memory management

Vaibhav Bajpai

OS 2013

motivation

- virtualize resources:
  - multiplex CPU (CPU scheduling)
  - multiplex memory (memory management)

motivation

- virtualize resources:
  - multiplex CPU (CPU scheduling)
  - multiplex memory (memory management)
- why manage memory?

motivation

- virtualize resources:
  - multiplex CPU (CPU scheduling)
  - multiplex memory (memory management)
- why manage memory?
  - controlled overlap
    - processes should NOT overlap in physical memory

motivation

- virtualize resources:
  - multiplex CPU (CPU scheduling)
  - multiplex memory (memory management)
- why manage memory?
  - controlled overlap
    - processes should NOT overlap in physical memory
  - translation
    - allows to give uniform view of memory to programs

motivation

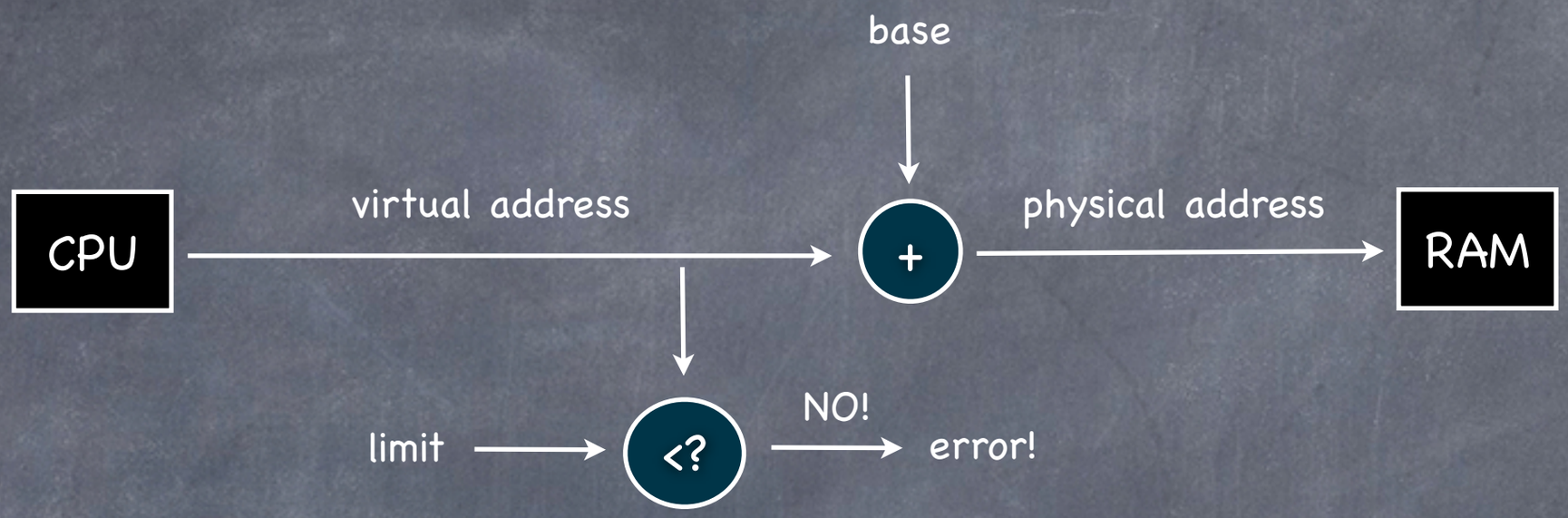
- virtualize resources:
  - multiplex CPU (CPU scheduling)
  - multiplex memory (memory management)
- why manage memory?
  - controlled overlap
    - processes should NOT overlap in physical memory
  - translation
    - allows to give uniform view of memory to programs

  - protection
    - a process should NOT access other process' memory
    - read-only memory locations: (kernel, process code, et al.)

memory management

- base-bound registers
- segmentation
- paging
- segmentation + paging
- multi-level page tables
- inverted page tables

