, no. 5, October 1998. [OT98-2]

Peyman Oreizy, Michael M. Gorlick, Richard N. Taylor, Dennis Heimbigner, Gregory Johnson, Nenad Medvidovic, Alex Quilici, David S. Rosenblum, and Alexander L. Wolf. *Self-Adaptive Software*. To appear in IEEE Intelligent Systems. [OGT+99]

Jason E. Robbins, David M. Hilbert, and David F. Redmiles. *Extending Design Environments to Software Architecture Design*. Automated Software Engineering, vol. 5, no. 3, pp. 261-290, July 1998. [RHR98-2]

Jason Robbins and David Redmiles. *Software Architecture Critics in the Argo Design Environment*. Journal of Knowledge-Based Systems, vol. 11, no. 1., pp. 47-60, September 1998. [RR98]

### 4. Interactions (Related Activities/Conferences)

#### 4.1. Hyperware

The Workshop on Internet-Scale Event Notification (WISEN) was produced and hosted by UCI on July 13-14. Attendees included The Aerospace Corp, Microsoft, Tibco, BLIP, Lotus, Oracle, Sun Microsystems, Netscape, Activerse, Novel, and Hewlett Packard, Raytheon, GTE, Lucent, IBM Research, FileNet, and Tandem.

Ken Anderson attended the Hypertext'98 conference held in Pittsburgh, Pennsylvania on June 20-24, 1998. There he participated in the 4th International Workshop on Open Hypermedia Systems and presented the paper Client-Side Services for Open Hypermedia: Getting past the 'foo'...[And98]. This paper represents work in the development of a standard protocol for client interoperability with open hypermedia systems. Chimera developers have been participating in this process for the past two years with the goal of producing a standard that can be taken to the

IETF for wider distribution.

Two papers by Ken Anderson were submitted and accepted for publication: one to the Hypertext 1999 Conference entitled “Data Scalability in Open Hypermedia Systems” [And99] and one to the 1999 International Conference on Software Engineering entitled “Supporting Industrial Hyperwebs: Lessons in Scalability” [And99-2].

Yuzo Kanomata gave a talk on Chimera to two groups at Raytheon in August, the first group (team lead Diana Chu) was looking to integrate Chimera with the F-15 program while the second group (team lead Keith Grindstaff) was looking for possible hyperware integrations on Fire Finder Block 2, Sentinel, and the Standard Missile programs.

Continuing its efforts to increase adoption of WebDAV by key Web technology companies, UCI conducted site visits to NetObjects, Documentum, FileNet, Microsoft, Adobe, IBM, Sun Microsystems (server development team) and Kofax for consultations on the WebDAV Distributed Authoring Protocol, giving presentations educating their staff about WebDAV, and discussing potential strategies for integrating WebDAV technology into their product lines.

Additionally, introductory presentations on WebDAV were delivered during the HTTP Track at the 7th International World Wide Web Conference in Brisbane, Australia in April, and at the American Society of Information Science (ASIS) 1998 Mid-Year conference in Orlando, Florida, in May. A WebDAV tutorial was presented during the Hypertext’98 Conference in Pittsburgh, PA, in June. Articles on WebDAV appeared in the general press as well, with positive articles in InfoWorld [Wal98], Mac Week On-line [Dud98], and PC Week On-line [Han98].

The paper, *Lessons from WebDAV for the Next Generation Web Infrastructure* [Whi98] was presented at the workshop, “Towards a New Generation of HTTP,” held at the WWW7 conference, evaluates the extensibility of HTTP based on the experiences of the WebDAV working group, giving requirements for future Web infrastructure development efforts.

The WebDAV working group held a meeting at the Los Angeles IETF, on April 2, 1998 where requirements for advanced collections functionality were discussed. A more substantial meeting was held on June 15-17, 1998, hosted by Microsoft in Redmond, Washington. The topics discussed at this meeting were advanced collections, access control, and versioning. The WebDAV working group held a meeting at the Chicago IETF on August 27. Topics discussed were advanced collections, access control, hierarchical URLs and collections, and versioning and variant authoring. Two meetings of the Versioning and Variant Authoring Design Team were held on October 1-2, 1998, at the offices of FileNet, in Costa Mesa, California, and on December 1-2, 1998, in Portland, Oregon, sponsored by Intersolv. These design team meetings focused on the development of a protocol for versioning and configuration management of Web content. A full WebDAV working group meeting was held on December 10, 1998, at the Orlando, Florida IETF meeting, including breakout sessions on the topics of advanced collections functionality, and access control.

