last time

signals versus exceptions
- hardware runs exception handlers of OS
- OS runs signal handlers of programs

signals for forwarding exceptions to programs

registering signal handlers

signal unsafety and blocking signals

authorization versus authentication

OS (kernel) tracking user IDs
- one for each program
- separate from user names

common issues in the lab

if input is `1234\n`,
then running `scanf("%d",...)` reads `1234` but not `\n`

- call fgets will return immediately
- caused some to send SIGUSR1 too early to other process

shm_open(FILENAME, ...); CONTENTS = mmap(...)

- some people called both inbox/outbox and got confused

if you don't exit from your SIGTERM/SIGINT handler...
then SIGTERM/SIGINT won't make your process exit

- handler replaces default "terminate program" action

anonymous feedback (1)

"I think the class goes pretty slow, we should definitely go faster. One thing I think you should consider is not answering so many questions during the lecture as Professor Hott also answered many questions and was dramatically slowed down in the process. I think the focus should be on content and remediation/help can be done in supplementary videos. Good luck. Looking forward to this semester."

> I'm not sure about balance between too slow/too fast
> usually assume that I have more problems with not getting enough questions than too many (but reality is probably in between)

anonymous feedback (2)

"The signal handling lab was way too difficult. I had a bug in my program that took 5 different TAs to figure out... I ended up staying in lab for 3 hours because each TA would be stuck for 20 minutes before leaving to help someone else."

- students should be debugging, not TAs (TAs should provide guidance but not do the debugging work)
- are there things re: debugging procedures we could've provided better guidance on??
- probably can mitigate by pointing out common problems above in future semesters

anonymous feedback (3)

"I would really appreciate if we were granted an extension on the signals lab from this week. The write-up wasn't that long, but actually implementing the features for the various steps (particularly steps 2 and 3) took quite a long time.....I think the signals material is important, so I really wish we could get some flexibility and some additional help. Perhaps a video walk-through of the thinking behind the lab to explain the program flow more could be really beneficial while still leaving the final work of generating a solution to us. Thank you for your consideration.

> we have late policy (90% credit until Sat morning, 80% until Sunday morning), but not planning on extension
>
> probably some ways of adding more examples to reading/lab writeup for this Fall?

opening a file?

```
open("/u/creiss/private.txt", O_RDONLY)
```

say, private file on portal

on Linux: makes *system call*

kernel needs to decide if this should work or not

how does OS decide this?

argument: needs extra metadata

what would be wrong using...

system call arguments?

where the code calling open came from?

authorization v authentication

authentication — who is who

authorization v authentication

authentication — who is who

authorization — who can do what

probably need authentication first...

authentication

password

hardware token

...

user IDs

most common way OSes identify what *domain* process belongs to:

(unspecified for now) procedure sets user IDs

every process has a user ID

user ID used to decide what process is authorized to do

POSIX user IDs

```
uid_t geteuid(); // get current process's "effective" user ID
```

process's user identified with unique number

kernel typically only knows about number

effective user ID is used for all permission checks

also some other user IDs — we'll talk later

POSIX user IDs

```
uid_t geteuid(); // get current process's "effective" user ID
```

process's user identified with unique number

kernel typically only knows about number

effective user ID is used for all permission checks

also some other user IDs — we'll talk later

standard programs/library maintain number to name mapping

- `/etc/passwd` on typical single-user systems
- network database on department machines

POSIX groups

```
gid_t getegid(void);
    // process's"effective" group ID

int getgroups(int size, gid_t list[]);
    // process's extra group IDs
```

POSIX also has *group IDs*

like user IDs: kernel only knows numbers

- standard library+databases for mapping to names

also process has some other group IDs — we'll talk later

id

```
cr4bd@power4
: /net/zf14/cr4bd ; id
uid=858182(cr4bd) gid=21(csfaculty)
        groups=21(csfaculty),325(instructors),90027(cs4414)
```

id command displays uid, gid, group list

names looked up in database

- kernel doesn't know about this database
- code in the C standard library

groups that don't correspond to users

example: video group for access to monitor

put process in video group when logged in directly

don't do it when SSH'd in

groups that don't correspond to users

example: video group for access to monitor

put process in video group when logged in directly

don't do it when SSH'd in

...but: user can keep program running with video group in the background after logout?

POSIX file permissions

POSIX files have a very restricted access control list

one user ID + read/write/execute bits for user

"owner" — also can change permissions

one group ID + read/write/execute bits for group

default setting — read/write/execute

on directories, 'execute' means 'search' instead

permissions encoding

permissions encoded as 9-bit number, can write as octal: XYZ

octal divides into three 3-bit parts:

user permissions (X), group permissions (Y), other permission (Z)

each 3-bit part has a bit for 'read' (4), 'write' (2), 'execute' (1)

`700` — user read+write+execute; group none; other none

`451` — user read; group read+execute; other none

chmod — exact permissions

```
chmod 700 file
chmod u=rwx,og= file
```

user read write execute; group/others no accesss

```
chmod 451 file
chmod u=r,g=rx,o= file
```

user read; group read/execute; others no access

chmod — adjusting permissions

```
chmod u+rx foo
```

add user read and execute permissions
leave other settings unchanged

```
chmod o-rwx,u=rx foo
```

remove other read/write/execute permissions
set user permissions to read/execute
leave group settings unchanged

POSIX/NTFS ACLs

more flexible access control lists

list of (user or group, read or write or execute or ...)