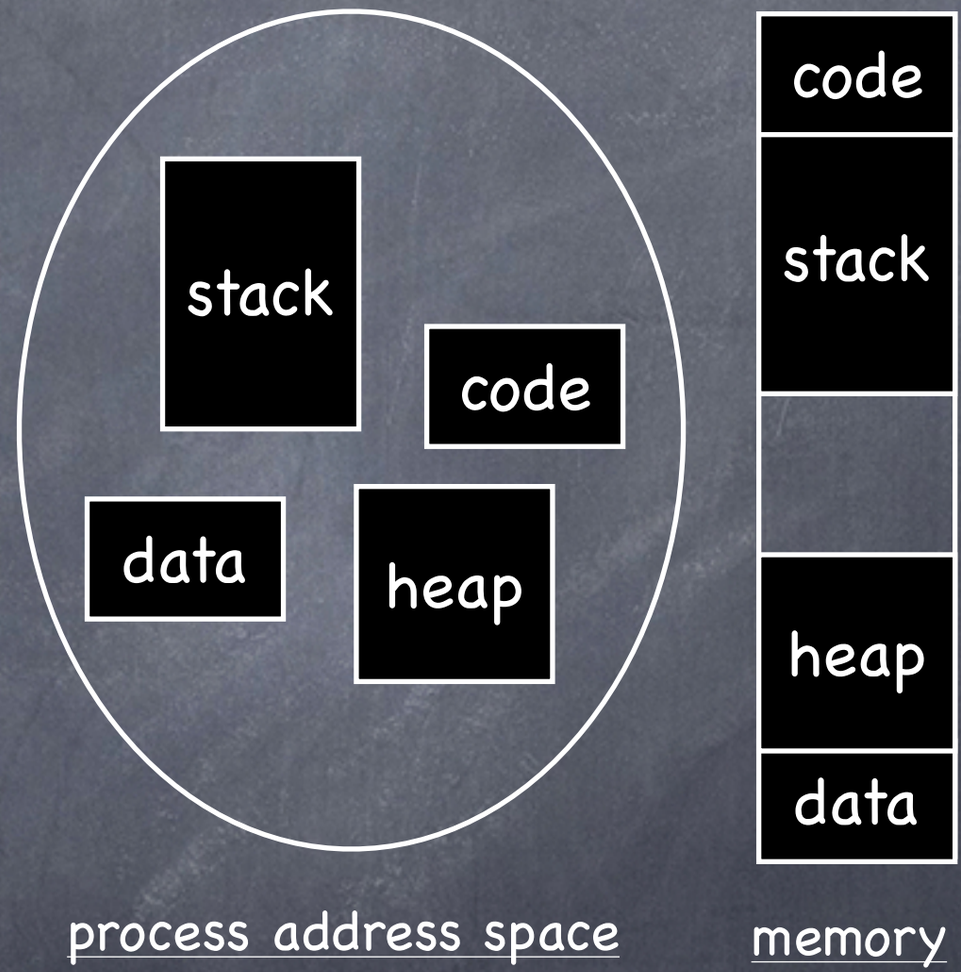
base and bound registers



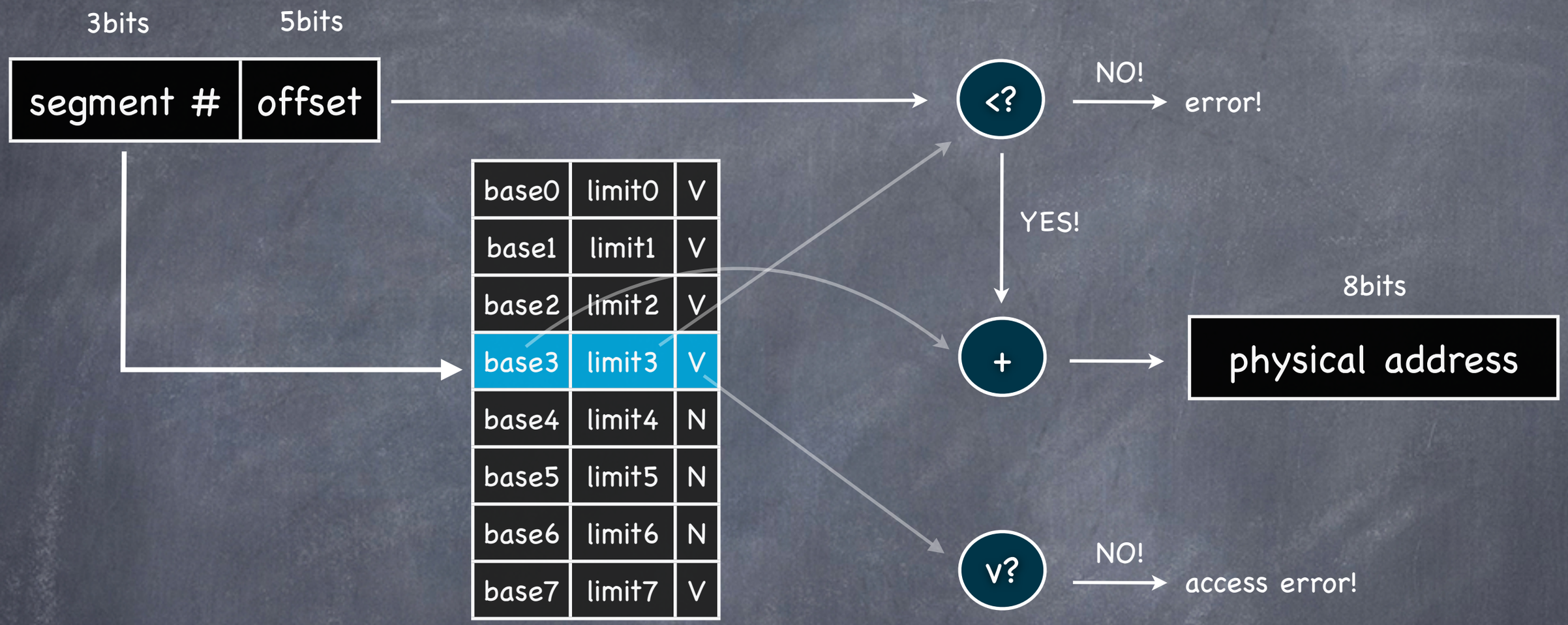
- dynamic address translation:
  - issues:
    - no inter-process sharing
    - cannot load a process bigger than an available hole
      - maybe load only a part of the process in memory?
    - heap and stack cannot grow within a process
    - not all processes are of same size: leads to external fragmentation

