ARPA ORDER NO. 2223

ISI/RR-77-66
November 1977

Mark S. Moriconi
University of Texas at Austin
and USC/Information Sciences Institute

A System for Incrementally Designing and Verifying Programs

(Appendix) Volume 2

INFORMATION SCIENCES INSTITUTE
UNIVERSITY OF SOUTHERN CALIFORNIA
4676 Admiralty Way/ Marina del Rey/ California 90291
(213) 822-1511

UNCLASSIFIED

AD55501

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: ISI/RR-77-66	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): A System for Incrementally Designing and Verifying Programs, Volume II	5. TYPE OF REPORT & PERIOD COVERED: Research report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Mark S. Moriconi	8. CONTRACT OR GRANT NUMBER(s): DAHC 15-72-C-0308, ~~MCS74-12866~~ ARPA Order 2223
9. PERFORMING ORGANIZATION NAME AND ADDRESS: USC/Information Sciences Institute, 4676 Admiralty Way, Marina del Rey, CA 90291	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Advanced Research Projects Agency, 1400 Wilson Blvd., Arlington, VA 22209	12. REPORT DATE: January 1978 / 13. NUMBER OF PAGES: 66 (12 69p.)
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified / 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This report is approved for public release and sale; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

asynchronous, data abstraction, incremental, interactive dialogue, interactive system, network, program design, program verification, security, specifications

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

This appendix contains a transcript of a session with SID in which a simple message switching network that allows secure, asynchronous message transfer among a fixed number of users is incrementally developed.

A

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE S/N 0102-014-6601

78 06 19 059

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

407 952

ACM

ARPA ORDER NO. 2223

ISI/RR-77-66
November 1977

Mark S. Moriconi
University of Texas at Austin
and USC/Information Sciences Institute

A System for Incrementally Designing and Verifying Programs

(Appendix) Volume 2

INFORMATION SCIENCES INSTITUTE

UNIVERSITY OF SOUTHERN CALIFORNIA

4676 Admiralty Way/ Marina del Rey/ California 90291
(213) 822-1511

THIS RESEARCH IS SUPPORTED BY THE ADVANCED RESEARCH PROJECTS AGENCY UNDER CONTRACT NO. DAHC15 72 C 0308, ARPA ORDER NO. 2223.

APPENDIX

MESSAGE SWITCHING NETWORK

This appendix contains a transcript of a session with SID in which a simple message switching network is incrementally designed and verified using a top-down strategy. Interleaved with the transcript are annotations explaining the development. This commentary focuses on how SID is used, rather than on SID's internal operation. An overview of what SID does in various situations is given in the example session in Section 1.2, and then elaborated throughout the text.

The network, which allows secure, asynchronous message transfer among a fixed number of users, is developed in several key stages:

- ***User/network interface.*** The network switches messages among a fixed number of user processes. These processes operate concurrently with the network and, except for their interface with the network, their operation is unspecified. Each user process communicates with the network through a port, as shown in Fig. A-1. Each port consists of an input buffer and an output buffer and has an associated security classification.

- ***Network specification.*** The network specification states that the mail received by user j is a subsequence of the secure mail intended for j. This requires that messages for each port arrive in the same order they were sent. The subsequence relation allows messages to be dropped due to unrecoverable transmission failures or security violations. This property is formalized using a hierarchically-structured collection of specifications.

- ***Network implementation and verification.*** The network is implemented as a set of concurrently running message switching processes, with each switcher accepting messages from only one user input buffer and routing messages to any output buffer. This configuration is shown in Fig. A-2. Also, properties about the switchers are stated and used in the verification of the top-level network program. These specifications say that for every pair of ports i,j, the mail actually sent from source i to destination j is a subsequence of the secure mail from i intended for j.

- ***Switcher implementation and verification.*** The switchers receive messages, determine their destination and check security, then send the message if nothing is wrong.

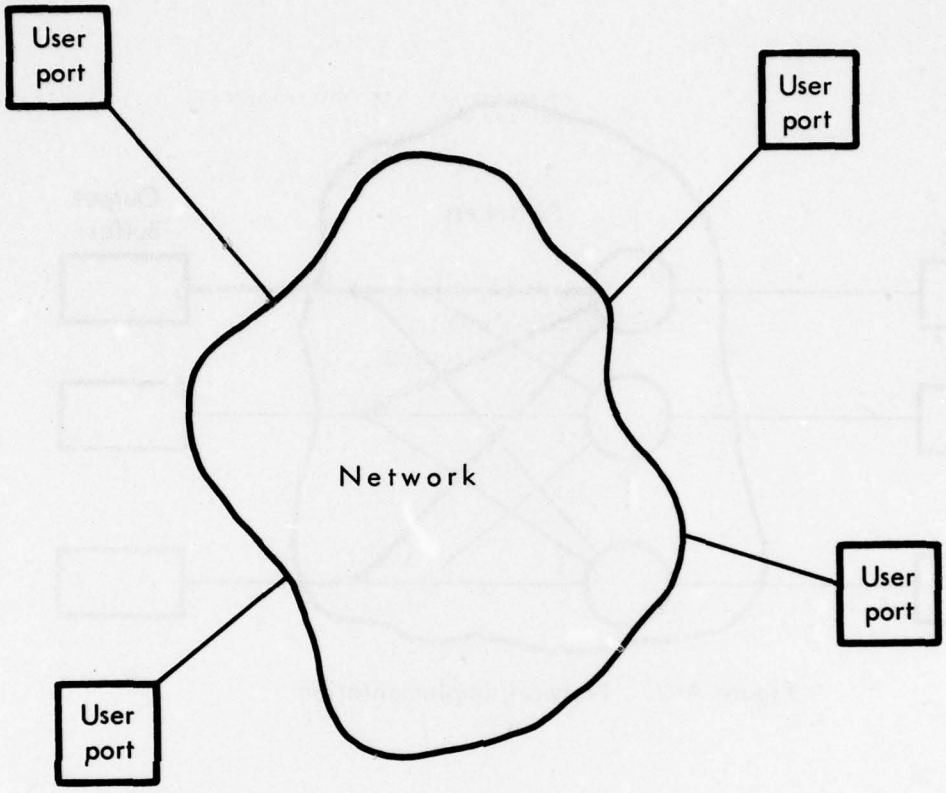


Figure A-1. User/network interface

- ***Message implementation and verification.*** Previously, messages were manipulated without knowledge of their internal structure. The message abstraction is now implemented as a record of three fields -- a source identification, a destination identification, and the message text. The functions which manipulate the internal structure of messages are also implemented and verified, completing the development.

Until the last stage, several partially-defined programs and data definitions are entered and refined. Annotations relate these intermediate stages of development to the above outline.

The transcript can be read at several levels of detail. An overview is obtained by ignoring specifics of the code, specifications, VC generation trace, and proofs. Focus should be

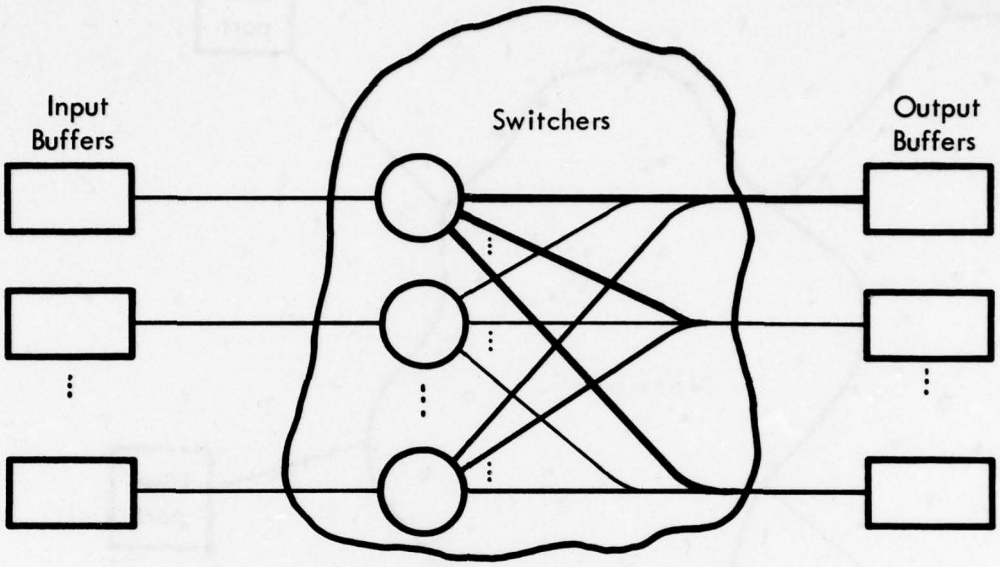


Figure A-2. Network implementation

on the kinds of things being done and their relation to the development scenario given above. After an initial reading, the transcript can be studied at increasingly finer levels of detail.

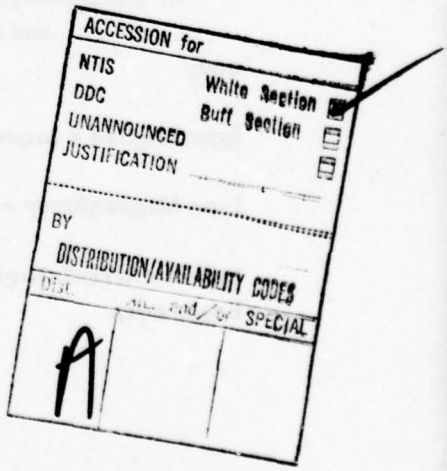
Annotations and status summaries aid in keeping track of progress and context. Annotations, in addition to providing general commentary, point out important transitions in the development. Status summaries are frequently printed by SID to describe the current state of the entire development.

As in Section 1.2, lines typed by a person are underlined to distinguish them from the computer's response. The text is taken verbatim from an actual session, and is all inclusive except where explicitly marked. Italicized lines are comments describing the flow of the development. The final version of the network, its specifications, and all used lemmas are displayed at the end of the session.

Exec-> ?
Commands are: Add, Delete, EDit, EXplain, Help, PRint, PROve,
Restore, SAve, SUggest, Translate, Vcs, ?E, ?, ??.
Exec-> Suggest

'The user asks SID to tell him how to get started. The entire development is guided by SID's suggestions.

```
Suggest one of:
  <esc> TRANSLATE (from file)
  RESTORE (problem from file)

 -> $

 Enter file name-> NetInt.Net


     process Network(var aUserPort:UserPortArray;
                     Security:SecurityArray) = pending;

     type UserPortArray = array(UserId) of UserPort;

     type UserId = integer[1..NUsers];

     const NUsers = 100;

     type UserPort =
       record ( SysIn:MsgInBuf;
                SysOut:MsgOutBuf
              );

     type MsgInBuf = buffer (1) of Msg;

     type MsgOutBuf = buffer (NUsers) of Msg;

     type Msg = pending;

     type SecurityArray = array([1..NUsers]) of SecurityClass;

     type SecurityClass =
       (unclassified,confidential,secret,topsecret);


 No syntax errors detected.
 No semantic errors detected.
```



The user/network interface is established by precisely defining the parameters to the network. The implementation of messages is postponed.

Suggest fully defining NETWORK-> Print Status All

The current design and verification status is:
Waiting for pending body to be filled in: NETWORK
Constants/Types: MSG, MSGINBUF, MSGOUTBUF, NUSERS, SECURITYARRAY, SECURITYCLASS, USERID, USERPORT, USERPORTARRAY

Suggest fully defining NETWORK-> Edit

.
.
.

Exec-> Translate NetSpc.Net

```
process Network(var aUserPort:UserPortArray;
                Security:SecurityArray) =
begin
block all j:userid,
      issubmerge(auserport(j).sysout.outto,
                 allsecuremailfor(auserport,j,security));
pending
end;

function IsSubMerge(s:MsgSeq;
                    a:MsgSeqArray) : Boolean =
begin
exit (assume IsSubMerge(s,a)
     iff (some x:MsgSeq,  IsMerge(x,ArrayToBag(a,1,Nusers))
                and s sub x));
end;

type MsgSeq = sequence of Msg;

type MsgSeqArray = array (UserId) of MsgSeq;

function ArrayToBag(a: MsgSeqArray; i,j: UserId): BagMsgSeq =
begin end;
```

```
type BagMsgSeq = Bag of MsgSeq;

function AllSecureMailFor(A:UserPortArray;
                          j:integer;
                          s:SecurityArray): MsgSeqArray =
begin
exit (assume all i:Userid,
        AllSecureMailFor(a,j,s)(i)
      = SecureMail(s(i),s(j),Mail(a(i).sysin.infrom,i,j)));
end;

function SecureMail(s1,s2:SecurityClass;
                          ms:MsgSeq):MsgSeq =
begin end;

function Mail(ms:MsgSeq;i,j:UserId):MsgSeq =
begin end;
```

The network specification uses several pre-defined constructs, some of which require explanation. The "infrom" and "outto" histories record transactions on buffers. In the specification of Network, auserport(j).sysout.outto is the sequence of all messages sent out to buffer auserport(j).sysout by the network. The infrom history refers to messages received by the network. The function "ismerge" determines if there exists a merge of a bag of sequences which is equal to a given sequence. Functions having only their headers defined (e.g., SecureMail) are used for type-checking purposes.

```
No syntax errors detected.
No semantic errors detected.

Exec-> Print Status All

The current design and verification status is:
   Waiting for pending body to be filled in: NETWORK
   For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE, MAIL,
        SECUREMAIL
   Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGINBUF, MSGOUTBUF,
        MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS, USERID,
        USERPORT, USERPORTARRAY

Exec-> Suggest

Suggest fully defining NETWORK-> Edit
```

.
.
.

