The Berkeley UNIX Network

Eric Schmidt

Overall Introduction

This set of papers documents a network constructed to satisfy the project option for the Master's degree from the EECS Department, C. S. Division, U. C. Berkeley. The first paper is a technical description of the history of the project, details of implementation, and summary points. The second paper is an introduction being sold to many users on the Berkeley campus. The third group of pages are the Programmers Manual sections for the network commands available. The last paper is a manual for systems staff about operation and setup of the network.

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The Berkeley Network – A Retrospective

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ABSTRACT

The Berkeley Network connects a number of UNIX† machines on the Berkeley campus. It provides facilities for file transfer, sending and reading mail, and remote printing. Operating in a batch mode, network requests are transferred one by one through an inter-connected network until they reach their final destination.

This document describes the history and goals of this project, the design decisions faced, discusses issues in portable software development in networks, and discusses the future of this project.

Introduction

This document is intended for readers with an interest in networking who are familiar with two other documents about the network, ‘‘An Introduction to the Berkeley Network’’, and the ‘‘Network System Manual’’, by this author. It is not necessary to read this document to set up and maintain the network, although systems persons will benefit if they are familiar with the concepts presented here.

The sections are presented as follows:

Principals
History
Overall System Description
Protocol Explanation
Portability
Security
Future Plans
Summary

The most important section is the last, which details a set of principles the author has learned during this project.

Principals

This project was a collaboration of many individuals. Dr. Robert S. Fabry participated in the initial design and has exerted the strongest influence on polishing the final product. Bill Joy and Ed Gould provided valuable technical expertise every step of the way, primarily about developing systems programs. The support staff of the EECS Department and the Computer Center (Bob Kridle, Jeff Schreibman, Vance Vaughan, Robyn Allsman, and Ricki Blau) were involved in setting up and administering this multi-

† UNIX is a Trademark of Bell Laboratories.

domain project. The lowest-level concepts the author used came from experience at XEROX PARC, primarily from discussions with David Boggs, one of the ETHERNET† designers.

History

The network project can be divided into two distinct phases. The first, from January 1978 to May 1978 (4½ months) involved designing and implementing the network facilities now available. The second, from October 1978 to March 1979 (5 months), saw the addition of many more machines to the network with emphasis on portability, security, and minor design changes. The network has been in almost continuous service to users since May 1, 1978.

First Phase

An initial design was worked out with Dr. Fabry in January 1978. A suitable connection was made between the Computer Center ''A'' and ''Q'' machines (then called ''D'').

A Q

Development proceeded on two fronts – a set of daemons were written to transfer files, using UNIX pipes for debugging. The lowest-level protocols were designed and implemented of the terminal-type connection between A and Q. These were debugged using simple programs to send and receive packets, and a pair of programs to transfer a file from one to the other. This was the first experience with a distributed software development – the Q machine is a DEC PDP-11/34 with no lineprinter, a non-standard tape drive, and terminal access only by telephone, so most development had to proceed on the A machine.

During this phase the goals of the project increased in scope. The implementor and only user had to use the network to transfer network source and worked out simple ways to automate this (the ''.netrc'' file is an example).

When it appeared usable by more than the implementor, the connection was changed to be between A and the Computer Center ''C'' machine:

A C

Up until now, the network had required an account on both machines. It became clear this was a handicap since the A machine had too many accounts and the password file was immense. Certain ''free'' commands were allowed, without an account.

The Cory machine was soon added to the network:

Cory A C

This produced major changes in the design – initially we had assumed network users would have

† ''Ethernet: Distributed Packet Switching for Local Computer Networks'', by Robert Metcalfe and David Boggs, CACM, July 1976.

accounts on all machines. This was unreasonably strict and a solution (kludge) was worked out where a request was examined and forwarded through the queue(s) on the intermediate machine. The network became table-driven to accomplish the routing, and distributed software development became more difficult because of the increased number of machines. The implementor quickly discovered only one solution: Always have a designated source machine for all changes. To this day, software changes are made only on this ‘‘source’’ machine, the others are guaranteed to have copies. This makes remote updating (copying new versions around the network) possible.

Documentation was written and sent off to about fifteen faculty, staff, and graduate student users. A few bugs were fixed and the system frozen from the end of May to October. End of Phase 1.

Second Phase

While the implementor was away at a summer job, the connection between the A and C machines was switched to reduce the loading on the A machine:

Cory C A

Unknown to the implementor, the network source was modified in divergent and incompatible ways, and the commands were moved to a different place. These changes invalidated certain assumptions about full pathnames and some commands such as inter-machine mail stopped working.

The Computer Center had also made absolutely incompatible changes to some system calls. This began a path of software divergence that became very painful and is still not completely solved.

Fortunately, the Computer Center placed Robyn Allsman in charge of maintaining the network on their machines – to lighten that routine part of the load from the implementor.

The Computer Center acquired a ‘‘D’’ machine, and the EECS Division a DEC VAX 11/780, running an experimental Version 7 UNIX system. The implementor decided to use the (at this point) unused VAX to to do software development and incorporate the Version 7 changes into the network code. By this time, the protocols were stable which made it possible to run a Version 7 network on the VAX connected to the old Version 6 code on the existing network, to facilitate debugging. Because of improved terminal availability and better machine response, many new ways were used to debug the network – using pipes, using TTY lines wired together on the VAX and over the usual machine-to-machine link. A file was added (‘‘initfile’’) which allowed quick reconfiguration of the daemons when system parameters were changed. A temporary connection between the VAX and C machines was arranged.

VAX

Cory C A

The network code had to be able to run on three different types of machines – the VAX running UNIX Version 7, the Cory machine running Version 6, and the anomalous Computer Center machines.

There was no conversion package available at the time,† and the old network code had not used any system header files, so after a great deal of experimentation, conditional compilation was used as much as possible and a procedural interface was used to elide system differences.

The new UNIX command *make* (I) was used with a ‘‘makefile’’ to organize this regime. The old network code was used to bootstrap the D machine onto a network running the new network code exclusively.

VAX

Cory C A

D

Shortly thereafter, over the Christmas break, the VAX and Cory connections went down for security reasons (discussed in the ‘‘Security’’ section). After seven weeks, they reentered the network in a new configuration.

