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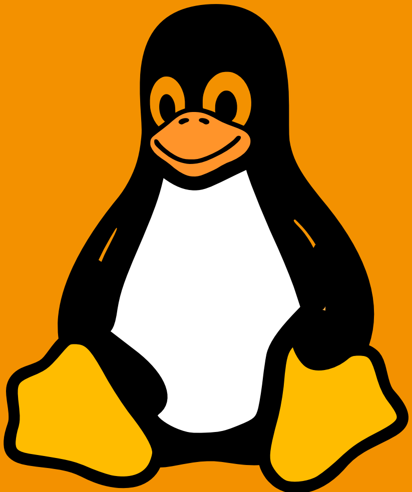
OS 12 – Memory Management


source: iconspng.com

The lecture is based on the work and the documents of Prof. Dr. Ludwig Frank

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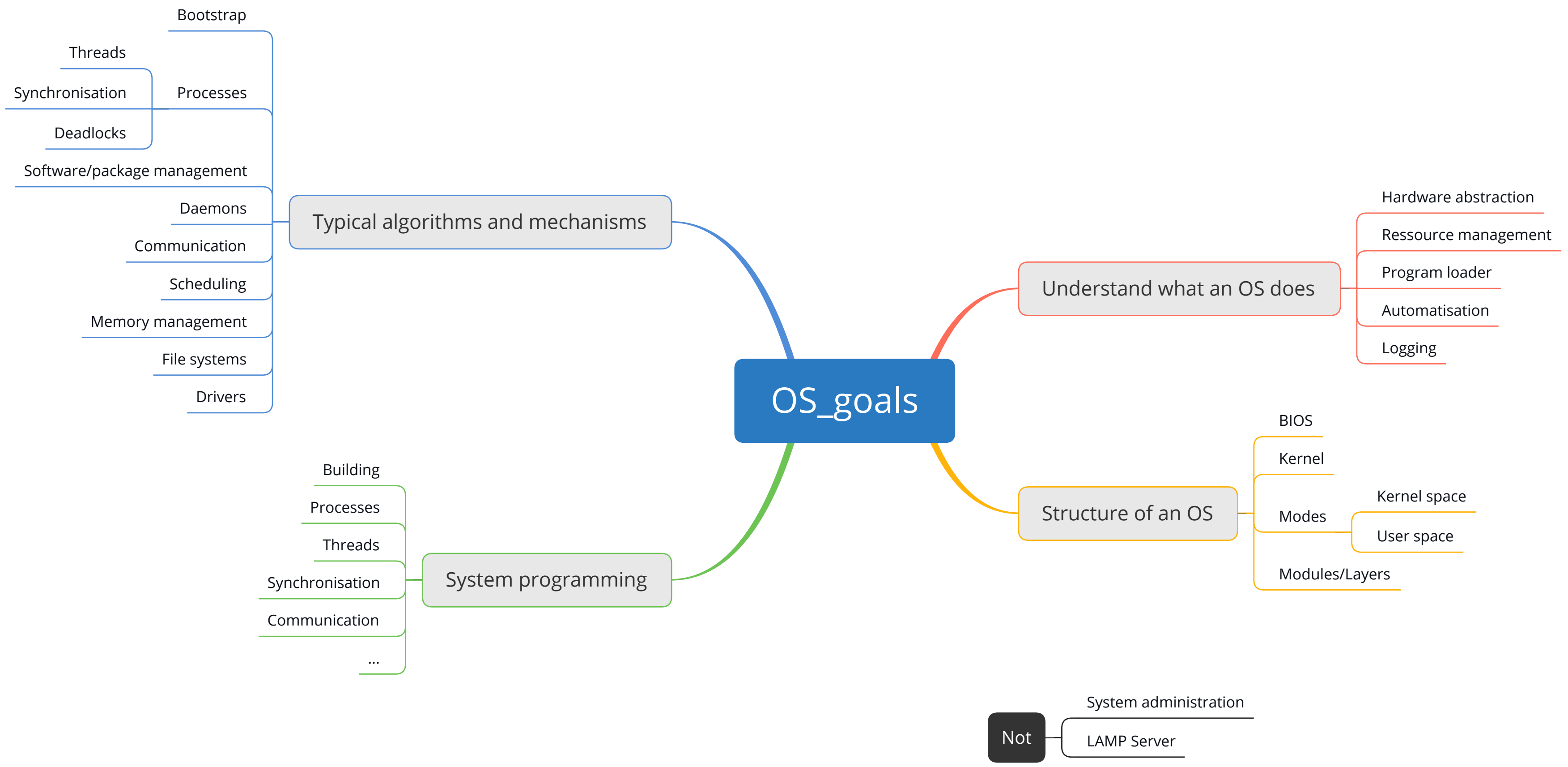
Goal



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Goal

OS::Memory Management

- Caching
- Partitioning
- Fragmentation
- Allocation strategies
- Swapping
- Virtual memory

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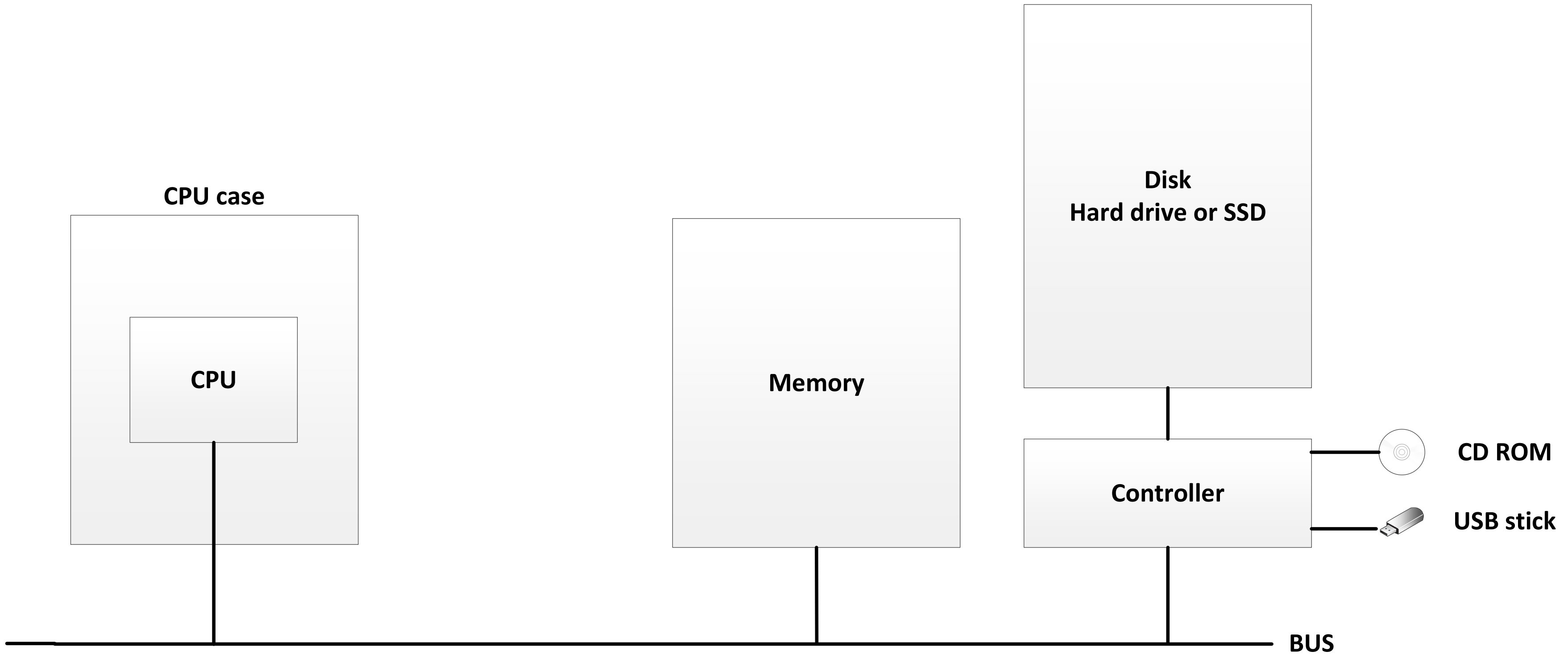
Memory overview



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Memory management requirements

Requirement	Description
Retrievability	Who is the **owner** of the **memory area**?
Protection	**Protect the memory areas** of the different processes against unwanted interference (read/write).
Efficient usage	**Memory** is (always) too **small**.
Sharing	Share memory between processes (**shared memory**).
Logical organisation	A process wants to see its memory as a **sequence of bytes**.
Transparency	The **programmer doesn't know** at programming time **how much memory** on the target computer **exists**. The memory management should transparently manage this.

