A VIRTUAL OPERATING SYSTEM

Dennis E. Hall, Deborah K. Scherrer, and Joseph S. Sventek

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A Virtual Operating System

Dennis E. Hall
Deborah K. Scherrer
Joseph S. Sventek

Lawrence Berkeley Laboratory

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Abstract

Significant progress toward disentangling computing environments from their underlying operating system has been made. An approach is presented that achieves inter-system uniformity at all three levels of user interface - virtual machine, utilities, and command language. Under specifiable conditions, complete uniformity is achievable without disturbing the underlying operating system. The approach permits accurate computation of the cost to move both people and software to a new system. The cost of moving people is zero, and the cost of moving software is equal to the cost of implementing a virtual machine. Efficiency is achieved through optimization of the primitive functions.
Key Words and Phrases

Computing environments, operating systems, virtual machines, system utilities, command languages, functional equivalence of operating systems, user mobility, user interface, moving costs.

CR Categories: 4.35, 4.40, 4.6

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"One complication you probably have no control over is your local computing environment. But even if it's horrible, as many are, you don't have to suffer stoically. Even a modest improvement of frequently used parts, like your programming and job control languages, is well worthwhile, and there's no excuse for not trying to conceal the worst aspects." [8]

1. Introduction

Associated with each computer system is a "local computing environment" or operating system interface. Today's computer marketplace offers a wide variety of such environments, each inextricably entwined with its own peculiar set of hardware components. Because of this, acquiring a new system usually requires that customers spend considerable time and effort moving both software and people to a new computing environment.

Under present conditions, even estimating the organizational impact of such a move can be extremely difficult. As a rule, moving to a new system is costly and error prone. Therefore, many organizations have elected to stay with a single computer vendor in spite of an increasingly competitive hardware marketplace.

Although computer manufacturers have been effective in developing highly reliable operating systems, their computing environments are not usually examples of good human
engineering. Customers, in an effort to minimize the cost of moving to new systems, have insisted that vendors remain compatible with historical precedent. This has tended to discourage removal of poor interfaces and inhibited development of improved ones. As a result, bad interfaces seem to live forever.

For many computer users there is no need to distinguish between the interface to an operating system and the operating system itself. We will show that under certain conditions a uniform system interface can be provided across machine boundaries without disturbing vendor software. The method consists of creating a virtual operating system.

2. The Virtual Operating System Approach

A real operating system presents three principal interfaces to its users [6]: the virtual machine or operating system primitives accessible through programming languages, the utility programs such as compilers, linkers, and editors, and the command language or means by which users access system resources from a terminal. Most system services are available through one or more of these interfaces (see fig. 1).

The idea of a virtual operating system is to provide standard versions of these interfaces based on organizational requirements. Possible applications include data
management environments, office information environments, real-time process control environments, and program development environments, to name a few.

A virtual operating system provides standardized versions of the three outermost system layers. Installation consists of interfacing the standardized virtual machine to the vendor supplied system.
Once the three interfaces are specified, implementation consists of:

* choosing one or more programming languages;

* developing run time libraries or extending the selected programming languages to support the chosen virtual machine on each target system;

* implementing the utilities and command language in one or more of the selected programming languages, relying on the virtual machine to interface to the target operating systems;

* writing the necessary documentation.

A virtual operating system becomes a real operating system when the associated virtual machine corresponds to a physical machine. However, the emphasis in building a virtual operating system is on the interface presented to the user. The virtual machine is a highly idealized set of primitive functions geared to organizational programming requirements. It bears almost no functional resemblance to the underlying hardware which actually performs the work. In general, a virtual operating system is restricted to those parts of an ordinary operating system which an organization finds important in getting its work done. Obviously a single real operating system can support many virtual
operating systems.

To achieve the full benefit of the approach, the virtual machine must be implementable without changing the vendor software. This implies a functional equivalence between the chosen virtual machine and the target systems. Hence, a bootstrapping design procedure is required. Each candidate virtual machine function must be tested on each target system before it can be finally adopted.

