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Research on Knowledge Based Programming

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Cordell Green, Principal Investigator

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the first six months of work on designing CHI, a system for the knowledge based synthesis of signal understanding systems in time-critical environments. This report covers progress on the following tasks: completing a near-term demonstration capability of knowledge based programming using the existing PSI program synthesis system; specifying the harmonic set-formation programs to be used as a target application; designing the CHI system for writing these (and other) programs; developing an in-house computing facility in support of this research; and disseminating results via technical publications.

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Table of Contents

1. Introduction

The goal of this research project is the automatic synthesis of signal understanding systems in time-critical environments. In particular, we are designing and implementing a working prototype computer system (called CHI) capable of automatic, knowledge based synthesis of harmonic set formation programs. CHI will accept a description of the desired program in a very high level language (and possibly other languages such as English, examples, or a special mathematical notation) and produce an efficient implementation of the program in a target language such as LISP. Progress has been made in determining appropriate ways to specify the application program, understanding the different set partitioning heuristics and algorithms that exist for doing the harmonic set formation, tracing the necessary steps which CHI must take to transform the program specification into a target program, and designing the language in which CHI will operate.

This report covers progress on the following tasks: completing a near-term demonstration capability of knowledge based programming using the existing PSI program synthesis system; specifying the harmonic set formation programs to be used as a target application; designing the CHI system for writing these (and other) programs; developing an in-house computing facility in support of this research; and disseminating results via technical publications.

The knowledge based programming research effort under this contract was initiated on 27 November 1978. However, the contract, with its requirement of quarterly technical reports, was not signed until 23 March 1979. Since this was after the end of the first quarter of the contract, this report covers the first two quarters of the project.

As a result of our discussions with Bob Engelmore of DARPA and Marv Denicoff and Gordon Goldstein of ONR, reporting procedures have been clarified. In future quarters, the quarterly technical report, which is primarily a technical progress report, will be incorporated into the quarterly research and development status report. Details of substantial technical results will continue to be presented in special interim technical reports.

2. Task 1: Near-Term Demonstration Capability

We plan to continue working on the existing PSI program synthesis system to provide a demonstration capability, to study the strengths and weaknesses of the system, and for use by the dissertations of Elaine Kant, Brian McCune, Lou Steinberg, and Dick Gabriel. Some of the actual code and many of the ideas of the old system will be applied to CHI.

2.1 PSI System Maintenance

Since joining the knowledge based programming group, Beverly Kedzierski's primary goal has been the integration of new PSI subsystems into a working system. The acquisition phase of PSI, primarily the programs by Jerry Ginsparg, Lou Steinberg, and Dick Gabriel, was dealt with first. The parser has been brought up and is currently running independently. Maintaining and possibly enhancing the parser/interpreter is a continuing task that may eventually result in replacement of the parser by some other currently available one. The dialogue moderator of Steinberg has been integrated and compiled. Final progress toward a working acquisition phase awaits modification of the explainer by Gabriel. The next step will then be to integrate the program model builder and synthesis phase to obtain a complete running version of PSI.

2.2 Explainer

Dick Gabriel is working on the explanation system, which produces an English explanation of the internal representation of a program acquired by PSI.

The part that generates English is now working and has been tested extensively. It repeatedly makes transformations on an initial paragraph in order to improve its style and clarity. The problem is to find an appropriate "expert" within the explainer to make such an improvement. Major progress has been made on the planning module, which is responsible for finding such an expert. This is done using two criteria: (1) how well the expert's knowledge applies to the current text and (2) how well the expert will promote a non-repetitious prose style.

Routines for planning the initial paragraph structure of a description of a simple program have been written and are being tested with the improved English generator. It is expected that this first program will be explained within two months.

2.3 Efficiency Expert

Elaine Kant has extended the efficiency module to handle the decisions involved in a news retrieval program, several variants of a classification program, and insertion and selection sorts. This work has included maintaining, and in some cases extending, the coding module and the interface between the program modelling language and the synthesis phase. The facilities for recording control and data flow in the programs being synthesized have been improved. The process of acquiring time estimates for the coding constructs used in the synthesis phase has been partially automated. We expect this work to be extendible to CHI and partitioning algorithms.