Exec-> Translate NetWrk.Net

```
process Network(var aUserPort:UserPortArray;
                Security:SecurityArray) =
begin
block all j:userid,
      issubmerge(auserport(j).sysout.outto,
                 allsecuremailfor(auserport,j,security));
  cobegin
  Switcher(i,aUserPort,Security)
    each i : [1..NUsers];
  end;
end;

process Switcher(i:UserId; var aports:UserPortArray;
                 Security:SecurityArray) =
begin
entry i in [1..NUsers];
block all j:userid,
      aports(j).sysout.outto sub
           securemail(security(i),security(j),
                mail(aports(i).sysin.infrom,i,j))
    and
     ( j ne i  ->  aports(j).sysin.infrom = MsgSeq() );
pending
end;

function Infrom!\ArrayToBag (a:MsgBufArray; i,j:UserId) :
                        BagMsgSeq = begin end;

function Outto!\ArrayToBag (a:MsgBufArray; i,j:UserId) :
                        BagMsgSeq = begin end;

type MsgBufArray = array (UserId) of MsgOutBuf;
```

No syntax errors detected.

```
No semantic errors detected.
```

The pending in the network program is replaced by executable code. The switcher processes are set into concurrent execution by the cobegin statement. The specifications of Switcher are given for use in the proof of Network, but the implementation of the actual switching algorithm is postponed.

```
Exec-> Print Status All

The current design and verification status is:
  Waiting for VC generation: NETWORK
  Waiting for pending body to be filled in: SWITCHER
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY
```

As reflected in this status summary, the top-level network program is ready to be verified. VCs are generated and then proved.

```
Exec-> Suggest

Suggest generating VCs for NETWORK-> $

Generating VCs for PROCESS NETWORK

Found 1-ST path
```

SID traces the generation of the single VC for Network below.

```
-------------------------------------------------
Beginning new path...
AUSERPORT' := AUSERPORT

Assume Initial Buffer Histories are null
    all I#1 : INTEGER [1..100],     AUSERPORT[I#1].SYSIN.INFROM = MSGSEQ()
                          and AUSERPORT[I#1].SYSIN.OUTTO = MSGSEQ()
                          and AUSERPORT[I#1].SYSOUT.INFROM = MSGSEQ()
                          and AUSERPORT[I#1].SYSOUT.OUTTO = MSGSEQ()


Assume (unit entry condition)
```

```
    TRUE

Entering cobegin . . .

Assume local buffer histories only changed by subprocesses
    all I#3 : INTEGER [1..100],      AUSERPORT#1[I#3].SYSIN.INFROM
                                  =   CO\AUSERPORT[I#3].SYSIN.INFROM
                                    @ AUSERPORT[I#3].SYSIN.INFROM
                                and  AUSERPORT#1[I#3].SYSIN.OUTTO
                                  =   CO\AUSERPORT[I#3].SYSIN.OUTTO
                                    @ AUSERPORT[I#3].SYSIN.OUTTO
                                and  AUSERPORT#1[I#3].SYSOUT.INFROM
                                  =   CO\AUSERPORT[I#3].SYSOUT.INFROM
                                    @ AUSERPORT[I#3].SYSOUT.INFROM
                                and  AUSERPORT#1[I#3].SYSOUT.OUTTO
                                  =   CO\AUSERPORT[I#3].SYSOUT.OUTTO
                                    @ AUSERPORT[I#3].SYSOUT.OUTTO

Assume no buffer actions of subprocesses lost
    all I#4 : INTEGER [1..100],
        ISMERGE(CO\AUSERPORT[I#4].SYSIN.INFROM,
                INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
      and ISMERGE(CO\AUSERPORT[I#4].SYSIN.OUTTO,
                OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
      and TRUE
      and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.INFROM,
                INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
      and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.OUTTO,
                OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
      and TRUE

Assume system blocks.
Assume blockage conditions for subprocesses.

Assume (blockage condition for subprocess SWITCHER)
    all I#2 : [1..NUSERS],
      all J : USERID,
              AUSERPORT#1[J].SYSOUT.PAR[I#2].OUTTO
          sub SECUREMAIL(SECURITY[I#2], SECURITY[J],
                      MAIL(AUSERPORT#1[I#2].SYSIN.PAR[I#2].INFROM,
                           I#2, J))
        and (J ne I#2 -> AUSERPORT#1[J].SYSIN.PAR[I#2].INFROM = MSGSEQ())
```

```
Blockage assertion is
      all J : USERID, ISSUBMERGE(AUSERPORT[J].SYSOUT.OUTTO,
                           ALLSECUREMAILFOR(AUSERPORT, J, SECURITY))
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (process blockage) condition
Verification condition NETWORK#1
 H1: all I#1 : INTEGER [1..100],     AUSERPORT[I#1].SYSIN.INFROM = MSGSEQ()
                           and AUSERPORT[I#1].SYSIN.OUTTO = MSGSEQ()
                           and AUSERPORT[I#1].SYSOUT.INFROM = MSGSEQ()
                           and AUSERPORT[I#1].SYSOUT.OUTTO = MSGSEQ()
 H2: all I#2 : [1..NUSERS],
       all J : USERID,
            ( I#2 ne J
            -> AUSERPORT#1[J].SYSIN.PAR[I#2].INFROM = MSGSEQ())
          and     AUSERPORT#1[J].SYSOUT.PAR[I#2].OUTTO
            sub SECUREMAIL(SECURITY[I#2], SECURITY[J],
                        MAIL(AUSERPORT#1[I#2].SYSIN.PAR[I#2].INFROM,
                           I#2, J))
 H3: all I#3 : INTEGER [1..100],
           CO\AUSERPORT[I#3].SYSIN.INFROM @ AUSERPORT[I#3].SYSIN.INFROM
         = AUSERPORT#1[I#3].SYSIN.INFROM
       and  CO\AUSERPORT[I#3].SYSIN.OUTTO @ AUSERPORT[I#3].SYSIN.OUTTO
         = AUSERPORT#1[I#3].SYSIN.OUTTO
       and  CO\AUSERPORT[I#3].SYSOUT.INFROM @ AUSERPORT[I#3].SYSOUT.INFROM
         = AUSERPORT#1[I#3].SYSOUT.INFROM
       and  CO\AUSERPORT[I#3].SYSOUT.OUTTO @ AUSERPORT[I#3].SYSOUT.OUTTO
         = AUSERPORT#1[I#3].SYSOUT.OUTTO
 H4: all I#4 : INTEGER [1..100],
         ISMERGE(CO\AUSERPORT[I#4].SYSIN.INFROM,
                  INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSIN.OUTTO,
                  OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.INFROM,
                  INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.OUTTO,
                  OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
 -->
 C1: all J : USERID, ISSUBMERGE(AUSERPORT#1[J].SYSOUT.OUTTO,
                           ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY))
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-----------------------------------------------
```

```
Suggest proving VC called NETWORK#1-> Print Status §

NETWORK#1 waiting to be proved.

Suggest proving VC called NETWORK#1-> §
Entering Prover with verification condition NETWORK#1
 H1: all I#1 : INTEGER [1..100],     AUSERPORT[I#1].SYSIN.INFROM = MSGSEQ()
                          and AUSERPORT[I#1].SYSIN.OUTTO = MSGSEQ()
                          and AUSERPORT[I#1].SYSOUT.INFROM = MSGSEQ()
                          and AUSERPORT[I#1].SYSOUT.OUTTO = MSGSEQ()
 H2: all I#2 : [1..NUSERS],
       all J : USERID,
            ( I#2 ne J
            -> AUSERPORT#1[J].SYSIN.PAR[I#2].INFROM = MSGSEQ())
          and    AUSERPORT#1[J].SYSOUT.PAR[I#2].OUTTO
            sub SECUREMAIL(SECURITY[I#2], SECURITY[J],
                        MAIL(AUSERPORT#1[I#2].SYSIN.PAR[I#2].INFROM,
                           I#2, J))
 H3: all I#3 : INTEGER [1..100],
           CO\AUSERPORT[I#3].SYSIN.INFROM @ AUSERPORT[I#3].SYSIN.INFROM
         = AUSERPORT#1[I#3].SYSIN.INFROM
       and  CO\AUSERPORT[I#3].SYSIN.OUTTO @ AUSERPORT[I#3].SYSIN.OUTTO
         = AUSERPORT#1[I#3].SYSIN.OUTTO
       and  CO\AUSERPORT[I#3].SYSOUT.INFROM @ AUSERPORT[I#3].SYSOUT.INFROM
         = AUSERPORT#1[I#3].SYSOUT.INFROM
       and  CO\AUSERPORT[I#3].SYSOUT.OUTTO @ AUSERPORT[I#3].SYSOUT.OUTTO
         = AUSERPORT#1[I#3].SYSOUT.OUTTO
 H4: all I#4 : INTEGER [1..100],
          ISMERGE(CO\AUSERPORT[I#4].SYSIN.INFROM,
                INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSIN.OUTTO,
                OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSIN.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.INFROM,
                INFROM\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
       and ISMERGE(CO\AUSERPORT[I#4].SYSOUT.OUTTO,
                OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4].SYSOUT.PAR, 1, NUSERS))
-->
 C1: all J : USERID, ISSUBMERGE(AUSERPORT#1[J].SYSOUT.OUTTO,
                          ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY))
```

Only key parts of proofs are included. All properties used are explicitly noted; some are referred to in interactive dialogs.

```
Backup point
(.)
```

Occasionally, backup points and theorem labels, such as "(.)", are printed. Although they serve a useful purpose, they can be ignored here. The prover skolemizes Network#1 to eliminate quantifiers, yielding the following theorem.

```
Prover-> Print Theorem

 H1. AUSERPORT[I#1$].SYSIN.INFROM = MSGSEQ()
 H2. AUSERPORT[I#1$].SYSIN.OUTTO = MSGSEQ()
 H3. AUSERPORT[I#1$].SYSOUT.INFROM = MSGSEQ()
 H4. AUSERPORT[I#1$].SYSOUT.OUTTO = MSGSEQ()
 H5. I#2$ ne J$ -> AUSERPORT#1[J$].SYSIN.PAR[I#2$].INFROM = MSGSEQ()
 H6.     AUSERPORT#1[J$].SYSOUT.PAR[I#2$].OUTTO
    sub SECUREMAIL(SECURITY[I#2$], SECURITY[J$],
                MAIL(AUSERPORT#1[I#2$].SYSIN.PAR[I#2$].INFROM, I#2$, J$))
 H7.  CO\AUSERPORT[I#3$].SYSIN.INFROM @ AUSERPORT[I#3$].SYSIN.INFROM
    = AUSERPORT#1[I#3$].SYSIN.INFROM
 H8.  CO\AUSERPORT[I#3$].SYSIN.OUTTO @ AUSERPORT[I#3$].SYSIN.OUTTO
    = AUSERPORT#1[I#3$].SYSIN.OUTTO
 H9.  CO\AUSERPORT[I#3$].SYSOUT.INFROM @ AUSERPORT[I#3$].SYSOUT.INFROM
    = AUSERPORT#1[I#3$].SYSOUT.INFROM
 H10.  CO\AUSERPORT[I#3$].SYSOUT.OUTTO @ AUSERPORT[I#3$].SYSOUT.OUTTO
     = AUSERPORT#1[I#3$].SYSOUT.OUTTO
 H11. ISMERGE(CO\AUSERPORT[I#4$].SYSIN.INFROM,
           INFROM\ARRAYTOBAG(AUSERPORT#1[I#4$].SYSIN.PAR, 1, NUSERS))
 H12. ISMERGE(CO\AUSERPORT[I#4$].SYSIN.OUTTO,
           OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4$].SYSIN.PAR, 1, NUSERS))
 H13. ISMERGE(CO\AUSERPORT[I#4$].SYSOUT.INFROM,
           INFROM\ARRAYTOBAG(AUSERPORT#1[I#4$].SYSOUT.PAR, 1, NUSERS))
 H14. ISMERGE(CO\AUSERPORT[I#4$].SYSOUT.OUTTO,
           OUTTO\ARRAYTOBAG(AUSERPORT#1[I#4$].SYSOUT.PAR, 1, NUSERS))
IMP
 C1. ISSUBMERGE(AUSERPORT#1[J].SYSOUT.OUTTO,
            ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY))
```