The virtual operating system approach reduces the problem of moving to a new system to the (non-trivial) problem of implementing a virtual machine. All utilities and user programs are completely portable since their interface to any particular operating system is through the virtual machine. Similarly, higher level procedures written for a portable utility are themselves portable. For example, a file containing editor commands will work on any machine supporting the editor utility. Finally, command language procedures are also portable, since the command language program is portable. The availability of the entire virtual operating system (virtual machine, utilities, and command language) makes it easy for users and programs to move from one vendor system to another.

We emphasize that this approach reduces the cost of moving both people and software to zero. The overhead is
the cost of implementing the virtual machine on the candidate system. This can be estimated by any knowledgable system programmer, and it is completely independent of the number of people and the amount of software to be moved.

3. When is a Virtual Operating System Approach Desirable?

The advantages and disadvantages of a virtual operating system are much the same as those for a real operating system. However, the effort to develop and maintain a virtual operating system is usually far less than for a real operating system: the most difficult problem is in specifying a virtual machine which can peacefully coexist with the desired target systems.

In some respects, the approach makes sense for any software development project. The identification of clear cut interfaces is a standard structured programming technique, which (in theory at least) reduces software maintenance costs. The only controversy might be over the particular choice of structure (i.e. the virtual machine). In general, whenever organizational software is likely to outlive its hardware, the approach warrants consideration. This is because of the high redevelopment costs.

4. One realization of a Virtual Operating System

To test the approach, a uniform program development
environment was installed on several distinct systems. A program development environment consists of resources which assist programmers in the development and maintenance of computer programs, such as text editors, programming language processors, and file systems. The types of system resources with which such a virtual machine is concerned (files, directories, processes, and the user environment) require a general-purpose operating system interface.

Since the primary goal was to achieve some practical results, the system was to be modelled after an existing real operating system. The major criteria for the selection of this real system were the popularity of it within its user community and the estimated relevance of it to the programming needs within the organization. After an extensive survey of existing systems, the Unix operating system [4] appeared to be a good candidate for emulation.

The actual virtual machine implementation permits the manipulation of files, directories, processes and the user environment. The complete list of primitives implemented are given in Appendix A. Most of the file manipulation primitives were adopted from the book *Software Tools* by Kernighan and Plauger [8], since these primitives already provided a virtual machine consistent with a subset of the Unix system. This virtual machine could be used to implement

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1 Unix is a trademark of Bell Laboratories.
most of the program development environments currently available. In particular, it permitted the implementation of many of the text manipulation utilities of the Unix system, as well as a command line interpreter similar to the Unix shell [3].

The primary requirements in the selection of a programming language for the virtual operating system were that the resulting code be portable to a wide range of machine architectures and that there be a substantial body of existing code upon which to base the system. The language chosen was RATFOR [7] (rational FORTRAN), a FORTRAN preprocessor which includes a reasonable set of flow-control structures (if-else, while, for, and repeat-until). This choice meets the two requirements, since ANSI-66 FORTRAN [1] compilers are available for use in most vendor environments and since the source code for the utilities in [8] is available in machine readable form. (These were implementations of many of the Unix text-processing utilities.) As an added incentive, RATFOR represented a reasonable way to encourage structured programming, since FORTRAN was already the predominant programming language.

Although implementation of the utility programs was greatly aided by the availability of the source code from [8], a fair amount of effort was necessary to increase the appeal of the system to a wider user community. In particu-
lar, all of the original utilities were substantially enhanced, and new ones were written as their needs were perceived. To complete the implementation of the virtual operating system, the command line interpreter was written, again emulating that of Unix [3]. On-line documentation of the system was provided [5], and a guide for installing the package on new systems was written [9]. In all cases, the system was offered in parallel with the existing environment, allowing users to experiment with the virtual operating system without giving up the familiar, vendor-supplied environment. A complete list of the utilities in the system is presented in Appendix B. A description of the command interpreter is provided in Appendix C.

