GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ____

Project No. G-36-605 GTRI/~~GIT~~ DATE 4/25/83

Project Director: R. L. LeBlanc ARMY School/~~Lab~~ ICS

Sponsor: MERADCOM, Procurement & Production Directorate, Ft. Belvoir, VA

Type Agreement: D.O. #0015 under BOA DAAK70-79-D-0087 (AIRMICS) (OCA File #42)

Award Period: From 3/7/83 To ~~3/6/85~~ 9/30/85 (Performance) --- (Reports)

Sponsor Amount: Total Estimated: $ 168,519 Funded: $ 78,385 (Est. through 12/31/83)

Cost Sharing Amount: $ None Cost Sharing No: N/A

Title: Interactive Monitoring of Distributed Systems

ADMINISTRATIVE DATA

OCA Contact William F. Brown Ext. 4820

1) Sponsor Technical Contact:

Mr. Kearns/ACSC-CLD
AIRMICS
115 O'Keefe Bldg.
Georgia Institute of Technology
Atlanta, GA 30332
(404) 894-3110

2) Sponsor Admin/Contractual Matters:

T. A. Bryant
ONR RR
Campus
(404) 881-4213

see Rev #3

Defense Priority Rating: DO-S1

Military Security Classification: None
(or) Company/Industrial Proprietary: ____

RESTRICTIONS

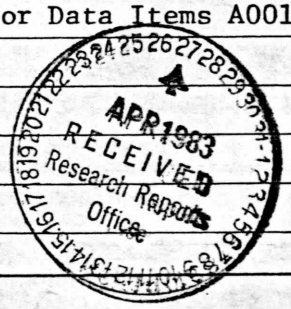
See Attached Gov't Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Government; however none proposed

COMMENTS:

Note: Request is being made to Sponsor to revise delivery date for Data Items A001 and A002 from the 7th to the 20th of the month.



COPIES TO:

Research Administrative Network
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
GTRI
Library
Research Communications (2)
Project File
Other LeBlanc
Other I. Newton

EORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 9/4/86

oject No. G-36-605 School/~~Lab~~ ICS

cludes Subproject No.(s) N/A

oject Director(s) R. J. LeBlanc GTRC /~~XXXX~~

onsor MERADCOm

tle Interactive Monitoring of Distributed Systems

fective Completion Date: 9/30/85 (Performance) (Reports)

ant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [X] Closing Documents
- [ ] Final Report of Inventions – Questionnaire sent to P.I.
- [X] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

ntinues Project No. Continued by Project No.

PIES TO:

- ject Director
- search Administrative Network
- search Property Management
- counting
- curement/GTRI Supply Services
- search Security Services
- orts Coordinator (OCA)
- al Services
- Library
- GTRC
- Research Communications (2)
- Project File
- Other A. Jones
  I. Newton
  R. Embry

RM OCA 69 285

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

April 7, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: March, 1983

Dear Sirs:

During the month of March, the principal investigator attended the ACM SIGPLAN/SIGSOFT Software Engineering Symposium on High-Level Debugging. At this symposium, I was able to talk to other researchers working on distributed debugging in order to compare approaches. It appears that by using the structural information available in a PRONET program, we will indeed be taking a unique approach to monitoring distributed programs.

Since the time the proposal was submitted, work has been completed on the PRONET implementation on the PRIME computers in the ICS Computing Laboratory. Experience with this implementation has shown that these machines are not a practical host for a language like PRONET, which requires the dynamic creation of processes. Thus we have decided to implement our monitor on Three Rivers Perq workstations running the Accent operating system which was developed at Carnegie-Mellon University. This will necessitate our reimplementing PRONET on this new system, which will lengthen the time needed to perform Task 1. However, Accent is much more supportive of the features of a language like PRONET than Primos is, so the other tasks should be easier.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: March, 1983

No man-hours were charged to this project this month.

Cumulative total to date: 0

Percentage of total expended to date: 0.0%

Total Funds Expended

Travel: $985.59

Cumulative total to date: $985.59

Percentage of total expended to date: 0.6%

Work Completion

Percentage of total work completed to date: 0%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

May 9, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: April, 1983

Dear Sirs:

During the month of April, 1983, two graduate students began working under this contract. Chu-Chung Liu has been assigned to Task 1, the PRONET interface, and Arnold Robbins is working on the communications monitor of Task 2.

We have decided to implement a status monitor first, in order to gain some experience with distributed program monitoring issues, before proceeding with the interactive monitor originally planned. The static monitor will be similar to the interactive one, except that the programmer will only be able to look at a replay of message traffic recorded by the monitor. Thus we will essentially be constructing prototypes for the programs described in Tasks 2 and 3.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O`Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: April, 1983

Man-hours Expended

Task 1: 88
Task 2: 103

Cumulative total to date: 191

Percentage of total expended to date: 3.4%

Total Funds Expended

Task 1: $2856.95
Task 2: $3514.69
Other: $ 170.31

Cumulative total to date: $7527.54

Percentage of total expended to date: 4.5%

Work Completion

Task 1: 4%
Task 2: 2%
Task 3: 0%
Task 4: 0%

Percentage of total work completed to date: 1.4%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

June 10, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: May, 1983

Dear Sirs:

Work on designs for the software to be developed in Tasks 1 and 2 proceeded during May. We have run into one major difficulty with using our Perqs: they don't have enough memory to run Accent effectively. Thus we have been delayed in familiarizing ourselves with the Accent environment. No testing of design ideas has been possible.

We have obtained funding from the School of ICS to purchase the additional memory we need. It has been ordered from Three Rivers. Delivery is expected during June.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O`Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: May, 1983

Man-hours Expended

Task 1: 88
Task 2: 78
Task 3: 25

Cumulative total to date: 382

Percentage of total expended to date: 6.9%

Total Funds Expended

Task 1: $2856.95
Task 2: $2661.61
Task 3: $853.08
Other: $575.32

Cumulative total to date: $14,474.50

Percentage of total expended to date: 8.6%

Work Completion

Task 1: 6%
Task 2: 4%
Task 3: 2%
Task 4: 0%

Percentage of total work completed to date: 4.4%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

July 12, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: June, 1983

Dear Sirs:

The memory for the Perqs we have been expecting has not arrived, so we have continued with only design work. Since Robbins has been with us only through August, he has begun working on a design for the interface (Task 3) to go along with his static communication monitor (Task 2). He will present these two designs as the main products described in his M.S. thesis.

Our study of the requirements for implementing PRONET and the capabilities provided by Accent continued during June. We have determined that the features of the extended Pascal supported by Accent are sufficiently powerful that we can use a pre-processor implementation approach. Programs written in ALSTEN and NETSLA, the two sublanguages of PRONET, will be translated to Pascal rather than compiled to Perq Q-code. This approach will greatly simplify our implementation task. Work on the ALSTEN pre-processor has begun, using the Zuse parser generator on our VAX 11/780.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: June, 1983

Man-hours Expended

Task 1: 88
Task 2: 50
Task 3: 53

Cumulative total to date: 573

Percentage of total expended to date: 10.3%

Total Funds Expended

Task 1: $2856.95
Task 2: $1706.16
Task 3: $1808.53
Other: $575.32

Cumulative total to date: $21,421.46

Percentage of total expended to date: 12.7%

Work Completion

Task 1: 10%
Task 2: 4%
Task 3: 4%
Task 4: 0%

Percentage of total work completed to date: 8.8%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

August 15, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: July, 1983

Dear Sirs:

The memory we needed has arrived and Accent is now running. However, the availability of a running system has highlighted its lack of documentation. Robbins has completed the prototype communications monitor design (Task 2) but is having difficulties with the interface design (Task 3) due to lack of information about the Canvas graphics package. In attempting to test some aspects of his implementation for ALSTEN, the process description component of PRONET (Task 1), Lin has been unable to even make process creation work correctly. We are attempting to obtain more information from Carnegie-Mellon.

Presuming we can overcome these problems in the near future, the contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: July, 1983

Man-hours Expended

Task 1: 25
Task 2: 8
Task 3: 8

Cumulative total to date: 614

Percentage of total expended to date: 11.0%

Total Funds Expended

Task 1: $473.16
Task 2: $131.66
Task 3: $131.66
Other:

Cumulative total to date: $22,157.89

Percentage of total expended to date: 13.1%

Work Completion

Task 1: 10%
Task 2: 4%
Task 3: 4%
Task 4: 0%

Percentage of total work completed to date: 13.2%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

September 12, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: August, 1983

Dear Sirs:

Considerable progress was made this month. The process creation problem in the ALSTEN implementation has been solved and the preprocessor has been transported from the Vax to the Perq. It is now fully functional and Task 1 effort can turn toward implementing NETSLA, the process interconnection component of PRONET.

Arnold Robbins has finished his designs for the Task 2 and 3 prototypes and has completed his M.S. thesis entitled "Design of a Passive Monitor for Distributed Programs." His interface design (Task 3) is dependent on some unverified assumptions about Canvas.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: August, 1983

Man-hours Expended

Task 1: 25
Task 2: 4
Task 3: 12

Cumulative total to date: 655

Percentage of total expended to date: 11.8%

Total Funds Expended

Task 1: $473.16
Task 2: $ 65.82
Task 3: $197.45
Other: $ 18.52

Cumulative total to date: $22,912.84

Percentage of total expended to date: 13.6%

Work Completion

Task 1: 10%
Task 2: 2%
Task 3: 6%
Task 4: 0%

Percentage of total work completed to date: 17.6%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

October 11, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: September, 1983

Dear Sirs:

Work has begun on the NETSLA sublanguage preprocessor (Task 1). A grammar has been written which meets the constraints of the parser generator. The Pascal code sequences to be generated for each of the NETSLA features are being planned.

Arnold Robbins has graduated and is no longer working on the project. He has been replaced by a new graduate student, Keith Harp, who will implement Arnold's prototype monitor design (Tasks 2 and 3). Roy Mongiovi, a member of the ICS Laboratory Staff is also participating in the implementation efforts now.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O`Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: September, 1983

Man-hours Expended

Task 1: 35
Task 2: 21
Task 3: 25
Clerical: 16

Cumulative total to date: 752

Percentage of total expended to date: 13.5%

Total Funds Expended

Task 1: $709.22
Task 2: $453.52
Task 3: $519.34
Other: $281.02

Cumulative total to date: $24,875.94

Percentage of total expended to date: 14.8%

Work Completion

Task 1: 10%
Task 2: 2%
Task 3: 2%
Task 4: 0%

Percentage of total work completed to date: 20.8%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

November 16, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: October, 1983

Dear Sirs:

A new release of Accent was received from Carnegie-Mellon University at the beginning of this month. Difficulties with bringing it up on our machines and time spent studying the documentation which arrived with the new release accounted for about half our effort this month.

Work continued on the NETSLA sublanguage preprocessor (Task 1). The focus this month was still design of Pascal code sequences corresponding to NETSLA features.

The work on the prototype monitor design (Tasks 2 and 3) has been slow while the new personnel on the project have been familiarizing themselves with Accent and the existing design. With the new release, we received the documentations we needed on the Canvas graphics package.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: October, 1983

Man-hours Expended

Task 1: 85
Task 2: 57
Task 3: 57
Task 4: 0
Clerical: 16

Cumulative total to date: 967

Percentage of total expended to date: 17.37%

Total Funds Expended

Task 1: $2173.47
Task 2: $1390.48
Task 3: $1390.48
Task 4: 0
Other: $ 176.64

Cumulative total to date: $30,007.01

Percentage of total expended to date: 17.81%

Work Completion

Task 1: 5%
Task 2: 2%
Task 3: 2%
Task 4: 0%

Percentage of total work completed to date: 23%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

December 13, 1983

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: November, 1983

Dear Sirs:

Work continued on the NETSLA sublanguage implementation of Task 1. Effort this month has included design of the required run-time support routines as well as work on the pre-processor.

Code is now being written to implement the prototype monitor (Tasks 2 and 3).

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: November, 1983

Man-hours Expended

Task 1: 85
Task 2: 57
Task 3: 57
Task 4: 0
Clerical: 16

Cumulative total to date: 1182

Percentage of total expended to date: 21.23%

Total Funds Expended

Task 1:
Task 2:
Task 3:
Task 4:
Other:

Cumulative total to date: $35,138.08

Percentage of total expended to date: 20.85%

Work Completion

Task 1: 10%
Task 2: 3%
Task 3: 3%
Task 4: 0%

Percentage of total work completed to date: 26.8%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

January 10, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: December, 1983

Dear Sirs:

Some difficulties have been encountered in using our parser generator to produce the NETSLA preprocessor (Task 1) apparently due to the size of the grammar. We are currently experimenting with ways to solve this problem.

Coding has continued on the prototype monitor (Tasks 2 and 3), with some testing also accomplished. This early testing has been done particularly to verify our understanding of the capabilities of canvas.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O`Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: December, 1983

Man-hours Expended

Task 1: 85
Task 2: 57
Task 3: 57
Task 4: 0
Clerical: 16

Cumulative total to date: 1397

Percentage of total expended to date: 25.09%

Total Funds Expended

Task 1:
Task 2:
Task 3:
Task 4:
Other:

Cumulative total to date: $40,269.15

Percentage of total expended to date: 23.9%

Work Completion

Task 1: 10%
Task 2: 3%
Task 3: 3%
Task 4: 0%

Percentage of total work completed to date: 30.6%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

March 23, 1984

AIRMICS
115 O'Keefe Building
Georgia Institute of Technology
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contract: Georgia Tech Research Institute
Month: January

Dear Sirs:

The NETSLA preprocessor has been completed (Task 1). A small amount of work remains to be done on the run-time support routines required to support PRONET. We will soon begin integration testing of the two preprocessors and the run-time routines.

Coding of the prototype monitor has essentially been completed (Tasks 2 & 3). Testing will now be our main focus.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: January, 1984

Man-hours Expended

Task 1: 63
Task 2: 25
Task 3: 43
Task 4: 0
Clerical: 16

Cumulative total to date: 1544

Percentage of total expended to date: 27.7%

Total Funds Expended

Task 1: $1565.55
Task 2: $ 658.33
Task 3: $1185.99
Task 4: 0
Other: $ 276.76

Cumulative total to date: $43,955.79

Percentage of total expended to date: 26.1%

Work Completion

Task 1: 7%
Task 2: 3%
Task 3: 3%
Task 4: 0%

Percentage of total work completed to date: 33.8%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

March 23, 1984

AIRMICS
115 O'Keefe Building
Georgia Institute of Technology
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: February

Dear Sirs:

Testing of the PRONET implementation is in progress (Task 1). Programs using a small subset of the language features have been executed successfully.

Testing of the prototype monitor is also in progress (Task 2 & 3).

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/np

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: February, 1984

Man-hours Expended

Task 1: 63
Task 2: 25
Task 3: 43
Task 4: 0
Clerical: 16

Cumulative total to date: 1692

Percentage of total expended to date: 30.4%

Total Funds Expended

Task 1: $1565.55
Task 2: $ 658.33
Task 3: $1185.90
Task 4: 0
Other: $ 276.76

Cumulative total to date: $47,642.43

Percentage of total expended to date: 28.3%

Work Completion

Task 1: 7%
Task 2: 3%
Task 3: 3%
Task 4: 0%

Percentage of total work completed to date: 37%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

May 3, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: March

Dear Sirs:

Testing of the PRONET implementation is in progress (Task 1). All features of the process sublanguage (ALSTEN) are now working.

Testing of the prototype monitor is also in progress (Tasks 2 and 3). All remaining problems are in the display interface routines.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: March

Man-hours Expended

Task 1: 63
Task 2: 21
Task 3: 47
Task 4: 16

Cumulative total to date: 1838

Percentage of total expended to date: 33.01%

Total Funds Expended

Task 1: 1559.51
Task 2: 583.72
Task 3: 1260.79
Task 4: 0.00
Other: 276.80

Cumulative total to date: 51311.61

Percentage of total expended to date: 30.45%

Work Completion

Task 1: 2
Task 2: 3
Task 3: 3
Task 4: 0

Percentage of total work completed to date: 39.2%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

May 3, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: April

Dear Sirs:

All currently implemented features of PRONET are working (Task 1). Only structured events and failure handling remain to be implemented.

The prototype monitor is now operational (Tasks 2 and 3) and was demonstrated during the IPR this month. The interface between PRONET programs and the monitor has been tested by hand construction. We must now have PRONET generate it automatically.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: April

Man-hours Expended

Task 1: 63
Task 2: 17
Task 3: 51
Task 4: 16

Cumulative total to date: 1985

Percentage of total expended to date: 35.65

Total Funds Expended

Task 1: 1559.51
Task 2: 509.04
Task 3: 1335.47
Task 4: 0.00
Other: 276.80

Cumulative total to date: 54992.43

Percentage of total expended to date: 32.63%

Work Completion

Task 1: 2
Task 2: 3
Task 3: 3
Task 4: 0

Percentage of total work completed to date: 41.4%

Richard J. LeBlanc Jr.,
Principal Investigator

June 20, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: May, 1984

Dear Sirs:

Work has begun to adapt the PRONET implementation for multiple machine operation (Task 1). Progress has been slow due to some networking hardware difficulties.

The interface between the prototype monitor is now being automated. The first step in this process is extending the ALSTEN and NETSLA preprocessors so that they generate code to collect the necessary information at run-time. Substantial progress has been made on this effort.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: May 1984

Man-hours Expended

Task 1: 63
Task 2: 11
Task 3: 57
Task 4: 0
Clerical: 40

Cumulative total to date: 2156

Percentage of total expended to date: 38.7%

Total Funds Expended

Task 1: $1,559.51
Task 2: $ 320.36
Task 3: $1,524.15
Task 4: -0-
Other: $1,852.67
(clerical and computing charges)

Cumulative total to date: $60,249.12

Percentage of total expended to date: 35.8%

Work Completion

Task 1: 2%
Task 2: 1%
Task 3: 5%
Task 4: 0%

Percentage of total work completed to date: 43.6%

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

July 24, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Contractor: Georgia Tech Research Institute
Month: June 1984

Dear Sirs:

Progress has been limited this month because of vacations during quarter break and lack of availability of our computers for over a week (when they were moved from our old offices to the ICS Lab). Efforts to resolve system problems have slowed work on multiple operation of PRONET (Task 1). Work on automating the interface between the preprocessors and the monitor has continued Tasks 2 and 3, though progress was limited as described above.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc, Jr.,
Principal Investigator

RJL/kkh

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: June 1984

Man-hours Expended

Task 1: 63
Task 2: 11
Task 3: 57
Task 4: 0
Clerical: 40

Cumulative total to date: 2327

Percentage of total expended to date: 41.7%

Total Funds Expended

Task 1: $ 1,559.51
Task 2: 320.36
Task 3: 1,524.15
Task 4: -0-
Other: 3,046.45
(clerical, supplies and computing charges)

Cumulative total to date: $64,918.51

Percentage of total expended to date: 38.5%

Work Completion

Task 1: 1%
Task 2: 1%
Task 3: 3%
Task 4: 0%

Percentage of total work completed to date: 45.0%

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

LIBRARY DOES NOT HAVE

R & D Status Report, July 1984

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

September 20, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: August, 1984

Dear Sirs:

The efforts under Task 1 continued to involve further extension of our preprocessors and run-time system to handle more Pronet features. A new version of Accent was received at the end of the month, which should allow us to proceed with work on multi-machine operation in the near future.

The work on automating the monitor interface (Tasks 2 & 3) is nearing completion.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc, Jr.
Principal Investigator

RJL/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: August, 1984

Man-hours Expended

Task 1:	92
Task 2:	50
Task 3:	107
Task 4:	0
Clerical:	24

Cumulative total to date: 2869

Percentage of total expended to date: 51.5%

Total Funds Expended

Task 1:	$2,609.63
Task 2:	1,380.61
Task 3:	3,326.99
Task 4:	-0-
Other:	2,533.75

(clerical and computing charges)

Cumulative total to date: $86,905.73

Percentage of total expended to date: 51.6%

Work Completion

Task 1:	1%
Task 2:	2%
Task 3:	3%
Task 4:	0%

Percentage of total work completed to date: 49.3%

Richard J. LeBlanc, Jr.
Principal Investigator

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

October 16, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: September, 1984

Dear Sirs:

Due to vacations between the summer and fall quarters and continuing difficulties with the Accent operating system, very little progress was made this month on any of the tasks.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

October 16, 1984

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: September 1984

Man-hours Expended

Task 1: 92
Task 2: 50
Task 3: 107
Task 4: 0
Clerical: 24

Cumulative total to date: 3142

Percentage of total expended to date: 56.4%

Total Funds Expended

Task 1: $2,609.63
Task 2: 1380.61
Task 3: 3,326.99
Task 4: -0-
Other: 2,533.75
(clerical and computing charges)

Cumulative total to date: $96,756.71

Percentage of total expended to date: 57.4%

Work Completion

Task 1: 0
Task 2: 1
Task 3: 1
Task 4: 0

Percentage of total work completed to date: 49.9%

Richard J. LeBlanc Jr.,
Principal Investigator

G-36-605

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

December 12, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: October, 1984

Dear Sirs:

Progress this month was limited by continuing difficulties with the Accent operating system. Some progress was made on interfacing with advanced Pronet features (Task 1). Work is continuing on the development of a Pronet program to test the usability of the prototype monitor (Tasks 2 and 3).

The contractually prescribed effort appears sufficient to achieve the objectives of the contract, but the prescribed calendar time will be insufficient. An extension of the completion date has been requested.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: October, 1984

Man-hours Expended

Task 1:	76
Task 2:	42
Task 3:	83
Task 4:	0
Clerical:	24

Cumulative total to date: 3367

Percentage of total expended to date: 60.5%

Total Funds Expended

Task 1:	$1,613.45
Task 2:	$ 882.52
Task 3:	$1,832.72
Task 4:	-0-
Other:	$2,533.75

(clerical and computing charges)

Cumulative total to date: $103,619.14

Percentage of total expended to date: 61.5%

Work Completion

Task 1:	1
Task 2:	1
Task 3:	1
Task 4:	0

Percentage of total work completed to date: 50.7%

Richard J. LeBlanc, Jr.
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

December 12, 1984

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: November, 1984

Dear Sirs:

Progress has again been limited by operating system difficulties. As of the date of this report, we have apparently received the new software we need, but it has not yet been installed. The only progress this month was continued work on testing the usability of the prototype monitor (Tasks 2 & 3).

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: November, 1984

Man-hours Expended

Task 1:	76
Task 2:	42
Task 3:	83
Task 4:	0
Clerical:	24

Cumulative total to date: 3592

Percentage of total expended to date: 64.5%

Total Funds Expended

Task 1:	$1,613.45
Task 2:	$ 882.52
Task 3:	$1,832.72
Task 4:	-0-
Other:	$2,533.75

(clerical and computing charges)

Cumulative total to date: $110,481.58

Percentage of total expended to date: 65.5%

Work Completion

Task 1:	0
Task 2:	1
Task 3:	1
Task 4:	0

Percentage of total work completed to date: 51.3%

Richard J. LeBlanc Jr.
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

February 18, 1985

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: December, 1984

Dear Sirs:

The new Accent operating system has been installed but changes in the terminal interface it provides require significant modifications in all of our existing programs. This modificiation work is currently in progress.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: December, 1984

Man-hours Expended

Task 1:	
PI	4
GRAs	72
TOTAL	76
Task 2:	
PI	2
GRAs	40
TOTAL	42
Task 3:	
PI	6
GRAs	77
TOTAL	83
Task 4:	
PI	0
GRAs	0
TOTAL	0
Clerical:	24

Cumulative total to date: 3817

Percentage of total expended to date: 68.55%

PI rate
GRA Rate
CLer Rate

Total Funds Expended

Task 1:	$1,613.45
Task 2:	$ 882.52
Task 3:	$1,832.72
Task 4:	-0-
Clerical	$ 415.20
Computing	$1,364.17
Supplies	-0-
Other:	$2,533.75

Cumulative total to date: $117,344.02

Percentage of total expended to date: 69.63%

Work Completion
(current)

Task 1:	0
Task 2:	1
Task 3:	1
Task 4:	0

Work Completion
(cumulative total)

Task 1	99
Task 2	50
Task 3	57
Task 4	0

Percentage to date 51.9%

Richard J. LeBlanc Jr.
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

February 18, 1985

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: January 1985

Dear Sirs:

Most program modifications to run with the new version of Accent are complete. However, we are still having difficulties making access to ports work across the network. Work has begun on Task 4, interfacing with a single process monitor, using the existing Accent debugging program.

A paper on our work has been accepted for the 5th International Conference on Distributed Computing Systems and will be presented there in May. Work on a final verison of that paper is in progress.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: January, 1985

Man-hours Expended

Task 1:	
PI	2
GRAs	20
TOTAL	22
Task 2:	
PI	2
GRAs	30
TOTAL	32
Task 3:	
PI	4
GRAs	50
TOTAL	54
Task 4:	
PI	4
GRAs	20
TOTAL	24
Clerical:	24

Cumulative total to date: 3973

Percentage of total expended to date: 71.35%

PI rate
GRA Rate
CLer Rate

Total Funds Expended

Task 1:	$ 503.52
Task 2:	$ 693.02
Task 3:	$1,196.55
Task 4:	628.05
Clerical	$ 415.20
Computing	$1,364.17
Supplies	-0-
Other:	$2,533.75

Cumulative total to date: $122,898.91

Percentage of total expended to date: 72.93%

Work Completion
(current)

Task 1:	0
Task 2:	1
Task 3:	1
Task 4:	5

Work Completion
(cumulative total)

Task 1	99
Task 2	51
Task 3	58
Task 4	5

Percentage to date 53.5%

Richard J. LeBlanc Jr.
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

April 11, 1985

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: February, 1985

Dear Sirs:

We are now operating successfully with the new version of Accent, except that name server problems limit us to programs running on a single workstation.

The final version of our paper for the 5th International Conference on Distributed Computing Systems has been completed.

Work has begun on Task 4, integrating a single process debugger with Radar.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

RJL/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: February, 1985

Man-hours Expended

Task 1:	22
Task 2:	27
Task 3:	27
Task 4:	56
Clerical:	24

Cumulative total to date: 4129

Percentage of total expended to date: 74.16%

Total Funds Expended

Task 1:	$ 503.52
Task 2:	$ 598.27
Task 3:	$ 598.27
Task 4:	$1,321.07
Other :	$2,533.75

(clerical and computing charges)

Cumulative total to date: $128,453.79

Percentage of total expended to date: 76.23%

Work Completion

Task 1:	0
Task 2:	3
Task 3:	3
Task 4:	5

Percentage of total work completed to date: 56.3%

Richard J. LeBlanc, Jr.
Principal Investigator

RJLjr/kkh

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INFORMATION AND COMPUTER SCIENCE • ATLANTA, GEORGIA 30332 • (404) 894-3152

May 3, 1985

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

RE: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems"
Contractor: Georgia Tech Research Institute
Month: March, 1985

Dear Sirs:

Due to spring breaks here and at CMU, we still haven't resolved the name server problem with Accent.

Work is continuing on Task 4, integrating a single process debugger with Radar. We are using the Kraut debugger distributed with Accent. We are also considering use of some concepts from Kraut as the basis of refinements to the Radar interface (Tasks 2 and 3).

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc, Jr.,
Principal Investigator

RJL/kkh

Performance and Cost Report
Contract No. DAAK70-79-D-0087-0015
"Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: March, 1985

Man-hours Expended

Task 1:	20
Task 2:	22
Task 3:	22
Task 4:	68
Clerical:	24

Cumulative total to date: 4285

Percentage of total expended to date: 76.96%

Total Funds Expended

Task 1:	$ 379.00
Task 2:	503.52
Task 3:	503.52
Task 4:	1,635.09
Other:	2,533.75

(clerical and computing charges)

Cumulative total to date: $134,008.68

Percentage of total expended to date: 79.52%

Work Completion

Task 1:	0
Task 2:	3
Task 3:	3
Task 4:	30

Percentage of total work completed to date: 64.1%

Richard J. LeBlanc Jr.,
Principal Investigator

G-36-605

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Information and Computer Science
Atlanta, Georgia 30332-0280
(404) 894-3152

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: April, 1985

Dear Sirs:

The name server problems with Accent are still unresolved; as a result, we remain unable to do any testing of Radar involving multiple machines. Our testing is thus limited to multiple processes on single machines. Although Accent makes machine boundaries invisible to processes, giving processes the same logical relationship regardlessof where they are located, we would still prefer to do some testing involving programs running on both of our Perqs. Because of the name server problem, little progress has been made on further work with the replay mechanism of Radar.

Work has continued on Task 4, integrating the single process debugger with Radar. One major problem has been encountered: dealing with conditional receive statements within the process being debugged. By using a message stream to simulate the rest of the program, messages are always available. Thus the "else branch" of the conditional receive will never be used during the debugging session. Dealing with this problem is now our highest priority.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

G-36-603

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Information and Computer Science
Atlanta, Georgia 30332-0280
(404) 894-3152

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: May, 1985

Dear Sirs:

The name server problems remain unresolved. We do not have the source code of this version of accent as we did with the last, so we have been hindered in our efforts to do anything. We are trying to get the source for this release from CMU.

Our paper on Radar was presented at the International Conference on Distributed Computing Systems this month. It was included in a session with two other distributed program debugging papers, which presented some interesting contrasting approaches to the problem.

Our problem with conditional receive statements in single process debugging (Task 4) has been solved by making execution of an else branch another kind of event to be recorded in the log file. This event is ignored by the multiple process replay driver. It is, of course, used in the single process debugging mode. The single process debugger is now finished and ready for testing.

We now have a new user who was not part of the implementation team attempting to implement a distributed program using Pronet on the Perqs. His experience is intended to provide feedback on our design and to further test our tools. His initial focus will be on the value of the multiple process replay (Tasks 2 and 3) in debugging a multiple process implementation of a minimal spanning tree algorithm.

The contractually prescribed effort appears sufficient to achieve the objectives of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

G-36-605

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Information and Computer Science
Atlanta, Georgia 30332-0280
(404) 894-3152

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: June, 1985

Dear Sirs:

The Accent name server problem remains unresolved. We have been promised source code from CMU, but have received nothing yet. Another problem has arisen due to the lack of source code. We are no longer able to produce templates for all messages, since we had done some compiler modifications in order to obtain the templates for records.

Work is proceeding slowly toward the goal of testing our system using a minimal spanning tree program.

The single process debugging capability (Task 4) has been tested by the implementor and is now ready for user testing. It will be used in debugging the minal spanning tree program when that effort reaches the appropriate point.

The Vax 780 in the ICS Lab which we use for some of our development work and where must read any tapes we get from CMU has recently been converted to version 4.2 of Berkeley Unix. Since that time, our file transfer program, which we have in object form only, no longer works. We will try to obtain another one from CMU or from someone on Usenet (the source of our current version).

Because of our problems with Accent and other software problems, it is unlikely that the contractually prescribed effort remaining will enable us to make any further refinements to Radar.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

G-36-605

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Information and Computer Science
Atlanta, Georgia 30332-0280
(404) 894-3152

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: July, 1985

Dear Sirs:

We still have not received the source code for Accent from CMU. Apparently the configuration of our Perqs is suffiently out-of-date that what we need must be recreated from backups, which nobody has gotten around to doing for us. We also still lack a working file transfer program to move programs between the Vax and the Perqs.

Progress with the minimal spanning tree program, to be used to evaluate Radar (Tasks 2 and 3) has been slow due to the need to fix problems with Pronet, compounded by out lack of file transfer capabilities.

In our work to develop a higher level interface to Radar, we are exploring the possibility of borrowing some ideas from a data compression technique. The essence of this approach will be to present the user with information about recurring groupings of events, which contrasts to our previously rejected alternative that required the user to describe the groupings he expected. The limited amount of contract effort remaining will not enable us to do more than just study this new approach.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

Georgia Institute of Technology
School of Information and Computer Science
Atlanta, Georgia 30332-0280
(404) 894-3152

AIRMICS
115 O'Keefe Building
Georgia Tech Research Institute
Atlanta, Georgia 30332

Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: August, 1985

Dear Sirs:

We still are waiting for the required Accent source code from CMU. Apparently their work on our request has uncovered some problems with their file backup system that they have not yet resolved. At this point, we don't really expect to receive anything from them before the end of the project, so we will remain unable to actually test Radar on programs executed on multiple machines.

Our file transfer program has been fixed by one of the ICS lab staff who took the object code of the old version and substituted in Unix 4.2 system calls where necessary. His efforts have been very valuable to us.

Our Radar evaluation effort (Tasks 2 and 3) has finally succeeded in getting the minimal spanning tree program executing on the Perqs. Just we hoped might be the case, the initial version contains at least one bug that can be used as an application for Radar. Unfortunately, that bug causes the program to loop and when we abort execution, we lose the log files required to drive Radar. This is a very fundamantal problem that will be a significant disadvantage of the replay style of debugging if we can't solve it.