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Intro

Towards modern memory management...

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Caching

Problem

The **CPU is much faster** than the memory and all the other peripherals (e.g. network).

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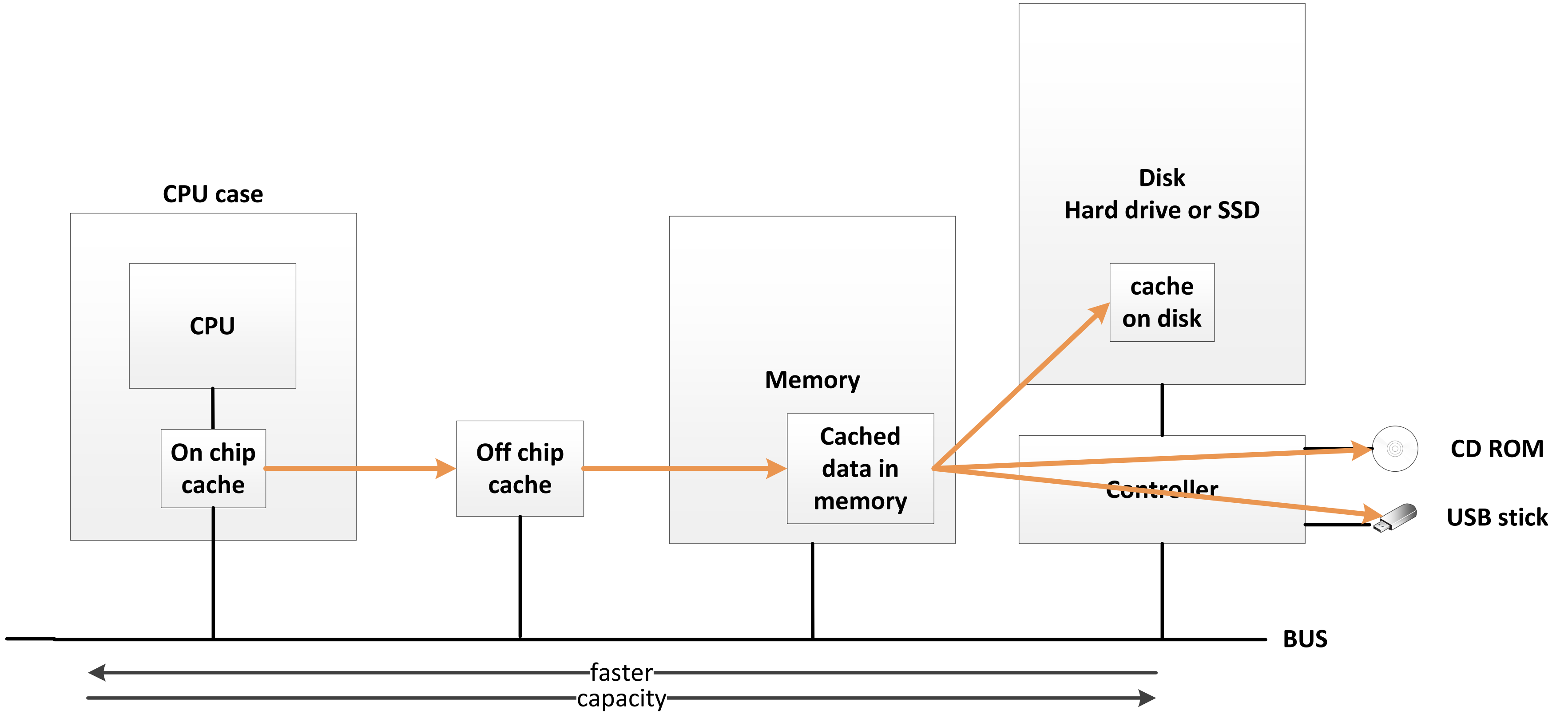
Caching

Idea Introduce caches (data buffers) on various places.



Caching terms

Hit

A hit occurs on repeated access of the same memory address.

Fault

Occurs on the first access. The cache is too small to buffer all data.

Locality

- **temporal**: If a memory address is accessed, there is a high probability that it will be **accessed again** very soon.
- **spatial**: If a memory address is accessed, it is very likely that **surrounding addresses will be accessed**, too.

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Caching examples

On chip cache
A small cache inside the CPU: L1, L2, and L3. The average access time appears faster.

Off chip cache
A cache outside of the CPU (e.g. a special PCIe device).

Disk cache
A cache inside the disk or inside the OS. Speeds up the access time to the data on disk.

Internet cache
An internet proxy (e.g. squid) placed in the local network. If everyone accesses the same website or downloads the same file.

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Questions?

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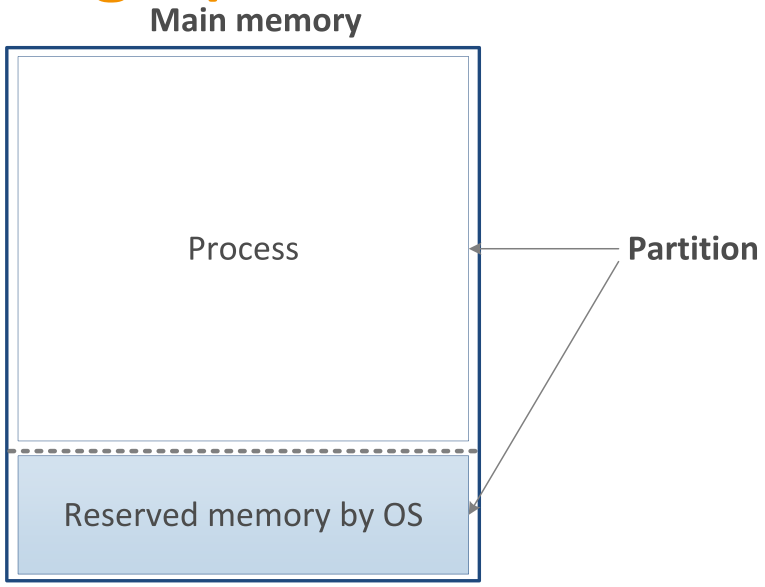
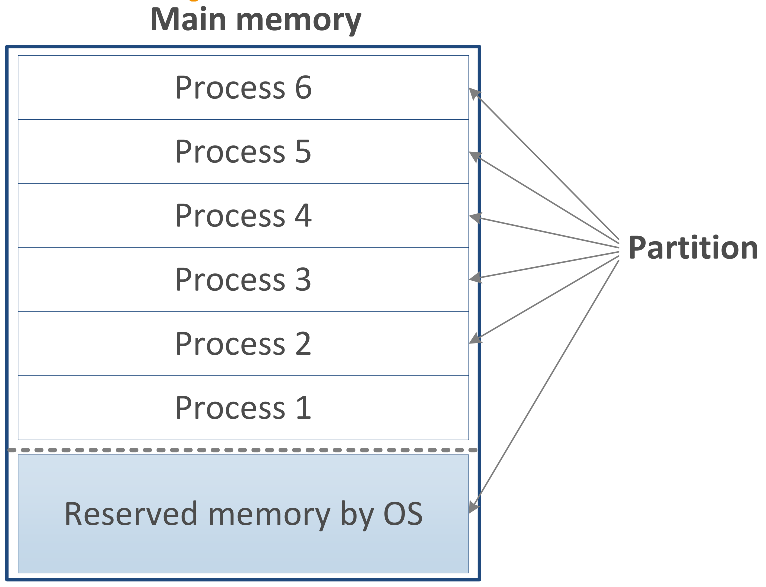
Partitioning

Single process mode



Multi process mode

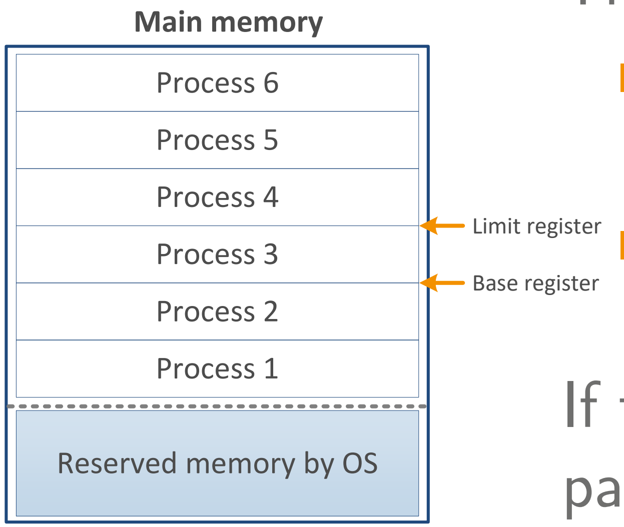


The main memory has to be divided into the OS part and the process part. If the process needs more memory that is physically available—it can't run.

