Norwegian University of Science and Technology

Operating Systems

Lecture 21: Security (1)

Michael Engel

Overview

- Overview of security problems
- Permission management
- System software and security
- Software bugs
- Examples
- Conclusions

Security problems

- Definitions of relevant terms
  - ***Safety***
    - protection against risks due to hardware and software errors or failures
  - ***Security***
    - protection of users and computers against *intended* errors (attacks)
- Both topics are highly relevant for system software
  - Today, we will only discuss security
- Exploitation of security holes
  - *malware*
  - social engineering

Operating system security

- **Someone...**
  - differentiation of persons and groups of persons
- **has to be deterred from doing...**
  - using technical and organizational methods
- **some...**
  - limited only by our imagination
- **unexpected things!**
  - 1) unauthorized reading of data (secrecy, confidentiality),
  - 2) unauthorized writing of data (integrity),
  - 3) working under a "false flag" (authenticity),
  - 4) unauthorized use of resources (availability),
  - etc…
- Differentiation between
  - internal
  - and external attacks

Example: fake login screen

- Attacker starts a user program that *simulates* a login screen
- The unsuspecting user enters username and (secret) password
  - Attacker program records user name and password
  - Attacker program terminates the current shell
- Login session of the attacker is closed and the regular login screen appears
  - User assumes incorrectly typed password
- Remedy: require the user to start the login sequence using a key combination that cannot be intercepted by a user program
  - e.g. CTRL-ALT-DEL in Windows NT and following

Malware example: viruses

- Program code inserted into another program, which can be replicated this way
  - Virus sleeps until the infected program is executed
  - Start of the infected program results in virus reproduction
  - Execution of the virus functionality can be time-controlled
- Sorts of viruses
  - Boot sector virus: executed at system startup time
  - Macro virus: in *scriptable* programs, e.g. Word, Excel
    - Reproduced through documents (e.g. sent by email)!
  - Executable program as virus
- Distribution through…
  - exchange of storage media (USB memory sticks etc.)
  - email attachments
  - web pages

Example: social engineering

- ***Not*** a system software problem
  - …but very important
- Gain access to information by exploiting human errors
- ***Phishing***
  - obtain data of an internet user using forged addresses (e.g. with similar names/typos)
  - e.g. by using forged emails from banks or government institutions
- ***Pharming***
  - manipulation of DNS requests by web browsers
  - redirect accesses, e.g. to forged bank websites
  - most users ignore browser warnings about invalid security certificates

Types of malware

- ***Viruses***
  - programs inadvertently distributed by a user
  - infect other programs
  - …and reproduce this way
- ***Worms***
  - do not wait for user actions to propagate to another computer
  - actively try to invade new systems
  - exploit security holes on target systems
- ***Trojan horses*** ("trojans")
  - program disguised as useful application (or game…)
  - in addition to the useful function, additional functionality is provided without the user noticing, e.g. providing an attacker with access to the local computer via internet

Types of malware (2)

- ***Root kit***
  - collection of software tools to...
    - disguise future logins of an attacker
    - hide processes and files
  - is installed after a computer system is compromised
  - can hide itself and its activities from the user
    - e.g. by manipulating tools to display processes (ps), directory contents (ls), network connections (netstat) ...
    - …or by manipulating system-wide shared libraries (libc)
    - …or directly by manipulating the OS kernel

- Often, malware uses a **combination** of these types

Permission management: objectives

- Protect stored information from
  - breach of confidentiality
  - theft of information
  - unwanted manipulation (including encryption: ***ransomware***)

- in all multi-user systems
  - …and every system connected to the Internet is in fact a multi-user system!

Permission management: requirements

- All **objects** of a system must be uniquely and unforgeably identifiable
- (external) **users** of a system must be uniquely and unforgeably identifiable
  - ➢ authentication
- Access to objects allowed only if the user has the required **permissions**

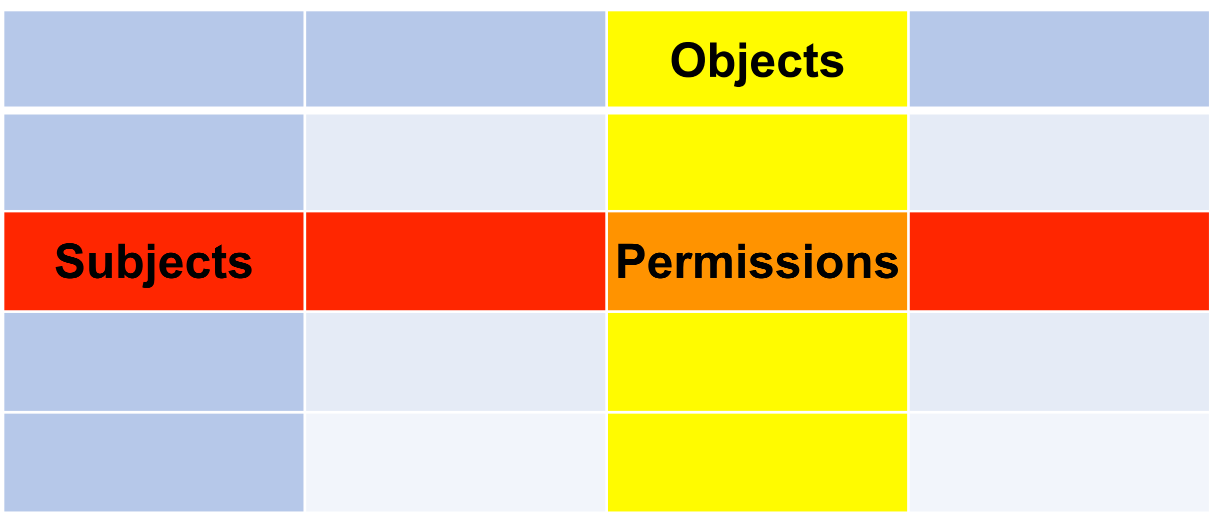
- Access to objects should only be allowed using the appropriate **object management**
  - permissions must be stored in an **unforgeable** way; transfer of permissions must only take place it a **controlled** way
  - it must be possible to validate basic protection mechanisms **with low overhead**

