STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

3 February 1970 R~

Proposal for Research
SRI No. ESU 69-127R

Part One--Technical Proposal

RESEARCH ON AUTOMATIC PROGRAM-SYNTHESIS SYSTEMS

Prepared for:

Electronic Systems Division (ESKK)
Air Force Systems Command
Laurence G. Hanscom Field
Bedford, Massachusetts 01730

Attention: Dr. Hans Zschirnt

In Response to Request No. F19628-70-Q-0298
CRL-01022

Prepared by:

Richard J. Waldinger, Research Mathematician
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Information Science and Engineering Division

Copy No. 7

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RESEARCH ON AUTOMATIC PROGRAM-SYNTHESIS SYSTEMS

I BACKGROUND

Computers are playing an ever-increasing role in their own programming--assemblers, compilers, and optimizers have been taking programming tasks out of human hands. However, the actual design of algorithms has largely been left up to the programmer. Even the user of a higher-level language must construct his own algorithms. It seems inevitable that this chore will also eventually be relegated to computer control. Artificial intelligence has now reached a position such that efforts in that direction will be fruitful.

Programs have been written with some program-synthesis capabilities.[1-4]* These programs have used automatic theorem proving as a tool; they have demonstrated the importance of theorem proving in program synthesis. However, they also have pointed to the inadequacy of current techniques. Their performance as program writers is unimpressive when compared with that of a human being, but they have at least provided us with a definition of the program-synthesis task and suggested a way to approach it.

The disappointing performance of the earlier work may be ascribed partially to the weakness of current mechanical theorem-proving techniques. Theorems are of necessity expressed in an unnatural language, and then are attacked with methods inadequate to their solution. Results are understandably meager. There is a clear need for more powerful techniques that can be applied to a more acceptable problem statement.

Furthermore, there is some evidence that theorem proving as we know it may be an inappropriate approach to certain programming tasks. For example, machine-language program construction may call for an entirely different attack. Thus, the past research points out the need for extensive work in several areas.

II PROGRAM OBJECTIVES

The general objective of the proposed research is to establish design criteria for an automatic program-synthesizing system. We mean to devise a natural way to define program-writing problems and describe programming languages, and then improve the known methods of program synthesis and investigate new ones.

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*References are listed at the end of part one of this proposal.

A. Problem Definition

The automatic program-writing systems that exist today force the user to express his problem in terms of the first-order predicate calculus. This description can be a sizable coding problem in itself. Certain innovations in problem statement must be made before automatic program synthesis is to become appealing.

Similar remarks may be made about the methods of describing the semantics of the programming languages under consideration. It is essential that the description be correct and easy to understand. For instance, we know of no good way to describe languages with side-effects that is suitable for automatic program synthesis.

B. Problem Solution

The art of programming applies a broad range of techniques to an equally wide range of tasks. The synthesizer, if it is to be successful, must also have a choice of routes toward the solution. Our effort to provide this may be broken down as follows:

(1) Devise improved theorem-proving methods that are not restricted to first-order logic. This is part of our "QA4" effort.[5]

(2) Adapt these methods to automatic program synthesis. A theorem prover is at a loss if it knows nothing about the semantic domain of its problem statement. A theorem prover that knows it is trying to write a program will be in a much better position. Special-purpose program-writing heuristics have already been devised; more must be developed.

(3) Consider alternatives to theorem proving. For example, a model-manipulation approach may be called for if machine-language programs are to be synthesized, or a nondeterministic analysis of the problem statement may permit the synthesizer to subdivide its problem, and these subdivisions would give rise to program segments or subroutines.

C. Easier Problems

Finally we would like to examine certain restricted or modified versions of the problem, interesting in themselves and maybe more amenable than complete synthesis. These problems span the gulf between theorem provers and current compilers.

(1) Program Completion--The user submits a partially completed program along with the specifications; the system completes the program.