The main memory is divided into the OS part and the rest is partitioned between the processes.

Problem 1: memory protection

How to detect that a process accesses memory that it does not own?



The hardware offers two additional registers:

- **Base register**: start address of memory partition
- **Limit register**: end address of memory partition

If the process access an address outside the partition, it is interrupted: the OS does than the error handling.

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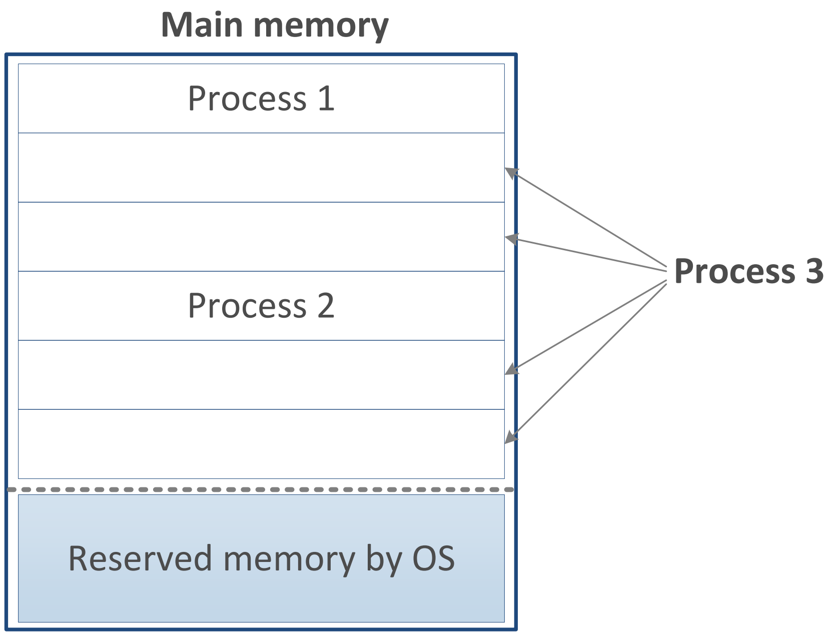
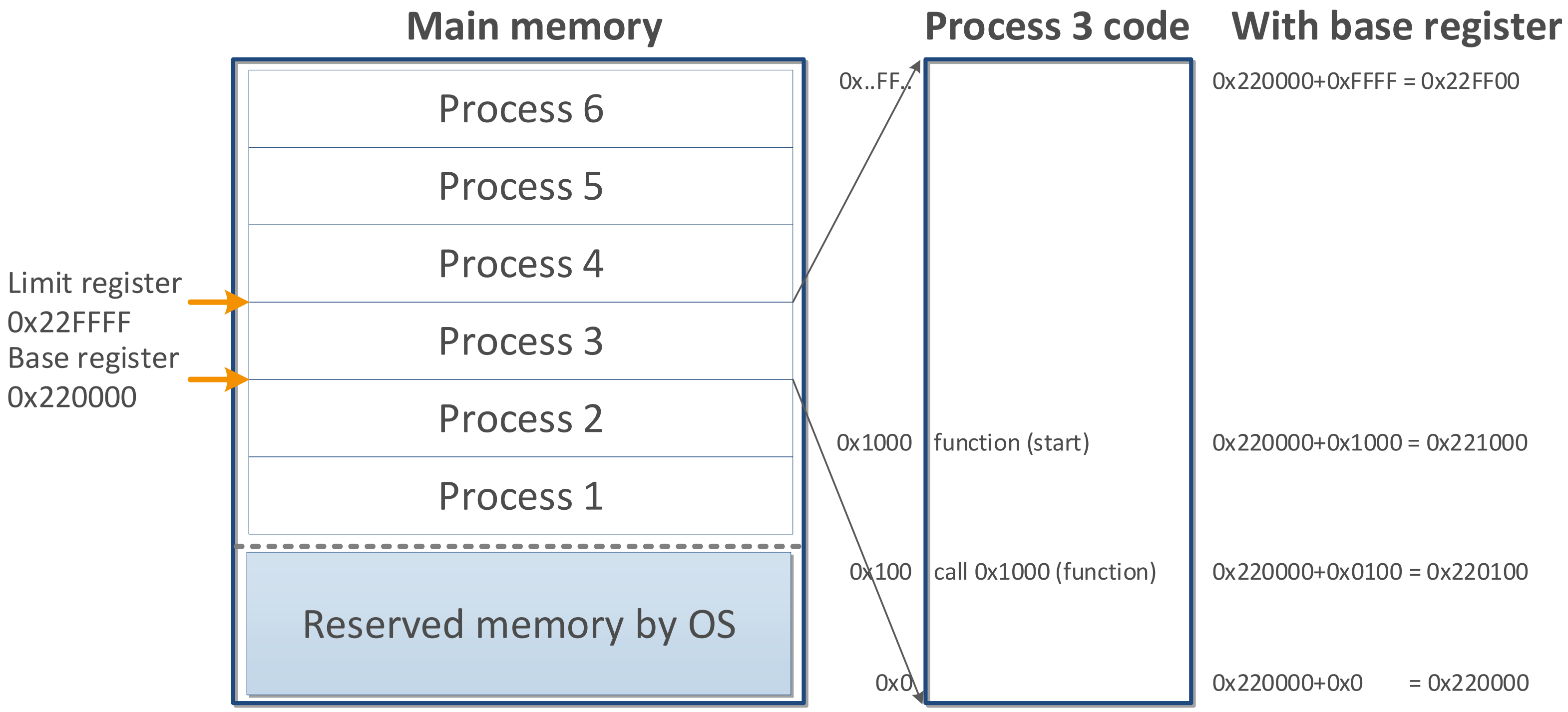
Problem 2: position dependent code

Where should the program be loaded? What happens with the addresses inside the process?



Problem 2: position independent code

Build the program as it would start at address 0. On every memory access, the base register is added to the address.



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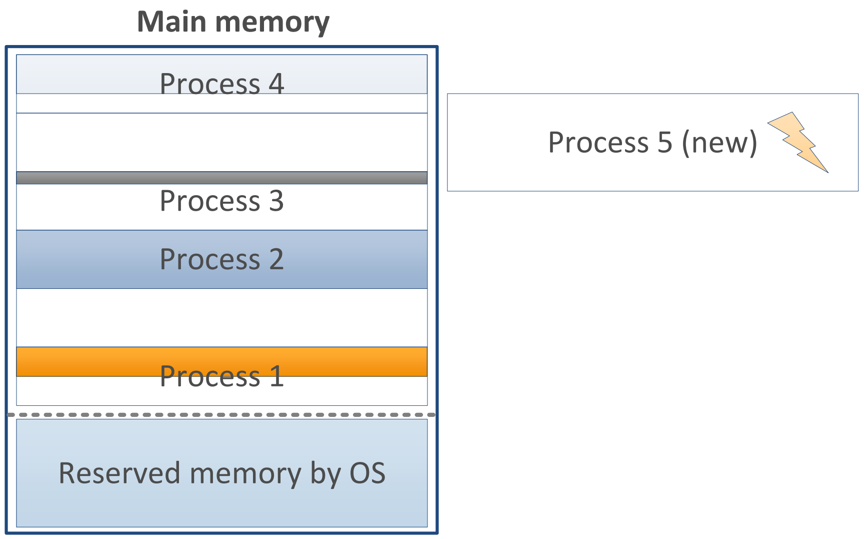
Fragmentation



Internal fragmentation

Partitions are allocated by processes, but **not fully used**. May be solved by variable partition size.