3. Task 2: Specification of Harmonic Set Formation Programs

The major milestone for the first year of this contract is to specify the ultimate goal, namely, reprogramming a harmonic set formation program. The milestone includes defining the target program itself, defining the inputs to CHI that specify the target program, and analyzing the knowledge necessary to create it. This harmonic set formation program determines harmonic relationships between acoustic signals collected from an ocean environment. Harmonically related signals are manifestations of a single source (e.g., a ship's engine, pump, etc.) which appear at evenly spaced frequency intervals when transformed into a frequency versus time display. Our attempts in the past several months have included developing a specification of the tasks involved in finding harmonically related signals and in defining the rules of behavior of those signals. In addition, efforts have been made to define sequences of refinements which could be made to the initial program specification to move it closer to machine executable code. Several different refinement paths have been considered. The problem specification and refinement path are being used to help develop an overall system design.

3.1 Input Specification

Harmonic set formation involves considering a set of *lines* (acoustic signals manifest in time) and grouping those lines into subsets of harmonically related lines (those emanating from the same source). Reasonably well-defined rules have been developed to determine when lines are harmonically related. More generally, the problem is one of looking at all *partitions* (harmonically related groupings) of a set of lines and choosing one which generates the minimum cost (the cost inversely indicates the "goodness" of the harmonic relations). The cost function is multifaceted and includes not only the local cost of each group in the partition (e.g., is it a well-formed harmonic set), but also the overall likelihood of this type of a partition (e.g., it is unlikely that each line would be in a separate harmonic set). The factors which have been considered in defining the goodness of a particular harmonic set include

Are the frequencies of the lines in the set integer multiples of a fundamental frequency?

Do the lines originate in approximately the same location (area of the ocean)?

Do lines in the set manifest in a reversable harmonic pattern (e.g., first harmonic, second harmonic)?

Do lines in the set tend to be less intense at higher frequencies?

Bob Drazovich has developed a set of these rules, written fairly concisely and precisely in English. An equivalent mathematical notation has been defined which may be used as an alternate input specification language or as an internal representation for the English rules.

3.2 Analysis of Programming Knowledge Required

Steve Westfold has been considering the programming knowledge necessary to write harmonic set formation programs. Starting with the initial specification of the harmonic set formation task, efforts have been made to develop a sequence of transformations which move toward machine executable code. Activities have centered on identifying a method for implementing the specification which finds the *minimum* cost (as described above) partition of a set of lines (acoustic signals). Among the approaches considered were these:

(1) Explicitly enumerate and evaluate the cost of each possible partition of the set of lines. This approach is easy to develop but impractical because of the large amount of computation involved. Typical real world situations often involve the analysis of large numbers of lines at a time. Explicit enumeration of all possible partitions is prohibitively expensive computationally.

(2) Start with an initial solution and move towards a better (lower cost) partition by some form of hill climbing. Initial solutions which were considered started with each line in a separate group (a singleton partition) and all lines in one group. In the case of a singleton partition, lines were then associated (combined) on the basis of rules of harmonic behavior. When starting with all lines in a single group, the group was evaluated for harmonic consistency, and inconsistent lines were removed (to another group) until the harmonic behavior rules were satisfied.

(3) Use a divide and conquer approach by using one feature dimension at a time to guide the partitioning. The goal was to divide the overall set formation task into subtasks by pregrouping the input lines. For example, lines could be grouped by location. The more manageable subtasks (smaller sets of lines) could then be analyzed separately using one or more of the other techniques specified in this section.

(4) Use an operations research approach. This is an attempt to define the harmonic set formation task as an integer programming problem. The task would be refined into maximizing (or minimizing) a cost function (about the goodness of a particular partition) while satisfying a set of constraints about the behavior of lines in a specific set.

In addition to considering refinements of the partitioning specification, attempts have been made to refine the rules of harmonic behavior. As may have been noticed above, the rules often denote general trends (e.g., harmonics *generally* become less intense at higher frequencies) which must be specified in a more quantitative fashion for machine evaluation. However, exceptions to single rules do occur in this environment and often should not by themselves veto a potential harmonic relationship. The two refinement approaches which have been considered either specify each rule such that only a true or false is returned and specify each rule such that a weight (either positive of negative) is returned. In this case, the final decision may be the (possibly weighted) sum of the individual rules.

The partitioning syntheses considered by Steve Tappel to date deal with exhaustive partitioning, i.e., generating all partitions of a set. This is a simpler problem than heuristic partitioning. Even here, however, it has become apparent that, without strong domain support in the form of knowledge about properties of partitions and schemata of partitioning algorithms, the transformations are too difficult for an automatic system to handle.