To encourage experimentation and to alleviate user frustration, the source code for the system was made available to all interested parties, implicitly designating the universe of users as the system-programming group. It was felt that the resulting variation would complicate maintenance initially, but that the eventual positive benefits might outweigh the disadvantages.

5. Experience

5.1 Achieving Functional Equivalence of Operating Systems

The virtual operating system was implemented on the sys-
tems listed in Table I. A virtual operating system based upon a restricted set of the primitives of Appendix A was implemented on a much wider variety of machine architectures as shown in Appendix D. The implementations listed in Table I indicate that these operating systems supply most of the system calls necessary to implement the virtual machine.

Complete uniformity across the different vendors may require modification of one or more of the host operating systems. This usually invalidates vendor-software maintenance contracts. Fortunately, a knowledgeable system programmer can often solve the problem through creative primitive implementation. But, regardless of the manner in which the virtual machine is implemented on existing machines, the mappability of the virtual machine may be used as a selection criterion for prospective vendors.

As an example of an apparent non-uniformity, most multi-programming operating systems supply a central portion of the executive which handles the communication with user terminals (the "terminal handler"). Certain keys on the terminal keyboard have special meaning to the terminal handler - e.g. erase previous character, interrupt process and suspend terminal output. Even though there is a standard [2] for the interpretation of the character codes generated by the terminals, most systems apply their own semantics to the non-printing ones, with the result that the key-
board interfaces to different systems are extremely non-uniform. To complicate the situation, these semantics are usually not under control of the user. User mobility in this situation is thus severely hindered.

One solution to this problem is to modify the terminal handler for each system to present a common keyboard interface on all systems, with the side-effect of invalidating software maintenance contracts. Fortunately, most systems also provide the capability of transmitting and receiving characters with no interpretation by the terminal handler ("raw terminal i/o"). If the virtual machine i/o primitives transfer raw i/o to and from terminals, then a common set of semantics may be applied to the character codes on all systems, thus creating a uniform keyboard interface. Systems which do not allow user-applied semantics to the character codes, or do not permit raw terminal i/o can be avoided by organizations wishing to preserve this common keyboard interface.

This is not the only example of the difficulties encountered in such an endeavor, but it is indicative because most problems can be solved without resorting to modification of the vendor software.

In conclusion, the functional equivalence of vendor operating systems is strongly dependent upon the virtual
machine specified. In the case outlined in section 4, the virtual operating system primitives are implementable over a wide range of machine architectures without modification to the host operating system. A more general conclusion is that if the virtual machine specification accurately represents the needs of a particular organization, the implementability of the virtual machine is the major criterion in the selection of a new computer system.

5.2 Estimating Cost

There are two types of costs incurred when using a virtual operating system approach:

i. The effort required to write the utilities: this is a one-time cost, since these utilities are independent of any real operating system. The program development costs for the utilities will be similar to those for any other software system designed for a specific machine, since the virtual operating system utilities are designed for the virtual machine.

ii. The costs to implement the virtual machine: these are incurred once for each different host operating system within the organization. It is important to note that this is the only cost in moving all personnel and software to the new computing environment.
It has been estimated\(^2\) that 8-10 person months of effort were required to implement the original utilities in [8]. In addition, 6-8 person months were spent enhancing these original utilities. The largest single investment in new code was writing the command line interpreter, which required 4 person months. In all, approximately 2 person years have been invested in the implementation of the utilities of Appendix B.

The costs incurred in the implementation of the virtual machine on several systems are given in Table I. It is notable that the average time necessary to port the entire system was approximately four person months. The dominance of Digital Equipment Corporation systems should not be interpreted as a lack of rigorous testing of the concept, since the operating systems on these machines are quite different.

