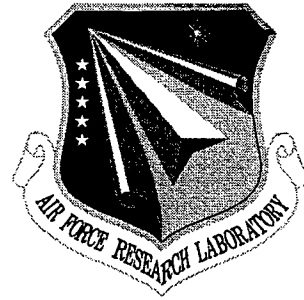


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NEXT GENERATION SOFTWARE PROCESSES AND THEIR ENVIRONMENT SUPPORT

University of Southern California

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NEXT GENERATION SOFTWARE PROCESSES
AND THEIR ENVIRONMENT SUPPORT

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13. ABSTRACT (Maximum 200 words) The USC Center for Software Engineering has developed a negotiation-based approach to software system requirements engineering, architecting, development, and management. It is based on three primary foundations: (1) Theory W, a management theory and approach. It is based on making winners of all of the system's key stakeholders as a necessary and sufficient condition for project success. (2) The WinWin Spiral Model, an extension to the Spiral Model of the software process. It is described further below. (3) The WinWin groupware tool for facilitating distributed stakeholders' negotiation of mutually satisfactory (WinWin) system specifications. The original spiral model [Boehm, 1988] uses a cyclic approach to develop increasingly detailed elaborations of a software system's definition, culminating in incremental releases of the system's operational capability. Each cycle involves four main activities: (1) Elaborate the system or subsystem's product and process objectives, constraints, and alternatives. (2) Evaluate the alternatives with respect to the objectives and constraints. Identify and resolve major sources of product and process risk. (3) Elaborate the definition of the product and process. (4) Plan the next cycle, and update the life-cycle plan, including partition of the system into subsystems to be addressed in parallel cycles. This can include a plan to terminate the project if it is too risky or infeasible. Secure the management's commitment to proceed as planned.				
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1.0 Objectives

The overall objectives of the effort were to develop, experiment with, and iteratively refine a Next Generation Process Model (NGPM) and a Next Generation Process Support System (NGPSS). The objectives of the NGPM and NGPSS were to better support the collaborative definition and development of the increasingly complex, commercial-off-the-shelf (COTS)-driven, user-intensive, and performance-critical software systems required to support current and future Department of Defense (DOD) missions.

The three primary individual objectives were:

- A. Development, evaluation, and refinement of a Next-Generation Process Model (NGPM).
- B. Development, Evaluation, and refinement of a Next-Generation Process Support System (NGPSS).
- C. Development, experimental use, and refinement of an NGPSS testbed supporting the experimental evaluation of the NGPM and NGPSS in Objectives A and B.

In response to a request from Mr. Lloyd Mosemann, Deputy Assistant Secretary of the Air Force for Command, Control, Computers, and Logistics, an additional objective was established to apply the NGPM concepts to an exploratory blue-ribbon panel:

- D. Study on Simulation and Modeling for Software Acquisition (SAMSA).

In response to a request from USAF Electronic Systems Center, a future objective was established to extend the COTS-driven NGPM concepts to:

- E. Develop an experimental COTS integration cost model.

2.0 Approach

The overall research approach has involved iterative experimental prototyping to develop increasingly capable and robust versions of NGPM and NGPSS.

Successive versions of the NGPM, now called the WinWin Spiral Model, developed an integration of win-win and spiral process concepts; refined this into a set of software life cycle anchor points providing entry and exit conditions for the key milestones of the software life cycle; and refined these into a specific set of documentation guidelines for the key anchor point artifacts (Operational Concept Description, Requirements Description, Architecture Description, Life Cycle Plan, and Feasibility Rationale). These continue to be used and iteratively refined under our current DARPA/AFRL contract, "WinWin Extensions for the Evolutionary Development of Complex Systems."

For successive versions of the NGPSS, now called WinWin, we developed an experimental WinWin system and applied it to representative Air Force satellite control system requirement negotiation situations. We then evaluated its strengths and shortfalls; developed a stronger WinWin-95 system with better collaboration support, information management, and instrumentation; and continued to evolve WinWin-95 based on an annual series of over 15 experimental applications, also being continued under our current DARPA/AFRL contract. An example of the approach is provided in Appendix 1, which describes one iteration of WinWin system definition, experimental application on 15 projects, instrumentation, analysis and refinement.

The approach for the SAMSA study involved convening a Government-industry-academia Blue Ribbon panel and holding two workshops to review and refine the concepts and content of a series of increasingly detailed versions of the study report.

The approach for the COTS integration task involved surveying contractor COTS integration experience; formulating a draft model, refining the model in a Government-industry workshop, and calibrating it to an initial set of 6 project data points.

3.0 Discussion of Tasks

3.1 Next Generation Process Model (WinWin Spiral Model)

Section 2 of Appendix 1 describes the WinWin Spiral Model and its evolution, and summarizes the content of its associated Life Cycle Objectives (LCO), Life Cycle Architecture (LCA), and Initial Operational Capability (IOC) anchor point milestones. Further detail has been provided in several technical reports (TR's) whose abstracts are in Appendix 2.

TR USC-CSE-94-501 summarizes the overall structure of the WinWin Spiral Model, and illustrates its application to such complex DOD acquisitions as STARS. TR USC-CSE-94-502 discusses how the Win Win Spiral Model copes with human-intensive processes such as requirements negotiation, which are not well supported by process-programming-language-based process models. TR's USC-CSE-95-504 and-505 provide more detailed models of the interaction between candidate requirements (win conditions) and candidate design solutions (options) within the WinWin framework.

TR USC-CSE-95-507 elaborates on the LCO, LCA and IOC anchor point milestones, and provides explicit mappings between representative WinWin Spiral cycles and anchor point milestones. TR USC-CSE-96-502 relates the stages and states of the WinWin negotiation process model to the stakeholder-satisfaction exit conditions of the LCO and LCA anchor point milestones.

3.2 Next Generation Process Support System (Win Win System)

The initial NGPSS-1 support system used on the contract is described in TR's USC-CSE-93-501 and 94-503. Stakeholder negotiation support involved a set of individual schemas for entering win conditions; identifying conflicts, risks, and uncertainties (CRU's) among win conditions; and defining points of agreement to resolve the CRU's. A top-level equilibrium model was provided of the stakeholder win-win state and the states involved in leaving it and recovering it.

Based on experimental applications of NGPSS-1 to representative Air Force satellite control system requirements negotiations, we defined a stronger negotiation model involving win conditions, issues, options and agreements; uniform schemas representing these, and stronger collaboration support and linkages to negotiation tradeoff tools such as the COCOMO cost model. We developed a new WinWin-95 support system based on these concepts and a cleaner object management infrastructure and user interaction approach. We have continued to evolve WinWin into the 1997 version described in the current WinWin Reference Manual, TR USC-CSE-97-503.

For large applications of WinWin, we found the need for stronger automated support for conflict identification and resolution. The Quality Attribute Risk and Conflict Consultant (QARCC) described in TR USC-CSE-95-506 provides top-level support for identifying conflicts among software quality attributes. The Software Cost Option Strategy Tool (S-COST) described in TR USC-CSE-96-500 provides more detailed support for software cost conflict solution option identification, tradeoff analysis, and win-win solution negotiation.

A detailed formal model of the various win-win, win-lose, and lose-lose states, their state transitions, and their relation to the WinWin equilibrium model is provided in TR USC-CSE-96-501. This formal model enabled us to detect and rectify several anomalous states in the WinWin tool implementation.

3.3 NGPM and NGPSS Experimental Use and Refinement

Our experimental approach in developing and refining NGPM and NGPSS is exemplified in TR USC-CSE-93-499, produced during the contract proposal stage. It describes our bootstrap experiment in using the NGPSS-0 prototype as user, developer, customer, and system engineer stakeholders in the requirements definition for NGPSS-1. The experiment succeeded in balancing stakeholder requirements for the development of NGPSS-1, and confirmed our WinWin Model hypothesis that this process would generate the process and product objectives, constraints, and alternatives needed for each spiral model cycle.

During 1994-95, we developed NGPSS-1, renamed WinWin, and experimentally applied it to a representative Air Force satellite control system in concert with Aerospace Corp. personnel. This experience, described in TR USC-CSE-94-503, enabled us to refine WinWin into the more capable WinWin-95 tool, which was robust enough to apply on a large scale.

TR USC-CSE-96-504 describes our first large-scale WinWin experiment, involving 35 teams role-playing as users, customers, and developers of a hypothetical Library Selective Dissemination of Information system. This experience enabled us to both strengthen WinWin and to integrate its use into the WinWin Spiral Model for the set of 15 real-client library multimedia requirements negotiations, and for the subsequent development of the 6 leading applications, that are described in Appendix 1 (also TR USC-CSE-97-504).

3.4 Simulation and Modeling for Software Acquisition

As indicated in the recent Air Force Scientific Advisory Board "New World Vistas" report, "The future force will become effective and efficient through the use of

information systems..." This particularly requires the Air Force to master the complexities of the rapidly evolving field of computer software, especially in the front end of the system life-cycle.

The need for better support technology for software acquisition was recognized by Mr. Lloyd Mosemann, Deputy Assistant Secretary of the Air Force for Computers, Communications, and Support Systems. He also identified Modeling and Simulation (M&S) technology as a strong candidate for such support. M&S technology has been extremely valuable in the acquisition of the hardware parts of Air Force systems, but appears underutilized for software acquisition. Mr. Mosemann commissioned USC-CSE to form a Blue Ribbon Panel to investigate the potential of M&S technology for software acquisition, and to develop a technology roadmap for creating and exploiting any promising technologies identified.

The Panel identified three emerging technology areas which provide the basis for a set of new capabilities worth pursuing:

- Software product architecture-based modeling and simulation;
- Hybrid analytic and dynamic cost and schedule modeling of software projects;
- An acquisition approach featuring the compatible co-evolution of system modeling, development, and instrumentation.