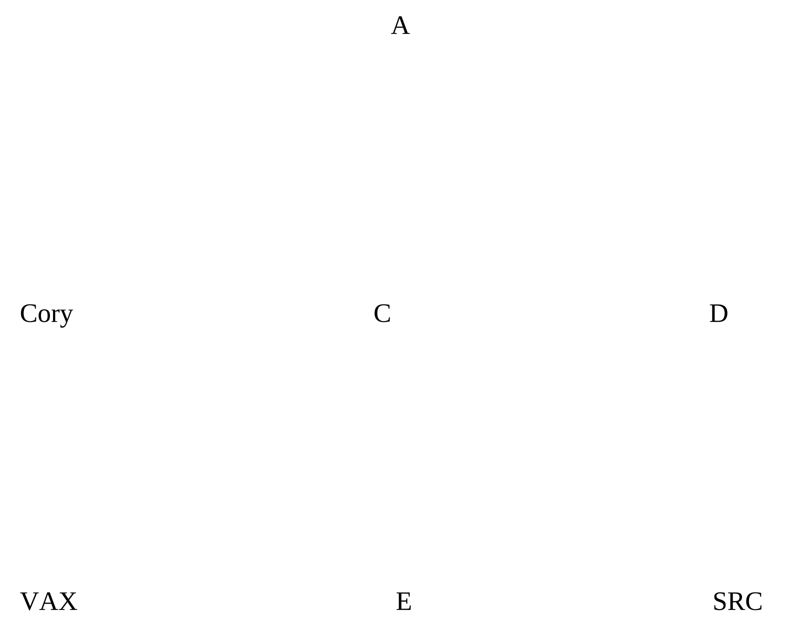
Cory C D

VAX A

Shortly after that, they were down again because of a lightning strike for another week but have been operational since then. During the last time period the network was made less Berkeley-specific and a

† The ‘‘retrofit’’ library, by Bill Joy, is now available.

copy was run on the Rand Corporation UNIX machines. Documentation was rewritten and prepared for release. The network queues were converted to send shortest-job first. Extensive monitoring of system load, network performance, and network use was added. The format of the *netq* command was changed to summarize more information on output. The E machine, and then later the Survey Research Center (SRC) machine, were added.



Tuning was still important − serious overloading problems caused by sluggish response stopped the network between Cory and C for a week. Network parameters were tuned to help solve this problem. The complexity of software development and maintenance became too great for unstructured changes. Versions on all the machines except the VAX were frozen for a month at a time. The protocols were almost immutable. People were delegated responsibility to observe and straighten out, if necessary, problems with the net queues.

As this is written, the software is stable and the user-documentation is finished and being sold, and there is hope of adding more UNIX machines to the network.

Overall System Description

The Berkeley network operates in a batch/ request mode, and is similar in concept to a line printer queue. ‘‘Requests’’ are queued up at the source, where they are sent in shortest job first order through an interconnected network of machines to their destination. At each intermediate node, they are queued as if they were originated locally.

The network consists of a set of user-executed commands, a queue of requests to be sent, and a continuously-running program called a *daemon* which transmits requests in the queue and listens for any request being sent to it. There are many network commands − one to send mail, one to read mail, one to copy files, etc. They all use the *net* command to access the network. The *net* command takes a command, assorted parameters, with any input data, and puts a request in the queue. These requests are composed of a header, the command to be executed, and any data for input to the command. The header contains network information such as the destination machine, login name, and password. This request is stored in the queue as a normal ASCII file, owned by the invoker. This way UNIX commands can be used to examine the file.

The daemon examines the queue to see if there is anything to send. If so, it begins sending to a remote daemon, using a protocol to establish this dialog, involving retransmissions and timeouts. The remote daemon accepts the requests, parses the header information, and takes any data for the command and puts it in a file. The main loop of the daemon then returns to a waiting state.

The command execution is done by 'forking' a series of processes. One of these is the user's login shell, which is given the command to execute. Another is a process which waits for the command to be executed, then examines the output of the command. The output is typically sent back to the user, via a *net* command, executed by the daemon.

In the reverse transmission, the command is called ''mwrite'', and it is routed and handled exactly as in the forward mode, except no password is required. The ''mwrite'' command is executed on the original machine with input data which is a copy of the output of the remote command. The user is either ''written'' or ''mailed'' to, depending on certain options. If ''written'', the user's screen is filled with the output† of the command executed remotely, just as if he had executed it locally. Otherwise, it is in his mailbox, as mail from the remote account he used. The user's terminal must be write-able (see the *mesg* (I) option), the originating user must still be logged in, and he must not have logged off and on again.

The output from the command is preceded by a line of information listing the command, the time it was sent, and the time elapsed.

Our design then tries to simulate local UNIX commands as much as possible. With defaults set correctly† the user in principle need only precede the command he is executing with the command *net.*

Copying Remote Files

The most frequent use of the network is file-transfer using the *netcp* command. The *netcp* command is based on the *cp* (I) command. Its two arguments are a source and destination file, optionally with remote machine names prepended:

netcp *from–file to–file*

where the names are local or remote. Since

Cory:/usr/pascal/sh

is a file on the Cory machine,

% netcp junk Cory:/usr/pascal/sh

will transfer the file ''junk'' to the named file on the Cory machine‡.

The way the transfer is accomplished depends on the type of file copy:

1. Copy local file to remote file –
   On the remote machine a *cat* (I) command is executed on the remote file with the local file as standard input.
2. Copy remote file to local file –
   A *cat* command is executed on the remote machine from the remote file to standard output. This standard output is sent back to the local machine into a *response file*, instead of being written or mailed to the user.
3. Copy remote file to another remote file –
   If both are on the same machine, a *cp* command is sent. Otherwise, a *netcp* command is sent to the remote machine where the *from–file* exists, to copy that file to the *to–file*'s machine.

This last case is experimental. Unfortunately, the system is structured only to carry one login name and password to a remote machine. Since the last option involves three machines, the second remote machine is handled imperfectly at best.

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† Standard output and standard error files.
† With a ''.netrc'' file, see below.
‡ For more examples, see the ''An Introduction to the Berkeley Network'' document.

Sending Mail

The *mail* (I) command on the network machines has been modified to examine the names of the recipients of a particular message. If their names have a remote prefix, *mail* executes an internal command ‘‘sendmail’’, which in turn executes a *net* command. This net command sends a mail command to the remote machine, with the message as input. Since the recipient would like to know which machine the message came from, a simple program ‘‘mmail’’ is executed to insert a pseudo-header indicating the real source of the mail. The net command logs in as user ‘‘network’’, so remote mail does not require an account on the destination machine. This facility has proven invaluable.

