On the Security of UNIX

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Recently there has been much interest in the security aspects of operating systems and software. At issue is the ability to prevent undesired disclosure of information, destruction of information, and harm to the functioning of the system. This paper discusses the degree of security which can be provided under the UNIX system and offers a number of hints on how to improve security.

The first fact to face is that UNIX was not developed with security, in any realistic sense, in mind; this fact alone guarantees a vast number of holes. (Actually the same statement can be made with respect to most systems.) The area of security in which UNIX is theoretically weakest is in protecting against crashing or at least crippling the operation of the system. The problem here is not mainly in uncritical acceptance of bad parameters to system calls_ there may be bugs in this area, but none are known_ but rather in the lack of any checks for excessive consumption of resources. Most notably, there is no limit on the amount of disk storage used, either in total space allocated or in the number of files or directories. Here is a particularly ghastly shell sequence guaranteed to stop the system:

```
: loop
mkdir x
chdir x
goto loop
```

Either a panic will occur because all the i-nodes on the device are used up or all the disk blocks will be consumed, thus preventing anyone from writing files on the device.

Processes are another resource on which the only limit is total exhaustion. For example, the sequence

```
command&
command&
command&
```

if continued long enough will use up all the slots in the system's process table and prevent anyone from executing any commands. Alternatively, if the commands use much core, swap space may run out, causing a panic. Incidently, because of the implementation of process termination, the above sequence is effective in stopping the system no matter how short a time it takes each command to terminate. (The process-table slot is not freed until the terminated process is waited for; if no commands without "&" are executed, the Shell never executes a "wait.")

It should be evident that unbounded consumption of disk space, files, swap space, and processes can easily occur accidentally in malfunctioning programs as well as at command level. In fact UNIX is essentially defenseless against this kind of abuse, nor is there any easy fix. The best that can be said is that it is generally fairly easy to detect what has happened when disaster strikes, to identify the user responsible, and take appropriate action. In practice, we have found that difficulties in this area are rather rare, but we have not been faced with malicious users, and enjoy a fairly generous supply of resources which have served to cushion us against accidental overconsumption.

The picture is considerably brighter in the area of protection of information from unauthorized perusal and destruction. Here the degree of security seems (almost) adequate theoretically, and the problems lie more in the necessity for care in the actual use of the system.

Each UNIX file has associated with it eleven bits of protection information together with a user identification number and a user-group identification number (UID and GID). Nine of the protection bits are used to specify independently permission to read, to write, and to execute the file to the user himself, to members of the user's group, and to all other users. Each process generated by or for a user has associated with it an effective UID and a real UID, and an effective and real GID. When an attempt is made to access the file for reading, writing, or execution, the user process's effective UID is compared against the file's UID; if a match is obtained, access is granted provided the read, write, or execute bit respectively for the user himself is present. If the UID for the file and for the process fail to match, but the GID's do match, the group bits are used; if the GID's do not match, the bits for other users are tested. The last two bits of each file's protection information, called the set-UID and set-GID bits, are used only when the file is executed as a program. If, in this case, the set-UID bit is on for the file, the effective UID for the process is changed to the UID associated with the file; the change persists until the process terminates or until the UID changed again by another execution of a set-UID file. Similarly the effective group ID of a process is changed to the GID associated with a file when that file is executed and has the set-GID bit set. The real UID and GID of a process do not change when any file is executed, but only as the result of a privileged system call.

The basic notion of the set-UID and set-GID bits is that one may write a program which is executable by others and which maintains files accessible to others only by that program. The classical example is the game-playing program which maintains records of the scores of its players. The program itself has to read and write the score file, but no one but the game's sponsor can be allowed unrestricted access to the file lest they manipulate the game to their own advantage. The solution is to turn on the set-UID bit of the game program. When, and only when, it is invoked by players of the game, it may update the score file ordinary programs executed by others cannot access the score.

There are a number of special cases involved in determining access permissions. Since executing a directory as a program is a meaningless operation, the execute-permission bit, for directories, is taken instead to mean permission to search the directory for a given file during the scanning of a path name; thus if a directory has execute permission but no read permission for a given user, he may access files with known names in the directory, but may not read (list) the entire contents of the directory. Write permission on a directory is interpreted to mean that the user may create and delete files in that directory; it is impossible for any user to write directly into any directory.

