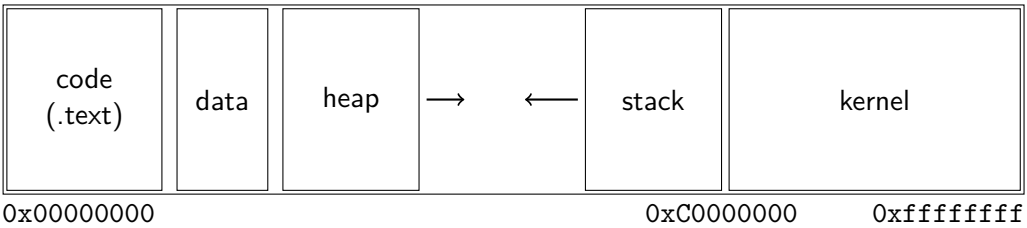
Virtual memory - Paging

Johan Montelius

KTH

2021

The process



Memory layout for a 32-bit Linux process

Segments - a could be solution

Processes in virtual space

Address translation by MMU
(base and bounds)

Physical memory

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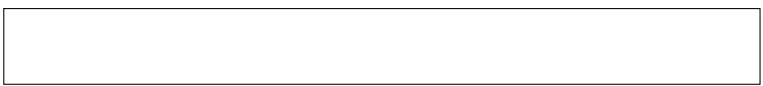

Physical memory

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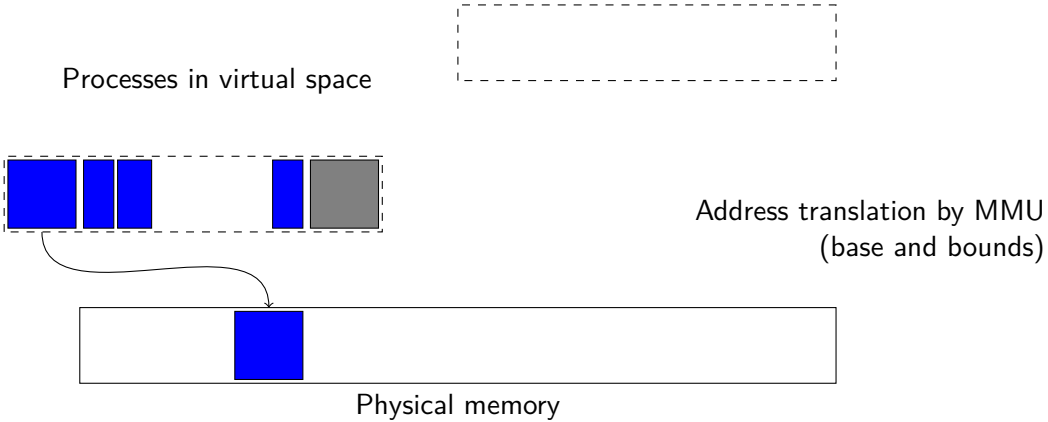

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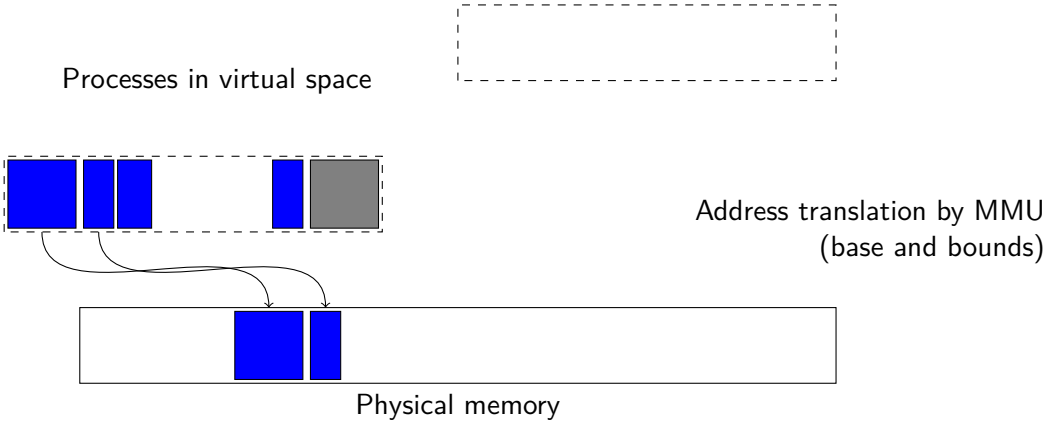

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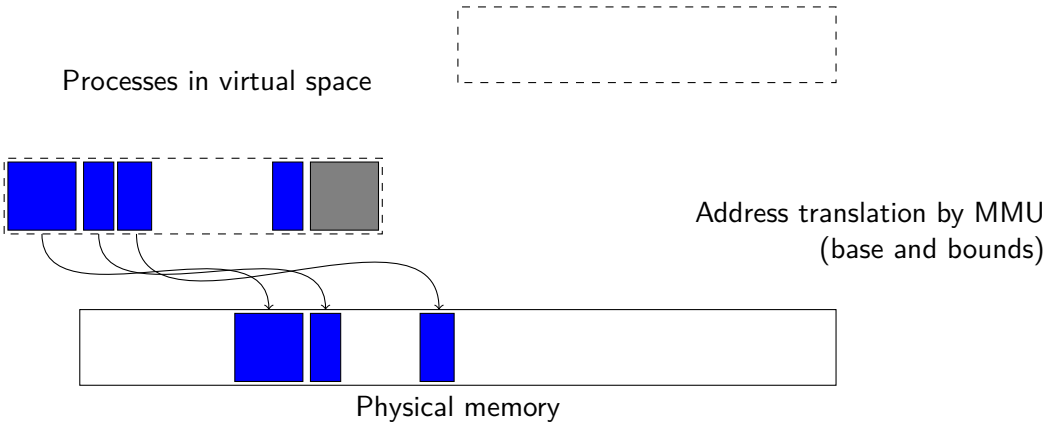

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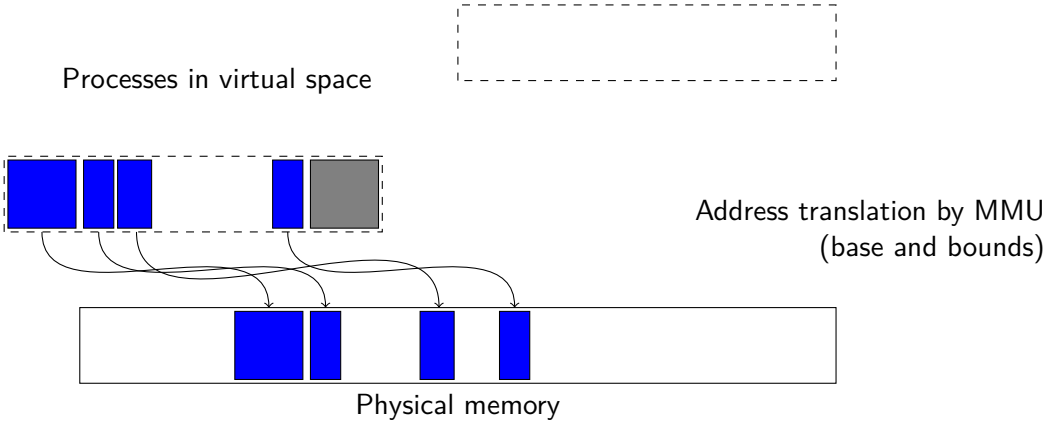

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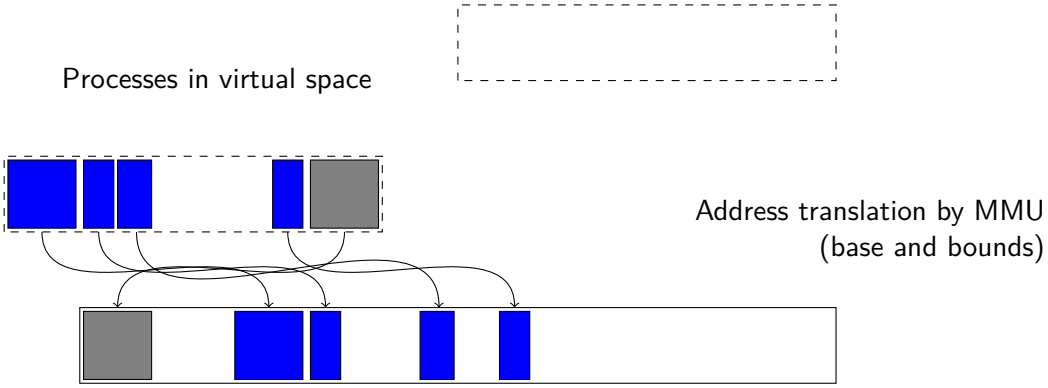

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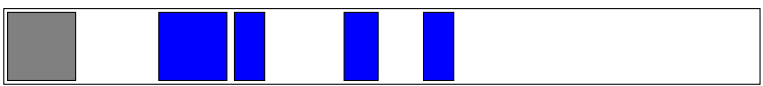

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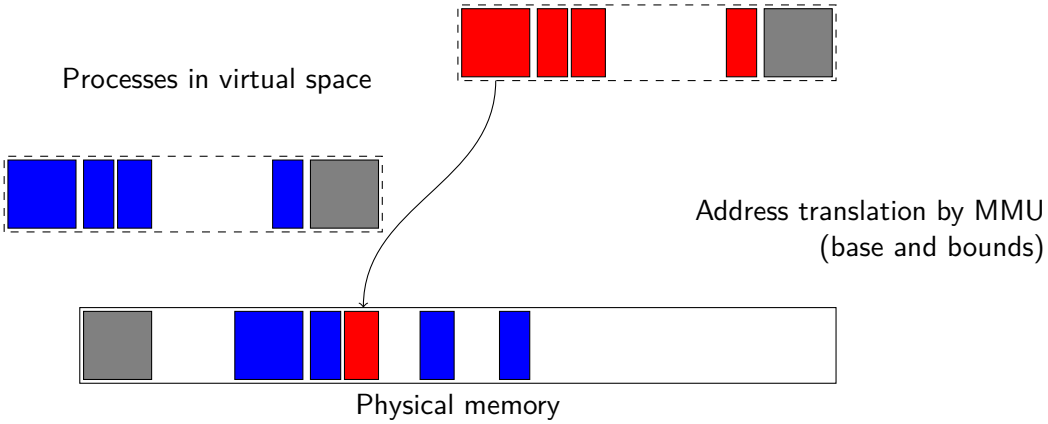

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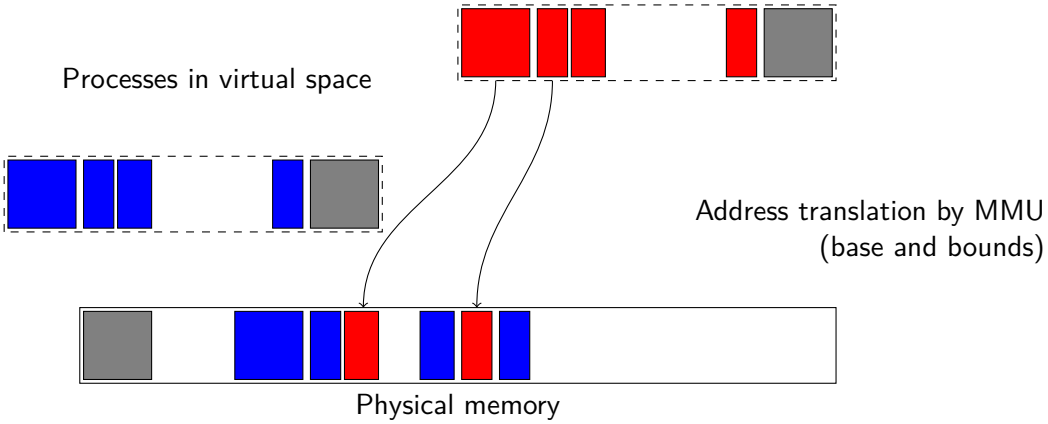

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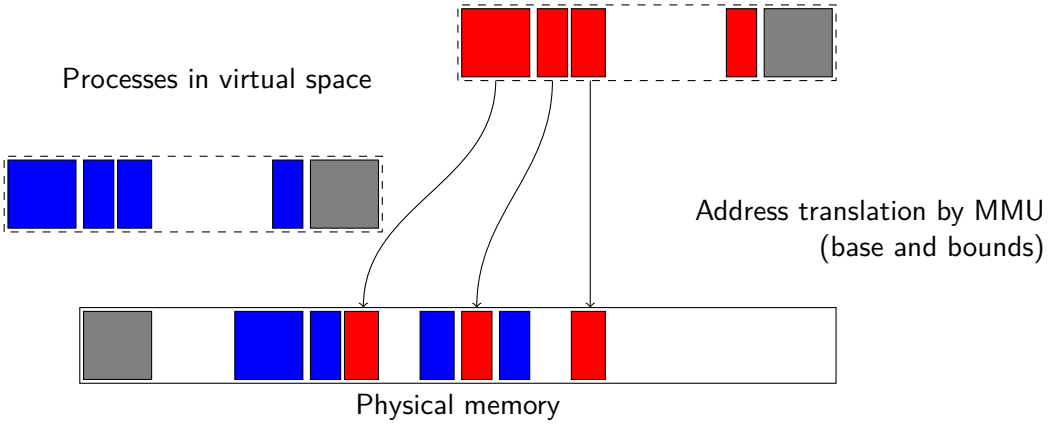

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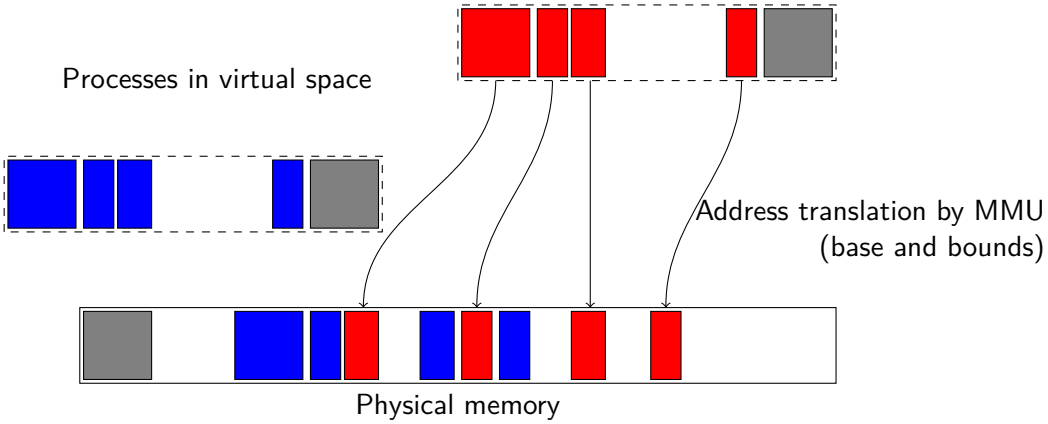