(2) Outline Programming--The user submits an outline of the program. Along with the problem statement he gives several subproblems he feels are relevant. In the case of program-synthesis theorem proving, for example, the user would state important lemmas.

(3) Man/Machine Interaction--During the derivation of the program the user may give hints and steer the course of the solution.

(4) Program Modification--The user presents the synthesizer with a completed program and its specifications along with some new conditions, and the system alters the program appropriately. A good deal of human programming consists of trying to apply someone else's program to new tasks.

We hope to develop the art of automatic synthesis until we can produce programs other than the hackneyed, trite examples common in early papers on the subject.

III STATEMENT OF WORK

Stanford Research Institute proposes to supply the necessary personnel, facilities, services, and materials towards performance of the following:

Item 1: Design a language for specifying programming problems. This language should be sufficiently general to state virtually any programming problem, and yet natural enough so that the statement of common tasks shall be close to our own way of thinking about them. The language will include a method of describing the semantics of the target machine, and will apply to both applicative and state-machine (machine-code-like) languages.

Item 2: Develop improved methods for automatic program synthesis. This includes adapting a higher-order theorem prover to program synthesis, and investigating alternatives to theorem proving.

Item 3: Explore the various gradations of automatic writing from compiling to complete synthesis.

IV METHOD OF APPROACH

We have under development a general problem solver called QA4. This program uses theorem proving in omega-order logic with lambda-calculus and types.[6] We feel that program synthesis would be an appropriate task for the QA4 system and we hope to adapt the system to this end as part of the proposed research. Although QA4 is spoken of as a theorem prover, it is more accurately described as an "expression manipulator," so that the techniques of program writing it will use may look quite different from those used by earlier systems.

QA4 will be applied to many examples, so that we will develop a feeling for the most natural form of problem statement, and will be better able to devise solution methods, which will then be incorporated into QA4 itself. Such evolutionary development is characteristic of the QA4 program in general. It is hoped that ultimately a program synthesizer will be developed that will demonstrate ingenuity and sophistication.

V PERSONNEL

The principal investigator in this work will be Dr. Richard Waldinger. Additionally, it is expected that Dr. Nils J. Nilsson, Mr. Johns F. Rulifson, and Mr. Robert A. Yates will work on the project.

Biographies of these individuals follow.

RICHARD J. WALDINGER, RESEARCH MATHEMATICIAN
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Artificial intelligence
- Automata theory
- Logic
- Recursive function theory
- Automatic theorem proving

Other professional experience

- Research assistant, teaching assistant, project scientist, Carnegie-Mellon University, Pittsburgh, Pennsylvania

- Mathematician, Heuristics Laboratory, National Institute of Health, Bethesda, Maryland

Academic background

- A.B. in mathematics (1964), Columbia College, New York, N.Y.

- Ph.D. in computer science (1969), Carnegie-Mellon University, Pittsburgh, Pennsylvania

Publications

- Coauthored "PROW: A Step Toward Automatic Program Writing," Proc. International Joint Conference on Artificial Intelligence, Washington, D.C. (1969).

NILS J. NILSSON, SENIOR RESEARCH ENGINEER
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Artificial intelligence
- Systems theory
- Pattern recognition

Representative research assignments at SRI (joined 1961)

- Studies in the theory of pattern recognition
- Feature detection studies
- Studies in heuristic search procedures
- Automatic theorem-proving studies
- Planning, promotion, and direction of robot systems research
- Head, Artificial Intelligence Group (1963-67)

Other professional experience

- Taught courses in pattern recognition at Stanford University and at University of California, Berkeley, 1962-63
- Acting Associate Professor at Stanford University, Computer Science Department (one-half time, 1968-69)

Academic background

- M.S. (1956) and Ph.D. (1958) in Electrical Engineering (Communication Theory) Stanford University

Publications

- Twelve articles on pattern recognition and artificial intelligence
- Learning Machines, (McGraw-Hill, 1965)