Reading Mail

The *netmail* command uses the *net* command to send a command to read mail for a specified user on a remote machine. Since the existing mail programs on different machines vary in their options, it was decided the only thing that would work on both UNIX Version 6 and 7 systems was to copy the mail from the remote to the local machine. If the user subsequently logs in on the remote machine, his mail will be there, as if it were unread. An internal program ‘‘prmail’’ is used to copy the user’s mail back to the local machine. It knows the location of the mailboxes and the user’s name.

The mail programs at Berkeley are being modified to search a database to see whether a user would like to receive all his mail on another machine and automatically forward it. This will diminish the need for the *netmail* command.

Printing on remote lineprinters

The *netlpr* command takes a list of arguments as files to be printed on a remote lineprinter. Unfortunately, there can only be one standard input file for the remote command, so each file is sent as a *net* command executing the command *lpr.*

Other System Components

The ‘‘.netrc’’ file.

A user must specify defaults for frequently repeated options on a per-machine basis. This is done in a file ‘‘.netrc’’ in the user’s login directory, and is fully described in the ‘‘An Introduction to the Berkeley Network’’.

The *netq* command.

To see the network queue, the user must type the *netq* command. It lists the queue for each directly-connected machine, in the order requests will be sent. Each request is listed, one per line, giving the local and remote machines, the destination machine, the time sent, and the command to be executed. Commands which are internal to the network are called ‘‘responses’’ in the *netq* listing.

The *netrm* command.

Requests may be removed from the send queue using the *netrm* command. Since the originator of the file owns the queue file, a simple user-id check suffices to validate permission. Unfortunately, this notion breaks down for queue files of requests on intermediate machines. On such a machine an appropriate user does not exist, and the files are owned by ‘‘root’’. There is an option to *netrm* to remove all the user’s queue files, to make *netrm* easier to use.

The *netlog* command and other information.

A number of log files are kept by the network. Users may execute a *netlog* command which prints the last few entries of a log of commands sent and received. Also listed is the user, the time of the entry, and the return code of the command.

A more unreadable logfile is ‘/usr/net/plogfile?’. This log file has all the information of *netlog,* in a more cryptic form, along with trace information about net errors. The beginning and ending of sending and receiving are noted. This way the exact state of the network can be determined.

Hourly and daily statistics in a file '/usr/net/netstat?'. The number of bytes transmitted, the number of commands, and a breakdown of their type, and system load is recorded. This information is recorded in both hourly and daily form to track the performance of the network under different system loads.

Every hour, a *netq* command is executed and the number of queue entries is recorded in a file '/usr/net/netqstats'. This gives an estimate of the queue length.

Finally, the login names of each local user are recorded in a file '/usr/net/usernames'. Periodically, these names are sorted and duplicates removed. This gives a complete listing of network users, useful for sending network-specific mail and for general interest.

Protocol Explanation

The network uses three distinct levels of protocol. The highest level of protocol (the ''command'' protocol) refers to the organization of the information sent to the remote machine. An intermediate level splits such a stream into distinct numbered packets with a small header in each packet. The lowest level refers to the appearance of these packets on the hardware connection. At the present, this is a modified 6-bit ASCII code. Each of these layers is distinct, and presents the interface through procedure calls.

The Command Protocol

Each machine sends a request using a precise command protocol involving a header, the command, and any associated data.

length	header	command	... data ...

All but the length field is formatted by the *net* command before the file is queued for transmission. The length is used to detect abnormally short, and poorly-formed, requests. The header includes all the information to route and verify the request. It includes

a) the origin and destination machines,

b) the login names on both machines,

c) a version stamp for this command protocol,

d) the time sent,

e) information about the originating terminal, and

f) the pseudo-command.

The pseudo-command is read by *netq,* and instead of printing the actual command being executed, prints something more appropriate. All the commands which use *net* (e.g. *netcp)* use the pseudo-command to list themselves rather than the command they are executing on the remote machine.

In order to be able to print the data on a normal UNIX terminal for debugging, the fields within the header are variable-length ASCII, separated by colons (':'). This forces the daemon to parse the header information and requires that literal colons (e.g. in the command being sent) be properly escaped within the protocol, but I felt the alternatives of using byte counts or fixed-length fields were too difficult to debug. The shortest header is approximately 85 bytes. Fortunately, this means the shortest command will fit into a single packet.†

The Packet Protocol

The above information is conveyed to each machine as a stream. This is done using subroutine calls to read and write data of arbitrary length over the link. The write procedure breaks the information into a set of numbered packets, with a length and exclusive-or check-sum in a header:

length	seqnum	type	chksum	... data ...

† (less than 100 bytes, see below).

The length, type and checksum are one byte each, and the sequence number is two bytes. Since the packets are variable length the checksum is in the header rather than at the end of the packet to avoid the extra computation required to access it.

Each packet is transmitted over a link to a listener. Normally an acknowledgement packet is sent back. If there is an error, nothing is sent back, and the sending end will retransmit after a certain number of seconds.

There are no windowing or piggyback acknowledgements for two reasons: 1) this scheme is very simple to implement and 2) the error rate if each packet were not acknowledged would be high because of the hardware involved. If the future, I hope that both hardware and kernel device drivers will allow this improvement.

The so-called ‘‘rendezvous’’ protocol, whereby two daemons agree to communicate, is a simple ‘‘contention’’ scheme. When one daemon wants to transmit, it sends a special packet ‘‘reset’’ to the possible receiver, then transmits his first packet. Normally a daemon able to receive listens for a ‘‘reset’’. If it receives one, it enters a section of code designed to receive a header command, and data, and ultimately will execute it. If not, after a prescribed time interval is checks to see if there are any requests to send. Should both send at once, the characters may be garbled, or both may receive resets at the same time. In each case they both will retransmit. Each has a randomizing factor to break any ties which might develop.

In retrospect, this protocol is very primitive. Now that the network is in production use, the extra acknowledgements and separate ‘‘reset’’ are too expensive. A redesign would modify the protocol to transmit more than one packet before acknowledging it (ACKs), use negative ACKs to indicate immediately that an error has occurred, and eliminate the separate ‘‘reset’’ entirely.

The ‘‘rendezvous’’ protocol consumes a fair amount of time when both daemons choose to send packets. The alternative of constantly sending status packets when the daemons would be idle was never seriously considered because it was felt that the daemon should have as light a system load as possible; it seems now the daemons are busy most of the time and thus the initial connection tradeoffs should have been studied more closely.

The Low-Level Protocol

The network transmits over TTY lines through terminal interfaces and system drivers which behave as if the characters coming from another machine are from a terminal. This mode was chosen because it is absolutely the simplest, cheapest interconnection scheme possible. Unfortunately, the UNIX terminal drivers cannot accept 8-bit bytes unless they are in *raw* mode. This was judged to be a high system load, so the TTY lines operate in *cooked,* the reverse of *raw,* mode. In this mode certain bit combinations, e.g. ASCII newline and escape, do not transmit through the terminal driver to the user’s program but rather are interpreted as control information.