The Panel also identified a hierarchical and incremental approach toward achieving and applying these capabilities. The initial and top-level steps involve developing capabilities for early use of M&S to assess the feasibility of proposed software solutions: in particular, the development of and experimentation with a Feasibility Analysis Model (FAM) for software systems.

As a result of two workshops, Panel members identified several important FAM requirements including the need to: (i) prototype a software acquisition requirements engineering expert support system as a demonstration of the FAM concept; (ii) integrate domain-specific product-line architecture and resource and scheduling information into the FAM; and (iii) when given a proposed software architecture for program solicitation, to apply FAM to analyze trade-offs and feasibility issues. Panel members also concluded that while useful near-term FAM capabilities were feasible, that full FAM capabilities were a long-range proposition. Thus, an incremental, hierarchical FAM approach is most appropriate.

The hierarchical approach to FAM should initially be focused on addressing the feasibility of top-level or first-cut system requirements, mission objectives, and possible software system architectures in terms of their impact of system reliability, cost, useability, etc. Subsequently, lower-level FAM capabilities should enable more detailed analysis by software system resource and scheduling models/components and later

architectural specification components. These elaborations are needed to more fully characterize and analyze the performance, resources, and schedule for a proposed software system's architecture. Later phases of the development of FAM would include incrementally evolving the focus of the FAM requirements from high-level conceptual system components to eventually address proposed or actual architectural product families, components, and implemented/reusable modules for large-scale software systems during their acquisition.

In terms of FAM research and development, the overall Panel consensus was for an incremental approach. In Stage 1, a top-level proof of principle prototype, designated FAM-1, would be developed. Assuming that the prototype convincingly demonstrates the potential value of a FAM capability, Stage 2 would then proceed in two directions. The first direction would produce an initial operational capability, designated FAM-2, incorporating and productizing the most attractive features of FAM-1. The second direction would involve research on high-leverage advanced FAM capabilities, such as architecture-based modeling and multi-attribute tradeoff analysis. Stage 3 would transition maturing research capabilities into downstream FAM-3 increments of capability.

3.5 Experimental COTS Integration Cost Model

This effort resulted in a 13-parameter model for estimating the costs of integrating COTS products into software application. The experimental model was tested on 6 projects, and found to be reasonably accurate in estimating a subset of the costs (glue code development), but it was also found that extensions were needed to estimate other sources of COTS integration effort (e.g. COTS product assessment and tailoring). Research and development of such extensions is being pursued under follow on contracts with FAA and ONR.

4.0 Discussion of Tools

4.1 NGPSS (WinWin)

In the WinWin support system, each stakeholder is associated with a WinWin client. The clients communicate via the WinWin Router. Stakeholders interact with the WinWin client support system interface to define their individual win conditions, raise issues, suggest options and draft and vote on agreements.

The WinWin negotiation process begins with stakeholders entering their Win Conditions. If a Win Condition is not controversial, it is covered by stakeholders voting on an Agreement. Otherwise, the conflicting Win Conditions are summarized in an Issue. Stakeholders propose Options to resolve the Issues; they explore tradeoffs among

options, and they formulate and vote on Agreements to adopt an Option which resolves an Issue.

Each artifact description is stated in informal text. The WinWin objects created or revised by the stakeholder are recorded in a local database by the WinWin client. Any update operations performed by a stakeholder are noted by the client and used to notify other clients and update their object base using the WinWin Router. Hence each client, in essence keeps a copy of all the WinWin objects. The WinWin support system also has facilities for stakeholder to express opinions on others' artifacts via comments and to attach reference documents or the results of architecture-based cost, schedule, performance and reliability tradeoff models.

It is fully described in the WinWin Reference Manual, TR USC-CSE-97-503.

4.2 *QARCC and S-COST*

The Quality Attribute Risk and Conflict Consultant (QARCC) tool, described in TR USC-CSE-95-506, is an exploratory knowledge-based tool for identifying potential quality attribute risks and conflicts early in the software life-cycle. It operates on the WinWin Domain Taxonomy descriptors for stakeholders' win conditions involving quality attributes, and then uses its knowledge base to suggest draft WinWin Issue forms for potential quality attribute conflicts.

The Software Cost Option Strategy Tool (S-COST), described in TR USC-CSE-96-500, is a more detailed exploratory knowledge-based tool for identifying cost conflict resolution options, and for visualizing the progress of cost conflict resolution negotiations. It is based on the COCOMO cost model knowledge base, and is used in concert with WinWin and the USC COCOMO tool.

5.0 *Technical Transition Activities*

Technical transition activities have included leadership and participation in several DARPA/AFRL public tool demonstrations, and special demonstrations for Air Force and Army programs. CSE has also presented and demonstrated the tools and techniques at its Annual Research Reviews for its roughly 30 Government and Industry Affiliates. Improvement agendas and usage feedback for the tools and techniques have been the topic of several of CSE's semiannual Focused Workshops, resulting in their increased practical value. Other transition facilitators have been the CSE's Web site, technical report series, and numerous presentations at workshops, conferences and symposia.

Among the transition results have been the adoption of the WinWin Spiral Model LCO and LCA anchor points as the key milestones recommended for use in Software Engineering Plan Reviews of DOD projects in the National Research Council's report "Ada and Beyond: Software Policies for DOD." Commercially, Rational, Inc has adopted the LCO, LCA, and IOC anchor points as the key milestones in their Objectory process.

The WinWin system has been experimentally used on several representative satellite control requirements negotiation experiments by Aerospace Corp., and TRW; in the B-2 domain by Northrop Grumman; and in a Synthetic Theater of War application by the DARPA CAETI program. It is one of the few tools to be selected for productization by MCC, Inc., in their shareholder-sponsored Software/System Engineering Productivity program.

The COTS integration cost model has been adopted for further extension and calibration by ONR and the FAA.

6.0 Summary and Lessons Learned

As evidenced by the technology transition results above, this project has provided DoD with a process model (the WinWin Spiral Model) and groupware support system (WinWin) that address many of DoD's current and future needs in developing and evolving extremely complex, high-performance, COTS-driven software on very short schedules. Further, as evidenced by the successful Digital Library projects described in Appendix 1, the techniques and tools have been shown to work well in practice on real-client applications.

The major lessons learned are:

- Successful win-win negotiations require stakeholders who are empowered, accountable, representative, knowledgeable, and collaborative.
- Stakeholder win-win negotiations can generate the objectives, constraints, and alternatives needed for each cycle of the Spiral Model.
- The techniques work best after an initial period of stakeholder training and teambuilding, and with concurrent prototyping.
- People-intensive requirements negotiations have not been repeatable in detail. Overemphasizing a goal of repeatable software processes is unrealistic and often harmful.
- The win-win approach has been able to build trust among software developers, customers, and users.

Additional lessons learned are provided in the Conclusions section of Appendix 1.

7.0 World Wide Web Home Pages

USC Center for Software Engineering:

<http://sunset.usc.edu/>

WinWin and WinWin Spiral Model:

<http://sunset.usc.edu/WinWin/winwin.html>

SAMSA Study:

<http://sunset.usc.edu/SAMSA/samcover.html>

Technical Reports:

<http://sunset.usc.edu/TechReports/electronicopy.html>

Developing Multimedia Applications with the WinWin Spiral Model

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Abstract

Fifteen teams recently used the WinWin Spiral Model to perform the system engineering and architecting of a set of multimedia applications for the USC Library Information Systems. Six of the applications were then developed into an Initial Operational Capability. The teams consisted of USC graduate students in computer science. The applications involved extensions of USC's UNIX-based, text-oriented, client-server Library Information System to provide access to various multimedia archives (films, videos, photos, maps, manuscripts, etc.).

Each of the teams produced results which were on schedule and (with one exception) satisfactory to their various Library clients. This paper summarizes the WinWin Spiral Model approach taken by the teams, the experiences of the teams in dealing with project challenges, and the major lessons learned in applying the Model. Overall, the WinWin Spiral Model provided sufficient flexibility and discipline to produce successful results, but several improvements were identified to increase its cost-effectiveness and range of applicability.

1. Introduction

At the last two International Conferences on Software Engineering, three of the six keynote addresses identified negotiation techniques as the most critical success factor in improving the outcome of software projects. Tom DeMarco stated that "how the requirements were negotiated is far more important than how the requirements were specified" [DeMarco, 1996]. In discussing "Death March" projects, Ed Yourdon stated that "Negotiation is the best way to avoid Death March projects," [Yourdon, 1997]. Mark Weiser concluded that "Problems with reaching agreement were more critical to his projects' success than such factors as tools, process maturity, and design methods" [Weiser, 1997].

At the USC Center for Software Engineering, we have been developing a negotiation-based approach to software system requirements engineering, architecting, development, and management. It is based on three primary foundations:

- Theory W, a management theory and approach. It is based on making winners of all of the system's key stakeholders as a necessary and sufficient condition for project success [Boehm-Ross, 1989].
- The WinWin Spiral Model, an extension to the Spiral Model of the software process. It is described further below.
- The WinWin groupware tool for facilitating distributed stakeholders' negotiation of mutually satisfactory (WinWin) system specifications [Boehm et al., 1995; Horowitz et al., 1997].

2. The WinWin Spiral Model

The original spiral model [Boehm, 1988] uses a cyclic approach to develop increasingly detailed elaborations of a software system's definition, culminating in incremental releases of the system's operational capability. Each cycle involves four main activities:

- Elaborate the system or subsystem's product and process objectives, constraints, and alternatives.
- Evaluate the alternatives with respect to the objectives and constraints. Identify and resolve major sources of product and process risk.
- Elaborate the definition of the product and process.