Permission management: design principles

- ***Principle of least privilege***
  - Allow a person or software component only those permissions that are required for the functionality to be realized
  - Standard case: deny permission
  - Counterexample: Unix "root"
- ***Fail-safe defaults***
  - Example: newly installed server software
- ***Separation of duties***
  - Multiple conditions exist to allow an operation

Access matrix

- Elements of the matrix:
  - Subjects (persons/users, processes)
  - Objects (data, devices, processes, memory, …)
  - Operations (read, write, delete, execute, …)
- Question: Is `operation(subject, object)` permitted?



Basic model: file/process attributes

- Properties related to a user:
  - for which user is the process being executed?
  - which user is the **owner** of a file?
  - which permissions does the owner of a file give to him/herself and which permissions to other users?
- Permissions of a process when accessing a file
  - Attributes of processes: **user ID**
  - Attributes of files: **owner ID**

	file 1	file 2	file 3
user 1			
user 2		read	
user 3			
user 4			

Access matrix variants

- Colums: ***ACL – Access Control Lists***
    - for every access to an object, the access permissions are validated based on the identity of the requesting subject (user)
- Rows: ***Capabilities***
    - for every access to an object a property is validated which is owned by the subject and which can be passed to other subjects on demand
- Rule-based: ***mandatory access control***
    - rules are evaluated for every access

ACLs

- Column-wise view of the access matrix:
  Access Control List (ACL)
- ACLs indicate for every object which subjects are allowed to perform which operations on it

		Objects	
Subjects		**Permissions**	

ACLs

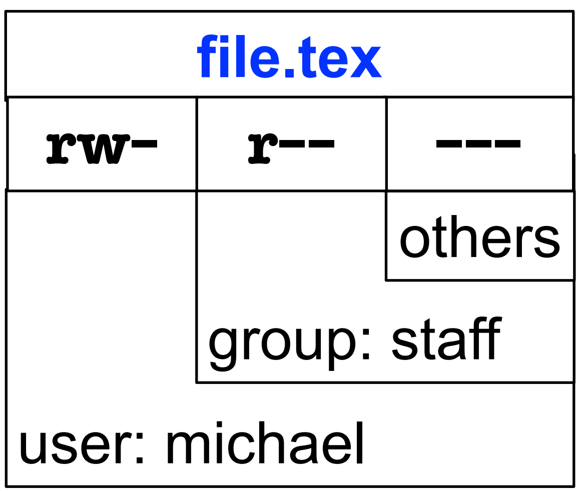
- ACLs can be configured by…
  - subjects having an appropriate ACL entry granting this permission
  - the creator of the object (file)
- Example: Multics OS – triplet (user, group, permissions)

```
File 0 (Jan, *, RWX)
File 1 (Jan, system, RWX)
File 2 (Jan, *, RW-), (Els, staff, R--), (Maike, *, RW-)
File 3 (*, student, R--)
File 4 (Jelle, *, ---), (*, student, R--)
```

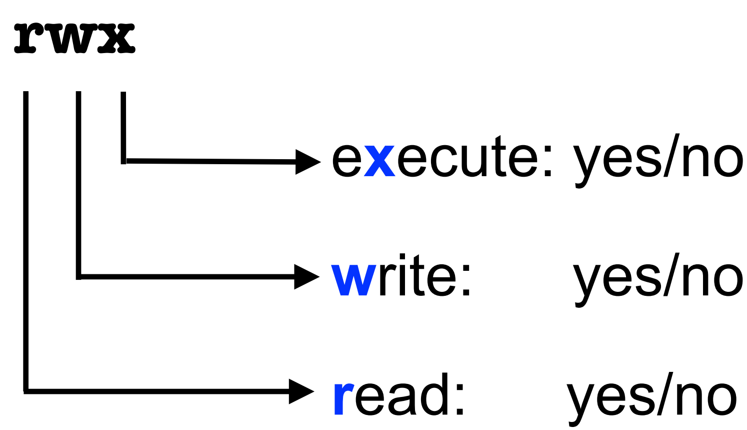
- Windows (starting with NT)
  - object: allow, deny
  - full control, modify, read&execute, ...

