Here we look at how our operating system can place the currently executing programs at least partially in memory, and how the memory management contributes to normal execution.

When we execute a program, the data to be used by that program has to first be in the registers coupled with the CPU. During the instruction exection cycle, the CPU will fetch the data from these addresses. If the instruction requires data from memory, then that data has to be brought over to the CPU before it's used.

The problem comes when we have to wait for the information to arrive at the CPU registers. Instead of having to go all the way to main memory every time we want to access some memory, we can also have some levels of memory closer to the CPU. Instead of having to go all the way to main memory every time we want to access some memory, we can also have some levels of memory closer to the CPU. This **cache** can then speed up subsequent memory accesses.

In actual memory, our processes have to have their own address space. This is done to ensure that processes can't access each other's memory space and so that each process only has a set size. There are two registers, the **base** and **limit** registers, which store the beginning and end of the address space for each process.

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When we CPU generates an address, it has to be checked with the base and limit registers to make sure that the address is valid. If the program tries to modify invalid addresses, then it will be sent as a trap to the operating system and the program will be removed from memory.

Address binding

When a program gets loaded into memory, it need not be in numerical order, it could be loaded at any available location. Thus there has to exist a process by which we can map some addresses from a logical perspective to the hardware. In the source program, such addresses are usually symbolic, meaning that during the compilation process usually we don't use the physical addresses. Once the linker is activated, it will map the addresses used by the loader and compiler and replace them with the actual physical addresses. However, this binding can be done at any step in the compilation process.

- **Compile Time**: If we know which address the program will start in, then we can just calculate all the addresses manually. However, we usually don't know where the program will be loaded.
- **Load Time**: If we don't know where the program will be loaded,

then we have to "fill in the blanks" when the program is loaded. For example, we could just calculate all addresses based on the initial address, and when we load the program and thus know the initial address, we can update the remainder of the addresses.

- **Run Time**: We could wait until the program is running to assign addresses if the program segment could be moved during execution. However, we would need special hardware to do this but apparently that's how it's done in modern operating systems.

The addresses used by the CPU are called **virtual** (logical) addresses. The **Memory Management Unit(MMU)** is the entity responsible for actually carrying out the conversion. The base register, which holds the initial possible address, is called the **relocation register**. This register's value is then added to all the addresses sent to the memory. So the CPU would deal with "offsets" and the relocation register is the amount they're offset to. So if the initial address is 14,000, and we want to access memory value 436, we would map it to the physical address 14,436.

This has the effect that the user program never really deals with physical addresses. Even when we use pointers and "interact with memory" all those instructions still have to pass through the MMU. [1]

[1] Maybe by differentiating logical/-physical addresses, we also remove the limitation of how big our memory address can be, since the MMU would know what the maximum address is.

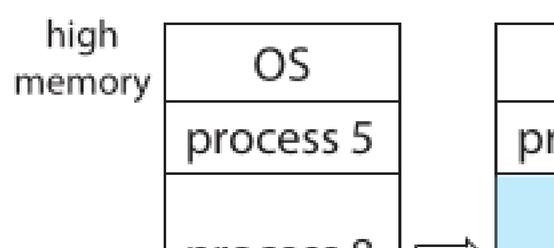
Dynamic Loading refers to loading some parts of our code when they're needed rather than loading it all at the same time. When our program wants to execute a certain routine, we have to check if the routine has been loaded or not. If it hasn't, we have to fetch it from memory and update the address tables to reflect the change.

Dynamically Linked Libraries are files that are linked to the user program when they are called. This is typically done for system libraries such as those in C. Instead of including the entire library, we can only call the required routines. In Linux these are **shared libraries**. We can also used shared libraries to update versions of the library. If we just have a new version of the library, the program will automatically use the new version of the library. However, to prevent a user program from using an incompatible version of the library, we can embed version information within the library so that the user program and operating system avoid using this version.

Coniguous Memory Allocation

This memory allocation scheme involves placing processes in contiguous areas of memory. The operating system can also be placed in different positions in memory. It can be placed in low addresses or high addresses. [2]Most operating systems now place the code in the higher addresses.

[2] This also depends on the interrupt vector



In a variable allocation scheme, we have **memory holes**, which refers to the space between two occupied regions of memory. When a process comes in ready to be scheduled, we choose a hole to load the program in. The hole is thus split in two, the part of the hole occupied by our program, and the area of the hole that remains free. This second part is returned to the set of free holes.

There are a couple of ways of deciding how to assign processes to available memory space:

- **First Fit**: Assign the process to the first hole that can fit it. We can start searchign sequentially from the beginning every time or from the location where it last stopped.
- **Best Fit**: Assign the process to the smallest hole that fits it. If the holes are not ordered by size, we would have to search the entire space.
- **Worst Fit**: Assign the largest hole to each program. Might have to search the entire space again, however might leave more contiguous space for some other programs.

Using the best fit or first fit approach suffers from **external fragmentation**. This means that as processes get loaded and removed from memory, there will be smaller and smaller pieces of contiguous memory that are unused. For example, suppose we want to add a new process, we might have a situation where there is enough free memory in total to add a process, but it is not conitguous, so the process cannot all fit in one place.

A possible solution to this might be to split memory into smaller partitions called **blocks**. Blocks might then be given to programs and the leftover memory within a block might in the end be less than if we jsut assigned contiguous memory without partiitoning it. **Internal Fragmentation** is the difference between the size of a memory block and the size of a process on that block.

A technique which can sometimes help with external fragmentation is **compaction**. Using this scheme, we could try and move all the free blocks of memory together into one large hole, having a ”tight fit” of the process memory space. However, this can only be done if the addresses are figured out dynamically during execution, since we might need to relocate the entire program around. Remember that if we can change the base register during execution and then update all the addresses automatically, then we can pull this off.

Another solution, and the one that is used most frequently, is called **paging**. Paging removes the limiation of a process to all reside in continuous memory, and so allows us to split a process and locate it wherever there is space available.

Logical memory is broken down into **pages** and physical memory is broken down into **frames**. This means that the physical address in memory is completely separated from logical memory. When a process is loaded into memory, we move the generate two values: the **page number** and the **page offset**. Then, the memeory unit keeps a page table where we can convert from logical addresses to physical frame number. One part of the logical addresses used by the CPU might refer to the offset from the page number.

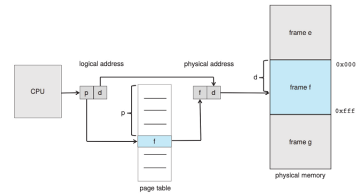


Figure 2: Part of the logical address will be composed of the page number d and the offset within that page d. Once the MMU converts d to the corresponding physical frame f in main memory, we can get the address by adding $f + d$.