- Plan the next cycle, and update the life-cycle plan, including partition of the system into subsystems to be addressed in parallel cycles. This can include a plan to terminate the project if it is too risky or infeasible. Secure the management's commitment to proceed as planned.

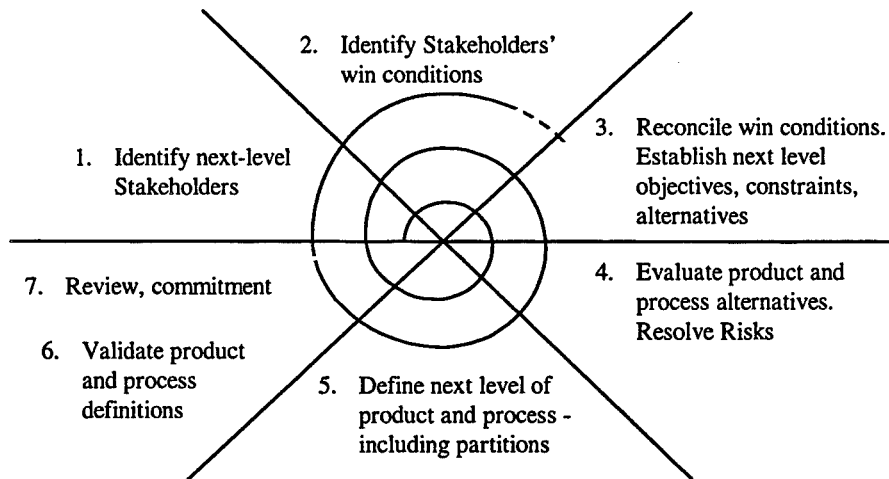
The Spiral Model has been extensively elaborated (e.g., SPC, 1994), and successfully applied in numerous projects (e.g., [Royce, 1990], [Frazier-Bailey, 1996]). However, some common difficulties have led to some further extensions to the model.

One difficulty involves answering the question, "Where do the elaborated objectives, constraints, and alternatives come from?" The WinWin Spiral Model resolves this difficulty by adding three activities to the front of each spiral cycle, as illustrated in Figure 1 [Boehm-Bose, 1994].

- Identify the system or subsystem's key stakeholders.
- Identify the stakeholders' win conditions for the system or subsystem.
- Negotiate win-win reconciliations of the stakeholders' win conditions.

In an experiment involving a bootstrap application of the WinWin groupware system to the definition of an improved version of itself, we found that these steps indeed produced the key product and process objectives, constraints, and alternatives for the next version [Boehm et al, 1994]. The overall stakeholder WinWin negotiation approach is similar to other team approaches for software and system definition such as CORE [Mullery, 1979], gIBIS [Conklin-Begeman, 1988], Viewpoints [Finkelstein, 1991], GRAIL [Dardenne et al., 1993], Tuiqiao [Potts-Takahashi, 1993], Participatory Design and JAD [Carmel et al., 1993]. Our primary distinguishing characteristic is the use of the stakeholder win-win relationship as the success criterion and organizing principle for the software and system definition process. Our negotiation guidelines are based on the Harvard Negotiation Project's techniques [Fisher-Ury, 1981].

Figure 1. The WinWin Spiral Model



2.1. Process Anchor Points

Another difficulty in applying the Spiral Model across an organization's various projects is that the organization can be left with no common reference points around which to organize its management procedures, cost and schedule estimates, etc. In the process of working out this difficulty with our COCOMO II cost model industry and government Affiliates (see Acknowledgments), we found a set of three process anchor points which could be related both to the completion of spiral cycles and to the organization's major decision milestones. Two of these, the Life Cycle Objectives (LCO) and Life Cycle Architecture (LCA) milestones, are elaborated in Table 1. The third, the Initial Operational Capability (IOC), is summarized in Table 2. These anchor points are further elaborated and related to WinWin Spiral Model cycles in [Boehm, 1996]. We also found that the LCO and LCA milestones are highly compatible with the use of the successful Architecture Review Board practice pioneered by AT&T and Lucent Technologies [AT&T, 1993].

Table 1. Contents of LCO and LCA Milestones

Milestone Element	Life Cycle Objectives (LCO)	Life Cycle Architecture (LCA)
Definition of Operational Concept	<ul style="list-style-type: none"> • Top-level system objectives and scope <ul style="list-style-type: none"> - System boundary - Environment parameters and assumptions - Evolution parameters • Operational concept <ul style="list-style-type: none"> - Operations and maintenance scenarios and parameters - Organizational life-cycle responsibilities (stakeholders) 	<ul style="list-style-type: none"> • Elaboration of system objectives and scope by increment • Elaboration of operational concept by increment
Definition of System Requirements	<ul style="list-style-type: none"> • Top-level functions, interfaces, quality attribute levels, including: <ul style="list-style-type: none"> - Growth vectors - Priorities • Stakeholders' concurrence on essentials 	<ul style="list-style-type: none"> • Elaboration of functions, interfaces, quality attributes by increment <ul style="list-style-type: none"> - Identification of TBDs (to-be-determined items) • Stakeholders' concurrence on their priority concerns
Definition of System and Software Architecture	<ul style="list-style-type: none"> • Top-level definition of at least one feasible architecture <ul style="list-style-type: none"> - Physical and logical elements and relationships - Choices of COTS and reusable software elements • Identification of infeasible architecture options 	<ul style="list-style-type: none"> • Choice of architecture and elaboration by increment <ul style="list-style-type: none"> - Physical and logical components, connectors, configurations, constraints - COTS, reuse choices - Domain-architecture and architectural style choices • Architecture evolution parameters
Definition of Life-Cycle Plan	<ul style="list-style-type: none"> • Identification of life-cycle stakeholders <ul style="list-style-type: none"> - Users, customers, developers, maintainers, interoperators, general public, others • Identification of life-cycle process model <ul style="list-style-type: none"> - Top-level stages, increments • Top-level WWWWWHH* by stage 	<ul style="list-style-type: none"> • Elaboration of WWWWWHH* for Initial Operational Capability (IOC) <ul style="list-style-type: none"> - Partial elaboration, identification of key TBDs for later increments
Feasibility Rationale	<ul style="list-style-type: none"> • Assurance of consistency among elements above <ul style="list-style-type: none"> - Via analysis, measurement, prototyping, simulation, etc. - Business case analysis for requirements, feasible architectures 	<ul style="list-style-type: none"> • Assurance of consistency among elements above • All major risks resolved or covered by risk management plan

* WWWWWHH: Why, What, When, Who, Where, How, How Much

Table 2. Contents of the Initial Operational Capability (IOC) Milestone

<p>The key elements of the IOC milestone are:</p> <ul style="list-style-type: none"> • <u>Software preparation</u>, including both operational and support software with appropriate commentary and documentation; data preparation or conversion; the necessary licenses and rights for COTS and reused software, and appropriate operational readiness testing. • <u>Site preparation</u>, including facilities, equipment, supplies, and COTS vendor support arrangements. • <u>User, operator and maintainer preparation</u>, including selection, teambuilding, training and other qualification for familiarization usage, operations, or maintenance.

3. Applying the WinWin Spiral Model

New software process models generally take years to validate. The Spiral Model was originated in 1978, first tried on a 15-person internal TRW project in 1980-82 [Boehm et al, 1982], and only in 1988-92 scaled up to a 100-person contract project [Royce, 1990] and fully-documented method [SPC, 1994]. For the WinWin Spiral Model, we were fortunate to find a family of multimedia applications upon which to test the model: a set of graduate student projects to develop candidate multimedia extensions for the USC Integrated Library System (ILS).

The ILS is a UNIX-based, client-server system based on the SIRSI commercial library information system package and the USC campus computing network. The ILS is primarily text-based, but the Library's management has been quite interested in providing multimedia services to the USC community. Exploratory discussions identified a number of USC multimedia archives--student films, photo and stereopticon archives, technical reports, medieval manuscripts, urban plans, etc.—which appeared to be attractive candidates for transformation into digitized, user-interactive archive management services.

The application of the WinWin Spiral Model to this potential family of multimedia applications involved four major spiral cycles:

- Cycle 0 (Summer 1996): Determining feasibility of an appropriate family of multimedia applications (project family LCO milestone);
- Cycle 1 (Fall 1996): Determining feasibility of individual applications (project LCO);
- Cycle 2 (Fall 1996): Achieving a feasible LCA project milestone for each application;
- Cycle 3 (Spring 1997): Achieving a workable project IOC for each application.

3.1. Cycle 0: Project Family Life Cycle Objectives

During 1993-96, the USC-CSE experimented with teaching the WinWin Spiral Model in its core 100-student MS-level software engineering course, using representative but hypothetical applications. In 1995-96, the application was a hypothetical advanced library application: a selective dissemination of information system using a form of “push” technology. Some of the library staff, primarily Kwan (then Director of the Science and Engineering Library, and Denise Bedford (then ILS Project Manager), detected an unusually high level of student interest in library operations resulting from this assignment. They followed up with the instructor (Boehm) to determine whether all of this student energy and talent could be channeled toward developing useful USC Library applications.