The user directs the prover to delete irrelevant hypotheses H2, H3, H8, H9, H12, and H13 and several equality substitutions are performed, resulting in the following theorem.

```
Prover-> Print Theorem
```

```
 H1. I#2$ ne J$ -> AUSERPORT#1[J$].SYSIN.PAR[I#2$].INFROM = MSGSEQ()
 H2. ISMERGE(AUSERPORT#1[I#1$].SYSIN.INFROM,
          INFROM\ARRAYTOBAG(AUSERPORT#1[I#1$].SYSIN.PAR, 1, NUSERS))
 H3. ISMERGE(AUSERPORT#1[I#1$].SYSOUT.OUTTO,
          OUTTO\ARRAYTOBAG(AUSERPORT#1[I#1$].SYSOUT.PAR, 1, NUSERS))
 H4.    AUSERPORT#1[J$].SYSOUT.PAR[I#2$].OUTTO
    sub SECUREMAIL(SECURITY[I#2$], SECURITY[J$],
                MAIL(AUSERPORT#1[I#2$].SYSIN.PAR[I#2$].INFROM, I#2$, J$))
IMP
 C1. ISSUBMERGE(AUSERPORT#1[J].SYSOUT.OUTTO,
             ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY))
```

This cannot be proved without expanding the definition of IsSubmerge and adding a new lemma. These two steps are shown below, followed by a display of the transformed theorem.

```
Prover-> Expand IsSubmerge
Backup point
(. D PUT . =S . =S . E .)

Prover-> Print Conclusion

 C1. ISMERGE(X$,
          ARRAYTOBAG(ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY), 1,
                NUSERS))
 C2. AUSERPORT#1[J].SYSOUT.OUTTO sub X$

Prover-> Use Lemma
Enter lemma . . .
* all A: MsgBufArray,  all B: MsgSeqArray,  all X: MsgSeq,
*       IsMerge(X,Outto!\ArrayToBag(A,1,Nusers))
*   and (all K: UserId, A[K].Outto  sub  B[K])
* -> some Y: MsgSeq,
*       IsMerge(Y, ArrayToBag(B,1,Nusers))
*    and X sub Y;
Lemma added . . . Its name is LEMMA#1
(. D PUT . =S . =S . E . U)

Prover-> Print Theorem

 H1.       A$[K].OUTTO sub B$[K]
       and ISMERGE(X$1, OUTTO\ARRAYTOBAG(A$, 1, NUSERS))
    -> ISMERGE(Y, ARRAYTOBAG(B$, 1, NUSERS)) and X$1 sub Y
```

.
.
.

Lemma#1 was skolemized and added as a new hypothesis, leaving the rest of the theorem unchanged. The prover backchains on H1, breaks the resulting theorem into two subgoals, then tries to prove the first subgoal and fails.

```
Prover-> Print Theorem

 H1.    AUSERPORT#1[J$].SYSOUT.PAR[I#2$].OUTTO
    sub SECUREMAIL(SECURITY[I#2$], SECURITY[J$],
                MAIL(AUSERPORT#1[I#2$].SYSIN.PAR[I#2$].INFROM, I#2$, J$))
 H2. ISMERGE(AUSERPORT#1[I#1$].SYSOUT.OUTTO,
          OUTTO\ARRAYTOBAG(AUSERPORT#1[I#1$].SYSOUT.PAR, 1, NUSERS))
 H3. ISMERGE(AUSERPORT#1[I#1$].SYSIN.INFROM,
          INFROM\ARRAYTOBAG(AUSERPORT#1[I#1$].SYSIN.PAR, 1, NUSERS))
 H4. I#2$ ne J$ -> AUSERPORT#1[J$].SYSIN.PAR[I#2$].INFROM = MSGSEQ()
IMP
 C1.    A$
          [K(AUSERPORT#1[J].SYSOUT.OUTTO,
            ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY), A$)]
          .OUTTO
    sub ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY)
          [K(AUSERPORT#1[J].SYSOUT.OUTTO,
            ALLSECUREMAILFOR(AUSERPORT#1, J, SECURITY), A$)]
```

The user directs the prover to establish an intermediate fact for use in the proof of C1.

```
Prover-> Claim
Newgoal:
* AUSERPORT#1[K].SYSIN.PAR[K].INFROM = AUSERPORT#1[K].SYSIN.INFROM;
```

After the user adds a lemma, the claim is established and then added as hypothesis H1.

```
Prover-> Use Lemma
Enter lemma . . .
* all A: MsgBufArray,  all I: UserId,  all X: MsgSeq,
*       (all J: UserId, I ne J -> A[J].Infrom=MsgSeq())
*   and IsMerge(X, Infrom!\ArrayToBag(A,1,Nusers))
* -> X = A[I].Infrom;
```

```
Lemma added . . . Its name is LEMMA*2

        .
        .
        .

Prover-> Print Theorem

  H1. AUSERPORT*1[K].SYSIN.PAR[K].INFROM = AUSERPORT*1[K].SYSIN.INFROM
  H2.     AUSERPORT*1[J$].SYSOUT.PAR[I*2$].OUTTO
     sub SECUREMAIL(SECURITY[I*2$], SECURITY[J$],
                 MAIL(AUSERPORT*1[I*2$].SYSIN.PAR[I*2$].INFROM, I*2$, J$))
  H3. ISMERGE(AUSERPORT*1[I*1$].SYSOUT.OUTTO,
           OUTTO\ARRAYTOBAG(AUSERPORT*1[I*1$].SYSOUT.PAR, 1, NUSERS))
  H4. ISMERGE(AUSERPORT*1[I*1$].SYSIN.INFROM,
           INFROM\ARRAYTOBAG(AUSERPORT*1[I*1$].SYSIN.PAR, 1, NUSERS))
  H5. I*2$ ne J$ -> AUSERPORT*1[J$].SYSIN.PAR[I*2$].INFROM = MSGSEQ()
IMP
  C1.    A$
          [K(AUSERPORT*1[J].SYSOUT.OUTTO,
            ALLSECUREMAILFOR(AUSERPORT*1, J, SECURITY), A$)]
          .OUTTO
     sub ALLSECUREMAILFOR(AUSERPORT*1, J, SECURITY)
          [K(AUSERPORT*1[J].SYSOUT.OUTTO,
            ALLSECUREMAILFOR(AUSERPORT*1, J, SECURITY), A$)]
```

The remaining sequence of events is (a) the specifications of AllSecureMailFor are added, (b) the prover fails to prove the theorem, (c) the user directs the prover to build a chain of equalities, and (d) the prover tries again and succeeds.

```
NETWORK*1 proved in theorem prover.

Suggest fully defining SWITCHER-> Print Status All

The current design and verification status is:
  Waiting for pending body to be filled in: SWITCHER
  Proved: NETWORK
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
       INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGINBUF, MSGOUTBUF,
       MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
       USERID, USERPORT, USERPORTARRAY
```

As indicated by the status summary, the top-level network program is completely proved and the switcher process is waiting to be implemented. The user has SID preview the potential effects of several possible changes before proceeding.

Suggest fully defining SWITCHER-> Explain

<- What are the effects of filling in Switcher's pending body?

No effects.

<- Why?

Because the body of SWITCHER is currently undefined.

<- What are the effects of changing its block specification?

No effects on SWITCHER. The verification of other programs is not affected if the formula

```
   Changed block specification
 -->
  C1: all J : USERID,        APORTS[J].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                  MAIL(APORTS[I].SYSIN.INFROM, I, J))
                     and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ())
```

is true. If not, the change invalidates the verification of NETWORK.

<- Why?

No effects on SWITCHER because it does not have any VCs. Invalid verification because the block specification of SWITCHER was used in proving NETWORK#1.

<- What are the effects of changing the header of SecureMail?

Possible effects of changing the header of SECUREMAIL are:
Incorrect semantics: ALLSECUREMAILFOR, SWITCHER
Invalid verification: NETWORK

<- Why is Network affected?

Invalid verification because the external specifications of ALLSECUREMAILFOR, which call SECUREMAIL, were used in proving NETWORK#1. Invalid verification because the external specifications of SWITCHER, which call SECUREMAIL, were used in proving NETWORK#1.

<- What are the effects of changing its exit?

No effects on SECUREMAIL. The verification of other programs is not affected.

<- Why?

No effects on SECUREMAIL because it is for specifications only and does not have VCs. No external effects because properties from SECUREMAIL have not been used in proving any VCs.

<- What are the effects of changing Mail's exit assertion?

No effects on MAIL. The verification of other programs is not affected.

<- Why?

No effects on MAIL because it is for specifications only and does not have VCs. No external effects because properties from MAIL have not been used in proving any VCs.

<- Done

Suggest fully defining SWITCHER-> Edit

.
.
.

Exec-> Translate Swichr.Net

```
process Switcher(i:UserId; var aports:UserPortArray;
                 Security:SecurityArray) =
begin
entry i in [1..NUsers];
block all j:userid,
        aports(j).sysout.outto sub
              securemail(security(i),security(j),
                    mail(aports(i).sysin.infrom,i,j))
      and
       ( j ne i  ->  aports(j).sysin.infrom = MsgSeq() );
var ms : Msg := MakeMsg(i,i,MsgText());

keep (assume source(ms) = i);
 loop
   assert all j:userid,
          aports(j).sysout.outto sub
                securemail(security(i),security(j),
                      mail(aports(i).sysin.infrom,i,j))
         and
          ( j ne i  ->  aports(j).sysin.infrom = MsgSeq() );
   begin
     receive ms from aports(i).SysIn;
     if Secure(Security(i),Security(Destination(ms)))
     then send ms to aports(Destination(ms)).SysOut
     end;
   when
   is ReceiveError: ;
   is SendError: ;
   end;
 end;
end;

function SecureMail(s1,s2:SecurityClass;
                    ms:MsgSeq):MsgSeq =
begin
  exit (assume SecureMail(s1,s2,ms) =
     ( if Secure(s1,s2) then ms
       else MsgSeq() fi));
end;

function Mail(ms:MsgSeq;i,j:UserId):MsgSeq =
begin
  exit (assume Mail(ms,i,j)=
```

```
        ( if ms = MsgSeq() then MsgSeq()
          else if Source(last(ms)) = i and
                  Destination(last(ms)) = j
               then Mail(nonlast(ms),i,j) @ MsgSeq(last(ms))
               else Mail(nonlast(ms),i,j) fi
          fi ));
    end;

    function Secure(s1,s2:SecurityClass):boolean = pending;

    function Source(M:Msg):UserId = pending;
    function Destination(M:Msg):UserId = pending;
    function MakeMsg(S,D : UserId; T : MsgText) : Msg =
    begin
      entry S in [1..NUsers] and D in [1..NUsers];
      pending
    end;

    type MsgText = pending;
```

```
No syntax errors detected.
No semantic errors detected.
```

The message switching process is completely implemented and specified. Several additional specifications are also entered for verification and type-checking purposes.

```
Exec-> Print Status All

The current design and verification status is:
  Waiting for VC generation: SWITCHER
  Waiting for pending body to be filled in: DESTINATION, MAKEMSG, SECURE,
      SOURCE
  Proved: NETWORK
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

Exec-> Suggest
```

```
Suggest generating VCs for SWITCHER-> §

Generating VCs for PROCESS SWITCHER

Found 1-ST path
Found 2-ND path
Found 3-RD path
Note: Loop has no exit paths
Found 4-TH path
Found 5-TH path
Found 6-TH path
Found 7-TH path
```