\(^2\) Brian Kernighan, private communication: "... Probably 8-10 person months, but we were writing the book too. (That's 4-5 months for two people.)"
### Table I

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Machine</th>
<th>Operating System</th>
<th>Person Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDC</td>
<td>6000</td>
<td>BKY</td>
<td>4</td>
</tr>
<tr>
<td>DEC</td>
<td>11/70</td>
<td>IAS</td>
<td>2</td>
</tr>
<tr>
<td>DEC</td>
<td>11/780</td>
<td>VMS</td>
<td>1</td>
</tr>
<tr>
<td>DEC</td>
<td>11/34</td>
<td>RSX-11M</td>
<td>3</td>
</tr>
<tr>
<td>DEC</td>
<td>PDP-10</td>
<td>TENEX</td>
<td>2</td>
</tr>
<tr>
<td>Modcomp IV</td>
<td></td>
<td>MAX4</td>
<td>5</td>
</tr>
</tbody>
</table>

In cases such as this, where the effort required to implement the virtual machine is small, an attempt in that direction can be made as part of the evaluation of new systems. The decision to purchase can then be based upon whether the virtual machine is implementable on the given system. Movement of personnel and software can be essentially instantaneous.

### 5.3 Optimizing Machine Efficiency

The issue of machine efficiency (the ability to minimize the demands of the software upon scarce hardware and software resources) is addressed through design and implementation of the virtual machine. The virtual machine selected indicates those resources which the utilities can manipulate and outlines any possible bottlenecks in the utilization of those resources.
The utilities of the virtual operating system described here are primarily oriented towards text processing (source code generation, documentation, inter-user communication, etc.). These types of utilities are characteristically bounded by input/output rates [8]. Since the input/output capabilities are isolated in the virtual machine, the effect of this particular problem can be reduced through efficient implementation of the i/o primitives.

The effect of the programming language on efficiency can also be studied. Snow [11] has reported on the automatic translation of RATFOR to BCPL [10] which resulted in substantial savings in memory requirements and enhanced execution speeds. Preliminary investigations at LBL have indicated that a 50% reduction in object code size and a 30% improvement in CPU utilization are attainable on a VAX-11/780 running the VMS operating system by automatically translating RATFOR to BLISS [12]. Table II summarizes code size and execution speed for various language translation alternatives. The example is "scopy", a frequently used string copy routine.
Table II

<table>
<thead>
<tr>
<th></th>
<th>Code size</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand coded assembly language</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>BLISS - simulated automatic translation</td>
<td>1.0</td>
<td>4.6</td>
</tr>
<tr>
<td>FORTRAN - hand coded</td>
<td>3.0</td>
<td>4.6</td>
</tr>
<tr>
<td>RATFOR</td>
<td>3.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

As a rule, it is necessary to anticipate bottlenecks in resource utilization during the design phase of the virtual machine. If manipulation of these resources is restricted to the virtual machine, efficiency can be achieved through optimization of the primitives alone. All utilities accessing these resources receive the benefits of such optimization automatically.

5.4 Proliferation of Variants

Distribution of source code to users invites the proliferation of variants. The existence of variants can destroy the uniformity provided by the approach. Traditional methods of controlling this restrict development to a small group of experts. However, this method tends to produce user frustration and inhibit system growth.

Although such variants are bothersome and undesirable, they are necessary for growth, like genetic variations in a
biological population. As conditions change, software that can be adapted to changing requirements will survive. The abstract virtual machine and high-level language used in a virtual operating system enable the software to be adapted to changing conditions.

When software is used by many organizations, a user group may perform the control functions necessary to limit variation. To test this particular scenario, a user group was organized. Current activities of the group include the establishment of a centralized distribution facility, distribution of a newsletter, organization of active special interest groups on various topics and sponsorship of bi-annual meetings. Standards for the various utilities are expected to result from the activities. In this manner, a benign form of control over the variation of the code is exercised.

6. Conclusions

Significant progress toward disentangling computing environments from their underlying operating system has been made. Using the virtual operating system approach, uniformity can be achieved at the three principal levels of user interface - the virtual machine, the system utilities, and the command language.
For at least one realization of the virtual machine interface, functional equivalence of vendor operating systems has been established. Complete uniformity of environment is achievable without disturbing vendor software.