Unix access permissions

- Unix: simple access control lists
- Processes have a **user ID** and a **group ID**
- Files have an **owner** and a **group**
- Permissions are related to the
  user (owner), **g**roup, and all **o**thers



File attributes:



Problem: permission extensions

- Example – keep a high score list for a game
  - High score list: `/home/me/games/tetris/highscores`
  - Program: `/home/me/bin/games/tetris`
- Every player should be able to enter his/her own high score

1. all users have write permission to the high score list
   - too many permissions (does not work)
   - every user could arbitrarily manipulate the high score list
2. SetUID: only "me" has write permissions
   - Tetris program has "setuid" permissions
   - as soon as the Tetris program is executed, the process is assigned the user ID of the ***owner*** of the executable program

Unix: users and processes

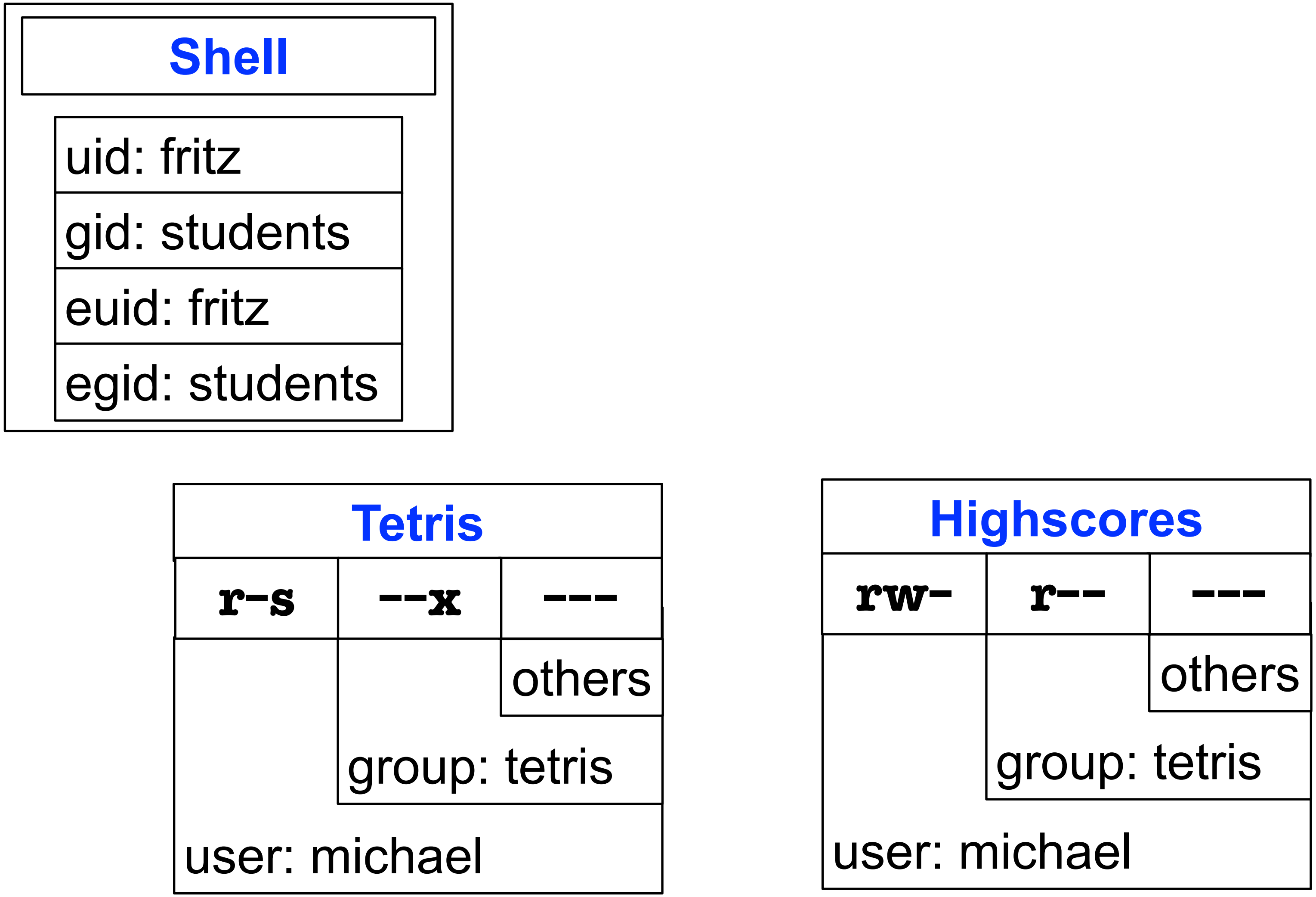
- Each process represents a user
- Process attributes:
  - User ID (**uid**), group ID (**gid**)
  - Effective uid (**euid**), effective gid (**egid**)
    - Determine permissions of a process when accessing files
- Only a few highly privileged processes are allowed to change their uid and gid
  - e.g. the login process
- After verifying the user’s password, the login process sets uid, gid, euid and egid
  - All other processes: children of login
- Child processes inherit the parent attributes