After much experimentation, the following transmission method was chosen. Each 3 byte triple is viewed as 24 bits, and broken into 4 6-bit groups. Each 6-bit number is in the range 0-63, and is added to a constant representing the lowest acceptable character code (a blank) in the ASCII sequence. This is sent as an ASCII character to a receiver who gathers 4 bytes, subtracts the increment, and shifts the 4 6-bit groups into 3 bytes. This represents a 3 to 4 expansion of all characters over the link, or a 33% loss of bandwidth.

In retrospect, this expansion has a considerable cost. The most scarce resource in the network is the actual hardware speed of the links. The alternative of using raw mode was never seriously considered.

The implementor’s hope is that better hardware will make better middle- and lower-level protocols easier. Until then, the difficulties of using TTY lines efficiently make further protocol improvements unlikely to yield big increases in speed.

A Note About Features this Protocol Lacks

In UNIX a process may only read or write one I/O device at a time. A daemon approach requires a single process reading and writing on a link to another machine. This process must decide who will receive this packet. I judged (correctly) that this decision was hard to schedule using UNIX pipes and signals, and only allow one kind of communication between daemons. This also makes it almost impossible to forward packets through intermediate machines. Thus intermediate machines copy whole requests before sending them again.

If the design specification required a simple packet-oriented driver within the system, the UNIX kernel could decide which of several special files this was destined to, and allow much more intermixing of traffic than before. I did not realize the importance of this and, in retrospect, would have chosen the other of the two approaches.

Portability

The acquisition of VAX/UNIX (Version 7) and the divergence of the Computer Center and Cory Hall Version 6 systems made the portability of the network source code important. Until then, the source code on all machines was identical. Fortunately, the UNIX implementors encountered these same problems and developed a number of facilities the network now uses.

Since many system calls use machine and version dependent data fields, so-called ‘‘include’’ files are available to hide the system differences and help standardize the system interface. The conditional compilation feature of the C language was used to select which kinds of code to generate, when the ‘‘include’’ files were not sufficient. Roughly, the following command included at the beginning of each C module:

```
# include <whoami.h>
```

would define which system, by name, the code was run on. For example, the above defines ‘‘VAX’’ on the VAX machine, and then lines such as

```
# ifdef VAX
 .
 .
# endif
```

control the code generated. In the network, sequences such as this in turn define other sequences, such as

```
# ifdef CORY
# define FUID
# define OLDTTY
# define PASSWDF
# endif
```

defines the unusual features of the Cory machine: the combined user-id and group-id returned by the *getuid()* system call, that it uses the old 1-character terminal names, and that it has a split password file for security reasons. Each of these symbols, e.g. ‘‘FUID’’, is tested in order to compile the correct code for that feature.

To help in isolating the changes, attempts were made to create a procedural interface to hide machines differences. These procedures are all in one file. Only one or two cases exist of conditional sections of code not in ‘‘mach.c’’ or ‘‘mach.h’’, its header file.

One problem these features pose is testing changes – the conditional sections hide errors in inapplicable code. A regimen was adopted: Testing was first done on the VAX (Version 7), then, after it was stable for a few days, moved to Cory, where typically there was some Version 6-dependent error, and after that was fixed and stable, it was moved to the Computer Center machines. This notion of a ‘‘testing’’ machine is very important – the VAX always has an up-to-date copy of the network source, even though other machines may lag in improvements.

There is now a ‘‘retrofit library’’ that simulates many of the features ‘‘mach.c’’ provides. It was not stable enough when the network was converted to Version 7, otherwise I would have used it.

At this point, when the entire source for the software for the network is transferred between machines only the first five lines of the ‘‘makefile’’ need be changed.

Security

Over Christmas vacation of 1978, a 15-year old high school student repeatedly broke into the Computer Center and Cory machines. He was able to use the network to gain access to privileged files on the VAX, and the fear of protection ‘‘holes’’ caused the staff to take the network down for seven weeks.

There were two security problems posed by the network:

1. The threat to the ‘‘root’’ account on another system.
2. The threat to a user’s remote accounts.

1. Threat to ‘‘root’’

Originally the network would allow a user logged in as ‘‘root’’ on one machine to execute any command as ‘‘root’’ on another network machine. As far as we know, this feature was never used to break into a system. However, the network has been changed to prevent a user from logging in as ‘‘root’’ on another machine, regardless of the password. This check is performed on the sending machine. Since ‘‘root’’ could conceivably circumvent this check by altering the command, the receiving end of a command checks the user-id of all commands being executed. If it is zero (i.e. ‘‘root’’) only a set of five commands is allowed, all needed by the network internally, and believed ‘‘safe’’.

We believe this makes the network ‘‘safer’’ than many local machine features such as the use of dial-up lines.

2. Threat to user’s remote accounts.

If a user places remote passwords in his ‘‘.netrc’’ file, an illicit superuser could get the password to all the user’s remote accounts. Even if the user does not care, system managers dislike this because the illicit superuser could now use a legal account on another system to break into it.

We have no good solutions to this. Users are now warned of this danger in the documentation, and a ‘‘.netrc’’ file with passwords must be readable only by the owner of the file.

Various solutions have been proposed:

a) Disallow passwords in ‘‘.netrc’’ files.
Unfortunately, heavy network users would have to repeatedly type their password.

b) Encrypt the ‘‘.netrc’’ file.
A program would have to exist to decrypt the file. A superuser could get access to whatever key technique that program used, if it were on the local machine. A public-key encryption scheme would make this option possible. We decided it was too much work to implement this.

c) Once-a-session passwords.
In this scheme, a user would register his password when he logged in, then use the network without needing to type in a password. When he logged off, the password would be removed. We discarded this because we could not guarantee the password would disappear unless we wrote a daemon, which itself could be compromised. The best solution along this line uses the ‘‘alias’’ feature of the C shell. Each net command is aliased with itself and the **–l**, **–p** options. When the user logs in, he sets a shell variable to his password. When he logs off, his shell dies and the passwords are forgotten.

I believe the current alternatives are sufficient for a conscientious user to protect himself and still have an easy-to-use network interface.