CSE had been looking for such a source of new applications, so in Summer 1996, Kwan, Bedford, Boehm, and Egyed (the prospective teaching assistant for the 1996-97 software engineering course), explored each other's win conditions to determine whether a feasible set of life-cycle objectives for a family of USC Library applications could be identified. The most feasible applications area turned out to be the exploratory multimedia applications. Table 3 summarizes the win conditions for the three primary stakeholders: the Library information technology community,

Table 3. Primary Stakeholder Win Conditions

Library Information Technology and Users	Library Operations and Users	Center for Software Engineering
<ul style="list-style-type: none"> • Accelerated transition to digital library capabilities; Dean's vision • Evaluation of emerging multimedia archiving and access tools • Empowering library multimedia users • Enhancing library staff capabilities in high-performance online library services • Leveraging limited budget for advanced applications 	<ul style="list-style-type: none"> • Continuity of service • No disruption of ongoing transition to SIRSI-based Library Information System • Operator career growth opportunities • No disruption of USC Network operations and services • More efficient operations via technology 	<ul style="list-style-type: none"> • Similarity of projects (for fairness, project management) • Reasonable match to WinWin Spiral Model • 15-20 projects at 5-6 students per team • Meaningful LCA achievable in 1 semester • Meaningful IOC achievable in 2 semesters • Adequate network, computer, infrastructure resources

including its users; the Library operational community, including its users; and the Center for Software Engineering.

As indicated in Table 3, the *Library information technology community* was energized by the vision of the new Dean of the University Libraries, Dr. Jerry Campbell, to accelerate the Libraries' transition to digital capabilities. A new dedicated computer-interactive facility, the Leavey Library, and the transition to the SIRSI client-server library information system were whetting users' appetites for advanced applications. However, there was little budget for evaluating emerging multimedia technology and developing exploratory applications.

The *Library operations community* and its users were already undergoing a complex transition to the new SIRSI system. They were continually on the lookout for new technology to enhance their operations, but also highly sensitive to the risks of disrupting continuity of service, and limited in their resources to experiment in new areas.

The *Center for Software Engineering* had a large pool of talent to develop exploratory applications, if the applications could fit within the constraints of student courses. These included not only schedule and computer resource constraints (e.g., 10 megabytes of disk storage per student), but also constraints on fairness of grading and available instructor and teaching assistant time, which translated into the need for a family of highly similar (but not identical) projects.

During Summer 1996, Kwan and Bedford identified a set of candidate Library multimedia projects and

Figure 2. Example Library Multimedia Problem Statements

<p>Problem Set #2: Photographic Materials in Archives Jean Crampon, Hancock Library of Biology and Oceanography</p> <p>There is a substantial collection of photographs, slides, and films in some of the Library's archival collections. As an example of the type of materials available, I would like to suggest using the archival collections of the Hancock Library of Biology and Oceanography to see if better access could be designed. Material from this collection is used by both scholars on campus and worldwide. Most of the Hancock materials are still under copyright, but the copyright is owned by USC in most cases.</p>
<p>Problem Set #8: Medieval Manuscripts Ruth Wallach, Reference Center, Doheny Memorial Library</p> <p>I am interested in the problem of scanning medieval manuscripts in such a way that a researcher would be able to both read the content, but also study the scribe's hand, special markings, etc. A related issue is that of transmitting such images over the network.</p>
<p>Problem Set #9: Formatting Information Caroline Sisneros, Crocker Business Library</p> <p>Increasingly the government is using the WWW as a tool for dissemination of information. Two much-used sites are the Edgar Database of Corporate Information (http://www.sec.gov/edgarhp.htm) and the Bureau of the Census (http://www.census.gov). Part of the problem is that some of the information (particularly that at the EDGAR site) is only available as ASCII files. For information that is textual in nature, while the files can be cleaned up, formatting of statistical tables is often lost in downloading, e-mailing, or transferring to statistical programs. And while this information is useful for the typical library researcher, who usually have a very distinct information need, the investment in what it would take to put this information in a usable format is often too much trouble.</p>
<p>Problem Set #13: Moving Image Archive Sandra Joy Lee, Moving Image Archive, School of Cinema/TV</p> <p>The USC Moving Image Archive houses USC student film and video productions dating from the 1930s to current productions in the School of Cinema-Television. Moving image materials in multiple formats, specialized viewing equipment, limited storage space, and complex access needs create challenges that may be solved with new computer technologies. Fifteen movie clips (.mov format), each approximately 45 minutes in length, over 100 digital film stills (.gif format), and textual descriptions of the films will be made available to students wishing to explore this project.</p>

clients, and provided brief summaries of each. Examples are shown in Figure 2. Successful convergence on the project-family LCO milestone was achieved by an exchange of memoranda between the Library and the CSE. A memo from Boehm to Charlotte Crockett, Director of the Leavey Library, summarized the proposed set of projects, the potential Library costs and risks and how they would be addressed, and the envisioned Library benefits in terms of their win conditions. A memo to Boehm from Lucy Wegner, the Library's interim Assistant Dean for Information Technology, provided specific constraints under which the Library would participate (e.g., no disruption of Library services; no interference with other librarian responsibilities; use of only the Library's test LIS host, only after LIS testing was complete; no advance commitments to use the results or to continue into product development in Spring 1997).

3.2. Cycle 1: Individual Application Life Cycle Objectives

Figure 3 shows the multimedia archive project guidelines as provided to the Library staff during Cycle 0 and provided to the students on the first day of class, August 28, 1996. The guidelines provided about 2 ½ weeks for the students to organize into teams, and 11½ weeks to complete the LCO and LCA milestones.

In addition, the projects were provided with guidelines for developing each of the five documents indicated in the Product Objectives of Figure 3, including approximate page budgets for the LCO and LCA version of the documents. They were also provided with guidelines and an example of a multimedia archive prototype, and a domain model for a typical information archive extension (Figure 4). The domain model identifies the key stakeholders involved in such systems, and such key concepts as the system boundary: the boundary between the system being developed and its environment.

The course lectures followed the WinWin Spiral Model in beginning with overviews of the project artifacts and how they fit together, and with key planning and organizing guidelines. The project teams were self-selected; a key risk management emphasis was on the risk of forming teams with incompatible people and philosophies. As a result, there were relatively few personnel problems during this phase, compared with previous offering of the course. Later lectures provided more detail on the artifacts, plus guest lectures from Kwan and others on Library operations and the SIRSI system, and from experts in such areas as user interface design and multimedia system architecting.

The Fall 1996 course ended up with 86 students. Most were in 6-person teams. To accommodate special cases, including roughly 25 off-campus students, there were 2 teams with four students, one with five, and one with seven, for a total of 15 teams. The course ended up with 12 Library multimedia applications to be architected. Table 4 lists these, and indicates which three applications were done by two teams, and also which were implemented directly (*) by five of the six teams in Spring 1997, and which were combined into a single implementation by the sixth team (**).

Table 4. Library Multimedia Applications

Team	Application	Client
* 1.	Stereoscopic Slides	John Ahouse
**2.	Latin American Pamphlets	Barbara Robinson
**3,5.	EDGAR Corporate Data	Caroline Cisneros
**4.	Medieval Manuscripts	Ruth Wallach
* 6,10.	Hancock Photo Archive	Jean Crampon
7.	ITV Courseware Delivery	Julie Kwan
**8,11.	Technical Reports Archives	Charles Phelps
**9.	CNTV Moving Image Archive	Sandra Joy Lee
12.	Student Access to Digital Maps	Julie Kwan
*13.	LA Regional History Photos	Dace Taube
14.	Korean-American Museum	Ken Klein
15.	Urban Planning Documents	Robert Labaree

* - Combined in Spring 1997

** - Implemented in Spring 1997

Figure 3. Multimedia Archive Project Guidelines

Project Objectives

Create the artifacts necessary to establish a successful life cycle architecture and plan for adding a multimedia access capability to the USC Library Information System. These artifacts are:

1. An Operational Concept Definition
2. A System Requirements Definition
3. A System and Software Architecture Definition
4. A Prototype of Key System Features
5. A Life Cycle Plan
6. A Feasibility Rationale, assuring the consistency and feasibility of items 1-5

Team Structure

Each of the six team members will be responsible for developing the LCO and LCA versions of one of the six project artifacts. In addition, the team member responsible for the Feasibility Rationale will serve as Project Manager with the following primary responsibilities:

1. Ensuring consistency among the team members' artifacts (and documenting this in the Rationale).
2. Leading the team's development of plans for achieving the project results, and ensuring that project performance tracks the plans.

Project Approach

Each team will develop the project artifacts concurrently, using the WinWin Spiral approach defined in the paper "Anchoring the Software Process." There will be two critical project milestones: the Life Cycle Objectives (LCO) and Life Cycle Architecture (LCA) milestones summarized in Table 1.

The LCA package should be sufficiently complete to support development of an Initial Operational Capability (IOC) version of the planned multimedia access capability by a CS577b student team during the Spring 1997 semester. The Life Cycle Plan should establish the appropriate size and structure of such a team.

WinWin User Negotiations

Each team will work with a representative of a community of potential users of the multimedia capability (art, cinema, engineering, business, etc.) to determine that community's most significant multimedia access needs, and to reconcile these needs with a feasible implementation architecture and plan. The teams will accomplish this reconciliation by using the USC WinWin groupware support system for requirements negotiation. This system provides facilities for stakeholders to express their Win Conditions for the system; to define Issues dealing with conflicts among Win Conditions; to support Options for resolving the Issues; and to consummate Agreements to adopt mutually satisfactory (win-win) Options.

There will be three stakeholder roles:

- Developer: The Architecture and Prototype team members will represent developer concerns, such as use of familiar packages, stability of requirements, availability of support tools, and technically challenging approaches.
- Customer: The Plan and Rationale team members will represent customer concerns, such as the need to develop an IOC in one semester, limited budgets for support tools, and low-risk technical approaches.
- User: The Operational Concept and Requirements team members will work with their designated user-community representative to represent user concerns, such as particular multimedia access features, fast response time, friendly user interface, high reliability, and flexibility of requirements.