segmentation

- idea:
  - divide each process into multiple segments each with their own BASE and LIMIT registers
- advantages:
  - segments can be shared!
  - a part of a process can also be in memory
  - heap and stack can grow within a process



segmentation



- the segment table is stored in processor; not memory
- the segment table should be protected from processes

- issues:
  - each segment differs in size, leads to external fragmentation
  - swapping requires a complete segment to be written to disk

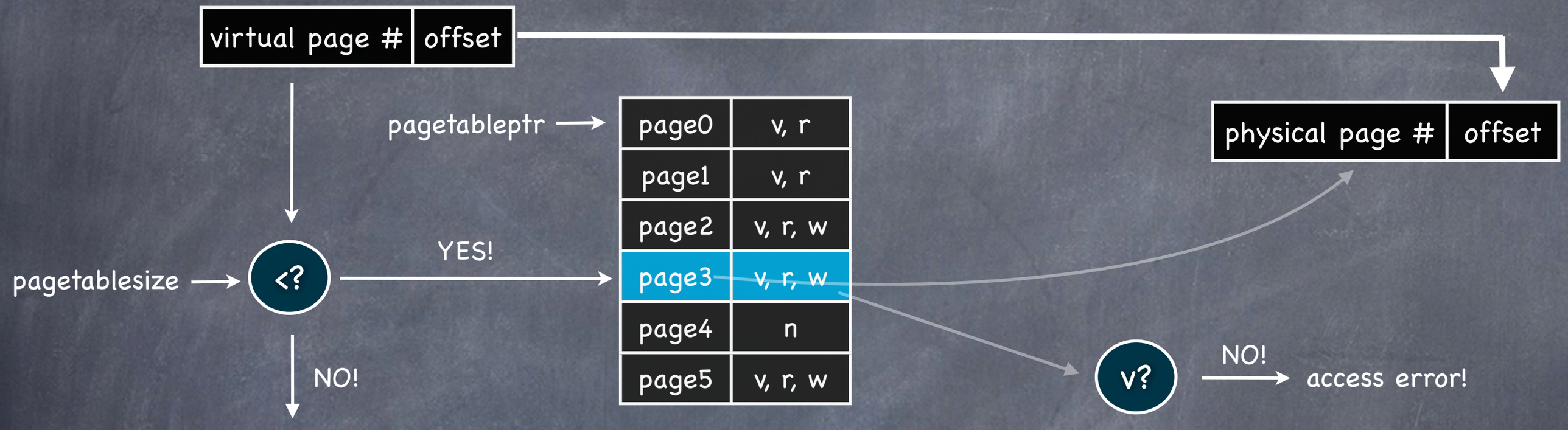
paging

- idea:
  - divide the physical memory into fixed size chunks (pages)
  - use a bit vector to handle allocation
- perspectives:
  - with 4GiB of physical memory, and 4KiB of pages, what should be the size of the bit vector?
  - use small page size to avoid huge internal fragmentation
- advantages:
  - no external fragmentation!
  - only small-sized pages need to be swapped to disk