Future Plans

1. Hardware

The net has suffered with low speed hardware. Short-term plans include speeding up the current terminal interface hardware from 1200 Baud to 9600 Baud and writing a driver for the device to bypass the internal UNIX character queues. This driver will improve the reliability of transmission and decrease the character interrupt overhead. The speedup from 1200 Baud to 9600 Baud may overload the systems due to the number of hardware interrupts it causes.

In the longer term, the EECS Department is considering acquiring direct-memory-access (DMA) devices such as the Logical Network Interface (LNI) or the Digital Corp. DMC-11 links for high-speed transmission. These devices are capable of over 1-megabit speeds, and would increase the speed of the current network by factors of hundreds.

2. Adding More Machines to the Network

The INGRES Research group and various other research units within the EECS department have expressed interest in being added to the network.

3. Remote Use of the Typesetter Facilities

The Computer Center A machine has a Graphics Systems phototypesetter and the VAX Research machine has a Versatec 36'' dot-matrix plotter with a *troff* simulator. Software now being debugged will allow remote use of the typesetter by running the *troff* program locally and sending the typesetter device codes to the remote machine.

This will distribute the typesetting load and help overloading on the A and VAX machines. It will also allow the use of *troff* macro packages only available on some machines.

4. Remote Mail Forwarding

The UNIX mail programs will be modified to forward mail to another account on another machine, allowing a user with accounts on many machines to read it all on one designated machine.

Summary Points

The author would like to stress these points about his experience:

1. Success in building networking software depends on having ready access to the correct hardware. The minimum is two terminals connected to two usable machines with two magnetic tape drives or some other existing means of software transfer.
2. Design in portability and security. More careful attention to machine dependence and security in the first phase would have saved much later re-programming.
3. Develop good local debugging techniques. The ''self-loop'' trick for network debugging depends on the accuracy of that simulation. UNIX pipes, for example, were not sufficient to simulate TTY lines because TTY lines are 7-bits with a restricted ASCII range.
4. Encourage users to use the system. Their feed back is important. However, it is necessary to have an unused network link for new protocol development, etc.
5. There is a fine line between support of an existing network and research. In the best of all possible worlds, support of research-developed software would be the responsibility of the systems staff for the machines it runs on. This is seldom the case.
6. The concept of layers of networks was very helpful in this project. There appear to be these levels:

user interface

queues and daemons

command protocol

packet protocol

transmission protocol

teletype lines

These levels are quite distinct. If a new, better network not involving queues is built, the transfer of files could still be by *netcp*. If state-of-the-art link hardware is used, perhaps all of the levels below the command protocol could be discarded.

7. The chief virtue of the current system is its extreme flexibility and low start-up costs. No modifications to the UNIX kernel are required and all local features are conditionally specified in a header file.

8. Networks are hard to build because

   a) They involve mutually-cooperating copies of software on (usually) differing computers.

   b) Many options are not practical because of compatibility considerations − new networks need drivers in unchangeable systems, and new protocols have to accept the old protocols until the old protocols are extinct.

An Introduction to the Berkeley Network

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(revised March 1980)

ABSTRACT

This document describes the use of a network between a number of UNIX machines on the Berkeley campus. This network can execute commands on other machines, including file transfers, sending and receiving mail, remote printing, and shell-scripts.

The network operates in a batch-request mode. Network requests are queued up at the source and sent in shortest-first order to the destination machine. To do this, the requests are forwarded through a network of inter-connected machines until they arrive at their destination where they are executed. The time this requires depends on system load, inter-machine transfer speed, and quantity of data being sent.

The network enforces normal UNIX security and demands a remote account with a

password for most commands. Information can be returned to the user in files, for later processing, or on the terminal for immediate viewing.

Introduction

A network between a number of UNIX machines on the Berkeley campus has been implemented. This document is a brief introduction to the use of this network. Information which is specific to the local network has been gathered into Appendix A. The new user should read both this introduction and Appendix A in order to learn to use the network effectively.

This document is subdivided into the following sections:

This manual is written in terms of three mythical machines, named X, Y, and Z. Specific names at Berkeley are in Appendix A, along with more local information.

Use of the Network

The network provides facilities for issuing a command on one machine (the *local* machine) which is to be executed on another (the *remote* machine). Network commands are available to transfer files from one machine to another, to send mail to a user on a remote machine, to retrieve one's mail from a remote account, or to print a file on a remote lineprinter. These commands are described below, as is the more general *net* command which allows users to specify the name of some command or shell script to be executed on a remote machine. Network requests are queued on the local machine and sent to the remote machine, forwarded through intermediate machines if necessary.

Most of the network commands require that you have an account on the remote machine. If a remote account is not needed for a particular command, it will be noted in the following discussion. The first example introduces procedures and responses which are applicable to all network commands.

5. Copying Files over the Network

Suppose that you have accounts on both the X and Y machines and that you are presently logged into the X machine. If you want to copy a file named 'file1' from your current directory on machine X to machine Y (the *remote* machine), use the command:

```
% netcp file1 Y:file1
```

The net will make a copy of 'file1' in your login directory on the Y machine. (The 'Y:' will not be part of the filename on the Y machine.) In order to verify your permission to write into the Y account, the *netcp* command will prompt you with:

```
Name (Y:your-name):
```

You should respond with your login name on the Y machine, followed by a carriage-return. If you have the same login name on both machines, just type a carriage-return. Next a password will be requested:

Password (Y:remote-name):

Now type in your password followed by a carriage-return (you must type it even if your passwords are the same on both machines). The *netcp* command will make a copy of your 'file1' in a queue destined for the Y machine, and will then return you to the shell.

Likewise if you wanted to transfer a file named 'scan.p' from Y to X,

% netcp Y:scan.p scan.p

would place that file in your current directory on X.

The network will ''write'' you when it has executed your request (if you are still logged in), or will ''mail'' you a message (if you are not). You may use the **–n** option (described later) to disallow the interruption and thus force mail to be sent. A typical message might look like this:

Message from Y:your-name at time ...
(command: netcp file1 Y:file1, R: 0, sent April 1 18:03, took 10 min 3 sec)

The message includes the current time, the time you sent the command on machine X, and the exit code of the command (zero normally means success).