Another, and from the point of view of security, much more serious special case is that there is a "super user" who is able to read any file and write any non-directory. The super-user is also able to change the protection mode and the owner UID and GID of any file and to invoke privileged system calls. It must be recognized that the mere notion of a super-user is a theoretical, and usually practical, blemish on any protection scheme.

The first necessity for a secure system is of course arranging that all files and directories have the proper protection modes. Unfortunately, UNIX software is exceedingly permissive in this regard; essentially all commands create files readable and writable by everyone. This means that more or less continuous attention must be paid to adjusting modes properly. If one wants to keep one's files completely secret, it is possible to remove all permissions from the directory in which they live, which is easy and effective; but if it is desired to give general read permission while preventing writing, things are more complicated. The main problem is that write permission in a directory means precisely that; it has nothing to do with write permission for a file in that directory. Thus a writeable file in a read-only directory may be changed, or even truncated, though not removed. This fact is perfectly logical, though in this case unfortunate. A case can be made for requiring write permission for the directory of a file as well as for the file itself before allowing writing. (This possibility is more complicated than it seems at first; the system has to allow users to change their own directories while forbidding them to change the user-directory directory.)

A situation converse to the above-discussed difficulty is also present_ it is possible to delete a file if one has write permission for its directory independently of any permissions for the file. This problem is related more to self-protection than protection from others. It is largely mitigated by the fact that the two major commands which delete named files (mv and rm) ask confirmation before deleting unwritable files.

It follows from this discussion that to maintain both data privacy and data integrity, it is necessary, and largely sufficient, to make one's directory inaccessible to others. The lack of sufficiency could follow from the existence of set-UID programs created by the user and the possibility of total breach of system security in one of the ways discussed below (or one of the ways not discussed below).

Needless to say, the system administrators must be at least as careful as their most demanding user to place the correct protection mode on the files under their control. In particular, it is necessary that special files be protected from writing, and probably reading, by ordinary users when they store sensitive files belonging to other users. It is easy to write programs that examine and change files by accessing the device on which the files live.

On the issue of password security, UNIX is probably better than most systems. Passwords are stored in an encrypted form which, in the absence of serious attention from specialists in the field, appears reasonably secure, provided its limitations are understood. Since both the encryption algorithm and the encrypted passwords are available, exhaustive enumeration of potential passwords is feasible up to a point. As a practical test of the possibilities in this area, 67 encrypted passwords were collected from 10 UNIX installations. These were tested against all five-letter combinations, all combinations of letters and digits of length four or less, and all words in Webster's Second unabridged dictionary; 60 of the 67 passwords were found. The whole process took about 12 hours of machine time. This experience suggests that passwords should be at least six characters long and randomly chosen from an alphabet which includes digits and special characters.

Of course there also exist feasible non-cryptanalytic ways of finding out passwords. For example: write a program which types out "login: " on the typewriter and copies whatever is typed to a file of your own. Then invoke the command and go away until the victim arrives. (It is this kind of possibility that makes it evident that UNIX was not designed to be secure.)

The set-UID (set-GID) notion must be used carefully if any security is to be maintained. The first thing to keep in mind is that a writable set-UID file can have another program copied onto it. For example, if the super-user *(su)* command is writable, anyone can copy the shell onto it and get a password-free version of *su.* A more subtle problem can come from set-UID programs which are not sufficiently careful of what is fed into them. In some systems, for example, the *mail* command is set-UID and owned by the super-user. The notion is that one should be able to send mail to anyone even if they want to protect their directories from writing. The trouble is that *mail* is rather dumb: anyone can mail someone else's private file to himself. Much more serious, is the following scenario: make a file with a line like one in the password file which allows one to log in as the super-user. Then make a link named ".mail" to the password file in some writeable directory on the same device as the password file (say /tmp). Finally mail the bogus login line to /tmp/.mail; You can then login as the super-user, clean up the incriminating evidence, and have your will.

The fact that users can mount their own disks and tapes as file systems can be another way of gaining super-user status. Once a disk pack is mounted, the system believes what is on it. Thus one can take a blank disk pack, put on it anything desired, and mount it. There are obvious and unfortunate consequences. For example: a mounted disk with garbage on it will crash the system; one of the files on the mounted disk can easily be a password-free version of *su;* other files can be unprotected entries for special files. The only easy fix for this problem is to forbid the use of *mount* to unprivileged users. A partial solution, not so restrictive, would be to have the *mount* command examine the special file for bad data, set-UID programs owned by others, and accessible special files, and balk at unprivileged invokers.