External fragmentation

A lot of free partitions can't be used, because they are **too small** for some processes. May be solved by dynamically move the partitions (base and limit register required). But this will take some time.

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Allocation strategies

How to find the best place for the new partitions in the memory?

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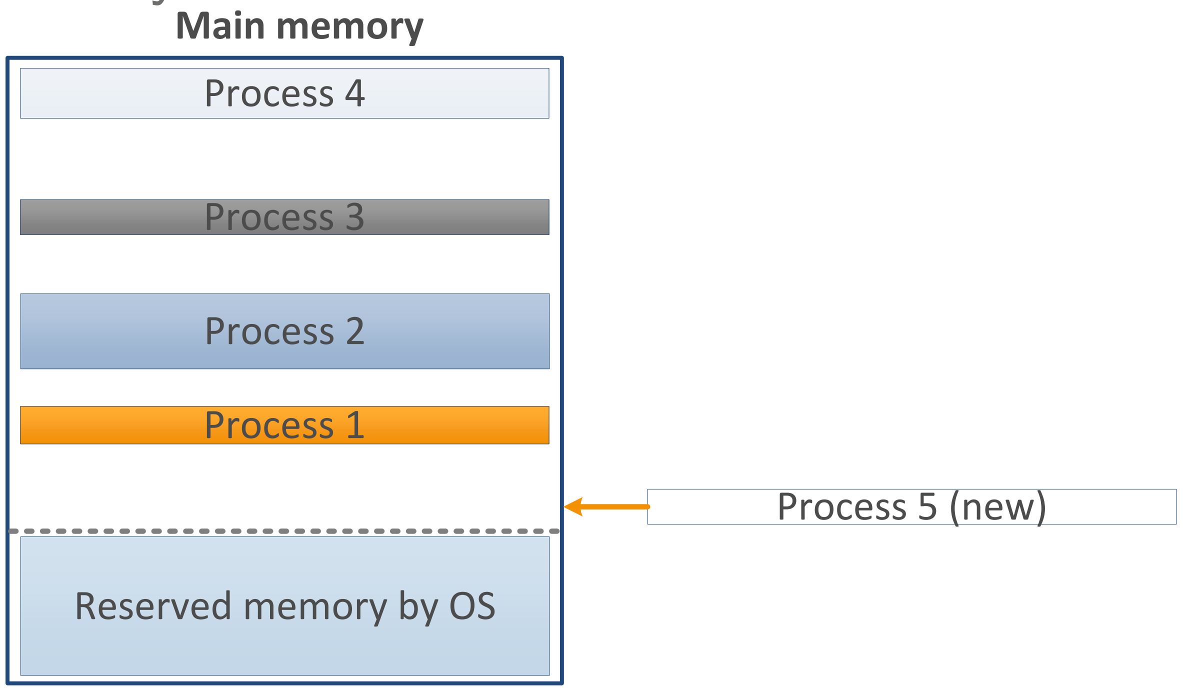
First fit

Starts at the beginning of the main memory and takes the first memory area that fits.



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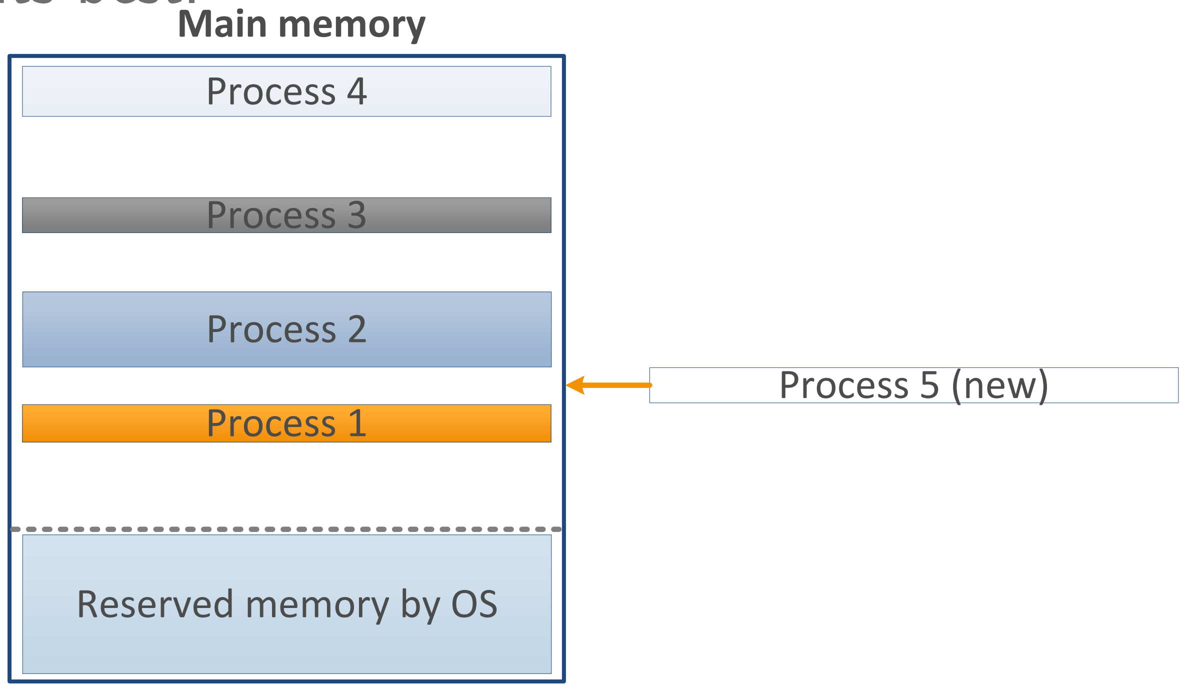
Best fit

Looks into all free memory areas and takes the memory area that fits best.



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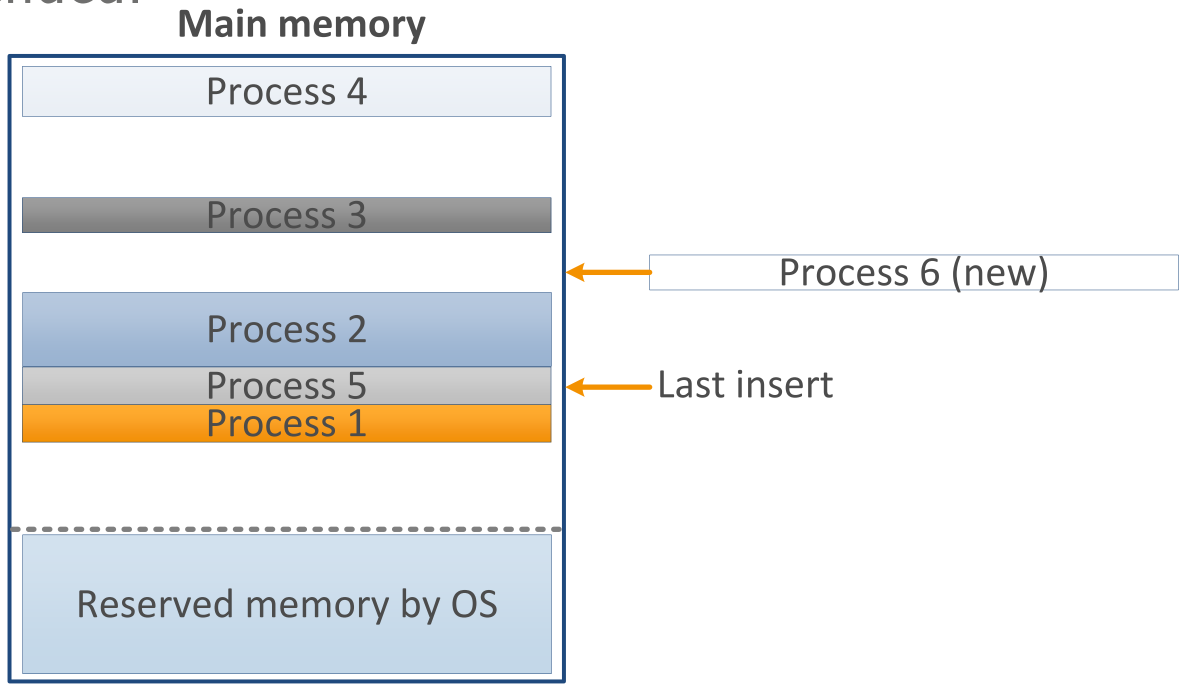
Next fit

The same as first fit, but it starts at the point, where the last search ended.