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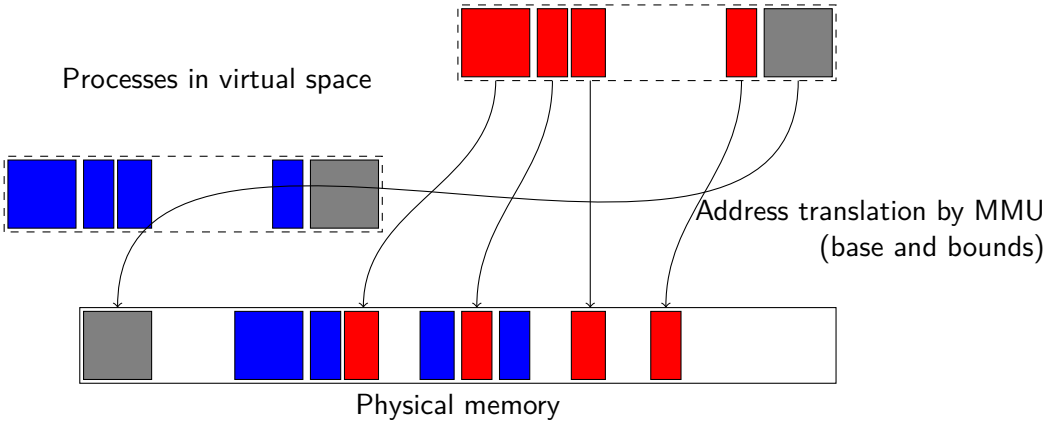
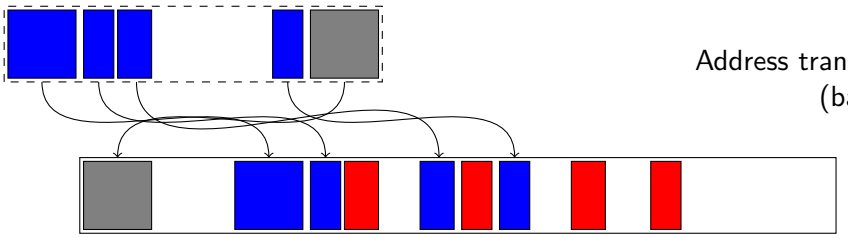


Segments - a could be solution

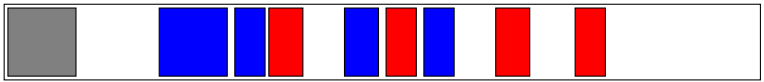
Processes in virtual space



Address translation by MMU
(base and bounds)

Physical memory

one problem



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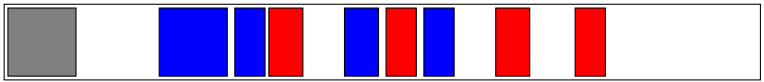

Physical memory

External fragmentation: free areas of free space that is hard to utilize.

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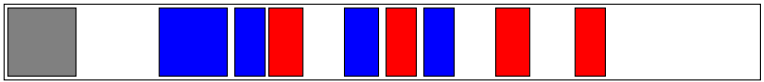

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Solution: allocate larger segments ...

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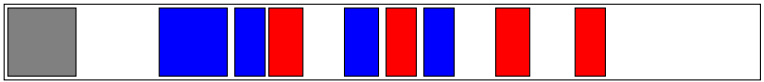
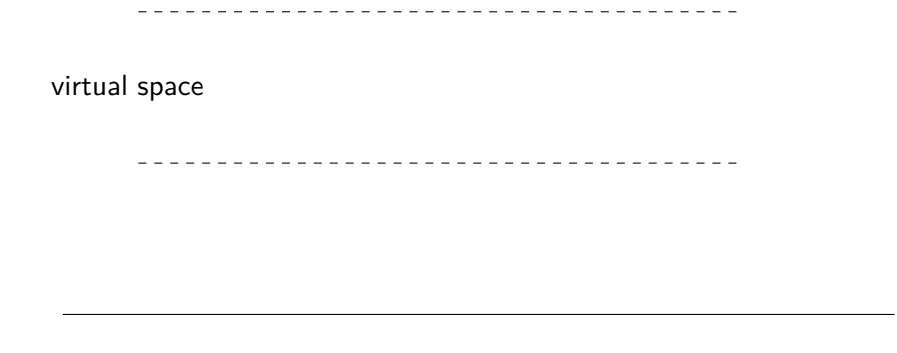


Physical memory

External fragmentation: free areas of free space that is hard to utilize.

Solution: allocate larger segments ... internal fragmentation.

another problem



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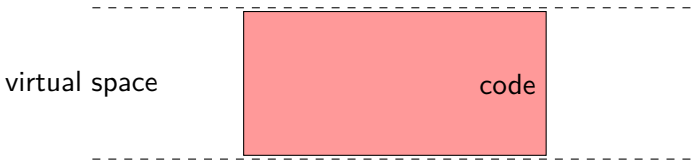
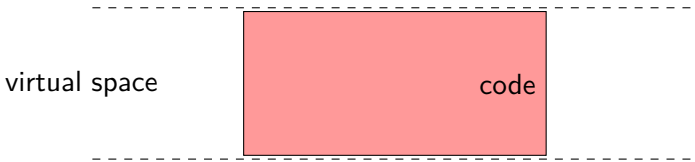


physical memory

another problem



physical memory

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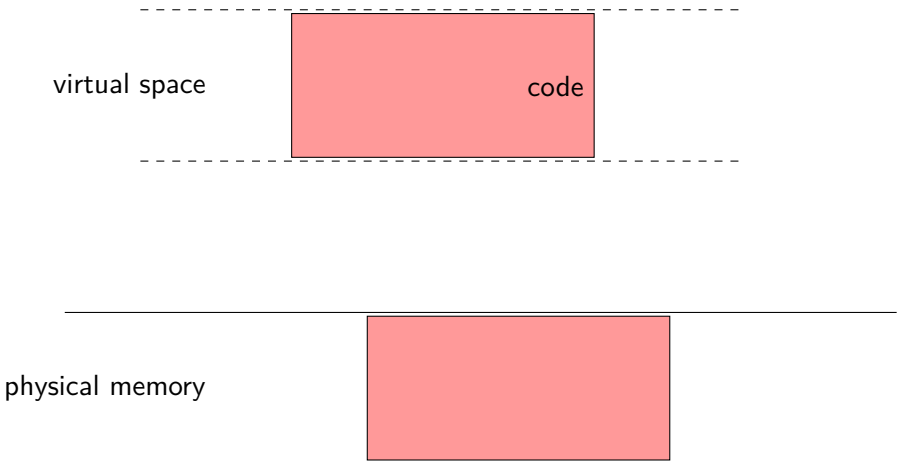

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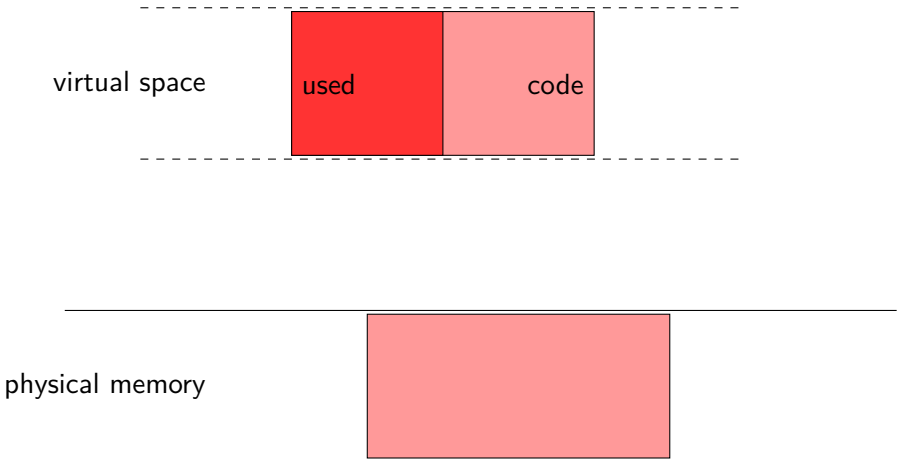

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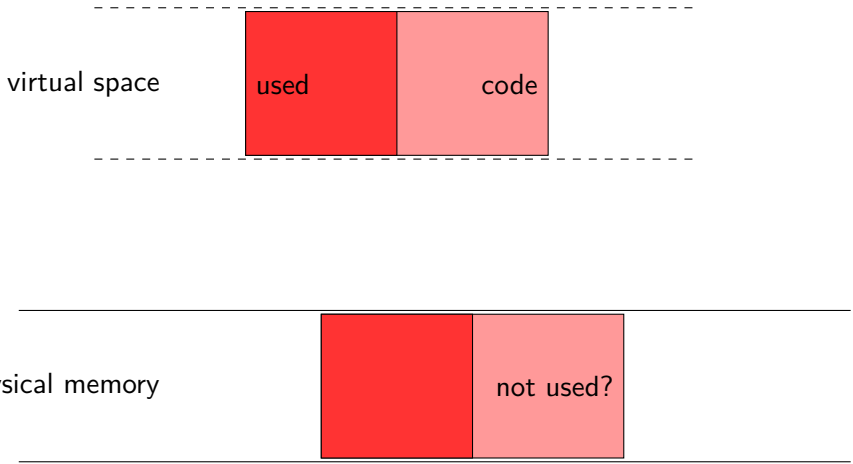

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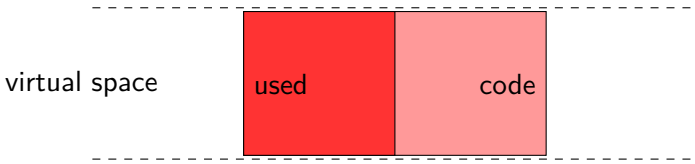
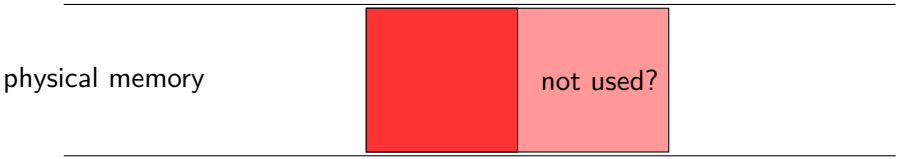


We're reserving physical memory that is not used.



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It's easier to handle fixed size memory blocks.

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Can we map a process virtual space to a set of equal size blocks?

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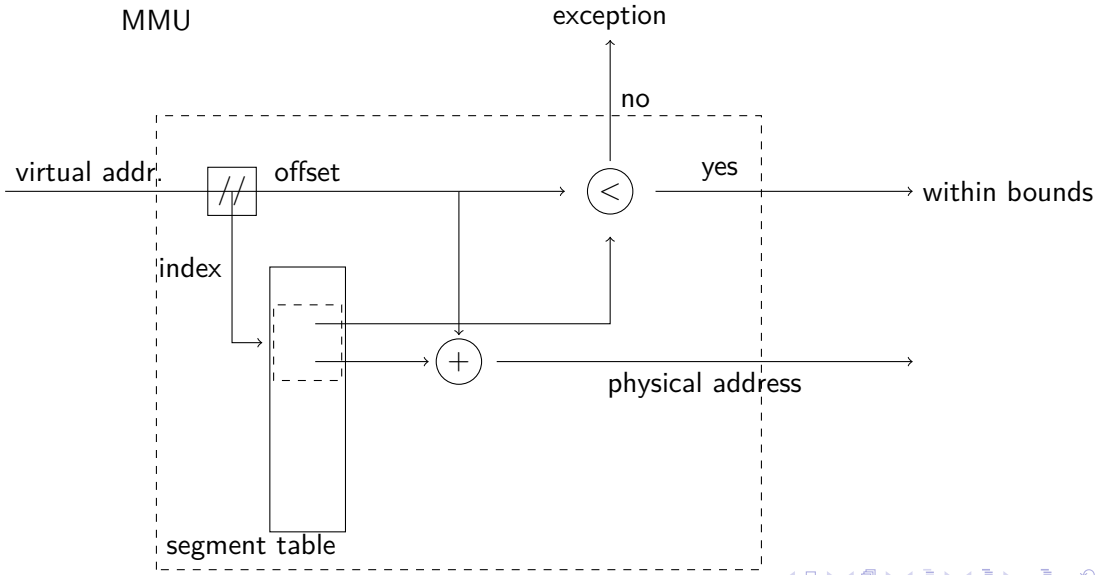
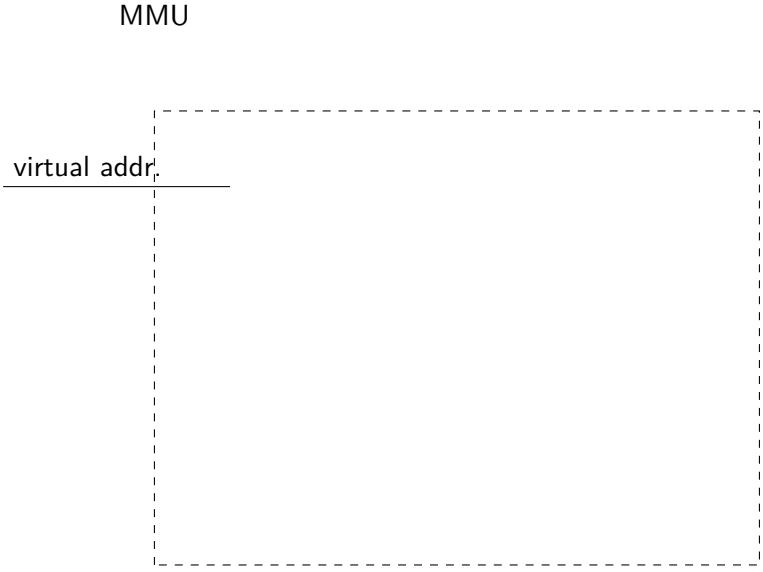
An address is interpreted as a *virtual page number* (VPN) and an *offset*.