4. Task 3: Design of CHI

Two major problems exhibited by state-of-the-art program synthesis systems are, first, the increasing difficulty of maintaining an evolving knowledge base of rules about programming as it increases in size and, second, the need for restricting the use of resources during the synthesis process in order to code problems of a practical size.

Jorge Phillips has developed an integrated language to specify both very high level programs and knowledge about programming in the form of rules. This language (called V, for Very high level language) will be used as the central framework for the CHI system. It attempts to provide a practical solution to the problems outlined in the preceding paragraph. The major goal is to facilitate algorithm development by providing a uniform basis for the specification of modular systems with arbitrary binding and accessing mechanisms. In addition, V provides a vehicle for the acquisition and modification of a knowledge base of rules about programming and of metarules that guide the application of these rules during the synthesis process.

Two major research efforts have been launched in the pursuit of V's design goals: the design of the program description component of the language, of which an example is given below, and the design of the rule and metarule components of the language. V provides a very rich vocabulary of programming concepts which can be used to reflect either program building actions or knowledge base modification and enhancement operations.

4.1 Specification Language

At the program description level, the major problem is to provide V constructs and semantics which allow easy coding of high level algorithm specifications into languages with very different binding and dynamic regimes (e.g., LISP, ALGOL, and FORTRAN). To achieve this effect, V allows explicit specification of variable binding and parameter passing mechanisms.

The following V program description exhibits the basic features of the language. The algorithm repeatedly finds all news stories in a database which match the keyword which is input.

```
module NEWS
    var DB     : relation
                     STORY,
                     KEYWORD;
        INPUT : alternative
                     KEYWORD,
                     ESCAPE;
    begin
        input DB;
        loop
            input INPUT;
            exit if type?(INPUT) = ESCAPE;
            output inverse_image(DB,INPUT);
        end;
    end;
end NEWS;
```

The following recursive algorithm finds all partitions of a set. At each level of recursion, it chooses an element of the set to partition and merges it with all possible partitions of the original set minus the removed element. This technique corresponds to divide and conquer using a singleton split.

```
module P
    type PARTITION : set of set;        "Powerset of an unspecified set"
    procedure entry PARTITIONS (S : set) : set of PARTITION;
        if S = PHI then PHI
            elseif size(S) = 1 then {S}
            else select x in S do
                (           U             [ U {{xUz} U (y-{z})}] ) U {{{x}}Uy}
                 y∈PARTITIONS(S-{x})   z∈y
end P;
```

4.2 Rule Language

At the metalevel, a language for expressing programming and efficiency knowledge has been defined by Jorge Phillips and Elaine Kant. The language is such that it allows complete expressibility of actions at the meta and synthesis levels. The basic entities dealt with in the language are program description nodes, rules (at all abstraction levels), history sequences of node transformations and rule applications, and data flow in the program description.

Metarules are greatly simplified in this design by extensive use of prototypes of metalevel entities that describe their structure and properties. These prototypes allow for declarative specification of constraints on properties, as well as explicit and implicit properties. The latter are object properties which, instead of being an explicit part of the object, have an explicit method or procedure for computing their values. The metalanguage has been tested by coding a small number of rules used in PSI's synthesis phase in the new formalism.

Previous experience with PSI by Kant has pointed out the usefulness of features such as prototypes and data flow constructs that were not included in the original design of PSI. She has translated a number of the efficiency rules into the new language as a test.

4.3 Codification of Programming Knowledge

Other aspects of this research are concerned with the use of the V foundation in a preliminary testbed. Programming knowledge is currently being defined and extracted for the specification and codification of algorithms in the partitioning, combinatorial, and symbolic manipulation domains. A prototype system that embeds these ideas is currently being built in INTERLISP.

5. Task 4: Computer Support

This task is managed by Brian McCune.

5.1 F2 Computer

DARPA funding for the Foonly F2 computer was provided in response to our *Three-Year Computing Addendum* to Proposal MPL 79-044, *Research on Knowledge Based Programming*. The F2, which emulates a PDP-10, will be installed during June.

5.1.1 Software

The F2 will run the latest public-domain version (1.34) of the TENEX operating system. All standard TENEX software will be supported, including LISP, SAIL, PASCAL, FORTRAN, text editors, document compilers, ARPAnet software, and systems support software. Of particular importance to this contract is the availability of INTERLISP, the EMACS display editor, and the PUB document compiler for programming and document preparation.

