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And then the access can continue as for a hit

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Virtual Memory: Paging

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Note there are two separate issues here:

- which entry in the TLB to remove when the TLB table is full
- which page in physical memory to swap out when physical memory is full

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Exercise Read about some of the algorithms to choose which TLB entry to remove

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The first time a (virtual) page is touched by a process it will cause a (major) page fault

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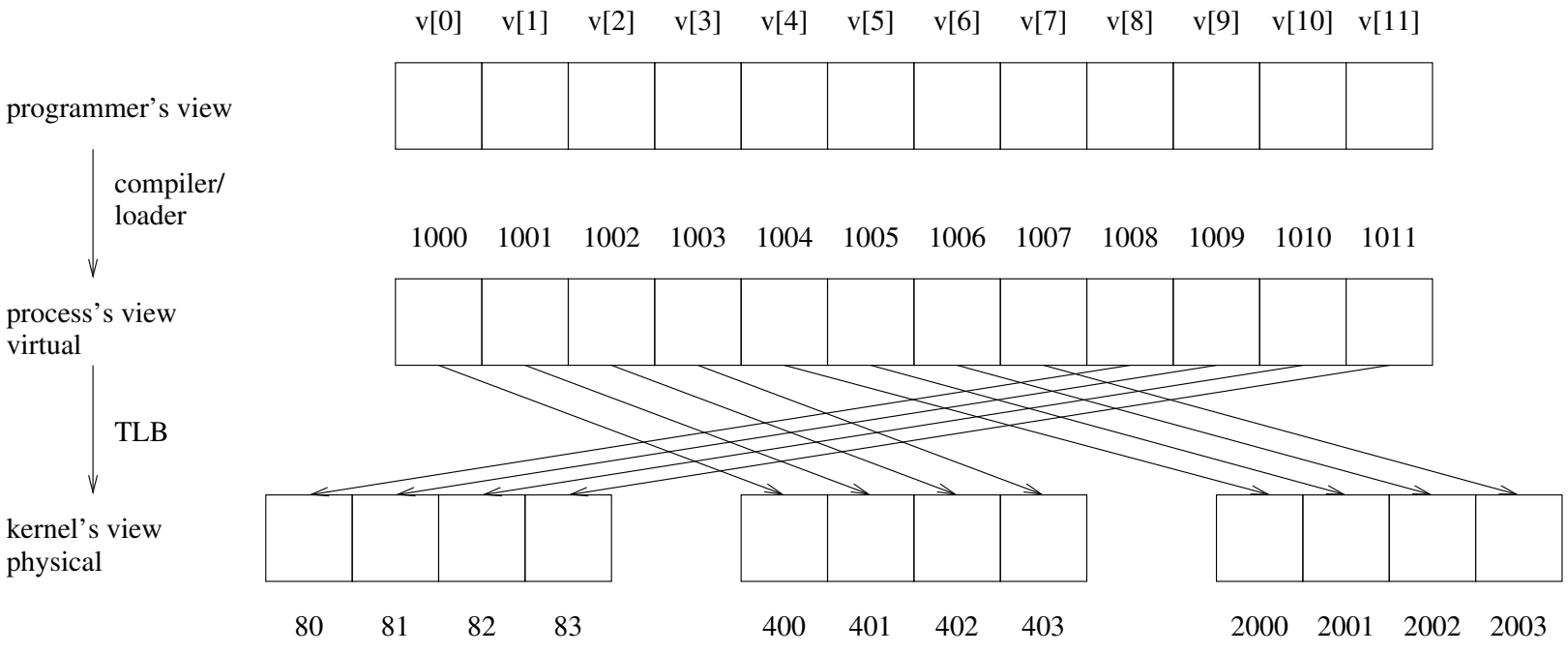
The first page on the freelist of pages is always suitable. No need to search, no size fit issues, no fragmentation issues

Memory

Virtual Memory

A single large datastructure (e.g., a vector, which you normally think of as a contiguous region of memory) in your process might actually be spread, in chunks, all over the place in physical memory



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Virtual Memory

Similarly for code: a chunk of code spanning multiple pages may well be distributed all over physical memory

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Code or data might be contiguous in the virtual address space, but definitely not contiguous in the physical address space

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If process requests 10GB and only uses 1GB, this is not a problem: only 1Gb will be mapped in the page table

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And the process's virtual size can easily be bigger than the physical memory size, either through unmapped or swapped pages

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This is something in the hands of the programmer: don't use memory stupidly!