paging

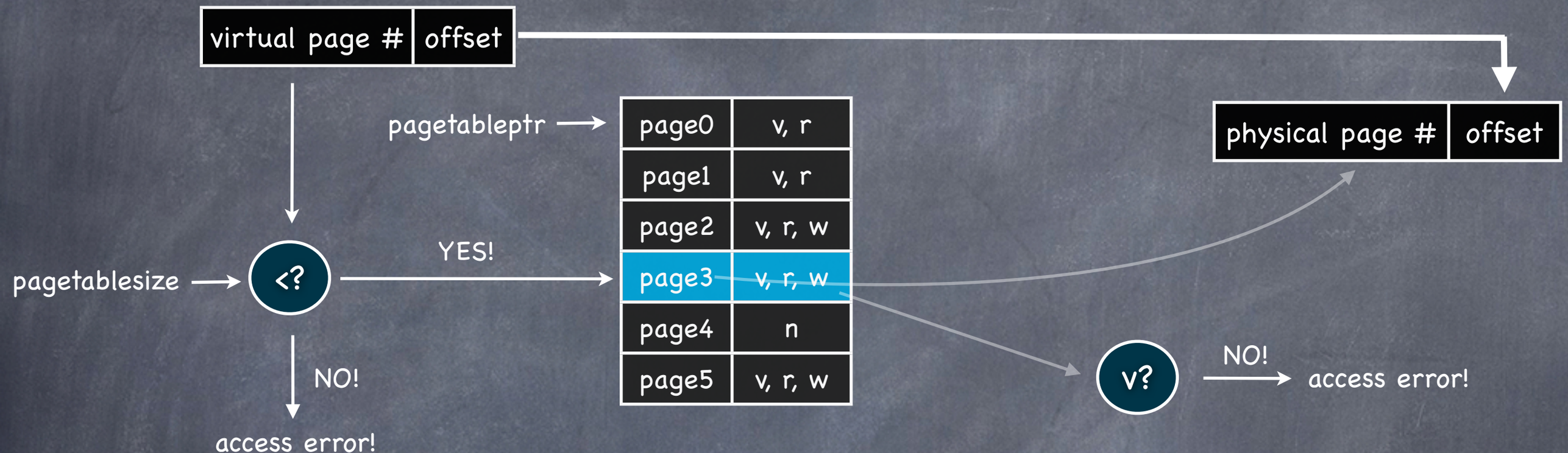
- idea:
  - divide the physical memory into fixed size chunks (pages)
  - use a bit vector to handle allocation
- perspectives:
  - with 4GiB of physical memory, and 4KiB of pages, what should be the size of the bit vector? 220KiB
  - use small page size to avoid huge internal fragmentation
- advantages:
  - no external fragmentation!
  - only small-sized pages need to be swapped to disk

paging



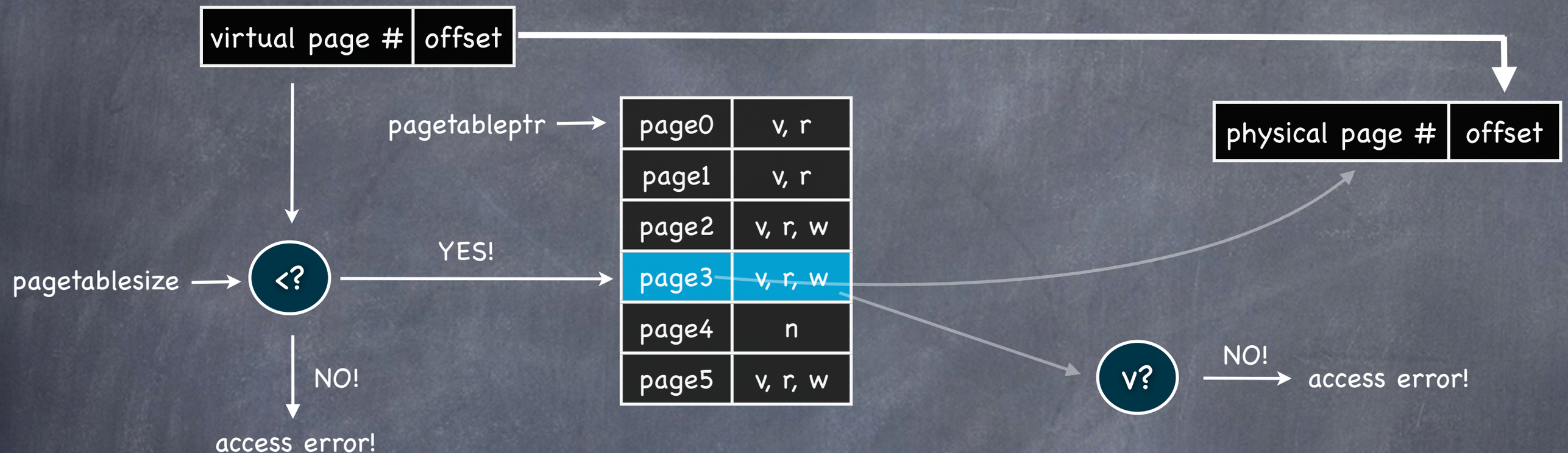
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need?
  - for a 4K page, for a 32 bit address space, how many page numbers are possible?
  - why are we not checking limit for the offset?
  - can data structures be allocated that span more than a page?
    - would it be contiguous in physical memory?
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