Although the effort to install a virtual operating system is large when compared to the effort to move a single program, it is small when compared to to the cost of moving the entirety of an organization's software. Moreover, when personnel retraining costs are considered, installation costs are insignificant. The approach permits accurate estimation of the cost of moving to a new system. The cost of moving people is zero, and the cost of software is equal to the cost of implementing the virtual machine.

The question of machine efficiency can also be addressed. By anticipating bottlenecks in resource utilization, critical functions can be isolated and solutions incorporated in the architecture of the virtual machine. This permits the benefits to be shared by all software.

The proliferation of variants brought on by wide distribution of source code does not appear to be a serious problem. The formation of a user group has helped standardize both utilities and the virtual machine in a practical application of the technique.
Acknowledgments

The authors gratefully acknowledge the cooperation of Brian Kernighan of Bell Labs, the Addison-Wesley Publishing Company, and the many individuals who implemented the package on other systems. A project of this magnitude necessarily involves many persons from numerous sites. The following provided especially helpful suggestions and comments: Don Austin of LBL, Mark Bronson of LBL, Bob Calland of NOSC, Doug Comer of Purdue, Phil Enslow of Georgia Tech., Dave Hanson of the University of Arizona, Terry Layman of IAC, Dave Martin of Hughes Aircraft, Robert Munn of the University of Maryland, Chris Petersen of ORINCON, Jim Pool of DOE Headquarters, and Bob Upshaw of LBL.
References


Designed for readers with a background in programming and a knowledge of elementary calculus and probability theory - focuses on general concepts illustrated with algorithms, techniques and performance figures from actual systems.

Discusses design criteria for a FORTRAN preprocessor, the RATFOR language and its implementation, and user experience.

Presents the principles of good programming practice in the context of actual working programs. The code is available in machine-readable form as a supplement to the text.

Provides guidelines for installing the software tools program development environment on new systems.

Describes a method for porting a BCPL compiler which includes the specification of OCODE, a language used as an interface between the machine independent and machine dependent parts of the compiler.

Describes an implementation project on a Burroughs B1700 computer using an automatic code translation technique.

Describes BLISS, a language designed to be especially suitable for use in writing production software systems for DEC machines.
Appendix A

Virtual Machine

The following summarizes the primitive functions of the virtual machine chosen to test the virtual operating system technique.

FILE ACCESS

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>open a file for reading, writing, or both</td>
</tr>
<tr>
<td>create</td>
<td>create a new file (or overwrite an existing one)</td>
</tr>
<tr>
<td>close</td>
<td>close (detach) a file</td>
</tr>
<tr>
<td>remove</td>
<td>remove a file from the file system</td>
</tr>
<tr>
<td>tty</td>
<td>determine if file is a teletype/CRT device</td>
</tr>
<tr>
<td>gettyp</td>
<td>determine if file is character or binary</td>
</tr>
</tbody>
</table>

I/O

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>getch</td>
<td>read character from file</td>
</tr>
<tr>
<td>putch</td>
<td>write character to file</td>
</tr>
<tr>
<td>seek</td>
<td>move read/write pointer</td>
</tr>
<tr>
<td>markl</td>
<td>pick up record position in file</td>
</tr>
<tr>
<td>readf</td>
<td>read 'n' bytes from file</td>
</tr>
<tr>
<td>writef</td>
<td>write 'n' bytes to file</td>
</tr>
<tr>
<td>flush</td>
<td>force flushing of I/O buffer</td>
</tr>
</tbody>
</table>

PROCESS CONTROL

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>spawn</td>
<td>execute subtask</td>
</tr>
<tr>
<td>pstat</td>
<td>determine status of process</td>
</tr>
<tr>
<td>kill</td>
<td>kill process</td>
</tr>
<tr>
<td>resume</td>
<td>resume process after a suspend</td>
</tr>
<tr>
<td>suspnd</td>
<td>suspend process</td>
</tr>
</tbody>
</table>
Appendix A