We have identified a data compression algorithm which we hope will be satisfactory to implement our event grouping concept. Due to lack of man-hours remaining in the project, we will not have a chance to implement this extension to Radar, but will be limited to studying its potential and related implementation issues.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

GEORGIA TECH 1885-1985
DESIGNING TOMORROW TODAY

Georgia Institute of Technology
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Atlanta, Georgia 30332-0280
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Re: R&D Status Report
Contract No. DAAK70-79-D-0087-0015
Interactive Monitoring of Distributed Systems
Contractor: Georgia Tech Research Institute
Month: September, 1985

Dear Sirs:

As expected, there have been no further developments involving Accent.

We have been successful in providing a capability to abort looping programs so that their log files are not lost. Since there is a "master process" controlling the execution of a Pronet program, we can have it periodically look for a command from the keyboard to abort the program. It can then send emergency messages to the processes, requiring them to terminate. This is not as general a solution as might be desired, since it depends on particular properties of Accent and Pronet. Any other application of the technology we have developed will have to consider handling the problem of looping programs an important constraint.

The bugs in the minimal spanning tree program were independently discovered while this problem with Pronet was being fixed, so Radar was not used very significantly in debugging it. However, this effort did contribute considerably to the removal of problems in Pronet and the data collection system upon which Radar is based.

Our studies of the data compression concept have led us to the conclusion that it will require some extensions, since the basic algorithm for compression works on a single data stream. Events in from a Pronet program, while they can be linearized, actually come from multiple streams, one for each process. We have identified an ICS student who is interested in continuing work on this problem as his senior design project, so work on this aspect of the problem will continue beyond the end of the contract.

Sincerely,

Richard J. LeBlanc Jr.,
Principal Investigator

USING PRONET AND RADAR

1) To compile a Netsla program NetslaFileName.n:

   1.1) translate NetslaFileName.n into NetslaFileName.pas which is a Pascal version of the program.

   ```
   % netsla NetslaFileName.n
   ```

   1.2) compile NetslaFileName.pas:

   ```
   % com NetslaFileName.pas
   ```

2) To compile a Alsten program AlstenFileName.a:

   2.1) translate AlstenFileName.a into AlstenFileName.pas which is a Pascal version of the program.

   ```
   % alsten AlstenFileName.a
   ```

   2.2) compile AlstenFileName.pas:

   ```
   % com AlstenFileName.pas
   ```

3) To run a Pronet program, just type

   ```
   % NetslaFileName
   ```

4) To replay program execution, just type

   ```
   % replay NetslaFileName
   ```

   At any time during the event replay the user can stop execution by causing a keyboard interrupt. This invokes an interrupt handler which presents the following menu:

   1. Change To/From Single-Step/Continuous Operation.
   2. Change The Number of Seconds Per Event.
   3. Skip Ahead to A Specific Event Number.
   4. Display Contents of the Message Under the Mouse.
   5. Instant Replay.
   6. Start Displaying From Scratch.
   7. Exit REPLAY.
   8. Help.
   9. Never Mind.

   After the interrupt handler does what the user wishes, the program returns to where it was executing before the interrupt occurred.

5) Single process debugging

   5.1) to prepare log files for single process debugging

   ```
   % ucap NetslaFileName ProcessName
   ```

   where ProcessName is the name of the process to be debugged.

   5.2) to start debugging a process instance

   ```
   % NetslaFileName -k ProcessName ProcessID
   ```

   where ProcessID is the Pronet ID that has been assigned to

the particular process instance.

The user then has to create a window for KRAUFT which is a process debugger for the Accent operating system.

After KRAUFT is invoked, the user should resume the execution of the debugged program by typing a key on the keyboard.

```
************************
* PRONET preprocessors *
************************
```

LLact.a
  Action code which specifies the steps to be taken by the Alsten preprocessor during translation.

LLact.n
  Action code which specifies the steps to be taken by the Netsla preprocessor during translation.

LLconst.a
  Constant declarations for Alsten preprocessor.

LLconst.n
  Constant declarations for Netsla preprocessor.

LLgram.a
  A modified version of grammar.a which has been compressed to facilitate use by the Alsten preprocessor.

LLgram.n
  A modified version of grammar.a which has been compressed to facilitate use by the Alsten preprocessor.

LLselect.a
  Reformatted Alsten grammar which contains the productions numbered in increasing order by line number from the orginal Alsten grammar.

LLselect.n
  Reformatted Netsla grammar which contains the productions numbered in increasing order by line number from the orginal Netsla grammar.

LLsup.a
  The support routines referenced in the Alsten preprocessor or the action code.

LLsup.n
  The support routines referenced in the Netsla preprocessor or the action code.

LLtype.a
  Type declarations for the Alsten preprocessor. LLtype.a is included into alsten.pas (the Alsten preprocessor.)

LLtype.n
  Type declarations for the Netsla preprocessor. LLtype.n is included into netsla.pas (the Netsla preprocessor.)

LLvar.a
  Variable declarations for the Alsten preprocessor.

LLvar.n
  Variable declarations for the Netsla preprocessor.

LLwrt.n
  The support routines referenced in the Netsla preprocessor. Used to generate Pascal code.

atables
  Parsing table that will be read by the Alsten preprocessor.

alsten.Pas
  The Alsten preprocessor.

gen.pas
A program which accepts a translation grammar as input and generates several files which will be needed for the language preprocessor.

grammar.a
LL(1) grammar for Alsten.

grammar.n
LL(1) grammar for Netsla.

netsla.Pas
The Netsla preprocessor.

ntables
Parsing table that will be read by the Netsla preprocessor.

****
* PRONET runtime library *
****

activities.pas
Supporting routines which are called to actually perform the Netsla and the Alsten activities.

alsten_supt.pas
Additional supporting routines to handle Alsten activities such as the message reception and the message transmission.

alsteninit.pas
Initialization code to set up parameters of a child process when it is created.

child_lib.pas
Library routines that are referenced by child processes.

db_procs.pas
Routines that create and maintain the run-time database of a Pronet program.

db_types.pas
Declarations of data types that are used in the database.

decl_types.pas
Type declarations.

defs.pas
Definitions of some system parameters.

events.pas
Event handlers. Defines steps to be taken when an event occurrs.

netslainit.pas
Codes to initialize a network.

****
* RADAR *
****

eventtypes.pas
This module is broken out separate from the rest of radartypes because it is the only one needed to do logging of events, and using all those identifiers when only these are needed is begging for doubly-defined

identifiers

files.pas
Filehandling module for REPLAY system, isolates getting the next event from all the log files.

history.pas
Self contained module for handling history of events, to help when performing the Instant Replay of RADAR.

screen.pas
Screen -- keep track of what is on the screen.

support.pas
Module containing miscellanious small support routines for the RADAR monitoring system.

template.pas
Routines to generate template files.

types.pas
Type definitions for RADAR, pronet/clouds monitor
This module is not designed to be actually compiled on the Perqs. It is used to put all the type definitions in one place. It then exports those definitions. It includes fudgemod.p only so that the module will be syntactically valid for the perqref cross referencing program.

ucap.pas
Up Close and Personal -- message filtering program to aid in single process debugging of Pronet process scripts.

vars.pas
Variable declarations for RADAR -- pronet/clouds monitor

proc.pas
Procedures for RADAR

process.pas
Processhandling -- keep track of actual processes, ports, destinations

radarlog.pas
Radarlog -- module which performs logging function for RADAR

****
* Test programs *
****

MSTnetnp.pas
mstnet.pas
mstnode1.pas
mstnode2.pas
mstnode3.pas
mstnode4.pas
Pronet programs that implement a distributed algorithm of minimum spanning tree.

int.n
int.pas
scan.a
scan.pas
parse.a
parse.pas
seman.a
seman.pas

Pronet programs that implement a simple arithmetic interpreter.

broadcast.n
broadcast.pas
sender.a
sender.pas
receiver.a
receiver.pas

Pronet programs that implement the message broadcasting.

ca1.pas
cb1.pas
cb2.pas
cc1.a
cc1.pas
cc2.Pas
cc2.a
cc3.a
cc3.pas
cd2.a
cd2.pas
ce1.a
ce1.pas
ce2.a
ce2.pas
cf1.a
cf1.pas
cf2.a
cf2.pas
cg0.a
cg0.pas
cg1.a
cg1.pas
cg2.a
cg2.pas
cg3.a
cg3.pas
pa.Pas
pb.pas
pc.n
pc.pas
pd.n
pd.pas
pe.n
pe.pas
pf.n
pf.pas
pg.n
pg.pas
ps1.a
ps1.pas
ps2.a

Programs to test various features of Pronet.

INTERIM REPORT

INTERACTIVE MONITORING OF DISTRIBUTED SYSTEMS

By
Richard J. LeBlanc

Prepared for
U.S. ARMY
Institute for Research in
Management Information and Computer Science
Atlanta, Georgia 30332

Under
Contract No. DAAK70-79-D-0087-0015
GIT Project No. G36-605

May 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF INFORMATION AND COMPUTER SCIENCE
ATLANTA, GEORGIA 30332

Interactive Monitoring of Distributed Systems
Interim Report

Richard J. LeBlanc

May, 1984

U.S. Army Institute For Research in
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Atlanta, Georgia 30332

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Section 1

INTRODUCTION

1.1 Problems with Monitoring Distributed Programs

In a conventional programming environment, there are two principal purposes for monitoring the run-time behavior of a program: performance measurement and debugging. (By "monitoring" we refer to some mechanism for obtaining information about the performance of a program, external to the program itself.) Performance measurement is a relatively mundane application of monitoring in such an environment, being principally concerned with the processor time requirements of various parts of a program and requiring little or no interactive intervention by a programmer. Debugging is considerably more interesting, requiring extensive programmer interaction by its very nature.

When we generalize our thinking to a distributed system from a traditional single-processor environment, the uses of monitoring become somewhat different and we must develop a new conceptual view of a major part of the monitoring task. We are, of course, still interested in performance measurement and debugging, but these tasks become quthis new environment. The reason for this difference is that we are now concerned with distributed programs - programs which cannot be monitored by considering a single address space on a single machine. Rather, we must now be concerned with the communication between the various parts of a program, for these interactions will play a crucial part in the monitoring task.

Performance measurement in a distributed system is made more complex by a number of new considerations. Communication costs and the overall time it

takes to execute a program, which is affected by the potential for parallel execution of subtasks and by time spent waiting for messages, are equally important considerations in many situations. Further, it is much more difficult for a measurement program to monitor an entire program, since the monitored program may be distributed arbitrarily across a network of machines. It will be necessary for any monitoring program to obtain information about the distribution of a program and about its communication linkage and behavior.

This need to obtain information from distributed execution sites naturally applies to debuggers as well as to performance monitors. In fact, it is a more complex problem in the case of a debugger since the debugger must somehow assist a programmer in comprehending the "state" of a program which consists of a number of processes running asynchronously on several machines. Conventional debugging tools are certainly of little use in this situation, since they are typically oriented toward monitoring the operation of what would only be a single process of a distributed program. Once again, tools which provide information about the status of process interactions will be required. (Such tools should also have the capability to interface with more traditional monitoring tools which can be used on the individual processes.)

Just as communication should play an important part in distributed performance measurement, it should also have a crucial role in debugging distributed programs. The correctness of such programs will undoubtedly depend on the correctness of the contents and sequencing of messages transmitted between their constituent processes. Thus a distributed debugging tool must deal with communication as a major part of its job. In fact, it is conceivable that a communication monitor may be the debugger at the interprocess level, complementing traditional debuggers which operate on individual processes.

As a final difficulty, any kind of monitoring of a distributed program will potentially generate a great deal of information, which must be conveyed to a programmer in a comprehensible manner. It will presumably not be satisfactory to produce all of this information independently for each of the processes. Rather, the information must be aggregated in some manner consistent with the nature of the monitoring task being performed.

1.2 Proposed Solutions Using PRONET

The network descriptors of PRONET will provide an excellent basis for the operation of distributed monitoring tools. The interconnection information these networks provide is exactly what is required by a monitor so that it can easily recognize the structure of an entire program. Thus the implementation of a distributed performance monitor or debugger can use our PRONET work as its basis.

As was indicated in the previous section, a communication monitor will be a crucial part of any of these tools. The interconnection specifications in PRONET networks, as currently designed, provide the minimum amount of information needed by a communication monitor. That is, they provide a listing of the message paths between processes and the types of the messages which may be transmitted. The task of a monitor will be to provide a programmer with information about message transmission between processes. For performance measurement purposes, the most important information will probably involve such factors as message queue lengths and the amount of time processes spend waiting for messages. A distributed debugger, on the other hand, will be concerned with the sequencing of messages and with their contents. It will probably also be required to provide some capabilities to examine the operation of individual processes, which may be accomplished by interfacing with

traditional single process debuggers.

1.3Overview of Project Status

The project was originally planned to include the following tasks as described in the original statement of work:

Task 1 - PRONET Interface

PRONET, a language that provides a high level description of interprocess communication, is currently being implemented on the full distributed system at Georgia Institute of Technology. The task is to develop an interface between PRONET and a distributed monitor.

Task 2 - Communication Monitor

The contractor shall determine what data should be collected by the monitor to facilitate development, debugging and maintenance of programs. This task is to develop a monitoring program that interfaces with the communication features of the operating system and collects the necessary data.

Task 3 - Interface to the Communication Monitor

The contractor shall determine what data should be collected by the monitor to facilitate development, debugging and maintenance of programs. The task is to develop a monitoring program that interfaces with the communication features of the operating system and collects the necessary data.

Task 4 - Interface with a Process-level Debugger

The contractor shall develop an interface with the communications monitor and an existing symbolic debugger. If this approach is infeasible, then

a symbolic debugger for individual processes must be implemented and interfaced with the single process debugger.

Since this project was initiated, some changes in the tasks have been made. The new approach to the project is described in the following list of tasks and justification for the changes:

Task 1: Implement PRONET on Perq computers and provide a monitor interface.

Task 2: Build a prototype monitor.

Task 3: Build a full monitor.

Task 4: Interface with a process-level debugger.

The change in task 1 involves use of different hardware than originally planned. The main reason for this change was that we found the implementation of PRONET on our Primes too expensive to be practical. The operating system on these machines does not effectively support dynamic process creation. The Accent operating system available on the Perqs, on the other hand, supports dynamic process creation as well as message passing between processes on different machines. Thus it makes PRONET implementation much simpler than on the Primes.

The Perqs also have high-resolution, bit-mapped displays. This feature gives considerable support to the development of a very effective user interface to our monitoring system.

The other major change in our approach involves the initial development of a prototype monitor rather than immediate development of the final system. This change has two motivations. First, it will give us some experience in dealing with distributed programs short of a full-scale implementation. Since the prototype will provide only a historical replay of program events, the

second motivation for this approach is that it allows us to address the hardest problem last. That problem is the question of how we will deal with real time interaction with the processes of a distributed program.

The following four sections describe various aspects of the design of the prototype monitor, called RADAR. They are extracted from Arnold Robbins' M.S. thesis. They are followed by sections on the PRONET implementation, the monitor implementation status and our plans for further work.

Section 2

RADAR DESIGN

2.1 Distributed Programs

The RADAR monitor is intended to support Pronet [Macc82], a message based language specifically designed for writing programs which can take advantage of the environment offered by an FDPS. However, it could be easily adapted to support other message-based programming systems. The relevant features of Pronet will be discussed in the section 3.1.

2.2 The RADAR System

The RADAR system takes a passive approach to monitoring distributed programs. Because it is not interactive the term "monitor" is used to describe it, and not the term "debugger."

RADAR is designed to support Pronet on PERQ computers [3RCC82]. The PERQ is a single user machine with a high resolution bit-mapped display and a mouse.

Pronet consists of two sublanguages: NETSLA for describing communication networks, and ALSTEN for describing processes. The Pronet compiler provides the monitor with information concerning the connectivity of the processes. This information is collected from the NETSLA runtime system. ALSTEN programs are loaded with a special communications library which records every standard or user-defined event during execution, and makes a copy of every message sent. The exact nature of the information supplied by the NETSLA runtime

system and the structure of ALSTEN event records will be described in section 3.2. This component of RADAR is known as the RADARLOG.

After the program has completed executing, the REPLAY component of RADAR is invoked to provide a graphical "replay" of the execution. Each message or event is stamped with a global event number. This imposes a partial ordering on events. The monitor then displays events one at a time. The programmer is able to watch the communications traffic amongst the processes. Processes have names in Pronet, so it is easy for the programmer to see which process is communicating with which other processes.

REPLAY provides the user with the ability to view the contents of any message currently represented on the screen. Messages are represented on the screen as small boxes. The user places the PERQ's mouse over the message which he wishes to examine. REPLAY then opens a new window in which the contents of the chosen message will be displayed in a formatted fashion. For instance, if the message contained an integer and two floating point numbers, the message would be displayed as an integer and two floating point numbers, not as 10 octal bytes. When the user is through with the message the new window disappears.

REPLAY also provides the ability to replay a certain number of events which have already happened. This can be done at any point during the display. The user can "rewind the video tape," so to speak. This replay is limited to a reasonable maximum number of previous events. This feature is known as an "Instant Replay."

Finally, as a separate utility, the user can name a given process and have all of the messages which were sent to that process selected from the recorded message traffic. This single process may then be run by itself with its messages derived from the stored messages. This feature is designed to

facilitate single process debugging using real input data (messages). This way, it is possible to observe a process' behavior under realistic conditions, without having to worry about controlling the rest of the processes of the distributed program.

Section 3

COLLECTING INFORMATION

RADAR is intended to support Pronet, a language designed for writing programs which can execute in a distributed processing environment. Pronet stands for Processes and Networks. The introduction to Chapter 2 of [Macc82] summarizes the description and design goals of Pronet:

> PRONET is composed of two complementary sublanguages: a network specification language, NETSLA, and a process description language, ALSTEN. Programs written in PRONET are composed of network specifications and process descriptions. Network specifications initiate process executions and oversee the operations of the processes they have initiated. The overseeing capacity of network specifications is limited to the maintenance of a communication environment for a collection of related processes. The processes initiated by a network specification can be simple processes, in which case the activities of the processes are described by ALSTEN programs, or they can be "composite processes", in which case their activities are described by a "lower-level" network specification.
>
> ALSTEN is an extension of Pascal which enables programmers to describe the activities of sequential processes. During their execution, processes may perform operations that cause events to be announced in their overseeing network specification. Network specifications, written in NETSLA, describe the activities to be performed when an executing process 'announces' an event.... Two principles have influenced the design of these features: independence of process descriptions and distributed execution of network specifications.

This section first describes the features of Pronet relevant to interprocess communication. Then it describes the information provided to the monitor by the NETSLA and ALSTEN compilers. Finally, it presents the format of the information collected at run-time by the special communications library.

3.1 The Features of Pronet

This presentation is derived from Chapter 2 of [Macc82].

3.1.1 ALSTEN

ALSTEN is essentially an extension of Pascal [Jens74]. The file concept has been removed entirely from the language. Processes communicate only through locally declared "ports", using the inline send and receive statements which are analogous to Pascal's read and write. Ports have a direction, either in or out. Ports may be placed together into port groups. One could define a duplex channel as:

port channel (incoming in bit; outgoing out bit);

To accomodate the notion of a server process, which serves many other processes, ALSTEN provides port sets and port tag variables. A port set is a collection of port groups or simple ports identified by one name. For instance, if a port set is a set of port groups, a receive on a port set would set a port tag variable to indicate which element of the set was actually used for communication. This tag may then be used in a send operation for sending replies to the process which originated the message.

The syntax of the send and receive statements is shown in Figure 1.

```
<send stmt> ::=
   send [<expr>] to <bound port denoter>

<receive stmt> ::=  <simple receive>
 | <conditional receive>

<simple receive> ::=
   receive [<variable>] from <free port denoter>

<conditional receive> ::=  when
                              {<receive part>}
                              [<otherwise part>]
                           end

<receive part> ::=  <simple receive> [do <stmt>]

<otherwise part> ::=  otherwise <stmt>
```

Figure 1 --- Send and Receive Statements in ALSTEN

A type is associated with every port. Only expressions of the type associated with a given port may be sent to or received from that port.

The <expr> is optional. In these forms of the send and receive statements, the port is of type signal. A signal is a message with no contents. Signals are often useful for sending control information, such as telling a process to start a particular task.

The syntax for port declarations is shown in Figure 2.

```
<port decl> ::= <simple port decl>
 | <port group decl>

<simple port decl> ::=
     port <port id> <direction> <msg type>

<port id> ::= <id>

<direction> ::= in | out

<msg type> ::= <type id>

<port group decl> ::=
   port [set] <port id> '(' <subport list> ')'

<subport list> ::=
   <subport decl> {';' <subport decl>}

<subport decl> ::=
   <subport id> <direction> <msg type>

<subport id> ::= <id>

<port tag type> ::= tag of <port id>
```

Figure 2 --- Port and Port Tag Declarations in ALSTEN

3.1.2 NETSLA

As stated earlier, the purpose of NETSLA specifications is to initiate and control the communications environment of ALSTEN processes:

> The features of NETSLA are aimed at specifying the initial configuration and subsequent modifications of a communication environment for processes. The overriding principle followed in the design of these features is that of "centralized expression--decentralized execution" [Live80]. Centralized expression is important in presenting the abstraction to be supported by network specifications. All of the inter-process relationships that describe a communication environment appear in a single network specification. However, this communication environment is not maintained in a centralized fashion. Processes maintain their communication environment indirectly. When they execute send or announce operations, processes perform the activities specified by their overseeing network specifications; however, the nature of these activities are unknown to the process. [Macc82]

The syntax of network specifications is shown in Figure 3.

```
<network specification> ::= <network header>
      {<process class specification>}
      {<event handling clause>}
      [<initialization clause>]
   end <identifier>

<network header> ::= network <net id> ';'
   {<port decl>}
   {<event decl>}

<process class specification> ::=
   process class <process id>
      [<process attributes>]
      {<port decl>}
      {<event decl>}
   end <process id>

<process attributes> ::= attributes
      <field list>
   end attributes
```

Figure 3 --- Network Specifications in NETSLA

When a network starts to run, its initialization clause is executed. The initialization clause is used to create instances of processes and connect the output ports of one process to the input ports of another. A simple network specification is presented in Figure 4; a graphical representation of the network is shown in Figure 5.

```
network static_net
   process class proc_class
      port input in integer;
      port output out integer;
   end proc_class

   initial
      create proc1 : proc_class;
      create proc2 : proc_class;
      create proc3 : proc_class;
      connect proc1.output to proc3.input;
      connect proc2.output to proc3.input;
      connect proc3.output to proc1.input;
      connect proc3.output to proc2.input;
end static_net
```

Figure 4 --- A Simple Network Specification

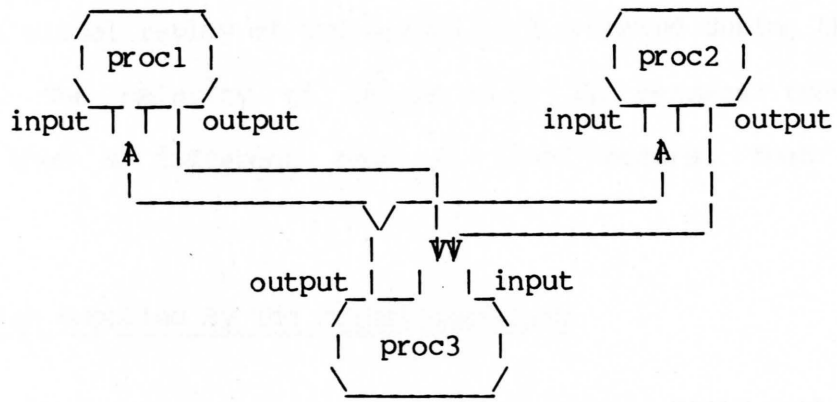

Figure 5 --- A Graphical Representation of the Simple Network

If one output port is connected to more than one input port, the messages sent out on it are replicated. This occurs in a manner invisible to the process sending the message. This allows one-to-one, one-to-many, and many-to one connections between ports.

Processes may define events. These events can then be announced by the processes in their overseeing network specifications. NETSLA provides features for handling these events when they are announced. The programmer specifies what actions to take, such as aborting processes or creating new ones. Other actions are also possible.

Pronet predefines several standard events. For instance, when a process terminates normally, the standard event 'done' is announced in its network.

Message transmission and reception are considered to be events. They simply have a separate syntax. The other standard events and the syntax of event declarations and handlers are discussed fully in [Macc82].

Since Pronet is oriented around events, so is RADAR. The special runtime routines record all the events and messages. The REPLAY program presents the user with a visual replay of the events that occurred during the execution of the program. The majority of events will be message transmission and reception. When a different type of event occurs, that event will be portrayed.

3.2 Information Supplied By The Pronet Compilers

The Pronet compilers and runtime system provide RADAR with the framework upon which to build the later description of events.

3.2.1 ALSTEN

Ports in Pronet are always associated with a type. Only messages of the type associated with a port may be sent to or received from that port.

In any given ALSTEN program, there will be a fixed number of different message types, i.e. the types associated with ports.

The ALSTEN compiler will generate a file with a list of message templates. A template looks like

| Identifier | size | total no elements | list of elements |

Figure 6 --- Message Templates

The list of elements is simply an ordered listing of the fields in a message. For instance,

| real | array character 19 | int | long |

Figure 7 --- Fields In A Message

If a field of a message is itself a record with further subfields, the compiler will expand it in line down to its basic elements. Elements can be bytes, integers, long integers, reals, or one dimensional arrays of these types. Bytes are treated as unsigned integers, even though they may have actually been signed quantities. If necessary, RADAR may be modified to allow specifying whether or not such numbers were signed or unsigned. Elements smaller than one byte occupy a byte to themselves. This implies that the Pascal keyword packed has no effect. Admittedly, this is a constraint on the compiler; see Section 5 of the thesis for further discussion of this constraint.

The purpose of the list of message templates is to allow the decoding of individual messages. A user can select any message on the screen with the PERQ's mouse. When he does so, RADAR will open a separate window and format

the contents of the message in it. Each message carries its type with it. The message is decoded according to the corresponding template and printed accordingly. One dimensional arrays are allowed, principally for use in displaying character strings. REPLAY will treat arrays as if they are indexed from 1.

3.2.2 NETSLA

NETSLA controls process and port creation and the interconnecting of output ports to input ports.

The information generated by the NETSLA system is a file describing each process. A process is described as follows:

```
machine   proc_num   proc_name   number_port_groups
  number of simple ports in each group
     direction  number  name  type { DESTINATIONS }
     direction  number  name  type { DESTINATIONS }
  number of simple ports in each group
     direction  number  name  type { DESTINATIONS }
     direction  number  name  type { DESTINATIONS }
```

Figure 8 --- Description Of A Process

The {} pairs enclose optional information. Only if a port is an output port does it have one or more destinations associated with it. The DESTINATIONS field in Figure 8 above represents the number of destinations to which an output port sends its messages, and the destinations themselves. A destination is uniquely identified by the destination machine, the process number on that machine, and the port number of the process to which the message is directed.

Machine and process id's are hidden from the programmer, but the NETSLA runtime system and the underlying global operating system must know about them, since they actually arrange for execution of the processes.

When REPLAY first starts up, it builds a table of records describing processes with all these structures attached to each element in the table. Later, when a send event occurs, REPLAY determines which process is the destination and depicts a message moving from the source process to the destination process.

3.3 Information Collected At Run-Time

Most of the information that RADAR needs is collected at run-time. Special runtime routines log every event that occurs. These routines are kept in a separate module called RADARLOG.

Events may be one of the following:

```
type
     eventtype = (createprocess, destroyprocess,
          message_transmission, message_reception,
          portcreation, failed, done
          aborted, userevent);
```

Figure 9 --- Types Of Events

The 'message_transmission' and 'message_reception' events are logged by the send and receive routines respectively. The other events are logged by the announce routine.

The ALSTEN compiler inserts a procedure call to the routine makelog as the very first executable statement in a program. This routine creates the log file and announces the process creation event. Before the final end of

the ALSTEN main program, the compiler inserts a call to the routine closelog, which closes the logfile and announces the standard event 'done.'

The structure of the log file records for each event is as follows.

message-transmission	machine-id	process-id	count
UniqueMesgId	success	checkpointing	mesg-type
bufsize	','	buffer	

message-reception	machine-id	process-id	count	success	{ UniqueMesgID }

userevent	machine-id	process-id	count	eventname

createprocess	machine-id	process-id	count

destroyprocess	machine-id	process-id	count

portcreation	machine-id	process-id	count

failed	machine-id	process-id	count

done	machine-id	process-id	count

aborted	machine-id	process-id	count

Figure 10 --- Event Records

Each process keeps a count of the events it has announced, including message transmission and reception. The event count starts at one and is incremented with each event.

When a process sends a message, it includes the value of its local event counter. If the receiving process' event count is lower than that of the sen-

der's, the receiver sets its count equal to that of the sender. After receiving the message, the process logs the message_reception event. If the message reception succeeded, the process logs the UniqueMesgId of the message it received. Since message_reception is an event like any other, the local event count is incremented before the event is logged. Thus, the message_reception event's sequence number will be one greater than the event count of the sender. This insures that there will be at least a partially correct ordering on events. In particular, interrelated events will always be correctly ordered.

Placing an ordering on events in a distributed system is a difficult task. One solution is to use the times on local clocks to time-stamp each event. This method is not acceptable since it is impossible to synchronize all the clocks on all the machines. This introduces the possibility of recording events out of order. E.g., it would be possible, due to synchronization errors among clocks, to record the reply to a message as having occured "before" the sending of the initial message.

By having the receiver of a message set its event count equal to that of the sender, and then incrementing the count before logging the message reception, the synchronization problem is avoided. The reply to a message will always be sent "after" the sending of the initial message.

Using this method, it is possible to have several events occuring at the same "time," i.e. several events might all have the same event number. In this case, it is impossible to determine the ordering of these events, but in fact, the ordering is unimportant. The fact that these events all have the same number indicates that they are <u>not</u> interrelated, since if one event depended on another to precede it, its event sequence number would have been greater than the sequence number of its predecessor.

Furthermore, this method makes no extra demands on the underlying global operating system to keep clocks synchronized across machines. It also fits in well with Pronet, which has no concept of global time.

3.4Discussion

Keeping a record of every event, along with a description of message contents and the interconnectivity of every port, provides a complete record of what went on.

Copying all the messages allows the user to view what was actually sent; the message description makes the message contents understandable, and the connectivity data allows graphically depicting the movement of a message from its source to its destination.

A valid question to raise here concerns the cost of recording all the messages and events. How much does the extra disk I/O affect the computation in progress? This is the Heisenberg Uncertainty Principle as applied to debugging, sometimes called the "Heisenbug" Principle [ACM83b]. We can present no definite answer to the question here. It is expected that the disk operations actually buffer to memory until the buffer fills up. If this is the case, there should be little extra overhead since the system will suspend a process only when its I/O buffers must be flushed. The main problem is that while one process is suspended, others can continue to run on other machines.

It can be argued that the fact that one process on one machine has been stopped should not affect the other processes on other machines, since the ALSTEN receive is defined to be a blocking operation. The other processes may wait longer to complete the receive than they otherwise would have to, but ultimately, the same actions should be accomplished.

Suspending one process for disk I/O can affect other processes which continue to run, in a different manner. The ALSTEN receive can specify several alternatives; in effect it can be non-deterministic; receiving from port sets is actually non-deterministic, since the programmer can not know which element of the set will be used. For instance, if there are three processes A, B, and C, and Process B was supposed to receive a message from Process A, but A was suspended, B could end up receiving a message from Process C instead. This should not affect the ultimate semantics of the program, since the receive could happen on any specified port. It merely changes the path by which the program arrives at its goal.

Section 4

REPLAYING PROGRAM EXECUTION

The major component of the RADAR system is the REPLAY program. After a Pronet program has executed and all the information described above has been collected, REPLAY is invoked to graphically display event occurences. More importantly, it also displays the message traffic amongst processes.

The PERQ's screen is a high resolution, bit-mapped black and white display. The PERQ has hardware and firmware instructions, called Raster Ops, for manipulating the screen. REPLAY uses the Canvas graphics package [Ball81], which provides a higher-level, more usable interface to control the screen.

This section discusses the algorithms REPLAY uses, describes the view of the program REPLAY presents to the user, and presents the user interface.

4.1Outline of the Algorithm

The overall algorithm is fairly simple. It is based on the notion of events as defined in previously. Since each event is numbered when recorded, an ordering of events is automatically made possible.