Process
uid: fritz
gid: students
euid: fritz
egid: students

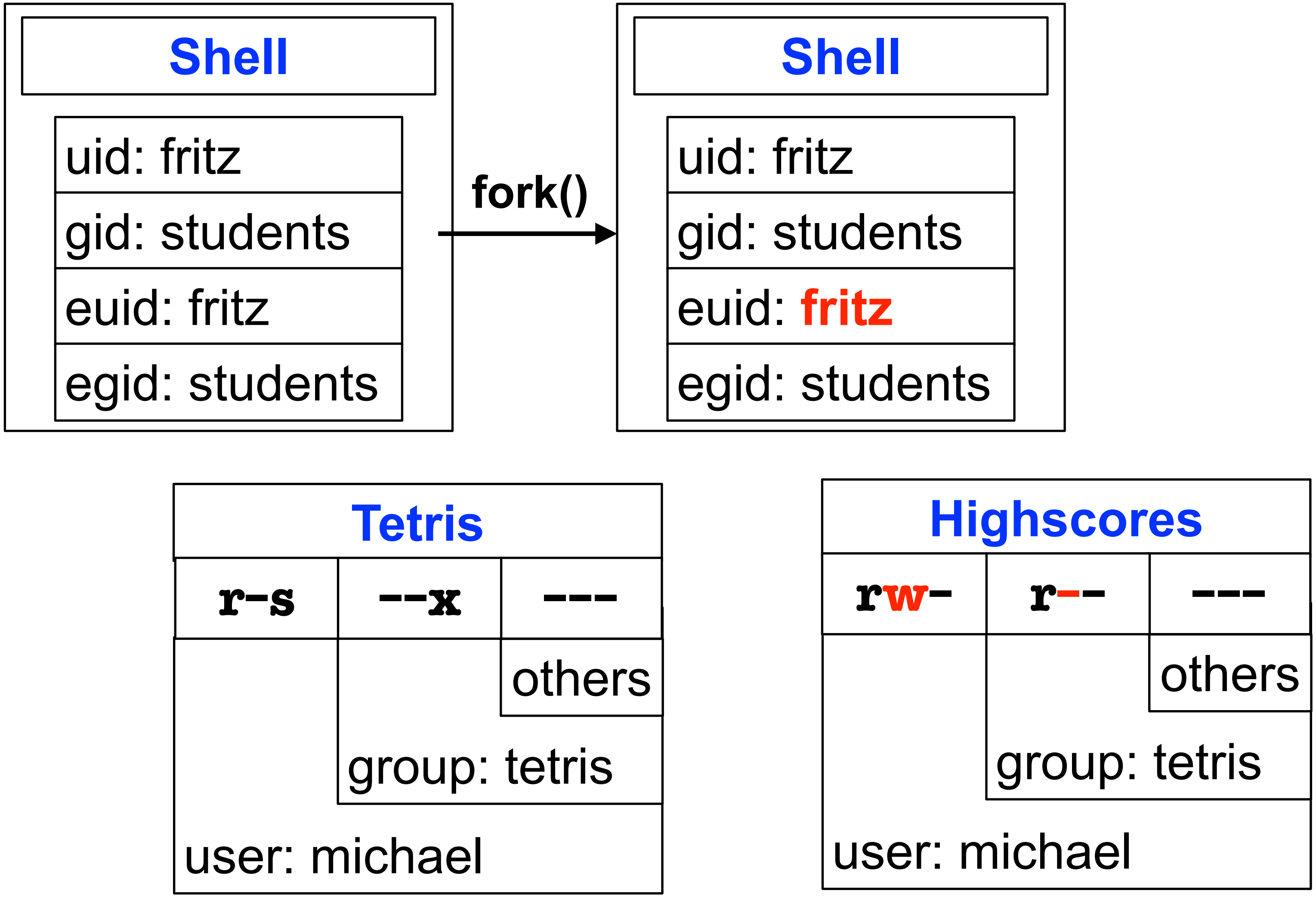
Unix solution: setuid mechanism

- File which contains trustworthy program code (e.g. Tetris) is given an additional permission bit: **setuid** (s bit)
  - shown as "s" instead of "x" for executable in directory listing
  - there is also a setgid bit (rarely used)
- `exec` of setuid programs:
  - executing process obtains the UID of the program owner as effective UID
  - precisely: the UID of the file containing the program
- Process execution performed using the permissions of this user as long as the program is not terminated
  - Contradicts the principle of least privilege
    - Workaround: create special user for the application instead of using "root"
  - It is considered good programming style to return any setuid permissions as soon as they are no longer required by a process

