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Again, this goes against the original design of an OS, so must be carefully set up and controlled

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- The memory protections must be set properly to allow only the authorised processes to read or write it

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**Exercise** Compare shared memory and pipes

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**Exercise** Read about these

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Gates’ Law: programs double in size every 18 months

(Really Wirth’s Law: Software is decelerating faster than hardware is accelerating)

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## Physical Memory

We first consider how processes (code and data) should be laid out in memory

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This is called *physical* memory layout to distinguish it from *virtual* memory, which comes later

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But also the kernel needs memory:

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- Allocation and freeing within the kernel. The kernel has to be dynamic otherwise it would be very difficult to get started, e.g., creating processor control blocks

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Dynamic allocation for both kernel and the processes was soon introduced in OSs, but computer languages took a while to catch up with the new facility

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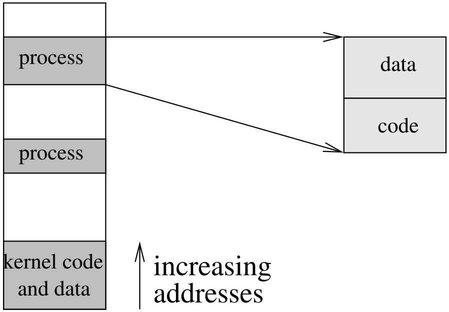
Physical memory in an early computers looked something like this:




Memory Layout

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Again, some early languages (FORTRAN, again) did not have a stack, and thus no recursion

## Partitioning

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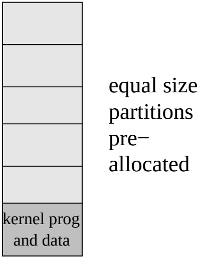
The earliest and simplest memory layout is a static system called *partitioning*, where areas are allocated at boot time



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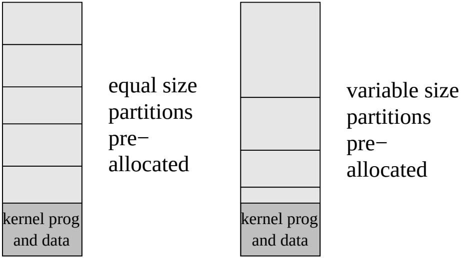


A process is loaded into the smallest free partition it will fit into

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Equal size is easy to implement, but usually causes wasted space when a process does not fill its allocation

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Variable size is not much harder to implement, but its efficiency depends heavily on the choice of partition sizes as ideally they should match the expected process sizes

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IBM's OS/360 (mid 1960s) had three partitions: one for spooling punched cards to disk; one for spooling disk to printers; and one to run jobs

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If that part of the process is needed again later, the programmer has to reload the code

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This trick of swapping memory back and forth to the disk gets a big boost later

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(But when we come to virtual memory later we shall see that exactly this *is* possible with modern hardware!)

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So an OS must be able to support this

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A lot more complicated to implement, but this allows the process (i.e., the job submission) to say how big a partition it needs and the OS allocates just that

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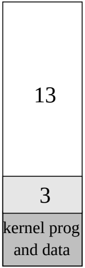

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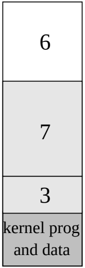

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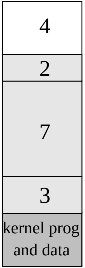

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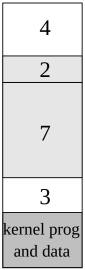

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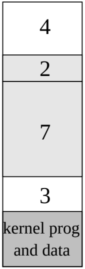


We have space enough to run a process of size 5, but nowhere to put it

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The more processes come and go, the worse the fragmentation gets

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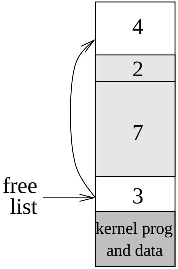

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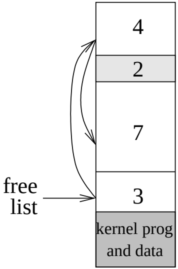

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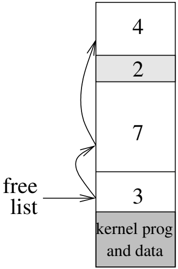

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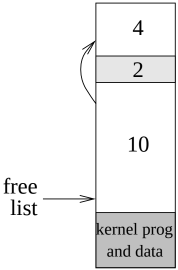
Slightly more clever is to *coalesce* physically adjacent blocks



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Strategies for choosing blocks include:

- Best Fit. Find the *smallest* available big enough hole. Slow as we always have to search the entire freelist and results in lots of small fragments that are effectively useless as they are too small to be allocated

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- First Fit. Use the *first* available big enough hole. Initially faster than Best Fit and tends to leave larger and more useful fragments. But fragments tend to be created near the front of the freelist, so we have to search further and further each time

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- Worst Fit. Find the *biggest* available big enough hole. Strangely this works out better than you think. Slicing chunks off bigger blocks tends to leave larger fragments that are more likely to be useful. Marginally faster than Best Fit as we have larger and therefore fewer blocks in the freelist to search through

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There are plenty of other memory management systems (e.g., Buddy memory allocation; Slab allocation; etc.) targeting the fragmentation problem

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The second generally gives us larger fragments, but both need to be addressed

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Allocation of physical memory is **still a problem** in current machines where certain kinds of hardware need large contiguous chunks of physical memory, e.g., GPUs