Remember the segmented MMU



The paging MMU



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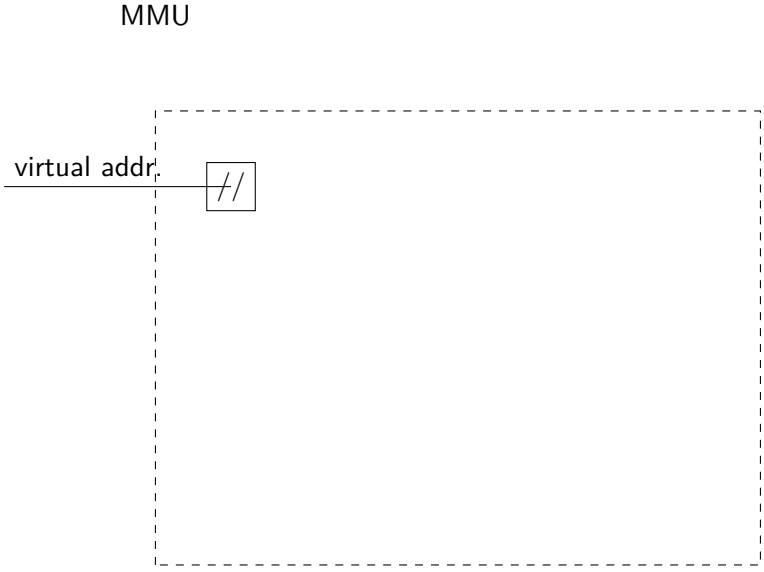

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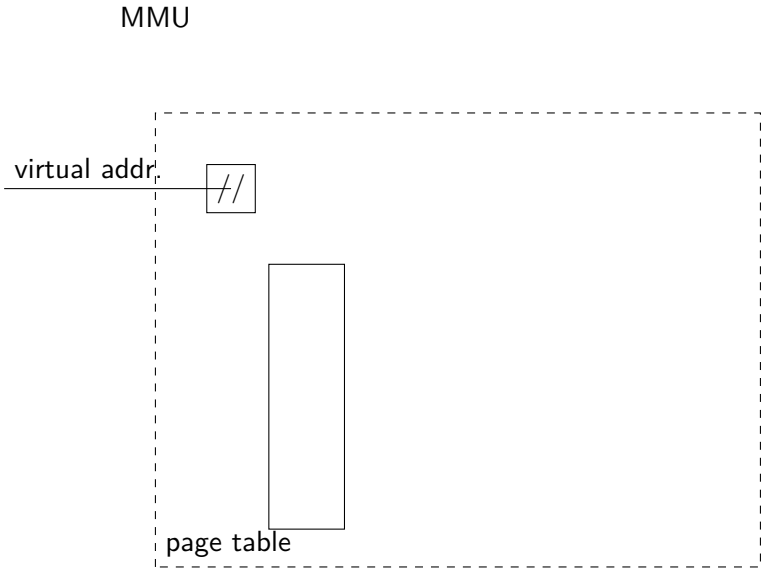

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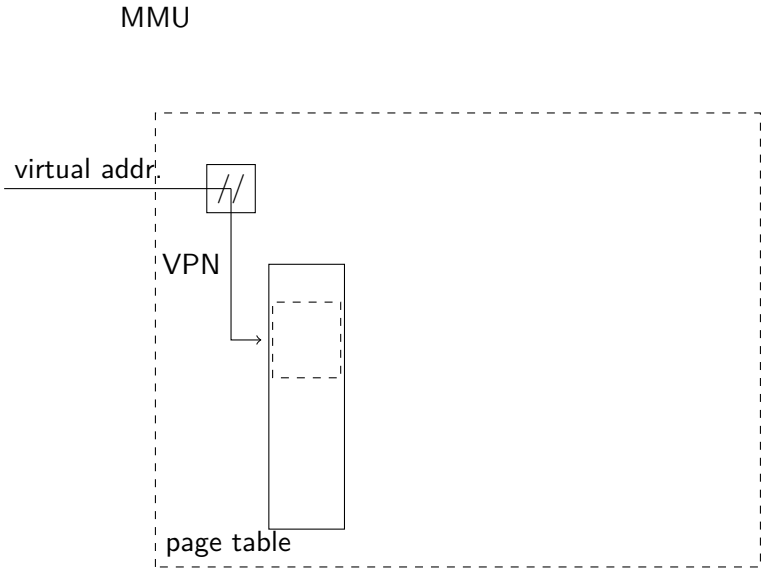

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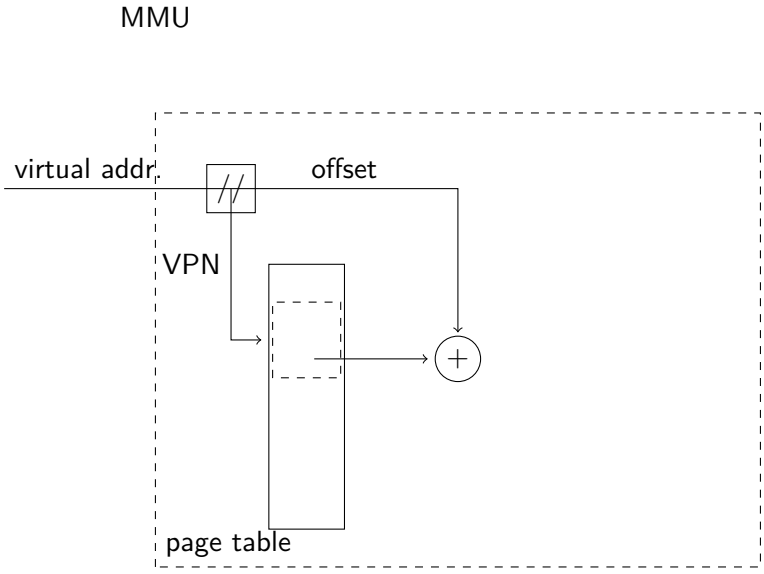

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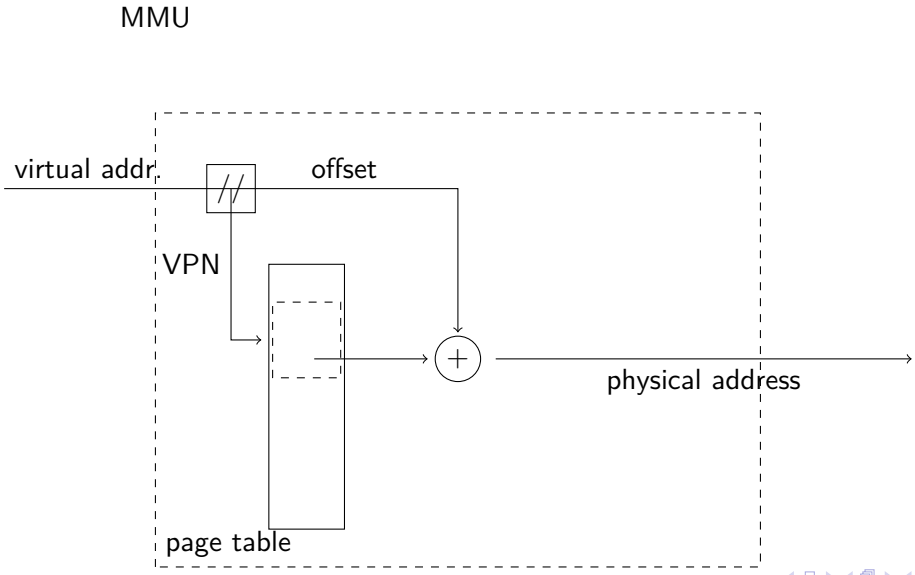

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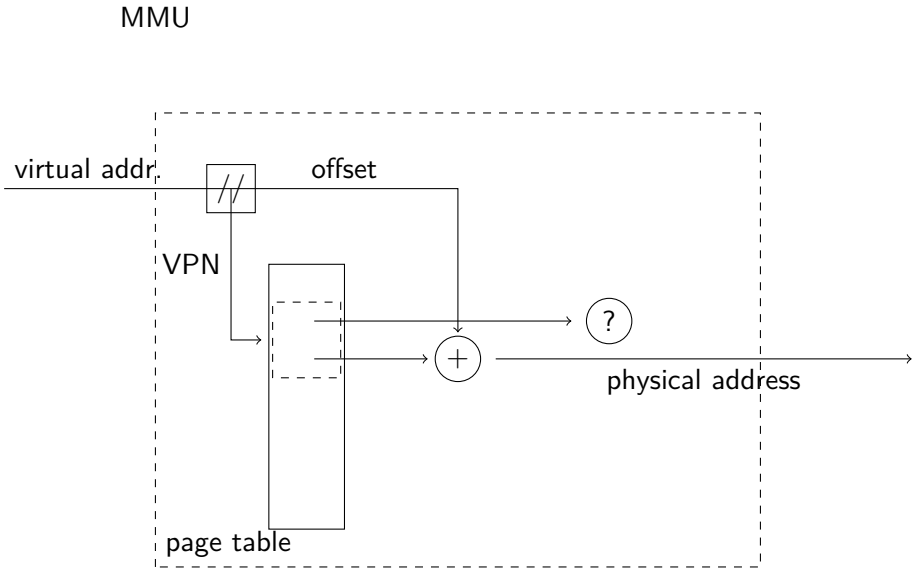

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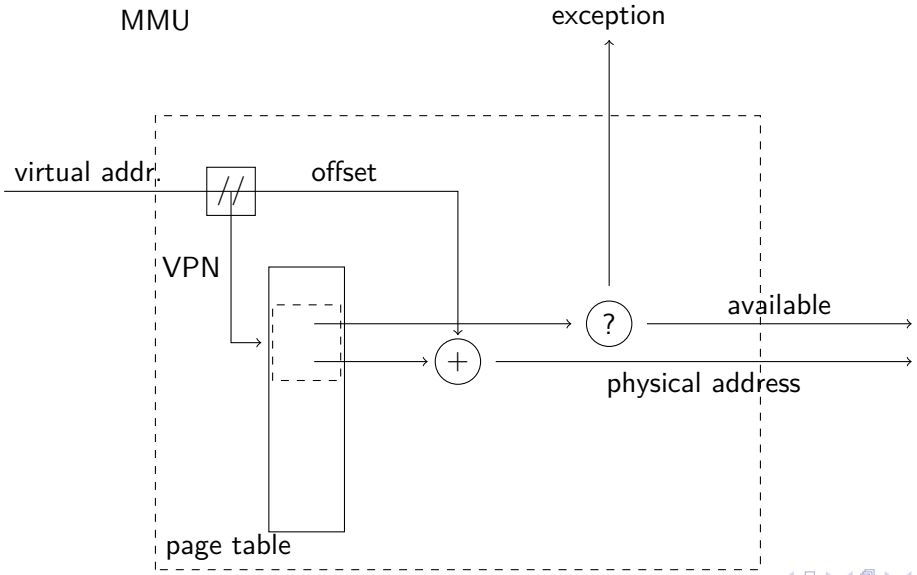

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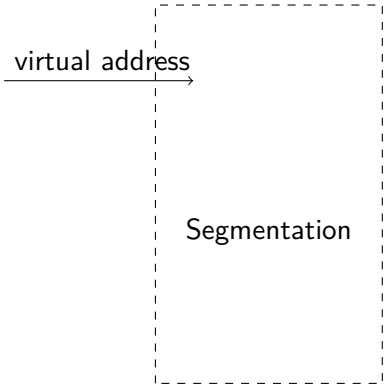

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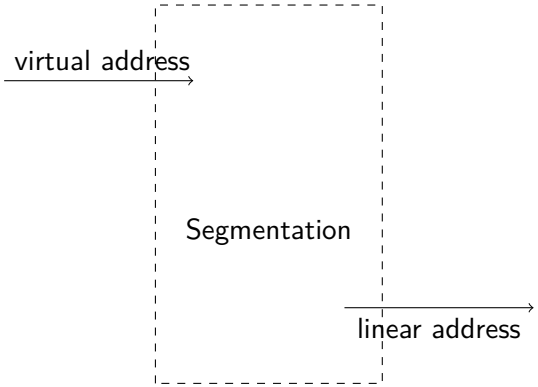

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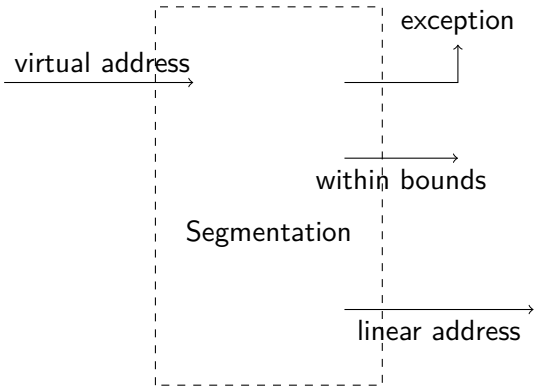
exception
virtual address
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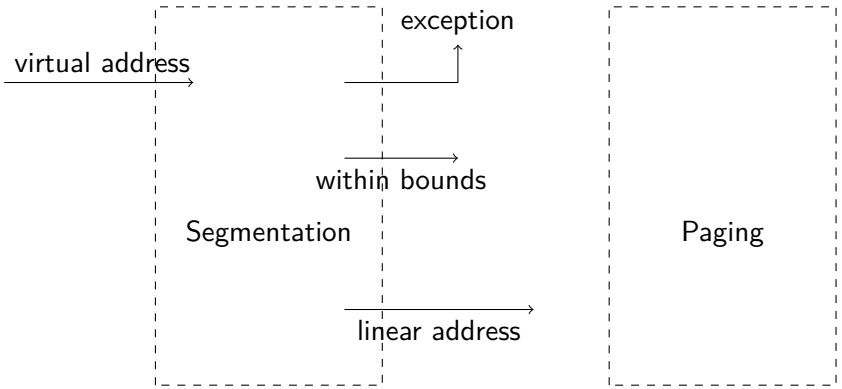
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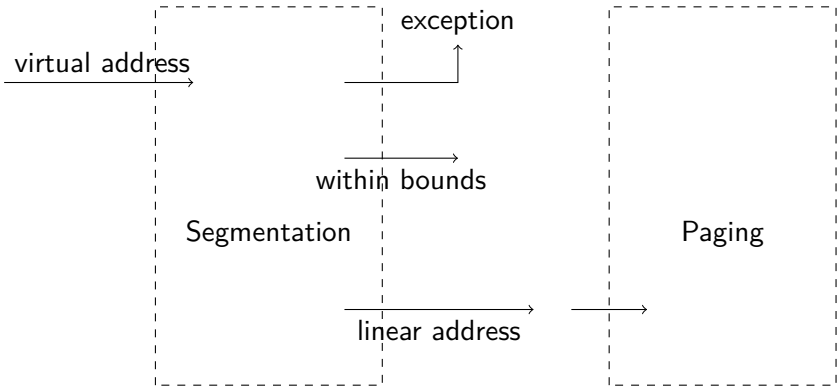
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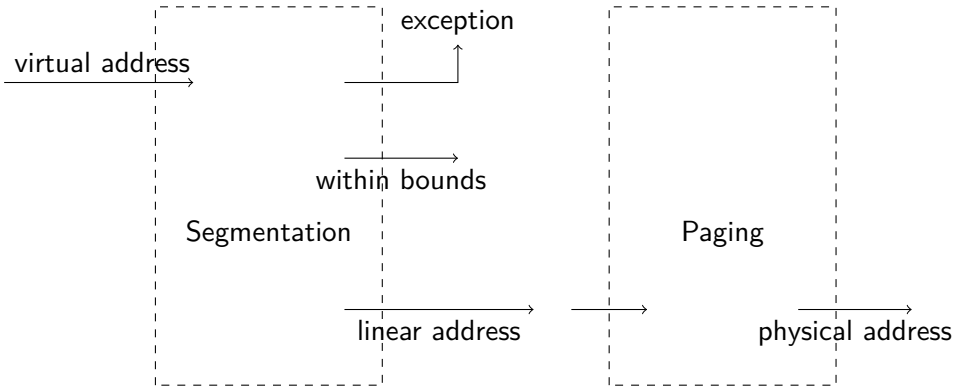
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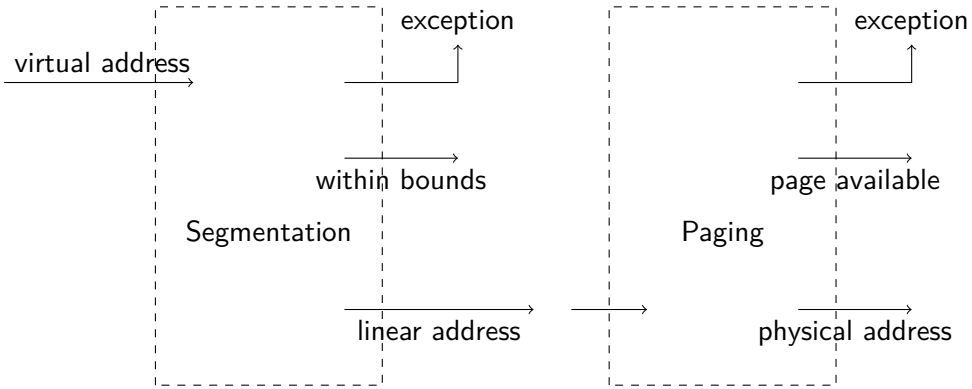
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a note on the x86 architecture

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Still used to manage *thread local storage* and *CPU specific data*.