Virtual Machine

DIRECTORY MANIPULATION

opendir
open directory for reading

closdr
close directory

gdrprm
get next file name from directory

gdraux
get auxiliary file information from directory

mkpath
generate full Unix pathname from local file name

mkloc

generate local file specification from pathname

cwd

change current directory

get file name from directory

mk

create a directory

rm

delete a directory

mv
move (rename) directory

MISCELLANEOUS

getarg
get command line arguments

delarg
delete command line argument 'n'

init
initialize all standard I/O and common blocks

end

close all open files and terminate program

date
generate full Unix pathname from local file name

generate local file specification from pathname

cwd
change current directory

MK

create a directory

RM

delete a directory

MV
move (rename) directory

QUASI PRIMITIVES

Many of the following were defined as primitives in the original Kernighan-Plauger package. However, since it is possible to implement these in terms of previously defined primitives, or (in one case) to adjust the RATFOR preprocessor to handle the problem, it was decided to move these functions to the portable category. Nevertheless,
Appendix A

Virtual Machine

Optimization is usually advisable for increased efficiency or capability.

- prompt: putlin with carriage return/line-feed suppressed
- getlin: read next line from file
- putlin: write a line to file
- remark: print single-line message
- scratf: generate unique (scratch) file name
- amove: move (rename) file1 to file2
Appendix B

Utilities

The following summarizes the utility functions which constitute one portion of the program development environment. These emulate many of the utilities found in the Unix operating system.

ar  archive file maintainer
cat  concatenate and print text files
ccnt character count
ch   make changes in text files
cmp  compare two files
comm print lines common to two files
cpress compress input files
crt  copy files to terminal
crypt crypt and decrypt standard input
cwd change working directory
date print date and time
detab convert tabs to spaces
echo print command line arguments
ed  text editor
entab convert spaces to tabs and spaces
expand uncompress input files
find search a file for a pattern
form generate form letter
help list on-line documentation
incl expand included files
kill kill process
<table>
<thead>
<tr>
<th>Appendix B</th>
<th>Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>kwic</td>
<td>make keyword in context index</td>
</tr>
<tr>
<td>lcnt</td>
<td>line count</td>
</tr>
<tr>
<td>ls</td>
<td>list contents of directory</td>
</tr>
<tr>
<td>macro</td>
<td>process macro definitions</td>
</tr>
<tr>
<td>mail</td>
<td>send or receive mail</td>
</tr>
<tr>
<td>man</td>
<td>run off section of users manual</td>
</tr>
<tr>
<td>mkdir</td>
<td>create a directory</td>
</tr>
<tr>
<td>mv</td>
<td>move (rename) a file</td>
</tr>
<tr>
<td>mvdir</td>
<td>move (rename) a directory</td>
</tr>
<tr>
<td>os</td>
<td>(overstrike) convert backspaces into multiple lines</td>
</tr>
<tr>
<td>postmn</td>
<td>see if user has mail</td>
</tr>
<tr>
<td>pstat</td>
<td>check process status</td>
</tr>
<tr>
<td>pwd</td>
<td>print working directory</td>
</tr>
<tr>
<td>rat4</td>
<td>RATFOR preprocessor</td>
</tr>
<tr>
<td>roff</td>
<td>format text</td>
</tr>
<tr>
<td>rmdir</td>
<td>remove directory</td>
</tr>
<tr>
<td>resolve</td>
<td>identify mail users</td>
</tr>
<tr>
<td>resume</td>
<td>resume suspended process</td>
</tr>
<tr>
<td>rm</td>
<td>remove files</td>
</tr>
<tr>
<td>sh</td>
<td>shell (command line interpreter)</td>
</tr>
<tr>
<td>sort</td>
<td>sort and/or merge text files</td>
</tr>
<tr>
<td>spell</td>
<td>find spelling errors</td>
</tr>
<tr>
<td>split</td>
<td>split a file into pieces</td>
</tr>
<tr>
<td>suspnd</td>
<td>suspend running process</td>
</tr>
<tr>
<td>tee</td>
<td>copy input to standard output and named files</td>
</tr>
<tr>
<td>tr</td>
<td>character transliteration</td>
</tr>
<tr>
<td>uniq</td>
<td>strip adjacent repeated lines from a file</td>
</tr>
</tbody>
</table>
unrot: unrotate lines rotated by kwic
wcnt: (character) word count
Appendix C

Command Language

The Shell

The shell is a command interpreter: it provides a user interface to the process-related facilities of the virtual operating system. It executes commands that are read either from a terminal or from a file.