The general algorithm for event replaying is given in pseudo-code in Figure 11.

```
get first event

while more events
   if event in { send_a_message, receive_a_message }
      do something visible with the message
   else
      announce the event conventionally
   end if
   get next event
```

```
end while
```

Figure 11 --- Top Level REPLAY Algorithm

Most of the work is involved with displaying events. REPLAY basically has to keep track of four things.

1) Which processes are represented on the screen and where they are.

2) Which messages are represented on the screen and where they are.

3) Rate of event display (see below).

4) How full the screen is; i.e., is there room for more processes?

Processes and the messages waiting in input queues take up the majority of the room on the screen. Most of the other events can be displayed simply by printing out a line on the screen of the form "Process P announces Event E as event Number N," in a prominent place. During the interval that the process is announcing an event, it changes color (actually a different shade of gray) so that it is clear which process is involved.

In fact, REPLAY provides a running narrative of this form. However, when a process is created or destroyed, or a message is sent or received, REPLAY will depict this graphically. Newly created processes will be drawn into a free spot on the screen. Messages are depicted as small boxes moving from the the sender's output port to the receiver's input port. When each message is received, its box disappears.

Much of the work involves doing all the bookkeeping necessary in as efficient a manner as possible. (It should be "efficient" in terms of both space and time.)

4.2 The User Interface

This section discusses various aspects of the operation of REPLAY's user interface.

4.2.1 What the User Sees

The user sees processes and messages queued on input ports. A process with one input port, one output port and a message just leaving the output port, is shown in Figure 12.

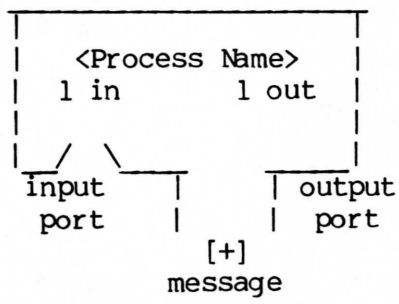

Figure 12 --- Picture of A Process and A Message

The drawing of a process indicates the number of input and output ports associated with that process. It is not possible to draw each port, since the notion of port sets allows a process to have a very large number of ports. When an output port sends a message, the port appears on the process' border. It closes up after the message arrives at its destination. Similarly, when a message arrives for an input port, the port opens up, and messages queue up in front of it. When all the queued messages have been received, the input port closes back up. The process name and identification appear inside the box, so that it is clear at a glance which process it is.

Figure 13 depicts an event replay on the PERQ's screen. The process Proc_B is shown sending a message to Proc_A. It has changed color during the event. A third process, Proc_C, is shown with one message waiting at its input port. The event narration at the top of the screen indicates what is happening.

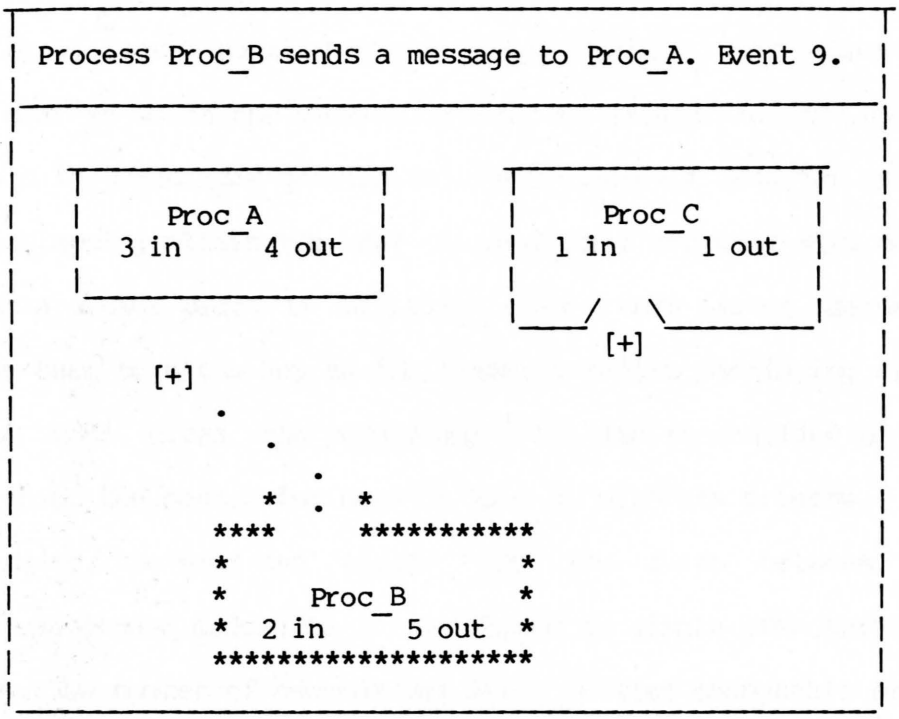

Figure 13 --- A Process Sending A Message

An interesting problem concerns the speed at which the replaying occurs. If events are described and messages move across the screen without any delays, events will happen too fast for the user to follow.

To solve this problem, REPLAY asks the user how many seconds to take to display each event. The default is three seconds per event. Even in single step mode (see below), each event takes the full N seconds (whatever the user

entered) to transpire. This is to allow the process to change color, and to remain on the screen in a different color for enough time to make an impression on the user before it changes back to normal.

4.2.2 Single Stepping

REPLAY gives the user the choice of either single stepped or continuous operation. In the second mode, events (message transmissions, process creation, etc.) occur continuously, without stopping. Continuous operation allows the user to watch the general pattern of message traffic and event occurences. This is useful for getting an overall idea of what the program did.

Single-stepping allows the user to watch what happened at a more detailed level and at a slower pace. In this mode, after each event occurs, REPLAY waits on the user to hit a key on the keyboard before continuing with the next event. This mode gives the programmer more time to consider his program's actions, without the continuing need to keep up with his program.

Furthermore, the user can toggle back and forth between the single stepped and continuous modes; he is not forced to single step through hundreds of messages. The number of seconds per event is also changeable at any time, to allow the user to speed up or slow down the rate of event display.

4.2.3 Displaying Messages

Messages on the screen are simply small boxes, queued on the input ports of their destination processes. In this form, the only information that they convey is the fact of their existence. This is only minimally useful.

REPLAY allows the user to actually see what his processes are sending to each other. Using the mouse, the user places the cursor over the particular message he wants to see and interrupts the event display. REPLAY will prompt

with a menu of actions available. The user will select the option for viewing a message.

REPLAY first finds the message indicated by the mouse. The message's type is an element in the Pascal record describing messages. This type indicates which of the message templates is to be used in decoding the contents of the message.

REPLAY then opens a new window on the screen. It steps through the message buffer and formats the raw bytes into characters, integers, or reals, as dictated by the message template. Enumerated types are treated as integers. Although this is not perfect, it is no more unreasonable than the restriction in standard Pascal against reading and writing enumerated types to and from text files. Message templates were described in Section 2.2.1.

When the user is through looking at the message, he issues the command to close the window. REPLAY then goes back to displaying events.

The value of this "Freeze Frame" facility should be clear. The user can verify not only that processes are sending messages to the right places, but that those messages have the right contents. Formatting message contents is absolutely necessary. Simply displaying the values of integers, characters and reals in octal gives the user no immediately understandable information (except in the rare case of the true hacker who can decode octal into its equivalent floating point or ASCII values). Furthermore, messages are displayed as a unit, unlike Schiffenbauer's system which displays small data packets in octal.

4.2.4 Selective Replaying of Events

It is possible while watching a program's actions that a particularly interesting sequence of events will occur which warrants further review. To accomodate this, REPLAY keeps a history of a fixed number of events which have occurred. At any time, the user can stop the normal replay and ask to see an "Instant Replay" of n previous events. The maximum number of events that can be replayed is a compile-time constant in one of the Pascal source code modules.

When this facility is invoked, REPLAY saves the screen state and marks those processes that were on the screen at the time. It clears the screen and starts as if the first event requested were the very first event to occur. Processes and messages are drawn as needed.

Some information which was on the screen but which may not relate to the n events being replayed will be lost during the instant replay. This loss is not permanent, since REPLAY restores the screen at the end of the instant replay. The user can run the instant replay as many times as desired before returning to the regular display. This facility is analogous to the rewinding of video tape and replaying an interesting series of events during a sports broadcast, hence the name "Instant Replay."

When the instant replay is through, the screen is restored and the processes which were marked as being saved are unmarked. Display then continues as before.

As a final possibility, the user may choose to restart the entire program replay from scratch. This provides the convenience of not having to quit the program and then start it again from the command level. Such small conveniences are often the most useful.

4.2.5 REPLAY Menu Options

At any time during the event replay the user can stop execution by causing a keyboard interrupt.

This invokes an interrupt handler which presents the menu shown in Figure 14.

1. Change To/From Single-Step/Continuous Operation
2. Change The Number of Seconds Per Event
3. Skip Ahead To A Specific Event Number
4. Display Contents of the Message Under the Mouse
5. Instant Replay
6. Start Displaying From Scratch
7. Exit REPLAY
8. Help
9. Never Mind

Figure 14 --- REPLAY Menu Options

The user may skip ahead to a given event, specified by the event sequence number. REPLAY will then skip to the first event which has the sequence number entered by the user. This is useful if the user knows that his program stopped working after a given event. He can make his changes, rerun the program, and then skip directly to where the change should have an effect.

The Help subsystem provides general information on how to use the RADAR monitor.

The 'Never Mind' option allows the user to recover in case he accidentally caused a keyboard interrupt. It does nothing.

In all cases, after the interrupt handler does what the user wishes, the program returns to where it was executing before the interrupt occurred.

Section 5

INTERFACE WITH PRONET

5.1 ALSTEN

The ALSTEN pre-processor will generate extra code for RADAR that is invisible to the user. These will be chiefly variable declarations and procedure calls. There will then be two different run-time libraries. The normal library routines will pass their arguments on to the appropriate Accent routines. The monitoring library will perform the data logging functions outlined above, and then call the Accent routines. In the case of the procedure which creates the log file, in the normal library it will simply announce the 'process_creation' event.

The value of using "invisible" code and two libraries is clear. In order to use the RADAR system, a programmer only has to re-link (load) his program -- he does not have to recompile it.

Furthermore, using Perq Pascal, it is possible to keep both versions of the library routines in a single source file. It provides a conditional compilation feature which allows selective inclusion of code at compile time, similar to the macro processing facilities of C and PL/1. For instance,

```
procedure librarycall;
const
   RADAR = true { or false, depending } ;
begin
   {$ifc RADAR then}
      (*
       * RADAR code
       *)
   {$elsec}
      (*
       * normal code
       *)
   {$endc}

   (* code common to both, i.e. always needed *)
end;
```

Figure 15 --- Conditional Compilation in Perq Pascal

This feature will greatly aid development and maintenance of the RADAR library routines, since only one file has to be kept current, not two.

As mentioned previously, when one output port is connected to more than one input port, messages are automatically replicated. However, the send routine cannot be called twice (or however many times needed), because the duplication occurs behind the scenes. The routines in REPLAY which keep track of interport connections will keep track of this, and will replicate the message when displaying the send event.

5.2NETSLA

The actions in NETSLA network specifications are compiled into run-time calls on a Run-time Support Module (RTSM). Calls on the system may come from multiple sites; however, in the PERQ implementation, the RTSM itself will only be at one node. A single site DMS is merely a degenerate case of the distributed DMS.

There are two reasons for implementing NETSLA this way initially. First, it is much easier to do. Second, the Clouds environment currently under development is expected to provide most if not all of the necessary distributed data management facilities, since it will need some of these facilities itself. Allowing Clouds to eventually provide the distributed data management is in keeping with the philosophy of "let someone else do the hard part." [Kern76]

In any case, the RTSM will provide the information concerning process location and port connectivity. The RADAR system will assume that this information will be available in the form it needs. The exact structure of the data was described above.

Section 6

PRONET IMPLEMENTATION

An implementation of PRONET is being developed for a Three Rivers Computer Corporation PERQ computer running under revision 2.0 of ACCENT, which is a communication oriented network operating system. The run-time support libraries developed for this implementation make use of ACCENT message and process primitives through a procedure-like interface to the kernel.

Two language preprocessors, one for ALSTEN and another for NETSLA, have been developed. These two preprocessors both translate a PRONET source program into a Pascal program. Then, the Pascal program generated can be compiled using the PERQ Pascal compiler.

In the current state, the implementation is being developed for a single processor environment with each active process being assigned a portion of the display screen.

6.1 The Preprocessors

The preprocessor actually consists of two parts: a scanner and a parser; both are table-driven. The table-driven approach makes the preprocessor very language independent; i.e., it can translate either ALSTEN or NETSLA so long as appropriate tables are provided.

The scanner tables are generated by LEXGEN from a description of each token that may occur as input to the scanner. Tokens are described by using a standard regular expression syntax. The parser tables are generated by ZUSE from LL(1) grammars (see Appendix A and Appendix B) which have action codes embedded into them. The action codes specify the steps to be taken by the parser during parsing.

The preprocessor accepts a scanner table, a parser table and source program as input and generates a sequence of Pascal codes as a result of parser actions. The Pascal code generated can then be compiled by using the PERQ Pascal compiler.

Figure 16 below illustrates the overall structure of the preprocessors.

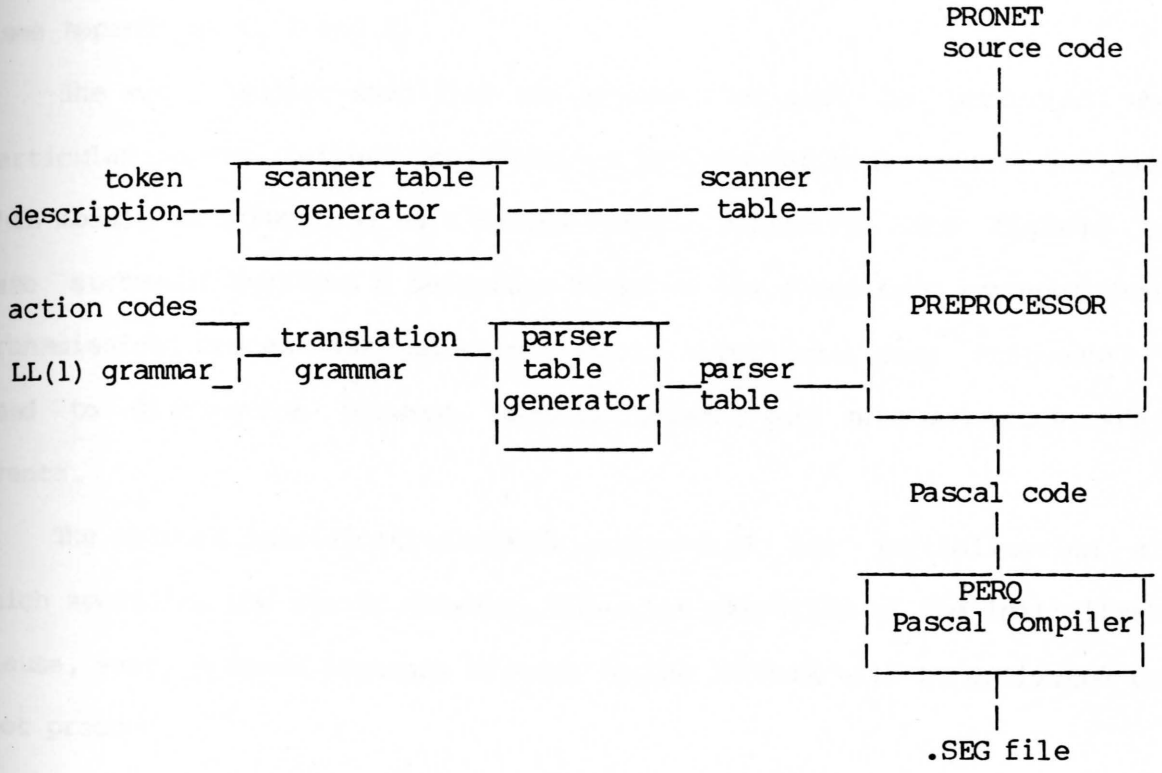

Figure 16 --- Preprocessor Structure

The approach of preprocessing has the following advantages although it is less efficient than direct compilation:

1. Ease of implementation.
2. All ACCENT kernel primitives are made available by calling to a PASCAL library of kernel interface procedures and functions.

In the current state, both preprocessors are operational and do not perform type checking.

6.2 Module Structures

The NETSLA preprocessor generates two code modules for each network specification: an "event handler module" and a "network specification module" (see Appendices C, D and E).

The event handler specifies the actions that must be performed when a particular event (either predefined or process-defined) occurs. The code in this module is structured as a nested "case" statement. The highest level case statement performs a selection based on the event type argument (message transmission, process-defined event, etc.). Lower level case statements are used to distinguish between process classes, port sets and process-defined events.

The network specification module consists of the initialization clause which specifies the static network. After the execution of the initialization clause, every process instance created in the network will be activated by the root process.

In addition to these two preprocessor-generated modules, there are two more modules in each NETSLA runnable file: a "DB manipulation module" and a "NETSLA run-time support module." The DB manipulation module contains all the routines that are needed to create and maintain the network representation. The NETSLA run-time support module consists of routines that implement those NETSLA activities (process creation, port creation, connection, etc ...) based on ACCENT kernel primitives.

Figure 17 below illustrates the structure of the object module generated for each NETSLA program. It is important to realize that both event handler module and network specification module are network specific codes while the other two modules are common to all network instances. The DB manipulation module and the NETSLA run-time support module are separately precompiled and imported by the main body of the NETSLA program.

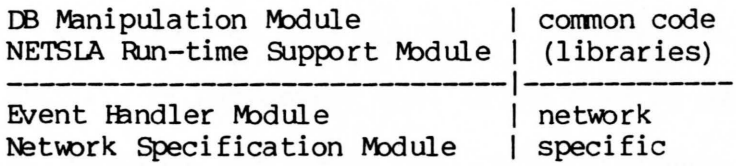

Figure 17 --- NETSLA Object Module Structure

The ALSTEN preprocessor generates a single code module for each process script (see Appendices F, G, H and I). This module is a simple translation of the process script which makes use of ALSTEN run-time support facilities for performing ALSTEN operations (send, receive, announce, etc ...).

6.3 Processes and Ports

Both ACCENT and PRONET use the notions of "processes" and "ports", but they are at different levels of abstraction. We implement the PRONET processes(ports) by using ACCENT processes(ports) and hide the details of the ACCENT processes(ports) from PRONET programmers.

A PRONET network specification is implemented as an ACCENT process from which any number of ACCENT child processes can be created to represent the PRONET process instances. Since we do not consider the case of "composite processes" in this implementation, the network can be thought of as a tree of

two levels with the network specification process as the root. Composite processes can be implemented without much effort later.

An ACCENT port is a protected kernel object and is used for sending and receiving messages. With each port the kernel associates send and receive (and ownership) rights. The process that creates the port possesses all three rights. In this implementation, we use ACCENT ports for two different purposes.

During the execution of the program, an ACCENT port will be allocated when a CONNECT activity is performed. This ACCENT port is used for transmitting the PRONET messages and will be deallocated when the corresponding DISCONNECT activity is performed. Initially, the receiving process possesses the receive and send rights. Then the send right will be passed to the sending process so that PRONET messages can be transmitted through this port.

There are three ACCENT ports allocated to each child process at the process creation time for the purpose of communicating with the root process (event handling request, port capabilities passing, etc ...).

6.4 The Network Representation

A representation of the logical network described by a PRONET program is maintained in the address space of the root process. This representation reflects the hierarchical structure expressed in the program by maintaining a tree of network class and network instance representations. The logical network representation also contains information about the connectivity among the ports of network instances. The root of this tree is a network class representation, the leaves are network instance representations which contain information about the currently active processes in the logical network.

The codes for manipulating the logical network representation also reside in the address space of the root process. All creations, updates and reads of the entities in the network representation must be performed by calling from the root process an appropriate procedure in the DB manipulation module.

This centralized approach of maintaining the logical network representation lowers the degree of parallelism but reduces the cost of message transmission.

6.5 Event Generation and Handling

Event generation can be either upward or downward. The term "upward event generation" is used to denote the generation of an event in the overseeing network while "downward event generation" is used to denote the generation of an event in a process instance.

Upward event generation of an event will occur when a process instance announces an event using the "announce" activity or transmits a message using the "send" statement. Downward event generation occurs when a network specification creates or removes a port instance on a process instance or sends a message to a process instance.

Event handling codes are generated by the NETSLA preprocessor and reside in the address space of the root process during run-time. Upward event generation is implemented by sending a message to the root process. This message includes all the information relevant to the event generated. This kind of message arrives at a port which belongs to the root process and holds at most four messages at a time due to the limitation of the size of the backlog for an ACCENT port.

Upon receiving a message from a child process, the root process will call an appropriate event handling routine based on the event type and other information included in the message. Event handler executions are performed in a serial fashion. This centralized approach of event handling has the disadvantage of a low degree of parallelism.

6.6 Current Status

Up to the present, we have implemented the complete set of features of ALSTEN and a subset of the features of NETSLA. The NETSLA features that have been implemented are process creation, port creation, connection, message transmission and disconnection. Structured activities will be implemented by augmenting the implementation of simple activities later. When the implementation for a single processor is complete, we will extend it to a multiprocessor environment.

Section 7

IMPLEMENTATION OF THE RADAR SYSTEM

The RADAR system, a passive monitor for distributed programs, was designed by Arnold Robbins for his master's thesis. The main component of this system is a program that graphically displays the interaction of the various processes in the distributed program. This monitor is designed to work within the Pronet environment, based on information provided by the NETSLA run-time database, the ALSTEN preprocessor, and run-time calls to the debugging log routines in RADARLOG.

This information consists of three types of files:

message template file -- supplied by ALSTEN preprocessor - contains the types of the various values sent in a message, allows RADAR to show values as characters, integers, reals, etc, instead of as octal bytes.

process information file -- supplied by NETSLA run-time database - contains the process class of each process.

log files -- supplied by run-time calls to RADARLOG - contains a log of the events (note that message sending and message reception are just special events) including the 'time' at which the event occurred.

This concept of time in the context of Pronet, which has no idea of a global time clock, is an interesting one, and one solution to maintaining an order for replaying is discussed in Robbins' thesis, section 2.3.

The implementation of the system is being done on the Three Rivers Corporation PERQ computer under the SPICE environment (developed at Carnegie Mellon University), an operating system and set of utilities designed for message-passing distributed systems. One package of routines available in the SPICE environment is Canvas, a set of graphics routines for the PERQs which support the graphics capabilities of the bit-mapped screen of the PERQs at a more usable level. The use of Canvas was probably the biggest factor in Rob-

bins' being unable to do a complete implementation of the RADAR system, since little or no documentation existed on Canvas while Robbins was doing his design.

Now that documentation has become available, the task of finishing the implementation of RADAR has been centered around correction of concepts which, once implemented, no longer work as they were designed, and implementation of screen display and control.

Major implementation errors were surprisingly rare, in view of the fact that Robbins was unable to test many of his features on the Perqs. Basically, the only such error which has surfaced so far was in assuming that message contents could always be written out as bytes by writing out the corresponding character code. This scheme saved both time and space, but has the disadvantage that encoding an eight bit value in a seven bit code does not always produce the desired results. Bytes are now written out as integers in the range 0..511. Other problems of this nature may exist in the interface between ALSTEN and RADAR, but none have yet surfaced.

The user interface presented for a RADAR user is divided into two subscreens or windows. The top window shows a running textual display of what events are occuring. At the same time, the lower window has a graphic representation of the same events. As an event is announced in the upper window, the box corresponding to that process changes color and remains that color for an appropriate delay (selectable by the user). If that event is a message_transmission, a box representing the message appears on the border of the sending process, and moves to the receiving process. If the event is a message_reception, the box representing that message disappears, and any other messages queued to that port move forward in the queue. At any time, one may stop the replay of the events by hitting a key on the keyboard, which halts

the action and presents a menu of choices in the upper window.

These windows are implemented as "sub-canvasses" under the Canvas graphics system. This means that each window can be treated by the programmer as a completely separate entity for input, output, and scaling of the size of the objects. Thus, the upper window is configured for text input and output, while the bottom window is structured for graphics. In fact, the bottom window is set up to scale appropriately to the size of the window available on the Perq at the time, thus always allowing the maximum number of processes to appear on the screen. However, since Canvas does not yet support the scaling of text, the labels on each process indicating the name of the process and the number of incoming and outgoing ports become unreadable if the screen space allotted for the program is too small.

With no examples to serve as guides, the hardest part of the screen implementation for any particular routine was often the trial and error process by which procedures were found to produce the desired results. Many of these changes are uninteresting in their detail, as one good example would have eliminated 90% of the problems in implementing them. However, three procedures had interesting problems and solutions: namely, how to quickly know whether or not a message is in the area pointed to by the mouse, how to interrupt the replay of events in order to get the replay menu, and how to move messages smoothly across the screen at a speed that will make them arrive at their destination at a time whereby the user-specified time for an event to occur will have elapsed.

As a temporary measure, the original design matched a message with the mouse only when they were exact matches. This restriction was unreasonable for ease of use, so a more relaxed specification was needed. However, the idea of a hash table to find the message was still appealing, as the time to

search through all the messages of a busy system was prohibitive. The solution was to have a hash function which hashed regions to the same hash value, which is easily enough done by dividing the original x and y by the error factor before using the x and y in the normal hash function:

```
new_hash(x,y : integer) :=
                old_hash (round(x/x_error), round(y/y_error))
```

Using the error factor as the divisor also ensures that only four hash values ($x \pm x\_error, y \pm y\_error$) need to be checked, which, for a table size of 37 as is currently used in the RADAR implementation, eliminates around 80% of the space on the screen.

The design of RADAR assumed that SPICE would provide some type of keyboard interrupt, since PERQ Pascal provides quite nice exception handlers, and such an interrupt is a natural extension used in several of the SPICE utilities (via a Ctrl-C as a "kill the process" interrupt). However, the only place that SPICE provided such a utility was labelled with the words "Subject to Change, Do not Use if You Want Upward Compatibility with Future Versions." As a substitue for such a utility, the delay routine, which is called very frequently, was used to check for the existence of a keypress. If one exists, then the exception is raised. This substitute works very well, as delay is called frequently enough that no perceptible delay occurs between the keypress and the appearance of the menu of choices discussed in Section 3.5 of Robbins' thesis.

Moving messages across the screen is not as hard as it might be, since Canvas provides some very handy procedures for drawing rectangles, as well as more interesting icons, and even provides an INVERSE color for drawing, which allows a message to pass through a process without destroying the process while maintaining visibility. More interesting, is the method for delivering

messages in a certain number of seconds. First, through experimention, a constant was found which represented the approximate number of times the program could move the message in one second. This number is used to compute the number of moves that should be made for the user-specified time. From this number, the given starting and ending locations, and the proper delta_x and delta_y are computed, and the message is moved. This routine still lacks one feature, however. When a port is broadcasting to more than one port, each individual message transmission currently takes up the entire number of seconds which the entire event is supposed to use, while the design specifies that each instruction is to take that long.

Currently, the preprocessor does not generate the calls to the RADARLOG routines, nor does it produce the message_template file. However, such calls have been hand-edited into some Pascal files produced by the preprocessor, and the replaying system of RADAR works on these files. Thus, the features which still need to be implemented or changed are primarily interface related. That is, the user interface needs to made bomb-proof and more usable, with additions of a real help facility. The preprocessor needs to generate the interface to the log calls and the message template information. Also, the run time support module needs to generate the process file information.

The RADAR system design also includes one other feature which is not yet implemented. This feature is the UCAP which can separate those messages sent to a single process in a distributed program. These messages can then be used to debug a single process with a standard single-process debugger without forcing the programmer to make up artificial test data which may or may not reflect the kind of input a program will encounter in actual use. The main implementation problem this facility has is in interfacing to the conventional debugger, as the rest of the facility is already available.

Section 8

PLAN FOR FURTHER WORK

There is further work to be done in several areas. The most obvious of these are the efforts described in this report. The PRONET implementation will require the following work in order to be complete:

1. Interface with the debugger. Add some code to both preprocessors so that the information needed by the debugger can be generated. The debugger needs two kinds of information from a Pronet program:
   1) templates : generated at preprocessor execution time,
   2) a log : generated at Pronet program execution time.
2. Complete the implementation of simple activities in NETSLA. Simple activities that have not been implemented:
   1) value construction,
   2) event announcement,
   3) attribute assignment.
3. Implement structured activities in NETSLA. Netsla preprocessor needs to be augmented. Structured activities include:
   1) alternation,
   2) iteration,
   3) location.
4. Implement type checking in both preprocessors.
5. Modify the window allocation procedure so that arbitrary number of process instance windows can be allocated.
6. Implement PRONET for a multiprocessor environment. This will be done when the implementation for a single processor environment is complete.

The ACCENT global naming scheme must be studied. The hardware problem of linking two PERQs together must be solved.

The implementation of RADAR also needs to be completed, finishing the development of our prototype monitoring capability. Action items for work on RADAR include:

1. User interface needs to be improved.
   a. bomb-proofed (don't read reals as reals, but as characters,etc)
   b. help facility added.
   c. optionally, beautified, as using the icon facilities to represent messages as letters or some such, rather than boxes.
2. The screen layout should be imporved.
   a. A better way to set up the screen for a given number of processes should be implemented.
   b. The restriction on the number of processes on the screen at one time should be eliminated.
   c. Some representation of existing connections between processes should be available (perhaps as an option, since lines representing connections might badly clutter the display).
3. The UCAP feature must be implemented.
   a. make sure it pulls out messages correctly.
   b. interface it with Kraut or other single-process debugger.

After this work completes our prototype monitor, we intend to evaluate it by building and debugging some distributed programs. A likely candidate for implementation is a distributed database update algorithm designed by J. Allchin as part of his recent Ph.D. research in our department. It should provide a significant test for the monitor, as far as determining whether it

provides sufficient information to understand the execution of a complex distributed program.

After this evaluation period, two lines of work can be considered. One approach would be to convert our prototype into a monitor which displays program activity dynamically as a program executes. Such a monitor would have the advantage of providing more immediate information about an execution, but it would have to interfere more with the timing of events in that execution. If our prototype evaluation shows that a historical replay is sufficient for our purposes, we will instead concentrate our efforts on providing more powerful tools for use of the replay. For example, if a programmer can specify that a some related collection of program events constitutes some "higher-level" event, it might be possible to replay executions in terms of such high-level events, thereby reducing the number of events the programmer needs to interpret.

Finally, we will evaluate our tools and techniques concerning their applicability to an Ada programming environment.