supported by NTFS (Windows)

a version standardized by POSIX, but usually not supported

POSIX ACL syntax

```
# group students have read+execute permissions
group:students:r-x
# group faculty has read/write/execute permissions
group:faculty:rwx
# user mst3k has read/write/execute permissions
user:mst3k:rwx
# user tj1a has no permissions
user:tj1a:---

# POSIX acl rule:
    # user take precedence over group entries
```

POSIX ACLs on command line

```
getfacl file
```

```
setfacl -m 'user:tj1a:---' file
```

add line to ACL

```
setfacl -x 'user:tj1a' file
```

REMOVE line from acl

```
setfacl -M acl.txt file
```

add to acl, but read what to add from a file

```
setfacl -X acl.txt file
```

remove from acl, but read what to remove from a file

authorization checking on Unix

checked on system call entry

- no relying on libraries, etc. to do checks

files (open, rename, ...) — file/directory permissions

processes (kill, ...) — process UID = user UID

...

keeping permissions?

which of the following would still be secure?

A. setting up a read-only page table entry that allows a process to directly access its user ID from its process control block in user mode

B. performing authorization checks in the standard library in addition to system call handlers

C. performing authorization checks in the standard library instead of system call handlers

D. making the user ID a system call argument rather than storing it in the process control block

superuser

user ID `0` is special

superuser or *root*

(non-Unix) or Administrator or SYSTEM or ...

some system calls: only work for uid `0`

shutdown, mount new file systems, etc.

automatically passes all (or almost all) permission checks

superuser v kernel mode

superuser : OS :: kernel mode : hardware

programs running as superuser still in user mode

- just change in how OS acts on system calls, etc.

how does login work?

```
somemachine login: jo
password: ********

jo@somemachine$ ls
...
```

this is a program which...

checks if the password is correct, and

changes user IDs, and

runs a shell

how does login work?

```
somemachine login: jo
password: ********

jo@somemachine$ ls
...
```

this is a program which...

checks if the password is correct, and

changes user IDs, and

runs a shell

Unix password storage

typical single-user system: `/etc/shadow`

- only readable by root/superuser

department machines: network service

- Kerberos / Active Directory:
- server takes (encrypted) passwords
- server gives tokens: "yes, really this user"
- can cryptographically verify tokens come from server

aside: beyond passwords

/bin/login entirely user-space code

only thing special about it: when it's run

could use any criteria to decide, not just passwords

- physical tokens
- biometrics
- ...

how does login work?

```
somemachine login: jo
password: ********

jo@somemachine$ ls
...
```

this is a program which...

checks if the password is correct, and

changes user IDs, and

runs a shell

changing user IDs

```
int setuid(uid_t uid);
```

if superuser: sets effective user ID to arbitrary value

- and a "real user ID" and a "saved set-user-ID" (we'll talk later)

system starts in/login programs run as superuser

- voluntarily restrict own access before running shell, etc.

sudo

```
tj1a@somemachine$ sudo restart
Password: *********
```

sudo: run command with superuser permissions

started by non-superuser

recall: inherits non-superuser UID

can't just call `setuid(0)`

set-user-ID sudo

extra metadata bit on *executables*: set-user-ID

if set: `exec()` syscall changes effective user ID to owner's ID

`sudo` program: owned by root, marked set-user-ID

marking setuid: `chmod u+s`

set-user ID gates

set-user ID program: gate to higher privilege

controlled access to extra functionality

make authorization/authentication decisions *outside the kernel*

way to allow normal users to do *one thing that needs privileges*

- write program that does that one thing — nothing else!
- make it owned by user that can do it (e.g. root)
- mark it set-user-ID

want to allow only some user to do the thing

- make program check which user ran it

uses for setuid programs

mount USB stick

- setuid program controls option to kernel mount syscall
- make sure user can't replace sensitive directories
- make sure user can't mess up filesystems on normal hard disks
- make sure user can't mount new setuid root files

control access to device — printer, monitor, etc.

- setuid program talks to device + decides who can

write to secure log file

- setuid program ensures that log is append-only for normal users

bind to a particular port number < 1024

- setuid program creates socket, then becomes not root

set-user-ID program v syscalls

hardware decision: some things only for kernel

system calls: *controlled* access to things kernel can do

decision about how can do it: in the kernel

kernel decision: some things only for root (or other user)

set-user-ID programs: controlled access to things root/... can do

decision about how can do it: made by root/...

privilege escalation

privilege escalation — vulnerabilities that allow more privileges

code execution/corruption in utilities that run with high privilege

- e.g. buffer overflow, command injection
- login, sudo, system services, ...
- bugs in system call implementations

logic errors in checking delegated operations

a broken setuid program: setup

suppose I have a directory all-grades on shared server

in it I have a folder for each assignment

and within that a text file for each user's grade + other info

say I don't have flexible ACLs and want to give each user access

a broken setuid program: setup

suppose I have a directory all-grades on shared server

in it I have a folder for each assignment

and within that a text file for each user's grade + other info

say I don't have flexible ACLs and want to give each user access

one (bad?) idea: setuid program to read grade for assignment

`./print_grade assignment`

outputs grade from `all-grades/assignment/USER.txt`

a very broken setuid program

print_grade.c:

```
int main(int argc, char **argv) {
    char filename[500];
    sprintf(filename, "all-grades/%s/%s.txt",
            argv[1], getenv("USER"));
    int fd = open(filename, O_RDWR);
    char buffer[1024];
    read(fd, buffer, 1024);
    printf("%s: %s\n", argv[1], buffer);
}
```