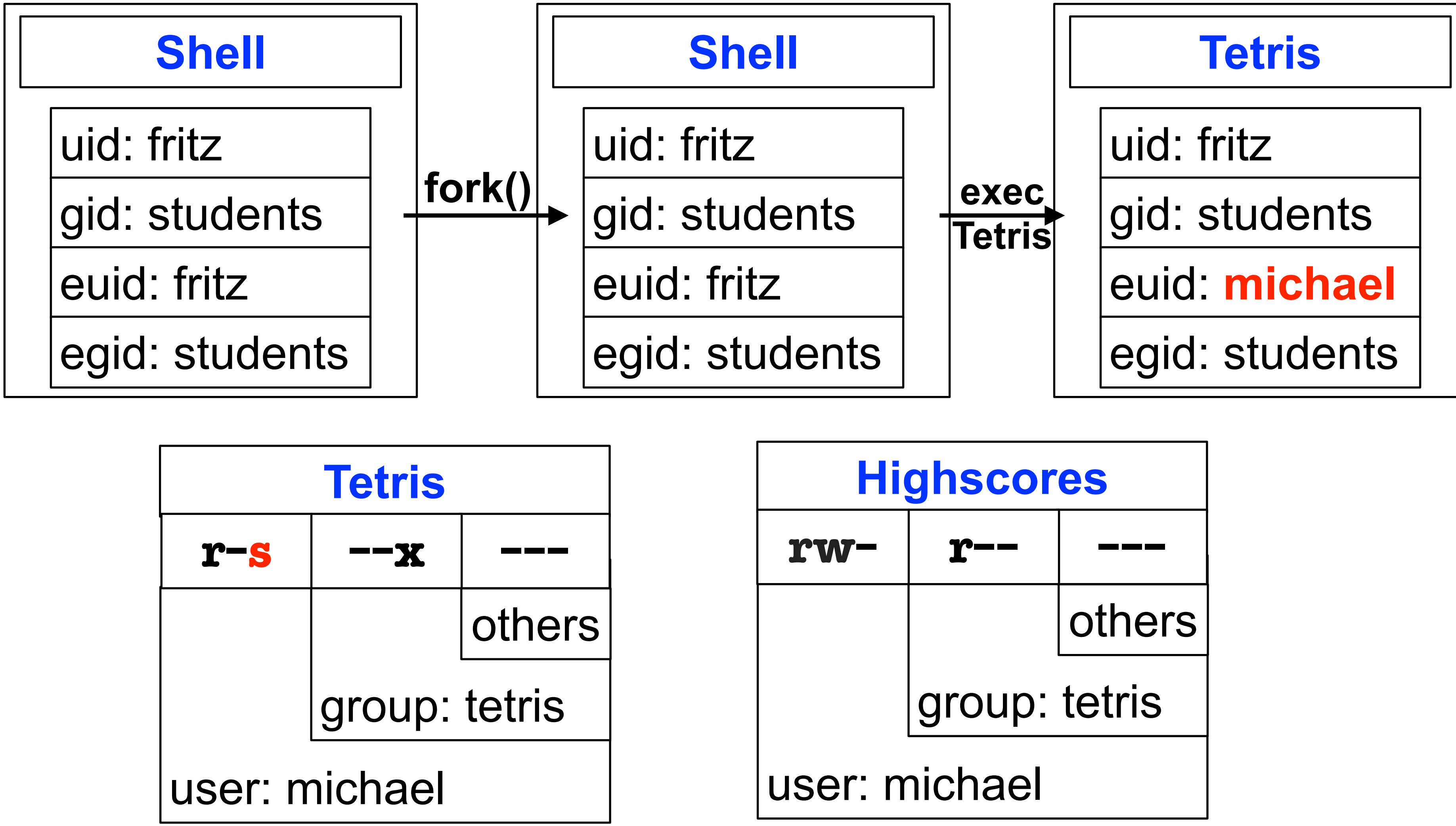
Example: high score list



Example: high score list (2)



Example: high score list (3)



setuid problems

- Extension of the permissions of a user *exactly* for the case of using the given program
- "Owner" of the program trusts the user who is using the program
  - Owner can be the administrator, but also normal users

- Problem: **program bugs**
  - can result in significant permission extensions
  - e.g. enable calling a shell (with inherited permissions of the owner of the setuid process) from such a program

- Practical experience: still to many permissions granted!

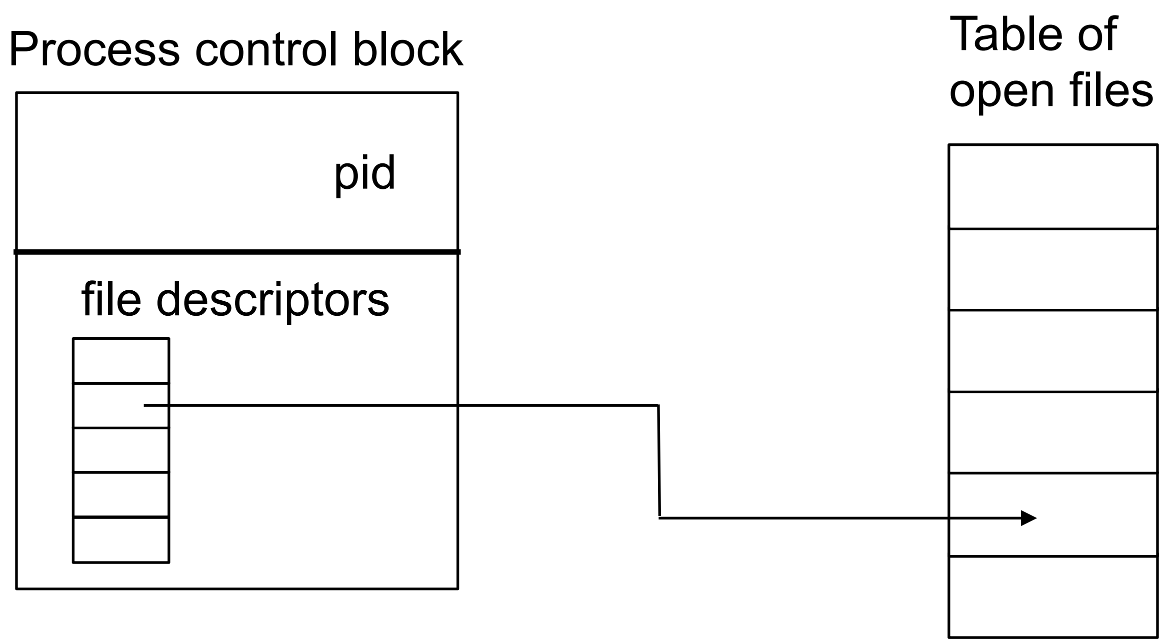
Capabilities

- Row-wise view of the access matrix: ***Capability***
- Capabilities indicate for each subject in which ways it is allowed to access which objects