APPENDIX A

The LL(1) Grammar of NETSLA

Grammar productions with selection sets added:

Prod # Production

```
 1   network_spec  =   net_head   const_pt type_pt port_decl_pt
       evnt_decl_pt proc_decl_10     evnt_clse_10
       init_clse0 end identifier
     %network  ;

 2   net_head  = network   identifier ;
     %network  ;

 3   proc_decl_10  =
     %arrive end enter initial leave when  ;

 4   proc_decl_10  = process_decl proc_decl_11
     %process  ;

 5   proc_decl_11  =
     %arrive end enter initial leave when  ;

 6   proc_decl_11  = process_decl proc_decl_11
     %process  ;

 7   evnt_clse_10  =
     %end initial  ;

 8   evnt_clse_10  = event_clause evnt_clse_11
     %arrive enter leave when  ;

 9   evnt_clse_11  =
     %end initial  ;

10   evnt_clse_11  = event_clause evnt_clse_11
     %arrive enter leave when  ;

11   init_clse0  =
     %end  ;

12   init_clse0  = initial activity_lst
     %initial  ;

13   const_pt  =
     %arrive end enter event initial leave
       port process type when  ;

14   const_pt  = const   con_def_list
```

```
      %const  ;

15    con_def_list  = const_def next_con_def
        %identifier  ;

16    next_con_def  =
        %arrive end enter event initial leave
          port process type when  ;

17    next_con_def  = const_def next_con_def
        %identifier  ;

18    const_def  = new_const_id =   constant ;
        %identifier  ;

19    new_const_id  =   identifier
        %identifier  ;

20    constant  = signed_const
        %+ -  ;

21    constant  = unsigned_con
        %char_const identifier int_const real_const string_const  ;

22    signed_const  = sign after_sign
        %+ -  ;

23    after_sign  =   real_const
        %real_const  ;

24    after_sign  =   int_const
        %int_const  ;

25    after_sign  =   const_id
        %identifier  ;

26    unsigned_con  =   identifier
        %identifier  ;

27    unsigned_con  =   int_const
        %int_const  ;

28    unsigned_con  =   char_const
        %char_const  ;

29    unsigned_con  =   string_const
        %string_const  ;

30    unsigned_con  =   real_const
        %real_const  ;

31    scalar_const  =   identifier
        %identifier  ;
```

```
32   scalar_const  = non_id_s_con
       %+ - char_const int_const  ;

33   non_id_s_con  = sign id_or_int
       %+ -  ;

34   non_id_s_con  =   int_const
       %int_const  ;

35   non_id_s_con  =   char_const
       %char_const  ;

36   id_or_int  =   const_id
       %identifier  ;

37   id_or_int  =   int_const
       %int_const  ;

38   const_id  =   identifier
       %identifier  ;

39   type_pt  =
       %arrive end enter event initial leave
         port process when  ;

40   type_pt  = type   typ_def_list
       %type  ;

41   typ_def_list  = type_def next_typ_def
       %identifier  ;

42   next_typ_def  =
       %arrive end enter event initial leave
         port process when  ;

43   next_typ_def  = type_def next_typ_def
       %identifier  ;

44   type_def  = new_type_id =   types ;
       %identifier  ;

45   new_type_id  =   identifier
       %identifier  ;

46   types  = type_case1
       %identifier  ;

47   types  = type_case2
       %( + - array char_const int_const
         packed record set  ;

48   type_case1  =   identifier type_tail
```

```
      %identifier  ;

49    type_tail  =
        %) ; case end  ;

50    type_tail  = ..   scalar_const
        %..  ;

51    type_case2  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

52    type_case2  = struct_type
        %array packed record set  ;

53    type_case2  = (   enu_id_list )
        %(  ;

54    non_id_type  = non_id_simp
        %( + - char_const identifier int_const  ;

55    non_id_type  = struct_type
        %array packed record set  ;

56    simple_type  =   type_id simp_ty_tail
        %identifier  ;

57    simple_type  = (   enu_id_list )
        %(  ;

58    simple_type  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

59    simp_ty_tail  =
        %) , ; ] case end  ;

60    simp_ty_tail  = ..   scalar_const
        %..  ;

61    non_id_simp  = (   enu_id_list )
        %(  ;

62    non_id_simp  = subrange_con ..   scalar_const
        %+ - char_const identifier int_const  ;

63    pt_class_nam  = identifier
        %identifier  ;

64    enu_id_list  =   identifier enumer_tail
        %identifier  ;

65    enumer_tail  =
        %)  ;
```

```
66    enumer_tail  = ,     identifier enumer_tail
        %,  ;

67    subrange_con  =   identifier
        %identifier  ;

68    subrange_con  = non_id_s_con
        %+ - char_const int_const  ;

69    type_id  =   identifier
        %identifier  ;

70    struct_type  = pack_prefix unpacked
        %array packed record set  ;

71    pack_prefix  = packed
        %packed  ;

72    pack_prefix  =
        %array record set  ;

73    unpacked  = array [   indx_ty_list ] of
          types
        %array  ;

74    unpacked  = record_head field_list end
        %record  ;

75    unpacked  = set of   simple_type
        %set  ;

76    record_head  = record
        %record  ;

77    indx_ty_list  = simple_type index_tail
        %( + - char_const identifier int_const  ;

78    index_tail  =
        %]  ;

79    index_tail  = ,   simple_type index_tail
        %,  ;

80    field_list  = rec_sec_list with_variant
        %) ; case end identifier  ;

81    rec_sec_list  = rec_section rec_sec_tail
        %) ; case end identifier  ;

82    rec_sec_tail  =
        %) case end  ;

83    rec_sec_tail  = ;   rec_section rec_sec_tail
```

```
      %;  ;

84    rec_section  = fieldid_list :   types
        %identifier  ;

85    rec_section  =
        %) ; case end  ;

86    fieldid_list  =   identifier field_id_end
        %identifier  ;

87    with_variant  =
        %) end  ;

88    with_variant  = variant_pref variant_list
        %case  ;

89    field_id_end  =
        %:  ;

90    field_id_end  = ,     identifier field_id_end
        %,  ;

91    variant_pref  = case   tag_type_ids of
        %case  ;

92    tag_type_ids  = tagfield_id tag_typ_tail
        %identifier  ;

93    tag_typ_tail  =
        %of  ;

94    tag_typ_tail  = :   scalar_ty_id
        %:  ;

95    tagfield_id  =   identifier
        %identifier  ;

96    scalar_ty_id  =   identifier
        %identifier  ;

97    variant_list  = variant variant_tail
        %) + - ; char_const end
          identifier int_const  ;

98    variant  = case_l_list : (   field_head field_list
        )
        %+ - char_const identifier int_const  ;

99    variant  =
        %) ; end  ;

100   field_head  =
```

```
        %) ; case identifier  ;

101     variant_tail  =
          %) end  ;

102     variant_tail  = ;   variant variant_tail
          %;  ;

103     case_l_list  = scalar_const caselabelend
          %+ - char_const identifier int_const  ;

104     caselabelend  =
          %:  ;

105     caselabelend  = ,   scalar_const caselabelend
          %,  ;

106     port_decl_pt  =
          %arrive end enter event initial leave
            process when  ;

107     port_decl_pt  = pt_decl_list
          %port  ;

108     pt_decl_list  = port_decl pt_decl_tail
          %port  ;

109     port_decl  = port_head pt_dir_mtype
          %port  ;

110     pt_dir_mtype  = in type_id   ;
          %in  ;

111     pt_dir_mtype  = out type_id   ;
          %out  ;

112     pt_dir_mtype  = port_group ;
          %(  ;

113     pt_decl_tail  =
          %arrive end enter event initial leave
            process when  ;

114     pt_decl_tail  = port_decl pt_decl_tail
          %port  ;

115     port_head  = port port_tail
          %port  ;

116     port_tail  =   identifier
          %identifier  ;

117     port_tail  = set   identifier
```

```
        %set  ;

118     port_group  = ( sbptdecllist )
          %(  ;

119     sbptdecllist  = subport_decl next_subport
          %identifier  ;

120     subport_decl  = subport_name direct_type
          %identifier  ;

121     direct_type  = in type_id
          %in  ;

122     direct_type  = out type_id
          %out  ;

123     subport_name  =   identifier
          %identifier  ;

124     next_subport  =
          %)  ;

125     next_subport  = ; subport_decl next_subport
          %;  ;

126     process_decl  = process_head attri_decls0 port_decl_pt evnt_decl_pt
           end identifier
          %process  ;

127     process_head  = process class   identifier
          %process  ;

128     attri_decls0  =
          %end event port  ;

129     attri_decls0  = attri_head attri_sec_ls attri_tail
          %attributes  ;

130     attri_head  = attributes
          %attributes  ;

131     attri_tail  = end attributes
          %end  ;

132     attri_sec_ls  = attri_sec attri_secl
          %; end identifier  ;

133     attri_secl  =
          %end  ;

134     attri_secl  = ; attri_sec
          %;  ;
```

```
135   attri_sec  = attri_id_ls : types
        %identifier  ;

136   attri_sec  =
        %; end  ;

137   attri_id_ls  = identifier attri_id_ls1
        %identifier  ;

138   attri_id_ls1  =
        %:  ;

139   attri_id_ls1  = , identifier
        %,  ;

140   evnt_decl_pt  =
        %arrive end enter initial leave process
          when  ;

141   evnt_decl_pt  = event_decl next_event
        %event  ;

142   next_event  =
        %arrive end enter initial leave process
          when  ;

143   next_event  = event_decl next_event
        %event  ;

144   event_decl  = event identifier about_ptnm0 ;
        %event  ;

145   about_ptnm0  =
        %;  ;

146   about_ptnm0  = about identifier
        %about  ;

147   event_clause  = arriv_clause
        %arrive  ;

148   event_clause  = enter_clause
        %enter  ;

149   event_clause  = leave_clause
        %leave  ;

150   event_clause  = when_clause
        %when  ;

151   arriv_clause  = arrive_head activity_lst close end arrive
        %arrive  ;
```

```
152   arrive_head  = arrive open arrive_bind do
        %arrive  ;

153   arrive_bind  = message_id0 on arrive_port from_proces0
        %identifier on  ;

154   message_id0  =
        %on  ;

155   message_id0  = identifier
        %identifier  ;

156   arrive_port  = identifier arrive_port1
        %identifier  ;

157   arrive_port1  =
        %do from  ;

158   arrive_port1  = : identifier
        %:  ;

159   arrive_port1  = of port_bind
        %of  ;

160   port_bind  = identifier port_bind1
        %identifier  ;

161   port_bind1  =
        %do from  ;

162   port_bind1  = : identifier
        %:  ;

163   from_proces0  =
        %do  ;

164   from_proces0  = from process_bind
        %from  ;

165   process_bind  = identifier proces_bind1
        %identifier  ;

166   proces_bind1  =
        %about do  ;

167   proces_bind1  = : identifier
        %:  ;

168   enter_clause  = enter_head activity_lst close end enter
        %enter  ;

169   enter_head  = enter open port_bind do
```

```
        %enter  ;

170     leave_clause  = leave_head activity_lst close end leave
          %leave  ;

171     leave_head  = leave open port_bind do
          %leave  ;

172     when_clause  = when_head activity_lst close end when
          %when  ;

173     when_head  = when open identifier announced by process_bind
           about_part0 do
          %when  ;

174     about_part0  =
          %do  ;

175     about_part0  = about port_bind
          %about  ;

176     activity_lst  = activity activities
          %) ; announce case connect construct
            create disconnect else end find identifier
            range remove send terminate  ;

177     activities  =
          %) else end  ;

178     activities  = ; activity activities
          %;  ;

179     activity  =
          %) ; else end  ;

180     activity  = simple_act
          %announce connect construct create disconnect identifier
            remove send terminate  ;

181     activity  = control_act
          %case find range  ;

182     simple_act  = creation
          %create  ;

183     simple_act  = termination
          %terminate  ;

184     simple_act  = removal
          %remove  ;

185     simple_act  = connection
          %connect  ;
```

```
186   simple_act  = disconnecton
        %disconnect  ;

187   simple_act  = msg_transfer
        %send  ;

188   simple_act  = construction
        %construct  ;

189   simple_act  = attri_assign
        %identifier  ;

190   simple_act  = event_trans
        %announce  ;

191   simple_bind  = object_id : identifier simple_bind1
        %identifier  ;

192   object_id  = identifier
        %identifier  ;

193   simple_bind1  =
        %do where  ;

194   simple_bind1  = on proc_denoter
        %on  ;

195   obj_denoter  = lhs
        %identifier  ;

196   port_denoter  = obj_denoter
        %identifier  ;

197   proc_denoter  = identifier
        %identifier  ;

198   creation  = create create_tail
        %create  ;

199   create_tail  =   identifier :   identifier create_tail1
        %identifier  ;

200   create_tail1  =
        %) ; else end  ;

201   create_tail1  = on   proc_denoter
        %on  ;

202   termination  = terminate proc_denoter
        %terminate  ;

203   removal  = remove obj_denoter
```

```
      %remove  ;

204   connection  =   connect port_denoter   to port_denoter
      %connect  ;

205   disconnecton  = disconnect port_denoter from_port0
      %disconnect  ;

206   from_port0  =
      %) ; else end  ;

207   from_port0  = from port_denoter
      %from  ;

208   msg_transfer  = send expr0 to port_denoter
      %send  ;

209   expr0  =
      %to  ;

210   expr0  = expr
      %( + - [ char_const identifier
        int_const not real_const string_const  ;

211   construction  = construct_hd [ field_as_lst ]
      %construct  ;

212   construct_hd  = construct object_id : identifier
      %construct  ;

213   field_as_lst  = field_assign fd_assign1
      %identifier  ;

214   fd_assign1  =
      %]  ;

215   fd_assign1  = ; field_assign
      %;  ;

216   field_assign  = lhs := expr
      %identifier  ;

217   attri_assign  = lhs := expr
      %identifier  ;

218   event_trans  = announce event_id about_port0
      %announce  ;

219   about_port0  =
      %) ; else end  ;

220   about_port0  = about port_denoter
```

```
        %about  ;

221     control_act  = alternation
          %case  ;

222     control_act  = selection
          %find  ;

223     control_act  = iteration
          %range  ;

224     alternation  = alternate_hd case_list else_part0 end case
          %case  ;

225     alternate_hd  = case expr of
          %case  ;

226     case_list  = case_element case_list1
          %+ - char_const identifier int_const  ;

227     case_list1  =
          %else end  ;

228     case_list1  = case_element case_list1
          %+ - char_const identifier int_const  ;

229     case_element  = const_list : ( open activity_lst close
           )
          %+ - char_const identifier int_const  ;

230     const_list  = scalar_const const_list1
          %+ - char_const identifier int_const  ;

231     const_list1  =
          %:  ;

232     const_list1  = , scalar_const
          %,  ;

233     select_crite  = simple_bind where_claus0
          %identifier  ;

234     selection  = find_head do activity_lst close else_part0 end
           find
          %find  ;

235     find_head  = find open object_id : find_head1
          %find  ;

236     find_head1  = string
          %string  ;

237     find_head1  = identifier simple_bind1 where_claus0
```

```
        %identifier  ;

238     iteration  = range open select_crite do activity_lst close
           else_part0 end range
          %range  ;

239     else_part0  =
          %end  ;

240     else_part0  = else open activity_lst close
          %else  ;

241     where_claus0  =
          %do  ;

242     where_claus0  = where expr
          %where  ;

243     open  =
          %) ; announce case connect construct
            create disconnect end find identifier on
            range remove send terminate  ;

244     close  =
          %) else end  ;

245     id_list  =   identifier id_list_tail
          %identifier  ;

246     id_list_tail  =
          % ;

247     id_list_tail  = ,     identifier id_list_tail
          %,  ;

248     actual_parms  = (   actual_parm next_a_parm
          %(  ;

249     actual_parm  = parm_expr field_width
          %( + - [ char_const identifier
            int_const not real_const string_const  ;

250     next_a_parm  =
          %)  ;

251     next_a_parm  = ,   actual_parm next_a_parm
          %,  ;

252     lhs  =   identifier rec_ary_ptr
          %identifier  ;

253     vars  =   identifier rec_ary_ptr
          %identifier  ;
```

```
254   rec_ary_ptr  =
        %) * + , - ..
          / : := ; = ]
          and div do else end from
          in mod noneqrelop of or to  ;

255   rec_ary_ptr  = .   identifier rec_ary_ptr
        %.  ;

256   rec_ary_ptr  = [   index_list ]   rec_ary_ptr
        %[  ;

257   index_list  = index next_index
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

258   next_index  = ,   index
        %,  ;

259   next_index  =
        %]  ;

260   index  = expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

261   expr  = parm_expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

262   parm_expr  = simple_expr parm_exp_end
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

263   parm_exp_end  =
        %) , .. : ; ]
          do else end of to  ;

264   parm_exp_end  = rel_op simple_expr
        %= in noneqrelop  ;

265   rel_expr  = simple_expr rel_op simple_expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

266   rel_op  = =
        %=  ;

267   rel_op  = in
        %in  ;

268   rel_op  =   noneqrelop
```

```
      %noneqrelop  ;

269   simple_expr  =   char_const add_term
        %char_const  ;

270   simple_expr  =   string_const add_term
        %string_const  ;

271   simple_expr  = sign term add_term
        %+ -  ;

272   simple_expr  = term add_term
        %( [ identifier int_const not real_const  ;

273   add_term  =
        %) , .. : ; =
          ] do else end in noneqrelop
          of to  ;

274   add_term  = add_op term add_term
        %+ - or  ;

275   term  = factor mult_factor
        %( [ identifier int_const not real_const  ;

276   mult_factor  =
        %) + , - .. :
          ; = ] do else end
          in noneqrelop of or to  ;

277   mult_factor  = mult_op factor mult_factor
        %* / and div mod  ;

278   factor  =   identifier var_funccall
        %identifier  ;

279   factor  =   real_const
        %real_const  ;

280   factor  =   int_const
        %int_const  ;

281   factor  = (   expr )
        %(  ;

282   factor  = [   elem_list ]
        %[  ;

283   factor  = not   factor
        %not  ;

284   var_funccall  = rec_ary_ptr
        %) * + , - .
```

```
        .. / : ; = [
        ] and div do else end
        in mod noneqrelop of or to  ;

285     var_funccall  = actual_parms )
          %(  ;

286     add_op  = sign
          %+ -  ;

287     add_op  = or
          %or  ;

288     mult_op  = *
          %*  ;

289     mult_op  = /
          %/  ;

290     mult_op  = div
          %div  ;

291     mult_op  = and
          %and  ;

292     mult_op  = mod
          %mod  ;

293     variable  = identifier rec_ary_ptr
          %identifier  ;

294     field_width  =
          %) ,  ;

295     field_width  = :   expr more_field
          %:  ;

296     more_field  =
          %) ,  ;

297     more_field  = :   expr
          %:  ;

298     elem_list  =
          %]  ;

299     elem_list  = elem next_elem
          %( + - [ char_const identifier
            int_const not real_const string_const  ;

300     elem  = expr elem_tail
          %( + - [ char_const identifier
            int_const not real_const string_const  ;
```

```
301   next_elem  =
        %]  ;

302   next_elem  = ,   elem next_elem
        %,  ;

303   elem_tail  =
        %, ]  ;

304   elem_tail  = ..   expr
        %..  ;

305   proc_id  =   identifier
        %identifier  ;

306   rec_var_list  =   variable next_rec_var
        %identifier  ;

307   next_rec_var  =
        % ;

308   next_rec_var  = ,     variable next_rec_var
        %,  ;

309   subport  =
        % ;

310   subport  = . subport_id
        %.  ;

311   pt_class_id  = identifier
        %identifier  ;

312   subport_id  = identifier
        %identifier  ;

313   expression0  =
        % ;

314   expression0  =     expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

315   event_id  =   identifier
        %identifier  ;

316   sign  = +
        %+  ;

317   sign  = -
        %-  ;
```

APPENDIX B

The LL(1) Grammar of ALSTEN

Grammar productions with selection sets added:

Prod # Production

```
 1   comp_unit  =   prog_head prog
       %@ process  ;

 2   prog_head  = process script   prog_id ;
       %process  ;

 3   prog_id  =   identifier
       %identifier  ;

 4   prog  = port_decl_pt label_pt const_pt type_pt evnt_decl_pt var_pt
          proc_fct_pt   stmt_pt   .
       %begin const event function label port
         procedure type var  ;

 5   block  = label_pt const_pt type_pt var_pt proc_fct_pt stmt_pt
       %begin const function label procedure type
         var  ;

 6   label_pt  = label   label_list ;
       %label  ;

 7   label_pt  =
       %begin const event function procedure type
         var  ;

 8   label_list  = labels next_label
       %identifier int_const  ;

 9   next_label  =
       %;  ;

10   next_label  = ,   labels next_label
       %,  ;

11   labels  =   int_const
       %int_const  ;

12   labels  =   identifier
       %identifier  ;

13   const_pt  =
       %begin event function procedure type var  ;
```

```
14    const_pt  = const   con_def_list
        %const  ;

15    con_def_list  = const_def next_con_def
        %identifier  ;

16    next_con_def  =
        %begin event function procedure type var  ;

17    next_con_def  = const_def next_con_def
        %identifier  ;

18    const_def  = new_const_id =   constant ;
        %identifier  ;

19    new_const_id  =   identifier
        %identifier  ;

20    constant  = signed_const
        %+ -  ;

21    constant  = unsigned_con
        %char_const identifier int_const real_const string_const  ;

22    signed_const  = sign after_sign
        %+ -  ;

23    after_sign  =   real_const
        %real_const  ;

24    after_sign  =   int_const
        %int_const  ;

25    after_sign  =   const_id
        %identifier  ;

26    unsigned_con  =   identifier
        %identifier  ;

27    unsigned_con  =   int_const
        %int_const  ;

28    unsigned_con  =   char_const
        %char_const  ;

29    unsigned_con  =   string_const
        %string_const  ;

30    unsigned_con  =   real_const
        %real_const  ;

31    scalar_const  =   identifier
        %identifier  ;
```

```
32    scalar_const  = non_id_s_con
        %+ - char_const int_const  ;

33    non_id_s_con  = sign id_or_int
        %+ -  ;

34    non_id_s_con  =   int_const
        %int_const  ;

35    non_id_s_con  =   char_const
        %char_const  ;

36    id_or_int  =   const_id
        %identifier  ;

37    id_or_int  =   int_const
        %int_const  ;

38    const_id  =   identifier
        %identifier  ;

39    type_pt  =
        %begin event function procedure var  ;

40    type_pt  = type   typ_def_list
        %type  ;

41    typ_def_list  = type_def next_typ_def
        %identifier  ;

42    next_typ_def  =
        %begin event function procedure var  ;

43    next_typ_def  = type_def next_typ_def
        %identifier  ;

44    type_def  = new_type_id =   types ;
        %identifier  ;

45    new_type_id  =   identifier
        %identifier  ;

46    types  = type_case1
        %identifier  ;

47    types  = type_case2
        %( + - array char_const int_const
          packed ptr record set tag  ;

48    type_case1  =   identifier type_tail
        %identifier  ;
```

```
49    type_tail  =
        %) ; case end  ;

50    type_tail  = ..   scalar_const
        %..  ;

51    type_case2  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

52    type_case2  = struct_type
        %array packed record set  ;

53    type_case2  = ptr     identifier
        %ptr  ;

54    type_case2  = (   enu_id_list )
        %(  ;

55    type_case2  = tag of pt_class_nam
        %tag  ;

56    non_id_type  = non_id_simp
        %( + - char_const identifier int_const
          tag  ;

57    non_id_type  = struct_type
        %array packed record set  ;

58    non_id_type  = ptr     identifier
        %ptr  ;

59    simple_type  =   type_id simp_ty_tail
        %identifier  ;

60    simple_type  = (   enu_id_list )
        %(  ;

61    simple_type  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

62    simple_type  = tag of pt_class_nam
        %tag  ;

63    simp_ty_tail  =
        %) , ; ] case end  ;

64    simp_ty_tail  = ..   scalar_const
        %..  ;

65    non_id_simp  = (   enu_id_list )
        %(  ;

66    non_id_simp  = subrange_con ..   scalar_const
```

```
      %+ - char_const identifier int_const  ;

67    non_id_simp  = tag of pt_class_nam
        %tag  ;

68    pt_class_nam  = identifier
        %identifier  ;

69    enu_id_list  =   identifier enumer_tail
        %identifier  ;

70    enumer_tail  =
        %)  ;

71    enumer_tail  = ,     identifier enumer_tail
        %,  ;

72    subrange_con  =   identifier
        %identifier  ;

73    subrange_con  = non_id_s_con
        %+ - char_const int_const  ;

74    type_id  =   identifier
        %identifier  ;

75    struct_type  = pack_prefix unpacked
        %array packed record set  ;

76    pack_prefix  = packed
        %packed  ;

77    pack_prefix  =
        %array record set  ;

78    unpacked  = array [   indx_ty_list ] of
          types
        %array  ;

79    unpacked  = record_head field_list end
        %record  ;

80    unpacked  = set of   simple_type
        %set  ;

81    record_head  = record
        %record  ;

82    indx_ty_list  = simple_type index_tail
        %( + - char_const identifier int_const
          tag  ;

83    index_tail  =
```

```
      %]  ;

84    index_tail  = ,   simple_type index_tail
        %,  ;

85    field_list  = rec_sec_list with_variant
        %) ; case end identifier  ;

86    rec_sec_list  = rec_section rec_sec_tail
        %) ; case end identifier  ;

87    rec_sec_tail  =
        %) case end  ;

88    rec_sec_tail  = ;   rec_section rec_sec_tail
        %;  ;

89    rec_section  = fieldid_list :   types
        %identifier  ;

90    rec_section  =
        %) ; case end  ;

91    fieldid_list  =   identifier field_id_end
        %identifier  ;

92    with_variant  =
        %) end  ;

93    with_variant  = variant_pref variant_list
        %case  ;

94    field_id_end  =
        %:  ;

95    field_id_end  = ,     identifier field_id_end
        %,  ;

96    variant_pref  = case   tag_type_ids of
        %case  ;

97    tag_type_ids  = tagfield_id tag_typ_tail
        %identifier  ;

98    tag_typ_tail  =
        %of  ;

99    tag_typ_tail  = :   scalar_ty_id
        %:  ;

100   tagfield_id  =   identifier
        %identifier  ;
```

```
101   scalar_ty_id  =   identifier
        %identifier  ;

102   variant_list  = variant variant_tail
        %) + - ; char_const end
          identifier int_const  ;

103   variant  = case_l_list : (   field_head field_list
          )
        %+ - char_const identifier int_const  ;

104   variant  =
        %) ; end  ;

105   field_head  =
        %) ; case identifier  ;

106   variant_tail  =
        %) end  ;

107   variant_tail  = ;   variant variant_tail
        %;  ;

108   case_l_list  = scalar_const caselabelend
        %+ - char_const identifier int_const  ;

109   caselabelend  =
        %:  ;

110   caselabelend  = ,   scalar_const caselabelend
        %,  ;

111   port_decl_pt  =
        %begin const event function label procedure
          type var  ;

112   port_decl_pt  = pt_decl_list
        %port  ;

113   pt_decl_list  = port_decl pt_decl_tail
        %port  ;

114   port_decl  = port_head pt_dir_mtype
        %port  ;

115   pt_dir_mtype  = in type_id   ;
        %in  ;

116   pt_dir_mtype  = out type_id   ;
        %out  ;

117   pt_dir_mtype  = port_group ;
        %(  ;
```

```
118   pt_decl_tail  =
        %begin const event function label procedure
          type var  ;

119   pt_decl_tail  = port_decl pt_decl_tail
        %port  ;

120   port_head  = port port_tail
        %port  ;

121   port_tail  =   identifier
        %identifier  ;

122   port_tail  = set   identifier
        %set  ;

123   port_group  = ( sbptdecllist )
        %(  ;

124   sbptdecllist  = subport_decl next_subport
        %identifier  ;

125   subport_decl  = subport_name direct_type
        %identifier  ;

126   direct_type  = in type_id
        %in  ;

127   direct_type  = out type_id
        %out  ;

128   subport_name  =   identifier
        %identifier  ;

129   next_subport  =
        %)  ;

130   next_subport  = ; subport_decl next_subport
        %;  ;

131   evnt_decl_pt  =
        %begin function procedure var  ;

132   evnt_decl_pt  = event_decl next_event
        %event  ;

133   next_event  =
        %begin function procedure var  ;

134   next_event  = event_decl next_event
        %event  ;
```

```
135   event_decl  = event event_id about_part0 ;
        %event  ;

136   about_part0  =
        %;  ;

137   about_part0  = about pt_class_id
        %about  ;

138   var_pt  =
        %begin function procedure  ;

139   var_pt  =   var   var_decl_lst
        %var  ;

140   var_decl_lst  = var_decl var_decl_end
        %identifier  ;

141   var_decl_end  =
        %begin function procedure  ;

142   var_decl_end  = var_decl var_decl_end
        %identifier  ;

143   var_decl  = id_list :   types ;
        %identifier  ;

144   proc_fct_pt  =
        %begin  ;

145   proc_fct_pt  = pf_decl_list
        %function procedure  ;

146   pf_decl_list  = pf_decl pf_decl_tail
        %function procedure  ;

147   pf_decl_tail  =
        %begin  ;

148   pf_decl_tail  = pf_decl pf_decl_tail
        %function procedure  ;

149   pf_decl  = pf_head ;   blkorfwd
        %function procedure  ;

150   blkorfwd  = forward   ;
        %forward  ;

151   blkorfwd  = block ;
        %begin const function label procedure type
          var  ;

152   proc_start  =
```

```
        %( : ;  ;

153     pf_head  = procedure   proc_id_dec proc_start p_head_tail
          %procedure  ;

154     pf_head  = function   func_id_dec proc_start f_head_tail
          %function  ;

155     p_head_tail  =
          %;  ;

156     p_head_tail  = (   fpsl )
          %(  ;

157     f_head_tail  =
          %;  ;

158     f_head_tail  = :   parm_type_id
          %:  ;

159     f_head_tail  = (   fpsl ) :
            parm_type_id
          %(  ;

160     proc_id_dec  =   identifier
          %identifier  ;

161     func_id_dec  =   identifier
          %identifier  ;

162     fpsl  = f_parm_sect fpsl_tail
          %identifier var  ;

163     fpsl_tail  =
          %)  ;

164     fpsl_tail  = ;   f_parm_sect fpsl_tail
          %;  ;

165     f_parm_sect  = parm_group
          %identifier  ;

166     f_parm_sect  = var   parm_group
          %var  ;

167     parm_type_id  =   type_id parm_ty_tail
          %identifier  ;

168     parm_type_id  = struct_type
          %array packed record set  ;

169     parm_type_id  = (   enu_id_list )
          %(  ;
```

```
170   parm_type_id  = tag of pt_class_nam
        %tag  ;

171   parm_type_id  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

172   parm_type_id  = ptr     identifier
        %ptr  ;

173   parm_ty_tail  =
        %) ;  ;

174   parm_ty_tail  = ..   scalar_const
        %..  ;

175   parm_group  = id_list :   parm_type_id
        %identifier  ;

176   id_list  =   identifier id_list_tail
        %identifier  ;

177   id_list_tail  =
        %:  ;

178   id_list_tail  = ,     identifier id_list_tail
        %,  ;

179   body_start  =
        %announce begin case for goto identifier
          if int_const receive repeat send when
          while with  ;

180   stmt_pt  = begin     body_start stmt_list end

        %begin  ;

181   stmt  = label_prefix unlabeled_st
        %announce begin case for goto if
          int_const receive repeat send when while
          with  ;

182   stmt  = stmt_with_id
        %identifier  ;

183   stmt_with_id  =   identifier asgn_cal_lab
        %identifier  ;

184   unlabeled_st  = begin   stmt_list end
        %begin  ;

185   unlabeled_st  = goto   labels
        %goto  ;
```

```
186   unlabeled_st  = case_head case_list otherwise_pt end
        %case  ;

187   unlabeled_st  = repeat   stmt_list until   expr
        %repeat  ;

188   unlabeled_st  = if_stmt
        %if  ;

189   unlabeled_st  = for_stmt
        %for  ;

190   unlabeled_st  = while_stmt
        %while  ;

191   unlabeled_st  = with_stmt
        %with  ;

192   unlabeled_st  = receive_stmt
        %receive when  ;

193   unlabeled_st  = send_stmt
        %send  ;

194   unlabeled_st  = announcestmt
        %announce  ;

195   asgn_cal_lab  = rec_ary_ptr :=   expr
        %. := [ ptr  ;

196   asgn_cal_lab  = actual_parms )
        %(  ;

197   asgn_cal_lab  = :   unlabeled_st
        %:  ;

198   asgn_cal_lab  =
        %; else end otherwise until  ;

199   actual_parms  = (   actual_parm next_a_parm
        %(  ;

200   actual_parm  = parm_expr field_width
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

201   next_a_parm  =
        %)  ;

202   next_a_parm  = ,   actual_parm next_a_parm
        %,  ;
```

```
203   if_stmt  = if_head stmt if_tail
        %if  ;

204   if_tail  = else   stmt
        %else  ;

205   if_tail  =
        %; end otherwise until  ;

206   for_stmt  = for_head do   stmt
        %for  ;

207   while_stmt  = while_head stmt
        %while  ;

208   with_stmt  = with_head stmt
        %with  ;

209   if_head  = if   expr then
        %if  ;

210   while_head  = while   expr do
        %while  ;

211   label_prefix  =
        %announce begin case for goto if
          receive repeat send when while with  ;

212   label_prefix  = int_const :
        %int_const  ;

213   lhs  =   identifier rec_ary_ptr
        %identifier  ;

214   vars  =   identifier rec_ary_ptr
        %identifier  ;

215   rec_ary_ptr  =
        %) * + , - ..
          / : := ; = ]
          and div do downto else end
          from in mod noneqrelop of or
          otherwise then to until  ;

216   rec_ary_ptr  = .   identifier rec_ary_ptr
        %.  ;

217   rec_ary_ptr  = [   index_list ]   rec_ary_ptr
        %[  ;

218   rec_ary_ptr  = ptr   rec_ary_ptr
        %ptr  ;
```

```
219   index_list  = index next_index
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

220   next_index  = ,   index
        %,  ;

221   next_index  =
        %]  ;

222   index  = expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

223   expr  = parm_expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

224   parm_expr  = simple_expr parm_exp_end
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

225   parm_exp_end  =
        %) , .. : ; ]
          do downto else end of otherwise
          then to until  ;

226   parm_exp_end  = rel_op simple_expr
        %= in noneqrelop  ;

227   rel_expr  = simple_expr rel_op simple_expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

228   rel_op  = =
        %=  ;

229   rel_op  = in
        %in  ;

230   rel_op  =  noneqrelop
        %noneqrelop  ;

231   simple_expr  =  char_const add_term
        %char_const  ;

232   simple_expr  =  string_const add_term
        %string_const  ;

233   simple_expr  = sign term add_term
        %+ -  ;

234   simple_expr  = term add_term
```

```
        %( [ identifier int_const nil not
          real_const  ;

235     add_term  =
          %) , .. : ; =
            ] do downto else end in
            noneqrelop of otherwise then to until  ;

236     add_term  = add_op term add_term
          %+ - or  ;

237     term  = factor mult_factor
          %( [ identifier int_const nil not
            real_const  ;

238     mult_factor  =
          %) + , - .. :
            ; = ] do downto else
            end in noneqrelop of or otherwise
            then to until  ;

239     mult_factor  = mult_op factor mult_factor
          %* / and div mod  ;

240     factor  =   identifier var_funccall
          %identifier  ;

241     factor  = nil
          %nil  ;

242     factor  =   real_const
          %real_const  ;

243     factor  =   int_const
          %int_const  ;

244     factor  = (   expr )
          %(  ;

245     factor  = [   elem_list ]
          %[  ;

246     factor  = not   factor
          %not  ;

247     var_funccall  = rec_ary_ptr
          %) * + , - .
            .. / : ; = [
            ] and div do downto else
            end in mod noneqrelop of or
            otherwise ptr then to until  ;

248     var_funccall  = actual_parms )
```

```
        %(  ;

249     add_op  = sign
          %+ -  ;

250     add_op  = or
          %or  ;

251     mult_op  = *
          %*  ;

252     mult_op  = /
          %/  ;

253     mult_op  = div
          %div  ;

254     mult_op  = and
          %and  ;

255     mult_op  = mod
          %mod  ;

256     variable  = identifier rec_ary_ptr
          %identifier  ;

257     field_width  =
          %) ,  ;

258     field_width  = :   expr more_field
          %:  ;

259     more_field  =
          %) ,  ;

260     more_field  = :   expr
          %:  ;

261     elem_list  =
          %]  ;

262     elem_list  = elem next_elem
          %( + - [ char_const identifier
            int_const nil not real_const string_const  ;

263     elem  = expr elem_tail
          %( + - [ char_const identifier
            int_const nil not real_const string_const  ;

264     next_elem  =
          %]  ;

265     next_elem  = ,   elem next_elem
```

```
        %,  ;

266     elem_tail  =
          %, ]  ;

267     elem_tail  = ..   expr
          %..  ;

268     proc_id  =   identifier
          %identifier  ;

269     stmt_list  = stmt more_stmt
          %announce begin case for goto identifier
            if int_const receive repeat send when
            while with  ;

270     more_stmt  =
          %end until  ;

271     more_stmt  = ;   stmt more_stmt
          %;  ;

272     case_head  = case   expr of
          %case  ;

273     case_list  = case_elem case_elems
          %+ - char_const identifier int_const  ;

274     case_elems  =
          %end otherwise  ;

275     case_elems  = ;   case_elem case_elems
          %;  ;

276     case_elem  = case_labels :   stmt
          %+ - char_const identifier int_const  ;

277     otherwise_hd  =   otherwise   :
          %otherwise  ;

278     case_labels  = scalar_const next_scalar
          %+ - char_const identifier int_const  ;

279     next_scalar  =
          %:  ;

280     next_scalar  = ,   scalar_const next_scalar
          %,  ;

281     otherwise_pt  =
          %end  ;

282     otherwise_pt  = otherwise_hd stmt_list
```

```
      %otherwise  ;

283   for_head  = for   identifier :=   expr
        to_part expr
      %for  ;

284   to_part  = to
      %to  ;

285   to_part  = downto
      %downto  ;

286   rec_var_list  =   variable next_rec_var
      %identifier  ;

287   next_rec_var  =
      %do  ;

288   next_rec_var  = ,     variable next_rec_var
      %,  ;

289   with_head  = with   rec_var_list do
      %with  ;

290   receive_stmt  =   simple_rcv
      %receive  ;

291   receive_stmt  =   when_stmt
      %when  ;

292   simple_rcv  =   receive variable0   from
        port_denoter freebinding0
      %receive  ;

293   variable0  =
      %from  ;

294   variable0  =     variable
      %identifier  ;

295   port_denoter  =   pt_class_id subport
      %identifier  ;

296   subport  =
      %; do else end otherwise set
        until use  ;

297   subport  = .   subport_id
      %.  ;

298   pt_class_id  = identifier
      %identifier  ;
```

```
299    subport_id  = identifier
         %identifier  ;

300    freebinding0  =
         %; do else end otherwise until  ;

301    freebinding0  = use   variable
         %use  ;

302    freebinding0  = set   variable
         %set  ;

303    when_stmt  =   when_head receives else_part0 end
         %when  ;

304    when_head  = when
         %when  ;

305    receives  =   receive_pt next_receive
         %; end otherwise receive  ;

306    next_receive  =
         %end otherwise  ;

307    next_receive  = ;     receive_pt next_receive
         %;  ;

308    receive_pt  =
         %; end otherwise  ;

309    receive_pt  = simple_rcv   do stmt
         %receive  ;

310    else_part0  =
         %end  ;

311    else_part0  =   otherwise stmt
         %otherwise  ;

312    send_stmt  =   send expression0 to   port_denoter
          use_part0
         %send  ;

313    expression0  =
         %to  ;

314    expression0  =     expr
         %( + - [ char_const identifier
           int_const nil not real_const string_const  ;

315    use_part0  =
         %; else end otherwise until  ;
```

```
316    use_part0  = use   variable
         %use  ;

317    announcestmt  =   announce event_id about_bind0
         %announce  ;

318    event_id  =   identifier
         %identifier  ;

319    about_bind0  =
         %; else end otherwise until  ;

320    about_bind0  = about   pt_class_id use_part0
         %about  ;

321    sign  = +
         %+  ;

322    sign  = -
         %-  ;
```