Jim Whitehead had his paper, “Control Choices and Network Effects in Hypertext Systems”, accepted for inclusion in the proceedings of the Hypertext’99 conference [Whi99], and was one of three papers nominated for the Engelbart best paper award.

Jim Whitehead and Rohit Khare presented two tutorials. The first, “Web Collaboration and Auto-

mation: XML, WebDAV, and ISEN”, was given in October at the 1998 California Software Symposium in Irvine, CA. The second, “XML and WebDAV: Emerging Web standards and their impact on Software Engineering” was presented in November at the Sixth International Symposium on the Foundations of Software Engineering (FSE-6), Lake Buena Vista, Florida.

Rohit Khare and Jim Whitehead successfully co-chaired the workshop, “Towards a New Generation of HTTP”, held with the 7th International World Wide Web Conference. Jim Whitehead was also a panel member at WWW7 on the panel titled, “Missing the 404: Link Integrity on the World Wide Web.”

Rohit Khare presented a plenary talk based on joint work with Adam Rifkin from Caltech at the DARPA/OMG Workshop on Compositional Software Architectures on “Composing Active Proxies to Extend the Web” [KR98]. He also presented “XML and WebDAV: a Tale of Two Standards” at XML’98 Developer’s Day based on joint work with Jim Whitehead. He also began a bimonthly column series in IEEE Internet Computing which surveys application-layer information transfer protocols [Kha98, Kha98-2, Kha98-3].

Rohit’s research into evolvable data interchange formats is reflected in the creation of a tutorial curriculum on Extensible Markup Language (XML) and Resource Description Format (RDF), presented in various forms at CSCW’98 [KR98-2], FSE’98, and graduate seminars at UCI. In addition, he spoke on the “Evolution of the World Wide Web Consortium” at Georgetown’s Media & Cultural Studies program and the “Web of Trust” for a Bay Area Roundtable on Internet-scale security.

Roy Fielding attended APACHECON’98 in San Francisco, October 14-16, as a speaker and founding member of the Apache Group where he gave a presentation on collaborative development of open source software. He also gave an invited, expanded version of this talk regarding “The Apache HTTP Server Project: Lessons Learned from Collaborative Software Development” at AT&T Labs Research in Florham Park, New Jersey, on October 26.

## 4.2. Software Architecture

A paper entitled “Software Architecture and Component Technologies: Bridging the Gap” was presented to the OMG-DARPA Workshop on Compositional Software Architectures [OMTR98].

At the EDCS Demo Days Dry-Run meeting held in Los Angeles, CA, Peyman Oreizy and Rick Brenner (PI from Draper Labs) organized a special interest group on dynamism. In attendance were: Peyman Oreizy, Rick Brenner, Paul Robertson, John Salasin, Bob Balzer, Jim Veitch, Greg Sullivan, Carolyn Talcot, Andre van der Hoeck, David Wile, and Michael Young. The group discussed issues pertaining to dynamism, specifically as dynamism is supported by different EDCS technologies. Topics included granularity of dynamism, the effects of open versus closed systems on dynamism, and separation of concerns in systems supporting dynamism.

Richard N. Taylor presented a paper entitled “Architectural Implications of Common Operator Interfaces” 1998 Ground System Architectures Workshop [TMO98]. He also participated in a panel of the same name.

Jason Robbins presented a paper entitled “Software Architecture Critics in Argo” at the 1998 Conference on Intelligent User Interfaces [RHR98]. The paper was selected as one of the best of

conference, and the authors were invited to submit an expanded version to Knowledge-Based Systems, an international journal.

A paper entitled “Architecture-Based Runtime Software Evolution” [OMT98] by Peyman Oreizy, Nenad Medvidovic, Richard N. Taylor was accepted and presented at the International Conference on Software Engineering (ICSE’98). The paper describes a software architecture-based approach to evolving mission critical software systems during runtime. The paper highlights the role of software connectors in facilitating runtime change.

A paper entitled “Decentralized Software Evolution” [Ore98] by Peyman Oreizy was accepted and presented at the International Conference on the Principles of Software Evolution (IWPSE 98), held in conjunction with ICSE’98. The paper describes the issues in supporting a decentralized model of software evolution, in which multiple, independent parties may evolve a software application.

A paper entitled “On the Role of Software Architectures in Runtime System Reconfiguration” [OT98] by Peyman Oreizy, Richard N. Taylor was accepted and presented at the International Conference on Configurable Distributed Systems (ICCDs 4). The paper describes how architectural style, architectural connectors, and architecture-based analyses combine to provide a reliable and systematic approach to runtime reconfiguration of mission-critical software systems.