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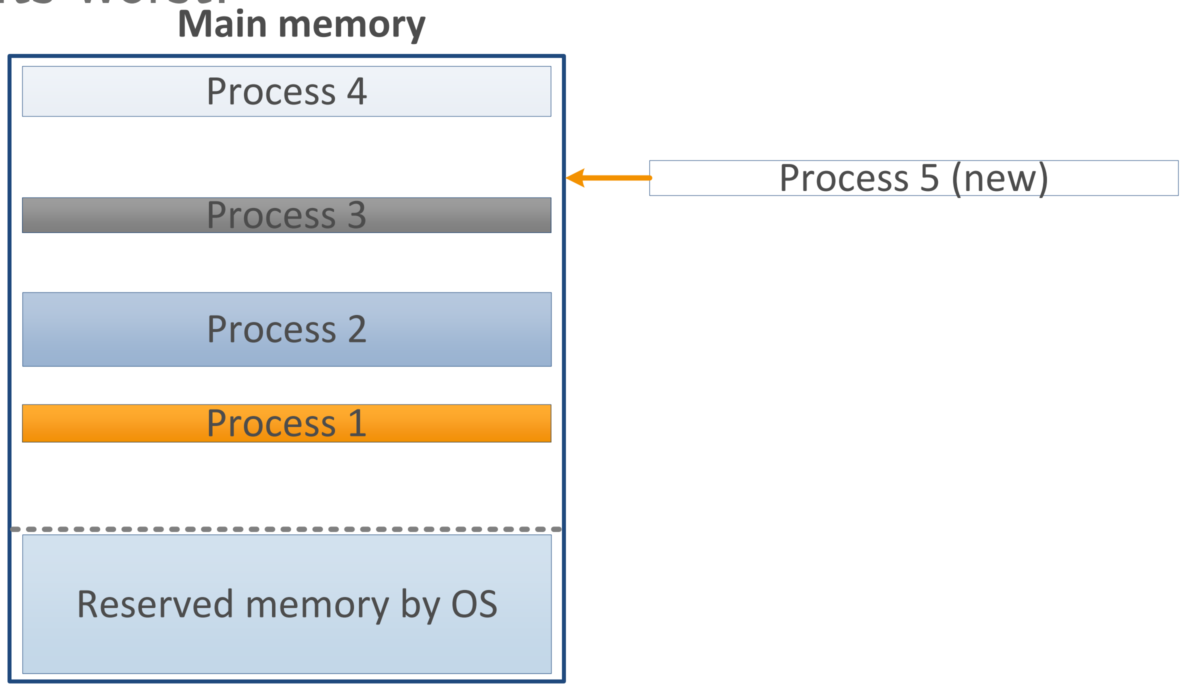
Worst fit

Looks into all free memory areas and takes the memory area that fits worst.



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Allocation strategies summary

Simulations show that generally best fit is worse than first and next fit.

Worst fit is the worst.

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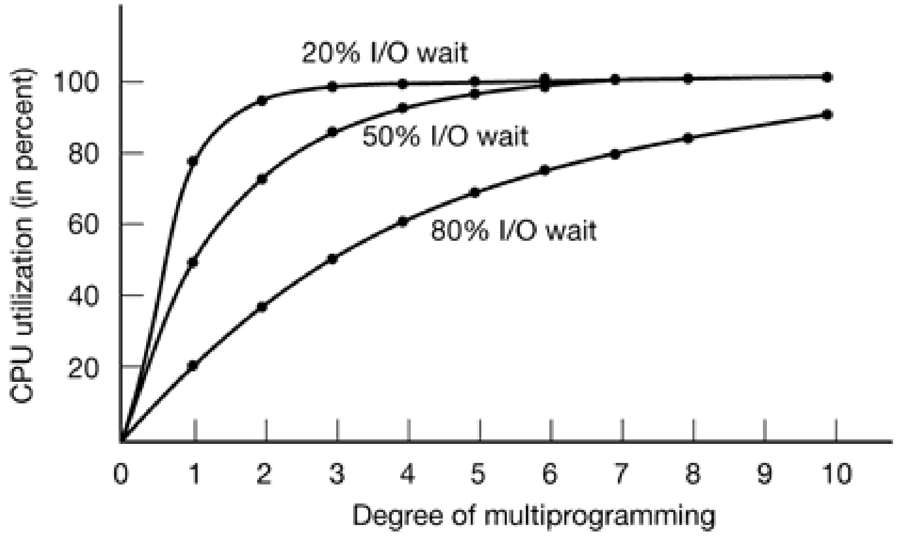
Still existing problems

- The number of processes is limited by the number of partitions.
- The processes often don't use the memory allocated to them for a long time.
- A lot of processes are required to fully utilise the CPU.



Source: Modern operating systems (Tanenbaum, second edition)

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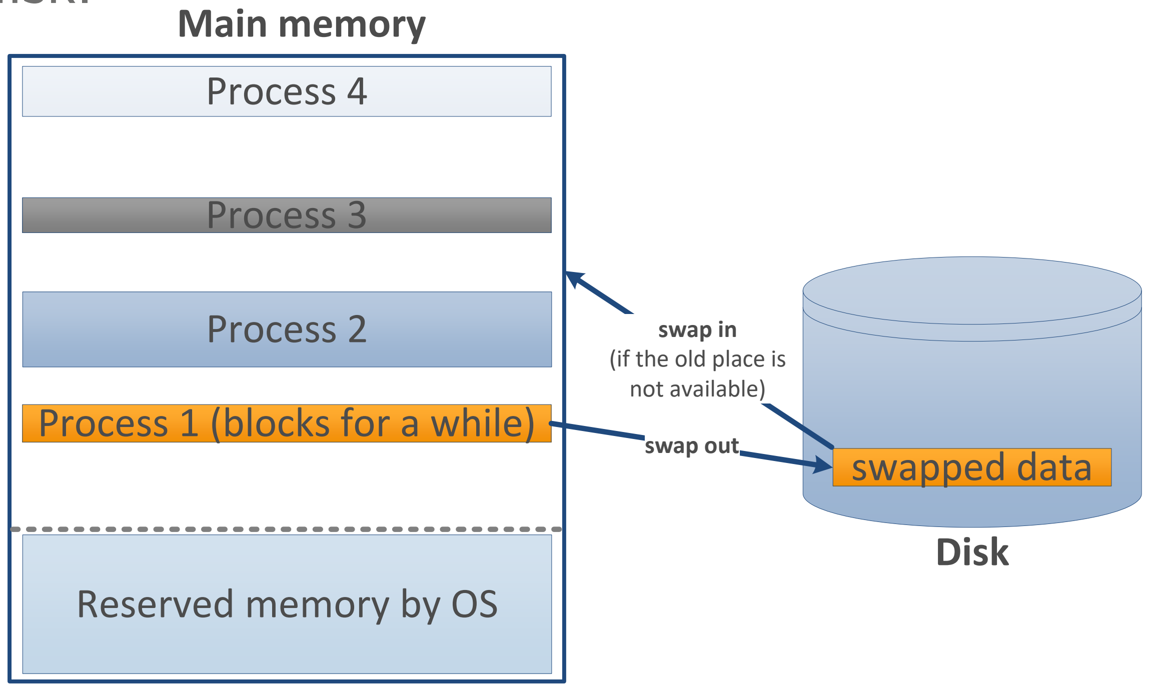
Swapping idea

Swap the memory of a process that is not actively running to the disk.