APPENDIX C

An Example NETSLA program - Broadcasting

```
network broadcast;
process class sender
port inport in integer;
port outport out integer;
end sender

process class receiver
port inp in integer;
port outp out integer;
end receiver

initial
   create sender : sender;
   create receiver1 : receiver;
   create receiver2 : receiver;
   connect sender.outport to receiver1.inp;
   connect sender.outport to receiver2.inp
end broadcast
```

APPENDIX D

A Network Specification Module

This code was generated by the Netsla preprocessor."

```
procedure init;
begin (*init*)
p_id := 0;
alive := 0;
total_procs := 0;
initialized := false;
Gr := AllocatePort(KernelPort, ChildtoParPort, MAXBACKLOG);
Gr := AllocatePort(KernelPort, EventPort, MAXBACKLOG);
build_net('broadcast');
build_proc('sender');
build_port('inport');
build_port('outport');
build_proc('receiver');
build_port('inp');
build_port('outp');
Gr := a_creation_pr (theroot,'sender','sender','sender.RUN',p_list_head);
Gr := a_creation_pr (theroot,'receiver','receiver1','receiver.RUN',p_list_head);
Gr := a_creation_pr (theroot,'receiver','receiver2','receiver.RUN',p_list_head);
Gr := connection(theroot,'sender','outport','','receiver1','inp','');
Gr := connection(theroot,'sender','outport','','receiver2','inp','');
wakeup;
end; (*init*)
```

APPENDIX E

The Event Handling Module

```
EvntMsg.Head.LocalPort := EventPort;
quit := False;
while (quit=FALSE) do
begin
writeln('Events before receive req');
Gr := Receive(EvntMsg.Head, 0, LOCALPT, RECEIVEIT);
if Gr=SUCCESS then
case shrink(EvntMsg.Head.ID) of
1: begin (* message transmission. *)
      writeln('Send_Msg Request Received.');
      Gr := send_msg(theroot, EvntMsg);
      if Gr=SUCCESS then
         writeln('Send_Msg Request Completed.')
      else
         writeln('***Send_Msg Request NOT Completed.');
      arrive_evnt;
   end;
2: begin (* message transmission. w/ tag *)
      writeln('Send_Msg(w/ Tag) Request Received.');
      Gr := send_msg_tag(theroot, EvntMsg);
      if Gr=SUCCESS then
         writeln('Send_Msg(w/ Tag) Request Completed.')
      else
         writeln('***Send_Msg(w/ Tag) Request NOT Completed.');
      arrive_evnt;
   end;
3: begin (* enter event *)
      enter_evnt;
   end;
4: begin (* leave event *)
      leave_evnt;
   end;
5: begin (* when evnt *)
      when_evnt;
   end;
6: begin (* when evnt. w/ about part *)
      when_evnt;
   end;
19: begin (* connectivity inquiry *)
      writeln('Conn Inq Request Received');
      Gr := inquiry(theroot, EvntMsg);
      if Gr=SUCCESS then
         writeln('Conn Inquiry Completed')
      else
         writeln('Conn Inquiry NOT Completed');
   end;
99: begin (* termination of a process instance *)
     with vparray[vpmap[EvntMsg.Data2]] do
```

```
      begin
        DeleteCanvas(canvs);
        PaintRectangle(UserCanvas,White,x0+1,x0+xlen-3,y0+2,y0+ylen-2);
        Used := False;
      end;
      alive := alive-1;
      if alive=0 then
      begin
         quit:=TRUE;
         EraseCanvas(UserCanvas,White);
         {DeleteCanvas(UserCanvas);}
      end;
    end;
(* more come here *)
otherwise:
   begin
   end
end; (* case *)
end; (* while *)
```

APPENDIX F

A Script for Sender Processes

```
process script sender;
port inport in integer;
port outport out integer;
var
   i:integer;
begin
   while i<>999 do
   begin
      write('Integer: ');
      readln(i);
      send i to outport
   end
end.
```

APPENDIX G

The Preprocessor-generated Code for Sender Processes

```
program sender;
imports Child_lib from Child_lib;

var
i:integer;
var
pinport  : port;
poutport  : port;

type
   signal = boolean;

   accentmsg = record
                  head : msg;
                  ipcname2 : TypeType;
                  arg2 : integer;
                  ipcname3 : TypeType;
                  arg3 : string[10];
                  ipcname4 : TypeType;
                  arg4 : string[10];
                  ipcname5 : TypeType;
                  arg5 : integer;
                  ipcname6 : TypeType;
                  arg6 : string[20];
                  ipcname1 : TypeType;
                  case integer of
                      1 : (msignal : signal);
                      2 : ( msginport : integer);
                      3 : ( msgoutport : integer);
               end;

var
   xxmsg : accentmsg;
   gr : generalreturn;
   whenflag : boolean;
   xxsignal : signal;
   commport : port;
   p_array : PortBitArray;
   pstr : string[12];

{$INCLUDE Alsten_supt.pas}
begin
{$INCLUDE AlstenInit.pas}
InitMsgn(NullPort);
Gr := Child_ack;
while i<>999 do
begin
write('Integer: ');
```

```
readln(i);
begin (* send *)
xxmsg.head.id := 1;
xxmsg.head.remoteport := InPorts^[1];
xxmsg.head.localport := DataPort;
xxmsg.msgoutport:=i;
xxmsg.arg2 := p_id;
xxmsg.arg3 := 'outport';
xxmsg.arg4 := '';
gr := send(xxmsg.head,0,wait)
end (* send *)
 end
;goaway;end.
```

APPENDIX H

A Script for the Receiver Processes

```
process script receiver;
port inp in integer;
port outp out integer;
var
   j:integer;
begin
   while j<>999 do
   begin
      receive j from inp;
      writeln(j)
   end
end.
```

APPENDIX I

The Preprocessor-generated Code for Receiver Processes

```
program receiver;
imports Child_lib from Child_lib;

var
j:integer;
var
pinp  : port;
poutp  : port;

type
   signal = boolean;

   accentmsg = record
                  head : msg;
                  ipcname2 : TypeType;
                  arg2 : integer;
                  ipcname3 : TypeType;
                  arg3 : string[10];
                  ipcname4 : TypeType;
                  arg4 : string[10];
                  ipcname5 : TypeType;
                  arg5 : integer;
                  ipcname6 : TypeType;
                  arg6 : string[20];
                  ipcname1 : TypeType;
                  case integer of
                      1 : (msignal : signal);
                      2 : ( msginp : integer);
                      3 : ( msgoutp : integer);
               end;

var
   xxmsg : accentmsg;
   gr : generalreturn;
   whenflag : boolean;
   xxsignal : signal;
   commport : port;
   p_array : PortBitArray;
   pstr : string[12];

{$INCLUDE Alsten_supt.pas}
begin
{$INCLUDE AlstenInit.pas}
InitMsgn(NullPort);
Gr := Child_ack;
while j<>999 do
begin
begin (* receive *)
```

```
rcv('inp','',999,1,rcv_result);
if rcv_result then
j:=xxmsg.msginp;
end (* receive *)
;
writeln(j) end
;goaway;end.
```

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FINAL REPORT
GIT Project No. G36-605

INTERACTIVE MONITORING OF DISTRIBUTED SYSTEMS

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Prepared by

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Under

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Final Report

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TABLE OF CONTENTS

Section 1

INTRODUCTION

1.1 Problems with Monitoring Distributed Programs

In a conventional programming environment, there are two principal purposes for monitoring the run-time behavior of a program: performance measurement and debugging. (By "monitoring" we refer to some mechanism for obtaining information about the performance of a program, *external* to the program itself.) Performance measurement is a relatively mundane application of monitoring in such an environment, being principally concerned with the processor time requirements of various parts of a program and requiring little or no interactive intervention by a programmer. Debugging is considerably more interesting, requiring extensive programmer interaction by its very nature.

When we generalize our thinking to a distributed system from a traditional single-processor environment, the uses of monitoring become somewhat different and we must develop a new conceptual view of a major part of the monitoring task. We are, of course, still interested in performance measurement and debugging, but these tasks become quite different in this new environment. The reason for this difference is that we are now concerned with distributed programs - programs which cannot be monitored by considering a single address space on a single machine. Rather, we must now be concerned with the communication between the various parts of a program, for these interactions will play a crucial part in the monitoring task.

Performance measurement in a distributed system is made more complex by a number of new considerations. Communication costs and the overall time it takes to execute a program, which is affected by the potential for parallel execution of subtasks and by time spent waiting for messages, are equally important considerations in many situations. Further, it is much more difficult for a measurement program to monitor an entire program, since the monitored program may be distributed arbitrarily across a network of machines. It will be necessary for

any monitoring program to obtain information about the distribution of a program and about its communication linkage and behavior.

This need to obtain information from distributed execution sites naturally applies to debuggers as well as to performance monitors. In fact, it is a more complex problem in the case of a debugger since the debugger must somehow assist a programmer in comprehending the "state" of a program which consists of a number of processes running *asynchronously* on several machines. Conventional debugging tools are certainly of little use in this situation, since they are typically oriented toward monitoring the operation of what would only be a single process of a distributed program. Once again, tools which provide information about the status of process interactions will be required. (Such tools should also have the capability to interface with more traditional monitoring tools which can be used on the individual processes.)

Just as communication should play an important part in distributed performance measurement, it should also have a crucial role in debugging distributed programs. The correctness of such programs will undoubtedly depend on the correctness of the contents and sequencing of messages transmitted between their constituent processes. Thus a distributed debugging tool must deal with communication as a major part of its job. In fact, it is conceivable that a communication monitor may be *the* debugger at the interprocess level, complementing traditional debuggers which operate on individual processes.

As a final difficulty, any kind of monitoring of a distributed program will potentially generate a great deal of information, which must be conveyed to a programmer in a comprehensible manner. It will presumably not be satisfactory to produce all of this information independently for each of the processes. Rather, the information must be aggregated in some manner consistent with the nature of the monitoring task being performed.

1.2 Proposed Solutions Using PRONET

The solution we have explored is based on our programming language PRONET [Macc82].

The network descriptors of PRONET provide an excellent basis for the operation of distributed monitoring tools. The interconnection information these descriptors provide is exactly what is required by a monitor so that it can easily recognize the structure of an entire program.

As was suggested in the previous section, a communication monitor is a crucial part of our tools. The interconnection specifications in PRONET networks provide the minimum amount of information needed by a communication monitor. That is, they provide a listing of the message paths between processes and the types of the messages which may be transmitted. The task of a monitor will be to provide a programmer with information about message transmission between processes, including information about the sequencing of messages and about their contents. The capability to examine the operation of individual processes (accomplished by interfacing with a traditional single process debugger) is an important part of our tool set.

1.3 Overview of Project Organization

The project was originally planned to include the following tasks as described in the original statement of work:

Task 1 - PRONET Interface

> PRONET, a language that provides a high level description of interprocess communication, is currently being implemented on a distributed system of Prime computers at Georgia Institute of Technology. The task is to develop an interface between PRONET and a distributed monitor.

Task 2 - Communication Monitor

> The contractor shall determine what data should be collected by the monitor to facilitate development, debugging and maintenance of programs. This task is to develop a monitoring program that interfaces with the communication features of the operating system and collects the necessary data.

Task 3 - Interface to the Communication Monitor

> The contractor shall develop a convenient user interface to the communications

monitor. The user interface will provide a graphical display of information collected by the monitor. Also, it will do additional automated processing of the data to consolidate into meaningful form the information generated by the monitor.

Task 4 - Interface with a Process-level Debugger

The contractor shall develop an interface with the communications monitor and an existing symbolic debugger. If this approach is infeasible, then symbolic debugger for individual processes must be implemented and interfaced with the single process debugger.

During the course of the project, some changes from the initial plans were found to be necessary. The most prominent change involved the use of different hardware than originally planned. The main reason for this change was that we found the implementation of PRONET on our Primes too inefficient to be practical. The operating system on these machines does not effectively support dynamic process creation. The Accent operating system available on our Perq computers, on the other hand, supports dynamic process creation as well as message passing between processes on different machines. Thus we chose to do the work using our Perq workstations, which meant that more work on the implementation of Pronet than originally had been planned turned out to be necessary. However, this work was minimized by implementing Pronet through use of a pre-processor which generates Perq pascal code.

The Perqs also have high-resolution, bit-mapped displays. This feature gave considerable support to the development of a very effective graphical user interface to our monitoring system. We consider this interface one of the most successful aspects of the project.

The other major change in our approach involved the development of a passive event recording system rather than a monitor which supports interaction with distributed programs during execution. This passive approach was initially seen as a prototype. However, we found that a simulated replay of program execution using the information we record during execution provides an effective visualization of a distributed programs, so it remained the focus of our

work throughout the project.

Only task 4 went just as it was originally planned. Our program replay system interfaces with the Kraut debugger, which is a standard high-level debugger under Accent.

1.4 Summary of Project Results

As discussed in the previous section, we made use of the bit-mapped displays on our Perq computers to develop a graphical user interface to our monitoring systems. In effect, it produces a high-level, animated view of program execution. We say this view is "high-level" because it includes only events visible at the process interconnection level (e.g., process creation and interprocess communication). This graphical display approach has proved to be an excellent technique for managing the large quantity of information collected in monitoring a distributed program.

One of the hardest issues to be dealt with in the design of a distributed program monitor or debugger is how to minimize the impact it has on the execution of a program under examination. Our ultimate decision to concentrate on passive monitoring followed by a replay was heavily influenced by this consideration. We believe we have developed tools which can be effectively used to debug applications level distributed programs, based on this minimally obtrusive passive monitoring approach.

Part of our methodology for making use of passive monitoring involves what we call multi-level debugging. In addition to looking at the high-level animation of execution described above, the user also has the ability to focus on the execution of a single process, once the source of a failure has been isolated. Our technique integrating of our monitoring system with an existing single-process debugger is the key to making multi-level debugging available.

The results of this project were reported at the 5th International Conference on Distributed Computing Systems in a paper by R. J. LeBlanc and A. D. Robbins, entitled "Event-Driven Monitoring of Distributed Programs".

1.5 Report Overview

The following three sections describe various aspects of the design of the prototype monitor, called RADAR. They are extracted from Arnold Robbins' M.S. thesis. They are followed by sections on the PRONET implementation, the monitor implementation and the conclusions we have drawn from our research.

Section 2

RADAR DESIGN

2.1 Distributed Programs

The RADAR monitor is intended to support Pronet [Macc82], a message based language designed as a part of previous research on distributed computing at Georgia Tech. However, it could be easily adapted to support other message-based programming systems. The relevant features of Pronet will be discussed in section 3.1.

2.2 The RADAR System

The RADAR system takes a passive approach to monitoring distributed programs. Because it is interactive the term "monitor" is used to describe it, and not the term "debugger."

RADAR is designed to support Pronet on PERQ computers [3RCC82]. The PERQ is a single user machine with a high resolution bit-mapped display and a mouse.

Pronet consists of two sublanguages: NETSLA for describing communication networks, and ALSTEN for describing processes. The Pronet compiler provides the monitor with information concerning the connectivity of the processes. This information is collected from the NETSLA runtime system. ALSTEN programs are loaded with a special communications library which records every standard or user-defined event during execution, and makes a copy of every message sent. The exact nature of the information supplied by the NETSLA runtime system and the structure of ALSTEN event records will be described in section 3.2. This component of RADAR is known as the RADARLOG.

After the program has completed executing, the REPLAY component of RADAR is invoked to provide a graphical "replay" of the execution. Each message or event is stamped with a global event number. This imposes a partial ordering on events. The monitor then displays events one at a time. The programmer is able to watch the communications traffic

amongst the processes. Processes have names in Pronet, so it is easy for the programmer to see which process is communicating with which other processes.

REPLAY provides the user with the ability to view the contents of any message currently represented on the screen. Messages are represented on the screen as small boxes. The user places the PERQ's mouse over the message which he wishes to examine. REPLAY then opens a new window in which the contents of the chosen message will be displayed in a formatted fashion. For instance, if the message contained an integer and two floating point numbers, the message would be displayed as an integer and two floating point numbers, not as 10 octal bytes. When the user is through with the message the new window disappears.

REPLAY also provides the ability to replay a certain number of events which have already happened. This can be done at any point during the display. The user can "rewind the video tape," so to speak. This replay is limited to a reasonable maximum number of previous events. This feature is known as an "Instant Replay."

Finally, as a separate utility, the user can name a given process and have all of the messages which were sent to that process selected from the recorded message traffic. This single process may then be run by itself with its messages derived from the stored messages. This feature is designed to facilitate single process debugging using real input data (messages). This way, it is possible to observe a process' behavior under realistic conditions, without having to worry about controlling the rest of the processes of the distributed program.

Section 3

COLLECTING INFORMATION

RADAR is intended to support Pronet, a language designed for writing programs which can execute in a distributed processing environment. Pronet stands for **P**rocesses and **N**etworks. The introduction to Chapter 2 of [Macc82] summarizes the description and design goals of Pronet:

> PRONET is composed of two complementary sublanguages: a network specification language, NETSLA, and a process description language, ALSTEN. Programs written in PRONET are composed of network specifications and process descriptions. Network specifications initiate process executions and oversee the operations of the processes they have initiated. The overseeing capacity of network specifications is limited to the maintenance of a communication environment for a collection of related processes. The processes initiated by a network specification can be simple processes, in which case the activities of the processes are described by ALSTEN programs, or they can be "composite processes", in which case their activities are described by a "lower-level" network specification.
>
> ALSTEN is an extension of Pascal which enables programmers to describe the activities of sequential processes. During their execution, processes may perform operations that cause events to be announced in their overseeing network specification. Network specifications, written in NETSLA, describe the activities to be performed when an executing process 'announces' an event... Two principles have influenced the design of these features: independence of process descriptions and distributed execution of network specifications.

This section first describes the features of Pronet relevant to interprocess communication. Then it describes the information provided to the monitor by the NETSLA and ALSTEN compilers. Finally, it presents the format of the information collected at run-time by the special communications library.

3.1 The Features of Pronet

This presentation is derived from Chapter 2 of [Macc82].

3.1.1 ALSTEN

ALSTEN is essentially an extension of Pascal [Jens74]. The file concept has been removed

entirely from the language. Processes communicate only through locally declared *ports*, using *send* and *receive* statements which are analogous to Pascal's *read* and *write*. Ports have a direction, either *in* or *out*. Ports may be combined into *port groups*. One could define a duplex channel as:

port channel (incoming *in* bit; outgoing *out* bit);

To accomodate the notion of a *server process*, which serves many other processes, ALSTEN provides *ports sets* and *port tag* variables. A port set is a collection of port groups or simple ports identified by one name. For instance, if a port set is a set of port groups, a *receive* on a port set would set a port tag variable to indicate which element of the set was actually used for communication. This tag may then be used in a *send* operation for sending replies to the process which originated the message.

The syntax of the *send* and *receive* statements is shown in Figure 1.

```
<send stmt> ::=
      send [<expr>] to <bound port denoter>

<receive stmt> ::= <simple receive>
  | <conditional receive>

<simple receive> ::=
      receive [<variable>] from <free port denoter>

<conditional receive> ::= when
                        {<receive part>}
                        [<otherwise part>]
                  end

<receive part> ::= <simple receive> [do stmt>]

<otherwise part> ::= otherwise <stmt>
```

Figure 1 -- Send and Receive Statements in ALSTEN

A type is associated with every port. Only expressions of the type associated with a given port may be sent to or received from that port.

The <expr> is optional. In these forms of the *send* and *receive* statements, the port is of type *signal*. A signal is a message with no contents. Signals are often useful for sending control information, such as telling a process to start a particular task.

The syntax for port declarations is shown in Figure 2.

```
<port decl> ::= <simple port decl>
  | <port group decl>

<simple port decl> ::=
      port <port id> <direction> <msg type>

<port id> ::= <id>

<direction> ::= in | out

<msg type> ::= <type id>

<port group decl> ::=
      port [set] <port id> '(' <subport list> ')'

<subport list> ::=
      <subport decl> {';' <subport decl>}

<subport decl> ::=
      <subport id> <direction> <msg type>

<subport id> ::= <id>

<port tag type> ::= tag of <port id>
```

Figure 2 --- Port and Port Tag Declarations in ALSTEN

3.1.2 NETSLA

As stated earlier, the purpose of NETSLA specifications is to initiate and control the communications environment of ALSTEN processes:

> The features of NETSLA are aimed at specifying the initial configuration and subsequent modifications of a communication environment for processes. The overriding principle followed in the design of these features is that of "centralized expression--decentralized execution" [Live80]. Centralized expression is important in presenting the abstraction to be supported by network specifications. All of the inter-process relationships that describe a communication environment appear in a single network specification. However, this communication environment is not maintained in a centralized fashion. Processes maintain their communication environment indirectly. When they execute send or announce operations, processes

perform the activities specified by their overseeing network specifications; however, the nature of these activities is unknown to the process (since network specifications are not visible to processes). [Macc82]

The syntax of network specifications is shown in Figure 3.

```
<network specification> ::= <network header>
            {<process class specification>}
            {<event handling clause>}
            [<initialization clause>]
      end <identifier>

<network header> ::= network <net id> ';'
      {<port decl>}
      {<event decl>}

<process class specification> ::=
      process class <process id>
            [<process attributes>]
            {<port decl>}
            {<event decl>}
      end <process id>

<process attributes> ::= attributes
            <field list>
      end attributes
```

Figure 3 --- Network Specifications in NETSLA

When a network starts to run, its initialization clause is executed. The initialization clause is used to create instances of processes and connect the output ports of one process to the input ports of another. A simple network specification is presented in Figure 4; a graphical representation of the network is shown in Figure 5.

```
network static_net
        process class proc_class
                port input in integer;
                port output out integer;
        end proc_class

        initial
                create proc1 : proc_class;
                create proc2 : proc_class;
                create proc3 : proc_class;
                connect proc1.output to proc3.input;
                connect proc2.output to proc3.input;
                connect proc3.output to proc1.input;
                connect proc3.output to proc2.input;
end static_net
```

Figure 4 --- A Simple Network Specification

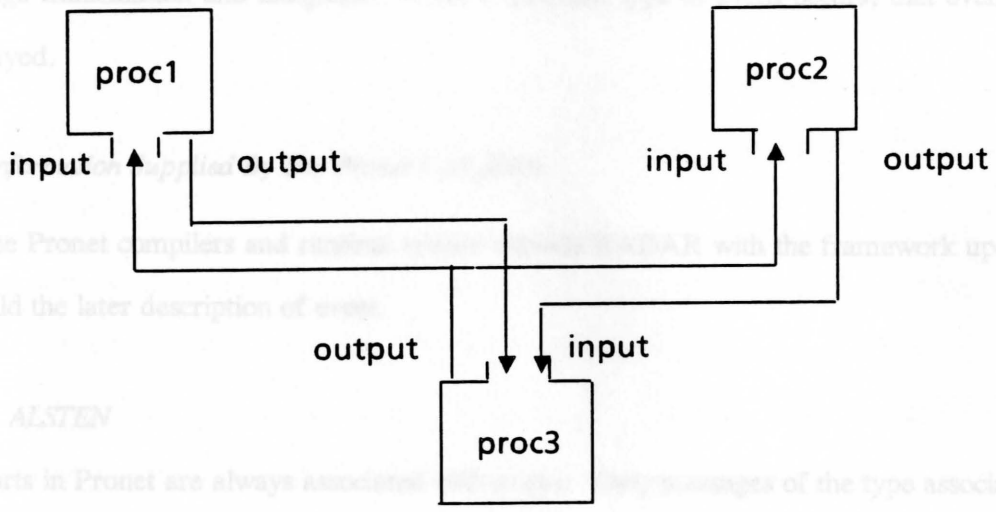

Figure 5 --- A Graphical Representation of a Simple Network

If one output port is connected to more than one input port, the messages sent out on it are replicated. This occurs in a manner invisible to the process sending the message. This allows one-to-one, one-to-many, and many-to-one connections between ports.

Processes may define events. These events can then be announced by the processes in their overseeing network specifications. NETSLA provides features for handling these events when they are announced. The programmer specifies what actions to take, such as aborting processes

or creating new ones. Other actions are also possible.

Pronet predefines several standard events. For instance, when a process terminates normally, the standard event 'done' is announced in its network.

Message transmission and reception are considered to be events. They simply have a separate syntax. The other standard events and the syntax of event declarations and handlers are discussed fully in [Macc82].

Since Pronet is oriented around events, so is RADAR. The special runtime routines record all the events and messages. The REPLAY program presents the user with a visual replay of the events that occurred during the execution of the program. The majority of events will be message transmission and reception. When a different type of event occurs, that event will be portrayed.

3.2 Information Supplied By The Pronet Compilers

The Pronet compilers and runtime system provide RADAR with the framework upon which to build the later description of event.

3.2.1 ALSTEN

Ports in Pronet are always associated with a type. Only messages of the type associated with a port may be sent to or received from that port.

In any given ALSTEN program, there will be a fixed number of different message types, i.e. the types associated with ports.

The ALSTEN compiler will generate a file with a list of *message templates*. A template looks like

Identifier	size	total no elements	list of elements

Figure 6 --- Message Templates

The list of elements is simply an order listing of the fields in a message. For instance,

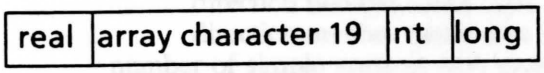

Figure 7 --- Fields In A Message

If a field of a message is itself a record with further subfields, the compiler will expand it in line down to its basic elements. Elements can be bytes, integers, long integers, reals, or one dimensional arrays of these types. Bytes are treated as unsigned integers, even though they may have actually been signed quantities. If necessary, RADAR may be modified to allow specifying whether or not such numbers were signed or unsigned. Elements smaller than one byte occupy a byte to themselves. This implies that the Pascal keyword *packed* has no effect. Admittedly, this is a constraint on the compiler; see Section 5 of the thesis for further discussion of this constraint.

The purpose of the list of message templates is to allow the decoding of individual messages. A user can select any message on the screen with the PERQ's mouse. When he does so, RADAR will open a separate window and format the contents of the message in it. Each message carries its type with it. The message is decoded according to the corresponding template and printed accordingly. One dimensional arrays are allowed, principally for use in displaying character strings. REPLAY will treat arrays as if they are indexed from 1.

3.2.2 NETSLA

NETSLA controls process and port creation and the interconnecting of output ports to input ports.

The information generated by the NETSLA system is a file describing each process. A process is described as follows:

```
machine  proc_num  proc_name  number_port_groups
    number of simple ports in each group
            direction number name type { DESTINATIONS }
            direction number name type { DESTINATIONS }
    number of simple ports in each group
            direction  number  name  type  { DESTINATIONS }
            direction  number  name  type  { DESTINATIONS }
```

Figure 8 --- Description Of A Process

The { } pairs enclose optional information. Only if a port is an output port does it have one or more destinations associated with it. The DESTINATIONS field in Figure 8 above represents the number of destinations to which an output port sends its messages, and the destinations themselves. A destination is uniquely identified by the destination machine, the process number on that machine, and the port number of the process to which the message is directed.

Machine and process id's are hidden from the programmer, but the NETSLA runtime system and the underlying global operating system must know about them, since they actually arrange for execution of the processes.

When REPLAY first starts up, it builds a table of records describing processes with all these structures attached to each element in the table. Later, when a *send* event occurs, REPLAY determines which process is the destination and depicts a message moving from the source process to the destination process.