HUGE amount of stuff can go wrong

examples?

another very broken setuid program (setup)

allow users to print files, but only if less than 1KB

another very broken setuid program

print_short_file.c:

```
int main(int argc, char **argv) {
    struct stat st;
    if (stat(argv[1], &st) == -1) abort();
    // make sure argv[1] is owned by user running this
    if (st.st_uid != getuid()) abort();
    // and that it's less than 1 KB
    if (st.st_size >= 1024) abort();
    char command[1024];
    sprintf(command, "print %1000s", argv[1]);
    system(command);
    return EXIT_SUCCESS;
}
```

set-user ID programs are very hard to write

what if stdin, stdout, stderr start closed?

what if signals setup weirldy?

what if the PATH env. var. set to directory of malicious programs?

what if `argc == 0`?

what if dynamic linker env. vars are set?

what if some bug allows memory corruption?

...

other privileged escalation issues

sudo problem: trusted code that's supposed to enforce restriction can be fooled into not really enforcing it

also can occur in other contexts:

system call letting program access things it shouldn't?

browser letting web page javascript access things it shouldn't?

web application giving users access to files they shouldn't have?

mobile phone OS allowing location access without location permission?

...

some security tasks (1)

helping students collaborate in ad-hoc small groups on shared server?

Q1: what to allow/prevent?

Q2: how to use POSIX mechanisms to do this?

some security tasks (2)

letting students assignment files to faculty on shared server?

Q1: what to allow/prevent?

Q2: how to use POSIX mechanisms to do this?

some security tasks (3)

running untrusted game program from Internet?

Q1: what to allow/prevent?

Q2: how to use POSIX mechanisms to do this?

backup slides

a delegation problem

consider printing program marked setuid to access printer

- decision: no accessing printer directly
- printing program enforces page limits, etc.

command line: file to print

can printing program just call open()?

a broken solution

```
if (original user can read file from argument) {
    open(file from argument);
    read contents of file;
    write contents of file to printer
    close(file from argument);
}
```

hope: this prevents users from printing files than can't read

problem: race condition!

a broken solution / why

setuid program	other user program
	create normal file `toprint.txt`
check: can user access? (yes)	—
	`unlink("toprint.txt")`
	`link("/secret", "toprint.txt"`
`open("toprint.txt")`	—
read ...	—

link: create new directory entry for file

another option: rename, symlink ("symbolic link" — alias for file/directory)

another possibility: run a program that creates secret file (e.g. temporary file used by password-changing program)

time-to-check-to-time-of-use vulnerability

TOCTTOU solution

temporarily ‘become’ original user

then open

then turn back into set-uid user

this is why POSIX processes have multiple user IDs

can swap out effective user ID temporarily

practical TOCTTOU races?

can use symlinks *maze* to make check slower

symlink `toprint.txt` → `a/b/c/d/e/f/g/normal.txt`
symlink `a/b` → `../a`
symlink `a/c` → `../a`
...

lots of time spent following symbolic links when program opening toprint.txt

gives more time to sneak in unlink/link or (more likely) rename

exercise

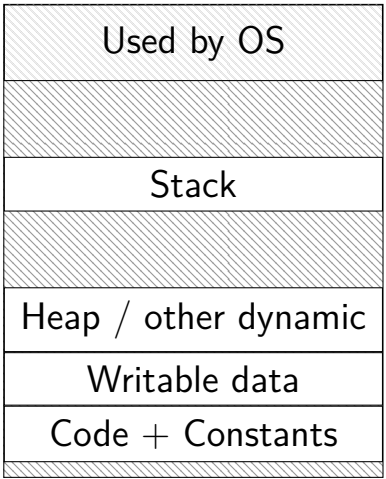
which (if any) of the following would fix for a TOCTTOU vulnerability in our setuid printing application? (assume the Unix-permissions without ACLs are in use)

[A] **both before and after** opening the path passed in for reading, check that the path is accessible to the user who ran our application

[B] after opening the path passed in for reading, using `fstat` with the file descriptor opened to check the permissions on the file

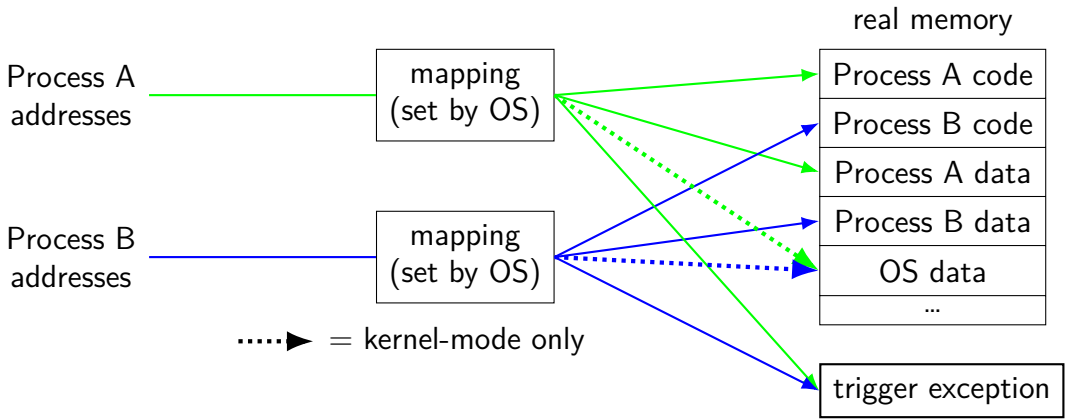
[C] before opening the path, verify that the user controls the file referred to by the path **and** the directory containing it