The network response will tell you if it was unable to execute the remote command successfully by returning an error message some time later. If, for example, you type the wrong password, you will get the response

Message from Y:your-name at time ...
(command: netcp file1 Y:file1, sent April 1 18:03, took 10 min 3 sec)
Error: bad login/password your-name

The *netcp* command is actually a generalization of the UNIX *cp* command, similar to *uucp*†. Its syntax is:

netcp [–**l** *login*] [–**p** *password*] [–**n**] [–**q**] [–**f**] *fromfile tofile*

where *fromfile* and *tofile* can be local or remote files. A filename which is not a full pathname is either from the current directory on the local machine or your login directory on the remote machine. The **–l** and **–p** options may be used to specify your remote login name and password on the command line. If the password contains shell meta-characters, it must be in quotes. (These options are useful in shell scripts, but be sure to make the shell script readable only by yourself if you've got passwords in it!) The **–n** option forces any responses from the remote machine to be mailed rather than written to you. The **–f** option forces prompting for a remote user name and password, even if they are set by other options or are in the ''.netrc'' file (see ''Setting Defaults'' below). Finally, the **–q** option prevents any confirmation messages from being sent back to you, if there were no errors, the exit code of the command is zero, and the command had no output.

Transferred files may or may not have the correct file protection mode; use the *chmod* (I) command to reset it. When files are to be brought from a remote machine, they are created zero-length at the time the command is issued; when they arrive, they assume their true length. Unlike *cp, netcp* does not allow the *tofile* to be simplified to a directory, if the files have the same name.

Examples:

% netcp file1 Y:file1	copy 'file1' from the current directory to Y
% netcp Y:file1 file1	copy 'file1' from Y to the current directory
% netcp Z:file1 Z:file2	*cp* command on remote machine
% netcp X:lex.c Y:lex.c	copy from X to Y
% netcp Y:subdir/file1 file1	copy from a sub-directory

† See the UNIX Programmers Manual (Version 7 only).

```
% netcp file1 file2          an error— use the cp command
```

6. Listing Requests in the Network Queue

To see where your command is in the queue, type

```
% netq
```

A typical output of which looks like:

```
  From           To              Len   Code      Time            Command
X:your-name  Y:remote-name    100  b99999    Mar 23 18:05    netcp file1 Y:file1
```

The format is similar to that of the *lpq* command. The files are sent one at a time, in the order listed. If *netq* tells you the queue is empty, your request has been sent already. The queues for different destinations are totally separate.

```
% netq Y
```

will list just the queue destined for the Y machine. *Netq* summarizes requests from other users. The command

```
% netq –a
```

will print the requests from all users.

7. Removing Requests from the Network Queue

If you want to cancel your net request, and ‘‘b99999’’ (see the *netq* example above) is your ‘‘Code,’’ use the command

```
% netrm b99999
```

which will remove the request (if it hasn’t already been sent). Furthermore,

```
% netrm –
```

will remove all your net requests in the queues on the local machine (you must have made the request in order to remove it).

8. Sending Mail over the Network

To send mail to remote machines, use the *mail* command with the remote account prefixed by the destination machine’s name and a ‘:’. ‘‘Y:schmidt’’, for example, refers to an account ‘‘schmidt’’ on the Y machine. The full sequence is illustrated below:

```
% mail Y:schmidt
   {your message to user ‘‘schmidt’’ }
{control-d}
```

This will send to user ‘‘schmidt’’ on the Y machine the text you type in. As with intra-machine mail, the message is terminated by a control-d.

You do not need an account on a remote machine to send mail to a user there.

9. Reading Mail over the Network

It is also possible to read your mail on remote machines. From the X machine, the command

% netmail Y

sends a command to the Y machine to take any mail you may have and mail it back to you. As a precaution, the mail on the remote machine (Y in this example) is appended to the file ‘‘mbox’’. Netmail has **–l**, **–p**, **–n** and **–f** options just like *netcp.* If a machine is not specified, the default machine† is used. If the **–q** option is specified (like *netcp)* no message is sent back if there is no mail.

Netmail also takes a **–c** option:

% netmail –c Y:username

which turns the command into a ‘‘mail check’’ command. A message is sent back telling the user whether the specified username has mail. No password is required. As above, the **–q** option suppresses the message if there is no mail. This command was designed to be put in C shell ‘‘.login’’ files.

10. Using the Lineprinter over the Network

Remote lineprinters can be used with the *netlpr* command:

netlpr [**–m** *machine*] [**–c** *command*] *file1 file2 ... filen*

which sends the files its arguments represent to the lineprinter on *machine.* It will prompt you for an account and password. The **–l**, **–p**, **–n** and **–f** options may be supplied, as in the *netcp* command. If the **–c** option is specified, a different printing *command* (default is ‘‘lpr’’) can be specified; see Appendix A for the list of printers allowed. Copies of the files are not made in the remote account.

11. Net Prototype Command

The above commands all use internally one more general command—the *net* command which has the following form:

net [**–m** *machine*] [**–l** *login*] [**–p** *password*] [**–r** *file*] [–] [**–n**] [**–q**] [**–f**] *command*

Net sends the given command to a remote machine. The machine may be specified either with the **–m** option or in the ‘‘.netrc’’ file (for the specific names, see Appendix A). If not specified, a default is used. **–l**, **–p**, **–n**, **–q** and **–f** are as explained above for the *netcp* command. The **–r** option indicates the local *file* which will receive the output (the standard output and standard error files) of *command* when it is executed on the remote machine. By default this output is written or mailed to you. Thus, for example, to find out who is on the Y machine when you are logged in on the X machine, execute the following command:

% net –m Y "who"

which will run the *who* command on the Y machine; the response will be written or mailed to you. Similarly,

% net –m Y –r resp "who"

will take the output (result) and return it to you in file ‘resp’ on the local machine. If instead you want the result of the *who* command to remain on the Y machine the command

† (see ‘‘Setting Defaults’’ below)

```
% net –m Y "who >resp"
```

will create a file ‘resp’ in your login directory on the Y machine. It is a good idea to put the command in quotes, and it *must* be in quotes if I/O redirection (<, >, or other syntax special to the shell) is used.

If you do not specify the remote machine explicitly (or in the ‘‘.netrc’’ file, explained below), the default machine will be used (see Appendix A).

The – option indicates that standard input from the local machine is to be supplied to the command executing remotely as standard input, thus if defaults for the login name and password are set up correctly as described below,

```
% net –m Y – "mail ripper"
   { message to ripper }
{control-d}
```

is equivalent to

```
% mail Y:ripper
   { message to ripper }
{control-d}
```

The net command also has other options not documented here. See the UNIX Programmer’s Manual sections for more details.