3.3 Information Collected At Run-Time

Most of the information that RADAR needs is collected at run-time. Special runtime routines log every event that occurs. These routines are kept in a separate module called RADARLOG.

Events may be one of the following:

```
type
        eventtype = (createprocess, destroyprocess,
                     message_transmission, message_reception,
                     portcreation, failed, done
                     aborted, userevent);
```

Figure 9 --- Types of Events

The 'message_transmission' and 'message_reception' events are logged by the *send* and *receive* routines respectively. The other events are logged by the *announce* routine.

The ALSTEN compiler inserts a procedure call to the routine *makelog* as the very first executable statement in a program. This routine creates the log file and announces the process creation event. Before the final *end* of the ALSTEN main program, the compiler inserts a call to the routine *closelog*, which closes the logfile and announces the standard event 'done'.

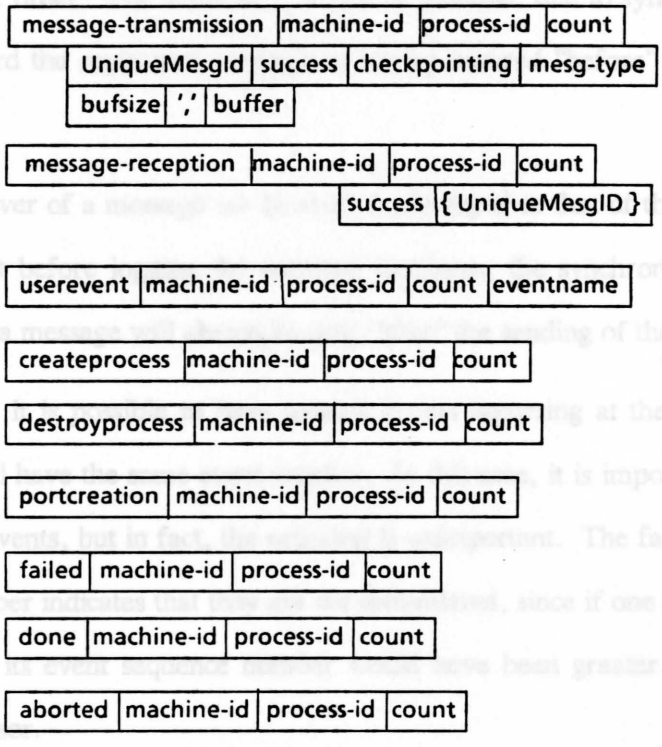

Figure 10 --- Event Records

Each process keeps a count of the events it has announced, including message transmission and reception. The event count starts at one and is incremented with each event.

When a process sends a message, it includes the value of its local event counter. If the receiving process' event count is lower than that of the sender's, the receiver sets its count equal to that of the sender. After receiving the message, the process logs the message_reception event. If the message reception succeeded, the process logs the UniqueMesg Id of the message it received. Since message_reception is an event like any other, the local event count is incremented before the event is logged. Thus, the message_reception event's sequence number will be one greater than the event count of the sender. This insures that there will be at least a partially correct ordering on events. In particular, interrelated events will always be correctly ordered.

Placing an ordering on events in a distributed system is a difficult task. One solution is to use the times on local clocks to time-stamp each event. This method is not acceptable since it is impossible to synchronize all the clocks on all the machines. This introduces the possibility of recording events out of order. For example it would be possible, due to synchronization errors among clocks, to record the reply to a message as having occured "before" the sending of the initial message.

By having the receiver of a message set its event count equal to that of the sender, and then incrementing the count before logging the message reception, the synchronization problem is avoided. The reply to a message will always be sent "after" the sending of the initial message.

Using this method, it is possible to have several events occurring at the same "time," i.e. several events might all have the same event number. In this case, it is impossible to determine the ordering of these events, but in fact, the ordering is unimportant. The fact that these events all have the same number indicates that they are *not* interrelated, since if one event depended on another to precede it, its event sequence number would have been greater than the sequence number of its predecessor.

Furthermore, this method makes no extra demands on the underlying global operating system to keep clocks synchronized across machines. It also fits in well with Pronet, which has no concept of global time.

3.3.0.1 Summary

Keeping a record of every event, along with a description of message contents and the interconnectivity of every port, provides a complete record of what went on.

Copying all the message allows the user to view what was actually sent; the message description makes the message contents understandable, and the connectivity data allows graphically depicting the movement of a message from its source to its destination.

Section 4

REPLAYING PROGRAM EXECUTION

The major component of the RADAR system is the REPLAY program. After a Pronet program has executed and all the information described above has been collected, REPLAY is invoked to graphically display event occurrences. More importantly, it also displays the message traffic amongst processes.

The PERQ's screen is a high resolution, bit-mapped black and white display. The PERQ has hardware and firmware instructions, called Raster Ops, for manipulating the screen. REPLAY uses the Sapphire graphics package which provides a higher-level, more usable interface to control the screen.

This section discusses the algorithms REPLAY uses, describes the view of the program REPLAY presents to the user, and presents the user interface.

4.1 Outline of the Algorithm

The overall algorithm is fairly simple. It is based on the notion of events as defined previously. Since each event is numbered when recorded, an ordering of events is automatically made possible.

The general algorithm for event replaying is given in pseudo-code in Figure 11.

```
get first event
while more events
        if event in { send_a_message, receive_a_message }
                do something visible with the message
        else
                announce the event conventionally
        end if
        get next event
        end while
```

Figure 11 --- Top Level REPLAY Algorithm

Most of the work is involved with displaying events. REPLAY basically has to keep track of four things.

1) Which processes are represented on the screen and where they are.

2) Which messages are represented on the screen and where they are.

3) Rate of event display (see below).

4) How full the screen is; i.e., is there room for more processes?

Processes and the messages waiting in input queues take up the majority of the room on the screen. Most of the other events can be displayed simply by printing out a line on the screen of the form "Process **P** announces Event **E** as event Number **N**," in a prominent place. During the interval that the process is announcing an event, it changes color (actually a different shade of gray) so that it is clear which process is involved.

In fact, REPLAY provides a running narrative of this form. However, when a process is created or destroyed, or a message is sent or received, REPLAY will depict this graphically. Newly created processes will be drawn into a free spot on the screen. Messages are depicted as small boxes moving from the sender's output port to the receiver's input port. When each message is received, its box disappears.

Much of the work involves doing all the bookkeeping necessary in as efficient a manner as possible. (It should be "efficient" in terms of both space and time).

4.2 The User Interface

This section discusses various aspects of the operation of REPLAY's user interface.

4.2.1 What the User Sees

The user sees processes and messages queued on input ports. A process with one input port,

one output port and a message just leaving the output port, is shown in Figure 12.

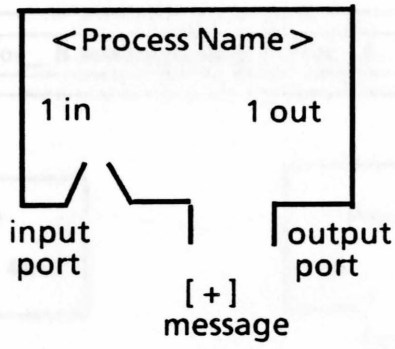

Figure 12 - Picture of a Process and a message

The drawing of a process indicates the number of input and output ports associated with that process. It is not possible to draw each port, since the notion of port sets allows a process to have a very large number of ports. When an output port sends a message, the port appears on the process' border. It closes up after the message arrives at its destination. Similarly, when a message arrives for an input port, the port opens up, and messages queue up in front of it. When all the queued messages have been received, the input port closes back up. The process name and identification appear inside the box, so that it is clear at a glance which process it is.

Figure 13 depicts an event replay on the PERQ's screen. The process **Proc_B** is shown sending a message to **Proc_A**, while process **Proc_C** is shown with one message waiting at its input port. The event narration at the top of the screen indicates what is happening. Appendix

J contains a sequence of figures portraying a more extended example.

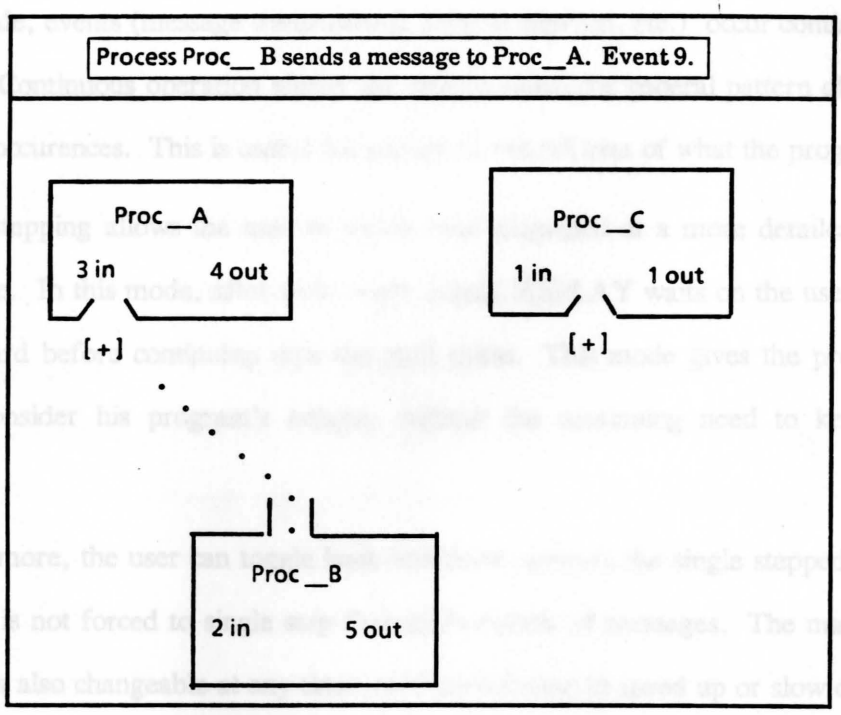

Figure 13 --- A Process Sending A Message

An interesting problem concerns the speed at which the replaying occurs. If events are described and messages move across the screen without any delays, events will happen too fast for the user to follow.

To solve this problem, REPLAY asks the user how many seconds to take to display each event. The default is three seconds per event. Even in single step mode (see below), each event takes the full *n* seconds (whatever the user entered) to transpire. This is to allow the process to change color, and to remain on the screen in a different color for enough time to make an impression on the user before it changes back to normal.

4.2.2 Single Stepping

REPLAY gives the user the choice of either single stepped or continuous operation. In the second mode, events (message transmission, process creation, etc.) occur continuously, without stopping. Continuous operation allows the user to watch the general pattern of message traffic and event occurences. This is useful for getting an overall idea of what the program did.

Single-stepping allows the user to watch what happened at a more detailed level and at a slower pace. In this mode, after each event occurs, REPLAY waits on the user to hit a key on the keyboard before continuing with the next event. This mode gives the programmer more time to consider his program's actions, without the continuing need to keep up with his program.

Furthermore, the user can toggle back and forth between the single stepped and continuous modes; he is not forced to single step through hundreds of messages. The number of seconds per event is also changeable at any time, to allow the user to speed up or slow down the rate of event display.

4.2.3 Displaying Messages

Messages on the screen are simply small boxes, queued on the input ports of their destination processes. In this form, the only information that they convey is the fact of their existence. This is only minimally useful.

REPLAY allows the user to actually see what his processes are sending to each other. Using the mouse, the user places the cursor over the particular message he wants to see and interrupts the event display. REPLAY will prompt with a menu of actions available. The user will select the option for viewing a message.

REPLAY first finds the message indicated by the mouse. The message's type is an element in the Pascal *record* describing messages. This type indicates which of the message templates is to be used in decoding the contents of the message.

REPLAY then opens a new window on the screen. It steps through the message buffer and formats the raw bytes into characters, integers, or reals, as dictated by the message template. Enumerated types are treated as integers. Although this is not perfect, it is no more unreasonable than the restriction in standard Pascal against reading and writing enumerated types to and from text files. Message templates were described in Section 2.2.1.

When the user is through looking at the message, he issues the command to close the window. REPLAY then goes back to displaying events.

The value of this "Freeze Frame" facility should be clear. The user can verify not only that processes are sending messages to the right places, but that those messages have the right contents. Formatting message contents is absolutely necessary. Simply displaying the values of integers, characters and reals in octal gives the user no immediately understandable information (except in the rare case of the true hacker who can decode octal into its equivalent floating point or ASCII values). Furthermore, messages are displayed as a unit, unlike Schiffenbauer's system which displays small data packets in octal.

4.2.4 Selective Replaying of Events

It is possible while watching a program's actions that a particularly interesting sequence of events will occur which warrants further review. To accomodate this, REPLAY keeps a history of a fixed number of events which have occurred. At any time, the user can stop the normal replay and ask to see an "Instant Replay" of *n* previous events. The maximum number of events that can be replayed is a compile-time constant in one of the Pascal source code modules.

When this facility is invoked, REPLAY saves the screen state and marks those processes that were on the screen at the time. It clears the screen and starts as if the first event requested were the very first event to occur. Processes and messages are drawn as needed.

Some information which was on the screen but which may not relate to the *n* events being replayed will be lost during the instant replay. This loss is not permanent, since REPLAY

restores the screen at the end of the instant replay. The user can run the instant replay as many times as desired before returning to the regular display. This facility is analogous to the rewinding of video tape and replaying an interesting series of events during a sports broadcast, hence the name "Instant Replay."

When the instant replay is through, the screen is restored and the processes which were marked as being saved are unmarked. Display then continues as before.

As a final possibility, the user may choose to restart the entire program replay from scratch. This provides the convenience of not having to quit the program and then start it again from the command level. Such small conveniences are often the most useful.

4.2.5 REPLAY Menu Options

At any time during the event replay the user can stop execution by causing a keyboard interrupt.

This invokes an interrupt handler which presents the menu shown in Figure 14.

1. Change To/From Single-Step/Continuous Operation
2. Change The Number of Seconds Per Event
3. Skip Ahead To A Specific Event Number
4. Display contents of the Message Under the Mouse
5. Instant Replay
6. Start Displaying From Scratch
7. Exit REPLAY
8. Help
9. Never Mind

Figure 14 --- REPLAY Menu Options

The user may skip ahead to a given event, specified by the event sequence number.

REPLAY will then skip to the first event which has the sequence number entered by the user. This is useful if the user knows that his program stopped working after a given event. He can make his changes, rerun the program, and then skip directly to where the change should have an effect.

The help subsystem provides general information on how to use the RADAR monitor.

The 'Never Mind' option allows the user to recover in case he accidentally caused a keyboard interrupt. It does nothing.

In all cases, after the interrupt handler does what the user wishes, the program returns to where it was executing before the interrupt occurred.

Section 5

PRONET IMPLEMENTATION

An implementation of PRONET has been developed for PERQ computers running under revision 2.0 of ACCENT, which is a communication oriented network operating system. The run-time libraries developed for this implementation make use of ACCENT message and process primitives through a procedure-like interface to the kernel.

Two language preprocessors, one for ALSTEN and another for NETSLA, have been developed. These two preprocessors both translate a PRONET source program into a Pascal program. Then, the Pascal program generated can be compiled using the PERQ Pascal compiler.

5.1 The Preprocessors

The preprocessor actually consists of two parts: a scanner and a parser; both are table-driven. The table-driven approach makes the preprocessor very language independent; i.e., it can translate either ALSTEN or NETSLA so long as appropriate tables are provided.

The scanner tables are generated by the LEXGEN scanner generator from a description of each token that may occur as input to the scanner. LEXGEN is similar to the standard Unix LEX program except that it produced no program, only tables. These tables may then be used in a scanner written in any language (PERQ Pascal, in this case). Tokens are described by using a standard regular expression syntax. The parser tables are generated by ZUSE from LL(1) grammers (see Appendix A and Appendix B) which have action codes embedded into them. ZUSE is similar to the Unix YACC program except that it generates a parsing program in Pascal rather than C. The action codes provide program fragments steps to be executed as the parser recognizes syntactic structures in the input. In the case of this preprocessor, appropriate Pascal codes is generated by these fragments.

The preprocessor accepts a scanner table, a parser table and source program as input and generates a sequence of Pascal codes as a result of parser actions. The Pascal code generated can then be compiled by using the PERQ Pascal compiler.

Figure 15 below illustrates the overall structure of the preprocessors.

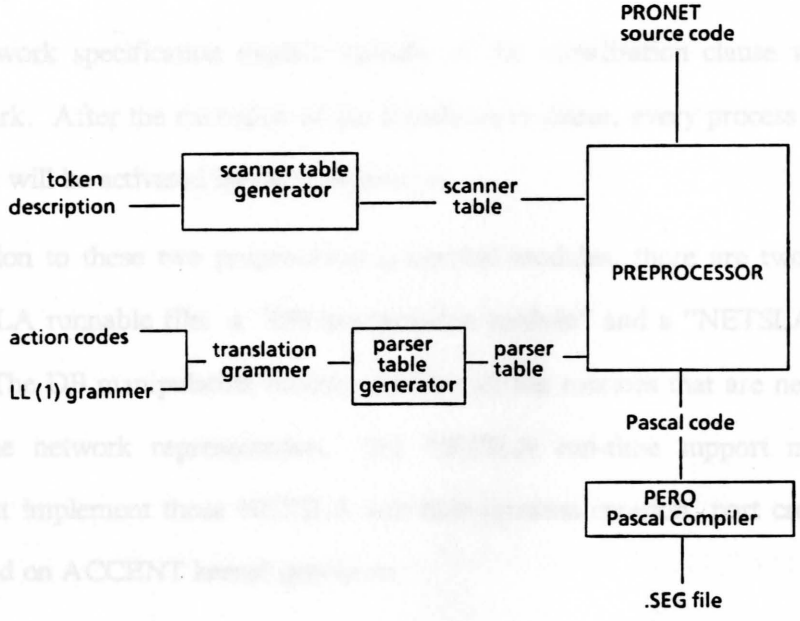

Figure 15 --- Preprocessor Structure

The approach of preprocessing has two important advantages, although it is less efficient than direct compilation. The first is that it was far easier to implement than a compiler would have been. The second is that it makes the full power of PERQ Pascal, particularly access to ACCENT kernal primitives, available to Pronet programmers, since kernel primitives are accessable through calls to kernel interface procedures and functions in the Pascal library. The preprocessors do no type checking, leaving that task to the Pascal compiler.

5.2 Module Structures

The NETSLA preprocessor generates two code modules for each network specification: an "event handler module" and a "network specification module" (see Appendices C, D and E).

The event handler specifies the action that must be performed when a particular event (either predefined or process-defined) occurs. The code in this module is structured as a nested "case" statement. The highest level case statement performs a selection based on the event type argument (message transmission, process-defined event, etc.). Lower level case statements are used to distinguish between process classes, port sets and process-defined events.

The network specification module consists of the initialization clause which specifies the static network. After the execution of the initialization clause, every process instance created in the network will be activated by the root process.

In addition to these two preprocessor-generated modules, there are two more modules in each NETSLA runnable file: a "DB manipulation module" and a "NETSLA run-time support module." The DB manipulation module contains all the routines that are needed to create and maintain the network representation. The NETSLA run-time support module consists of routines that implement those NETSLA activities (process creation, port creation, connection, etc ...) based on ACCENT kernel primitives.

Figure 16 below illustrates the structure of the object module generated for each NETSLA program. It is important to realize that both the event handler module and the network specification module are network specific while the other two modules are common to all network instances. The DB manipulation module and the NETSLA run-time support module are separately precompiled and imported by the main body of the NETSLA program.

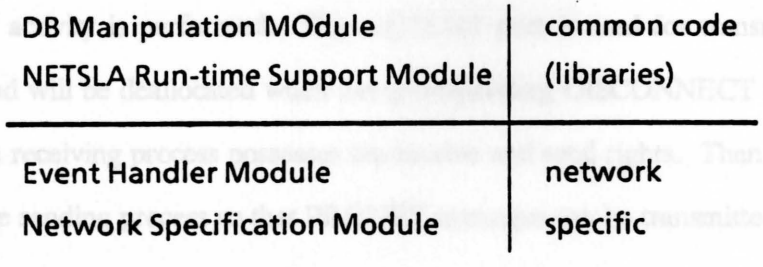

Figure 16 --- NETSLA Object Module Structure

The ALSTEN preprocessor generates a single code module for each process script (see

Appendices F, G, H and I). This module is a simple translation of the process script which makes use of ALSTEN run-time support facilities for performing ALSTEN operations (send, receive, announce, etc ...).

5.3 Processes and Ports

Both ACCENT and PRONET use the notions of "processes" and "ports", but they are at different levels of abstraction. We implement PRONET processes and ports by using ACCENT processes and ports; the details of this mapping are hidden from PRONET programmers.

A PRONET network specification is implemented as an ACCENT process from which any number of ACCENT child processes can be created to represent the PRONET process instances. Since we do not consider the case of "composite processes" in this implementation, the network can be thought of as a tree of two levels with the network specification process as the root. Composite processes can be implemented without much effort later.

An ACCENT port is a protected kernel object and is used for sending and receiving messages. With each port the kernel associates send and receive (and ownership) rights. The process that creates the port possesses all three rights. In this implementation, we use ACCENT ports for two different purposes.

During the execution of the program, an ACCENT port will be allocated when a CONNECT activity is performed. This ACCENT port is used for transmitting the PRONET messages and will be deallocated when the corresponding DISCONNECT activity is performed. Initially, the receiving process possesses the receive and send rights. Then the send right will be passed to the sending process so that PRONET messages can be transmitted through this port.

There are three ACCENT ports allocated to each child process at the process creation time for the purpose of communicating with the root process. One is for the root process to send the child its process ID, the second is for implementing dynamic port connections and the third is

needed to implement port groups.

5.4 The Network Representation

A representation of the logical network described by a PRONET program is maintained in the address space of the root process. This representation reflects the hierarchical structure expressed in the program by maintaining a tree of network class and network instance representations. The logical network representation also contains information about the connectivity among the ports of network instances. The root of this tree is a network class representation, the leaves are network instance representations which contain information about the currently active processes in the logical network.

The codes for manipulating the logical network representation also reside in the address space of the root process. All creations, updates and reads of the entities in the network representation must be performed by calling from the root process an appropriate procedure in the DB manipulation module.

This centralized approach of maintaining the logical network representation lowers the degree of parallelism but reduces the cost of message transmission.

5.5 Event Generation and Handling

Event generation can be either upward or downward. The term "upward event generation" is used to denote the generation of an event in the overseeing network while "downward event generation" is used to denote the generation of an event in a process instance.

Upward event generation occurs when a process instance announces an event using the "announce" statement of PRONET or transmits a message using the "send" statement. Downward event generation occurs when a network specification creates or removes a port instance on a process instance or sends a message to a process instance.

Event handling codes are generated by the NETSLA preprocessor and reside in the address

space of the root process during run-time. Upward event generation is implemented by sending a message to the root process. This message includes all the information relevant to the event generated. This kind of message arrives at a port which belongs to the root process and holds at most four messages at a time due to the limitation of the size of the backlog for an ACCENT port.

Upon receiving a message from a child process, the root process will call an appropriate event handling routine based on the event type and other information included in the message. Event handler executions are performed in a serial fashion. This centralized approach of event handling has the disadvantage of a low degree of parallelism.

5.6 Implementation Limitations

All of the features of ALSTEN and NETSLA have been implemented and tested on a single machine. However, because of continuing problems with Accent, we have never been able to successfully run a program with processes located at more than one site. Thus all of our testing of PRONET and RADAR has involved programs consisting of multiple processes running on a single machine.

Section 6

RESULTS AND CONCLUSIONS

The principal results of our efforts, task by task, were:

Task 1 - implementation of Pronet on our Perq workstations, through use of pre-processors which generate Perq Pascal code.

Task 2 - the development of a passive event recording system for multi-process Pronet programs.

Task 3 - the development of a replay system which produces a high-level graphical simulation of distributed program execution.

Task 4 - integration of the replay system with a single-process debugger.

6.1 Passive Event Recording

The decision to go with a passive monitor rather than an interactive debugger was one major change in our philosophy during the course of this work. This change in approach resulted from consideration of the basic conceptual problem presented by active interaction with a distributed program: the intrusiveness of interaction might substantially change the behavior of the program being debugged. Thus we chose to minimize the intrusiveness of Radar, but there still remains the question of just how non-intrusive our monitor is.

Radar relies on the collection of information during the normal execution of a program. The program runs to completion without any external interference or control. In particular, the data collection is invisible, since it is done inside the ALSTEN message and event primitives.

How much does the extra disk I/O affect the computation in program? This is the Heisenberg Uncertainty Principle as applied to Debugging, sometimes called the "Heisenbug" Principle [ACM83]. We can present no definite answer here. It is expected that the disk

operations actually buffer to memory until the buffer fills up. If this is the case, there should be little extra overhead since the system will suspend a process only when its I/O buffers must be flushed. The main problem is that while one process is suspended, others can continue to run on other machines.

It can be argued that the fact that one process on one machine has been stopped should not affect the other processes on other machines, since the ALSTEN *receive* is defined to be a blocking operation. The other processes may wait longer to complete the *receive* than they otherwise would have to, but ultimately, the same actions should be accomplished.

Suspending one process for disk I/O can affect other processes which continue to run, in a different manner. The ALSTEN receive can specify several alternatives; in effect it can be non-deterministic; receiving from port sets is actually non-deterministic, since the programmer can not know which element of the set will be used. For instance, if there are three processes A,B, and C, and process B was supposed to receive a message from process A, but A was suspended, B could end up receiving a message from process C instead. This should not affect the ultimate semantics of the program, since the *receive* could happen on any specified port. it merely changes the path by which the program arrives at its goal.

One practical problem we encountered in initially using our recording and replay system concerned programs which had to be aborted due to a loop in one or more processes. Simply having Accent abort the processes caused the event files they produced to be discarded. It was necessary to build a special capability into the root process representing the Pronet runtime system to have it terminate the processes in an orderly manner. The basic lesson here is that any passive monitor must make sure that it saves information in a way that will keep that information available under adverse circumstances, because that is just when the information will be needed.

6.2 Graphical Replay of Program Execution

The Perqs have high-resolution, bit-mapped black-and-white displays. This feature gave considerable support to the development of a very effective graphical user interface to our monitoring system. We consider this interface one of the most successful aspects of the project.

In the introduction, we noted that one of the most difficult aspects of designing a tool to support distributed programming debugging was finding a comprehensible way to display information about the program to a user. The graphical replay provided by Radar attacks this problem by providing an abstract view of the behavior of the individual processes. The information provided by the replay involves only activities at the "network" level: process creation and deletion, establishment of connections between ports, message sending and retrieving, etc. None of these activities is exclusively concerned with the internal state of a single process. Thus the replay provides a user with a view of program execution at the "process interaction" level. Only after an erroneous pattern of interaction is identified at that level is it necessary to consider the internal details of any of the processes.

The alternative approach, only possible for a more intrusive debugger active during actual program execution, would be to provide a multi-window display, with each window displaying state information about and allowing interaction with a single process. For programs with more than a few processes, all of the windows wouldn't fit on the screen at the same time. Further, so much detail about individual process activity would be available that it would be virtually impossible to perceive the higher level structure that our replay system makes so apparent. Thus, given our linkage to a single-process debugger, we believe that our more abstract representation of program execution is a superior design choice.

After the program has completed executing, Radar is invoked to provide a graphical "replay" of the execution. Each message or event is stamped with an event number, imposing a partial ordering on events. The monitor then displays events one at a time. The programmer is able to watch the communications traffic amongst the processes. Processes have names in

Pronet, so it is easy for the programmer to see which process is communicating with which other processes.

Radar provides the user with the ability to view the contents of any message currently represented on the screen. Messages are represented on the screen as small boxes. The user places the PERQ's mouse over the message which he wishes to examine. Radar then displays the contents of the chosen message in a formatted fashion. For instance, if the message contained an integer and two floating point numbers, the message would be displayed as an integer and two floating point numbers, not as 10 octal bytes.

Radar also provides the ability to replay a certain number of events which have already happened. This can be done at any point during the display. The user can "rewind the video tape," so to speak. This replay is limited to a fixed maximum number of previous events. The user also has the choice of watching a continuous stream of events (occuring at an interactively settable rate), or single-stepping through events. This prevents information from flowing too fast to be comprehended.

Finally, as a separate utility, the user can name a given process and have all of the messages which were sent to that process selected from the recorded message traffic. This single process may then be run by itself with its messages derived from the stored messages. This feature is designed to facilitate single process debugging under realistic conditions, without having to worry about controlling the rest of the processes of the distributed program.

6.3 Integration with a Single-Process Debugger

Only task 4 went just as it was originally planned. Our program replay system interfaces with the Kraut debugger, which is a standard high-level debugger under Accent. All of the messages to a single process can be collected from the event files. Then that process may be executed again, along with a special driver that simulates the rest of the program. Note that the selected process is actually executed, not simulated; however, the rest of the program is

simulated. The driver simulates the rest of the program by providing messages received by the selected process as they are needed. Thus the process under examination should execute just as it did when the event files were originally collected.

The debugging methodology these mechanisms support works as follows. A program is executed with event files being collected. Its execution is replayed by Radar until the user identifies some particular process as exihibiting inappropriate behavior. Such behavior might be such things as inappropriate or missing message transmission, incorrect contents in a message or any other event visible at the network level. The user than asks for a re-execution of that process and examines its internal state during this replay using Kraut. Whenever the process executes a message receive statement, the Radar driver supplies the appropriate message. Whenever the process sends a message, the driver discards it. This process continues until the cause of the inappropriate behavior can be determined and (hopefully) corrected.

There is only one problem with the above scenario. ALSTEN includes a conditional receive statement which allows the program to go on executing rather than blocking if it tries to receive a message and none is available in its incoming message buffer. Such an unsuccessful attempt to receive is not an externally visible event and thus was not originally recorded in the event files. During re-execution with the special Radar driver and Kraut, messages are always available upon request. Thus a process whose execution originally included unsuccessful conditional receives would not execute in exactly the same way during re-execution. We found it necessary to begin recording unsuccessful conditional receives so that it would be possible to faithfully re-execute processes in this situation.

The ability to examine program execution at the two different levels of abstraction provided by Radar and Kraut provide a very effective technique for tackling the information overload problem of monitoring distributed programs. This idea of replaying a process using stored messages has also appeared recently in a slightly different context: crash recovery in a message based distributed system ([Borg83] and [Powe83]).

6.4 Approaches Taken by Other Researchers

Bates and Wileden [Bate83] take the approach of viewing the 'Behavioral Abstraction' of a program's execution. Basically, the system is viewed 'in terms of its activity rather than its state.' They provide for primitive events such as process creation, page faulty, message transmission, and message reception. Higher level events or 'event abstractions' are built up by designating sequences of primitive events. The debugger then recognizes higher level events and displays these for the programmer, while filtering out other unimportant events.

Gross and Zwaenepoel [Gros83] discuss those aspects of a distributed system both necessary and desirable for easy debugging. They do not present an actual debugging system. The system they propose would support the debugger as a separate process, with kernel facilities which would allow the debugger control over the program's execution, memory and kernel calls. They also make a distinction between the *micro level* of execution, which is the computations made by each process, and the *macro level*, where the overall computation proceeds via messages passed amongst the processes.

Schiffenbauer [Schi81] presents an ambitious project implemented on a network of Xerox Alto minicomputers. He gives an introduction to the problems of distributed debugging and then a discussion of the major issues in designing a debugging facility. The two major issues are *transparency* of the debugger (a practical consideration), and the theoretical consideration of *causality* and logical clocks. He then described the implementation of his debugging facility. One of the more important parts of his work is his implementation of 'logical clocks' and his proof that through the use of logical (rather than actual) clocks, his debugger simulates a valid execution of the distributed program. He further proves that the debugger simulates a probable execution of the program, i.e. that the program behaves the same while being debugged as it probably would have behaved had it been allowed to execute unmonitored.

Curtis and Wittie [Curt82] present their design of a debugging system for parallel programming environments. A parallel programming environment is either a conventional

multiprogramming single processor system, or a 'network computer,' an ensemble of semiautonomous nodes, each with its own memory, peripherals, and communication links. The nodes communicate by passing messages over their links.

The debugging system consists of local event monitors on each node, a central database system, and a user interface. The user interface is based on production rules, which the user expands into sequences of symbols describing what events he wants recorded, what variables saved, and what actions are to be taken upon the occurrence of any given event. This debugger, like that of Bates and Wileden, must be programmed.

Harter [Hart85] proposes a debugging system which includes a standard sequential debugger plus an assertion language, based on temporal logic, to control the automatic monitoring of distributed programs. The system allows a programmer to expand the assertion set interactively. It also includes a graphics interface to display and filter information about program execution.