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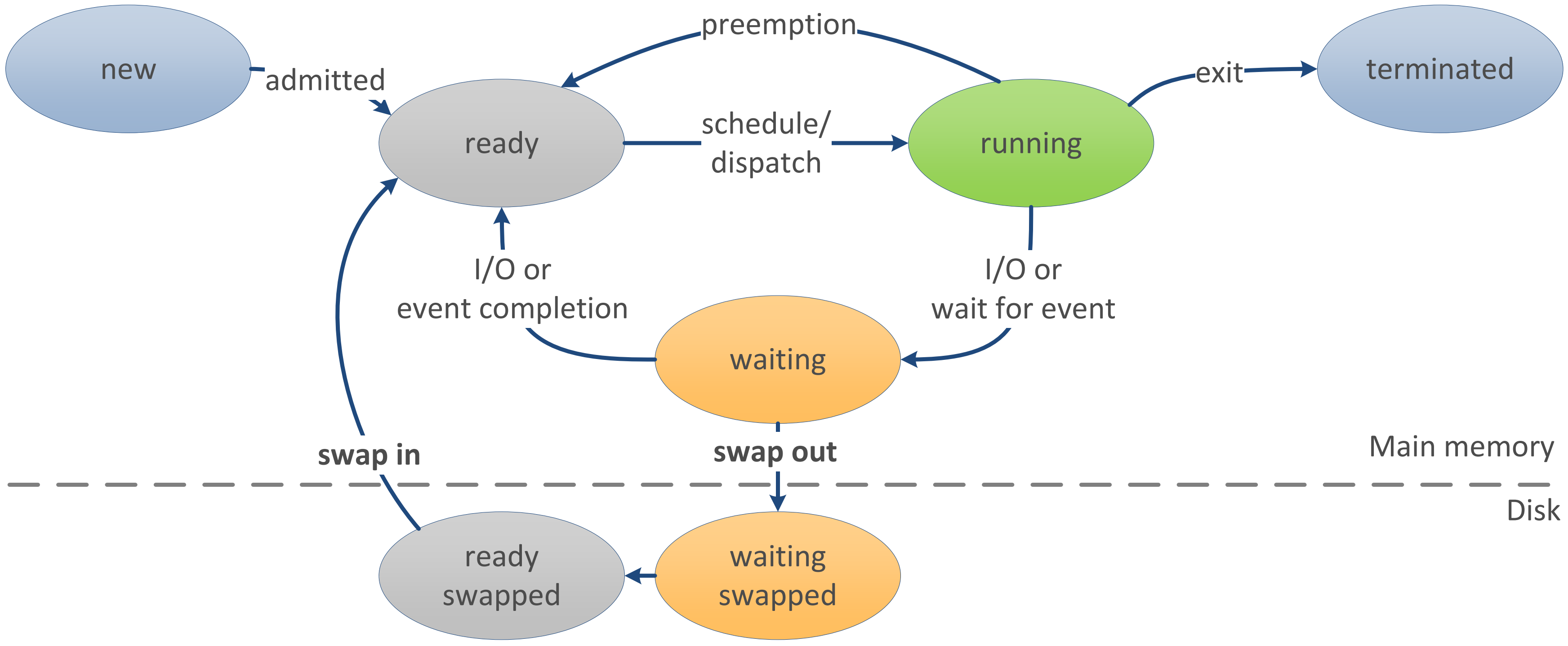
Enhanced process states for swapping



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Where are we?

Achieved so far

The sum of the memory for all processes can be larger than the physically available memory.

Still existing problems

- Every process is limited by the physically available memory size.
- The processes often don't use the memory allocated to them for a long time.
- Problem with fragmentation still exists (dynamically move of partitions takes a long time).
- Swapping is time consuming. The advantage is often difficult to evaluate.

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Virtual memory

Idea

Only load the required memory parts of a process into the memory.

Requirement

But neither the user nor the programmer should notice anything about it.

=> **Virtual memory with virtual addresses!**

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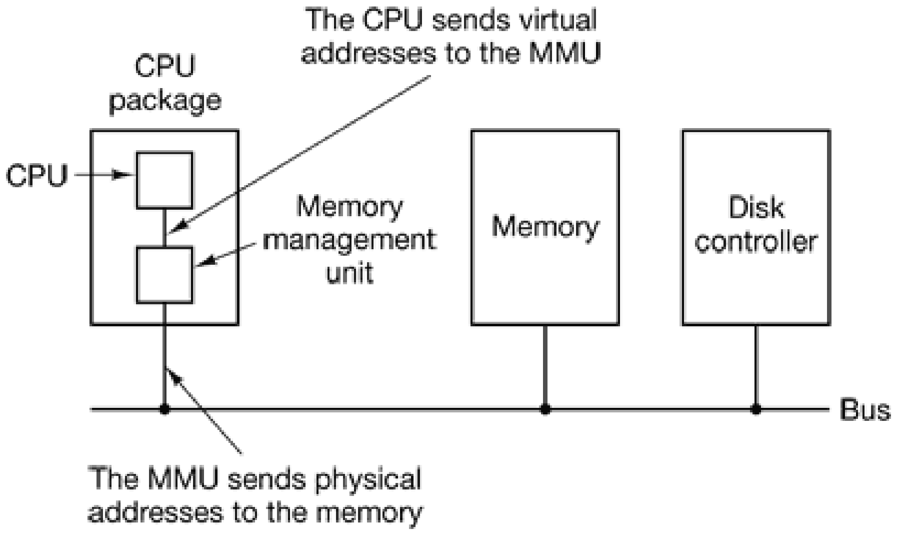
Virtual address

The MMU (a special hardware inside the CPU) supports the address calculation: virtual address -> real address.


The CPU sends virtual addresses to the MMU
CPU package
CPU
Memory management unit
Memory
Disk controller
Bus
The MMU sends physical addresses to the memory

Source: Modern operating systems (Tanenbaum, second edition)

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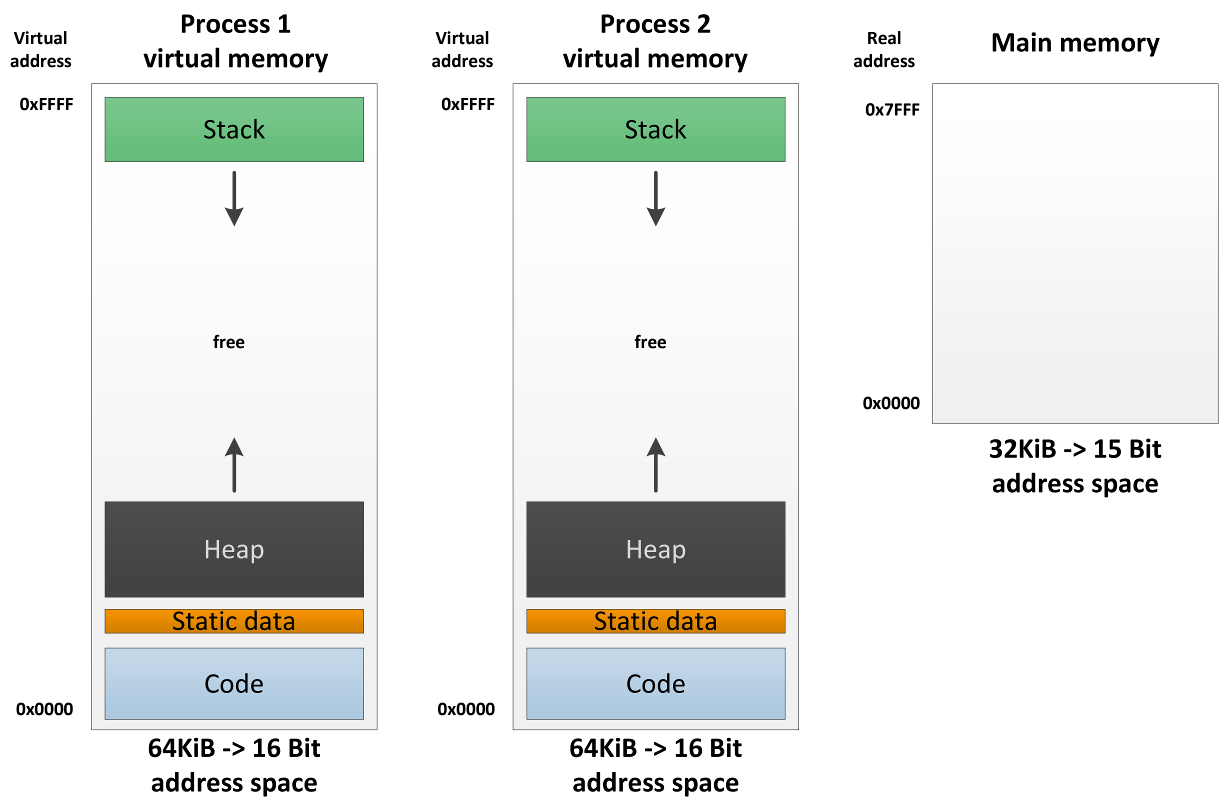
Virtual address space



Virtual address space

Each process has its own virtual address space. The theoretically available memory.