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Physical memory

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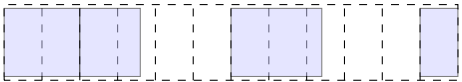

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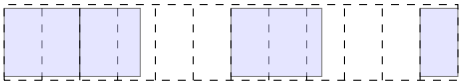

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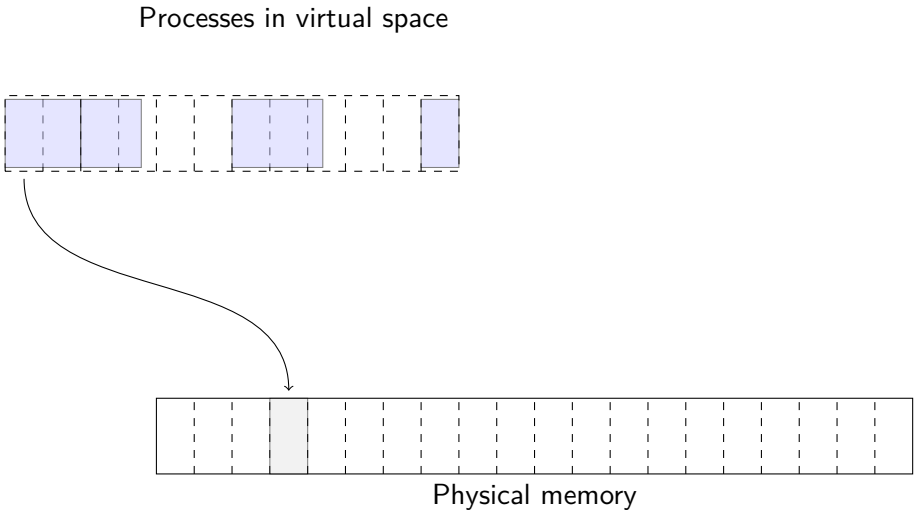
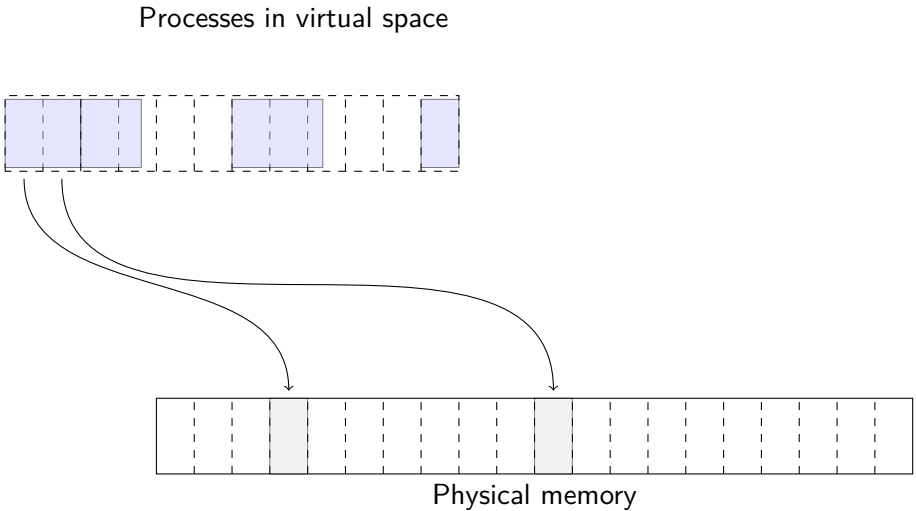

Processes in virtual space
Physical memory

the process



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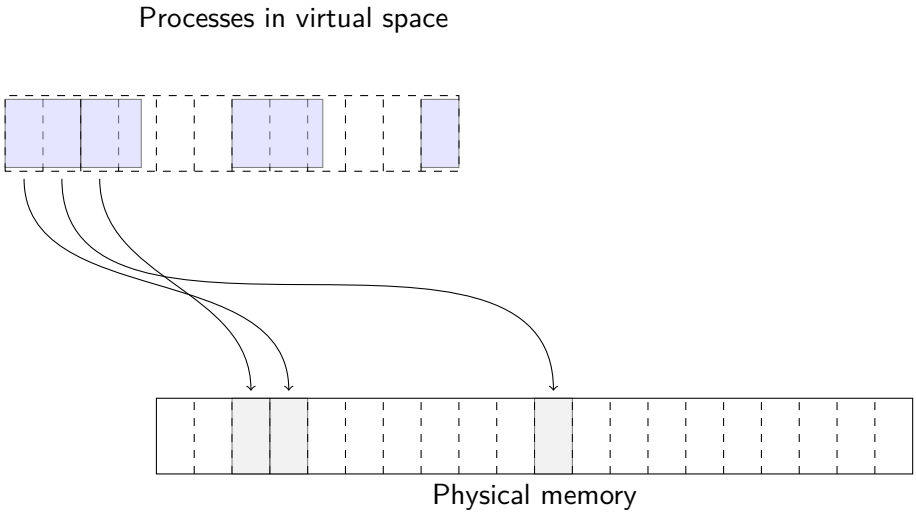

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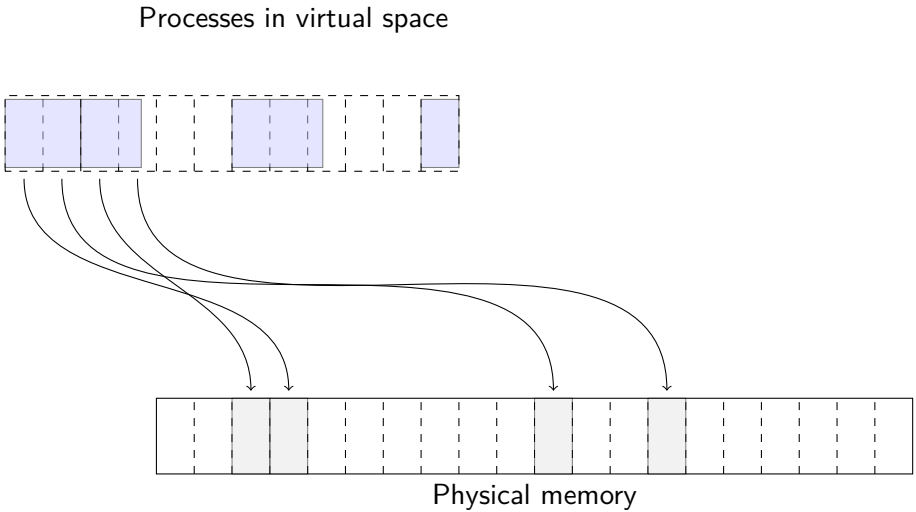

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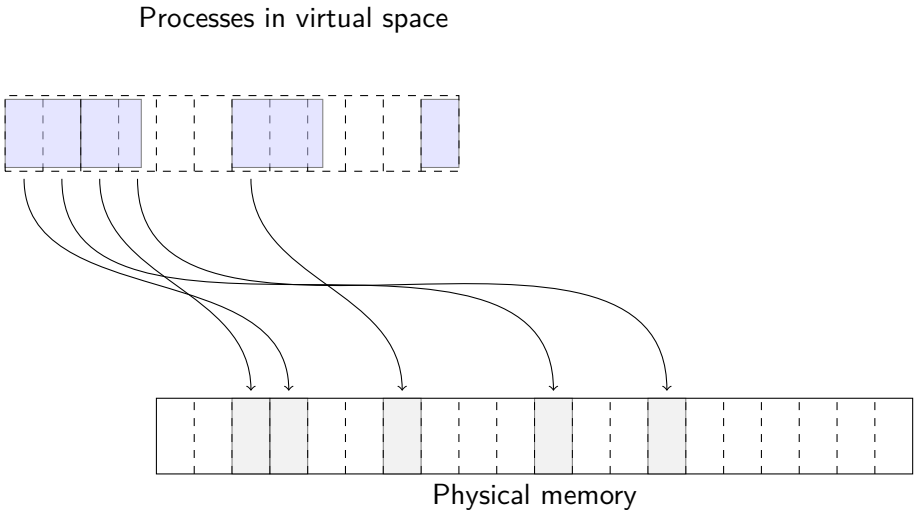

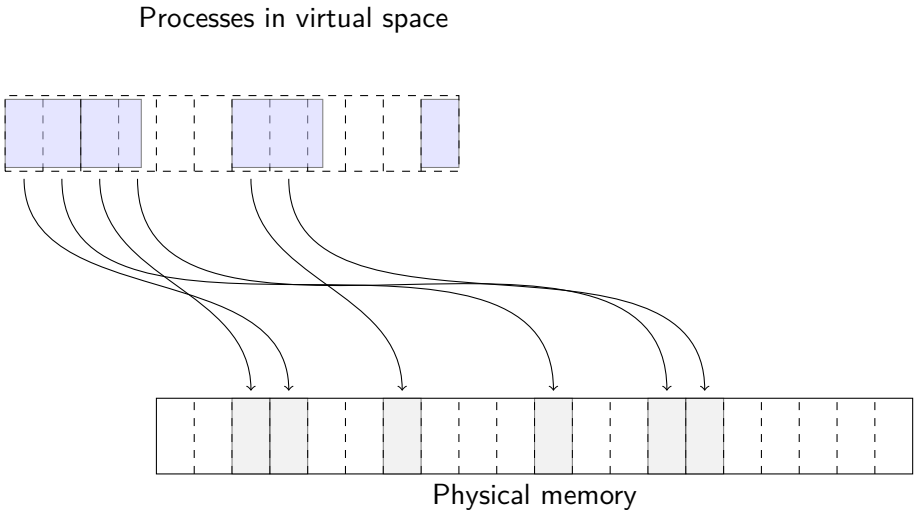
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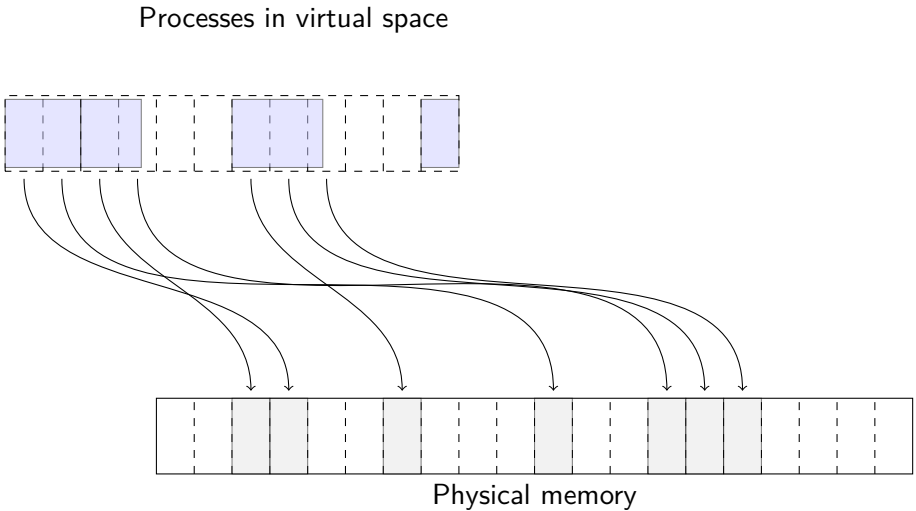
Physical memory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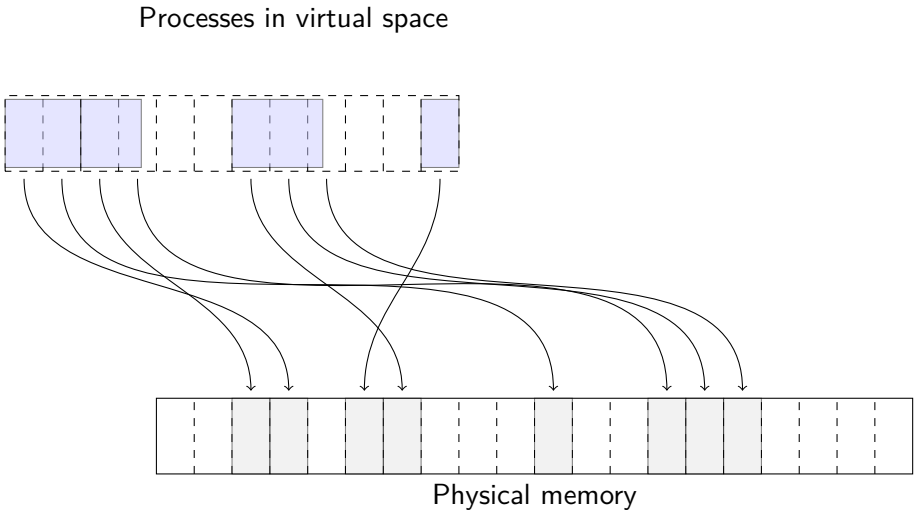
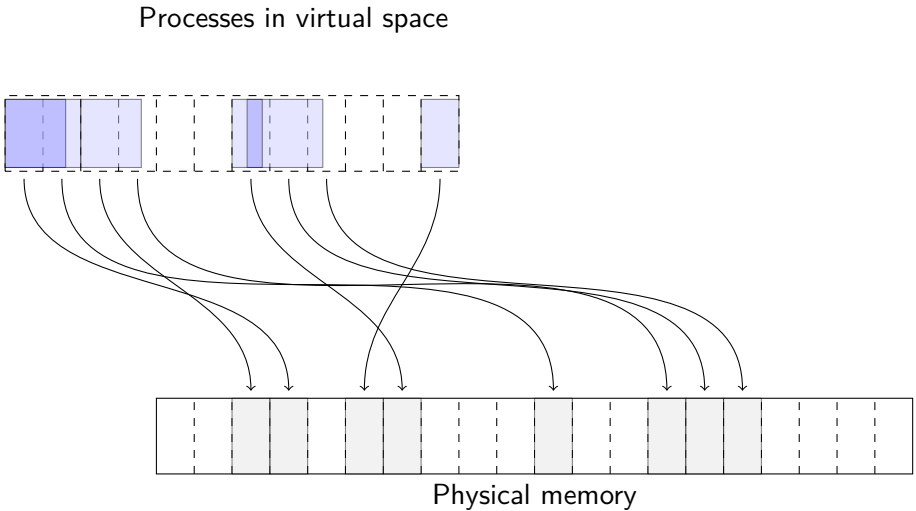