Our work described below attempts to present a higher level view of message traffic that Schiffenbauer's minimally intrusive view of program execution. We agree with and support the distinction between micro and macro levels of execution suggested by Gross & Zwaenepoel. The interface to our system is simpler than those provided by Harter, Curtis & Wittie and Bates & Wileden, since it need not be programmed.

6.5 Possibilities for Further Research

When a user watches the replay of a program using Radar, he quickly begins to recognize "patterns" consisting of sequences of several events. It would be desirable if Radar had some capability to display execution in terms os such higher-level events. An important question is how such structuring might be made to take place.

6.5.1 A Common Structuring Methodology

One very prevalent and well understood method of imposing structure on incoming information is via lexical analysis and/or parsing techniques. These techniques are well understood, and often easy to use.

Breugege [Breu84] uses Path Expressions, an extension of Regular Expressions. A path expression describes a sequence of events to be looked for, and actions to be executed when that sequence is matched, or not matched. The notation provides good flexibility of description, and would seem to supply a good method for RADAR to use for dealing with its stream of Pronet events.

6.5.2 The Problems with Path Expressions

Path expressions, or more generally, regular expressions and LALR(1) parsing techniques, are a natural first choice for the computer scientist wishing to impose structure on a data stream. Here however, it may be a case of using a useful, but inappropriate, tool for the job.

Why? In this case, the major flaw with these techniques, particularly path expressions, is that they are *predictive*. The debugging programmer must describe what he *expects* the debugger to see, and then what to do. But is a program is bug-ridden, it may never do what the programmer expects it to, even if he is looking for aberrant behavior! So, an interesting and possibly important stream of events could conceivably end up being missed by the debugger, and therefore by the programmer. In sum, a debugger should present a distillation of what happened, not what the programmer expected to happened.

A secondary, although in our view still major, flaw is that this kind of debugger has to be programmed. The user must learn (and remember!) yet another kind of notation, and yet another set of commands. If a debugger is hard to use, it may not get used at all. One of the major RADAR design goals was that it should not have to be programmed.

6.5.3 Using a Data Compression Approach

If regular expressions, LALR(1) grammers, and path expressions are not the answer, what is? For the reasons we are about to present, we feel that an approach based on data compression would be an interesting area for future research.

6.5.4 Why a Data Compression Approach?

When one stops to think about it, it becomes clear that the problem is really one of data compression. We want to replace sequences of low level events with a shorter symbol that represents that sequence. This is exactly what data compression techniques do, although usually they are just acting upon simple byte streams.

The shorter symbol can be given a name that describes the sequence in a "higher level" fashion. For example, replace the sequence "find Fred's number in the phone book", "lift the phone handset", "listen for dial tone", and "dial the number", with, "call Fred".

This approach has several advantages. First, it is not predictive, looking for one thing and missing another. Instead, it is empirical, condensing what is there. It represents *all* the event sequences as they happened. Second, it fits in very well with RADAR's current passive, post-mortem approach to program monitoring. Third, the machine does the work of detecting event sequences and condensing them, not the programmer. There are no new notations or commands to learn.

6.5.5 Possible Implementation Plan

There are numerous data compression techniques. A recently developed, and very powerful technique is the Adaptive Lempel-Ziv Compression described in [Welc84]. On "normal" files of English text it often achieves compression of 50% or greater. One of its strongest points is that it tends to compress the longest possible sequence into a single code.

RADAR gives unique identifies (numbers) to each kind of Pronet message. A single RADAR event would consist of the sending process id, the receiving process id, and the

message type. These events should be representable as unique integers of at most two bytes. A first (conceptual) pass over the recorded data would build a table of event triples (sender, destination, message type) and their corresponding integers.

Next, the second pass performs Adaptive Lempel-Ziv compression on the integer stream, saving the compressed output. As part of the compression algorithm, the Lempel-Ziv method builds a table of codes and what each code represents.

After compression, this table is presented to the user. RADAR presents each sequence and asks for a high level name for that sequence ("call Fred").

Once that is done, the compressed data is then "decompressed"; but not back into an integer stream. Instead, as each higher level code is recognized, the corresponding high level event is displayed graphically on the screen.

6.5.6 Problems with This Approach

The method outlined above is not without its problems. In particular, the ordering of events that RADAR imposes is only a partial ordering. Events are sometimes depicted on the screen in an order different from that in which they actually occurred. Only related events are guaranteed to be ordered. This is because RADAR currently works by merging multiple event streams into a single event stream for display. The problem with this approach is that nonrelated events end up being interleaved with each other. This could conceivably affect the data compression algorithm. Non-related events could be compressed together, i.e. treated as related! (instead of being compressed with their related events).

A major thrust of any future research would be to see if a data compression approach is feasible, and to learn whether or not non related interleaved events would detrimentally affect the data compression, or if the nature of the algorithm is such that it would not matter. Another goal would be to see if some approach could be found to work directly from the original multiple data streams, instead of from the merged single data stream.

As an alternative, some sort of knowledge-based pattern recognition approach might be tried. The data compression approach is essentially syntactic; a pattern recognition mechanism could conceivably work better by making use of information in messages or about network interconnections. Relative computational demands of these two approaches are an obvious tradeoff.

6.6 Conclusions

Finally, we restate our principal conclusions:

- Graphical display of information is an excellent technique for providing information about the execution of a distributed program.

- Passive monitoring and simulated replaying is a successful approach for minimizing the impact of the monitor on the execution of the program under examination.

- Multi-level tools are required to deal effectively with all aspects of distributed program debugging.

We must state that these conclusions are based on relatively little experience with Radar. Because Accent has not been as stable as we had anticipated, there is really no user community on the Perqs other than the people who have worked on the Radar project. A much more extensive evaluation of our tools would be highly desirable.

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APPENDIX A

The LL(1) Grammar of NETSLA

Grammar productions with selection sets added:

```
Prod #    Production

  1    network_spec  =   net_head   const_pt type_pt port_decl_pt
         evnt_decl_pt proc_decl_10     evnt_clse_10
         init_clse0 end identifier
         %network  ;

  2    net_head  = network   identifier ;
         %network  ;

  3    proc_decl_10 =
         %arrive end enter initial leave when  ;

  4    proc_decl_10  = process_decl proc_decl_11
         %process  ;

  5    proc_decl_11  =
         %arrive end enter initial leave when  ;

  6    proc_decl_11  = process_decl proc_decl_11
         %process  ;

  7    evnt_clse_10  =
         %end initial  ;

  8    evnt_clse_10  = event_clause evnt_clse_11
         %arrive enter leave when  ;

  9    evnt_clse_11  =
         %end initial  ;

 10    evnt_clse_11  = event_clause evnt_clse_11
         %arrive enter leave when  ;

 11    init_clse0  =
         %end  ;

 12    init_clse0  = initial activity_lst
         %initial  ;

 13    const_pt  =
         %arrive end enter event initial leave
           port process type when  ;

 14    const_pt  = const   con_def_list
```

```
      %const  ;

15    con_def_list  = const_def next_con_def
        %identifier  ;

16    next_con_def  =
        %arrive end enter event initial leave
          port process type when  ;

17    next_con_def  = const_def next_con_def
        %identifier  ;

18    const_def  = new_const_id =   constant ;
        %identifier  ;

19    new_const_id  =   identifier
        %identifier  ;

20    constant  = signed_const
        %+ -  ;

21    constant  = unsigned_con
        %char_const identifier int_const real_const string_const  ;

22    signed_const  = sign after_sign
        %+ -  ;

23    after_sign  =   real_const
        %real_const  ;

24    after_sign  =   int_const
        %int_const  ;

25    after_sign  =   const_id
        %identifier  ;

26    unsigned_con  =   identifier
        %identifier  ;

27    unsigned_con  =   int_const
        %int_const  ;

28    unsigned_con  =   char_const
        %char_const  ;

29    unsigned_con  =   string_const
        %string_const  ;

30    unsigned_con  =   real_const
        %real_const  ;

31    scalar_const  =   identifier
        %identifier  ;
```

```
32   scalar_const  = non_id_s_con
       %+ - char_const int_const  ;

33   non_id_s_con  = sign id_or_int
       %+ - ;

34   non_id_s_con  =   int_const
       %int_const  ;

35   non_id_s_con  =   char_const
       %char_const  ;

36   id_or_int  =   const_id
       %identifier  ;

37   id_or_int  =   int_const
       %int_const  ;

38   const_id  =   identifier
       %identifier  ;

39   type_pt  =
       %arrive end enter event initial leave
         port process when  ;

40   type_pt  = type   typ_def_list
       %type  ;

41   typ_def_list  = type_def next_typ_def
       %identifier  ;

42   next_typ_def  =
       %arrive end enter event initial leave
         port process when  ;

43   next_typ_def  = type_def next_typ_def
       %identifier  ;

44   type_def  = new_type_id =   types ;
       %identifier  ;

45   new_type_id  =   identifier
       %identifier  ;

46   types  = type_case1
       %identifier  ;

47   types  = type_case2
       %( + - array char_const int_const
         packed record set  ;

48   type_case1  =   identifier type_tail
```

```
    %identifier  ;

49  type_tail  =
      %) ; case end  ;

50  type_tail  = ..   scalar_const
      %..  ;

51  type_case2  = non_id_s_con ..   scalar_const
      %+ - char_const int_const  ;

52  type_case2  = struct_type
      %array packed record set  ;

53  type_case2  = (   enu_id_list )
      %(  ;

54  non_id_type  = non_id_simp
      %( + - char_const identifier int_const  ;

55  non_id_type  = struct_type
      %array packed record set  ;

56  simple_type  =   type_id simp_ty_tail
      %identifier  ;

57  simple_type  = (   enu_id_list )
      %(  ;

58  simple_type  = non_id_s_con ..   scalar_const
      %+ - char_const int_const  ;

59  simp_ty_tail  =
      %) , ; ] case end  ;

60  simp_ty_tail  = ..   scalar_const
      %..  ;

61  non_id_simp  = (   enu_id_list )
      %(  ;

62  non_id_simp  = subrange_con ..   scalar_const
      %+ - char_const identifier int_const  ;

63  pt_class_nam  = identifier
      %identifier  ;

64  enu_id_list  =   identifier enumer_tail
      %identifier  ;

65  enumer_tail  =
      %)  ;
```

```
66   enumer_tail  = ,     identifier enumer_tail
       %,  ;

67   subrange_con  =   identifier
       %identifier  ;

68   subrange_con  = non_id_s_con
       %+ - char_const int_const  ;

69   type_id  =   identifier
       %identifier  ;

70   struct_type  = pack_prefix unpacked
       %array packed record set  ;

71   pack_prefix  = packed
       %packed  ;

72   pack_prefix  =
       %array record set  ;

73   unpacked  = array [   indx_ty_list ] of
          types
       %array  ;

74   unpacked  = record_head field_list end
       %record  ;

75   unpacked  = set of   simple_type
       %set  ;

76   record_head  = record
       %record  ;

77   indx_ty_list  = simple_type index_tail
       %( + - char_const identifier int_const  ;

78   index_tail  =
       %]  ;

79   index_tail  = ,   simple_type index_tail
       %,  ;

80   field_list  = rec_sec_list with_variant
       %) ; case end identifier  ;

81   rec_sec_list  = rec_section rec_sec_tail
       %) ; case end identifier  ;

82   rec_sec_tail  =
       %) case end  ;

83   rec_sec_tail  = ;   rec_section rec_sec_tail
```

```
      %;  ;

84    rec_section  = fieldid_list :   types
        %identifier  ;

85    rec_section  =
        %) ; case end  ;

86    fieldid_list  =   identifier field_id_end
        %identifier  ;

87    with_variant  =
        %) end  ;

88    with_variant  = variant_pref variant_list
        %case  ;

89    field_id_end  =
        %: ;

90    field_id_end  = ,     identifier field_id_end
        %, ;

91    variant_pref  = case   tag_type_ids of
        %case  ;

92    tag_type_ids  = tagfield_id tag_typ_tail
        %identifier ;

93    tag_typ_tail  =
        %of  ;

94    tag_typ_tail  = :   scalar_ty_id
        %:  ;

95    tagfield_id  =   identifier
        %identifier  ;

96    scalar_ty_id  =   identifier
        %identifier  ;

97    variant_list  = variant variant_tail
        %) + - ; char_const end
          identifier int_const  ;

98    variant  = case_l_list : (   field_head field_list
        )
        %+ - char_const identifier int_const  ;

99    variant  =
        %) ; end  ;

100   field_head  =
```

```
        %) ; case identifier  ;

101     variant_tail  =
          %) end  ;

102     variant_tail  = ;   variant variant_tail
          %;  ;

103     case_l_list  = scalar_const caselabelend
          %+ - char_const identifier int_const  ;

104     caselabelend  =
          %:  ;

105     caselabelend  = ,   scalar_const caselabelend
          %,  ;

106     port_decl_pt  =
          %arrive end enter event initial leave
            process when  ;

107     port_decl_pt  = pt_decl_list
          %port  ;

108     pt_decl_list  = port_decl pt_decl_tail
          %port  ;

109     port_decl  = port_head pt_dir_mtype
          %port  ;

110     pt_dir_mtype  = in type_id   ;
          %in  ;

111     pt_dir_mtype  = out type_id   ;
          %out  ;

112     pt_dir_mtype  = port_group ;
          %(  ;

113     pt_decl_tail  =
          %arrive end enter event initial leave
            process when  ;

114     pt_decl_tail  = port_decl pt_decl_tail
          %port  ;

115     port_head  = port port_tail
          %port  ;

116     port_tail  =   identifier
          %identifier  ;

117     port_tail  = set   identifier
```

```
        %set  ;
118     port_group  = ( sbptdecllist )
        %(  ;
119     sbptdecllist  = subport_decl next_subport
        %identifier  ;
120     subport_decl  = subport_name direct_type
        %identifier  ;
121     direct_type  = in type_id
        %in  ;
122     direct_type  = out type_id
        %out  ;
123     subport_name  =  identifier
        %identifier  ;
124     next_subport  =
        %)  ;
125     next_subport  = ; subport_decl next_subport
        %; ;
126     process_decl  = process_head attri_decls0 port_decl_pt evnt_decl_pt
          end identifier
        %process  ;
127     process_head  = process class   identifier
        %process  ;
128     attri_decls0  =
        %end event port  ;
129     attri_decls0  = attri_head attri_sec_ls attri_tail
        %attributes  ;
130     attri_head  = attributes
        %attributes  ;
131     attri_tail  = end attributes
        %end  ;
132     attri_sec_ls  = attri_sec attri_secl
        %; end identifier  ;
133     attri_secl  =
        %end  ;
134     attri_secl  = ; attri_sec
        %; ;
```

```
135   attri_sec  = attri_id_ls : types
        %identifier  ;

136   attri_sec  =
        %; end  ;

137   attri_id_ls  = identifier attri_id_ls1
        %identifier  ;

138   attri_id_ls1  =
        %:  ;

139   attri_id_ls1  = , identifier
        %,  ;

140   evnt_decl_pt  =
        %arrive end enter initial leave process
          when  ;

141   evnt_decl_pt  = event_decl next_event
        %event  ;

142   next_event  =
        %arrive end enter initial leave process
          when  ;

143   next_event  = event_decl next_event
        %event  ;

144   event_decl  = event identifier about_ptnm0 ;
        %event  ;

145   about_ptnm0  =
        %;  ;

146   about_ptnm0  = about identifier
        %about  ;

147   event_clause  = arriv_clause
        %arrive  ;

148   event_clause  = enter_clause
        %enter  ;

149   event_clause  = leave_clause
        %leave  ;

150   event_clause  = when_clause
        %when  ;

151   arriv_clause  = arrive_head activity_lst close end arrive
        %arrive  ;
```

```
152   arrive_head  = arrive open arrive_bind do
        %arrive  ;

153   arrive_bind  = message_id0 on arrive_port from_proces0
        %identifier on  ;

154   message_id0  =
        %on  ;

155   message_id0  = identifier
        %identifier  ;

156   arrive_port  = identifier arrive_port1
        %identifier  ;

157   arrive_port1  =
        %do from  ;

158   arrive_port1  = : identifier
        %:  ;

159   arrive_port1  = of port_bind
        %of  ;

160   port_bind  = identifier port_bind1
        %identifier  ;

161   port_bind1  =
        %do from  ;

162   port_bind1  = : identifier
        %:  ;

163   from_proces0  =
        %do  ;

164   from_proces0  = from process_bind
        %from  ;

165   process_bind  = identifier proces_bind1
        %identifier  ;

166   proces_bind1  =
        %about do  ;

167   proces_bind1  = : identifier
        %:  ;

168   enter_clause  = enter_head activity_lst close end enter
        %enter  ;

169   enter_head  = enter open port_bind do
```

```
        %enter  ;
170     leave_clause  = leave_head activity_lst close end leave
        %leave  ;
171     leave_head  = leave open port_bind do
        %leave  ;
172     when_clause  = when_head activity_lst close end when
        %when  ;
173     when_head  = when open identifier announced by process_bind
          about_part0 do
        %when  ;
174     about_part0  =
        %do  ;
175     about_part0  = about port_bind
        %about  ;
176     activity_lst  = activity activities
        %) ; announce case connect construct
          create disconnect else end find identifier
          range remove send terminate  ;
177     activities  =
        %) else end  ;
178     activities  = ; activity activities
        %;  ;
179     activity  =
        %) ; else end  ;
180     activity  = simple_act
        %announce connect construct create disconnect identifier
          remove send terminate  ;
181     activity  = control_act
        %case find range  ;
182     simple_act  = creation
        %create  ;
183     simple_act  = termination
        %terminate  ;
184     simple_act  = removal
        %remove  ;
185     simple_act  = connection
        %connect  ;
```

```
186   simple_act  = disconnecton
        %disconnect  ;

187   simple_act  = msg_transfer
        %send  ;

188   simple_act  = construction
        %construct  ;

189   simple_act  = attri_assign
        %identifier  ;

190   simple_act  = event_trans
        %announce  ;

191   simple_bind  = object_id : identifier simple_bind1
        %identifier  ;

192   object_id  = identifier
        %identifier  ;

193   simple_bind1  =
        %do where  ;

194   simple_bind1  = on proc_denoter
        %on  ;

195   obj_denoter  = lhs
        %identifier  ;

196   port_denoter  = obj_denoter
        %identifier  ;

197   proc_denoter  = identifier
        %identifier  ;

198   creation  = create create_tail
        %create  ;

199   create_tail  =  identifier :  identifier create_tail1
        %identifier  ;

200   create_tail1  =
        %) ; else end  ;

201   create_tail1  = on  proc_denoter
        %on  ;

202   termination  = terminate proc_denoter
        %terminate  ;

203   removal  = remove obj_denoter
```

```
        %remove  ;

204     connection  =   connect port_denoter   to port_denoter
        %connect  ;

205     disconnecton  = disconnect port_denoter from_port0
        %disconnect  ;

206     from_port0  =
        %) ; else end  ;

207     from_port0  = from port_denoter
        %from  ;

208     msg_transfer  = send expr0 to port_denoter
        %send  ;

209     expr0  =
        %to  ;

210     expr0  = expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

211     construction  = construct_hd [ field_as_lst ]
        %construct  ;

212     construct_hd  = construct object_id : identifier
        %construct  ;

213     field_as_lst  = field_assign fd_assign1
        %identifier  ;

214     fd_assign1  =
        %]  ;

215     fd_assign1  = ; field_assign
        %;  ;

216     field_assign  = lhs := expr
        %identifier  ;

217     attri_assign  = lhs := expr
        %identifier  ;

218     event_trans  = announce event_id about_port0
        %announce  ;

219     about_port0  =
        %) ; else end  ;

220     about_port0  = about port_denoter
```

```
        %about  ;

221     control_act  = alternation
          %case  ;

222     control_act  = selection
          %find  ;

223     control_act  = iteration
          %range  ;

224     alternation  = alternate_hd case_list else_part0 end case
          %case  ;

225     alternate_hd  = case expr of
          %case  ;

226     case_list  = case_element case_list1
          %+ - char_const identifier int_const  ;

227     case_list1  =
          %else end  ;

228     case_list1  = case_element case_list1
          %+ - char_const identifier int_const  ;

229     case_element  = const_list : ( open activity_lst close
          )
          %+ - char_const identifier int_const  ;

230     const_list  = scalar_const const_list1
          %+ - char_const identifier int_const  ;

231     const_list1  =
          %:  ;

232     const_list1  = , scalar_const
          %,  ;

233     select_crite  = simple_bind where_claus0
          %identifier  ;

234     selection  = find_head do activity_lst close else_part0 end
          find
          %find  ;

235     find_head  = find open object_id : find_head1
          %find  ;

236     find_head1  = string
          %string  ;

237     find_head1  = identifier simple_bind1 where_claus0
```

```
        %identifier  ;

238     iteration  = range open select_crite do activity_lst close
           else_part0 end range
          %range  ;

239     else_part0  =
          %end  ;

240     else_part0  = else open activity_lst close
          %else  ;

241     where_claus0  =
          %do  ;

242     where_claus0  = where expr
          %where  ;

243     open  =
          %) ; announce case connect construct
            create disconnect end find identifier on
            range remove send terminate  ;

244     close  =
          %) else end  ;

245     id_list  =   identifier id_list_tail
          %identifier  ;

246     id_list_tail  =
          % ;

247     id_list_tail  = ,     identifier id_list_tail
          %,  ;

248     actual_parms  = (   actual_parm next_a_parm
          %(  ;

249     actual_parm  = parm_expr field_width
          %( + - [ char_const identifier
            int_const not real_const string_const  ;

250     next_a_parm  =
          %)  ;

251     next_a_parm  = ,   actual_parm next_a_parm
          %,  ;

252     lhs  =   identifier rec_ary_ptr
          %identifier  ;

253     vars  =   identifier rec_ary_ptr
          %identifier  ;
```

```
254   rec_ary_ptr  =
        %) * + , - ..
          / : := ; = ]
          and div do else end from
          in mod noneqrelop of or to  ;

255   rec_ary_ptr  = .   identifier rec_ary_ptr
        %.  ;

256   rec_ary_ptr  = [   index_list ]   rec_ary_ptr
        %[  ;

257   index_list  = index next_index
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

258   next_index  = ,   index
        %,  ;

259   next_index  =
        %]  ;

260   index  = expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

261   expr  = parm_expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

262   parm_expr  = simple_expr parm_exp_end
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

263   parm_exp_end  =
        %) , .. : ; ]
          do else end of to  ;

264   parm_exp_end  = rel_op simple_expr
        %= in noneqrelop  ;

265   rel_expr  = simple_expr rel_op simple_expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

266   rel_op  = =
        %=  ;

267   rel_op  = in
        %in  ;

268   rel_op  =   noneqrelop
```

```
        %noneqrelop  ;

269     simple_expr  =   char_const add_term
          %char_const  ;

270     simple_expr  =   string_const add_term
          %string_const  ;

271     simple_expr  = sign term add_term
          %+ -  ;

272     simple_expr  = term add_term
          %( [ identifier int_const not real_const  ;

273     add_term  =
          %) , .. : ; =
            ] do else end in noneqrelop
            of to  ;

274     add_term  = add_op term add_term
          %+ - or  ;

275     term  = factor mult_factor
          %( [ identifier int_const not real_const  ;

276     mult_factor  =
          %) + , - .. :
            ; = ] do else end
            in noneqrelop of or to  ;

277     mult_factor  = mult_op factor mult_factor
          %* / and div mod  ;

278     factor  =   identifier var_funccall
          %identifier  ;

279     factor  =   real_const
          %real_const  ;

280     factor  =   int_const
          %int_const  ;

281     factor  = (   expr )
          %(  ;

282     factor  = [   elem_list ]
          %[  ;

283     factor  = not   factor
          %not  ;

284     var_funccall  = rec_ary_ptr
          %) * + , - .
```

```
        .. / : ; = [
        ] and div do else end
        in mod noneqrelop of or to  ;

285     var_funccall  = actual_parms )
          %(  ;

286     add_op  = sign
          %+ -  ;

287     add_op  = or
          %or  ;

288     mult_op  = *
          %*  ;

289     mult_op  = /
          %/  ;

290     mult_op  = div
          %div  ;

291     mult_op  = and
          %and  ;

292     mult_op  = mod
          %mod  ;

293     variable  = identifier rec_ary_ptr
          %identifier  ;

294     field_width  =
          %) , ;

295     field_width  = :   expr more_field
          %: ;

296     more_field  =
          %) , ;

297     more_field  = :   expr
          %:  ;

298     elem_list  =
          %]  ;

299     elem_list  = elem next_elem
          %( + - [ char_const identifier
            int_const not real_const string_const  ;

300     elem  = expr elem_tail
          %( + - [ char_const identifier
            int_const not real_const string_const  ;
```

```
301   next_elem  =
        %]  ;

302   next_elem  = ,   elem next_elem
        %,  ;

303   elem_tail  =
        %,  ]  ;

304   elem_tail  = ..   expr
        %..  ;

305   proc_id  =   identifier
        %identifier  ;

306   rec_var_list  =   variable next_rec_var
        %identifier  ;

307   next_rec_var  =
        %  ;

308   next_rec_var  = ,     variable next_rec_var
        %,  ;

309   subport  =
        %  ;

310   subport  = . subport_id
        %.  ;

311   pt_class_id  = identifier
        %identifier  ;

312   subport_id  = identifier
        %identifier  ;

313   expression0  =
        %  ;

314   expression0  =     expr
        %( + - [ char_const identifier
          int_const not real_const string_const  ;

315   event_id  =   identifier
        %identifier  ;

316   sign  = +
        %+  ;

317   sign  = -
        %-  ;
```