program memory



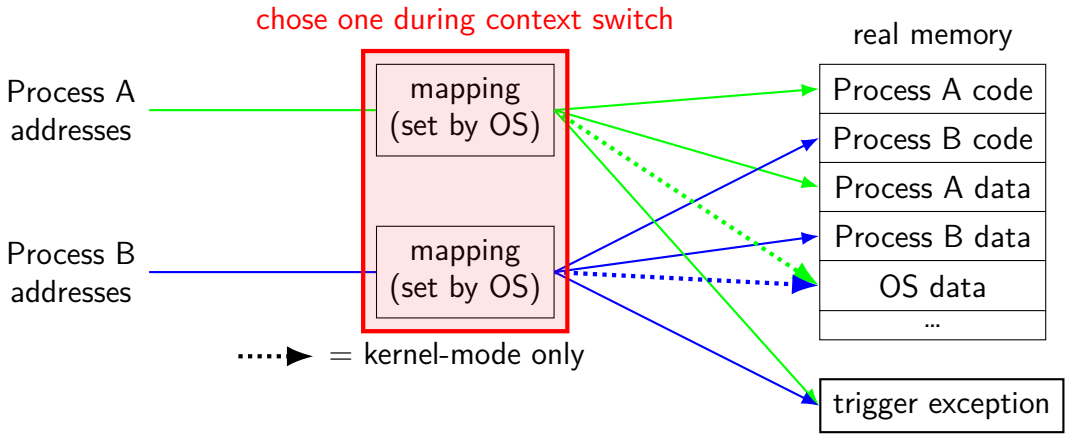
address spaces

illuision of dedicated memory

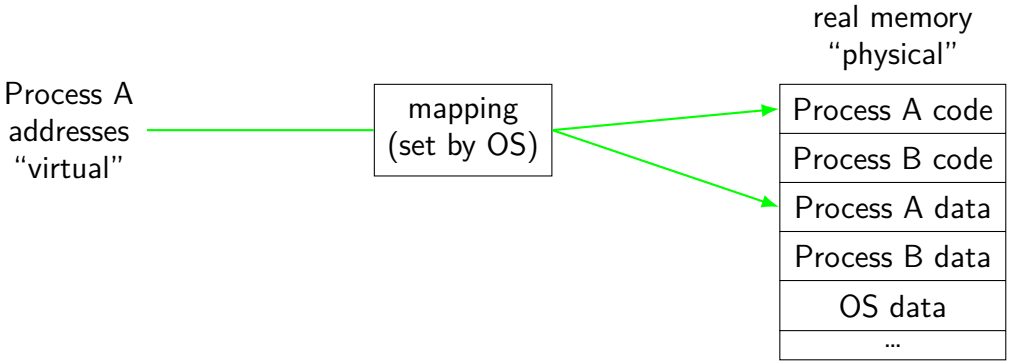


address spaces

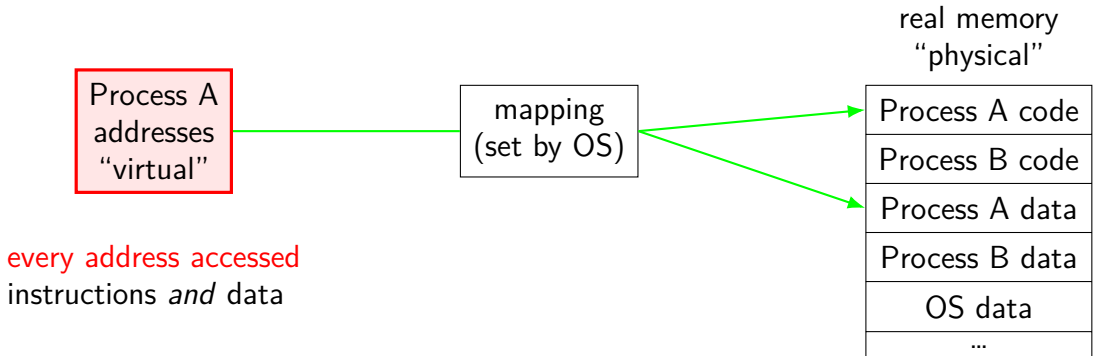
illuision of dedicated memory



address translation

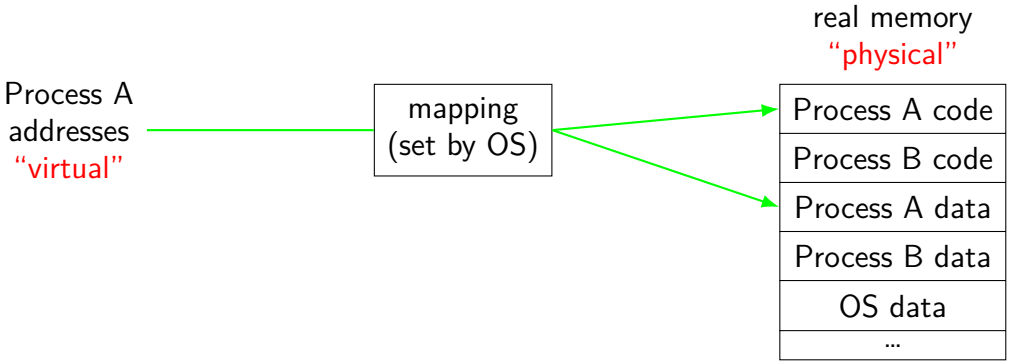


address translation



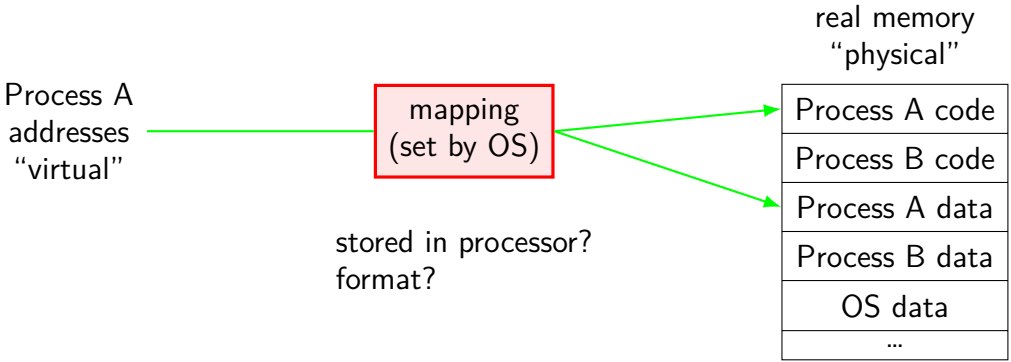
every address accessed
instructions *and* data

address translation