Professional associations

- Institute of Electrical and Electronic Engineers
- Association for Computing Machinery
- Tau Beta Pi
- Sigma Xi

JOHNS F. RULIFSON, RESEARCH MATHEMATICIAN
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Translator writing systems
- Interactive display systems
- Automatic program synthesis

Representative research assignments at SRI (joined 1966)

- Design and implementation of Metacompilers and special-purpose languages
- Development of interactive text and graphic systems
- Studies of time-sharing systems
- Design of problem-solving system for program synthesis and robot direction

Other professional experience

- Systems Programmer, University of Washington, Seattle, Washington
- Operations and Systems Maintenance Staff, Boeing Company, Seattle

Academic background

- B.S. in Mathematics (1966), University of Washington

Professional associations

- Association for Computing Machinery

ROBERT A. YATES, SYSTEMS PROGRAMMER
INFORMATION SCIENCE LABORATORY
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

. Mathematics
. Programming languages
. Compilers
. Diffraction

Representative research assignments at SRI (joined 1967)

. Design and development of a question-answering computer system based on first-order predicate calculus

Other professional experience

. Member of technical staff, Bell Telephone Laboratories, Holmdel, New Jersey; work on design and implementation of SNOBOL4 programming language
. Programmer, Johns Hopkins University, Physics Department
. Programmer, Politecnico, Mexico City; design and implementation of LISP system and compiler

Academic background

. B.A. in mathematics (1965), Johns Hopkins University
. M.A. in mathematics (1967), Stanford University

Professional associations

. Phi Beta Kappa

REFERENCES

1. C. Green, "Application of Theorem Proving to Problem Solving," in Proc. International Joint Conference on Artificial Intelligence, D. E. Walker and L. M. Norton, eds. (Association for Computing Machinery, New York, 1969).

2. C. Green, "The Application of Theorem Proving to Question-Answering Systems," Thesis, Stanford Artificial Intelligence Project Memo AI-96, Stanford University (June 1969).

3. R. J. Waldinger and R. C. T. Lee, "PROW: A Step Toward Automatic Program Writing," in Proc. International Joint Conference on Artificial Intelligence, D. E. Walker and L. M. Norton, eds. (Association for Computing Machinery, New York, 1969).

4. R. J. Waldinger, "Constructing Programs Automatically Using Theorem Proving," Computer Science Department, Carnegie-Mellon University, Pittsburgh, Pa. (1969).

5. C. Green, R. Yates, B. Raphael, and C. Rosen, "Research in Advanced Formal Theorem-Proving Techniques," SRI Proposal for Research No. ESU 69-73, Stanford Research Institute, Menlo Park, Ca. (24 June 1969).

6. J. A. Robinson, "Mechanizing Higher-Order Logic," in Machine Intelligence 4, D. Michie and B. Meltzer, eds. (Edinburgh University Press, Edinburgh, 1969).

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3 February 1070

Proposal for Research
SRI No. ESU 69-127R

Part Two--Contractual Provisions

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Prepared for:

Electronic Systems Division (ESKK)
Air Force Systems Command, USAF
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Part Two--Contractual Provisions

I ESTIMATED TIME AND CHARGES

The estimated time required to complete the proposed research work is ten months. The Institute could begin work on receipt of a fully executed contract.

II GOVERNMENT-FURNISHED EQUIPMENT

Any contract that results from this proposal contemplates the use of the Digital Equipment Corporation PDP-10 facility currently being installed at the Institute, which is Government furnished equipment being funded by ARPA and administered by USAF RADC. The installation of the facility will be completed shortly. Accordingly, permission for use of the facility on the research proposed herein would then be secured. We do not contemplate any difficulty in obtaining permission to utilize such facility for this research, as we believe such research would benefit the overall program being undertaken by the use of the PDP-10 facility.