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Note that when swapping a page back into memory, it doesn’t matter where in physical memory we put it : the page table/TLB ensures the process sees it in the same virtual place

Memory

Virtual Memory

Exercise. Think about the difference between vectors and linked lists in terms of virtual memory and TLBs

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Exercise to think about: the page tables in memory can grow so large they need to be swapped themselves. . .

Memory

Virtual Memory

Examples. A “Hello world” program in C, Java, Python and Perl

	C	Java	Python	Perl
Resident size KB	430	16500	4300	1850
Minor Fault	150	3800	1200	530
Major Fault	0	0	0	0
Context switch	2	150	8	4

In Linux 3.11.10; 8GB memory

Numbers are approximate and vary on runs due to scheduling

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Shared Memory

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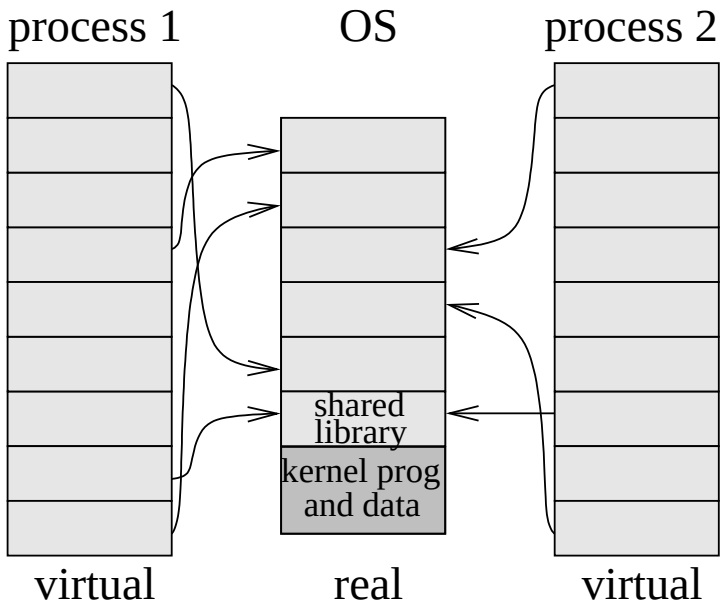
There are many libraries of code to do mundane things like read or writing to files, formatted printing, drawing on the screen and so on

If 10 processes are in memory, each of them using the library `read` function, does that mean there are 10 copies of the code for `read` scattered about in memory?

Memory

Virtual Memory



Shared Libraries

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Now the OS can load the code for `read` just once and direct all other processes to use that single copy

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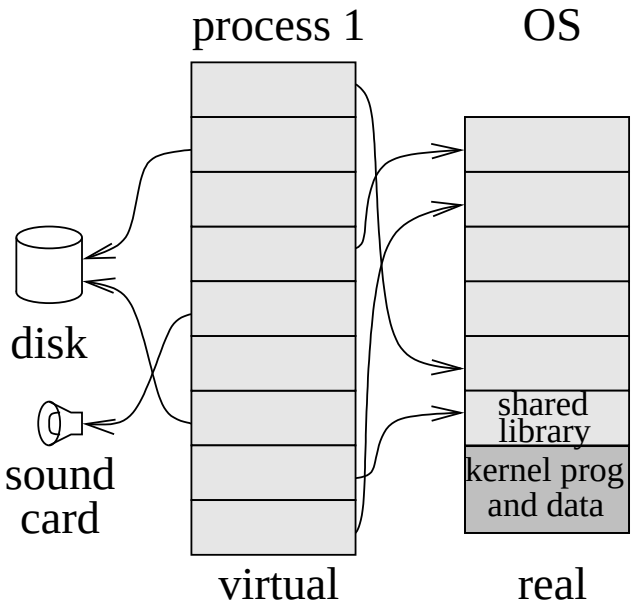
Exercise Read about how virtual memory and *copy on write* allows processes to share data, too

Memory

Virtual Memory

Exercise Read about how virtual memory can be used to map memory accesses into access of peripherals, like sound cards, disk and network cards



Memory map

Filesystems

We now turn to files and filesystems

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To be able to manipulate more data and to make it *persistent* we turn to larger, but slower, devices like disks

And to organise everything we need *filesystems*

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In general, a filesystem is what people want: a simple, efficient way of accessing their data

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Another note: a filesystem is just an organisation of data, and doesn't need to be associated with *disks*

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It's even occasionally useful to have a filesystem *in memory*, again as an organisational mechanism

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Exercise. Compare with using virtual memory to do the same

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A *file* is simply a named chunk of data stored somehow on a disk

Humans like easy names like `prog.c`, so there needs to be a mechanism to convert names to the place on disk where the data is stored

And when we have thousands or millions of files, meaning thousands or millions of names, we need some way of organising the names (even before we have thought of organising the data itself!)