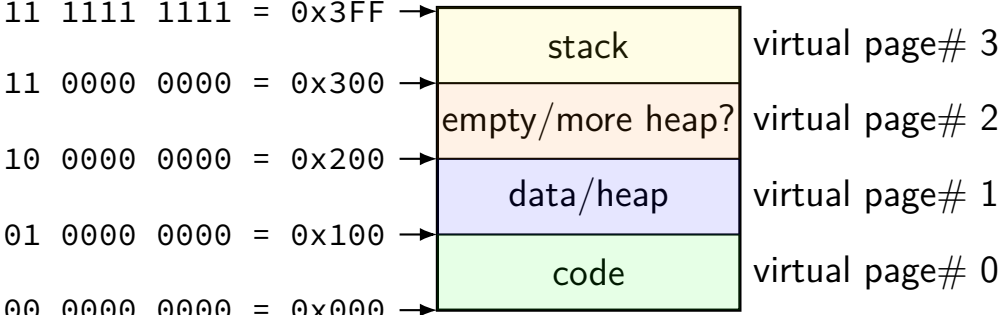
program addresses are 'virtual'
real addresses are 'physical'
can be different sizes!

address translation

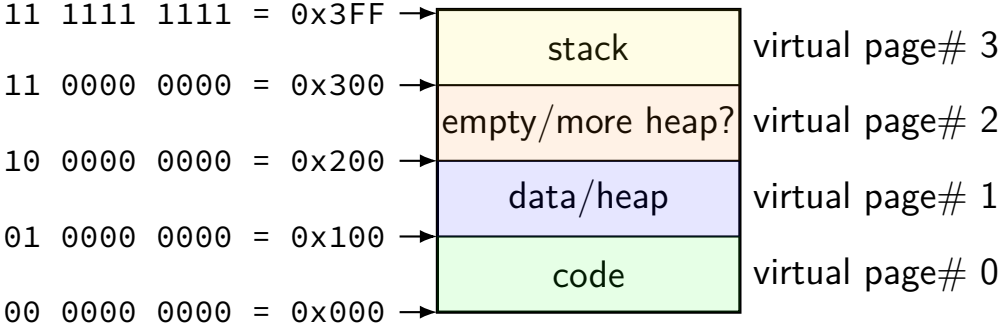


toy program memory

toy program memory

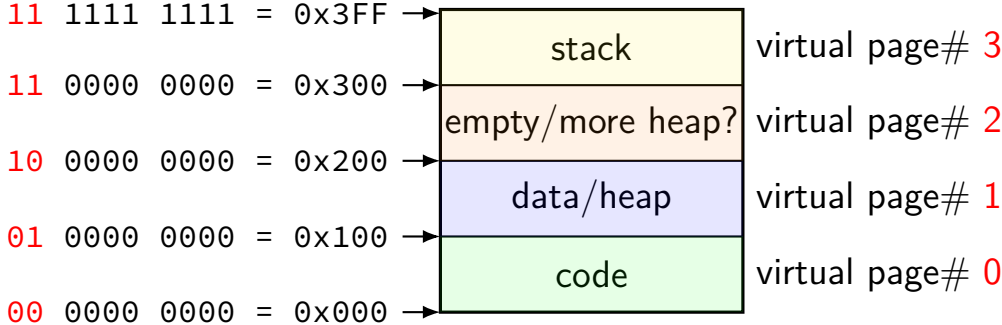


toy program memory



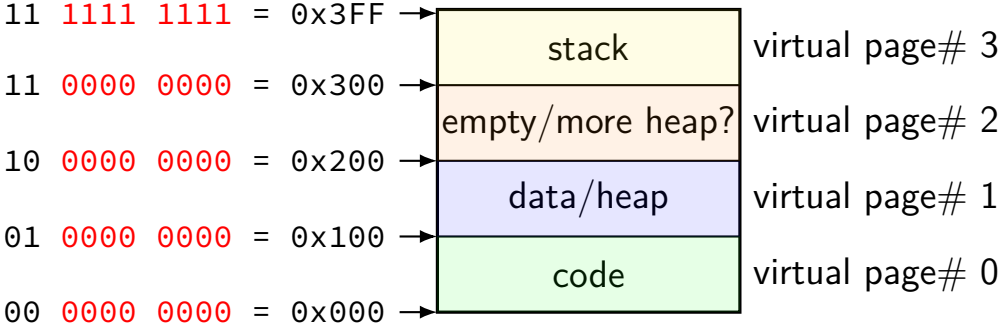
divide memory into pages (2^8 bytes in this case)
"virtual" = addresses the program sees