		Objects	
Subjects		**Permissions**	

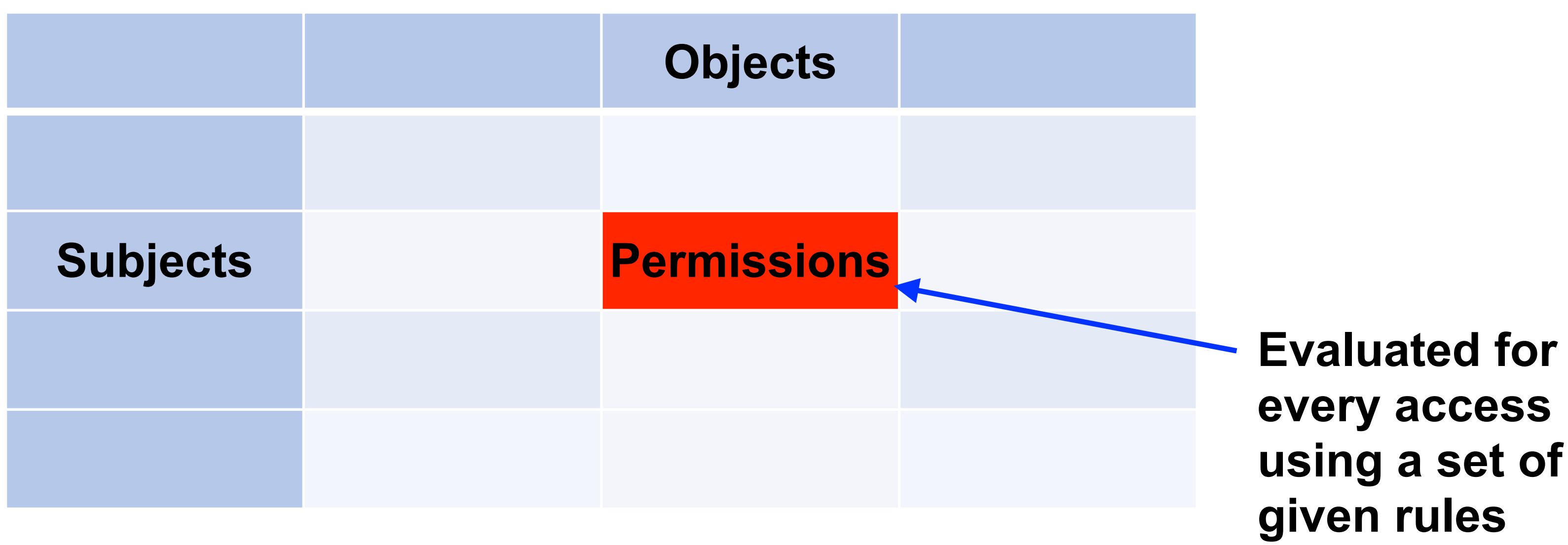
Example

- Basic implementation: Unix file descriptors
- Propagated using the `fork` system call
  - Allows access to files without repeated validation of the Unix access permissions



Rule-based access matrix

- ***Mandatory Access Control***
- Concept:
  - subjects and objects possess attributes ("labels")
  - decision about granting access by evaluating rules
- Implemented in "security kernels", e.g. SELinux



System software and security

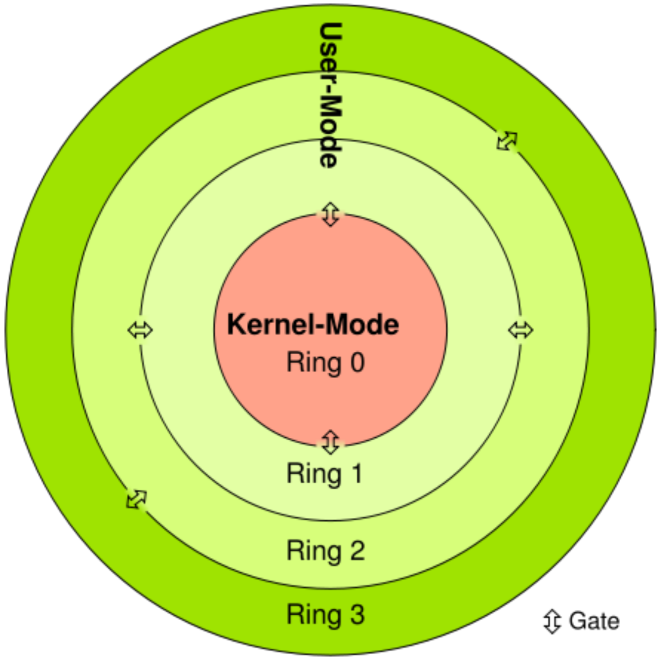
- Hardware-based protection
  - MMU
  - protection rings
- …complemented by protection in the system software
  - Exclusive control of the hardware by the OS
  - Exclusive control of all processes
  - Exclusive control of all resources
  - Provisioning of
    - identification mechanisms
    - authentication mechanisms
    - privilege separation
    - cryptographic protection of information