Major Milestones

September 16	---	All teams formed
October 14	---	WinWin Negotiation Results
October 21,23	---	LCO Reviews
October 28	---	LCO Package Due
November 4	---	Feedback on LCO Package
December 6	---	LCA Package Due, Individual Critique Due

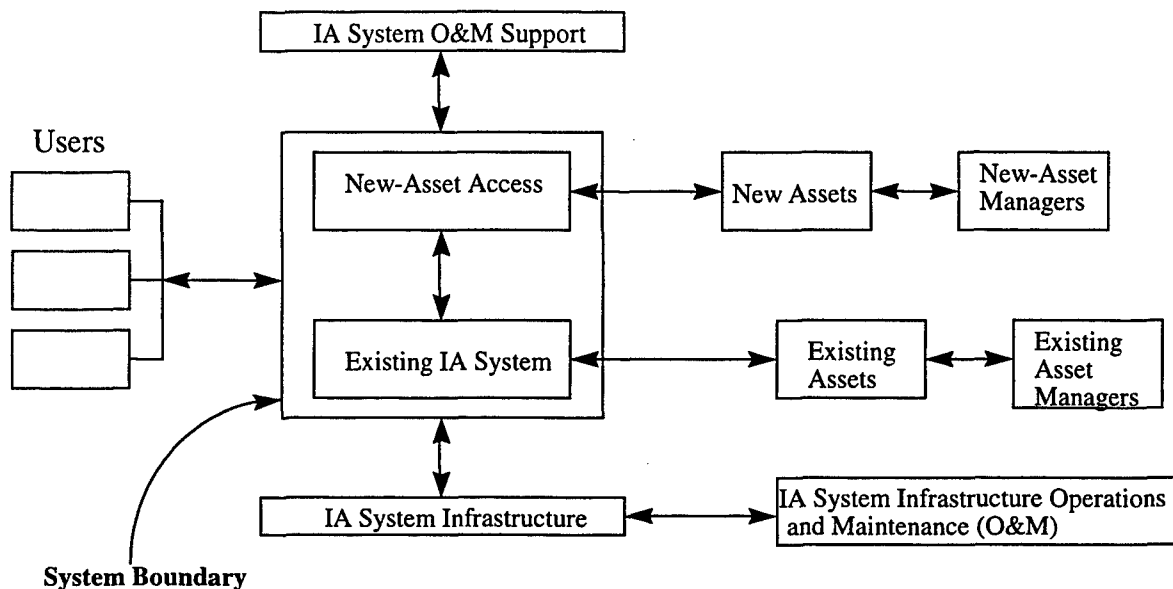
Individual Project Critique

The project critique is to be done by each individual student. It should be about 3-5 pages, and should answer the question, "If we were to do the project over again, how would we do it better - and how does that relate to the software engineering principles in the course?"

Figure 4. Information Archive Extension Domain Model

1. System Block Diagram:

This diagram shows the usual block diagram for extensions providing access to new information archive assets from an existing information archive (IA) System:



The system boundary focuses on the automated applications portion of the operation, and includes such entities as users, operators, maintainers, assets, and infrastructure (campus networks, etc.) as part of the system environment. The diagram abstracts out such capabilities as asset catalogues and direct user access to O&M support and asset managers.

2. Some Stakeholder Roles and Responsibilities

- 2.1 Asset Managers. Furnish and update asset content and catalogue descriptors. Ensure access to assets. Provide accessibility status information. Ensure asset-base recoverability. Support problem analysis, explanation, training, instrumentation, operations analysis.
- 2.2 Operators. Maintain high level of system performance and availability. Accommodate asset and services growth and change. Protect stakeholder privacy and intellectual property rights. Support problem analysis, explanation, training, instrumentation, operations analysis.
- 2.3 Users. Obtain training. Access system. Query and browse assets. Import and operate on assets. Establish, populate, update, and access asset-related user files. Comply with system policies. Provide feedback on usage.
- 2.4 Application Software Maintainer. Perform corrective, adaptive and perfective (tuning, restructuring) maintenance on software. Analyze and support prioritization of proposed changes. Plan design, develop, and verify selected changes. Support problem analysis, explanation, training, instrumentation, operations analysis.
- 2.5 Service providers (e.g. network, database, or facilities management services).
Similar roles and responsibilities to Asset Managers under 2.1

Each project's LCO cycle was focused by the use of the USC-CSE WinWin groupware system for requirements negotiation [Boehm et al, 1995; Horowitz et al, 1997]. "The WinWin User Negotiations" section of Figure 3 summarizes the WinWin artifacts and the stakeholder (developer, customer, and user) roles to be played by the various project team members. To minimize the impact on Library operations, the user artifacts were entered by the student Operational Concept and Requirements team members, rather than the librarians themselves.

Besides support for entering, refining, and negotiating Win Conditions, Issues, Options, and Agreements, WinWin includes a Domain Taxonomy to aid in organization, navigation, and terminology control of these artifacts. Table 5 shows the domain taxonomy for multimedia archive systems furnished to the teams, along with guidelines for relating the taxonomy elements to the requirements specification elements needed for the LCO package.

Table 5. Multimedia Archive Domain Taxonomy

1. Operational Modes
 - 1.1 Classes of Service (research, education, general public)
 - 1.2 Training
 - 1.3 Graceful Degradation and Recovery
2. Capabilities
 - 2.1 Media Handled
 - 2.1.1 Static (text, images, graphics, etc.)
 - 2.1.2 Dynamic (audio, video, animation, etc.)
 - 2.2 Media Operations
 - 2.2.1 Query, Browse
 - 2.2.2 Access
 - 2.2.3 Text Operations (find, reformat, etc.)
 - 2.2.4 Image Operations (zoom in/out, translate/rotate, etc.)
 - 2.2.5 Audio Operations (volume, balance, forward/reverse, etc.)
 - 2.2.6 Video/Animation Operations (speedup/slowdown, forward/reverse, etc.)
 - 2.2.7 Adaptation (cut, copy, paste, superimpose, etc.)
 - 2.2.8 File Operations (save, recall, print, record, etc.)
 - 2.2.9 User Controls
 - 2.3 Help
 - 2.4 Administration
 - 2.4.1 User Account Management
 - 2.4.2 Usage Monitoring and Analysis
3. Interfaces
 - 3.1 Infrastructure (SIRSI, UCS, etc.)
 - 3.2 Media Providers
 - 3.3 Operators
4. Quality Attributes
 - 4.1 Assurance
 - 4.1.1 Reliability/Availability
 - 4.1.2 Privacy/Access Control
 - 4.2 Interoperability
 - 4.3 Usability
 - 4.4 Performance
 - 4.5 Evolvability/Portability
 - 4.6 Cost/Schedule
 - 4.7 Reusability
5. Environment and Data
 - 5.1 Workload Characterization
6. Evolution
 - 6.1 Capability Evolution
 - 6.2 Interface and Technology Evolution
 - 6.3 Environment and Workload Evolution

The taxonomy serves as a requirements checklist and navigation aid:

- The taxonomy elements map onto the Requirements Description table of contents in the Course Notes.
- Every WinWin stakeholder artifact should point to at least one taxonomy element (modify elements if appropriate).
- Every taxonomy element should be considered as a source of potential stakeholder win conditions and agreements.

Figure 5 shows two examples of Win Condition artifacts from the Moving Image Archive (student films) team. It shows how the artifacts are related to each other (the Referenced By entries) and to the domain taxonomy elements (the Taxonomy Element entries), plus additional information on the artifact's owner, priority, status, etc. It also shows how the Comments field is used by the team members in clarifying concepts, removing inconsistencies, and informally exploring negotiated agreements.

The WinWin negotiation period took longer than expected. Complexities in scaling up the tool to 15 on-campus/off-campus teams caused difficulties, and the teams needed to simultaneously learn enough about WinWin, team operations, and the library multimedia applications domain to succeed. As a result, the deadlines for completing

Figure 5. Example WinWin Artifacts

<ul style="list-style-type: none"> • ID: arucker-WINC-6 • Owner: arucker • Role: user • Creation_Date: 10/15/96 12:25 • Revision_Date: 10/15/96 12:25 • Name: View holdings • Body: The system should be capable of showing the different types of media holdings (production notebook, vhs, 16mm film, etc) that are available for a particular movie. • Priority: High • Status: Active • State: Covered • Taxonomy Elements: 3.2.1 Query • Taxonomy Elements: 3.2.2 Browse • ReferencedBy: arucker-AGRE-2, LinkFromAgre,Passed • Comments : <p>firouzta 10/16/96 07:52</p> <p>I am not clear on this win condition. Does this mean that for the material that is not digitized, the system should only present information on the type of the media on which the material is stored? Or, is it that all material, digitized or not, has information on other types of media that the material is stored on, and the system will provide the user with this information?</p> <p>arucker 10/16/96 12:51</p> <p>It means that for each movie, the system will provide information about the various types of media that the movie is stored on.</p>
<ul style="list-style-type: none"> • ID: arucker-WINC-7 • Owner: arucker • Role: user • Creation_Date: 10/16/96 13:00 • Revision_Date: 10/17/96 13:13 • Name: Online Request • Body: The system should allow online requests of movies from the Moving Image Archive. • Priority: Medium • Status: Active • State: Covered • Taxonomy Elements: 3.2.1 Query • Taxonomy Elements: 3.2.2 Browse • ReferencedBy: arucker-AGRE-1, LinkFromAgre,Passed • Comments : <p>arucker 10/16/96 16:30</p> <p>I'm not sure which item of the taxonomy this should refer to.</p> <p>firouzta 10/16/96 21:05</p> <p>2.2.1 and 2.2.2</p>

the WinWin package and the LCO package were moved back a week. Fortunately, the LCO packages were good enough that the LCA cycle could be compressed by a week.