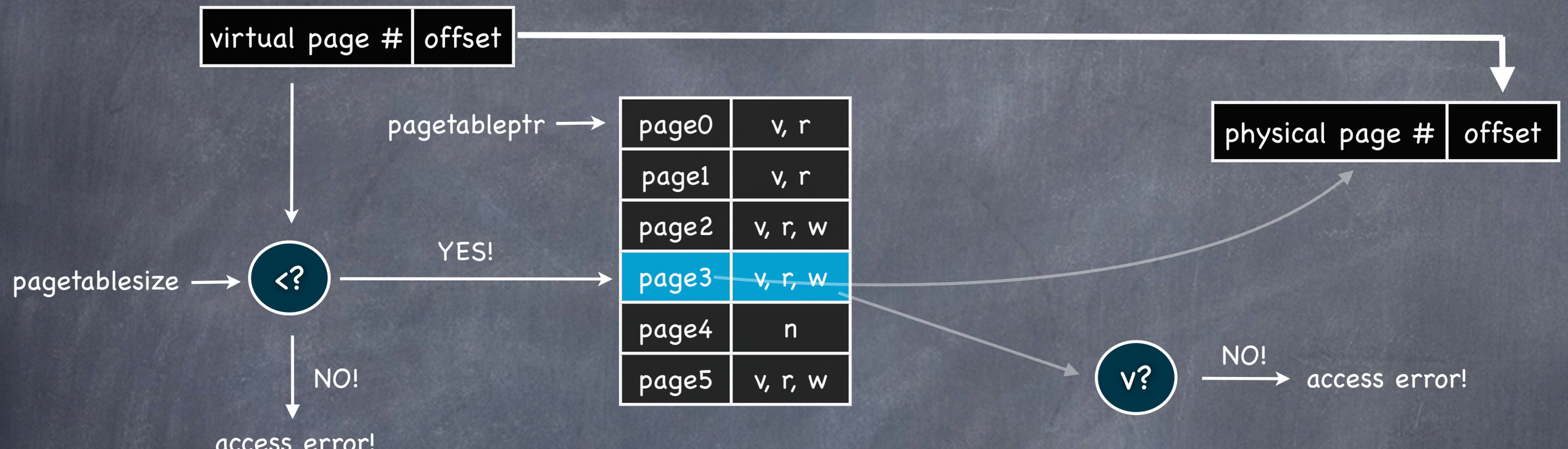
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible?
  - why are we not checking limit for the offset?
  - can data structures be allocated that span more than a page?
    - would it be contiguous in physical memory?
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