Filesystems

Names

Notice the distinction between the *name* and the *data*

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The same name can refer to different data (otherwise the whole thing would be useless, we could never fix bugs in `prog.c`)

Different names can refer to the same data. We tend to forget that, in real life, we can use different names to refer to the same thing: “Lewis Carroll” and “Charles Dodgson”

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All but the simplest filesystems allow the same file to have multiple filenames

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Names

For the philosophers:

It is possible to have a thing without a name (so how can we refer to it?)

It is possible to have a name without a thing it refers to

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And explain the use of quotes ’“” in the above

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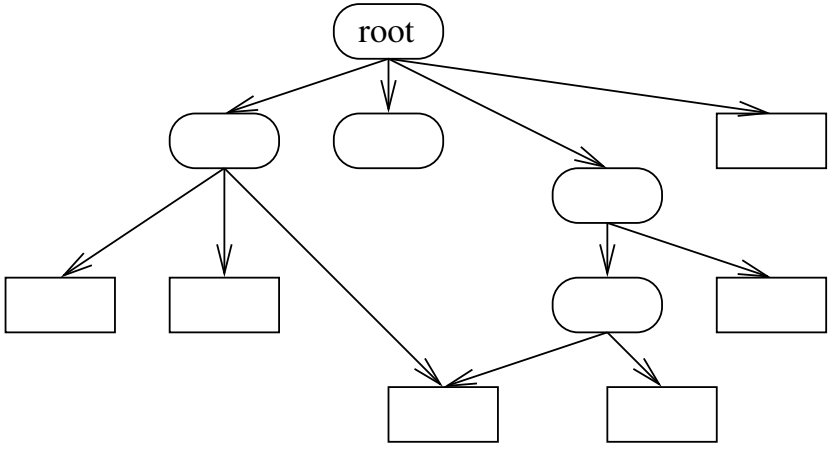
And (names of) directories can be collected in other directories and so on until we get to the top of the hierarchy, the *root*