The trace of how the VCs for Switcher are generated is covered in the next several pages.

```
-------------------------------------------------
Beginning new path...
APORTS' := APORTS

Assume Initial Buffer Histories are null
    all I#1 : INTEGER [1..100],     APORTS[I#1].SYSIN.INFROM = MSGSEQ()
                          and APORTS[I#1].SYSIN.OUTTO = MSGSEQ()
                          and APORTS[I#1].SYSOUT.INFROM = MSGSEQ()
                          and APORTS[I#1].SYSOUT OUTTO = MSGSEQ()


Assume (unit entry condition)
    I in [1..NUSERS]

Initializing local variables

Evaluating  MAKEMSG(I, I, MSGTEXT())
Continuing in path...
MS := MAKEMSG(I, I, MSGTEXT())

Assume (KEEP assertion)
    SOURCE(MS) = I

Entering loop...

Evaluating  SECUREMAIL(SECURITY[I], SECURITY[J#1],
                  MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
```

```
Continuing in path...

Evaluating  MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
Continuing in path...
ASSERT all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I,
                                            J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - -
Must verify ASSERT condition
Verification condition SWITCHER#1
  H1: all I#1 : INTEGER [1..100],     APORTS[I#1].SYSIN.INFROM = MSGSEQ()
                              and APORTS[I#1].SYSIN.OUTTO = MSGSEQ()
                              and APORTS[I#1].SYSOUT.INFROM = MSGSEQ()
                              and APORTS[I#1].SYSOUT.OUTTO = MSGSEQ()
  H2: I = SOURCE(MAKEMSG(I, I, MSGTEXT()))
  H3: I in [1..NUSERS]
 -->
  C1: all J#i : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                      MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
- - - - - - - - - - - - - - - - - - - - - - -
End of path
-------------------------------------------------



-------------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I
```

```
RECEIVE MS FROM APORTS[I].SYSIN
MS := FIRST(APORTS*1[I].SYSIN.BUFQ)

Assume (KEEP assertion)
    SOURCE(MS) = I

Assume new buffer history
        (all I*2 : INTEGER [1..100],
              APORTS[I*2].SYSIN.OUTTO = APORTS*1[I*2].SYSIN.OUTTO
           and APORTS[I*2].SYSOUT.INFROM = APORTS*1[I*2].SYSOUT.INFROM
           and APORTS[I*2].SYSOUT.OUTTO = APORTS*1[I*2].SYSOUT.OUTTO
           and ( I*2 ne I
              -> APORTS[I*2].SYSIN.INFROM = APORTS*1[I*2].SYSIN.INFROM))
    and   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
       = APORTS*1[I].SYSIN.INFROM

APORTS := APORTS*1

Evaluating  DESTINATION(MS)
Continuing in path...

Evaluating  SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])
Continuing in path...

Assume (IF test succeeded)
    SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])

SEND MS TO APORTS[DESTINATION(MS)].SYSOUT

Assume new buffer history
    all I*4 : INTEGER [1..100],       APORTS*2[I*4].SYSIN.INFROM
                                 = APORTS[I*4].SYSIN.INFROM
                              and  APORTS*2[I*4].SYSIN.OUTTO
                                 = APORTS[I*4].SYSIN.OUTTO
                              and  APORTS*2[I*4].SYSOUT.INFROM
                                 = APORTS[I*4].SYSOUT.INFROM
                              and  APORTS*2[I*4].SYSOUT.OUTTO
                                 = APORTS[I*4].SYSOUT.OUTTO

APORTS := APORTS*2

Assume (SEND blocked)
    FULL(APORTS[DESTINATION(MS)].SYSOUT)
```

```
Blockage assertion is
      all J : USERID,          APORTS[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS[I].SYSIN.INFROM, I, J))
                  and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (process blockage) condition
Verification condition SWITCHER*2
 H1: all I*2 : INTEGER [1..100],       APORTS[I*2].SYSIN.OUTTO
                                  = APORTS*1[I*2].SYSIN.OUTTO
                                and   APORTS[I*2].SYSOUT.INFROM
                                  = APORTS*1[I*2].SYSOUT.INFROM
                                and   APORTS[I*2].SYSOUT.OUTTO
                                  = APORTS*1[I*2].SYSOUT.OUTTO
                                and ( I ne I*2
                                  ->   APORTS[I*2].SYSIN.INFROM
                                    = APORTS*1[I*2].SYSIN.INFROM)
 H2: all I*4 : INTEGER [1..100],       APORTS*1[I*4].SYSIN.INFROM
                                  = APORTS*2[I*4].SYSIN.INFROM
                                and   APORTS*1[I*4].SYSIN.OUTTO
                                  = APORTS*2[I*4].SYSIN.OUTTO
                                and   APORTS*1[I*4].SYSOUT.INFROM
                                  = APORTS*2[I*4].SYSOUT.INFROM
                                and   APORTS*1[I*4].SYSOUT.OUTTO
                                  = APORTS*2[I*4].SYSOUT.OUTTO
 H3: all J*1 : USERID,     (I ne J*1 -> APORTS[J*1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J*1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J*1],
                                      MAIL(APORTS[I].SYSIN.INFROM, I, J*1))
 H4:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
    = APORTS*1[I].SYSIN.INFROM
 H5: I = SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ))
 H6: I = SOURCE(MS)
 H7: FULL(APORTS*2[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))].SYSOUT)
 H8: SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))])
 -->
 C1: all J : USERID,     (I ne J -> APORTS*2[J].SYSIN.INFROM = MSGSEQ())
                   and     APORTS*2[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS*2[I].SYSIN.INFROM, I, J))
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
```

```
-----------------------------------------------

-----------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                     MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
                  and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I

RECEIVE MS FROM APORTS[I].SYSIN

Assume new buffer history
    all I#5 : INTEGER [1..100],       APORTS#1[I#5].SYSIN.INFROM
                                 = APORTS[I#5].SYSIN.INFROM
                              and  APORTS#1[I#5].SYSIN.OUTTO
                                 = APORTS[I#5].SYSIN.OUTTO
                              and  APORTS#1[I#5].SYSOUT.INFROM
                                 = APORTS[I#5].SYSOUT.INFROM
                              and  APORTS#1[I#5].SYSOUT.OUTTO
                                 = APORTS[I#5].SYSOUT.OUTTO

APORTS := APORTS#1

Assume (RECEIVE blocked)
    EMPTY(APORTS[I].SYSIN)

Blockage assertion is
      all J : USERID,          APORTS[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS[I].SYSIN.INFROM, I, J))
                  and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - -
Must verify (process blockage) condition
Verification condition SWITCHER#3
```

```
 H1: all I#5 : INTEGER [1..100],       APORTS[I#5].SYSIN.INFROM
                                  = APORTS#1[I#5].SYSIN.INFROM
                               and   APORTS[I#5].SYSIN.OUTTO
                                  = APORTS#1[I#5].SYSIN.OUTTO
                               and   APORTS[I#5].SYSOUT.INFROM
                                  = APORTS#1[I#5].SYSOUT.INFROM
                               and   APORTS[I#5].SYSOUT.OUTTO
                                  = APORTS#1[I#5].SYSOUT.OUTTO
 H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H3: EMPTY(APORTS#1[I].SYSIN)
 H4: I = SOURCE(MS)
-->
 C1: all J : USERID,     (I ne J -> APORTS#1[J].SYSIN.INFROM = MSGSEQ())
                   and     APORTS#1[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS#1[I].SYSIN.INFROM, I, J))
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-------------------------------------------------



-------------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J#1 : USERID,         APORTS[J#1].SYSOUT.OUTTO
                         sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                        MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I

RECEIVE MS FROM APORTS[I].SYSIN
MS := FIRST(APORTS#1[I].SYSIN.BUFQ)

Assume (KEEP assertion)
```

```
    SOURCE(MS) = I

Assume new buffer history
        (all I#2 : INTEGER [1..100],
              APORTS[I#2].SYSIN.OUTTO = APORTS#1[I#2].SYSIN.OUTTO
            and APORTS[I#2].SYSOUT.INFROM = APORTS#1[I#2].SYSOUT.INFROM
            and APORTS[I#2].SYSOUT.OUTTO = APORTS#1[I#2].SYSOUT.OUTTO
            and ( I#2 ne I
              -> APORTS[I#2].SYSIN.INFROM = APORTS#1[I#2].SYSIN.INFROM))
    and   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
        = APORTS#1[I].SYSIN.INFROM

APORTS := APORTS#1

Evaluating  DESTINATION(MS)
Continuing in path...

Evaluating  SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])
Continuing in path...

Assume (IF test succeeded)
    SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])

SEND MS TO APORTS[DESTINATION(MS)].SYSOUT

Assume new buffer history
        (all I#3 : INTEGER [1..100],
              APORTS[I#3].SYSIN.INFROM = APORTS#2[I#3].SYSIN.INFROM
            and APORTS[I#3].SYSIN.OUTTO = APORTS#2[I#3].SYSIN.OUTTO
            and APORTS[I#3].SYSOUT.INFROM = APORTS#2[I#3].SYSOUT.INFROM
            and ( I#3 ne DESTINATION(MS)
              -> APORTS[I#3].SYSOUT.OUTTO = APORTS#2[I#3].SYSOUT.OUTTO))
    and   APORTS[DESTINATION(MS)].SYSOUT.OUTTO @ MSGSEQ(MS)
        = APORTS#2[DESTINATION(MS)].SYSOUT.OUTTO

APORTS := APORTS#2
Entering next iteration of loop...

Evaluating  SECUREMAIL(SECURITY[I], SECURITY[J#1],
                    MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
Continuing in path...

Evaluating  MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
```

```
Continuing in path...
ASSERT all J#1 : USERID,        APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I,
                                            J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify ASSERT condition
Verification condition SWITCHER#4
  H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                  = APORTS#1[I#2].SYSIN.OUTTO
                              and   APORTS[I#2].SYSOUT.INFROM
                                  = APORTS#1[I#2].SYSOUT.INFROM
                              and   APORTS[I#2].SYSOUT.OUTTO
                                  = APORTS#1[I#2].SYSOUT.OUTTO
                              and ( I ne I#2
                                  ->   APORTS[I#2].SYSIN.INFROM
                                     = APORTS#1[I#2].SYSIN.INFROM)
  H2: all I#3 : INTEGER [1..100],
           APORTS#1[I#3].SYSIN.INFROM = APORTS#2[I#3].SYSIN.INFROM
        and APORTS#1[I#3].SYSIN.OUTTO = APORTS#2[I#3].SYSIN.OUTTO
        and APORTS#1[I#3].SYSOUT.INFROM = APORTS#2[I#3].SYSOUT.INFROM
        and ( I#3 ne DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))
           -> APORTS#1[I#3].SYSOUT.OUTTO = APORTS#2[I#3].SYSOUT.OUTTO)
  H3: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                      and     APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
  H4:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
     = APORTS#1[I].SYSIN.INFROM
  H5:      APORTS#1[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT.OUTTO
        @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
     = APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT.OUTTO
  H6: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
  H7: I = SOURCE(MS)
  H8: SECURE(SECURITY[I],
           SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
 -->
  C1: all J#1 : USERID,     (I ne J#1 -> APORTS#2[J#1].SYSIN.INFROM = MSGSEQ())
                      and     APORTS#2[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS#2[I].SYSIN.INFROM, I,
                                            J#1))
```

```
- - - - - - - - - - - - - - - - - - - - - - -
End of path
-------------------------------------------------


-------------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I

RECEIVE MS FROM APORTS[I].SYSIN
MS := FIRST(APORTS#1[I].SYSIN.BUFQ)

Assume (KEEP assertion)
    SOURCE(MS) = I

Assume new buffer history
        (all I#2 : INTEGER [1..100],
              APORTS[I#2].SYSIN.OUTTO = APORTS#1[I#2].SYSIN.OUTTO
            and APORTS[I#2].SYSOUT.INFROM = APORTS#1[I#2].SYSOUT.INFROM
            and APORTS[I#2].SYSOUT.OUTTO = APORTS#1[I#2].SYSOUT.OUTTO
            and ( I#2 ne I
               -> APORTS[I#2].SYSIN.INFROM = APORTS#1[I#2].SYSIN.INFROM))
    and   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
       = APORTS#1[I].SYSIN.INFROM

APORTS := APORTS#1

Evaluating  DESTINATION(MS)
Continuing in path...

Evaluating  SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])
Continuing in path...
```

```
Assume (IF test succeeded)
    SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])


Evaluating  DESTINATION(MS)
Continuing in path...
SEND MS TO APORTS[DESTINATION(MS)].SYSOUT
Signalling condition SENDERROR
Entering WHEN part...
Entering next iteration of loop...

Evaluating  SECUREMAIL(SECURITY[I], SECURITY[J#1],
                  MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
Continuing in path...

Evaluating  MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
Continuing in path...
ASSERT all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                   MAIL(APORTS[I].SYSIN.INFROM, I,
                                      J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - -
Must verify ASSERT condition
Verification condition SWITCHER#5
  H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                 = APORTS#1[I#2].SYSIN.OUTTO
                               and   APORTS[I#2].SYSOUT.INFROM
                                 = APORTS#1[I#2].SYSOUT.INFROM
                               and   APORTS[I#2].SYSOUT.OUTTO
                                 = APORTS#1[I#2].SYSOUT.OUTTO
                               and (  I ne I#2
                                 ->   APORTS[I#2].SYSIN.INFROM
                                   = APORTS#1[I#2].SYSIN.INFROM)
  H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                      and     APORTS[J#1].SYSOUT.OUTTO
                         sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                      MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
  H3:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
     = APORTS#1[I].SYSIN.INFROM
  H4: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
  H5: I = SOURCE(MS)
  H6: SECURE(SECURITY[I],
```

```
          SECURITY[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))])
 -->
  C1: all J*1 : USERID,     (I ne J*1 -> APORTS*1[J*1].SYSIN.INFROM = MSGSEQ())
                      and     APORTS*1[J*1].SYSOUT.OUTTO
                         sub SECUREMAIL(SECURITY[I], SECURITY[J*1],
                                        MAIL(APORTS*1[I].SYSIN.INFROM, I,
                                             J*1))
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-----------------------------------------------


-----------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J*1 : USERID,         APORTS[J*1].SYSOUT.OUTTO
                         sub SECUREMAIL(SECURITY[I], SECURITY[J*1],
                                        MAIL(APORTS[I].SYSIN.INFROM, I, J*1))
                    and (J*1 ne I -> APORTS[J*1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I

RECEIVE MS FROM APORTS[I].SYSIN
MS := FIRST(APORTS*1[I].SYSIN.BUFQ)

Assume (KEEP assertion)
    SOURCE(MS) = I

Assume new buffer history
       (all I*2 : INTEGER [1..100],
            APORTS[I*2].SYSIN.OUTTO = APORTS*1[I*2].SYSIN.OUTTO
          and APORTS[I*2].SYSOUT.INFROM = APORTS*1[I*2].SYSOUT.INFROM
          and APORTS[I*2].SYSOUT.OUTTO = APORTS*1[I*2].SYSOUT.OUTTO
          and ( I*2 ne I
             -> APORTS[I*2].SYSIN.INFROM = APORTS*1[I*2].SYSIN.INFROM))
    and   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
      = APORTS*1[I].SYSIN.INFROM
```

```
APORTS := APORTS#1

Assume (IF test failed)
    (not SECURE(SECURITY[I], SECURITY[DESTINATION(MS)]))

Entering next iteration of loop...

Evaluating  SECUREMAIL(SECURITY[I], SECURITY[J#1],
                  MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
Continuing in path...

Evaluating  MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
Continuing in path...
ASSERT all J#1 : USERID,          APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                  MAIL(APORTS[I].SYSIN.INFROM, I,
                                     J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify ASSERT condition
Verification condition SWITCHER#6
 H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                              = APORTS#1[I#2].SYSIN.OUTTO
                            and   APORTS[I#2].SYSOUT.INFROM
                              = APORTS#1[I#2].SYSOUT.INFROM
                            and   APORTS[I#2].SYSOUT.OUTTO
                              = APORTS#1[I#2].SYSOUT.OUTTO
                            and (  I ne I#2
                              ->   APORTS[I#2].SYSIN.INFROM
                                = APORTS#1[I#2].SYSIN.INFROM)
 H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                  MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H3:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
   = APORTS#1[I].SYSIN.INFROM
 H4: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H5: I = SOURCE(MS)
 H6: (not SECURE(SECURITY[I],
             SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))]))
-->
 C1: all J#1 : USERID,     (I ne J#1 -> APORTS#1[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS#1[J#1].SYSOUT.OUTTO
```

```
                    sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                   MAIL(APORTS#1[I].SYSIN.INFROM, I,
                                     J#1))
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-----------------------------------------------



-----------------------------------------------
Beginning new path...
Continuing in LOOP ...

Assume (from last assertion)
    all J#1 : USERID,        APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
                  and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())


Assume (KEEP assertion)
    SOURCE(MS) = I

RECEIVE MS FROM APORTS[I].SYSIN

Assume new buffer history
        (all I#2 : INTEGER [1..100],
             APORTS[I#2].SYSIN.OUTTO = APORTS#1[I#2].SYSIN.OUTTO
           and APORTS[I#2].SYSOUT.INFROM = APORTS#1[I#2].SYSOUT.INFROM
           and APORTS[I#2].SYSOUT.OUTTO = APORTS#1[I#2].SYSOUT.OUTTO
           and ( I#2 ne I
              -> APORTS[I#2].SYSIN.INFROM = APORTS#1[I#2].SYSIN.INFROM))
    and   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
      = APORTS#1[I].SYSIN.INFROM

Signalling condition RECEIVEERROR
Entering WHEN part...
Entering next iteration of loop...

Evaluating  SECUREMAIL(SECURITY[I], SECURITY[J#1],
                   MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
Continuing in path...
```

```
Evaluating  MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
Continuing in path...
ASSERT all J#1 : USERID,        APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                MAIL(APORTS[I].SYSIN.INFROM, I,
                                    J#1))
                    and (J#1 ne I -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify ASSERT condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-----------------------------------------------
```