Hardware-based protection: MMU

- Memory Management Unit
  - Hardware component of the CPU that translates and controls program accesses to memory
  - Translation of the process view (virtual addresses) into the hardware view (physical addresses)
- Main memory is partitioned into pages
- Protection by...
  - only *mapping* the exact set of required main memory pages into the virtual address space of a process
  - isolation of the physical address spaces of different processes
  - protection bits for each page, controlled at every access
    - read/write/execute code
    - access permitted in user mode/supervisor mode

Protection rings

- Privilege concept
  - All code is executed in the context of a given ***protection ring***
  - Code running in ring 0 has access to all system resources
  - User programs run in ring 3
  - Rings 1 & 2 for OS-like code
    - e.g. device drivers
- Rings restrict…
  - the usable subset of processor machine instructions
    - e.g. disabling interrupts (sei/cli) not permitted in rings > 0
  - the accessible address range for the process
    - disabling of I/O accesses

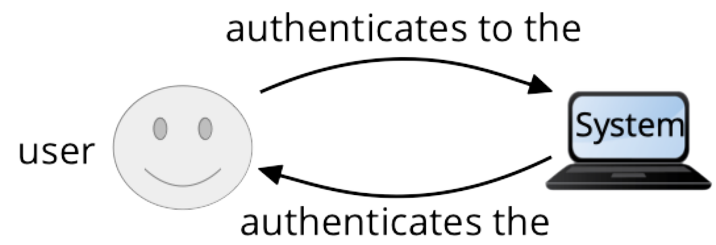


Software-based protection

- Identification mechanisms
- Unix: user and group identification
  - Numeric value
  - Translated into texts (user and group names) durch lookup in `/etc/passwd`
- Resources are assigned an owner

- Superuser: uid = 0
  - Has all permissions possible in the system

Software-based protection (2)



- Authentication mechanisms
  - Unix login
  - Reads user name and password
  - Verification of the entered password with the one recorded in the system
    - Either by encrypting the entered password and comparison with the recorded encrypted value
    - Or by verification of a hash value
  - The login process then starts the first user process (e.g., a shell) with the uid and gid of this user

Software-based protection (3)

- Cryptographic protection of information
  - e.g. DES encryption of user passwords
  - Originally in Unix stored in the file `/etc/passwd`

```
root:4t6f4rt3423:0:0:System Administrator:/var/root:/bin/sh
daemon:ge53r3rfrg:1:1:System Services:/var/root:/usr/bin/false
me:1x3Fe5$gRd:1000:1000:Michael Engel:/home/me:/bin/bash
```

- Problem: encrypted passwords were readable for all users!
  - …could be decrypted using a "brute force" attack given enough time
  - readily available tools, e.g. "John the Ripper"
- Today: only user information stored in `/etc/passwd`
  - Passwords are now stored separately in `/etc/shadow`!

```
-rw-r--r-- 1 root root   1353 May 28 22:43 /etc/passwd
-rw-r----- 1 root shadow  901 May 28 22:43 /etc/shadow
```

Software bugs

- Trade-off: performance ↔ security
- C, C++, Assembler: *unmanaged* languages
  - Pointers, array bounds, value overflows
- C#, Java: *managed* languages
  - Not usable for system software development!
  - …why?
  - Managed languages also have security problems!
- Problems
  - Buffer overflows
  - Value range overflows
- Error statistics
  - One error per 1000 lines of code on average
  - Independent of the implementation language!

Value ranges

- Problem: integer numbers are represented as bit strings with a limited number of bits
- Example: "char" data type in C
  - Represented as signed 8 bit value
  - Value range: -2^7 ... $+2^7 - 1$
  - …or -128 ... +127

```
char a = 127;
char b = 3;
char result = a + b;
```

- The C code results in the following calculation in binary:

```
 01111111 (a)
+00000011 (b)
 10000010 (result
           is negative!)
```

- Only the least significant 8 bits are significant
  - thus the result = -126!

Value ranges (2)

- The following code results in problems:

```
char string[127] = "Hello World!\n"
char a = 127;
char b = 3;

...

char myfunc(char *string, char index) {
    return string[index];
}

...
printf("%x", myfunc(string, a+b));
```

Heap overflow

- Heap: memory area for dynamically allocated data (e.g. via malloc)
- Buffer overflows in the heap can be problematic
  - Memory ranges separately allocated with malloc can be contiguous in main memory
  - There are no checks for overflows
  - By passing incorrect sizes for data regions, an attacker can overwrite other data on the heap
- Example: Microsoft JPEG GDI+ (MS04-028)
  - Size values in JPEG image files were not controlled
  - "Normal" images files contain valid values
    - These do not result in erroneous behavior
  - Manipulated image files contain invalid values
    - Overwrite other data on the heap

Heap overflow (2)

```
#define BUFSIZE 16
#define OVERSIZE 8 /* overflow buf2 by OVERSIZE bytes */

int main(void) {
  u_long diff;
  char *buf1 = malloc(BUFSIZE),
       *buf2 = malloc(BUFSIZE);

  diff = (u_long)buf2 - (u_long)buf1;
  printf("buf1 = %p, buf2 = %p, diff = 0x%x\n", buf1, buf2, diff);

  memset(buf2, 'A', BUFSIZE-1);
  buf2[BUFSIZE-1] = '\0';

  printf("before overflow: buf2 = %s\n", buf2);
  memset(buf1, 'B', (u_int)(diff + OVERSIZE));
  printf("after overflow: buf2 = %s\n", buf2);
  return 0;
}
```