Commands

Simple commands are written as sequences of "words" separated by blanks. The first word is the name of the command to be executed, and any remaining words are passed as arguments to the invoked command. The command name actually specifies a file which should be brought into memory and executed. If the file cannot be found in the current directory or through its pathname, the shell searches one or more specific directories of commands intended to be available to shell users in general.

Standard I/O

The utilities of the virtual operating system have three standard files associated with them: standard input, standard output, and standard error output. All three are initially assigned to the user's terminal, but may be redirected to a disk file for the duration of the command by preceding the file name argument with special characters:
"<name" causes the file "name" to be used as the standard input file of the associated command.

">name" causes file "name" to be used as the standard output (">>name" appends to the end of the file).

">?name" causes the file "name" to be used as the standard error output (">?name" appends to the end of the file).

Most utilities also have the capability to read their input from a series of files simply by having the files listed as arguments to the command.

Filters and Pipes

The output from one command may be directed to the input of another. A sequence of commands separated by vertical bars (|) or carets (^) causes the shell to arrange that the standard output of each command be delivered to the standard input of the next command in sequence. For example, the command line:

```
tr <name A-Z a-z | sort | uniq
```

translates all the upper case characters in file "name" to lower case, sorts them, and then strips out multiple occurrences of lines.

The vertical bar is called a "pipe". Programs such as
tr, sort, and uniq, which copy standard input to standard output (making some changes along the way), are called filters.

Command separators and groupings

Commands need not be on different lines; instead they may be separated by semicolons.

The shell also allows commands to be grouped together with parentheses, where the group can then be used as a filter. For example,

```
(find <file1 this; find <file2 that) | sort
```

locates all lines containing "this" in file1, plus all lines containing "that" in file2, and sorts them together.

Multitasking

On many systems the shell also allows processes to be executed in the background. That is, the shell will not wait for the command to finish executing before prompting again. Any command may be run in the background by following it with the operator "&".

Script files

The shell may be used to read and execute commands contained in a file. Such a file is called a "script file". It can be used any place a regular command can
be issued. Arguments supplied with the call are referred to within the shell procedure using the positional parameters $1, $2, etc.

Script files sometimes require in-line data to be available to them. A special input redirection notation "<<" is used to achieve this effect. For example, the editor normally takes its commands from the standard input. However, within a script file commands could be embedded this way:

```
ed file <<!
... editing requests
!
```

The lines between "<<! and ! are called a "here" document; they are read by the shell and made available as the standard input. The character "!" is arbitrary, the document being terminated by a line which consists of whatever character followed the "<<."

**Shell Flags**

The shell accepts several special arguments when it is invoked: causing it to print each line of a script file as it is read and/or executed, suppress execution of the command entirely, or read the remaining arguments and execute them as a shell command.
The following summarizes the machines and systems used by members of the software tools user group. Most support at least the RATFOR preprocessor and the i/o primitives.

Burroughs B1700 local

CDC 1784 local

CDC 6000s, Cybers KRONOS, UT-LD, local, DUAL-MACE, SCOPE3, NOS

CDC 7600 LTSS, SCOPE II, local

CDC MP-32 MPX/OS

Cray CPSS

DataGeneral Eclipse AOS, RDOS

(C & S series)

DataGeneral Nova RDOS

DataGeneral MP-100 MP/OS

ROLM 1602 RDOS

GEC 4070 OS 4000

Honeywell 6000S GCOS-3

Honeywell Level 6 MOD 6 OS

Multics Multics

ACOS 700 GCOS

AN/UYK-20 Level 2
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