toy program memory



page number is upper bits of address
(because page size is power of two)

toy program memory



rest of address is called page offset

toy physical memory

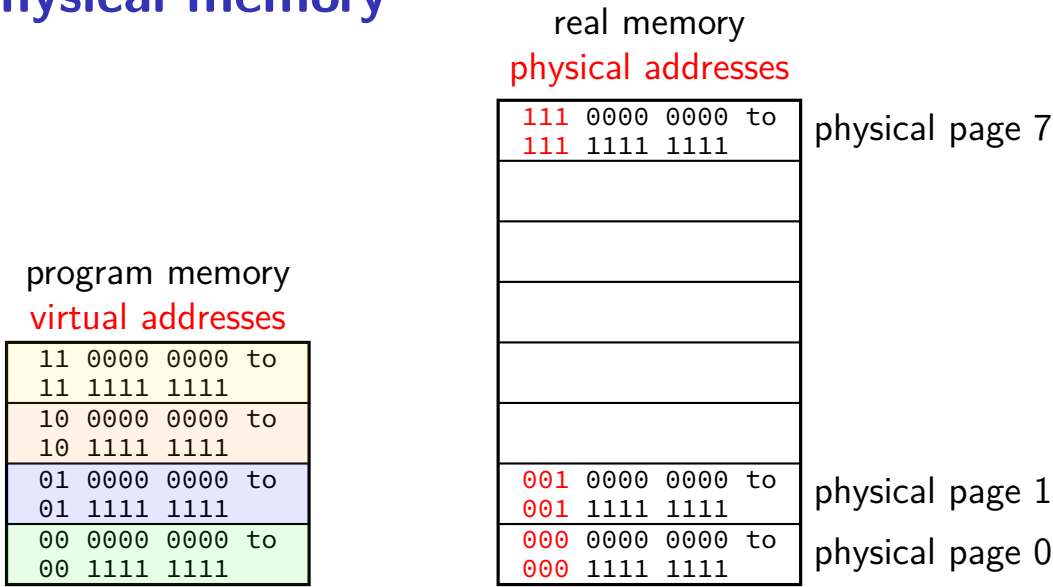
program memory
virtual addresses

11 0000 0000 to 11 1111 1111
10 0000 0000 to 10 1111 1111
01 0000 0000 to 01 1111 1111
00 0000 0000 to 00 1111 1111

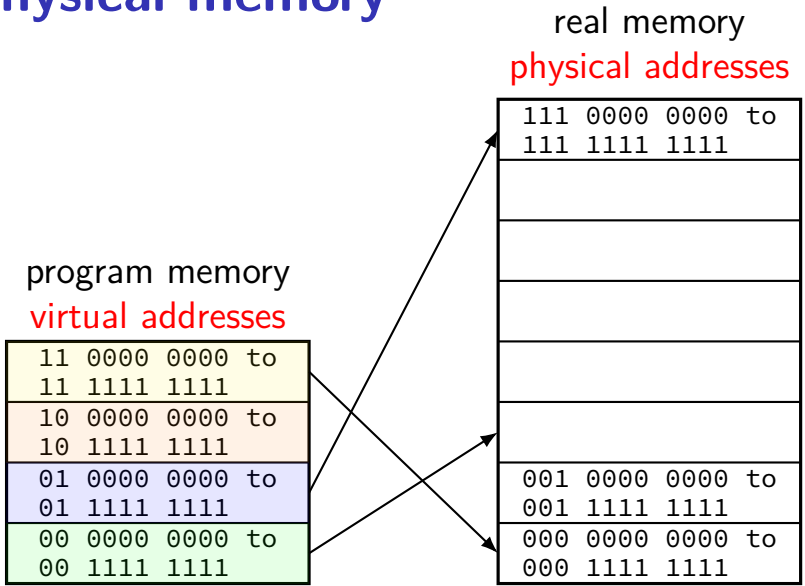
real memory
physical addresses

111 0000 0000 to 111 1111 1111
001 0000 0000 to 001 1111 1111
000 0000 0000 to 000 1111 1111