APPENDIX B

The LL(1) Grammar of ALSTEN

Grammar productions with selection sets added:

```
Prod #    Production

  1    comp_unit  =   prog_head prog
         %@ process  ;

  2    prog_head  = process script   prog_id ;
         %process  ;

  3    prog_id  =   identifier
         %identifier  ;

  4    prog  = port_decl_pt label_pt const_pt type_pt evnt_decl_pt var_pt
           proc_fct_pt   stmt_pt   .
         %begin const event function label port
           procedure type var  ;

  5    block  = label_pt const_pt type_pt var_pt proc_fct_pt stmt_pt
         %begin const function label procedure type
           var  ;

  6    label_pt  = label   label_list ;
         %label  ;

  7    label_pt  =
         %begin const event function procedure type
           var  ;

  8    label_list  = labels next_label
         %identifier int_const  ;

  9    next_label  =
         %;  ;

 10    next_label  = ,   labels next_label
         %,  ;

 11    labels  =   int_const
         %int_const  ;

 12    labels  =   identifier
         %identifier  ;

 13    const_pt  =
         %begin event function procedure type var  ;
```

```
14    const_pt  = const   con_def_list
        %const  ;

15    con_def_list  = const_def next_con_def
        %identifier  ;

16    next_con_def  =
        %begin event function procedure type var  ;

17    next_con_def  = const_def next_con_def
        %identifier  ;

18    const_def  = new_const_id =   constant ;
        %identifier  ;

19    new_const_id  =   identifier
        %identifier  ;

20    constant  = signed_const
        %+ -  ;

21    constant  = unsigned_con
        %char_const identifier int_const real_const string_const  ;

22    signed_const  = sign after_sign
        %+ -  ;

23    after_sign  =   real_const
        %real_const  ;

24    after_sign  =   int_const
        %int_const  ;

25    after_sign  =   const_id
        %identifier  ;

26    unsigned_con  =   identifier
        %identifier  ;

27    unsigned_con  =   int_const
        %int_const  ;

28    unsigned_con  =   char_const
        %char_const  ;

29    unsigned_con  =   string_const
        %string_const  ;

30    unsigned_con  =   real_const
        %real_const  ;

31    scalar_const  =   identifier
        %identifier  ;
```

```
32    scalar_const  = non_id_s_con
        %+ - char_const int_const  ;

33    non_id_s_con  = sign id_or_int
        %+ -  ;

34    non_id_s_con  =   int_const
        %int_const  ;

35    non_id_s_con  =   char_const
        %char_const  ;

36    id_or_int  =   const_id
        %identifier  ;

37    id_or_int  =   int_const
        %int_const  ;

38    const_id  =   identifier
        %identifier  ;

39    type_pt  =
        %begin event function procedure var  ;

40    type_pt  = type   typ_def_list
        %type  ;

41    typ_def_list  = type_def next_typ_def
        %identifier  ;

42    next_typ_def  =
        %begin event function procedure var  ;

43    next_typ_def  = type_def next_typ_def
        %identifier  ;

44    type_def  = new_type_id =   types ;
        %identifier  ;

45    new_type_id  =   identifier
        %identifier  ;

46    types  = type_case1
        %identifier  ;

47    types  = type_case2
        %( + - array char_const int_const
          packed ptr record set tag  ;

48    type_case1  =   identifier type_tail
        %identifier  ;
```

```
49    type_tail  =
        %) ; case end  ;

50    type_tail  = ..   scalar_const
        %..  ;

51    type_case2  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

52    type_case2  = struct_type
        %array packed record set  ;

53    type_case2  = ptr     identifier
        %ptr  ;

54    type_case2  = (   enu_id_list )
        %(  ;

55    type_case2  = tag of pt_class_nam
        %tag  ;

56    non_id_type  = non_id_simp
        %( + - char_const identifier int_const
          tag  ;

57    non_id_type  = struct_type
        %array packed record set  ;

58    non_id_type  = ptr     identifier
        %ptr  ;

59    simple_type  =   type_id simp_ty_tail
        %identifier  ;

60    simple_type  = (   enu_id_list )
        %(  ;

61    simple_type  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

62    simple_type  = tag of pt_class_nam
        %tag  ;

63    simp_ty_tail  =
        %) , ; ] case end  ;

64    simp_ty_tail  = ..   scalar_const
        %..  ;

65    non_id_simp  = (   enu_id_list )
        %(  ;

66    non_id_simp  = subrange_con ..   scalar_const
```

```
        %+ - char_const identifier int_const  ;

67      non_id_simp  = tag of pt_class_nam
          %tag  ;

68      pt_class_nam  = identifier
          %identifier  ;

69      enu_id_list  =   identifier enumer_tail
          %identifier  ;

70      enumer_tail  =
          %)  ;

71      enumer_tail  = ,     identifier enumer_tail
          %,  ;

72      subrange_con  =   identifier
          %identifier  ;

73      subrange_con  = non_id_s_con
          %+ - char_const int_const  ;

74      type_id  =   identifier
          %identifier  ;

75      struct_type  = pack_prefix unpacked
          %array packed record set  ;

76      pack_prefix  = packed
          %packed  ;

77      pack_prefix  =
          %array record set  ;

78      unpacked  = array [   indx_ty_list ] of
            types
          %array  ;

79      unpacked  = record_head field_list end
          %record  ;

80      unpacked  = set of   simple_type
          %set  ;

81      record_head  = record
          %record  ;

82      indx_ty_list  = simple_type index_tail
          %( + - char_const identifier int_const
            tag  ;

83      index_tail  =
```

```
      %] ;

84    index_tail  = ,   simple_type index_tail
      %, ;

85    field_list  = rec_sec_list with_variant
      %) ; case end identifier  ;

86    rec_sec_list  = rec_section rec_sec_tail
      %) ; case end identifier  ;

87    rec_sec_tail  =
      %) case end  ;

88    rec_sec_tail  = ;   rec_section rec_sec_tail
      %; ;

89    rec_section  = fieldid_list :   types
      %identifier  ;

90    rec_section  =
      %) ; case end  ;

91    fieldid_list  =  identifier field_id_end
      %identifier ;

92    with_variant  =
      %) end  ;

93    with_variant  = variant_pref variant_list
      %case  ;

94    field_id_end  =
      %: ;

95    field_id_end  = ,     identifier field_id_end
      %, ;

96    variant_pref  = case   tag_type_ids of
      %case  ;

97    tag_type_ids  = tagfield_id tag_typ_tail
      %identifier ;

98    tag_typ_tail  =
      %of  ;

99    tag_typ_tail  = :   scalar_ty_id
      %: ;

100   tagfield_id  =   identifier
      %identifier  ;
```

```
101   scalar_ty_id  =   identifier
        %identifier  ;

102   variant_list  = variant variant_tail
        %) + - ; char_const end
          identifier int_const  ;

103   variant  = case_l_list : (   field_head field_list
        )
        %+ - char_const identifier int_const  ;

104   variant  =
        %) ; end  ;

105   field_head  =
        %) ; case identifier  ;

106   variant_tail  =
        %) end  ;

107   variant_tail  = ;   variant variant_tail
        %;  ;

108   case_l_list  = scalar_const caselabelend
        %+ - char_const identifier int_const  ;

109   caselabelend  =
        %:  ;

110   caselabelend  = ,   scalar_const caselabelend
        %,  ;

111   port_decl_pt  =
        %begin const event function label procedure
          type var  ;

112   port_decl_pt  = pt_decl_list
        %port  ;

113   pt_decl_list  = port_decl pt_decl_tail
        %port  ;

114   port_decl  = port_head pt_dir_mtype
        %port  ;

115   pt_dir_mtype  = in type_id   ;
        %in  ;

116   pt_dir_mtype  = out type_id   ;
        %out  ;

117   pt_dir_mtype  = port_group ;
        %(  ;
```

```
118   pt_decl_tail  =
        %begin const event function label procedure
          type var  ;

119   pt_decl_tail  = port_decl pt_decl_tail
        %port  ;

120   port_head  = port port_tail
        %port  ;

121   port_tail  =   identifier
        %identifier  ;

122   port_tail  = set   identifier
        %set  ;

123   port_group  = ( sbptdecllist )
        %(  ;

124   sbptdecllist  = subport_decl next_subport
        %identifier  ;

125   subport_decl  = subport_name direct_type
        %identifier  ;

126   direct_type  = in type_id
        %in  ;

127   direct_type  = out type_id
        %out  ;

128   subport_name  =   identifier
        %identifier  ;

129   next_subport  =
        %)  ;

130   next_subport  = ; subport_decl next_subport
        %;  ;

131   evnt_decl_pt  =
        %begin function procedure var  ;

132   evnt_decl_pt  = event_decl next_event
        %event  ;

133   next_event  =
        %begin function procedure var  ;

134   next_event  = event_decl next_event
        %event  ;
```

```
135   event_decl  = event event_id about_part0 ;
        %event  ;
136   about_part0  =
        %;  ;
137   about_part0  = about pt_class_id
        %about  ;
138   var_pt  =
        %begin function procedure  ;
139   var_pt  =   var   var_decl_lst
        %var  ;
140   var_decl_lst  = var_decl var_decl_end
        %identifier  ;
141   var_decl_end  =
        %begin function procedure  ;
142   var_decl_end  = var_decl var_decl_end
        %identifier  ;
143   var_decl  = id_list :   types ;
        %identifier  ;
144   proc_fct_pt  =
        %begin  ;
145   proc_fct_pt  = pf_decl_list
        %function procedure  ;
146   pf_decl_list  = pf_decl pf_decl_tail
        %function procedure  ;
147   pf_decl_tail  =
        %begin  ;
148   pf_decl_tail  = pf_decl pf_decl_tail
        %function procedure  ;
149   pf_decl  = pf_head ;  blkorfwd
        %function procedure  ;
150   blkorfwd  = forward  ;
        %forward  ;
151   blkorfwd  = block ;
        %begin const function label procedure type
          var  ;
152   proc_start  =
```

```
        %( : ;  ;

153     pf_head  = procedure   proc_id_dec proc_start p_head_tail
          %procedure  ;

154     pf_head  = function   func_id_dec proc_start f_head_tail
          %function  ;

155     p_head_tail  =
          %;  ;

156     p_head_tail  = (   fpsl )
          %(  ;

157     f_head_tail  =
          %;  ;

158     f_head_tail  = :   parm_type_id
          %:  ;

159     f_head_tail  = (   fpsl ) :
            parm_type_id
          %(  ;

160     proc_id_dec  =   identifier
          %identifier  ;

161     func_id_dec  =   identifier
          %identifier  ;

162     fpsl  = f_parm_sect fpsl_tail
          %identifier var  ;

163     fpsl_tail  =
          %)  ;

164     fpsl_tail  = ;   f_parm_sect fpsl_tail
          %;  ;

165     f_parm_sect  = parm_group
          %identifier  ;

166     f_parm_sect  = var   parm_group
          %var  ;

167     parm_type_id  =   type_id parm_ty_tail
          %identifier  ;

168     parm_type_id  = struct_type
          %array packed record set  ;

169     parm_type_id  = (   enu_id_list )
          %(  ;
```

```
170   parm_type_id  = tag of pt_class_nam
        %tag  ;

171   parm_type_id  = non_id_s_con ..   scalar_const
        %+ - char_const int_const  ;

172   parm_type_id  = ptr     identifier
        %ptr  ;

173   parm_ty_tail  =
        %) ;  ;

174   parm_ty_tail  = ..   scalar_const
        %..  ;

175   parm_group  = id_list :   parm_type_id
        %identifier  ;

176   id_list  =  identifier id_list_tail
        %identifier  ;

177   id_list_tail  =
        %:  ;

178   id_list_tail  = ,     identifier id_list_tail
        %,  ;

179   body_start  =
        %announce begin case for goto identifier
          if int_const receive repeat send when
          while with  ;

180   stmt_pt  = begin     body_start stmt_list end

        %begin  ;

181   stmt  = label_prefix unlabeled_st
        %announce begin case for goto if
          int_const receive repeat send when while
          with  ;

182   stmt  = stmt_with_id
        %identifier  ;

183   stmt_with_id  =   identifier asgn_cal_lab
        %identifier  ;

184   unlabeled_st  = begin   stmt_list end
        %begin  ;

185   unlabeled_st  = goto   labels
        %goto  ;
```

```
186   unlabeled_st  = case_head case_list otherwise_pt end
        %case  ;

187   unlabeled_st  = repeat   stmt_list until   expr
        %repeat  ;

188   unlabeled_st  = if_stmt
        %if  ;

189   unlabeled_st  = for_stmt
        %for  ;

190   unlabeled_st  = while_stmt
        %while  ;

191   unlabeled_st  = with_stmt
        %with  ;

192   unlabeled_st  = receive_stmt
        %receive when  ;

193   unlabeled_st  = send_stmt
        %send  ;

194   unlabeled_st  = announcestmt
        %announce  ;

195   asgn_cal_lab  = rec_ary_ptr :=   expr
        %. := [ ptr  ;

196   asgn_cal_lab  = actual_parms )
        %(  ;

197   asgn_cal_lab  = :   unlabeled_st
        %:  ;

198   asgn_cal_lab  =
        %; else end otherwise until  ;

199   actual_parms  = (   actual_parm next_a_parm
        %(  ;

200   actual_parm  = parm_expr field_width
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

201   next_a_parm  =
        %)  ;

202   next_a_parm  = ,   actual_parm next_a_parm
        %,  ;
```

```
203   if_stmt  = if_head stmt if_tail
        %if  ;

204   if_tail  = else   stmt
        %else  ;

205   if_tail  =
        %; end otherwise until  ;

206   for_stmt  = for_head do   stmt
        %for  ;

207   while_stmt  = while_head stmt
        %while  ;

208   with_stmt  = with_head stmt
        %with  ;

209   if_head  = if   expr then
        %if  ;

210   while_head  = while   expr do
        %while  ;

211   label_prefix  =
        %announce begin case for goto if
          receive repeat send when while with  ;

212   label_prefix  = int_const :
        %int_const  ;

213   lhs  =   identifier rec_ary_ptr
        %identifier  ;

214   vars  =   identifier rec_ary_ptr
        %identifier  ;

215   rec_ary_ptr  =
        %) * + , - ..
          / : := ; = ]
          and div do downto else end
          from in mod noneqrelop of or
          otherwise then to until  ;

216   rec_ary_ptr  = .   identifier rec_ary_ptr
        %.  ;

217   rec_ary_ptr  = [   index_list ]   rec_ary_ptr
        %[  ;

218   rec_ary_ptr  = ptr   rec_ary_ptr
        %ptr  ;
```

```
219   index_list  = index next_index
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

220   next_index  = ,  index
        %, ;

221   next_index  =
        %] ;

222   index  = expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

223   expr  = parm_expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

224   parm_expr  = simple_expr parm_exp_end
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

225   parm_exp_end  =
        %) , .. : ; ]
          do downto else end of otherwise
          then to until  ;

226   parm_exp_end  = rel_op simple_expr
        %= in noneqrelop  ;

227   rel_expr  = simple_expr rel_op simple_expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

228   rel_op  = =
        %= ;

229   rel_op  = in
        %in ;

230   rel_op  =  noneqrelop
        %noneqrelop ;

231   simple_expr  =  char_const add_term
        %char_const ;

232   simple_expr  =  string_const add_term
        %string_const ;

233   simple_expr  = sign term add_term
        %+ - ;

234   simple_expr  = term add_term
```

```
        %( [ identifier int_const nil not
          real_const  ;

235     add_term  =
          %) , .. : ; =
            ] do downto else end in
            noneqrelop of otherwise then to until  ;

236     add_term  = add_op term add_term
          %+ - or  ;

237     term  = factor mult_factor
          %( [ identifier int_const nil not
            real_const  ;

238     mult_factor  =
          %) + , - .. :
            ; = ] do downto else
            end in noneqrelop of or otherwise
            then to until  ;

239     mult_factor  = mult_op factor mult_factor
          %* / and div mod  ;

240     factor  =  identifier var_funccall
          %identifier  ;

241     factor  = nil
          %nil  ;

242     factor  =  real_const
          %real_const  ;

243     factor  =  int_const
          %int_const  ;

244     factor  = (  expr )
          %(  ;

245     factor  = [  elem_list ]
          %[  ;

246     factor  = not  factor
          %not  ;

247     var_funccall  = rec_ary_ptr
          %) * + , - .
            .. / : ; = [
            ] and div do downto else
            end in mod noneqrelop of or
            otherwise ptr then to until  ;

248     var_funccall  = actual_parms )
```

```
        %(  ;

249     add_op  = sign
          %+ -  ;

250     add_op  = or
          %or  ;

251     mult_op  = *
          %*  ;

252     mult_op  = /
          %/  ;

253     mult_op  = div
          %div  ;

254     mult_op  = and
          %and  ;

255     mult_op  = mod
          %mod  ;

256     variable  = identifier rec_ary_ptr
          %identifier  ;

257     field_width  =
          %) ,  ;

258     field_width  = :   expr more_field
          %:  ;

259     more_field  =
          %) ,  ;

260     more_field  = :   expr
          %:  ;

261     elem_list  =
          %]  ;

262     elem_list  = elem next_elem
          %( + - [ char_const identifier
            int_const nil not real_const string_const  ;

263     elem  = expr elem_tail
          %( + - [ char_const identifier
            int_const nil not real_const string_const  ;

264     next_elem  =
          %]  ;

265     next_elem  = ,   elem next_elem
```

```
        %, ;

266     elem_tail =
          %, ] ;

267     elem_tail = ..   expr
          %.. ;

268     proc_id =   identifier
          %identifier ;

269     stmt_list = stmt more_stmt
          %announce begin case for goto identifier
            if int_const receive repeat send when
            while with ;

270     more_stmt =
          %end until ;

271     more_stmt = ;   stmt more_stmt
          %; ;

272     case_head = case   expr of
          %case ;

273     case_list = case_elem case_elems
          %+ - char_const identifier int_const ;

274     case_elems =
          %end otherwise ;

275     case_elems = ;   case_elem case_elems
          %; ;

276     case_elem = case_labels :   stmt
          %+ - char_const identifier int_const ;

277     otherwise_hd =   otherwise   :
          %otherwise ;

278     case_labels = scalar_const next_scalar
          %+ - char_const identifier int_const ;

279     next_scalar =
          %: ;

280     next_scalar = ,   scalar_const next_scalar
          %, ;

281     otherwise_pt =
          %end ;

282     otherwise_pt = otherwise_hd stmt_list
```

```
      %otherwise ;

283   for_head = for identifier := expr
        to_part expr
        %for ;

284   to_part = to
        %to ;

285   to_part = downto
        %downto ;

286   rec_var_list = variable next_rec_var
        %identifier ;

287   next_rec_var =
        %do ;

288   next_rec_var = , variable next_rec_var
        %, ;

289   with_head = with rec_var_list do
        %with ;

290   receive_stmt = simple_rcv
        %receive ;

291   receive_stmt = when_stmt
        %when ;

292   simple_rcv = receive variable0 from
        port_denoter freebinding0
        %receive ;

293   variable0 =
        %from ;

294   variable0 = variable
        %identifier ;

295   port_denoter = pt_class_id subport
        %identifier ;

296   subport =
        %; do else end otherwise set
          until use ;

297   subport = . subport_id
        %. ;

298   pt_class_id = identifier
        %identifier ;
```

```
299   subport_id  = identifier
        %identifier  ;

300   freebinding0  =
        %; do else end otherwise until  ;

301   freebinding0  = use   variable
        %use  ;

302   freebinding0  = set   variable
        %set  ;

303   when_stmt  =   when_head receives else_part0 end
        %when  ;

304   when_head  = when
        %when  ;

305   receives  =   receive_pt next_receive
        %; end otherwise receive  ;

306   next_receive  =
        %end otherwise  ;

307   next_receive  = ;     receive_pt next_receive
        %;  ;

308   receive_pt  =
        %; end otherwise  ;

309   receive_pt  = simple_rcv   do stmt
        %receive  ;

310   else_part0  =
        %end  ;

311   else_part0  =   otherwise stmt
        %otherwise  ;

312   send_stmt  =   send expression0 to   port_denoter
         use_part0
        %send  ;

313   expression0  =
        %to  ;

314   expression0  =     expr
        %( + - [ char_const identifier
          int_const nil not real_const string_const  ;

315   use_part0  =
        %; else end otherwise until  ;
```

```
316   use_part0  = use   variable
        %use  ;

317   announcestmt  =   announce event_id about_bind0
        %announce  ;

318   event_id  =   identifier
        %identifier  ;

319   about_bind0  =
        %; else end otherwise until  ;

320   about_bind0  = about   pt_class_id use_part0
        %about  ;

321   sign  = +
        %+  ;

322   sign  = -
        %-  ;
```

APPENDIX C

An Example NETSLA program - Broadcasting

```
network broadcast;
process class sender
port inport in integer;
port outport out integer;
end sender

process class receiver
port inp in integer;
port outp out integer;
end receiver

initial
  create sender : sender;
  create receiver1 : receiver;
  create receiver2 : receiver;
  connect sender.outport to receiver1.inp;
  connect sender.outport to receiver2.inp
end broadcast
```

APPENDIX D

A Network Specification Module

This code was generated by the Netsla preprocessor."

```
procedure init;
begin (*init*)
p_id := 0;
alive := 0;
total_procs := 0;
initialized := false;
Gr := AllocatePort(KernelPort, ChildtoParPort, MAXBACKLOG);
Gr := AllocatePort(KernelPort, EventPort, MAXBACKLOG);
build_net('broadcast');
build_proc('sender');
build_port('inport');
build_port('outport');
build_proc('receiver');
build_port('inp');
build_port('outp');
Gr := a_creation_pr (theroot,'sender','sender','sender.RUN',p_list_head);
Gr := a_creation_pr (theroot,'receiver','receiver1','receiver.RUN',p_list_head);
Gr := a_creation_pr (theroot,'receiver','receiver2','receiver.RUN',p_list_head);
Gr := connection(theroot,'sender','outport','','receiver1','inp','');
Gr := connection(theroot,'sender','outport','','receiver2','inp','');
wakeup;
end; (*init*)
```

APPENDIX E

The Event Handling Module

```
EvntMsg.Head.LocalPort := EventPort;
quit := False;
while (quit=FALSE) do
begin
writeln('Events before receive req');
Gr := Receive(EvntMsg.Head, 0, LOCALPT, RECEIVEIT);
if Gr=SUCCESS then
case shrink(EvntMsg.Head.ID) of
1: begin (* message transmission. *)
     writeln('Send_Msg Request Received.');
     Gr := send_msg(theroot, EvntMsg);
     if Gr=SUCCESS then
        writeln('Send_Msg Request Completed.')
     else
        writeln('***Send_Msg Request NOT Completed.');
     arrive_evnt;
   end;
2: begin (* message transmission. w/ tag *)
     writeln('Send_Msg(w/ Tag) Request Received.');
     Gr := send_msg_tag(theroot, EvntMsg);
     if Gr=SUCCESS then
        writeln('Send_Msg(w/ Tag) Request Completed.')
     else
        writeln('***Send_Msg(w/ Tag) Request NOT Completed.');
     arrive_evnt;
   end;
3: begin (* enter event *)
     enter_evnt;
   end;
4: begin (* leave event *)
     leave_evnt;
   end;
5: begin (* when evnt *)
     when_evnt;
   end;
6: begin (* when evnt. w/ about part *)
     when_evnt;
   end;
19: begin (* connectivity inquiry *)
     writeln('Conn Inq Request Received');
     Gr := inquiry(theroot, EvntMsg);
     if Gr=SUCCESS then
        writeln('Conn Inquiry Completed')
     else
        writeln('Conn Inquiry NOT Completed');
   end;
99: begin (* termination of a process instance *)
    with vparray[vpmap[EvntMsg.Data2]] do
```

```
      begin
        DeleteCanvas(canvs);
        PaintRectangle(UserCanvas,White,x0+1,x0+xlen-3,y0+2,y0+ylen-2);
        Used := False;
      end;
      alive := alive-1;
      if alive=0 then
      begin
         quit:=TRUE;
         EraseCanvas(UserCanvas,White);
         {DeleteCanvas(UserCanvas);}
      end;
    end;
(* more come here *)
otherwise:
   begin
   end
end; (* case *)
end; (* while *)
```

APPENDIX F

A Script for Sender Processes

```
process script sender;
port inport in integer;
port outport out integer;
var
   i:integer;
begin
   while i<>999 do
   begin
      write('Integer: ');
      readln(i);
      send i to outport
   end
end.
```

APPENDIX G

The Preprocessor-generated Code for Sender Processes

```
program sender;
imports Child_lib from Child_lib;

var
i:integer;
var
pinport  : port;
poutport  : port;

type
   signal = boolean;

   accentmsg = record
                  head : msg;
                  ipcname2 : TypeType;
                  arg2 : integer;
                  ipcname3 : TypeType;
                  arg3 : string[10];
                  ipcname4 : TypeType;
                  arg4 : string[10];
                  ipcname5 : TypeType;
                  arg5 : integer;
                  ipcname6 : TypeType;
                  arg6 : string[20];
                  ipcname1 : TypeType;
                  case integer of
                      1 : (msignal : signal);
                      2 : ( msginport : integer);
                      3 : ( msgoutport : integer);
               end;

var
   xxmsg : accentmsg;
   gr : generalreturn;
   whenflag : boolean;
   xxsignal : signal;
   commport : port;
   p_array : PortBitArray;
   pstr : string[12];

{$INCLUDE Alsten_supt.pas}
begin
{$INCLUDE AlstenInit.pas}
InitMsgn(NullPort);
Gr := Child_ack;
while i<>999 do
begin
write('Integer: ');
```

```
readln(i);
begin (* send *)
xxmsg.head.id := 1;
xxmsg.head.remoteport := InPorts^[1];
xxmsg.head.localport := DataPort;
xxmsg.msgoutport:=i;
xxmsg.arg2 := p_id;
xxmsg.arg3 := 'outport';
xxmsg.arg4 := '';
gr := send(xxmsg.head,0,wait)
end (* send *)
 end
;goaway;end.
```

APPENDIX H

A Script for the Receiver Processes

```
process script receiver;
port inp in integer;
port outp out integer;
var
   j:integer;
begin
   while j<>999 do
   begin
      receive j from inp;
      writeln(j)
   end
end.
```

APPENDIX I

The Preprocessor-generated Code for Receiver Processes

```
program receiver;
imports Child_lib from Child_lib;

var
j:integer;
var
pinp  : port;
poutp  : port;

type
   signal = boolean;

   accentmsg = record
                  head : msg;
                  ipcname2 : TypeType;
                  arg2 : integer;
                  ipcname3 : TypeType;
                  arg3 : string[10];
                  ipcname4 : TypeType;
                  arg4 : string[10];
                  ipcname5 : TypeType;
                  arg5 : integer;
                  ipcname6 : TypeType;
                  arg6 : string[20];
                  ipcname1 : TypeType;
                  case integer of
                      1 : (msignal : signal);
                      2 : ( msginp : integer);
                      3 : ( msgoutp : integer);
               end;

var
   xxmsg : accentmsg;
   gr : generalreturn;
   whenflag : boolean;
   xxsignal : signal;
   commport : port;
   p_array : PortBitArray;
   pstr : string[12];

{$INCLUDE Alsten_supt.pas}
begin
{$INCLUDE AlstenInit.pas}
InitMsgn(NullPort);
Gr := Child_ack;
while j<>999 do
begin
begin (* receive *)
```

```
rcv('inp','',999,1,rcv_result);
if rcv_result then
j:=xxmsg.msginp;
end (* receive *)
;
writeln(j) end
;goaway;end.
```

APPENDIX J

Event Replay Example

The following figures show a sequence of 6 events taken from a multiprocess arithmetic expression interpreter program developed during this project for testing and demonstrations. The SCANNER process reads an expression from the keyboard and then produces two messages: one containing token classifications for the PARSER and one containing token values (of constants and identifiers) for the INTERPRETER. The PARSER sends a message to the INTERPRETER describing the syntactic structure of the expression. This structure drives the interpratation.

Dotted lines are included in the figures to indicate port connections. These are not present in the actual presentation done by our replay system.

Sending a message is represented by two pictures. The first shows a message box leaving an output port, while the second shows it arriving at an input port. The second picture represents the static state of the display after completion of the event. These two pictures show the beginning and end of the presentation of the event. In the actual presentation, the message box moves smoothly across the screen from the output port to the input port.

Receiving a message is represented by a single picture that shows the state of the display after the message box is removed from the input queue of the appropriate port.

Figure J – 1

SCANNER sends message to PARSER

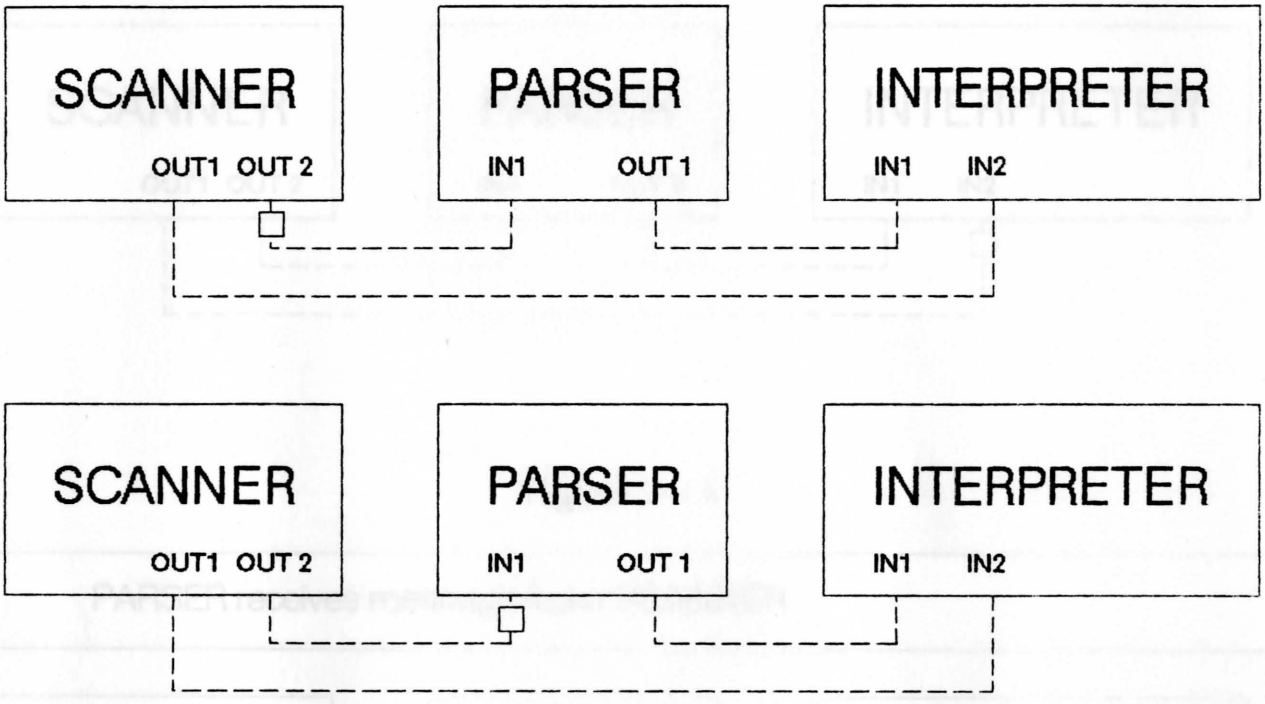

Figure J – 2

SCANNER send message to INTERPRETER

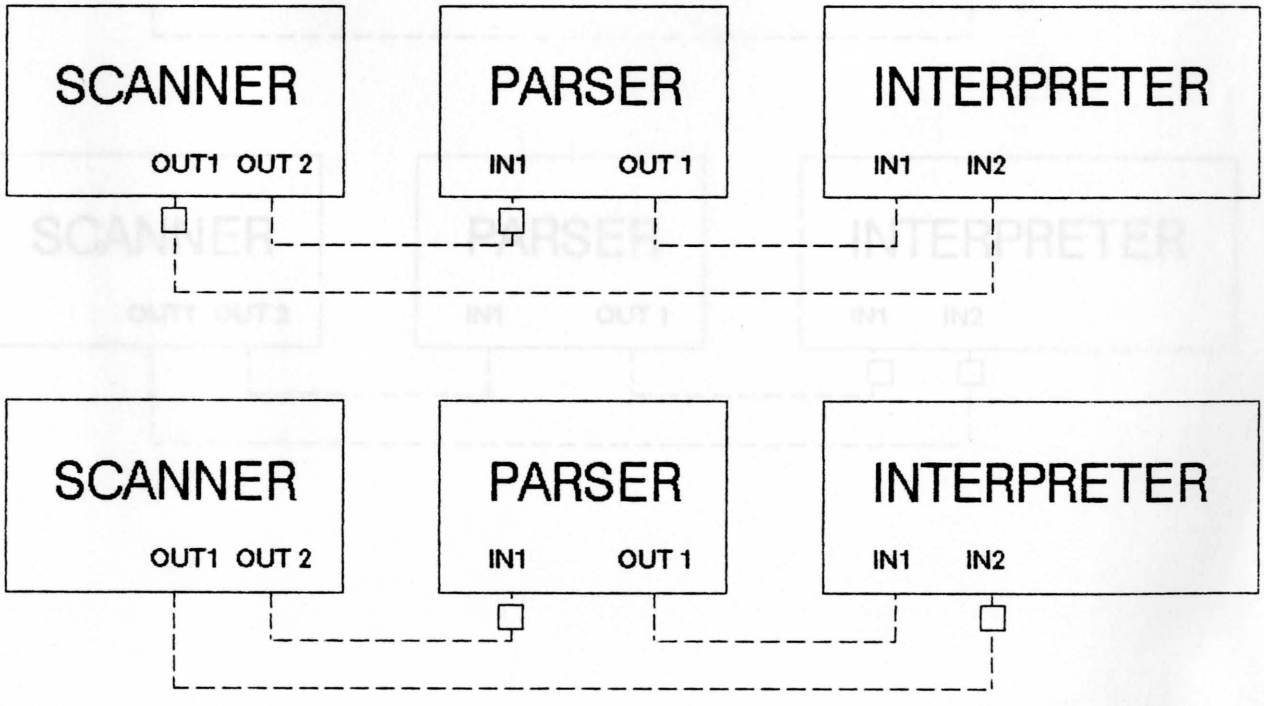

Figure J – 3

PARSER receives message from SCANNER

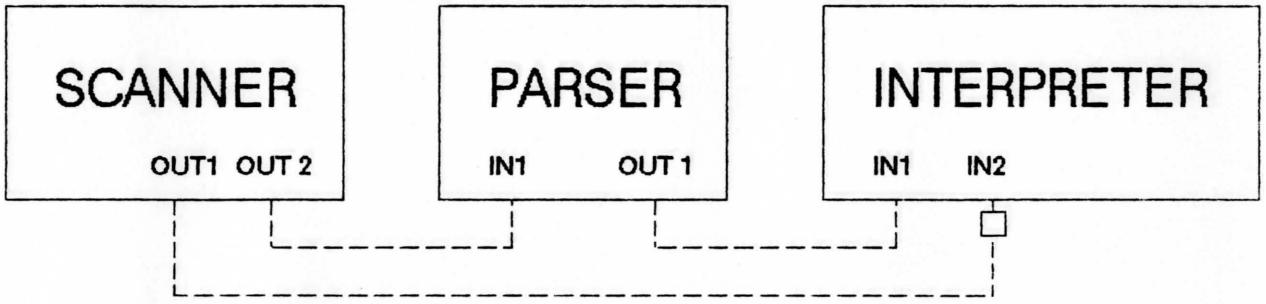

Figure J – 4

PARSER receives message from SCANNER

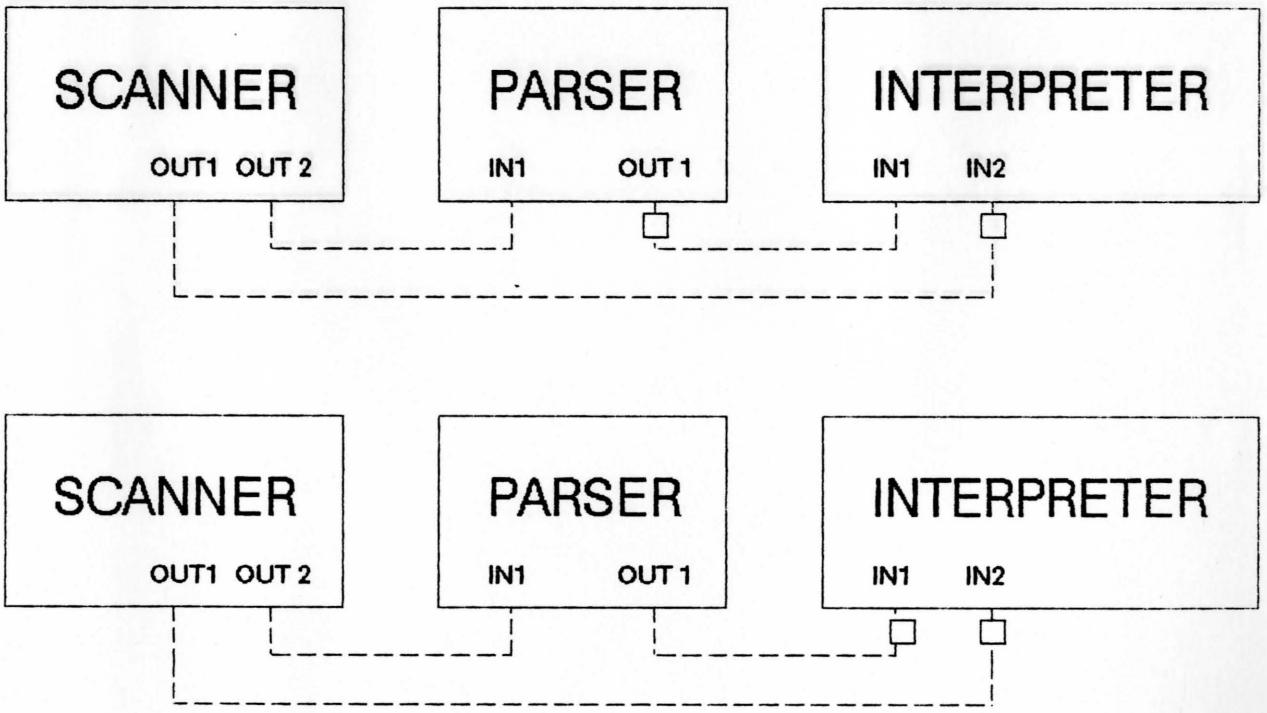

Figure J – 5

INTERPRETER receives message from PARSER

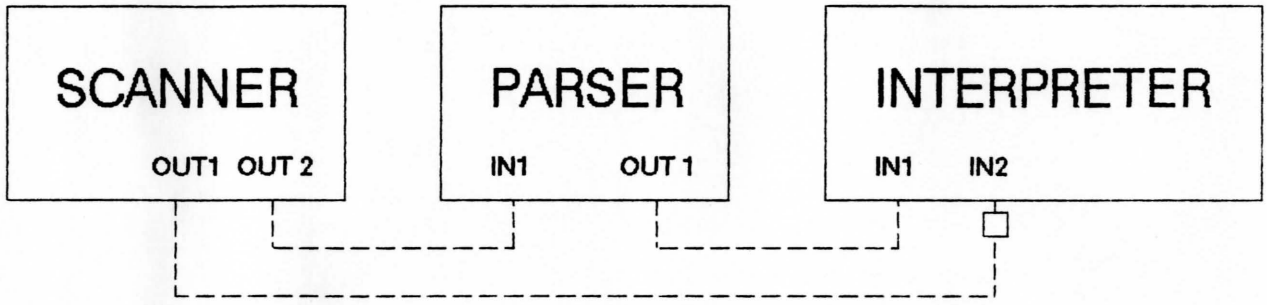

Figure J – 6

iNTERPRETER receives message from SCANNER