All 15 of the project LCO packages were delivered on time with respect to the revised schedule. Their degree of completeness was generally appropriate for an LCO package, but the components often had serious inconsistencies in assumptions, relationships, and terminology. Most teams had planned time for members to review each others' artifacts, but this time was generally spent finishing up one's own artifacts. Some concepts caused problems for many teams: the nature of the system boundary; organizational relationships; and the primary focus of the life-cycle plan (development of the Initial Operational Capability). These were then discussed further in the course lectures.

3.3. Cycle 2. Individual Application Life Cycle Architectures

All 15 of the project LCA packages were delivered on time, including the prototypes, which were demonstrated to the instructors and librarian clients in two special half-day sessions. The documentation packages had effectively fixed the problems surfaced in the LCO packages but had additional challenges in accommodating the new user insights stimulated by the prototypes.

Although the librarians created the problem statement and participated in the requirements negotiation with the student teams and with various stages of the prototype, the final prototype presentations yielded insightful surprises. Caroline Sisneros, the librarian who proposed the Edgar corporate data problem was "blown away" with the resultant product which built upon the seemingly simple text formatting problem and delivered a one-stop Java site which synthesized several kinds of business information. She commented in her evaluation memo "[The team] obviously looked beyond the parameters of the problem and researched the type of information need the set of data meets. My interactions with the team were minimal, not because of any difficulty, but because as a group they had a synergy and grasped the concepts presented to them. The solution the team came up with was innovative, with the potential to be applied to other, similar problems."

The library clients were generally very satisfied with the value added relative to their time invested. Sandra Joy Lee, the proposer for the Digital Moving Image Archive, commented "They were very instrumental in the discovery of solutions that did not demand too much staff time from my office. In short order, they solved all the problems with creativity and technical sophistication."

The projects also surmounted a number of challenges characteristic of real-world projects. The Library Information System test server continued to be needed for the LIS cutover, and was therefore unavailable to the project prototypes. There were delays in arranging for a suitable alternative Web server for developing prototypes. At times librarians were unavailable to provide inputs on critical decisions, leading to extra rework. Inevitable personnel conflicts arose among the 15 teams. However, the WinWin Spiral Process provided an appropriate mix of flexibility and discipline to enable the projects to adapt to these challenges while staying on schedule. In particular, the use of risk management and a continuously-evolving Top 10 Risk Item list for prioritizing team effort [Boehm, 1991] helped the teams focus their effort on the most critical success factors for their projects.

With respect to the LCO-LCA process, the student critiques provided a number of areas for future improvement. The WinWin groupware tool helped with team building and feature prioritization, but people needed more preliminary training and experience in its use. It was also cumbersome to modify groups of WinWin artifacts. Several items, particularly the prototyping capabilities, should have been provided and employed earlier. The prototypes helped a great deal in clarifying and stabilizing the librarians' requirements; they could have helped even more if available during the initial WinWin requirements negotiation process.

Although it was strongly emphasized during the initial lectures, students felt that an even stronger emphasis was needed on the risks of forming teams with personality conflicts and critical-skill shortfalls. The strong focus on the six specific team member roles was good in ensuring that each product component was successfully generated, but it caused difficulties in keeping all the team members apprised of issues and developments with the other components. Consistency management of partially redundant components (operational concept, requirements, architecture) became particularly difficult, especially in adapting to change. There was strong consensus that smaller teams and fewer, better-integrated components would have been more effective.

Another difficulty involved consistency maintenance among the multiple views. The various product views required were synthesized from multiple sources: the [Sommerville, 1996] course textbook, evolving commercial standards [IEEE-EIA, 1995], and object-oriented methods, particularly [Booch, 1994] and [Rumbaugh et al, 1991]. The views included system block diagrams, requirements templates, usage scenarios, physical architecture diagrams,

class hierarchies, object interaction diagrams, data flow diagrams, state transition diagrams, data descriptions, and requirements traceability relations. Each had its value, but the overall set was both an overkill and was weakly supported by integrated tools. We plan on using a more concise and integrated set of views next year, based on the Rational Unified Modeling Language and toolset [Booch-Jacobson-Rumbaugh, 1997].

3.4. Cycle 3: Development of Initial Operational Capabilities

The transition from an LCO/LCA phase with 86 students, 15 teams, and 12 applications to an IOC phase with 28 students, 6 teams, and 8 applications caused a number of challenges. Only one team retained the majority of their LCO/LCA participants for their IOC phase. The other teams had to work with a mix of participants with varying project backgrounds.

Even more challenging was the integrating of teams who had produced different LCA artifacts for the same application: the two EDGAR Corporate Data teams and the two Technical Reports teams. In two cases, the instructors had to persuade students to join different teams rather than continuing to fight about whose architecture was best. Other conflicts developed within teams where some team members had extensive LCA experience on the application and others had none (in one case, the experienced members exploited the less experienced members; in another case, vice versa).

Other challenges included a change of instructor (Boehm to Madachy), a change of process model (spiral to risk-driven waterfall), and documentation approach (*laissez-faire* to everything-on-the-Web). Also, there were infrastructure surprises: the SIRSI server and the SIRSI-related search engine were expected to be available for Cycle 3, but were not.

Nonetheless, each of the projects successfully delivered their IOC packages of code, life cycle documentation, and demonstrations on time. A major reason was the strong emphasis on risk management, which enabled teams to depart from a pure waterfall approach to resolve whatever critical risk items surfaced. An example of one of the teams' initial Top-N risk item lists is shown as Table 6. Risks were prioritized by assessments of their risk exposure (probability-of-loss times magnitude-of-loss), and reassessed weekly with respect to changes in criticality and progress in risk resolution. As indicated in Table 6, a key strategy was design-to-schedule: identifying a feasible core capability and optional features to be implemented as schedule permitted.

In the student critiques for Cycle 3, the most common suggestion for *course improvement* was to provide a solid DBMS and search engine (13 of 28 critiques). The next highest was again to reduce the quantity and redundancy of the documentation (9 of 28 critiques). Project timesheets indicated that total documentation-related effort (requirements, plans, design, product documentation) during Cycle 3 was 47% of the total, with two projects as high as 54% and 60%.

Other common suggestions (appearing in 6 to 8 critiques) were for better documentation guidelines, better match of course notes and lectures to project activities, more timely feedback on intermediate products, more disk space, better tools (scanning, HTML conversion, CM) and more training on key Web skills. The most common suggestions for *project improvement* were improved intra-team communication (8 critiques), early error elimination (7), improved client communication (5), and improved on/off-campus team coordination (5). We are using these insights to improve the organization of next year's projects.

From the client standpoint, all of the librarian participants had been very pleased with the prototype demonstration and LCA packages, and were fully supportive of continuing work with their student teams during the second semester. However, the second semester had a smaller enrollment since it was not a required course as during the first semester. Consequently, only six projects were continued during the IOC phase due to the reduction in the number of teams. The LCA projects performed by the continuing students then directed the choice of continuing projects rather than any priority views of the librarians.

The librarians' involvement with the student teams during the second semester was, for the most part, qualitatively and quantitatively different than during the preceding semester. Major system requirements had already been negotiated, but there were typically a few new requirements when the project was taken on by newly reconstituted project teams whose views added subtle differences to the original concepts. Nonetheless, the time required for the librarians' participation was not as extensive as during the preceding semester with the exception of one team. The LAPIS project faced another challenge, having technical problems with scanning and OCR of sample documents until just before the final IOC demonstration. Consultation with a faculty member who uses these technologies for his research in machine translation indicated that the types of documents used, given their historic type fonts, represented

Table 6. Example Top-N Risk Item List

Risk	Risk Aversion Options	Risk Monitoring
1. Changes of requirements from previous semester.	<p>Option 1: Propose a solution for the system (describing the requirements in details) to the users and having them commit to the requirements.</p> <p>Option 2: Adopt an incremental approach to the development by building a prototype first.</p>	<p>Option 1: Once committed, the requirements must be closely monitored. Changes to requirements must be thoroughly assessed and if excessive, they should be defer till later.</p> <p>Option 2: This has an impact on the schedule and hence close monitoring on progress and effort are required.</p>
2. Tight Schedule	Study the requirements carefully so as not to overcommit. Descope good-to-have features if possible. Concentrate on core capabilities.	Close monitoring of all activities is necessary to ensure that schedule are met.
3. Size of project	If requirements are too excessive, descope good-to-have features and capabilities out of the project. Identify the core capabilities to be built.	
4. Finding a search engine	Conduct a software evaluation of search engine. Have team members actively source for free search engines and evaluate them. Determine the best for the project.	Have team members submit evaluation report and conduct demos so that an informed decision can be made.
5. Required technical expertise lacking	Identify the critical and most difficult technical areas of the project and have team members look into them as soon as possible.	Monitor the progress of these critical problems closely. If need be, seek external help.

a separate OCR research problem in itself; the faculty member was then able to help the project implement a fallback solution.

With one exception, the librarians were delighted with the final IOC presentations. The skillful integration of the requirements and functionality of finished products was evident to all. Kwan noted in her evaluation memo "The interaction between the student teams and the librarians produced obvious differences in products designed for different users. For example, the technical reports interface mirrored the technical nature of the type of material included and expected future users of the system while the moving image archive interface reflected the needs and interests of a very different clientele." Barbara Robinson, who proposed LAPIS (Latin American Pamphlet Information System), saw the project as a means for the international community of Latin Americanists to preserve fragile material, a difficult conservation issue for the community; after the IOC delivery, she prepared a proposal to expand the project for full-scale implementation.

The one exception project was the attempt to integrate the three photographic-image application (stereoscopic slides, Hancock photo archive, LA regional history photos) into a single application. The short schedule required the team to patch together pieces of the three architectures and user interfaces. Some features of the result were good (e.g., a colored-glasses stereo capability with good resolution), but none of the clients were enthusiastic about implementing the results. The other five application are either being adopted or extended for possible adoption by the Library elements.