Result…

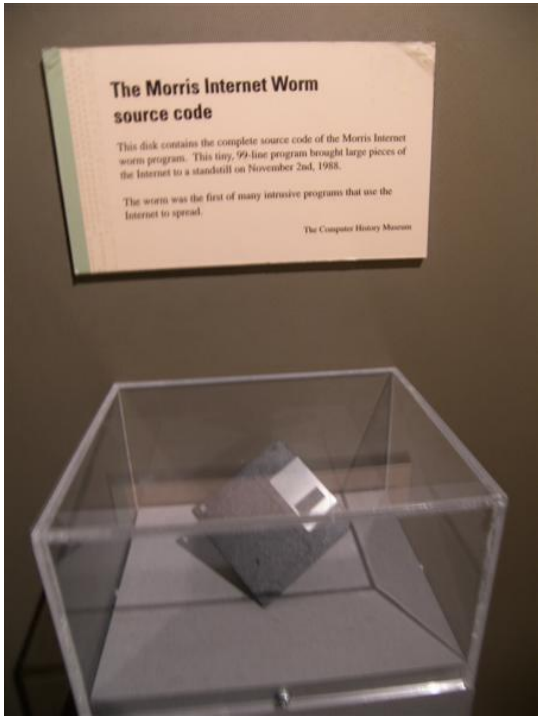
- The value range is exceeded by 8 bytes

```
root /w00w00/heap/examples/basic]# ./heap1
buf1 = 0x804e000, buf2 = 0x804eff0, diff = 0xff0 bytes
before overflow: buf2 = AAAAAAAAAAAAAAA
after overflow: buf2 = BBBBBBBAAAAAAA
```

- `buf1` exceeds its limit and arrives at the heap area in which `buf2` is stored
- This heap area of `buf2` still has valid contents
- Thus, the program does not terminate, but rather unexpectedly manipulates the data stored in `buf2`!

Unix Morris worm (sendmail)

- One of the first worms distributed over the Internet
- Written by a student of Cornell University, Robert Tappan Morris, and activated on November 2, 1988, from a computer at the MIT
  - From the MIT to disguise the real origin of the worm
  - Today, Robert Tappan Morris is professor at the MIT! :-)
- Exploited a security hole in the sendmail system
  - **Buffer overflow** in `gets()`
  - Written to determine the size of the Internet, should infect each system only once
  - …but had a **fatal bug** in its replication function!
- 6000 Unix systems infected
  - Cost of fixing damages estimated between US$10 and US$100 million
  - …Morris was convicted to 3 years jail on probation and a US$10.000 fine...



Michelangelo virus

- First discovered in New Zealand in 1991
- Boot sector virus, infects e.g. MS-DOS systems
  - Only uses BIOS functions, no DOS system calls
- Time-activated virus, active on March 6th
- Overwrites the first 100 sectors of the (first) hard disk with zeros
- Distribution using boot sectors of floppy disks
  - Installed itself in the boot sector of the hard disk
- One of the first viruses broadly discussed in the media
  - …but its effects were spectacularly exaggerated ;-)
- Some commercial software was accidentally delivered on disks with a boot sector virus
  - Today: viruses on USB memory sticks, mobile phones with USB interfaces, …fresh from the factory!

Sony BMG root kit

- Software on copy protected CD-ROMs with Digital "Rights" Management (DRM) technology
  - Filtering driver for CD-ROM drives and IDE disk controllers to control access to media
  - Installed without informing the user or asking for approval
- Control over the use of data of Sony BMG
  - …on Windows systems
- Hidden from analysis using root kit functionality
  - Does not appear in the installed software list of the Windows control center and is not removable using uninstaller tools
  - Does not only hide related files, directories, processes and registry entries, but globally everything starting with the string sys
  - Enables other malware to hide itself using this root kit functionality!

Blue Pill – VM-based root kit

- Discovery and removal of root kits on OS level is possible
  - But costly
- Objective: "undiscoverable" root kit
- "Blue Pill" tried to infect a PC with a root kit without requiring a system reboot
  - Exploits hardware virtualization technology of current CPUs
  - No (significant) performance impact
  - All devices, e.g. GPUs, continue to be fully available to the OS
- Undiscoverable, since the OS does not notice that it is now running in a virtual machine
  - …but there are still side effects that enable the detection of root kits like this

Conclusion

- Security gains increasing relevance in networked environments
  - Extremely significant damages due to **viruses, phishing, bot nets, ransomware**, ...
  - Experienced computer users are not safe either!
- Security checks in code are essential!
  - Automated tests cannot find all errors; manual **audits** still required
  - Still, security problems are unavoidable
    - Thus, system software has to be constantly updated
- Whack-a-mole game…
  - "**Zero day exploits**", newly discovered security holes which are not yet published (or fixed) are extremely dangerous
  - Reaction time of system software vendors are in the range of hours to months…
- Hardware is also increasingly problematic: "**Meltdown**" and "**Spectre**"