Suggest proving VC called SWITCHER#1-> Print Status All

```
The current design and verification status is:
  Waiting for pending body to be filled in: DESTINATION, MAKEMSG, SECURE,
      SOURCE
  Proved: NETWORK
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

  SWITCHER
    Waiting to be proved: SWITCHER#1, SWITCHER#2, SWITCHER#3, SWITCHER#4,
      SWITCHER#5, SWITCHER#6
    Proved in VC generator: SWITCHER#7
```

As reflected in the status summary, seven VCs were generated for Switcher, six of which are unproved. They are proved in sequence below.

```
Suggest proving VC called SWITCHER#1-> §
Entering Prover with verification condition SWITCHER#1
 H1: all I#1 : INTEGER [1..100],     APORTS[I#1].SYSIN.INFROM = MSGSEQ()
                          and APORTS[I#1].SYSIN.OUTTO = MSGSEQ()
                          and APORTS[I#1].SYSOUT.INFROM = MSGSEQ()
                          and APORTS[I#1].SYSOUT.OUTTO = MSGSEQ()
 H2: I = SOURCE(MAKEMSG(I, I, MSGTEXT()))
 H3: I in [1..NUSERS]
```

```
-->
 C1: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                   MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
```

.
.
.

SWITCHER#1 proved in theorem prover.

This proof was done automatically except for a few interactive equality substitutions.

```
Suggest proving VC called SWITCHER#2-> §
Entering Prover with verification condition SWITCHER#2
 H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                  = APORTS#1[I#2].SYSIN.OUTTO
                               and   APORTS[I#2].SYSOUT.INFROM
                                  = APORTS#1[I#2].SYSOUT.INFROM
                               and   APORTS[I#2].SYSOUT.OUTTO
                                  = APORTS#1[I#2].SYSOUT.OUTTO
                               and (  I ne I#2
                                  ->   APORTS[I#2].SYSIN.INFROM
                                     = APORTS#1[I#2].SYSIN.INFROM)
 H2: all I#4 : INTEGER [1..100],       APORTS#1[I#4].SYSIN.INFROM
                                  = APORTS#2[I#4].SYSIN.INFROM
                               and   APORTS#1[I#4].SYSIN.OUTTO
                                  = APORTS#2[I#4].SYSIN.OUTTO
                               and   APORTS#1[I#4].SYSOUT.INFROM
                                  = APORTS#2[I#4].SYSOUT.INFROM
                               and   APORTS#1[I#4].SYSOUT.OUTTO
                                  = APORTS#2[I#4].SYSOUT.OUTTO
 H3: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                   MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H4:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
 H5: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H6: I = SOURCE(MS)
```

```
 H7: FULL(APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT)
 H8: SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
-->
 C1: all J : USERID,     (I ne J -> APORTS#2[J].SYSIN.INFROM = MSGSEQ())
                  and     APORTS#2[J].SYSOUT.OUTTO
                    sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                MAIL(APORTS#2[I].SYSIN.INFROM, I, J))
```

The proof of this theorem is representative of many of the other proofs and is therefore presented in its entirety. The current theorem is printed frequently to aid in following the manipulations.

```
Backup point
(.)

Prover-> Print Theorem

 H1.   I
    in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
        ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
 H2. APORTS[I#2$].SYSIN.OUTTO = APORTS#1[I#2$].SYSIN.OUTTO
 H3. APORTS[I#2$].SYSOUT.INFROM = APORTS#1[I#2$].SYSOUT.INFROM
 H4. APORTS[I#2$].SYSOUT.OUTTO = APORTS#1[I#2$].SYSOUT.OUTTO
 H5. I ne I#2$ -> APORTS[I#2$].SYSIN.INFROM = APORTS#1[I#2$].SYSIN.INFROM
 H6. APORTS#1[I#4$].SYSIN.INFROM = APORTS#2[I#4$].SYSIN.INFROM
 H7. APORTS#1[I#4$].SYSIN.OUTTO = APORTS#2[I#4$].SYSIN.OUTTO
 H8. APORTS#1[I#4$].SYSOUT.INFROM = APORTS#2[I#4$].SYSOUT.INFROM
 H9. APORTS#1[I#4$].SYSOUT.OUTTO = APORTS#2[I#4$].SYSOUT.OUTTO
 H10. I ne J#1$ -> APORTS[J#1$].SYSIN.INFROM = MSGSEQ()
 H11.    APORTS[J#1$].SYSOUT.OUTTO
     sub SECUREMAIL(SECURITY[I], SECURITY[J#1$],
                 MAIL(APORTS[I].SYSIN.INFROM, I, J#1$))
 H12.  APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
     = APORTS#1[I].SYSIN.INFROM
 H13. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H14. I = SOURCE(MS)
 H15. FULL(APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT)
 H16. SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
IMP
 C1. I ne J -> APORTS#2[J].SYSIN.INFROM = MSGSEQ()
 C2.    APORTS#2[J].SYSOUT.OUTTO
```

```
    sub SECUREMAIL(SECURITY[I], SECURITY[J],
                MAIL(APORTS*2[I].SYSIN.INFROM, I, J))
```

Prover-> **Delete H2,H3,H7,H8**

Several irrelevant hypotheses are deleted.

Prover-> **$Proceeding**

```
(. D 1)
Backup point
(. D 1 P-> .)
```

Prover-> **Print Theorem**

```
  H1. I ne J
  H2.   I
      in [MAX(SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ)), SOURCE(MS))
          ..MIN(SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ)), SOURCE(MS))]
  H3. APORTS[I*2$].SYSOUT.OUTTO = APORTS*1[I*2$].SYSOUT.OUTTO
  H4. I ne I*2$ -> APORTS[I*2$].SYSIN.INFROM = APORTS*1[I*2$].SYSIN.INFROM
  H5. APORTS*1[I*4$].SYSIN.INFROM = APORTS*2[I*4$].SYSIN.INFROM
  H6. APORTS*1[I*4$].SYSOUT.OUTTO = APORTS*2[I*4$].SYSOUT.OUTTO
  H7. I ne J*1$ -> APORTS[J*1$].SYSIN.INFROM = MSGSEQ()
  H8.     APORTS[J*1$].SYSOUT.OUTTO
      sub SECUREMAIL(SECURITY[I], SECURITY[J*1$],
                  MAIL(APORTS[I].SYSIN.INFROM, I, J*1$))
  H9.   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
      = APORTS*1[I].SYSIN.INFROM
  H10. I = SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ))
  H11. I = SOURCE(MS)
  H12. FULL(APORTS*2[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))].SYSOUT)
  H13. SECURE(SECURITY[I],
            SECURITY[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))])
IMP
  C1. APORTS*2[J].SYSIN.INFROM = MSGSEQ()
```

The prover split the theorem into two subgoals and promoted the hypothesis of C1 to hypothesis H1 of the theorem. Hypotheses not relevant to this subgoal are deleted, retaining only four.

Prover-> **Retain H1,H4,H5,H7**

Prover-> **Print Theorem**

```
 H1. I ne J
 H2. I ne I#2$ -> APORTS[I#2$].SYSIN.INFROM = APORTS#1[I#2$].SYSIN.INFROM
 H3. APORTS#1[I#4$].SYSIN.INFROM = APORTS#2[I#4$].SYSIN.INFROM
 H4. I ne J#1$ -> APORTS[J#1$].SYSIN.INFROM = MSGSEQ()
IMP
 C1. APORTS#2[J].SYSIN.INFROM = MSGSEQ()
```

The proof of this theorem requires establishing a chain of equalities involving H3, C1, and the conclusions of H2 and H4.

```
Prover-> Eq Chain
New subgoal
Backup point
(. D 1 P-> . D =CHAIN .)

Prover-> Print Conclusion

 C1. I ne J
 C2. I ne J
```

C1 and C2 are hypotheses from H2 and H4 that must be proved for the chain to be valid.

```
Prover-> Simplify Theorem

Prover-> Print Conclusion

 C1. TRUE
```