Real address space

Physically available address space

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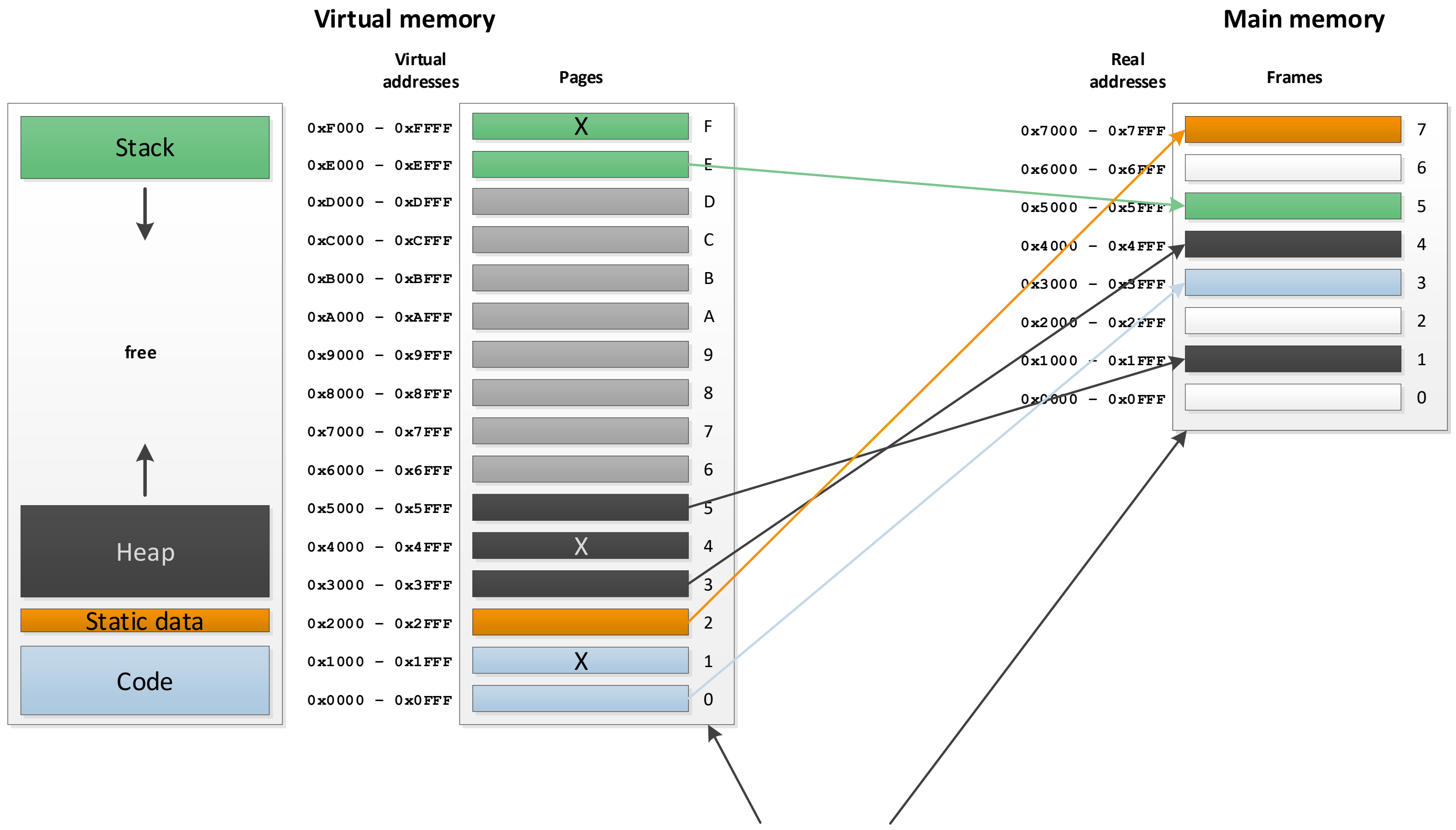
Pages and frames



Pages and frames have same size (here 4KiB)

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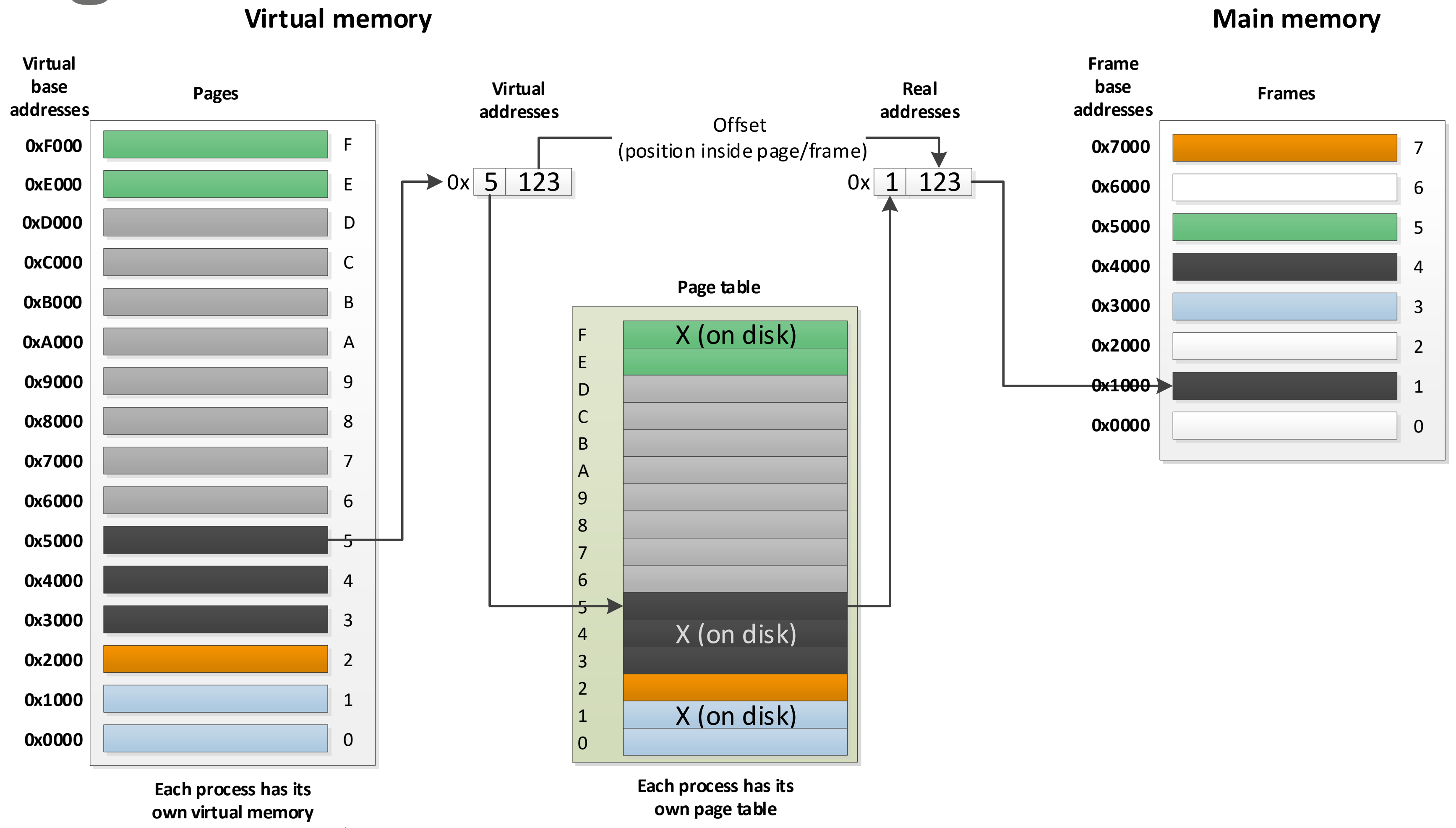
Page table