5.1.2 Peripherals

Peripherals were selected for the F2 with the goal of utilizing state-of-the-art technology at reasonable cost. The disk drive is an Ampex DM 9300 CD, which features 312 megabytes of unformatted capacity (compared to the largest DEC drive of 200 megabytes), a data rate of 1.2 megabytes per second, and the industry standard "storage module" interface. The tape drive is a Telex 6250, which features 9-track recording, a speed of 125 inches per second (compared to the more typical 45 or 75), recording densities of 1600 and 6250 bytes per inch (compared to today's minicomputer standard of 800 and 1600), maximum data rate of 781 kilobytes per second, automatic loading and unloading of tapes, and a chassis which mounts in only half of a standard 19 inch hardware cabinet. The printer/plotter is a Versatec 3200A, which features resolution of 200 points per inch, printing or plotting at 500 lines of text per minute, paper 11 inches wide, and desktop size. The modems, built by Universal Data Systems, have data rates of either 300 baud (full duplex) or 150/1200 baud (i.e., full duplex with 150 baud from the display terminal's keyboard and 1200 baud to its screen) and are allowed to directly connect to the telephone network.

5.1.3 Terminal System

As an interim display terminal, we are renting Datamedia 3025s, the standard interactive text editing terminal used by the ARPAnet community in the Stanford area. Currently we are considering the Z80-based Ann Arbor 4080 COMPAT with a microprocessor-based Microswitch keyboard and Products Associates 150/1200 baud modem. This terminal would feature the top keyboard in the industry (long in use at Stanford, MIT, and CMU), both ASCII and Stanford ASCII compatibility, Datamedia 2500 and 3025 compatibility, a 15 inch screen, display of 40 lines of text, and an integral modem.

Eventually we want high resolution bitmap terminals in house. The current standard is the Grinnell display system with an array of 1024 x 1024 bits, coupled with Microswitch keyboards. Before choosing this route, we are waiting to evaluate new progress in the area of personal computers that would provide distributed text editing and perhaps LISP, in addition to a high resolution display. Candidates that should be available within the next year are from Xerox, Three Rivers Computer, Image Automation, and MIT.

5.1.4 ARPAnet Connection

Shortly after the F2 is installed, Error Correcting Units (ECUs) from Associated Computer Consultants (ACC) will be installed at SCI and Xerox PARC in order to connect the F2 to the ARPAnet as a local host on the XEROX IMP. The F2 will be a limited server with host name SCI-ICS. SRI is purchasing the ECUs for DARPA, and they will be connected by a 56 kilobaud digital telephone line. McCune assisted in the planning coordination for this equipment between DARPA, SCI, PARC, ACC, BBN, PT&T, and SRI.

5.1.5 Packet Radio Network Link

We are adding a second BBN 1822 interface to SCI-ICS, a Distant Host interface to a packet [illegible] connected to the Bay Area Packet Radio Network. SCI-ICS will provide a testbed as the first s[illegible] host on the PRnet. DARPA will supply and install the radio and TENEX software, including TCP and server and user protocol handlers.

5.2 In-House TIP or IMP

In anticipation of being provided a TIP or IMP by DARPA, we are installing enough telephone lines to handle many 50 kilobaud wideband circuits and TIP ports, as well as direct dialups to SCI-ICS and other, future computers. As discussed in Section IV of the *Three-Year Computing Addendum*, SCI already has a need for high-speed terminal access to the ARPAnet independent of the F2. Work on many DARPA contracts (listed in Appendix A, "Breadth of SCI's ARPAnet Access Requirements") is slowed down by the fact that only 300 and 1200 baud dialup access to remote TIPs is available. In the future a second F2 will likely be procured and put on the ARPAnet. Using multiple ECU links to remote IMPs is an uneconomic way to provide network access for more than one host. An in-house TIP would solve both of these problems.

5.3 Computing Lab

SCI is building a computing laboratory separate from its current computer facilities, primarily for Defense Division computer science and signal processing research, including knowledge based programming, algorithm creation, distributed sensor nets, speech, vision, radar, and sonar. This laboratory will include the SCI-ICS F2, the ECU linking it to the ARPAnet, the packet radio linking it to the PRnet, probably a link to the SCI corporate VAX, a PDP 11/35 realtime signal processing frontend to the F2, an LSI-11 De Anza color graphics system, a Grinnell 8-bit grayscale graphics system, two Tektronix storage tube graphics displays, and probably a second F2. SCI is investing its own funds out of overhead to enhance this environment. In particular, it is funding part of the F2, 11/35, VAX, and physical plant upgrades such as power, air conditioning, and raised flooring.