This completes the proof of subgoal C1. The prover tries and fails to prove C2, which cannot be proved without an additional lemma.

```
Prover-> $Proceeding
(. D 2)
.....Ran out of tricks

Prover-> Print Theorem

 H1.  I
    in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
        ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
 H2. APORTS[I#2$].SYSOUT.OUTTO = APORTS#1[I#2$].SYSOUT.OUTTO
 H3. I ne I#2$ -> APORTS[I#2$].SYSIN.INFROM = APORTS#1[I#2$].SYSIN.INFROM
```

```
 H4. APORTS#1[I#4$].SYSIN.INFROM = APORTS#2[I#4$].SYSIN.INFROM
 H5. APORTS#1[I#4$].SYSOUT.OUTTO = APORTS#2[I#4$].SYSOUT.OUTTO
 H6. I ne J#1$ -> APORTS[J#1$].SYSIN.INFROM = MSGSEQ()
 H7.    APORTS[J#1$].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J#1$],
                MAIL(APORTS[I].SYSIN.INFROM, I, J#1$))
 H8.  APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
 H9. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H10. I = SOURCE(MS)
 H11. FULL(APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT)
 H12. SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
IMP
 C1.    APORTS#2[J].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J],
                MAIL(APORTS#2[I].SYSIN.INFROM, I, J))

Prover-> Use Lemma
Enter lemma . . .
* all A,B: MsgSeq, all C:Msg, all K,L: UserId, all S1,S2: SecurityClass,
*       A sub SecureMail(S1,S2,Mail(B,K,L))
* ->    A sub SecureMail(S1,S2,Mail(B@MsgSeq(C),K,L));
Lemma added . . . Its name is LEMMA#3
(. D 2 U)

Prover-> Print Theorem

 H1.    A$ sub SECUREMAIL(S1$, S2$, MAIL(B$, K$, L$))
    -> A$ sub SECUREMAIL(S1$, S2$, MAIL(B$@MSGSEQ(C$), K$, L$))
 H2.    I
    in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
        ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
 H3. APORTS[I#2$].SYSOUT.OUTTO = APORTS#1[I#2$].SYSOUT.OUTTO
 H4. I ne I#2$ -> APORTS[I#2$].SYSIN.INFROM = APORTS#1[I#2$].SYSIN.INFROM
 H5. APORTS#1[I#4$].SYSIN.INFROM = APORTS#2[I#4$].SYSIN.INFROM
 H6. APORTS#1[I#4$].SYSOUT.OUTTO = APORTS#2[I#4$].SYSOUT.OUTTO
 H7. I ne J#1$ -> APORTS[J#1$].SYSIN.INFROM = MSGSEQ()
 H8.    APORTS[J#1$].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J#1$],
                MAIL(APORTS[I].SYSIN.INFROM, I, J#1$))
 H9.  APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
```

```
  H10. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
  H11. I = SOURCE(MS)
  H12. FULL(APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT)
  H13. SECURE(SECURITY[I],
            SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
IMP
  C1.    APORTS#2[J].SYSOUT.OUTTO
     sub SECUREMAIL(SECURITY[I], SECURITY[J],
                 MAIL(APORTS#2[I].SYSIN.INFROM, I, J))
```

Lemma#3 has been added to the theorem as hypothesis H1. Two equality chains are needed to complete the proof.

```
Prover-> Eq Chain
New subgoal
Backup point
(. D 2 U . =CHAIN .)

Prover-> Print Conclusion

  C1.    APORTS#2[J].SYSOUT.OUTTO
     sub SECUREMAIL(SECURITY[I], SECURITY[J],
                 MAIL(APORTS[I].SYSIN.INFROM, I, J))

Prover-> Retain H3,H6,H8

Prover-> Print Theorem

  H1. APORTS[I#2$].SYSOUT.OUTTO = APORTS#1[I#2$].SYSOUT.OUTTO
  H2. APORTS#1[I#4$].SYSOUT.OUTTO = APORTS#2[I#4$].SYSOUT.OUTTO
  H3.    APORTS[J#1$].SYSOUT.OUTTO
     sub SECUREMAIL(SECURITY[I], SECURITY[J#1$],
                 MAIL(APORTS[I].SYSIN.INFROM, I, J#1$))
IMP
  C1.    APORTS#2[J].SYSOUT.OUTTO
     sub SECUREMAIL(SECURITY[I], SECURITY[J],
                 MAIL(APORTS[I].SYSIN.INFROM, I, J))

Prover-> Eq Chain
New subgoal
Backup point
(. D 2 U . =CHAIN . D =CHAIN .)
```

```
Prover-> Print Conclusion

 C1. TRUE

Prover-> §Proceeding

SWITCHER#2 proved in theorem prover.

Suggest proving VC called SWITCHER#3-> §
Entering Prover with verification condition SWITCHER#3
 H1: all I#5 : INTEGER [1..100],       APORTS[I#5].SYSIN.INFROM
                                  = APORTS#1[I#5].SYSIN.INFROM
                               and  APORTS[I#5].SYSIN.OUTTO
                                  = APORTS#1[I#5].SYSIN.OUTTO
                               and  APORTS[I#5].SYSOUT.INFROM
                                  = APORTS#1[I#5].SYSOUT.INFROM
                               and  APORTS[I#5].SYSOUT.OUTTO
                                  = APORTS#1[I#5].SYSOUT.OUTTO
 H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                    and     APORTS[J#1].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                      MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H3: EMPTY(APORTS#1[I].SYSIN)
 H4: I = SOURCE(MS)
-->
 C1: all J : USERID,     (I ne J -> APORTS#1[J].SYSIN.INFROM = MSGSEQ())
                   and     APORTS#1[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS#1[I].SYSIN.INFROM, I, J))
```

The proof of this VC is entirely automatic, with the user initiating two equality chains.

.
.
.

```
SWITCHER#3 proved in theorem prover.

Suggest proving VC called SWITCHER#4-> §
Entering Prover with verification condition SWITCHER#4
 H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                  = APORTS#1[I#2].SYSIN.OUTTO
```

```
                                and   APORTS[I*2].SYSOUT.INFROM
                                   = APORTS*1[I*2].SYSOUT.INFROM
                                and   APORTS[I*2].SYSOUT.OUTTO
                                   = APORTS*1[I*2].SYSOUT.OUTTO
                                and (  I ne I*2
                                   ->   APORTS[I*2].SYSIN.INFROM
                                     = APORTS*1[I*2].SYSIN.INFROM)
 H2: all I*3 : INTEGER [1..100],
          APORTS*1[I*3].SYSIN.INFROM = APORTS*2[I*3].SYSIN.INFROM
       and APORTS*1[I*3].SYSIN.OUTTO = APORTS*2[I*3].SYSIN.OUTTO
       and APORTS*1[I*3].SYSOUT.INFROM = APORTS*2[I*3].SYSOUT.INFROM
       and (  I*3 ne DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))
          -> APORTS*1[I*3].SYSOUT.OUTTO = APORTS*2[I*3].SYSOUT.OUTTO)
 H3: all J*1 : USERID,     (I ne J*1 -> APORTS[J*1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS[J*1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J*1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J*1))
 H4:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
    = APORTS*1[I].SYSIN.INFROM
 H5:      APORTS*1[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))].SYSOUT.OUTTO
       @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
    = APORTS*2[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))].SYSOUT.OUTTO
 H6: I = SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ))
 H7: I = SOURCE(MS)
 H8: SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))])
-->
 C1: all J*1 : USERID,     (I ne J*1 -> APORTS*2[J*1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS*2[J*1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J*1],
                                       MAIL(APORTS*2[I].SYSIN.INFROM, I,
                                            J*1))
```

.
.
.

The first subgoal was proved with a promotion and an equality chain. The proof of the second requires a cases argument, as shown below.

Prover-> Print Theorem

```
H1.   I
   in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
       ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
H2. APORTS[I#2$#1].SYSIN.OUTTO = APORTS#1[I#2$#1].SYSIN.OUTTO
H3. APORTS[I#2$#1].SYSOUT.INFROM = APORTS#1[I#2$#1].SYSOUT.INFROM
H4. APORTS[I#2$#1].SYSOUT.OUTTO = APORTS#1[I#2$#1].SYSOUT.OUTTO
H5.   I ne I#2$#1
   -> APORTS[I#2$#1].SYSIN.INFROM = APORTS#1[I#2$#1].SYSIN.INFROM
H6. APORTS#1[I#3$].SYSIN.INFROM = APORTS#2[I#3$].SYSIN.INFROM
H7. APORTS#1[I#3$].SYSIN.OUTTO = APORTS#2[I#3$].SYSIN.OUTTO
H8. APORTS#1[I#3$].SYSOUT.INFROM = APORTS#2[I#3$].SYSOUT.INFROM
H9.   DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ)) ne I#3$
   -> APORTS#1[I#3$].SYSOUT.OUTTO = APORTS#2[I#3$].SYSOUT.OUTTO
H10. I ne J#1$#2 -> APORTS[J#1$#2].SYSIN.INFROM = MSGSEQ()
H11.    APORTS[J#1$#2].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J#1$#2],
                MAIL(APORTS[I].SYSIN.INFROM, I, J#1$#2))
H12.  APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
H13.     APORTS#1[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT
           .OUTTO
      @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#2[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))].SYSOUT.OUTTO
H14. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
H15. I = SOURCE(MS)
H16. SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
IMP
C1.    APORTS#2[J#1].SYSOUT.OUTTO
   sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
               MAIL(APORTS#2[I].SYSIN.INFROM, I, J#1))

Prover-> Cases
CASE:
* J#1 = DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ));
CASE:
* $ DONE
Attempting CASE1
```

The remaining "not equal" case is generated by the prover. After deleting some irrelevant hypotheses and doing several equality substitutions, we come to the key part of the proof.

```
Prover-> Print Theorem

 H1.  APORTS#1[J#1].SYSOUT.OUTTO @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#2[J#1].SYSOUT.OUTTO
 H2. APORTS[J#1].SYSOUT.OUTTO = APORTS#1[J#1].SYSOUT.OUTTO
 H3. J#1 = DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H4. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H5. I = SOURCE(MS)
 H6. SECURE(SECURITY[I], SECURITY[J#1])
 H7. I ne J#1 -> APORTS#1[I].SYSOUT.OUTTO = APORTS#2[I].SYSOUT.OUTTO
 H8.    APORTS[J#1].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
IMP
 C1.    APORTS#2[J#1].SYSOUT.OUTTO
    sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                MAIL(  APORTS[I].SYSIN.INFROM
                   @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ)), I, J#1))
```

The proof of this theorem requires the definitions of SecureMail and Mail.

```
Prover-> Expand SecureMail
More than one to expand.
Which do you want to expand? All
Backup point
(. 2 . CASE1 . D PUT . =S . E .)

Prover-> Print Theorem

 H1.  I
    in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
        ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
 H2.    APORTS[J#1].SYSOUT.OUTTO
    sub if SECURE(SECURITY[I], SECURITY[J#1])
         then MAIL(APORTS[I].SYSIN.INFROM, I, J#1) else MSGSEQ() fi
 H3. I ne J#1 -> APORTS#1[I].SYSOUT.OUTTO = APORTS#2[I].SYSOUT.OUTTO
 H4. SECURE(SECURITY[I], SECURITY[J#1])
 H5. I = SOURCE(MS)
 H6. I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H7. J#1 = DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H8. APORTS[J#1].SYSOUT.OUTTO = APORTS#1[J#1].SYSOUT.OUTTO
 H9.  APORTS#1[J#1].SYSOUT.OUTTO @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#2[J#1].SYSOUT.OUTTO
```

```
IMP
  C1.     APORTS*2[J*1].SYSOUT.OUTTO
     sub if SECURE(SECURITY[I], SECURITY[J*1])
          then MAIL(   APORTS[I].SYSIN.INFROM
                  @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ)), I, J*1)
          else MSGSEQ() fi

Prover-> Expand Mail
More than one to expand.
Which do you want to expand? Show

  1. MAIL(APORTS[I].SYSIN.INFROM, I, J*1)
  2. MAIL(APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ)), I,
        J*1)

Which do you want to expand? 2
Backup point
(. 2 . CASE1 . D PUT . =S . E . E .)

Prover-> Print Theorem

  H1.   APORTS*1[J*1].SYSOUT.OUTTO @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
     = APORTS*2[J*1].SYSOUT.OUTTO
  H2. APORTS[J*1].SYSOUT.OUTTO = APORTS*1[J*1].SYSOUT.OUTTO
  H3. J*1 = DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))
  H4. I = SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ))
  H5. I = SOURCE(MS)
  H6. SECURE(SECURITY[I], SECURITY[J*1])
  H7. I ne J*1 -> APORTS*1[I].SYSOUT.OUTTO = APORTS*2[I].SYSOUT.OUTTO
  H8.     APORTS[J*1].SYSOUT.OUTTO
     sub if SECURE(SECURITY[I], SECURITY[J*1])
          then MAIL(APORTS[I].SYSIN.INFROM, I, J*1) else MSGSEQ() fi
  H9.    I
     in [MAX(SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ)), SOURCE(MS))
         ..MIN(SOURCE(FIRST(APORTS*1[I].SYSIN.BUFQ)), SOURCE(MS))]
IMP
  C1.     APORTS*2[J*1].SYSOUT.OUTTO
     sub if SECURE(SECURITY[I], SECURITY[J*1])
          then if      APORTS[I].SYSIN.INFROM
                    @ MSGSEQ(FIRST(APORTS*1[I].SYSIN.BUFQ))
                 = MSGSEQ() then MSGSEQ()
                 else if      J*1
                           = DESTINATION(FIRST(APORTS*1[I].SYSIN.BUFQ))
```

```
                    and I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
                    then    MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
                        @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
                    else MAIL(APORTS[I].SYSIN.INFROM, I, J#1) fi fi
          else MSGSEQ() fi

Prover->
        .
        .
        .

Prover-> Print Theorem

  H1.   I
     in [MAX(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))
          ..MIN(SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ)), SOURCE(MS))]
  H2. if SECURE(SECURITY[I], SECURITY[J#1])
        then     APORTS[J#1].SYSOUT.OUTTO
             sub MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
        else APORTS[J#1].SYSOUT.OUTTO = MSGSEQ() fi
  H3. SECURE(SECURITY[I], SECURITY[J#1])
  H4. APORTS[J#1].SYSOUT.OUTTO = APORTS#1[J#1].SYSOUT.OUTTO
  H5.  APORTS#1[J#1].SYSOUT.OUTTO @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
     = APORTS#2[J#1].SYSOUT.OUTTO
IMP
  C1.      APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
        = MSGSEQ()
     -> APORTS#2[J#1].SYSOUT.OUTTO = MSGSEQ()
  C2.    (not      APORTS[I].SYSIN.INFROM
              @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
            = MSGSEQ())
     ->     APORTS#2[J#1].SYSOUT.OUTTO
        sub    MAIL(APORTS[I].SYSIN.INFROM, I, J#1)
           @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
```