The librarians expressed in their evaluations that working with Theory W and WinWin philosophy made it easy for them to "think big" about their projects. The negotiation process, however, made it possible for the teams and librarians to agree mutually on a feasible set of deliverables for the final IOC products during the academic session. And, although the time commitment was not great, participation in this project allowed the librarians to focus a part of their time and thinking on multimedia applications and software engineering. One of the greatest advantages for the librarians involved was to become more familiar with digital library issues and the software engineering techniques which are involved in their implementation.

Further details on the project processes and artifacts can be found in their USC-CSE Web pages: 'http://sunset.usc.edu/classes/cs577a' and 'http://sunset.usc.edu/classes/cs577b.'

4. Conclusions

We had a number of hypotheses we wished to test with respect to the use of the WinWin Spiral Model for multimedia applications or other similar applications. Unfortunately, considerations of stakeholder satisfaction (successful applications for the library clients; fairness of grading for the students) conflict with the most rigorous forms of experimental design. For example, having some teams operate in a contract-oriented, adversarial, waterfall-model mode would have been a better test of the relative benefits of using the WinWin Spiral Model. However, given available experience, it did not seem feasible or fair to consign some projects to use such a mode.

Modulo these caveats, here are the main hypotheses we wished to test, and a summary of the best evidence we can provide about them.

Hypothesis 1. Teams can use the WinWin Spiral Model to simultaneously develop the components of a consistent and feasible LCA package for a new multimedia application in 11 weeks. Each of the 15 LCA teams delivered their packages on time, and satisfied an extensive set of grading criteria covering each LCA component the conceptual integrity of the integrated package, and client evaluations of the prototypes.

Hypothesis 2. Using two (LCO and LCA) spiral cycles to develop the LCA package was feasible and value-adding. Feasibility of two cycles is covered under Hypothesis 1. Based on the results of the LCO reviews, using a single spiral cycle would have produced less satisfactory results in about half of the projects. Several projects produced unbalanced detail in either the archiving or the query/browsing part of their LCO packages; the LCA cycle enabled than to balance their architecture packages. On the other hand, using three cycles would have left insufficient time to both produce and coordinate three sets of artifacts.

Hypothesis 3. The Library clients will see enough prospective value in the LCA packages to decide to continue as many as possible into full-scale development. There were more than enough clients for the six project teams available in Spring 1997. Perhaps erroneously, we tried to have one project team address all three image-archive applications. Some additional LCA packages (historical maps, urban plans) had considerable client interest but could not be pursued.

Hypothesis 4. The LCA packages would be adequate to ensure satisfactory IOC development in 11 weeks. Again, all six teams completed full IOC packages on time. The projects having the most difficulties were the ones which started with two LCA packages for the same application (startup difficulties) or with LCA packages for three separate image archive applications (conceptual integrity difficulties).

Hypothesis 5. The WinWin Spiral approach will produce wins for the stakeholders. Five of the six completed projects had highly enthusiastic clients who are continuing with the applications developed. The sixth IOC product's clients did not wish to continue with the product developed, but were receptive to another try. The preponderance of the student critiques indicated that the experience had been valuable and career-enhancing. Even the documentation overkill was considered by some students as good preparation for many industrial projects with similar overkill.

Hypothesis 6. The WinWin Spiral approach will be flexible enough to adapt to real-world conditions. Section 3 summarized many real-world conditions (pleasant and unpleasant surprises with COTS packages; unavailability of expected infrastructure packages and library information system expertise; personnel complications and changes) to which the projects were successfully able to adapt. More formal or contract-oriented approaches would not have been able to accommodate the necessary change processing in the short times available for architecting and development.

Hypothesis 7. The WinWin Spiral approach will efficiently use the developers' time. As indicated under Hypothesis 6, the approach avoided some inefficiencies. However, as implemented, it had some significant inefficiencies in document overkill and multiple-view coordination. Next year's projects will have less redundant and voluminous documentation, an integrated toolset (the Rational ROSE system and its associated packages), and smaller development teams.

Hypothesis 8. The WinWin tool outputs can transition smoothly into requirements specifications. This had been a problem in previous uses of WinWin. Mapping the WinWin domain taxonomy onto the table of contents of the requirements specification, and requiring the use of the domain taxonomy as a checklist for developing WinWin Agreements, effectively focused stakeholder negotiations and facilitated transitioning WinWin Agreements into

requirements specifications. The manual transition engendered some inefficiencies; we are exploring automated aids for the transition.

Hypothesis 9. The WinWin approach will improve developer-client relations. In terms of the fear, uncertainty, and doubt often exhibited by clients toward new applications, the Library clients exhibited virtually no fear, considerable uncertainty, and some doubt about going forward with the projects, as indicated by the project conditions stipulated by the Library memo (Section 3.1). By the LCA milestone, as indicated by a meeting between the computer science principals and Dean Campbell and the Library principals, the uncertainty and doubt about working with the student teams had been replaced by enthusiasm and considerable trust (although a good deal of uncertainty remained about the applications' technical parameters). This growth of enthusiasm and trust continued through the development period, and has led to a mutual commitment to pursue further projects in 1997-98. The ability of the WinWin approach to foster trust was consistent with earlier experiences [Boehm-Bose,1994].

Bottom Line:

Overall, the projects' results indicate that the WinWin Spiral Model is a good match for multimedia applications, and likely for other applications with similar characteristics (rapidly moving technology; many candidate approaches; little user or developer experience with similar systems; premium on rapid completion). It provides sufficient flexibility to adapt to the accompanying risks and uncertainties, and the discipline to maintain focus on achieving its anchor-point milestones. Finally, it provides the means for growing trust among stakeholders, enabling them to evolve away from adversarial contract-oriented system development approaches toward mutually supportive and cooperative approaches.

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Appendix 2

USC-CSE Technical Reports Produced on the Contract

A. WinWin Spiral Model Reports

USC-CSE-94-501

A Collaborative Spiral Software Process Model Based on Theory W, 1994.

B. Boehm and P. Bose

A primary difficulty in applying the spiral model has been the lack of explicit process guidance in determining the prospective system's objectives, constraints, and alternatives that get elaborated in each cycle. This paper presents an extension of the spiral model, called the Next Generation Process Model (NGPM), which uses the Theory W (win-win) approach [Boehm-Ross, 1989] to converge on a system's next-level objectives, constraints, and alternatives. The refined Spiral Model explicitly addresses the need for concurrent analysis, risk resolution, definition, and elaboration of both the software product and the software process in a collaborative manner. This paper also describes some of the key elements of the support system developed based on the model and refined through experiments with it.

Appeared in: The Proceedings of the 3rd International Software Process Conference, 1994.

USC-CSE-94-502

Humans and Process Frameworks: Some Critical Process Elements, 1994.

B. Boehm and P. Bose

Successful engineering of complex software systems require humans to engage collaboratively in multiple critical process elements. This paper identifies those necessary process elements and defines WinWin, a collaborative process model that addresses the process elements. It briefly describes a process support system for the WinWin model.

Appeared in: The Proceedings of the Software Process Workshop, 1994.

USC-CSE-95-504

A Model for Decision Maintenance in the WinWin Collaboration Framework, 1995

Prasanta Bose

Cost-effective engineering and evolution of complex software must involve the different stakeholders concurrently and collaboratively. The hard problem is providing computer support for such collaborative activities. The WinWin approach being developed and experimented at the USC Center for Software Engineering provides a domain independent solution for the stakeholders to cooperate in the requirements engineering phase of the software lifecycle. The key ideas in the WinWin approach and its support are: i) defining a win-win process for obtaining requirements through collaboration and negotiation, ii) defining a decision rationale model using a minimal set of conceptual elements, such as win conditions, issues, options and agreements, that serves as an agreed upon ontology for collaboration and negotiation defined by the winwin process, and, iii)

defining a support framework, based on manipulation of explicit representation of the decision rationale and reasoning about it. A major problem confronted in the WinWin framework is aiding decision coordination - coordinating the decision making activities of the stakeholders. A key element in supporting decision coordination is decision maintenance. As decisions undergo evolution, the effects of such changes on existing decision elements must be determined and the decision structure appropriately revised. This paper presents an approach to addressing the problem of supporting decision maintenance. The key ideas involve a) defining an extended ontology for decision rationale, that models the WinWin decision space and their states, b) formally describing a theory based on that ontology that specify conditions for states to hold, and c) defining an agent that utilizes the theory to determine revisions and coordinate with other agents to propagate revisions in a distributed support framework.

USC-CSE-95-505

Conceptual Design Model based Requirements Analysis in the WinWin Framework for Concurrent Requirements Engineering, 1995

Prasanta Bose

The WinWin framework provides a domain independent framework for the stakeholders to collaborate and negotiate in the requirements engineering phase of the software lifecycle. Requirements engineering in the framework leads to defining a win-win requirements model expressed using a set of conceptual elements that record stakeholder objectives, constraints, concerns and negotiated agreements. A major problem confronted in the current WinWin framework is win-win requirements model analysis that lead to mapping the win-win requirements model which is primarily problem oriented to a solution-oriented requirements specification model that aids in win condition analysis and consequently negotiation. This paper presents a constructive and goal-directed modeling approach to aid in win-win requirements model analysis. The approach involves concurrently elaborating a high-level conceptual design model along with the win-win model creation. The design model representation makes explicit partially specified constraints that form the conceptual architectural basis of the win-win requirements model and aids in win-win requirements model analysis. In this paper we present the key ideas of our approach: a) defining a domain-independent ontology for conceptual modeling of high-level design and its relationship with the WinWin model b) win-win artifact based representation of analysis goals and an abstract domain independent theory that encapsulate the conditions for satisfying the goals, and c) defining capabilities of an extended WinWin support system that to aid in analysis.