6. Task 5: Technical Publications

6.1 Publications on PSI

With the editorial efforts of Kedzierski, a paper on PSI [Green et al.-79] was accepted for presentation at the Sixth International Joint Conference on Artificial Intelligence (IJCAI-79), to be held in Tokyo, Japan, this August. This paper summarizes recent progress on and present capabilities of PSI.

A paper on knowledge for synthesizing sorting programs, by Cordell Green and Dave Barstow[1], was published in *Artificial Intelligence* [Green & Barstow-78]. A revised version of Barstow's thesis on the PSI coder will appear in book form [Barstow-79].

Elaine Kant's thesis on the PSI efficiency expert [Kant-79A] is nearly completed. A paper based on this work [Kant-79B] has been accepted for presentation at IJCAI-79.

Brian McCune expects to have a draft of his thesis on the program model builder [McCune-79] completed in August 1979.

6.2 Publications on CHI

A paper by Cordell Green and Brian McCune outlining the goals of our current research [Green & McCune-78] was presented at the Distributed Sensor Nets Workshop held at Carnegie-Mellon University in December 1978. An expanded version of this paper, including a discussion of other possible applications [Green & McCune-79], was given at the Technical Workshop on the Application of Artificial Intelligence and Spatial Processing to Radar Signals for Automatic Ship Classification, held in New Orleans in February 1979.

A draft of Jorge Phillips' thesis on the design of CHI [Phillips-79] should be available in July 1979.

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[1] now Assistant Professor of Computer Science at Yale University

7. References

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[Green et al.-79] Cordell Green, Richard P. Gabriel, Elaine Kant, Beverly I. Kedzierski, Brian P. McCune, Jorge V. Phillips, Steve T. Tappel, and Stephen J. Westfold, "Results in Knowledge Based Program Synthesis", proceedings, Sixth International Joint Conference on Artificial Intelligence, Tokyo, Japan, August 1979.

[Kant-79A] Elaine Kant, *Efficiency Considerations in Program Synthesis: A Knowledge Based Approach*, Ph.D. thesis, Artificial Intelligence Laboratory, Computer Science Department, Stanford University, Stanford, California, June 1979, technical report, Computer Science Department, Systems Control, Inc., Palo Alto, California, 1979 (in progress).

[Kant-79B] Elaine Kant, "A Knowledge Based Approach to Using Efficiency Estimation in Program Synthesis", proceedings, Sixth International Joint Conference on Artificial Intelligence, Tokyo, Japan, August 1979.

[McCune-79] Brian P. McCune, *Building Program Models Incrementally from Informal Descriptions*, Ph.D. thesis, Artificial Intelligence Laboratory, Computer Science Department, Stanford University, Stanford, California, technical report, Computer Science Department, Systems Control, Inc., Palo Alto, California, 1979 (in progress).

[Phillips-79] Jorge V. Phillips, *Knowledge Based Algorithm Development*, Ph.D. thesis, Electrical Engineering Department, Stanford University, Stanford, California, technical report, Computer Science Department, Systems Control, Inc., Palo Alto, California, 1979 (in progress).

Appendix A. Breadth of SCI's ARPAnet Access Requirements

Below is a list of SCI's current contracts and pending proposals with DARPA that use or will use the ARPAnet, listing the contract name, principal investigator, and ARPAnet sites used, by DARPA office.

IPTO

"Knowledge Based Programming", Cordell Green, USC-ISIC, USC-ISIE, SU-AI, and SU-SCORE

"Algorithm Creation by Intelligent Systems", Cordell Green, USC-ISIC, USC-ISIE, SU-AI, and SU-SCORE (proposal pending)

"Radar Target Classification", Cordell Green and Roland Payne, TENEX systems (proposal pending to NAVELEX)

TTO

"Surveillance Integration Automation Project", Robert Drazovich, I4-TENEX, MOFFETT-ARC, USC-ISI, and SU-AI

"Surgical Countermeasures", A. J. Rockmore, USC-ECL

STO

"Performance Evaluation of Image Registration", Hassan Mostafavi, USC-ECL

"Cruise Missile Path Optimization", Jim Marsh, USC-ECL (proposal pending)

"Almost Terminal Viewing, Synthetic Aperture Radar", Fred Smith, USC-ECL (proposal pending)

"Experimental Definition for Spaceborne Distributed Aperture Radar Concepts", Hugh Pearce, USC-ECL (proposal pending)

Appendix B. Distribution List

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