Setting Defaults

Instead of repeatedly typing frequently-needed options for every invocation of the various network commands, the user may supply in his login directory a file ‘‘.netrc’’, which contains the repeated information. The ‘‘.netrc’’ file is typically used to specify login names on remote machines, as well as other options. An example of such a file is given below:

```
default Y
machine Y, login dracula
machine Z login dracula, quiet yes
```

This example sets the default machine to Y so that for net commands where a remote machine is not explicitly specified, the command will then be executed on the Y machine. The second and third lines indicate for the Y and Z machines a login name of ‘‘dracula’’ should be used to network commands, and to assume the ‘‘quiet’’ option on all commands destined for the Z machine. The complete list of options that may follow the machine indication is:

.netrc options for each machine			
Option	Parameter	Default	Comment
login	name	localname	login name for remote machine
password	password	(none)	password for remote login name
command	command	(none)	default command to be executed
write	yes/no	yes	if possible, write to user
force	yes/no	no	always prompt for name and password
quiet	yes/no	no	like the **–q** option

In setting up the ‘‘.netrc’’ file, if the ‘‘default’’ option is present, it must be the first line of the file. The information for each machine starts with the word ‘‘machine’’ and the machine name and continues one or more lines up to another machine indication (or the end of the file). Input is free-format. Multiple spaces, tabs, newlines, and commas serve as separators between words. Double quotes (") must surround passwords with blanks or special characters in them.

How to Specify Remote Passwords

For the commands which require the password for the account on the remote machine, there are a number of ways to specify the password:

1) letting the command ask you, as in the *netcp* example in Section 1,
2) specifying it with an alias (if using the C shell),
3) putting it into the current environment if the local machine is running UNIX Version 7,
4) specifying it on the command line with the **–p** option,
5) storing it in the ‘‘.netrc’’ file, described in the previous section.

These can be ranked in order of security, from 1 = greatest security to 5 = lowest security, from the point of view of security of passwords from unauthorized use by other users and possibly an illicit superuser. Each is described in turn:

1) If you make no effort to specify the remote password elsewhere, the network commands will prompt you with:

    Password(mach:username):

   Type your password, followed by a carriage return. This is the most secure mode of specifying passwords. If the net command is executed in the background (i.e. with ‘‘&’’) then the command can’t read the password from your terminal and one of options 2-5 below must be used.

2) The alias feature of the C shell can be used to specify the remote password. The command

    % alias netcp netcp –l godzilla –p $pass

   in the ‘‘.cshrc’’ file, followed by

    % set path=your-passwd

   right before using the network will set for subsequent *netcp* commands the login name ‘‘godzilla’’ and password ‘‘passwd’’. This alias command must be given everytime you login (see the UNIX Programmers Manual section for the C shell (csh (1)) for more information about *alias.* Do *not* put this alias command in your ‘‘.login’’ file.

3) If running on a Version 7 UNIX system, the password can be put in the current environment. The command (to the C shell)

    % setenv MACH*mch* `netlogin –m *mch*`

   or (to the default Version 7 ‘‘Bourne’’ shell)

    % MACH*mch*=`netlogin –m *mch*`
    % export MACH*mch*

   will prompt you for a login name and password for the remote machine *mch* and put an encrypted copy of the password in your environment. (Note the back-quotes to the shell.) Subsequent network commands will find it in your environment and not prompt you for it. These encrypted passwords are invalidated after the user logs out. Type ‘‘man netlogin’’ for more information on the *netlogin* command.

4) Each net command takes a **–p** option on the command line to specify the password. These are usually put in shell command scripts. These shell script files should have file mode 0600 – use the chmod(I) command to set the mode.

5) The remote password can be specified in the user’s ‘‘.netrc’’ file. If passwords are present, the ‘‘.netrc’’ file must have mode 0600 (as in #4 above).

The system managers recommend options 1-3 and warn against 4 and 5. Should someone break into your account on one machine, and you use option 4 or 5, you will have to change your passwords on all net machines for which your passwords have been stored in shell script files or in the ‘‘.netrc’’ file.

Log File

The file ''/usr/spool/berknet/logfile'' has a record of the most recent requests and responses, each line of which is dated. Lines indicating ''sent'' show the file name sent; lines indicating ''rcv'' show commands executed on the local machine (C:), their return code (R:), and their originator. For example, on the Y machine, the logfile:

Feb 28 10:29: rcv X: neil (neil) R: 0 C: netcp design Y:design
Feb 28 10:43: sent tuck to Z (z00466, 136 bytes, wait 2 min 3 sec)
Feb 28 11:05: rcv X: bill (bill) R: 0 C: netcp structures Y:structures

shows three entries. In this example, there are two *netcp* commands sending files from the X machine to Y, each from a different user. The second command sent was originated here by ''tuck'' and is 136 bytes long; the command that was sent is not shown. The command

% netlog

will print the last few lines of this file. Its prototype is

netlog −*num*

where *num* is an integer will print the last *num* lines from the file.

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Appendix A

The Network at Berkeley

1. The Configuration (March 1, 1980)

The Current State of the Berkeley UNIX Network

Machine Name	Internal Name	Run By	Default Machine	Other Name(s)
A	A	Computer Center	C	
B	B	Computer Center	D	
C	C	Computer Center	A	
D	D	Computer Center	C	
E	E	Computer Center	C	
Ing70	I	INGRES Group	IngVAX	Ingres
IngVAX	J	INGRES Group	Ing70	
Image	M	Sakrison	ESVAX	
ESVAX	O	EE-CE Research	CSVAX	
SRC	S	Survey Res. Cent.	D	
CSVAX	V	CS Research	Cory	
Cory	Y	EECS Dept.	CSVAX	
EECS40	Z	EECS Dept.	ESVAX	

If a path exists from the local machine to the requested remote machine, the network will forward the request to the correct machine. Thus Cory users may communicate with all the other machines on the network as well as C and CSVAX (with a degradation in speed because of the intermediate machine(s)). The links between Ing70–IngVAX, Ing70–CSVAX, A–C, C–D, C–E, and B–D run at 9600 Baud, the other links run at 1200 Baud.

2. Documentation

The network commands *(net, netq, netrm, netlog, netcp, netmail, netlpr, netlogin)* are all documented in the UNIX Programmers Manual. For example,

% man netq

will print the *netq* manual section.

There are two more documents available:

Network System Manual
Berkeley Network Retrospective

The Manual is intended for the systems staff who will maintain the network. The Retrospective is my Master's report and details the history of the project, discusses the design, and lists future plans.

There is an up-to-date news file:

% news net

or

% help net

or

% cat /usr/net/news {if those fail}

which prints news about the network, dated and with the most recent news first.