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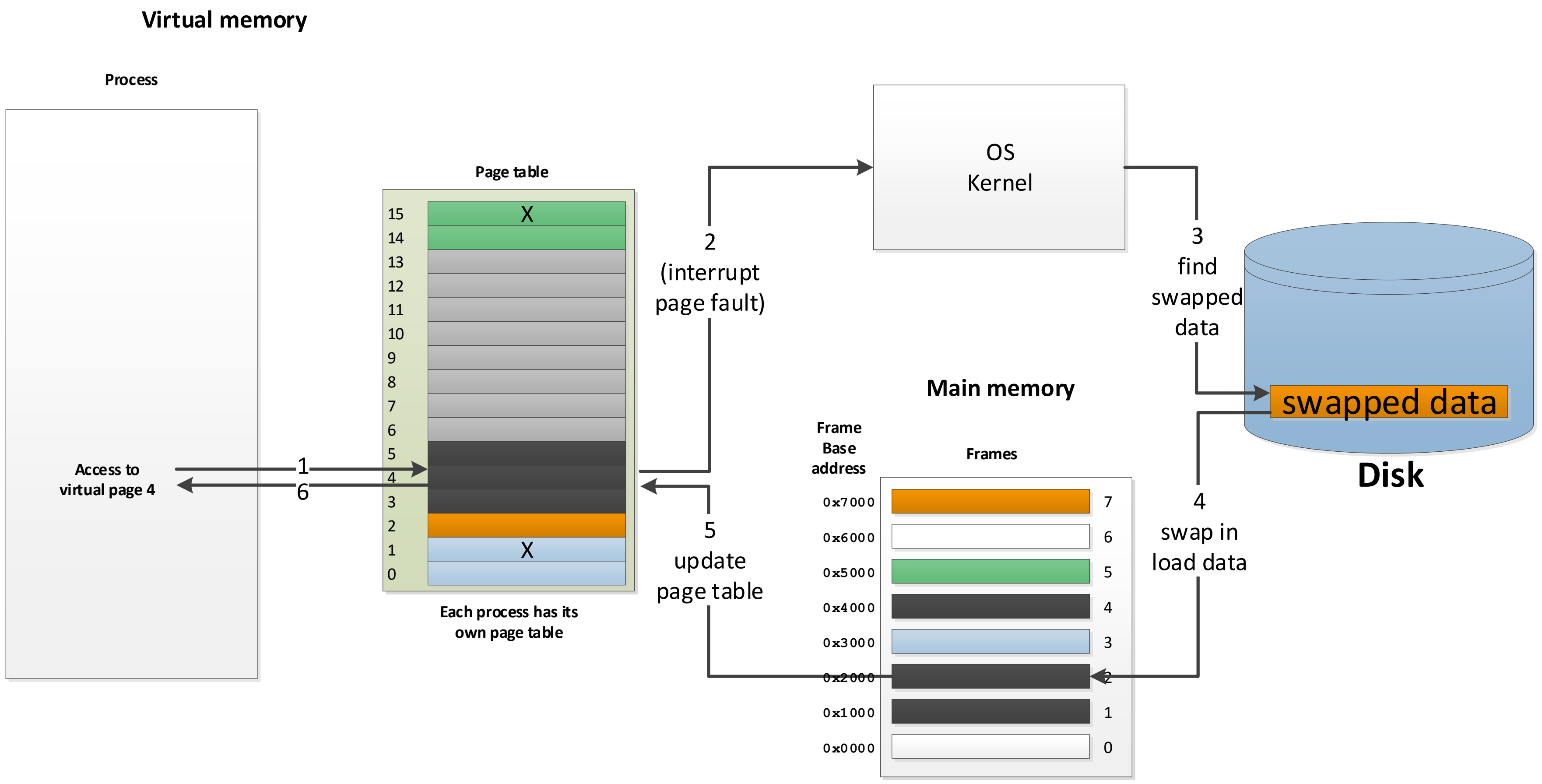
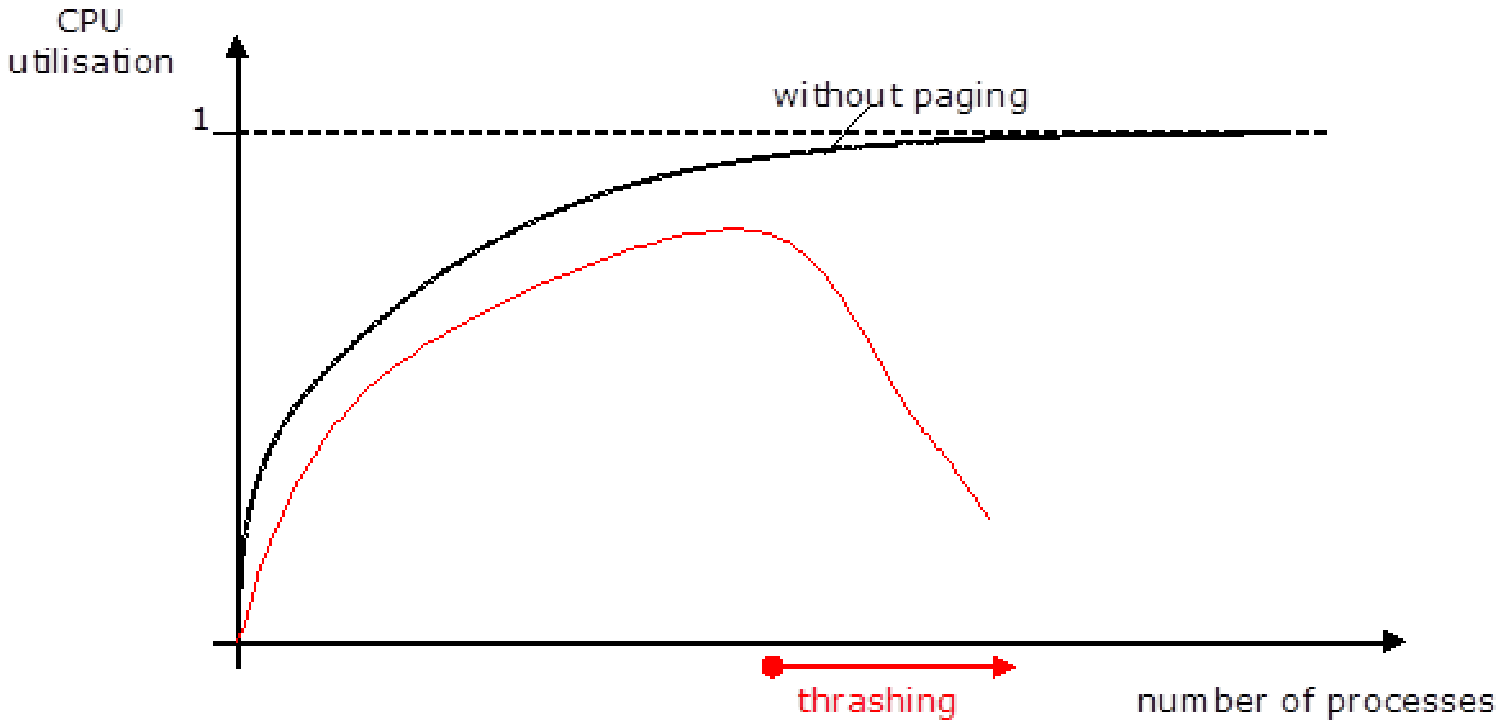
Page fault



Thrashing

Thrashing happens if processes with swapped pages are concurrently be activated and the OS needs swap in and swap out very often.



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Summary and outlook

Summary

- Caching
- Partitioning
- Fragmentation
- Allocation strategies
- Swapping
- Virtual memory

Outlook

- Shared libraries
- User management
- File systems