Filesystems

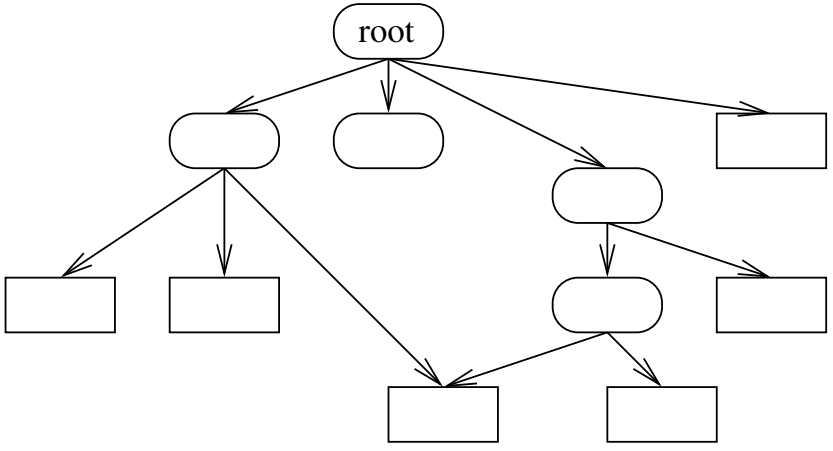
Names



Files can appear at all levels

Filesystems

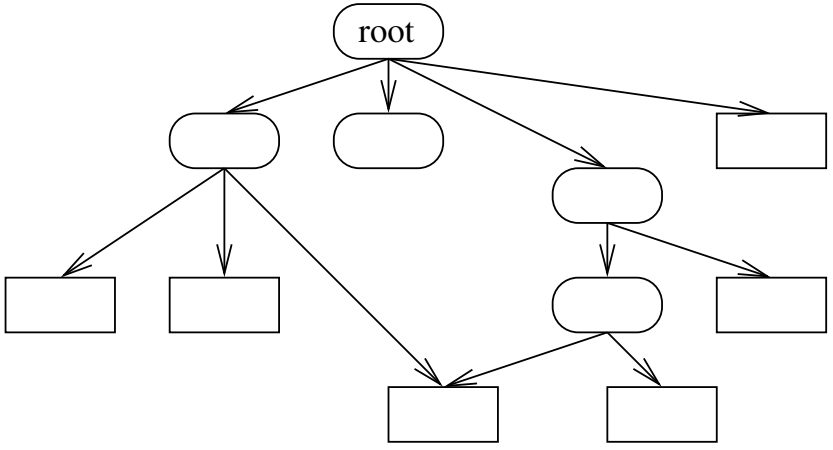
Names



But always within a directory

Filesystems

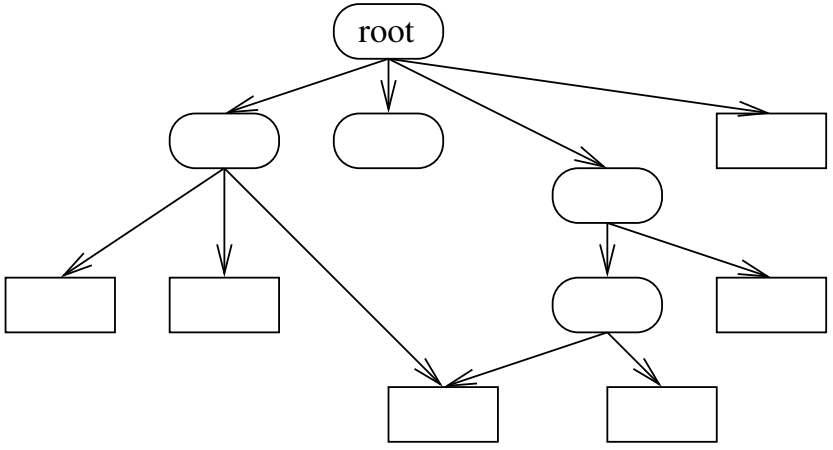
Names



In some systems, a file can be in more than one directory

Filesystems

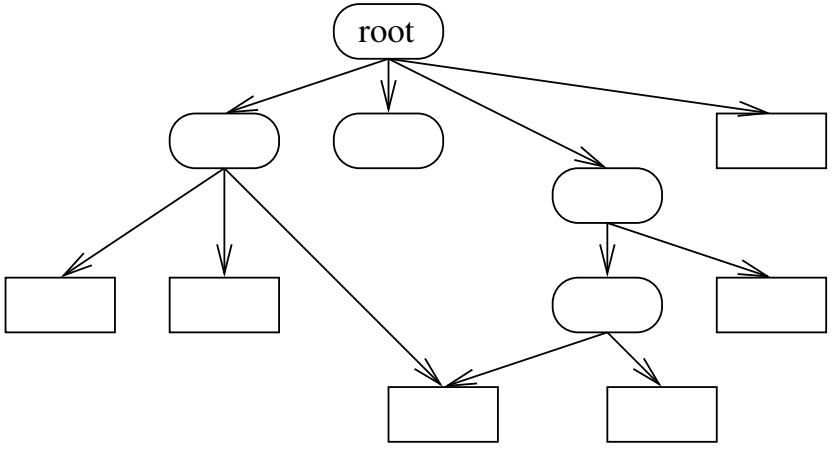
Names



Generally, directories can only be within exactly *one* directory, for implementation reasons

Filesystems

Names



Directories can be empty

Filesystems

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Files can have multiple names: we might find that `/usr/local/bin/dir` refers to the same file as `/usr/bin/ls`

Filesystems

Names

The directory hierarchy forms a *directed acyclic graphs* (DAG)

Filesystems

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This is a tradeoff of flexibility vs. ease of system implementation

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With a cwd of `/u/cs/1/cs1def` a process that asks for file `prog.c` gets file `/u/cs/1/cs1def/prog.c`

Filesystems

Names

This is how different processes can refer to the same name `prog.c` but get different files

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The cwd is a convenience for the programmer and may be changed as often as you like (`cd`, `chdir`)