USC-CSE-95-507

Anchoring the Software Process, November 1995

Barry Boehm

The current proliferation of software process models provides flexibility for organizations to deal with the unavoidably wide variety of software project situations, cultures, and environments. But it weakens their defenses against some common sources of project failure, and leaves them with no common anchor points around which to plan and control.

This article identifies three milestones-- Life Cycle Objectives, Life Cycle Architecture, and Initial Operational Capability -- which can serve as these common anchor points. It also discusses why the presence or absence of these three milestones or their equivalents is a critical success factor, particularly for large software projects, but for other software projects as well.

Appeared In: IEEE Software, July 1996

USC-CSE-96-502

The WinWin Requirements Negotiation System: A Model-Driven Approach

Mingjune Lee and Barry Boehm

Requirements Engineering constitutes an important part of Software Engineering. The USC WinWin requirements negotiation system addresses critical issues in requirements engineering including (1) multi-stakeholder considerations, (2) change management, and (3) groupware support. This paper presents our current research efforts on constructing and reconciling several formal and semi-formal models of the system and its operations, including inter-artifact relationships, artifact life cycles, and equilibrium model. It concentrates on determining the relationships among the various models or views of the WinWin requirements engineering process.

Keywords: concurrent engineering, groupware, model-driven processes, negotiation, requirements engineering, spiral model, Theory W, win condition.

B. WinWin System Reports

USC-CSE-93-501

Software Requirements as Negotiated Win Conditions, 1994.

Boehm, P. Bose, E. Horowitz and M. J. Lee

Current processes and support systems for software requirements determination and analysis often neglect critical needs of important classes of stakeholders and limit themselves to concerns of the developers, users and customers. Besides developers, customers, and users, these stakeholders can include maintainers, interfacers, testers, product line managers, and sometimes members of the general public. This paper describes the results to date in researching and prototyping a Next Generation Process Model (NGPM) and support system (NGPSS) which directly addresses these issues. The NGPM emphasizes collaborative processes, involving all of the significant constituents with a stake in the software product. Its conceptual basis is a set of Theory W (win-win) extensions to the Spiral Model of software development.

Appeared In: The Proceedings of the ICRE, 1994.

USC-CSE-94-503:

Software Requirements Negotiation and Renegotiation Aids: A Theory-W Based Spiral Approach, 1994

B. Boehm, P. Bose, E. Horowitz and M. J. Lee

A major problem in requirements engineering is obtaining requirements that address the concerns of multiple stakeholders. An approach to such a problem is the Theory-W based

Spiral Model. One key element of this model is stakeholder collaboration and negotiation to obtain win-win requirements. This paper focuses on the problem of developing a support system for such a model. In particular it identifies needs and capabilities required to address the problem of negotiation and renegotiation that arises when the model is applied to incremental requirements engineering. The paper formulates elements of the support system, called WinWin, for providing such capabilities. These elements were determined by experimenting with versions of WinWin and understanding their merits and deficiencies. The key elements of WinWin are described and their use in incremental requirements engineering are demonstrated, using an example renegotiation scenario from the domain of software engineering environments for satellite ground stations.

Appeared In: The Proceedings of ICSE-17.

USC-CSE-95-506

Aids for Identifying Conflicts Among Quality Requirements, 1995

Barry Boehm and Hoh In

One of the biggest risks in software requirements engineering is the risk of over emphasizing one quality attribute requirement (e.g., performance) at the expense of others at least as important (e.g., evolvability and portability). This paper describes an exploratory knowledge-based tool for identifying potential quality attribute risks and conflicts early in the software/system life cycle.

The Quality Attribute Risk and Conflict Consultant (QARCC) examines the quality attribute tradeoffs involved in software architecture and process strategies (e.g., one can improve portability via a layered architecture, but usually at some cost in performance). It operates in the context of the USC-CSE WinWin system, a groupware support system for determining software and system requirements as negotiated win conditions.

Keywords: Software requirements engineering, Quality attribute requirements, WinWin, Spiral Model, Software Architectures, Concurrent engineering, Software risk analysis, Knowledge based software engineering

Appeared in: The Proceedings of ICRE-96 and IEEE Software (March 1996)

USC-CSE-96-500

Software Cost Option Strategy Tool (S-COST)

Barry Boehm and Hoh In

The resolution process of cost conflicts among requirements is complex because of highly collaborative and coordinated processes, complex dependencies, and exponentially increasing option space. This paper describes an exploratory knowledge-based tool (called "S-COST") for assisting stakeholders to surface huge option space and diagnose risks of each option.

The S-COST operates in the context of the USC-CSE WinWin system (a groupware support system for determining software and system requirements as negotiated win conditions), QARCC (a support system for identifying conflicts in quality requirements), and COCOMO (CONstructive COst estimation MODEL).

Keywords: Software requirements engineering, Software quality, WinWin, Spiral Model, Software Architectures, Concurrent engineering, Software risk analysis, Knowledge based software engineering.

Appeared In: COMPSAC '96 (the 20th International Computer Software and Application Conference).

USC-CSE-96-501

Foundations of the WinWin Requirements Negotiation System

Mingjune Lee

Requirements Engineering (RE) constitutes an important part of Software Engineering. The USC WinWin requirements negotiation system addresses critical issues in requirements engineering including (1) multi-stakeholder considerations, (2) change management, and (3) groupware support. The WinWin approach to date has primarily involved exploratory prototyping. The system is now converging on a relatively stable set of artifacts and relationships. This makes it feasible and important to formalize these artifacts and relationships to provide a solid scientific framework for the WinWin system. This is the focused problem addressed by the research presented in this paper.

USC-CSE-97-503

WinWin Reference Manual---A System for Collaboration and Negotiation

Ellis Horowitz

WinWin is a computer program that aids in the capture, negotiation, and coordination of requirements for a large system. It assumes that a group of people, called stakeholders, have signed on with the express purpose of discussing and refining the requirements of their proposed system. The system can be of any type.

This is the WinWin Reference Manual as of June 1997.

C. Testbed and Experiment Reports

USC-CSE-93-499

Experimental Results from a Prototype Next-Generation Process Support System, 1993.

B. Boehm, P. Bose, E. Horowitz, M.-J. Lee

The Next-Generation Process Model (NGPM) involves a set of Theory W (win-win) extensions to the Spiral Model of software development. It uses the Theory W steps of win condition identification and negotiation to determine the objectives, constraints, and alternatives required to initiate each cycle of the Spiral Model. The Next-Generation Process Support System is an evolving prototype of a groupware support environment for the NGPM. To test the scalability and process support capabilities of the initial NGPSS-0 prototype, we performed a bootstrap experiment: using the NGPSS-0:

1. to identify NGPSS user, customer, developer, and system engineer win conditions for future versions of the NGPSS
2. to identify win condition conflicts
3. resolve the conflicts into points of agreement which then transform into objectives, constraints, and alternatives for NGPSS.

The experiment partially confirmed each of the four primary experimental hypotheses. These covered the adequacy of NGPSS-0; the comparability of NGPSS win conditions with a previous set of TRW software environment win conditions; the adequacy of win

conditions as generators of Spiral Model objectives, constraints, and alternatives; and the adequacy of the bootstrap process in defining the next increment of NGPSS.

Appeared In: TRW Systems Integration Group Technology Review, Summer 1994.

USC-CSE-96-504

Analysis of Software Requirements Negotiation Behavior Patterns

Alexander Egyed and Barry Boehm

Roughly 35 three-person teams played the roles of user, customer, and developer in negotiating the requirements of a library information system. Each team was provided with a suggested set of stakeholder goals and implementation options, but were encouraged to exercise creativity in expanding the stakeholder goals and in creating options for negotiating an eventually satisfactory set of requirements.

The teams consisted of students in a first-year graduate course in software engineering at USC. They were provided with training in the Theory W (win-win) approach to requirements determination and the associated USC WinWin groupware support system. They were required to complete the assignment in two weeks.

Data was collected on the negotiation process and results, with 23 projects providing sufficiently complete and comparable data for analysis. A number of hypotheses were formulated about the results, e.g. that the uniform set of initial conditions would lead to uniform results. This paper summarizes the data analysis, which shows that expectations of uniform group behavior were generally not realized.

Appeared in: Proceedings, INCOSE97, August 1997.

USC-CSE-97-504

Developing Multimedia Applications with the WinWin Spiral Model

Barry Boehm, Alex Egyed, USC-Center for Software Engineering

Julie Kwan, USC University Libraries Ray Madachy, USC-CSE and Litton Data Systems

Fifteen teams recently used the WinWin Spiral Model to perform the system engineering and architecting of a set of multimedia applications for the USC Library Information Systems. Six of the applications were then developed into an Initial Operational Capability. The teams consisted of USC graduate students in computer science. The applications involved extensions of USC's UNIX-based, text-oriented, client-server Library Information System to provide access to various multimedia archives (films, videos, photos, maps, manuscripts, etc.).

Each of the teams produced results which were on schedule and (with one exception) satisfactory to their various Library clients. This paper summarizes the WinWin Spiral Model approach taken by the teams, the experiences of the teams in dealing with project challenges, and the major lessons learned in applying the Model. Overall, the WinWin Spiral Model provided sufficient flexibility and discipline to produce successful results, but several improvements were identified to increase its cost-effectiveness and range of applicability.

Appeared in: Proceedings, ESEC/FSE 97, September 1997, and ACM Software Engineering Notes, November 1997.

Also Appendix 1 of this Report.

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