Processes in virtual space
Physical memory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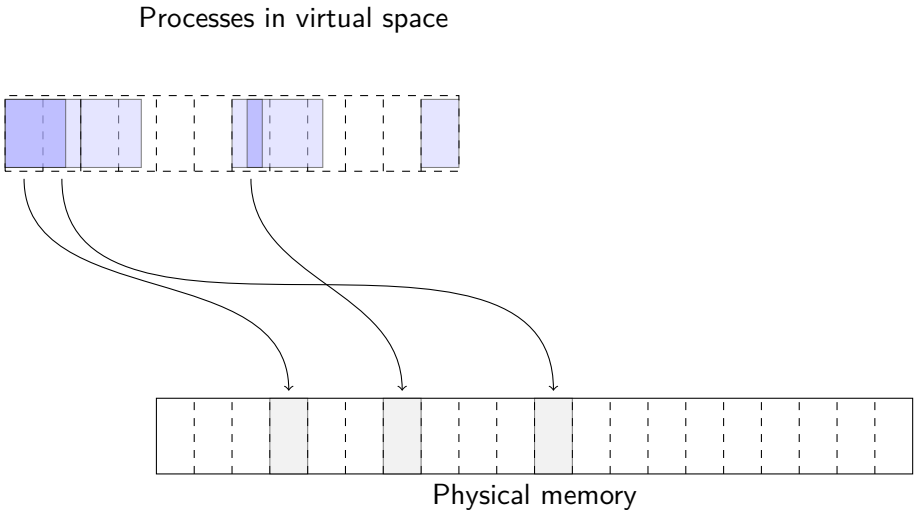
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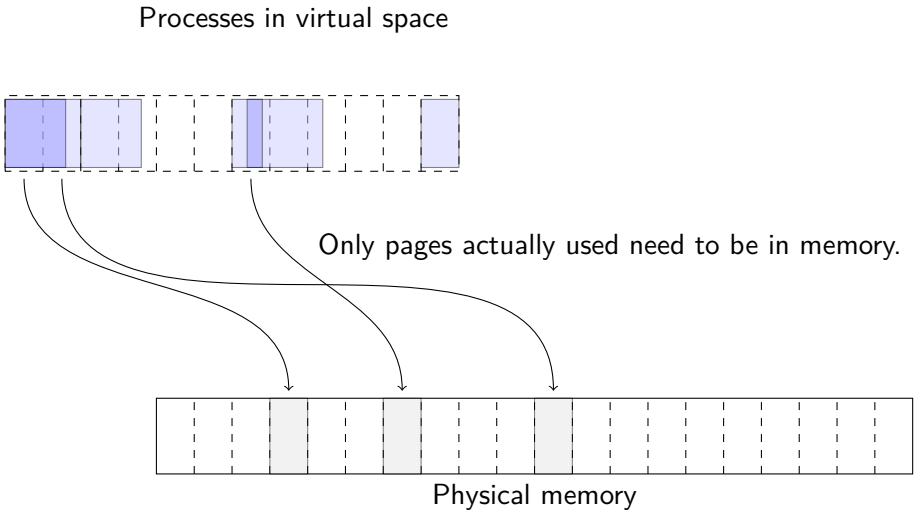
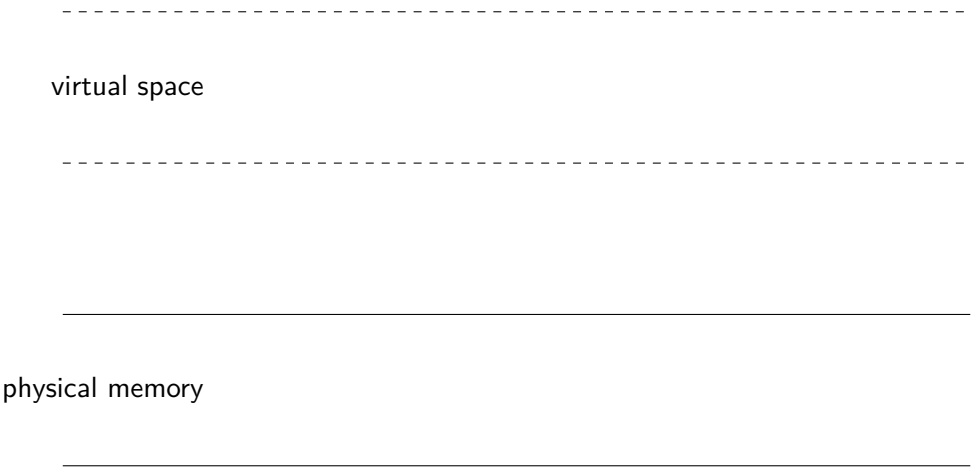

Processes in virtual space
Only pages actually used need to be in memory.
Physical memory

three pages



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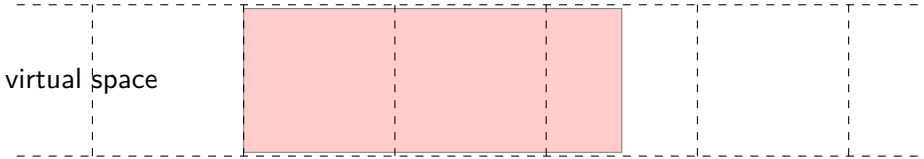

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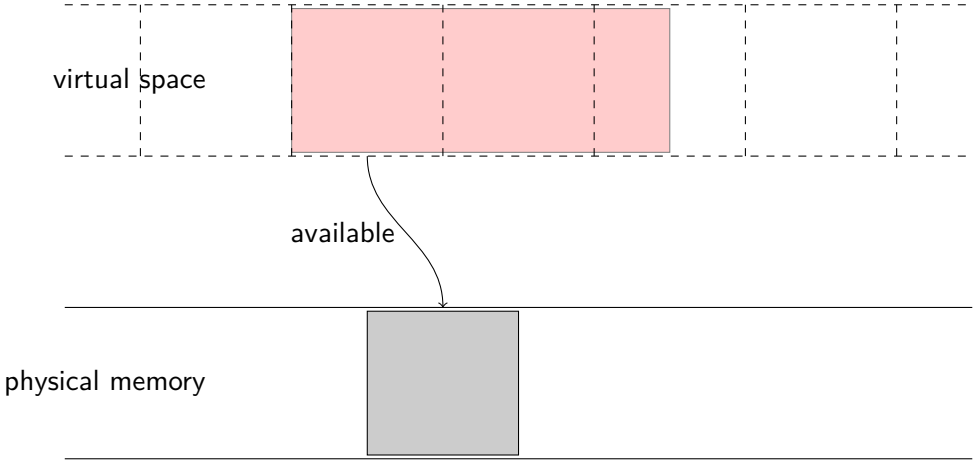

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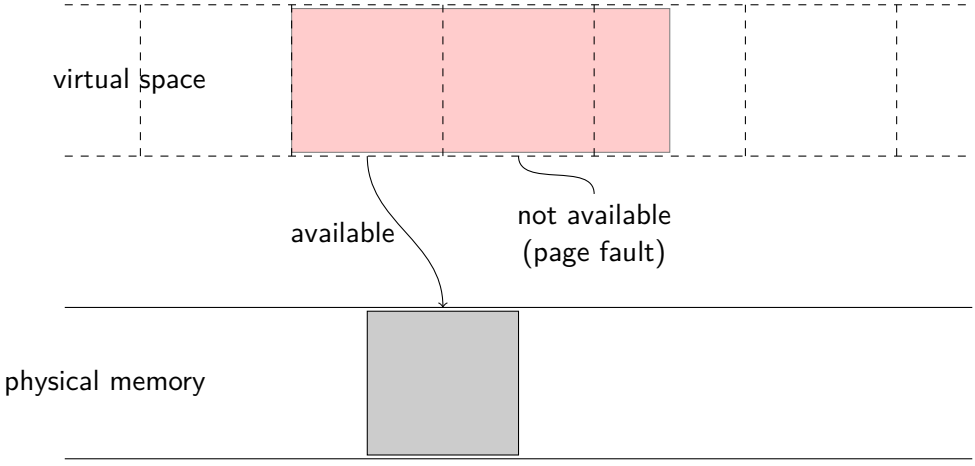
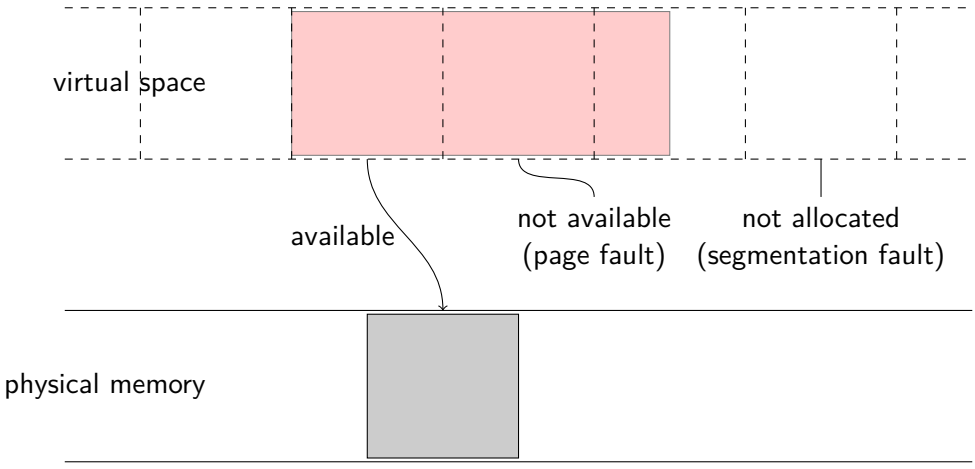
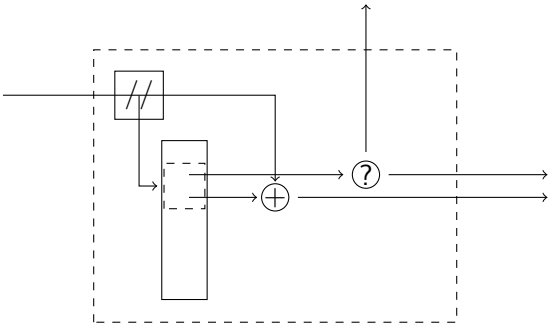

virtual space
available
not available
(page fault)
physical memory

three pages


virtual space
available
not available
(page fault)
not allocated
(segmentation fault)
physical memory

The pagetable

The MMU page module



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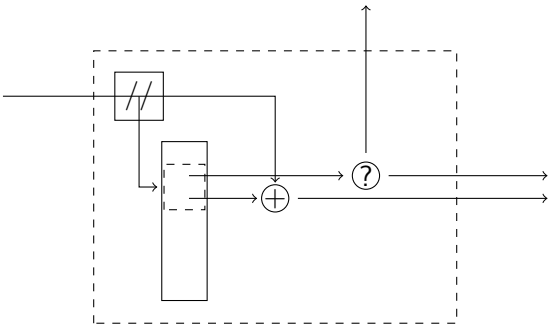

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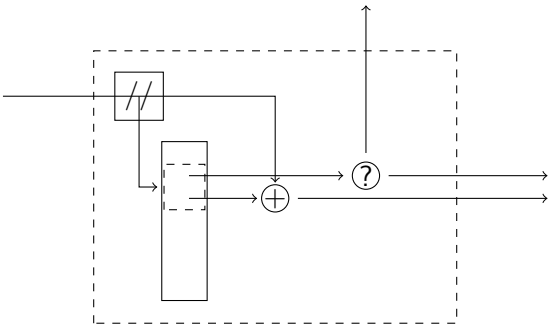

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Note: the page table is to large to fit into the MMU hardware, it is in main memory.

The page table entry

example Linux on (32bit) x86

31

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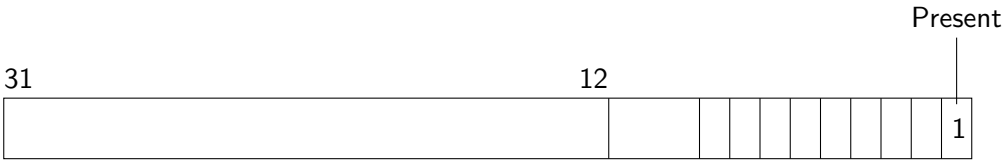

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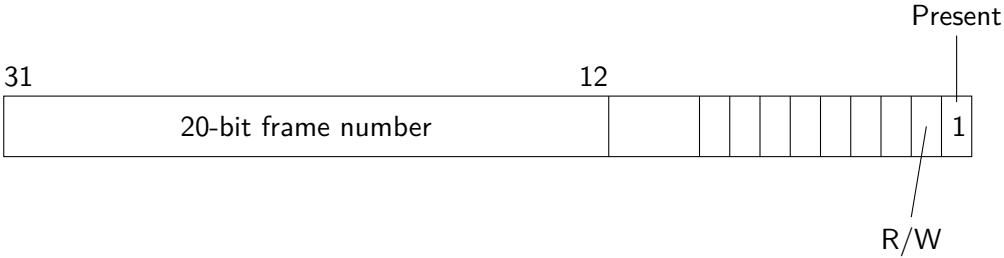

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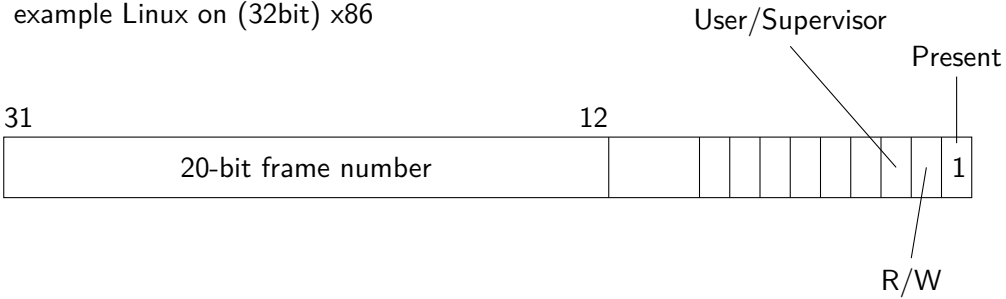

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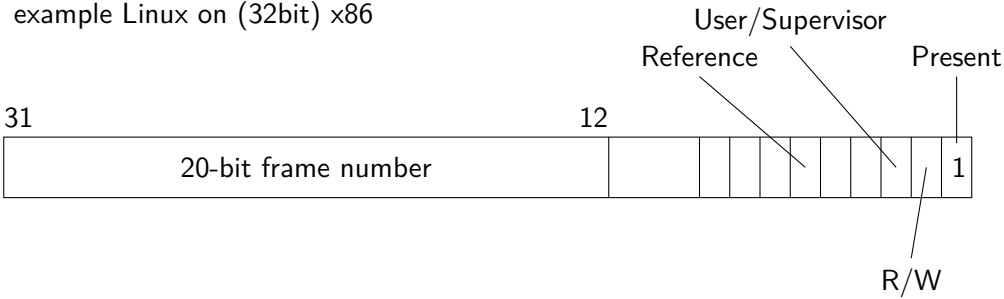

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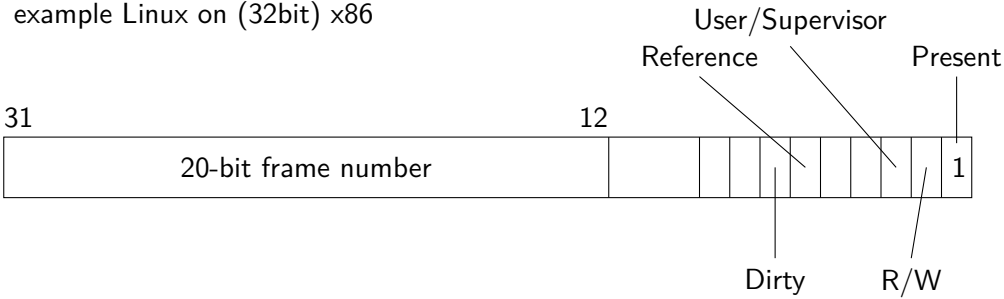

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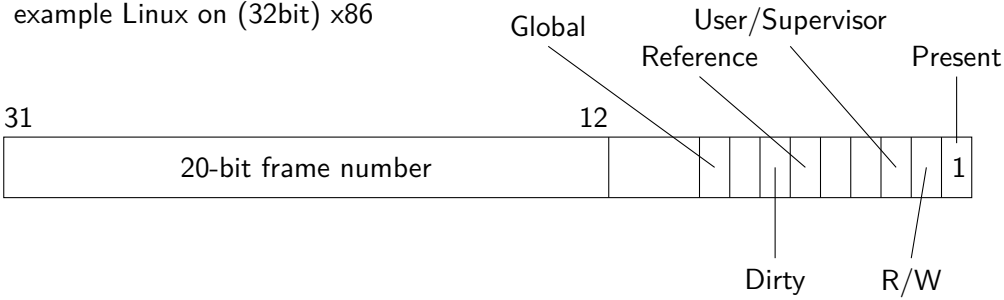

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Physical memory is in reality limited by chipset, motherboard, memory modules etc. Check your available memory in `/proc/meminfo`.

largest server

Largest server on the market, SGI 3000, can scale up to 256 CPUs and 64 Tibyte of RAM (NUMA) - running Linux.