The proof of this theorem requires three additional lemmas.

```
Prover-> Use Lemma
Enter lemma . . .
* all A:MsgSeq, all M:Msg, A @ MsgSeq(M) ne MsgSeq();
Lemma added . . . Its name is LEMMA#4
        .
        .
```

```
Prover-> Use Lemma
Enter lemma . . .
* all A,B,C:MsgSeq,   A sub B  ->  A@C sub B@C;
Lemma added . . . Its name is LEMMA#5
        .
        .
        .

Prover-> Use Lemma#3
        .
        .
        .

SWITCHER#4 proved in theorem prover.

Suggest proving VC called SWITCHER#5-> §
Entering Prover with verification condition SWITCHER#5
 H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                  = APORTS#1[I#2].SYSIN.OUTTO
                               and   APORTS[I#2].SYSOUT.INFROM
                                  = APORTS#1[I#2].SYSOUT.INFROM
                               and   APORTS[I#2].SYSOUT.OUTTO
                                  = APORTS#1[I#2].SYSOUT.OUTTO
                               and ( I ne I#2
                                  ->   APORTS[I#2].SYSIN.INFROM
                                     = APORTS#1[I#2].SYSIN.INFROM)
 H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H3:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
 H4: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H5: I = SOURCE(MS)
 H6: SECURE(SECURITY[I],
          SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))])
 -->
 C1: all J#1 : USERID,     (I ne J#1 -> APORTS#1[J#1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS#1[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS#1[I].SYSIN.INFROM, I,
```

```
                                    J#1))
```

The scenario for this proof is the same as for Switcher#2. The only additional property required in the proof is Lemma#3.

.
.
.

```
SWITCHER#5 proved in theorem prover.

Suggest proving VC called SWITCHER#6-> §
Entering Prover with verification condition SWITCHER#6
 H1: all I#2 : INTEGER [1..100],       APORTS[I#2].SYSIN.OUTTO
                                    = APORTS#1[I#2].SYSIN.OUTTO
                                 and   APORTS[I#2].SYSOUT.INFROM
                                    = APORTS#1[I#2].SYSOUT.INFROM
                                 and   APORTS[I#2].SYSOUT.OUTTO
                                    = APORTS#1[I#2].SYSOUT.OUTTO
                                 and ( I ne I#2
                                    ->   APORTS[I#2].SYSIN.INFROM
                                       = APORTS#1[I#2].SYSIN.INFROM)
 H2: all J#1 : USERID,     (I ne J#1 -> APORTS[J#1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS[I].SYSIN.INFROM, I, J#1))
 H3:   APORTS[I].SYSIN.INFROM @ MSGSEQ(FIRST(APORTS#1[I].SYSIN.BUFQ))
    = APORTS#1[I].SYSIN.INFROM
 H4: I = SOURCE(FIRST(APORTS#1[I].SYSIN.BUFQ))
 H5: I = SOURCE(MS)
 H6: (not SECURE(SECURITY[I],
              SECURITY[DESTINATION(FIRST(APORTS#1[I].SYSIN.BUFQ))]))
-->
 C1: all J#1 : USERID,     (I ne J#1 -> APORTS#1[J#1].SYSIN.INFROM = MSGSEQ())
                     and     APORTS#1[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                       MAIL(APORTS#1[I].SYSIN.INFROM, I,
                                            J#1))
```

This proof is also done like Switcher#2 and uses Lemma#3.

.
.

SWITCHER#6 proved in theorem prover.

Suggest fully defining SECURE-> Print Status All

The current design and verification status is:
  Waiting for pending body to be filled in: DESTINATION, MAKEMSG, SECURE,
      SOURCE
  Proved: NETWORK, SWITCHER
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

Suggest fully defining SECURE-> Explain

<- What are the effects of defining the body of Secure?

No effects.

<- Done

Suggest fully defining SECURE-> Edit

.
.
.

Exec-> Translate Msg.Net

```
function Secure(s1,s2:SecurityClass):boolean =
  begin
  exit Secure(s1,s2) iff s1 le s2;
    Result:=s1 le s2;
  end;
```

```
type Msg<Source,Destination,Text,MakeMsg,MsgEq> =
  record ( SourcePart,DestPart : UserId;
           TextPart : MsgText
         );
type MsgText = array([1..1024]) of character;

function Source(M:Msg):UserId =
  begin
  exit Source(M) in [1..NUsers] otherwise routineerror;
  cexit Source(M) = M.SourcePart;
    Result :=M.SourcePart;
  end;
function Destination(M:Msg):UserId =
  begin
  exit Destination(M) in [1..NUsers] otherwise routineerror;
  cexit Destination(M) = M.DestPart;
    Result := M.DestPart;
  end;
function Text(M:Msg):MsgText =
  begin
  cexit Text(M) = M.TextPart;
    Result := M.TextPart;
  end;
function MakeMsg(S,D : UserId; T : MsgText) : Msg =
  begin
  entry S in [1..NUsers] and D in [1..NUsers];
  cexit MakeMsg(S,D,T) = Msg(S,D,T);
    Result := Msg(S,D,T);
  end;

function MsgEq(M1,M2: Msg): boolean =
  begin
  cexit MsgEq(M1,M2)
      iff M1.SourcePart = M2.SourcePart
        and M1.DestPart = M2.DestPart
        and M1.TextPart = M2.TextPart;

    Result:=M1.SourcePart = M2.SourcePart and
            M1.DestPart = M2.DestPart and
            M1.TextPart = M2.TextPart;
  end;
```

No syntax errors detected.
No semantic errors detected.

This implements messages and the functions which manipulate them.

Exec-> Print Status All

The current design and verification status is:
  Waiting for VC generation: DESTINATION, MSGEQ, MAKEMSG, SECURE, SOURCE,
      TEXT
  Proved: NETWORK, SWITCHER
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

Exec-> Suggest

The suggestion mechanism carries the user through the remainder of the verification. Every proof is automatic and requires no additional information.

Suggest generating VCs for SECURE-> $

Generating VCs for FUNCTION SECURE

Found 1-ST path

Beginning new path...

Assume (unit entry condition)
    TRUE

RESULT := S1 le S2

Evaluating SECURE(S1, S2)
Continuing in path...

```
Leaving unit SECURE
ASSERT RESULT iff S1 le S2
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-------------------------------------------------


Suggest generating VCs for SOURCE-> $

Generating VCs for FUNCTION SOURCE

Found 1-ST path




-------------------------------------------------
Relate Concrete and Abstract Specs...

Assume (SOURCE Concrete exit)
   SOURCE(M) = M.SOURCEPART

- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (SOURCE Abstract exit) condition
Verification condition SOURCE=1
  H1: SOURCE(M) = M.SOURCEPART
 -->
  C1: TRUE
- - - - - - - - - - - - - - - - - - - - - - - -

-------------------------------------------------




-------------------------------------------------
Beginning new path...

Assume (unit entry condition)
    TRUE
```

```
RESULT := M.SOURCEPART

Evaluating  SOURCE(M)
Continuing in path...
Leaving unit SOURCE
ASSERT RESULT = M.SOURCEPART
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
------------------------------------------------


Suggest proving VC called SOURCE#1-> $
Entering Prover with verification condition SOURCE#1
  H1: SOURCE(M) = M.SOURCEPART
 -->
  C1: TRUE

Backup point
(.)

Prover-> $Proceeding

SOURCE#1 proved in theorem prover.

Suggest generating VCs for DESTINATION-> $

Generating VCs for FUNCTION DESTINATION

Found 1-ST path



------------------------------------------------
Relate Concrete and Abstract Specs...

Assume (DESTINATION Concrete exit)
    DESTINATION(M) = M.DESTPART

- - - - - - - - - - - - - - - - - - - - - - - -
```

```
Must verify (DESTINATION Abstract exit) condition
Verification condition DESTINATION#1
  H1: DESTINATION(M) = M.DESTPART
 -->
  C1: TRUE
- - - - - - - - - - - - - - - - - - - - - - - -

-----------------------------------------------



-----------------------------------------------
Beginning new path...

Assume (unit entry condition)
     TRUE

RESULT := M.DESTPART

Evaluating  DESTINATION(M)
Continuing in path...
Leaving unit DESTINATION
ASSERT RESULT = M.DESTPART
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-----------------------------------------------


Suggest proving VC called DESTINATION#1-> $
Entering Prover with verification condition DESTINATION#1
  H1: DESTINATION(M) = M.DESTPART
 -->
  C1: TRUE

Backup point
(.)

Prover-> $Proceeding

DESTINATION#1 proved in theorem prover.
```

```
Suggest generating VCs for TEXT-> §

Generating VCs for FUNCTION TEXT

Found 1-ST path



--------------------------------------------------
Relate Concrete and Abstract Specs...

Assume (TEXT Concrete exit)
    TEXT(M) = M.TEXTPART

- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (TEXT Abstract exit) condition
Verification condition TEXT#1
  H1: TEXT(M) = M.TEXTPART
 -->
  C1: TRUE
- - - - - - - - - - - - - - - - - - - - - - - -

--------------------------------------------------



--------------------------------------------------
Beginning new path...

Assume (unit entry condition)
     TRUE

RESULT := M.TEXTPART
Leaving unit TEXT
ASSERT RESULT = M.TEXTPART
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
--------------------------------------------------
```

```
Suggest proving VC called TEXT#1-> §
Entering Prover with verification condition TEXT#1
  H1: TEXT(M) = M.TEXTPART
 -->
  C1: TRUE

Backup point
(.)

Prover-> §Proceeding

TEXT#1 proved in theorem prover.

Suggest generating VCs for MAKEMSG-> §

Generating VCs for FUNCTION MAKEMSG

Found 1-ST path

------------------------------------------------
Relate Concrete and Abstract Specs...

Assume (MAKEMSG Concrete exit)
    MAKEMSG(S, D, T) = MSG(S, D, T)

- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (MAKEMSG Abstract exit) condition
Verification condition MAKEMSG#1
  H1: MAKEMSG(S, D, T) = MSG(S, D, T)
 -->
  C1: TRUE
- - - - - - - - - - - - - - - - - - - - - - - -

------------------------------------------------


------------------------------------------------
Beginning new path...
```

```
Assume (unit entry condition)
    S in [1..NUSERS] and D in [1..NUSERS]

RESULT := MSG(S, D, T)
Leaving unit MAKEMSG
ASSERT RESULT = MSG(S, D, T)
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
-------------------------------------------------


Suggest proving VC called MAKEMSG#1-> $
Entering Prover with verification condition MAKEMSG#1
  H1: MAKEMSG(S, D, T) = MSG(S, D, T)
 -->
  C1: TRUE

Backup point
(.)

Prover-> $Proceeding

MAKEMSG#1 proved in theorem prover.

Suggest generating VCs for MSGEQ-> $

Generating VCs for FUNCTION MSGEQ

Found 1-ST path



-------------------------------------------------
Relate Concrete and Abstract Specs...

Assume (MSGEQ Concrete exit)
       MSGEQ(M1, M2)
   iff     M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
       and M1.TEXTPART = M2.TEXTPART
```

```
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (MSGEQ Abstract exit) condition
Verification condition MSGEQ#1
  H1:    MSGEQ(M1, M2)
     iff    M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
        and M1.TEXTPART = M2.TEXTPART
 -->
  C1: TRUE
- - - - - - - - - - - - - - - - - - - - - - - -

------------------------------------------------


------------------------------------------------
Beginning new path...

Assume (unit entry condition)
    TRUE

RESULT :=    M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
        and M1.TEXTPART = M2.TEXTPART
Leaving unit MSGEQ
ASSERT    RESULT
      iff    M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
         and M1.TEXTPART = M2.TEXTPART
- - - - - - - - - - - - - - - - - - - - - - - -
Must verify (unit exit) condition
VC is trivially TRUE
- - - - - - - - - - - - - - - - - - - - - - - -
End of path
------------------------------------------------


Suggest proving VC called MSGEQ#1-> §
Entering Prover with verification condition MSGEQ#1
  H1:    MSGEQ(M1, M2)
     iff    M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
        and M1.TEXTPART = M2.TEXTPART
 -->
  C1: TRUE

Backup point
```

(.)

