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13. **ABSTRACT (Maximum 200 words)**
   The broad goal of the project is to investigate techniques to minimize the soaring cost of software evolution, focusing on component-based systems where predictable behavior and performance are important. Key research results include techniques for reusable component and pattern design, formal specification of behavior and performance, modular verification of behavior and performance correctness, and principles for contract-checking components. Languages and tools that incorporate these findings are key technology transfer results. Key educational results include a formal approach and materials for teaching component-based software engineering at the graduate and undergraduate levels in Computer Science, and statistical evaluation of the approach.

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A. Problem Statement

The overall problem is to minimize the soaring cost of software evolution in the context of component-based systems, in particular, those systems where predictable behavior and performance are fundamental concerns. While the problem exists in the case of legacy systems and systems especially designed for predictability and evolution, the focus of the project is on designing predictable systems to evolve gracefully. Goals include investigation of research techniques, development of tools, and identification of education and technology transfer activities to minimize the cost of evolution. The proposed techniques should minimize the cost for understanding, reasoning, reuse and adaptation during development and evolution.

Summary of Key Results

The central results of the project are listed are aimed at addressing the above goals. They include:

- Reusable software component and pattern design principles;
- Modular verification of behavior, including the need for abstraction relations;
- Principles and practical techniques for contract-checking components;
- Formal specification of performance and modular verification of performance correctness;
- Languages and tools for predictable component-based software development and evolution;
- A formal approach to component-based software engineering: education and statistical evaluation.

Follow-up research and educational work are funded by National Science Foundation grants, including an Information Technology Research (ITR) grant in 2001. The results from the project have been widely disseminated in over 50 publications. Section C of the report contains a listing of publications during each year of the project. Journal publications have appeared in practical and theoretical places such as IEEE Transactions of Software Engineering, John Wiley Software — Practice and Experience, and Springer-Verlag Formal Aspects of Computing. Conference publications include ones in the International Conference on Software Engineering (ICSE), International Conference on Software Reuse (ICSR), Symposium on Software Reuse, International Symposium on Software Reliability Engineering, and ACM SIGCSE Technical Symposium on Computer Science Education. An edited book on Foundations of Component-Based Systems published by Cambridge University Press in 2000 contains articles from leading software engineering researchers and practitioners, and it has benefited from this project.

It is important to emphasize that the impact of this project will remain. Follow-up research and educational work have been funded by National Science Foundation grants, including an Information Technology Research (ITR) grant in 2001. At least three more journal submissions on performance analysis, parameter passing of objects using swapping, and contract-checking principles are planned in the near future. These planned
submissions are not included in this report.

The project has been instrumental in continued development and refinement of RESOLVE as a research and educational vehicle for component-based software engineering. During the course of the project, a variety of practical component development issues and foundational formal specification questions in software engineering have been addressed. The project has laid the foundation for the RESOLVE software composition workbench – an environment for predictable component-based software construction – in collaboration with investigators at The Ohio State University. Researchers have developed a variety of tools, including compilers, translators, editors, and an interactive environment. These tools are at varying levels of maturity and sophistication. They have been demonstrated at DARPA meetings and conferences. The tools will serve as our principal vehicle for transitioning the results from the project to academia, industry, and the U. S. defense program. They are available at http://www.cs.clemson.edu/~resolve.

Four Ph. D. dissertations and seven M. S. project reports and theses have also resulted from the project, in addition to several education-oriented materials and publications. These results and some of our efforts in technology transition are document in Section IV. Together with NSF and Department of Education grants, this project has facilitated introduction of a formal approach to component-based software development in undergraduate Computer Science education. The approach and positive results from statistical evaluation of student attitudes and learning have been published.
C. List of Publications

C.1 Topic Area Dissemination Publications


C.2 Research Publications


Eighth Annual Workshop on Software Reuse, Columbus, Ohio, March 1997, 4 pages.


C.3 Education and Technology Transfer Publications


C.4 Human Resource Development
Ph. D. Dissertations


58. S. M. Yacoub, Pattern-Oriented Analysis and Design (POAD), Ph.D. Dissertation, Department of Computer Science and Electrical Engineering, West Virginia University, October 1999.


60. G. Rinard, Performance-Tunable Distributed Execution of Object-Based Software, Department of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506, 1997.


D. Participating Scientific Personnel

Dr. Edward Addy (Logicon, Inc., FL), received Ph. D., 1999.
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Dr. Steve Atkinson (Moms Desk Commerce Corporation, CA).
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