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An extra memory operation for each memory reference.

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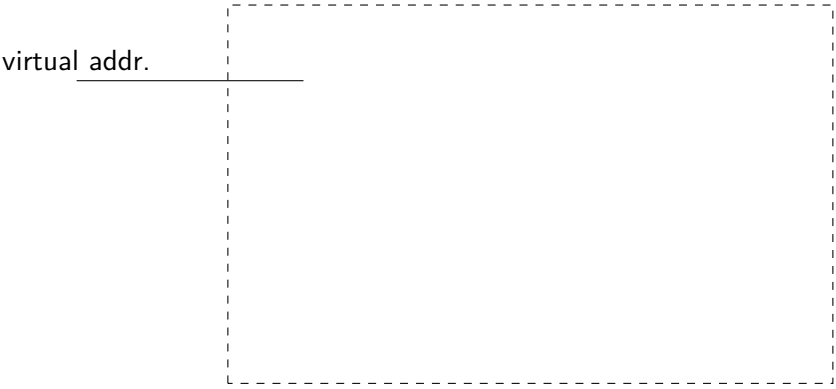

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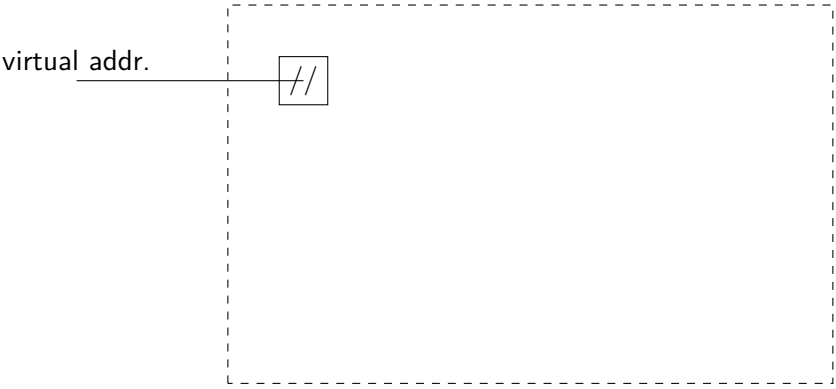

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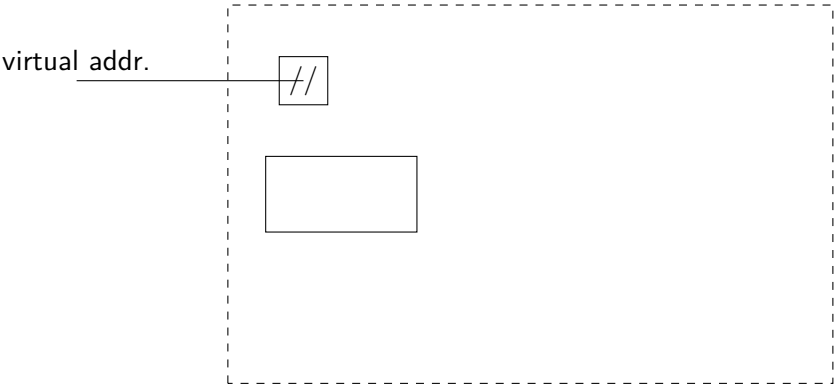

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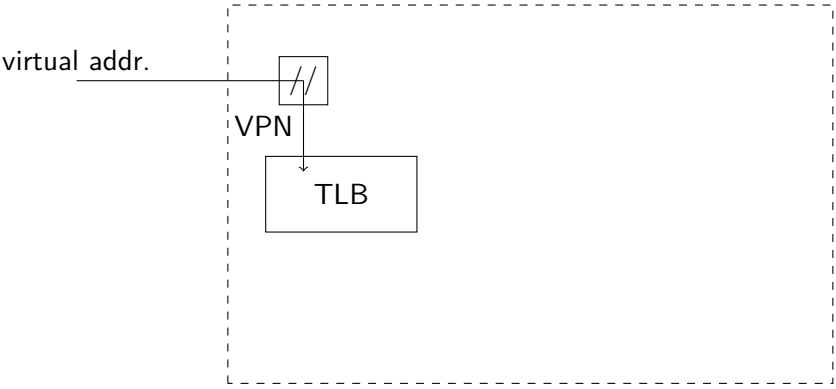

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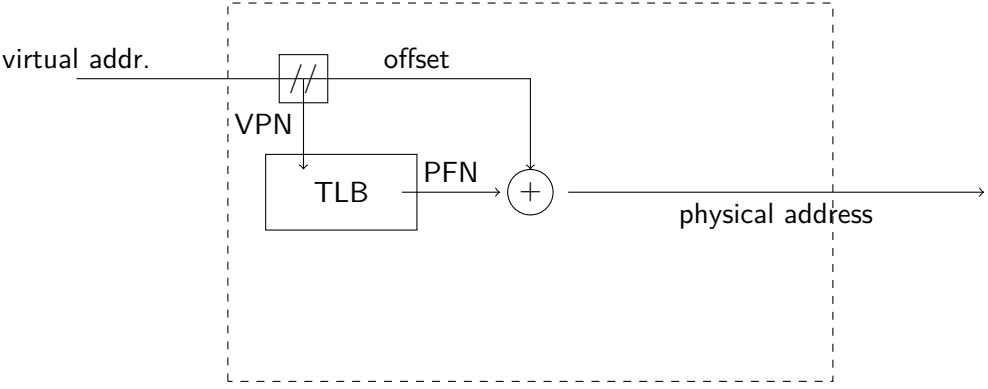

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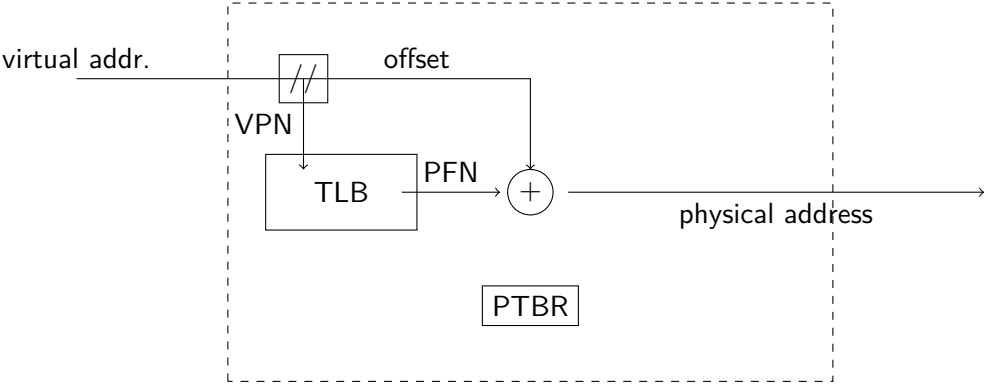

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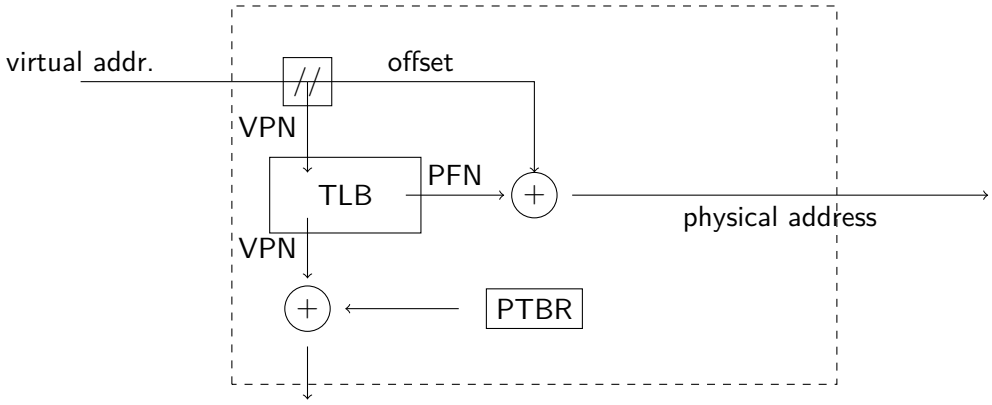

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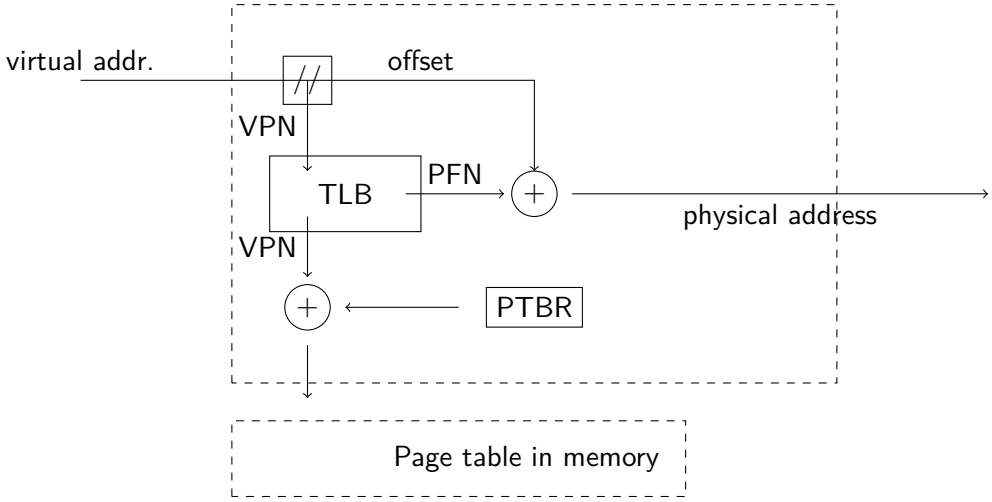

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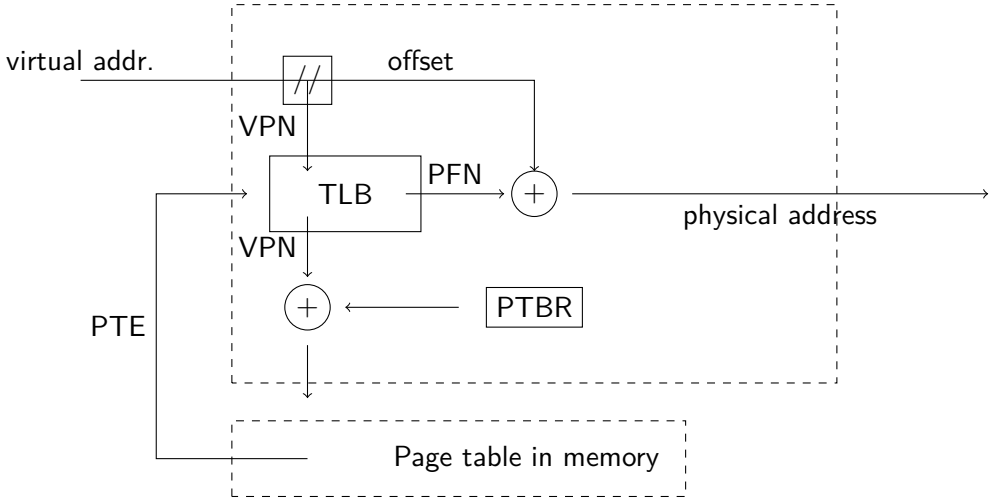

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4 Mibyte pages are used and do have advantages but it is not a general solution.