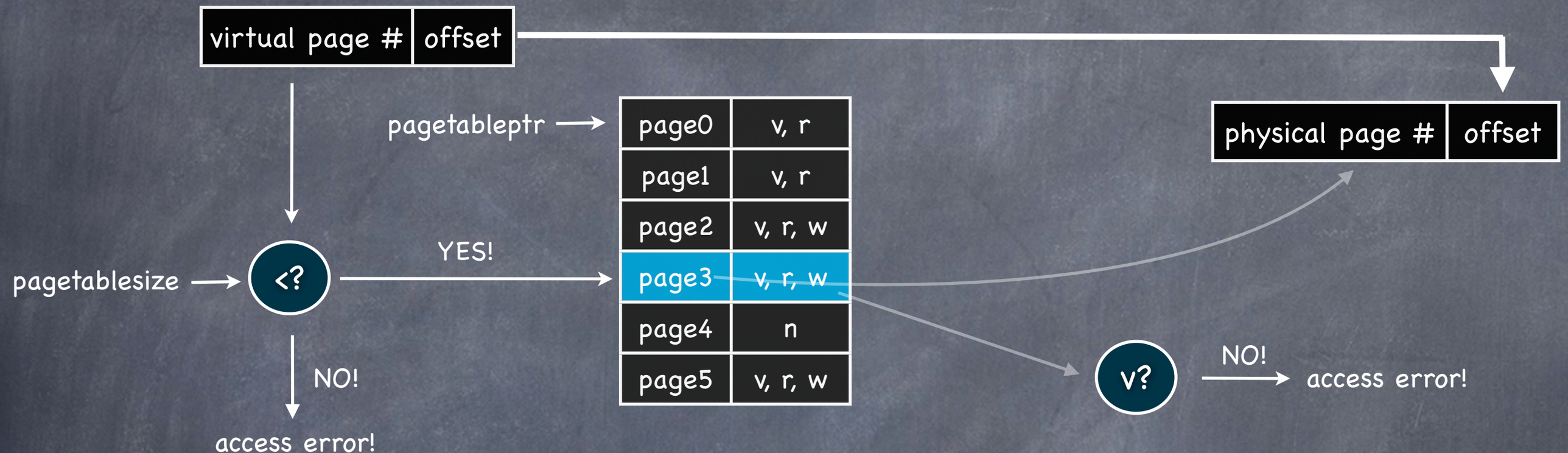
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset?
  - can data structures be allocated that span more than a page?
    - would it be contiguous in physical memory?
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



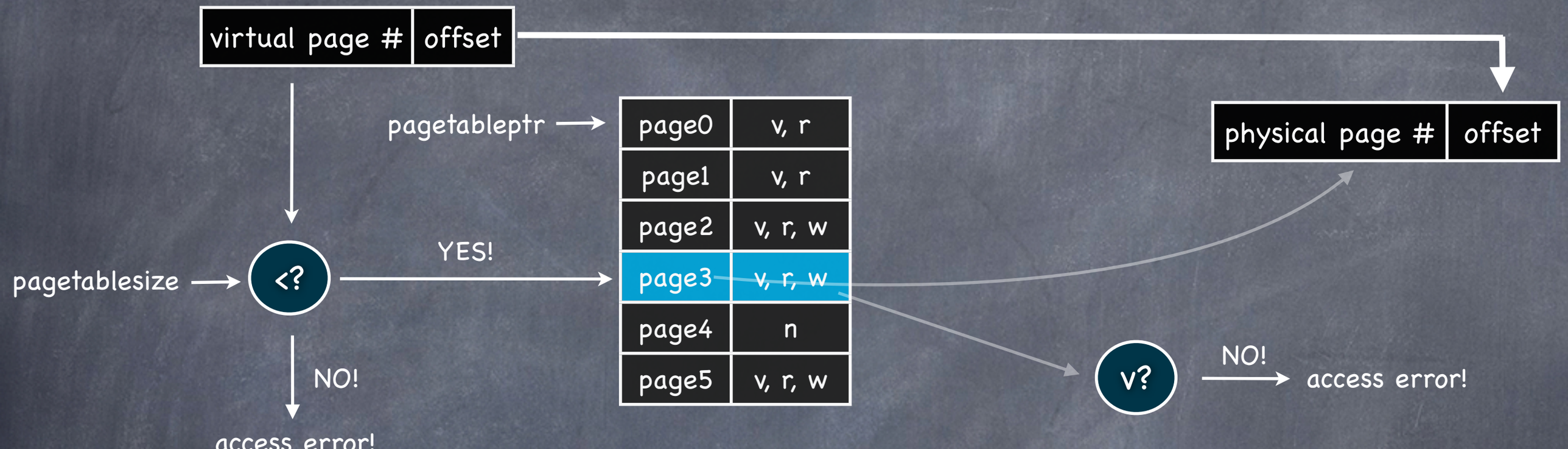
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset? all pages are of same size!
  - can data structures be allocated that span more than a page?
    - would it be contiguous in physical memory?
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