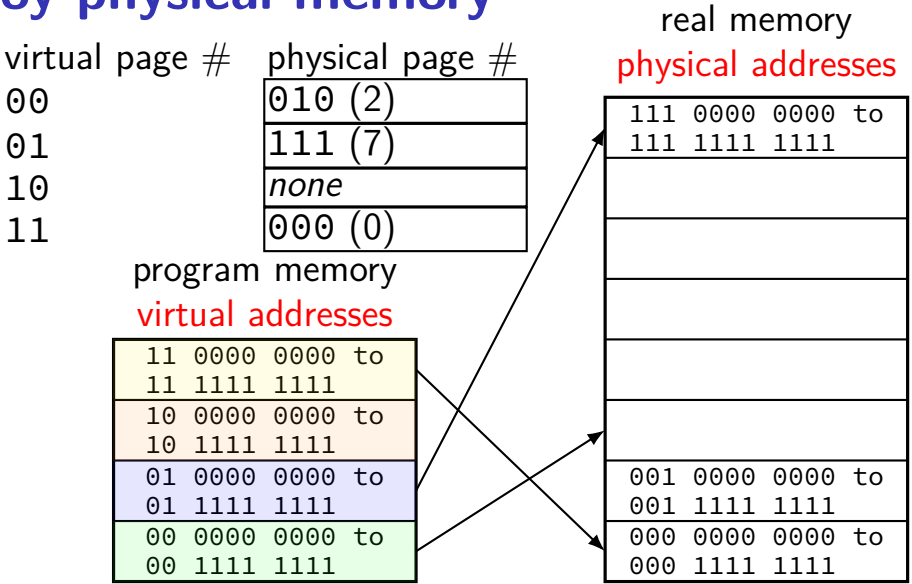
toy physical memory



toy physical memory



toy physical memory



toy physical memory

page table!

virtual page #	physical page #
00	010 (2)
01	111 (7)
10	*none*
11	000 (0)

program memory
virtual addresses

- 11 0000 0000 to 11 1111 1111
- 10 0000 0000 to 10 1111 1111
- 01 0000 0000 to 01 1111 1111
- 00 0000 0000 to 00 1111 1111

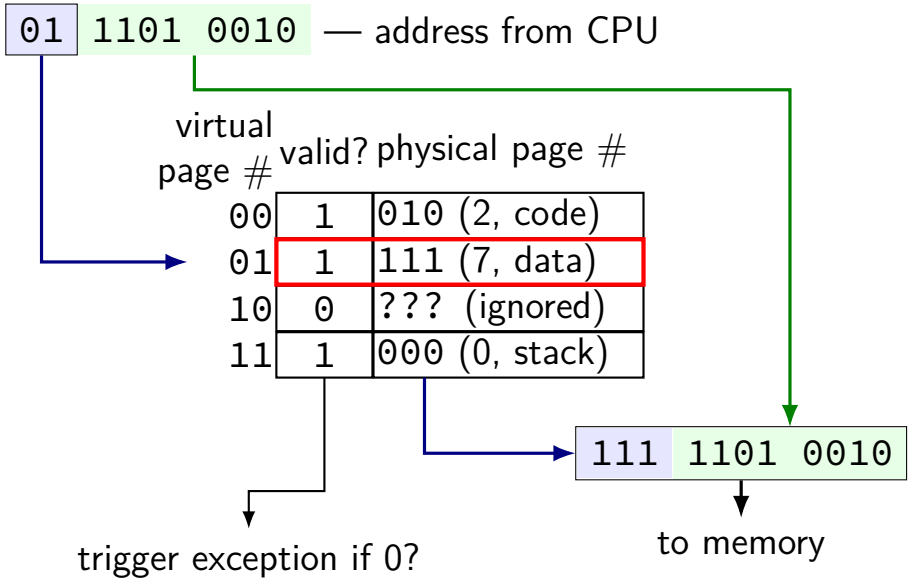
real memory
physical addresses

- 111 0000 0000 to 111 1111 1111
- 001 0000 0000 to 001 1111 1111
- 000 0000 0000 to 000 1111 1111

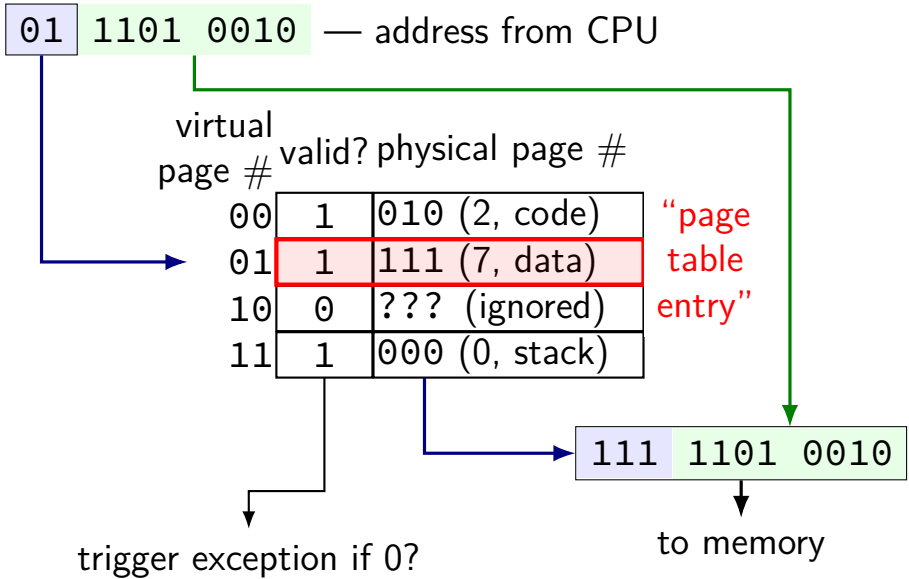
toy page table lookup

virtual page #	valid?	physical page #
00	1	010 (2, code)
01	1	111 (7, data)
10	0	??? (ignored)
11	1	000 (0, stack)