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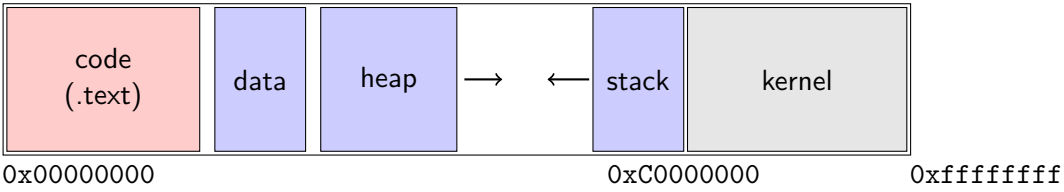

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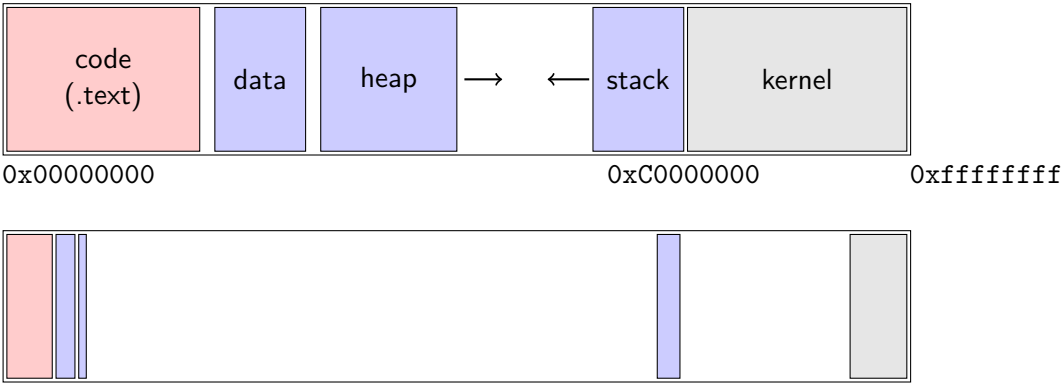

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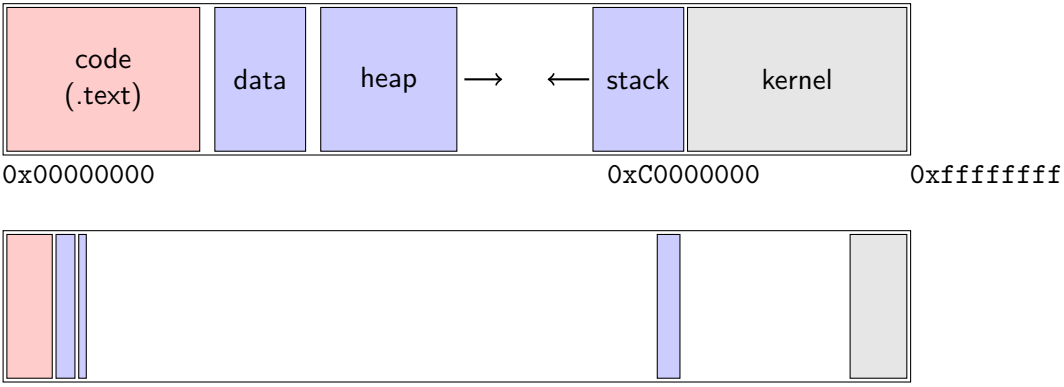

Map only the areas that are actually used.

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What if each segment was rarely larger than 1Ki pages of 4Kibyte.

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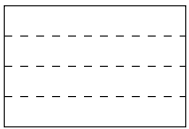

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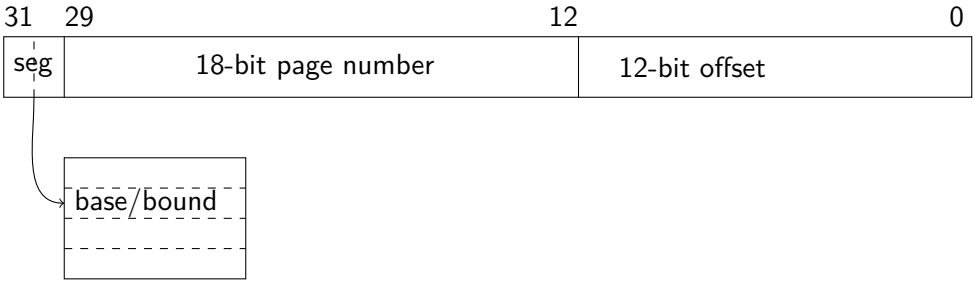

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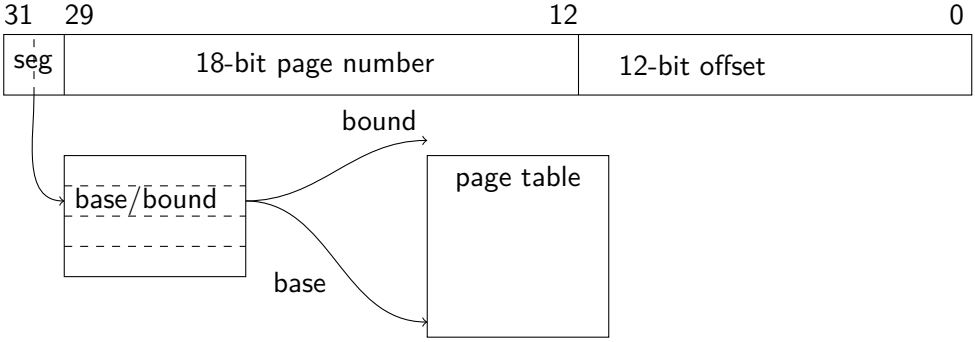

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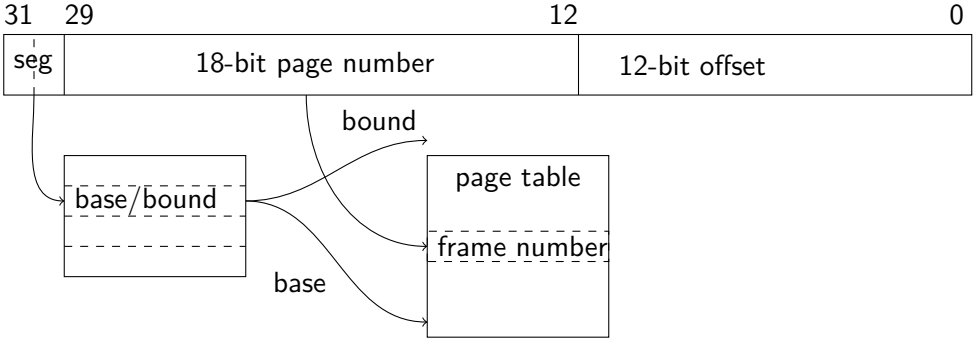

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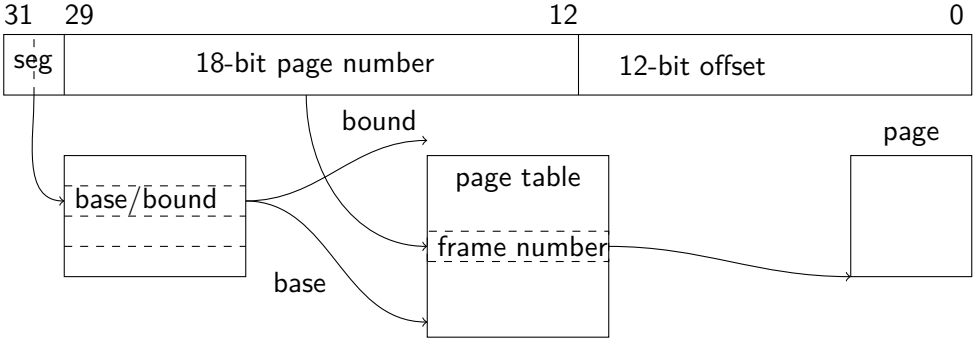

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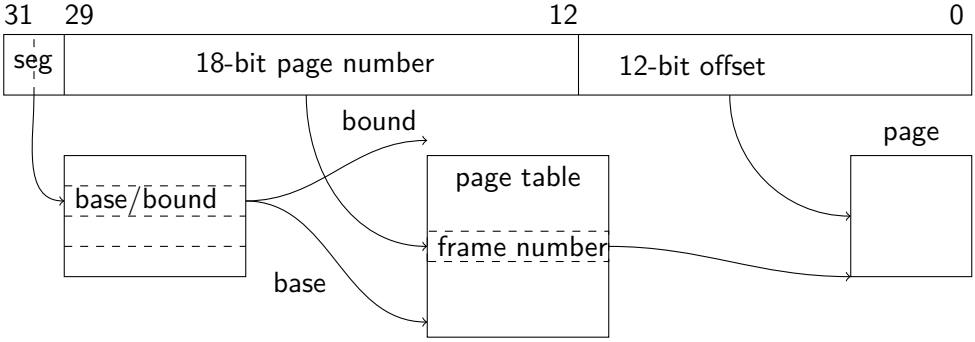
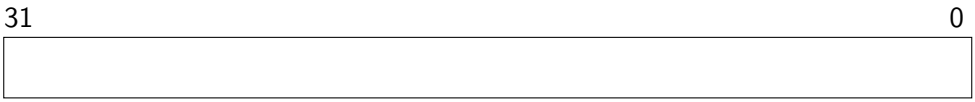


Multi-level page table



Used by Intel 80386

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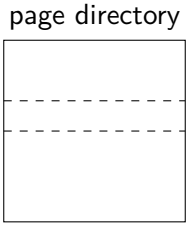

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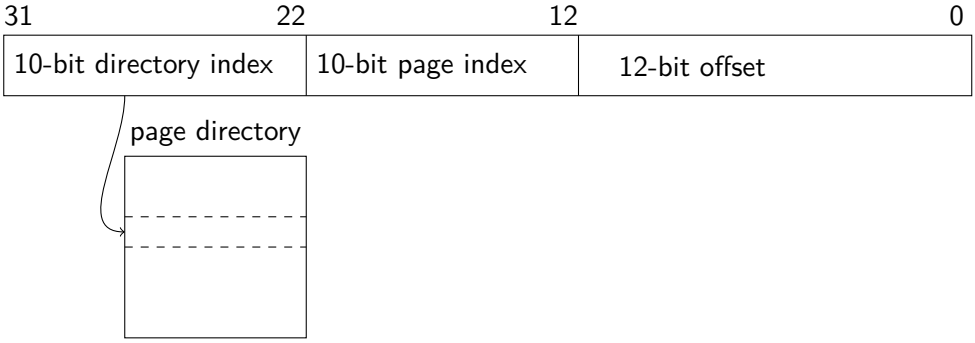

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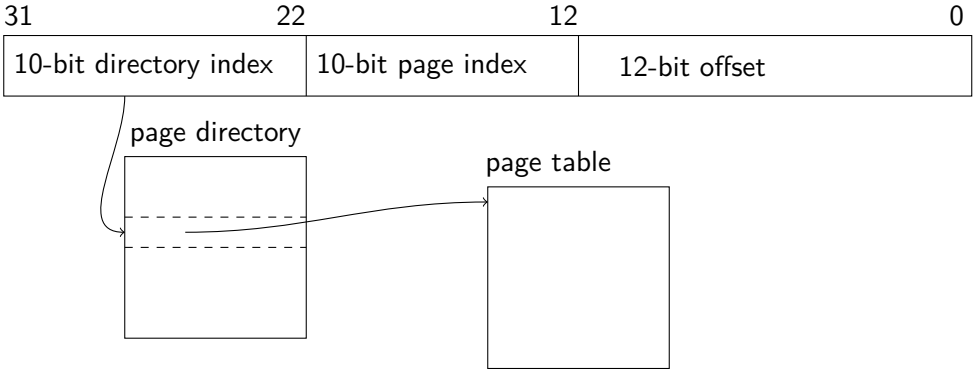

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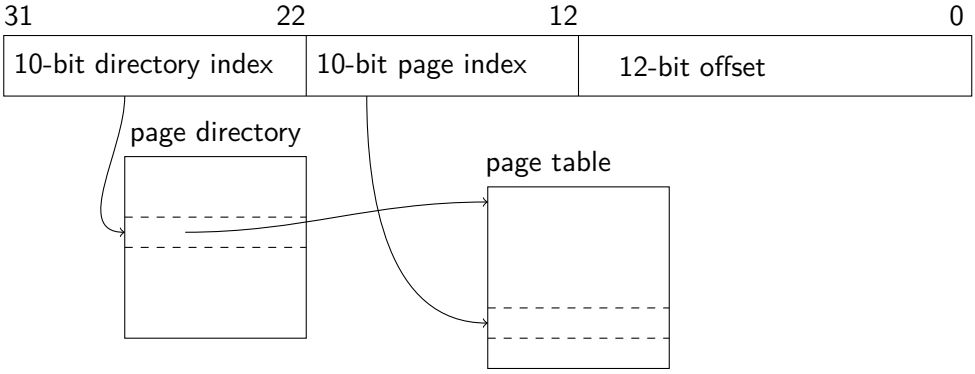

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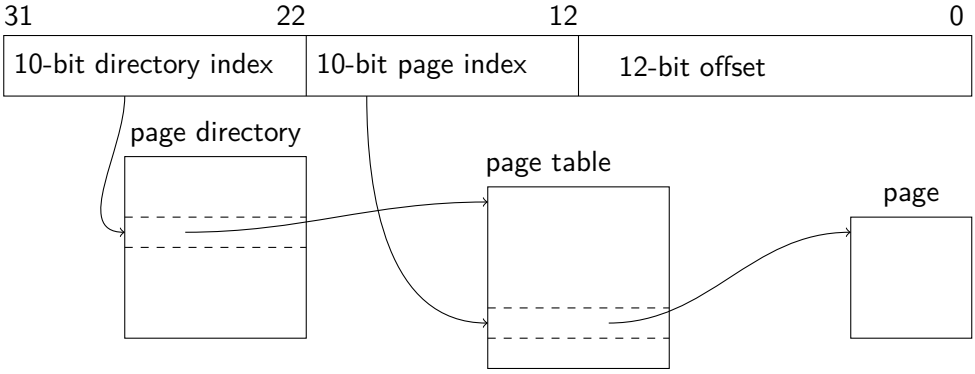

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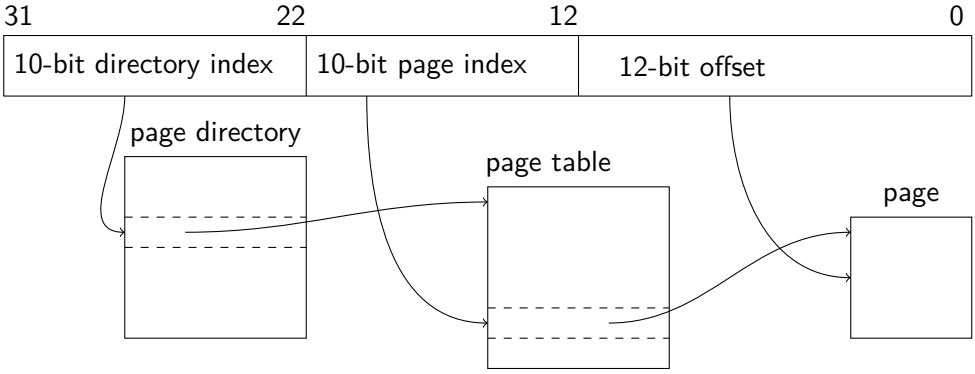

Used by Intel 80386

Mostly empty space

page directory

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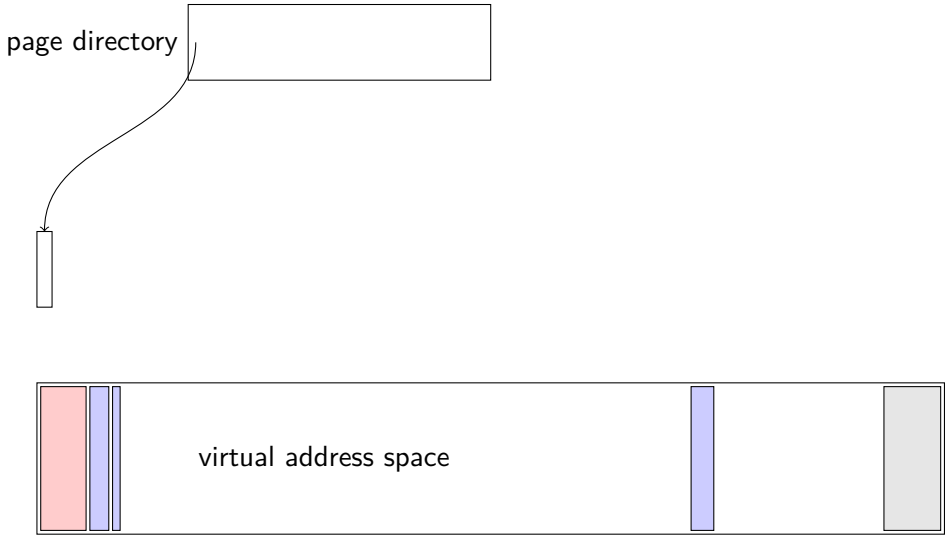