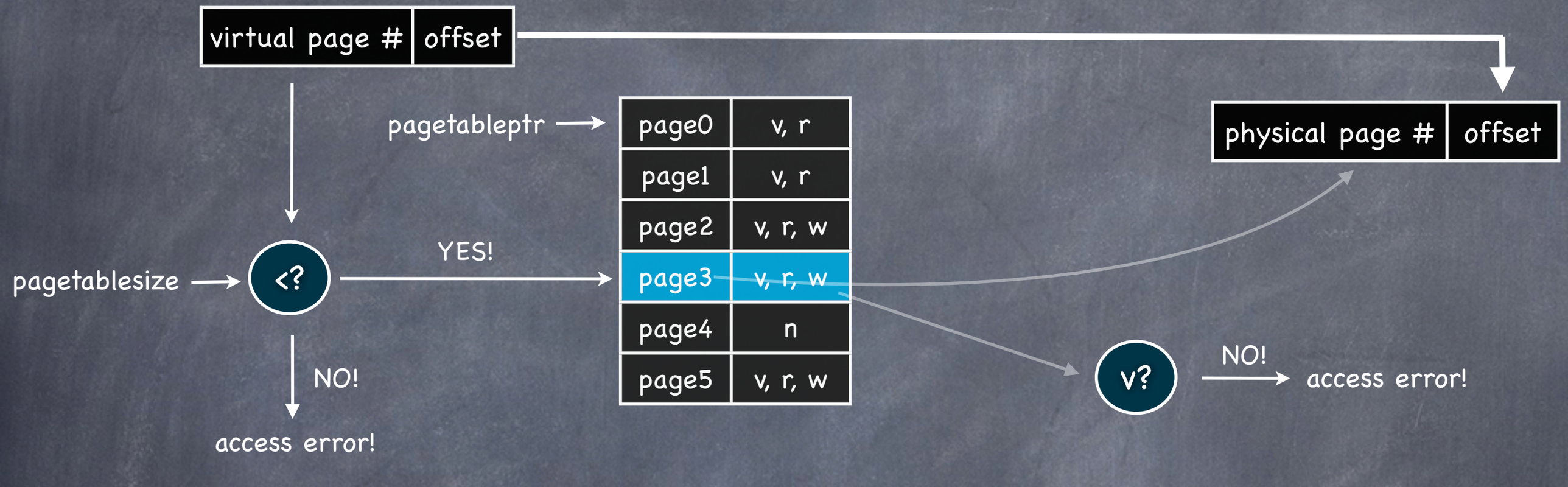
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset? all pages are of same size!
  - can data structures be allocated that span more than a page? yes!
    - would it be contiguous in physical memory?
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



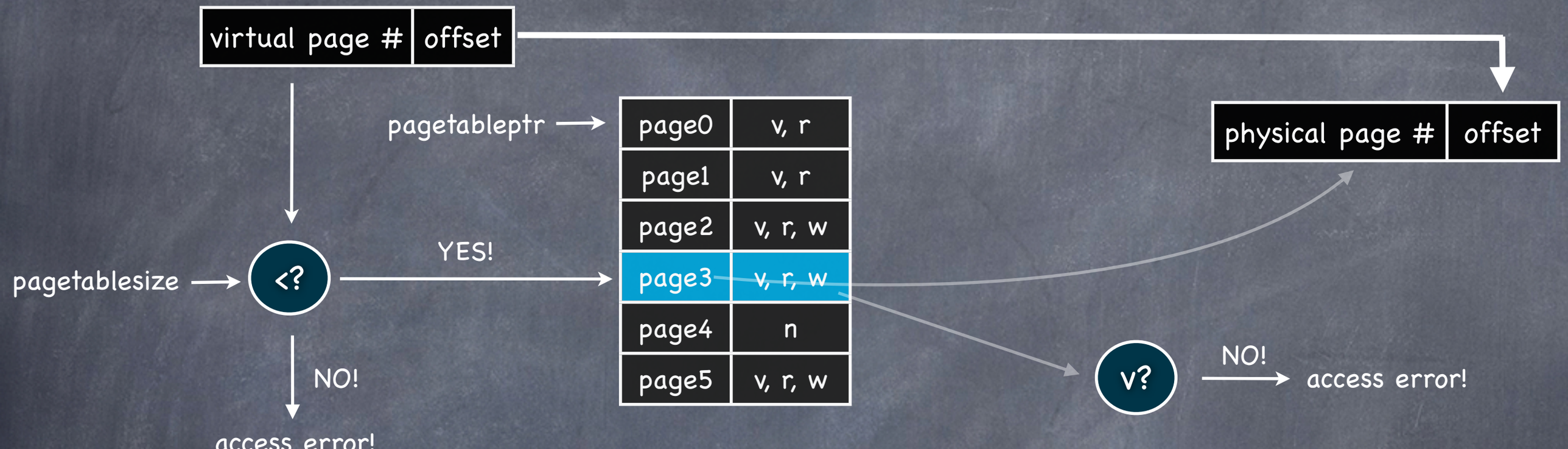
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset? all pages are of same size!
  - can data structures be allocated that span more than a page? yes!
    - would it be contiguous in physical memory? not guaranteed!
  - why do we have a page table size?
  - can stack/heap grow in this scheme?