Neno Medvidovic presented a paper titled “An Architecture-Based Approach to Software Evolution” [MTR98], authored by Nenad Medvidovic, Richard N. Taylor, and David S. Rosenblum, at the International Workshop on the Principles of Software Evolution, held in conjunction with the International Conference on Software Engineering (ICSE’98).

The paper “Integrating Architecture Description Languages with a Standard Design Method” [RMRR98] was presented by David Redmiles at the International Conference on Software Engineering (ICSE’98).

Nenad Medvidovic presented a paper entitled “Employing Off-the-Shelf Connector Technologies in C2-Style Architectures” at the California Software Symposium (CSS’98) [MDT98].

Rema Natarajan, Nenad Medvidovic, David Rosenblum, Richard Taylor, Elisabetta Di Nitto, and Roy Fielding participated in the Third International Software Architecture Workshop (ISAW-3) [NR98, MT98, CDRW98]. Rema’s paper entitled “Merging Component Models and Architectural Styles” was one of only 8 out of 40-odd position papers to be selected for a presentation in a plenary session of the workshop.

A paper entitled “A Language and Environment for Architecture-Based Software Development and Evolution” by Nenad Medvidovic, David S. Rosenblum, and Richard N. Taylor was accepted to the 1999 International Conference on Software Engineering [MRT99].

A paper entitled “Using Off-The-Shelf Middleware to Implement Connectors in Distributed Software Architectures” by Eric M. Dashofy, Nenad Medvidovic, and Richard N. Taylor was accepted to the 1999 International Conference on Software Engineering [DMT99].

A paper entitled “Exploiting ADLs to Specify Architectural Styles Induced by Middleware” by Elisabetta Di Nitto and David Rosenblum was accepted to the 1999 International Conference on Software Engineering [DR99].

Dick Taylor, David Rosenblum, Gregory Alan Bolcer, Rohit Khare, James Whitehead co-organized the Workshop on Internet Scale Event Notification (WISSEN'98), which was held at the University of California, Irvine, July 13-14, 1998. David Rosenblum gave the opening presentation on "Internet Scale Event Notification" and co-chaired a working group on "Requirements for Internet Scale Event Notification".

Peyman Oreizy and David Rosenblum were invited to attend the NSF/CNR Workshop on the Role of Software Architecture in Testing and Analysis (ROSATEA), held in Marsala, Sicily, Italy, June 30-July 3, 1998. Peyman Oreizy's presented a position paper entitled "Issues in Modeling and Analyzing Dynamic Software Architectures" [Ore98-2]. This paper describes the current state of dynamic software architecture research, and presents a number of open research problems in the area. David Rosenblum presented a paper entitled "Challenges in Exploiting Architectural Models in Software Testing" [Ros98].

### 4.3. Process

Arthur Hitomi gave a 40 minute talk on SWAP (Simple Workflow Access Protocol) at the IETF in Florida, Orlando. He and industry workflow vendors (Oracle, C4, ...) promoted the SWAP mechanism for supporting interoperability of workflows using HTTP and XML technologies. SWAP extends and leverages the HTTP protocol to allow different workflow applications to communicate over this ubiquitous service. SWAP also leverages XML to allow better interoperability and extensibility of workflow data. Gregory Bolcer co-authored an article on SWAP with Gail Kaiser to appear in IEEE Internet Computing [BK99].

Peter Kammer presented a paper entitled "Supporting Distributed Workflow Using HTTP" at ICSP5 [KBTH98].

Peter Kammer participated in the Workshop on Internet-based Groupware for User Participation in Product Development held in conjunction with CSCW'98 [KBB98].

An EDEM paper and demonstration was presented at the 1998 Conference on Intelligent User Interfaces (IUI98) by David Redmiles [HRR98].

David Redmiles presented a paper entitled "An Approach to Large-Scale Collection of Application Usage Data Over the Internet" [HR98] at the 1998 International Conference on Software Engineering (ICSE'98).

David Hilbert presented an EDEM paper entitled "Agents for Collecting Application Usage Data Over the Internet" at the 1998 Conference on Autonomous Agents (Agents'98) [HR98-2].

David Hilbert and David Redmiles presented a paper entitled "Separating the Wheat from the Chaff in Internet-Mediated User Feedback" at the Workshop on Internet-based Groupware for User Participation in Product Development held in conjunction with CSCW'98 [HR98-3].

Shilpa Shukla attended an Activity Theory Tutorial at CSCW '99 in November where she gave an invited presentation on how she applied ethnography and Activity Theory to study collaborative problem resolution contexts within companies such as Apple and Hewlett Packard.

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