III REPORTING SCHEDULE

A final report draft will be submitted one month after completion of the research. Additional reports will be submitted as required.

IV CONTRACT FORM

It is requested that any contract resulting from this proposal be awarded on a cost-plus-fixed-fee basis.

V ACCEPTANCE PERIOD

This proposal will remain in effect until 3 May, 1970. If consideration of the proposal requires a longer period, the Institute will be glad to consider a request for an extension in time.

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COST ESTIMATE

Personnel Costs

Project Supervision, .25 man-month at [redacted]	$ [redacted]	
Senior Professional, .75 man-month at [redacted]	[redacted]	
Professional, 5.0 man-months at [redacted]	[redacted]	
Support Services (including drafting, data clerk, secretarial, etc.), .7 man-month at [redacted]	[redacted]	
Total Direct Labor	[redacted]	
Payroll Burden at 25%	[redacted]	
Total Salaries and Wages		[redacted]
Overhead at 100% of Salaries and Wages		[redacted]
Total Personnel Costs		[redacted]

Direct Costs

Travel:		
Air-Rail Fares: 1 trip to Boston at [redacted]	$ [redacted]	
Subsistence: 1 day at Boston at [redacted]/day	[redacted]	
Report Production	[redacted]	
Total Direct Costs		$ [redacted]
Total Estimated Cost		[redacted]
Fixed Fee		[redacted]
TOTAL ESTIMATED COST PLUS FIXED FEE		[redacted]

SCHEDULE A - DIRECT LABOR

Direct labor charges are based on the actual salaries for the staff members contemplated for the project work, plus a factor of 2% of base salary for merit increases during the contract period of performance. Frequency of salary reviews and level of merit increases are in accordance with the Institute's Salary and Wage Payment Policy as published in Topic No. 505 of the SRI Administration Manual and as approved by the Defense Contract Administration Services Region.

SCHEDULE B - OVERHEAD AND PAYROLL BURDEN RATES

The provisional overhead and payroll burden rates used in the cost estimate are those currently approved by SRI's cognizant Government agency, the TRI-Service Overhead Negotiations Committee, U. S. Army Electronics Command, Fort Monmouth, New Jersey. A copy of a letter of 24 January 1969 from the chairman of the aforementioned committee, attesting to this approval, is available upon request. These rates can be verified through the Defense Contract Audit Agency. The mailing address for the resident DCAA office at SRI is Branch Manager, Peninsula Branch Office, Defense Contract Audit Agency, 801 East Charleston Road, Palo Alto, California 94303. Telephone number is Area Code 415, 326-6200, Extension 2089.

The rates quoted are based on our best prediction as to financial performance for the calendar year of 1970. Rather than setting specific provisional rates, it is requested that contracts provide for reimbursement at billing rates acceptable to the Contracting Officer, subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation, holiday and sick leave pay, social security taxes, and contributions to employee benefit plans.

SCHEDULE C - MATERIALS AND SERVICES

Travel

1 trip to Boston at [redacted] [redacted]
Subsistence, 1 day at Boston at [redacted] [redacted]

Air fares are based on the current issue of the Official Airline Guide Quick Reference.

Domestic subsistence rates are established standards based on cost data submitted to and approved by DCAA.

SCHEDULE D - REPORT COSTS

Report costs are estimated on the basis of the number of pages of text and illustrations and the number of copies of reports required in accordance with the following rates per page, which have been reviewed by DCAA.

Editing	[redacted]
Composition	[redacted]
Coordination	[redacted]
Proofreading	[redacted]
Illustration	[redacted]
Press & Bindery	[redacted]

Following is a cost breakdown of the estimated cost of report production:

Printing, 45 pages at [redacted] per page (including editing, composition, report coordination, and proofreading)	[redacted]
Illustration, 5 pages at [redacted] per illustration	[redacted]
Press, bindery, and photography for 3,150 printed pages at [redacted] per printed page	[redacted]