The UNIX Programmer's Manual, section I, has information on the *chmod, cp, mail, who,* and *write* commands mentioned in the text. Also, the *help* command has information about file protections:

% news access {on the Cory machine}

or

% help permissions {on the CC machines}

3. Features at Berkeley

a) There is a built-in character limit of 100,000 characters per single transmission, which cannot be overridden. The limit is 500,000 characters between the INGRES machines. Longer files must be split into smaller ones in order to be sent.

b) The 1200 Baud links between machines seldom transmit any faster than 50 characters per second (for 9600 Baud links, 350 characters a second), and can slow to a fraction of that in peak system loading periods. This is due to an expansion of the data packets to accomodate a seven-bit data path, wakeup time on the machines, and the packet sent in acknowledgement. Heavy file transfer is faster by magnetic tape.

c) On the CSVAX, IngVAX, and ESVAX the net commands are all in '/usr/ucb'. Your search path on these VAX's should be set to include the directory '/usr/ucb'; otherwise you will have to prefix all net commands by '/usr/ucb', as in '/usr/ucb/netcp'.

d) Limited Free Commands

Users who do not have accounts on remote machines may still execute certain commands by giving a remote login name of ''network'', and no remote password. The commands currently allowed are:

bpq	netlog	rcs	vpq	whom
epq	netq	rcslog	w	write
finger	ps	rcsq	where	yank
lpq	pstat	trq	who	

The *lpr* command is allowed on the INGRES machine. Also, *mail* to remote machines and *netlpr* between Computer Center machines do not require a remote account. The EECS40 machine allows no free commands (but allows the sending of mail).

For example, to execute an *lpq* command on the A machine, the user would type:

% net –l network –m A ‘‘who’’

e) If no machine name specification is in the front of a full path name, the first four characters are checked and the machine is inferred from that if possible. In the command

% netcp file1 /ca/schmidt/file1

the second file name is equivalent to ‘‘C:file1’’, if you are ‘‘schmidt’’ on the C machine.

f) The network can only send files in one direction at a time. Thus confirmations can slow down heavy file transfer. If you regularly use a shell script to transfer a set of files, the **–q** option to *netcp* will improve transfer time.

g) The network creates a heavy load on the system and thus is expensive to run. If general user throughput is adversely affected, a charge will be implemented on the Computer Center machines.

h) When transferring files, quota overflow will result in a partial copy, so you should check the space requirements of the file being sent.

i) The Computer Center ‘‘A’’ machine’s phototypesetter is usable from other network machines. If on one of the B-E machines, you do not need an account on the A machine. You simply type

% troff –Q other-options file(s)

instead of the normal

% troff other-options file(s)

The troff command is executed on the local machine and the phototypesetter instructions are sent to the A machine. You will be sent mail both when the file is queued and when it is finally typeset. To see your place in the *troff* queue, type:

% trq

on any Computer Center machine. There is a command

% trrm code

(where *code* is the code from the *trq* command) to remove queue files before they have been typeset. *Trrm* must be executed on the same machine from which the job was submitted.

If you are on a non-Computer Center machine, you may use the *nettroff* command:

% nettroff options file(s)

which is similar to the ‘‘troff –Q’’ command earlier. You will need an account on the A machine and the *trrm* command doesn’t work from a non-Computer Center machine.

If using *nettroff,* no more than 15 pages may be sent to the typesetter. If using *troff* more than 15 pages may be sent only if the **–s** option is specified (see troff(1) for more information). The network will not transfer any file longer than 100,000 characters to the A machine. (It is best to aim for files of 25,000 characters or less)†. For more information, type

man troff {on the Computer Center machines}
or
man nettroff {on the other machines}

The *nettroff* command is not supported by the Computer Center.

j) The *netlpr* command allows ‘‘epr’’, ‘‘bpr’’, and ‘‘vpr’’ as alternate lineprinters (using the **–c** option).

† Characters from *troff*’s output, not the user’s source files. It is our general experience that *troff* outputs roughly twice as many characters as are in the source file (before any *eqn* or *tbl* preprocessing.)

4. Bugs in systems at Berkeley (As of March 1, 1980)

a) If you are on the Computer Center machines using obsolete shells (/usr/pascal/sh, /usr/pascal/nsh) and have a ‘‘.profile’’ or ‘‘.shrc’’ file to change your shell prompt, you must make sure that you don’t turn on ‘‘prompting’’ for non-interactive shells. This will interfere with the net commands. You should use this shell command to change your prompt:

```
${prompt?prompt=P}
```

where ‘‘P’’ is the prompt desired. This will avoid the problem.

If you set the variable *time* in the C shell, extraneous time stamps may appear in response messages. The correct way to set the variable *time* in the C shell is

```
if ($?prompt) then
        set time=num
endif
```

where *num* is the time interval in seconds.

b) The file mode should be preserved by *netcp* and it should be possible to default the second file name to a directory as in cp(I).

c) Various response messages are lost. This includes ‘‘fetching’’ files when the file being retrieved never arrives. I suspect this has something to do with unreliable delivery of error messages, but this is not reliably reproducible.

d) The network makes no provision for errors in transit on intermediate machines, such as ‘‘No more processes’’ or ‘‘File System Overflow’’. While these occur only rarely, when they do, no message or notification is sent to anyone.

e) The network commands are too slow on heavily-loaded instructional machines. The *net* command has to read the password file, ‘‘.netrc’’ file and the ‘‘/etc/utmp’’ file.

f) The queue files are normally sent shortest-job first. Unfortunately, under heavy loading the queue-search becomes too expensive and the network will choose the next file to send from the first 35 queue entries it finds in the queue directory, so the user should not depend on the requests being sent shortest-first.

g) Comments and bug discoveries are encouraged and can be sent by local or remote mail to ‘‘csvax:schmidt’’.

Appendix B

Getting Started — An Example

The best way to start out is to follow this example. Suppose you're a Cory user, and you have accounts on the A and CSVAX machines.

1) Add a file ''.netrc'' (mode 600) to your login directory, as in the following example:

   default CSVAX
   machine A login *yourNameOnA*
   machine CSVAX login *yourNameOnCSVax*

   (If ''default'' occurs, it must be the first line of the file.)

2) Make sure that

   a) if you are on one of the VAX's, you have in your search path the directory '/usr/ucb'. Otherwise, on those machines you will have to prefix all commands by '/usr/ucb/' (e.g. '/usr/ucb/netcp').

   b) on the Computer Center machines, if you choose to set your shell prompt, you have done so correctly (details in Appendix A).

3) Then type

   % net ''who''
   % netq

   which will send a *w* command to the CSVAX; some undetermined time later you will have written (or mailed) to you the output from the command executed on the CSVAX machine.

   The adventuresome may try:

   % net –m A ''who''

   with the effect of being routed more slowly through an intermediate link in the net.