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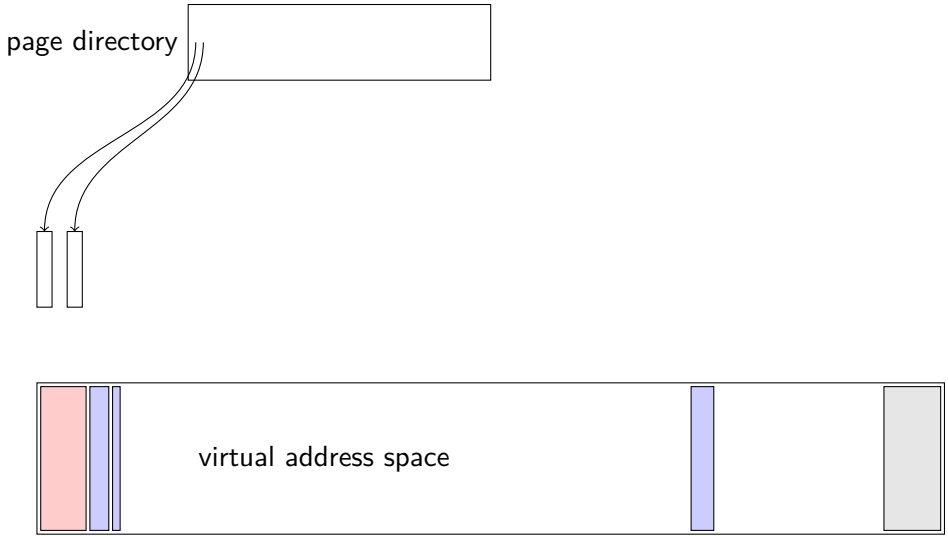

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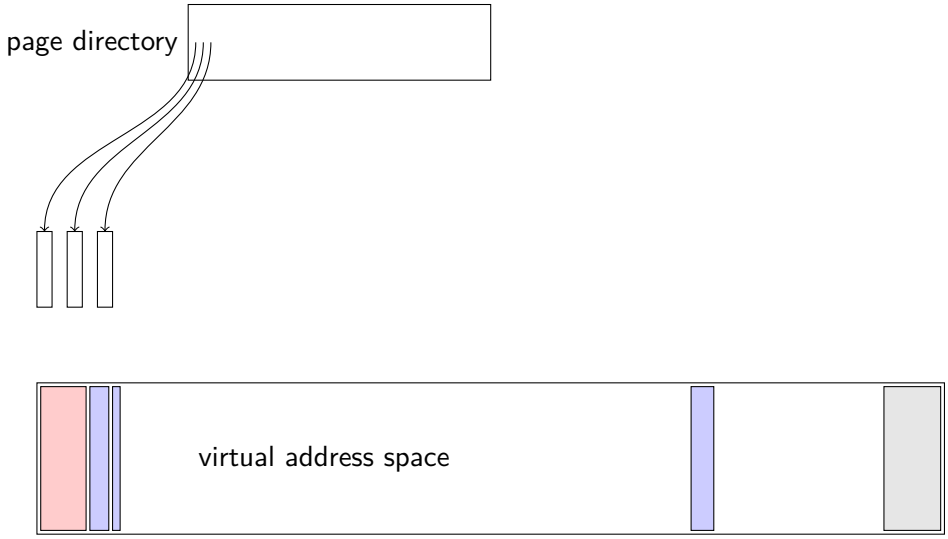

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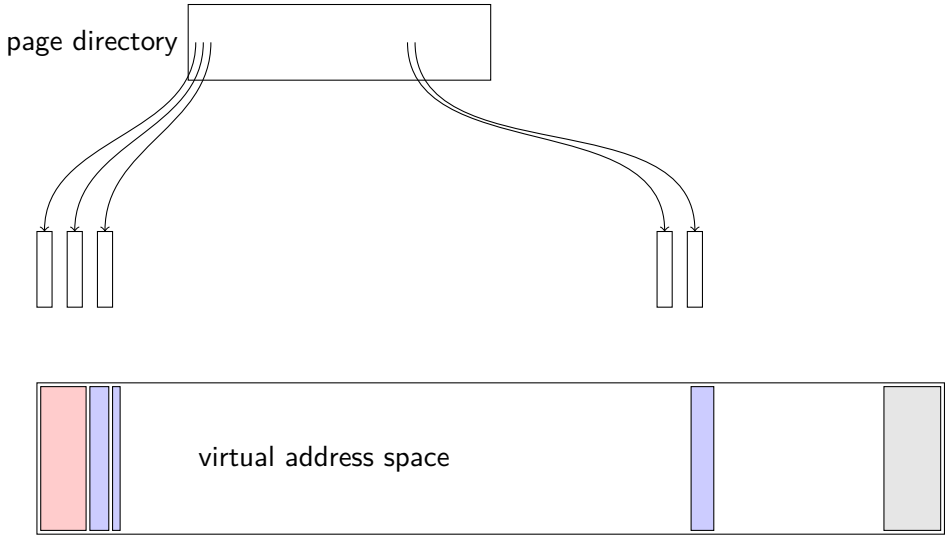

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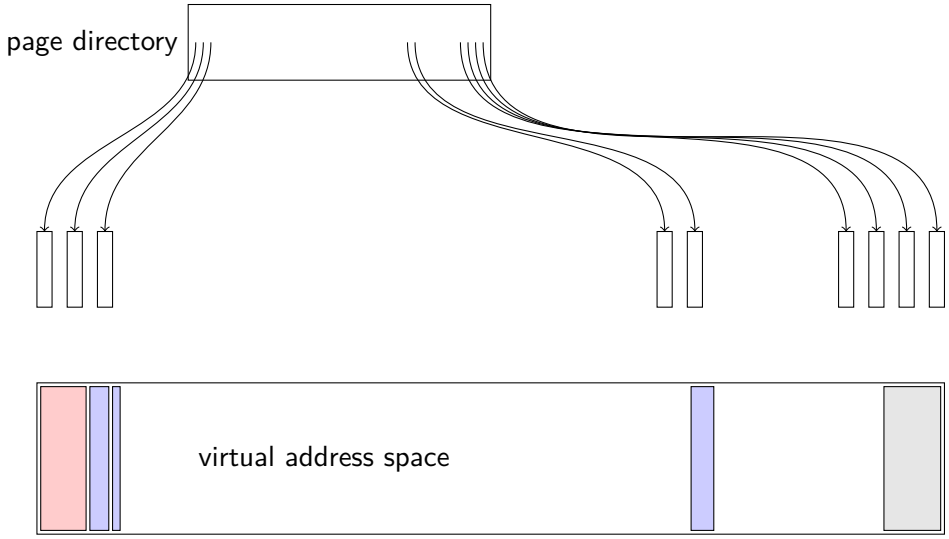

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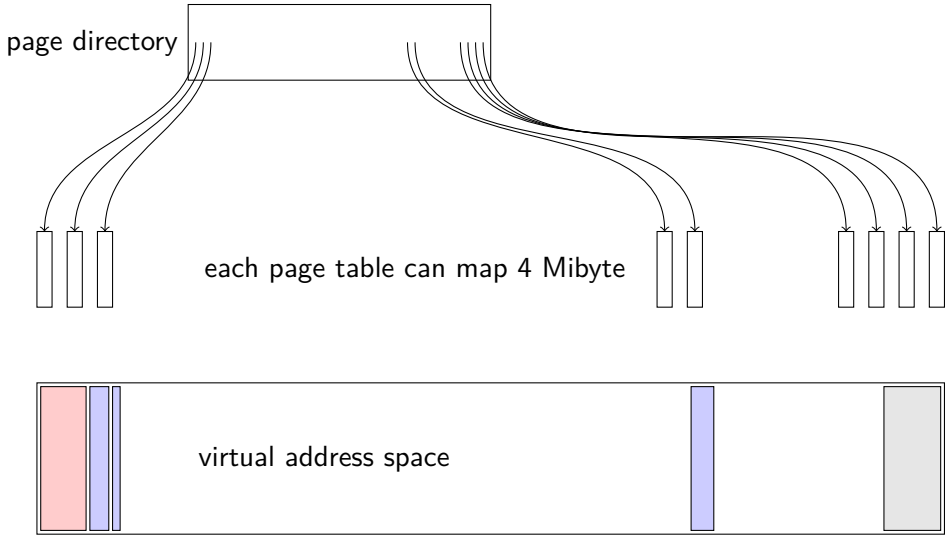
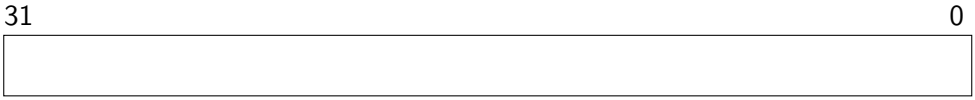


More than two levels



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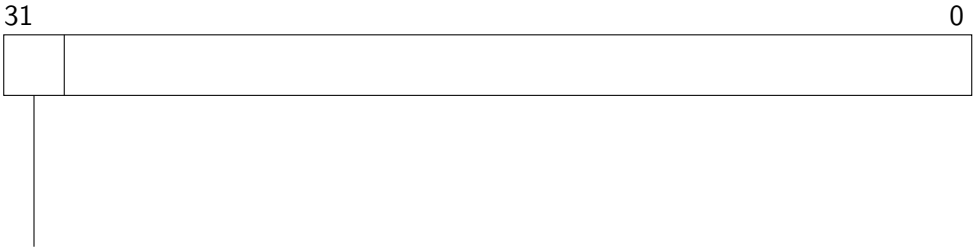

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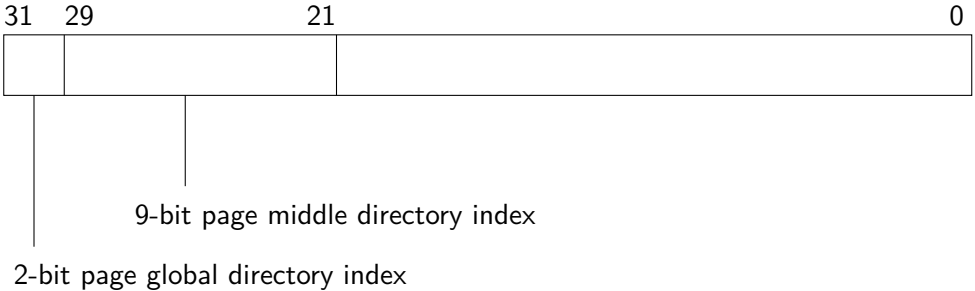

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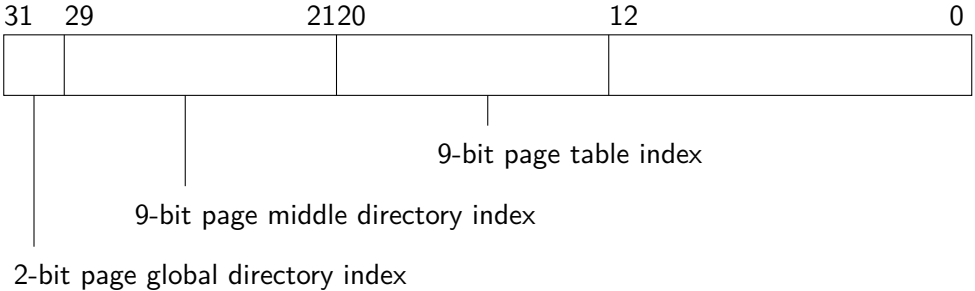

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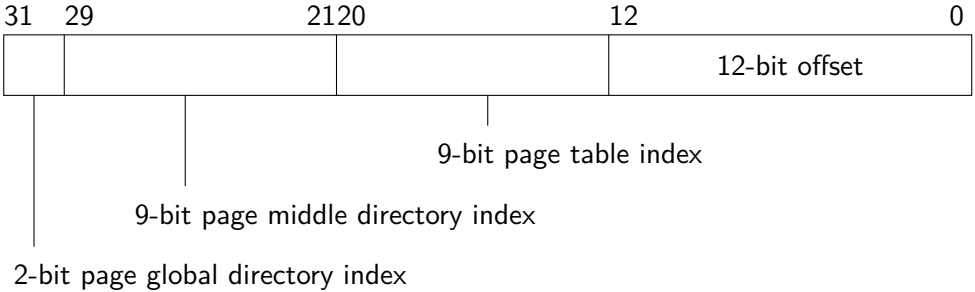

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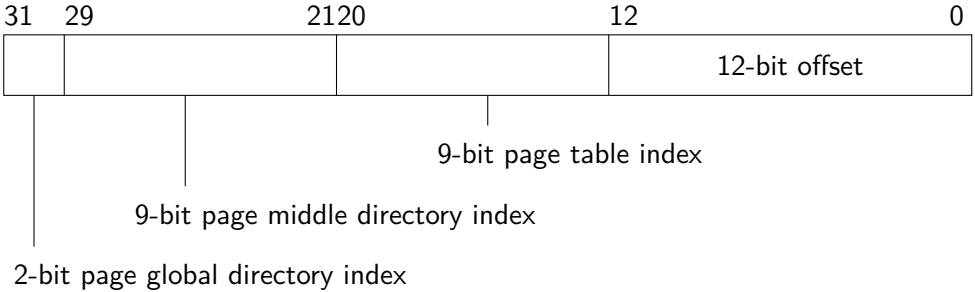

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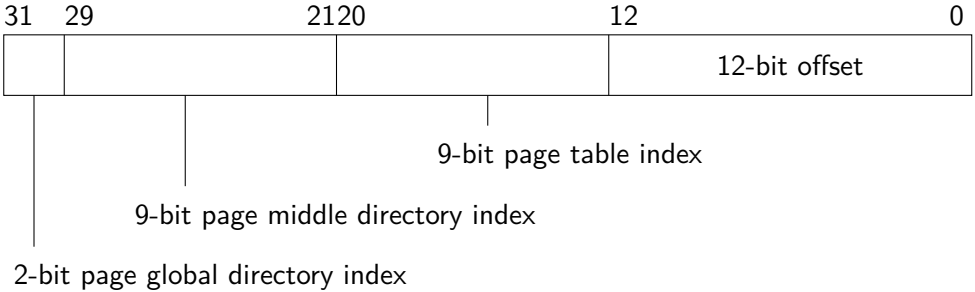

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Trace the translation of a 32-bit virtual address to a 36-bit physical address.

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Linux can only handle 64 Tbyte of RAM i.e. 46 bits.

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- Used by some models of PowerPC, Ultra Sparc and Itanium.

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- Inverted page tables - an alternative approach.

AC/DC - TLB

TLB - dynamite, makes paging possible.