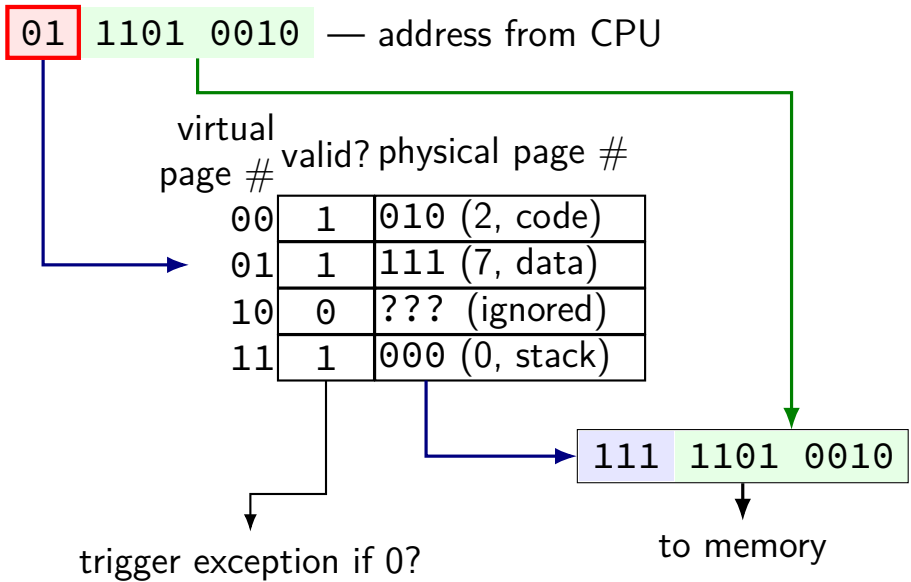
toy page table lookup



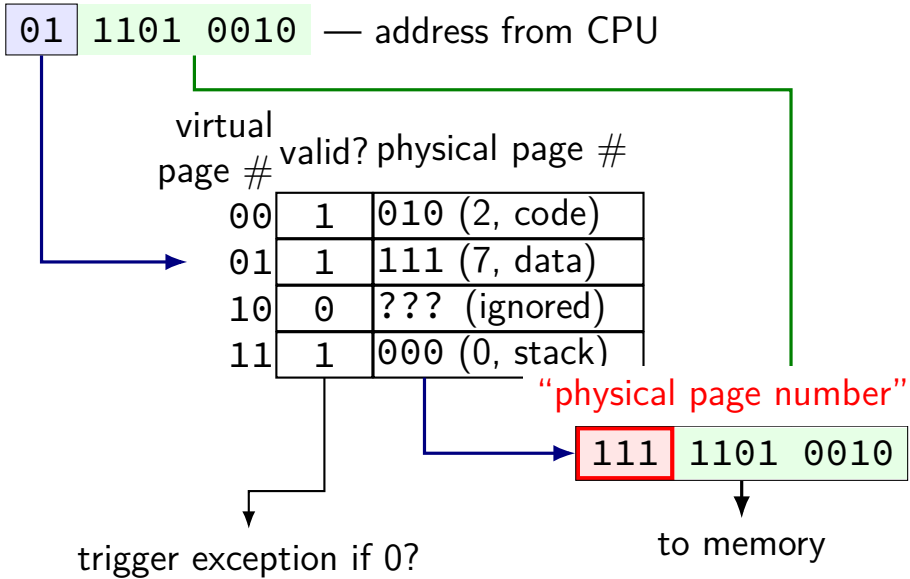
toy page table lookup



t "virtual page number" lookup



toy page table lookup



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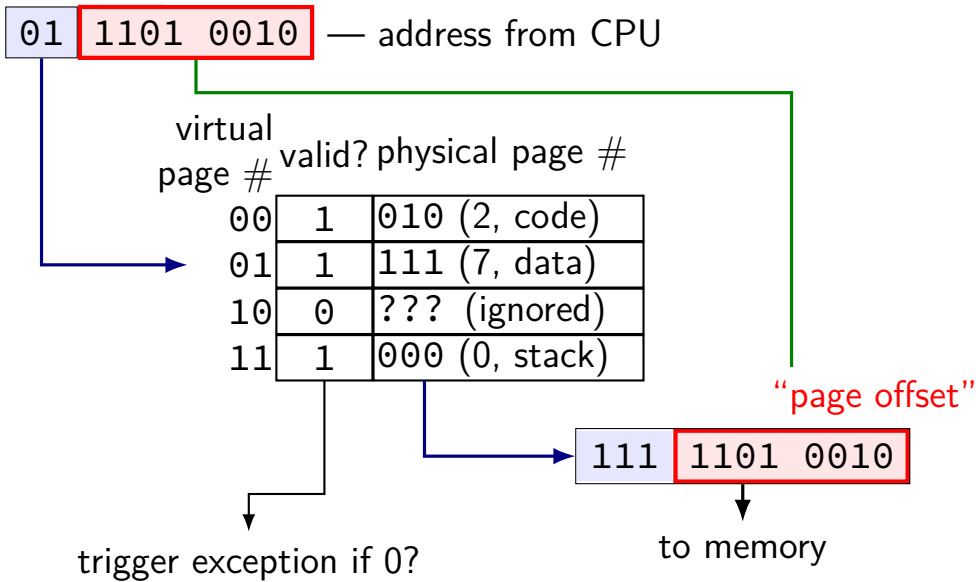

backup slides