Prover-> $Proceeding

MSGEQ#1 proved in theorem prover.

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

 -> Print Status All

The current design and verification status is:
  Proved: DESTINATION, MSGEQ, MAKEMSG, NETWORK, SECURE, SOURCE, SWITCHER,
      TEXT
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

As indicated by the status summary, the design and verification of the network is complete. The final version of all network programs and their specifications are displayed below.

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

 -> Print Unit Alphabetical

Units are printed alphabetically by name.

```
function ALLSECUREMAILFOR(A : USERPORTARRAY; J : INTEGER; S : SECURITYARRAY)
        : MSGSEQARRAY =
begin
  exit
   (assume all I : USERID,   ALLSECUREMAILFOR(A, J, S)[I]
                    = SECUREMAIL(S[I], S[J],
                                 MAIL(A[I].SYSIN.INFROM, I, J)));
end;

function ARRAYTOBAG(A : MSGSEQARRAY; I, J : USERID) : BAGMSGSEQ =
```

```
begin
end;

type BAGMSGSEQ = bag of MSGSEQ;

function DESTINATION(M : MSG) : USERID =
begin
  exit DESTINATION(M) in [1..NUSERS] otherwise ROUTINEERROR;
  cexit DESTINATION(M) = M.DESTPART;
  RESULT := M.DESTPART
end;

function INFROM\ARRAYTOBAG(A : MSGBUFARRAY; I, J : USERID) : BAGMSGSEQ =
begin
end;

function ISSUBMERGE(S : MSGSEQ; A : MSGSEQARRAY) : BOOLEAN =
begin
  exit
   (assume    ISSUBMERGE(S, A)
        iff (some X : MSGSEQ,    ISMERGE(X, ARRAYTOBAG(A, 1, NUSERS))
                          and S sub X));
end;

function MAIL(MS : MSGSEQ; I, J : USERID) : MSGSEQ =
begin
  exit
   (assume  MAIL(MS, I, J)
        = if MS = MSGSEQ() then MSGSEQ()
            else if    SOURCE(LAST(MS)) = I
                   and DESTINATION(LAST(MS)) = J
                   then   MAIL(NONLAST(MS), I, J)
                       @ MSGSEQ(LAST(MS))
                   else MAIL(NONLAST(MS), I, J) fi fi);
end;

function MAKEMSG(S, D : USERID; T : MSGTEXT) : MSG =
begin
  entry S in [1..NUSERS] and D in [1..NUSERS];
  cexit MAKEMSG(S, D, T) = MSG(S, D, T);
  RESULT := MSG(S, D, T)
end;
```

```
type MSG <SOURCE, DESTINATION, TEXT, MAKEMSG, MSGEQ> =
    record
      (SOURCEPART, DESTPART : USERID;
       TEXTPART             : MSGTEXT);

type MSGBUFARRAY = array (USERID) of MSGOUTBUF;

function MSGEQ(M1, M2 : MSG) : BOOLEAN =
begin
  exit     MSGEQ(M1, M2)
       iff     M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
           and M1.TEXTPART = M2.TEXTPART;
  RESULT :=     M1.SOURCEPART = M2.SOURCEPART and M1.DESTPART = M2.DESTPART
           and M1.TEXTPART = M2.TEXTPART
end;

type MSGINBUF = buffer (1) of MSG;

type MSGOUTBUF = buffer (NUSERS) of MSG;

type MSGSEQ = sequence of MSG;

type MSGSEQARRAY = array (USERID) of MSGSEQ;

type MSGTEXT = array ( [1..1024]) of CHARACTER;

process NETWORK(var AUSERPORT : USERPORTARRAY; SECURITY : SECURITYARRAY) =
begin
  block all J : USERID, ISSUBMERGE(AUSERPORT[J].SYSOUT.OUTTO,
                                   ALLSECUREMAILFOR(AUSERPORT, J, SECURITY));
  cobegin
    SWITCHER(I, AUSERPORT, SECURITY) each I: [1..NUSERS]
  end
end;

const NUSERS = 100;

function OUTTO\ARRAYTOBAG(A : MSGBUFARRAY; I, J : USERID) : BAGMSGSEQ =
begin
end;

function SECURE(S1, S2 : SECURITYCLASS) : BOOLEAN =
begin
```

```
  exit SECURE(S1, S2) iff S1 le S2;
  RESULT := S1 le S2
end;

function SECUREMAIL(S1, S2 : SECURITYCLASS; MS : MSGSEQ) : MSGSEQ =
begin
  exit
   (assume   SECUREMAIL(S1, S2, MS)
        = if SECURE(S1, S2) then MS else MSGSEQ() fi);
end;

type SECURITYARRAY = array ( [1..NUSERS]) of SECURITYCLASS;

type SECURITYCLASS = (UNCLASSIFIED, CONFIDENTIAL, SECRET, TOPSECRET);

function SOURCE(M : MSG) : USERID =
begin
  exit SOURCE(M) in [1..NUSERS] otherwise ROUTINEERROR;
  cexit SOURCE(M) = M.SOURCEPART;
  RESULT := M.SOURCEPART
end;

process SWITCHER(I : USERID; var APORTS : USERPORTARRAY;
            SECURITY : SECURITYARRAY) =
begin
  entry I in [1..NUSERS];
  block all J : USERID,        APORTS[J].SYSOUT.OUTTO
                       sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                 MAIL(APORTS[I].SYSIN.INFROM, I, J))
                   and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ());
  var MS : MSG := MAKEMSG(I, I, MSGTEXT());
  keep
   (assume SOURCE(MS) = I);
  loop
   assert all J#1 : USERID,        APORTS[J#1].SYSOUT.OUTTO
                        sub SECUREMAIL(SECURITY[I], SECURITY[J#1],
                                  MAIL(APORTS[I].SYSIN.INFROM, I,
                                     J#1))
                       and (  J#1 ne I
                          -> APORTS[J#1].SYSIN.INFROM = MSGSEQ());
   begin
     receive MS from APORTS[I].SYSIN;
     if SECURE(SECURITY[I], SECURITY[DESTINATION(MS)])
```

```
        then send MS to APORTS[DESTINATION(MS)].SYSOUT
        end
    when
      is RECEIVEERROR : ;
      is SENDERROR : ;
    end
  end
end;

function TEXT(M : MSG) : MSGTEXT =
begin
  cexit TEXT(M) = M.TEXTPART;
  RESULT := M.TEXTPART
end;

type USERID = INTEGER [1..NUSERS];

type USERPORT = record
                (SYSIN  : MSGINBUF;
                 SYSOUT : MSGOUTBUF);

type USERPORTARRAY = array (USERID) of USERPORT;

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

 -> Print Lemma All


 LEMMA#1 is
  all A : MSGBUFARRAY,
    all B : MSGSEQARRAY,
      all X : MSGSEQ,
              ISMERGE(X, OUTTO\ARRAYTOBAG(A, 1, NUSERS))
            and (all K : USERID, A[K].OUTTO sub B[K])
          -> (some Y : MSGSEQ,     ISMERGE(Y, ARRAYTOBAG(B, 1, NUSERS))
                                   and X sub Y)

 LEMMA#2 is
  all A#1 : MSGBUFARRAY,
    all I#5 : USERID,
      all X#1 : MSGSEQ,
```

```
            (all J#1 : USERID, I#5 ne J#1 -> A#1[J#1].INFROM = MSGSEQ())
          and ISMERGE(X#1, INFROM\ARRAYTOBAG(A#1, 1, NUSERS))
        -> X#1 = A#1[I#5].INFROM

LEMMA#3 is
  all A, B : MSGSEQ,
    all C : MSG,
      all K, L : USERID,
        all S1, S2 : SECURITYCLASS,        A
                                  sub SECUREMAIL(S1, S2,
                                                 MAIL(B, K, L))
                                ->     A
                                  sub SECUREMAIL(S1, S2,
                                                 MAIL(B @ MSGSEQ(C),
                                                      K, L))

LEMMA#4 is
  all A#1 : MSGSEQ, all M : MSG, A#1 @ MSGSEQ(M) ne MSGSEQ()

LEMMA#5 is
  all A#2, B#1, C#1 : MSGSEQ, A#2 sub B#1 -> A#2@C#1 sub B#1@C#1
```

These are all the lemmas used in the verification of the network.

```
Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)
```

SID is useful not only during a design and verification, but also afterwards as a maintenance tool. Without a facility like SID, determining the potential effects of changes to a fairly large, complex, and interrelated collection of data is a formidable task. The following is a further illustration of how SID is even more essential as the amount of data grows.

-> Explain

<- What are the effects of changing the header of SecureMail?

```
Possible effects of changing the header of SECUREMAIL are:
   Incorrect semantics: ALLSECUREMAILFOR, LEMMA#3, SWITCHER, SECUREMAIL
   Invalid verification: NETWORK, SWITCHER
```

<- Why?

Incorrect semantics because calls to SECUREMAIL may become inconsistent. Invalid verification because the external specifications of ALLSECUREMAILFOR, which call SECUREMAIL, were used in proving NETWORK#1. Invalid verification because the external specifications of SWITCHER, which call SECUREMAIL, were used in proving NETWORK#1. Invalid verification because the external specifications of SECUREMAIL, which recursively call SECUREMAIL, were used in proving SWITCHER#4. Invalid verification because basis property LEMMA#3, which calls SECUREMAIL, was used in proving SWITCHER#2, SWITCHER#4, SWITCHER#5, and SWITCHER#6.

<- What are the effects of changing the block specification of Switcher?

Changing the block specification of SWITCHER does not affect SWITCHER if the formula

```
 H1: all J : USERID,          APORTS[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS[I].SYSIN.INFROM, I, J))
                    and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ())
-->
   Changed block specification
```

is true. If not, some of SWITCHER's VCs are incorrect. The verification of other programs is not affected if the formula

```
   Changed block specification
-->
 C1: all J : USERID,          APORTS[J].SYSOUT.OUTTO
                      sub SECUREMAIL(SECURITY[I], SECURITY[J],
                                     MAIL(APORTS[I].SYSIN.INFROM, I, J))
                    and (J ne I -> APORTS[J].SYSIN.INFROM = MSGSEQ())
```

is true. If not, the change invalidates the verification of NETWORK.

<- Why?

The effects on SWITCHER are a change in its VCs. Invalid verification because the block specification of SWITCHER was used in proving NETWORK#1.

<- What are the effects of modifying Lemma#3?

Changing basis property LEMMA#3 does not affect the verification if

```
   Changed lemma
```

```
-->
 C1: all A, B : MSGSEQ,
       all C : MSG,
         all K, L : USERID,
           all S1, S2 : SECURITYCLASS,        A
                                    sub SECUREMAIL(S1, S2,
                                                   MAIL(B, K, L))
                                 ->     A
                                    sub SECUREMAIL(S1, S2,
                                                   MAIL(B @ MSGSEQ(C),
                                                     K, L))
```

is true. If not, the change invalidates the verification of SWITCHER.

<- Why?

Because it was used in the proof of SWITCHER#2, SWITCHER#4, SWITCHER#5, and SWITCHER#6.

<- Done

Suggest one of:
<esc> TRANSLATE (from file)
SAVE (problem on file)

-> Prove Lemma#3

In the above dialog, the user saw that several proofs depend upon Lemma#3. So he directs SID to attempt its proof.

Entering Prover with basis property LEMMA#3

```
all A, B : MSGSEQ,
  all C : MSG,
    all K, L : USERID,
      all S1, S2 : SECURITYCLASS,        A
                                  sub SECUREMAIL(S1, S2, MAIL(B, K, L))
                               ->     A
                                  sub SECUREMAIL(S1, S2,
                                                 MAIL(B @ MSGSEQ(C), K,
                                                   L))
```

This proof requires the definitions of Mail, SecureMail, and a new lemma.

.
.
.

LEMMA#3 proved in theorem prover.

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

-> Print Status All

The current design and verification status is:
  Proved: DESTINATION, LEMMA#3, MSGEQ, MAKEMSG, NETWORK, SECURE, SOURCE,
      SWITCHER, TEXT
  For specifications only: ARRAYTOBAG, ALLSECUREMAILFOR, ISSUBMERGE,
      INFROM\ARRAYTOBAG, MAIL, OUTTO\ARRAYTOBAG, SECUREMAIL
  Constants/Types: BAGMSGSEQ, MSG, MSGSEQ, MSGTEXT, MSGINBUF, MSGOUTBUF,
      MSGBUFARRAY, MSGSEQARRAY, NUSERS, SECURITYARRAY, SECURITYCLASS,
      USERID, USERPORT, USERPORTARRAY

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

-> Print Lemma Lemma#6
LEMMA#6 is
  all X, Y, Z : MSGSEQ, X sub Y -> X sub Y@Z

This is the lemma used in the proof of Lemma#3.

Suggest one of:
  <esc> TRANSLATE (from file)
  SAVE (problem on file)

-> Save Net.Dmp

That's all, folks!