paging



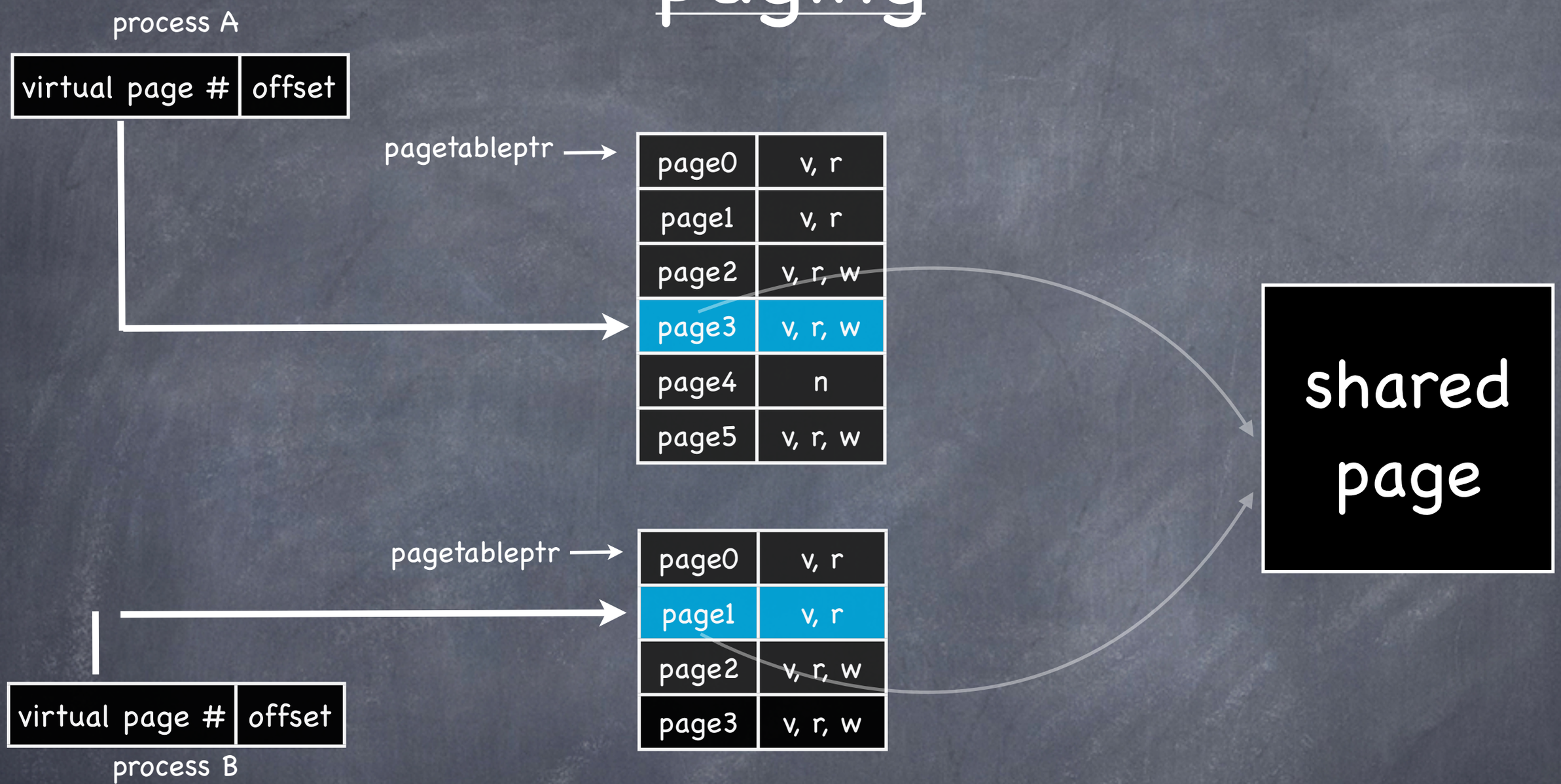
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset? all pages are of same size!
  - can data structures be allocated that span more than a page? yes!
    - would it be contiguous in physical memory? not guaranteed!
  - why do we have a page table size? the page table grows ...
  - can stack/heap grow in this scheme?

paging



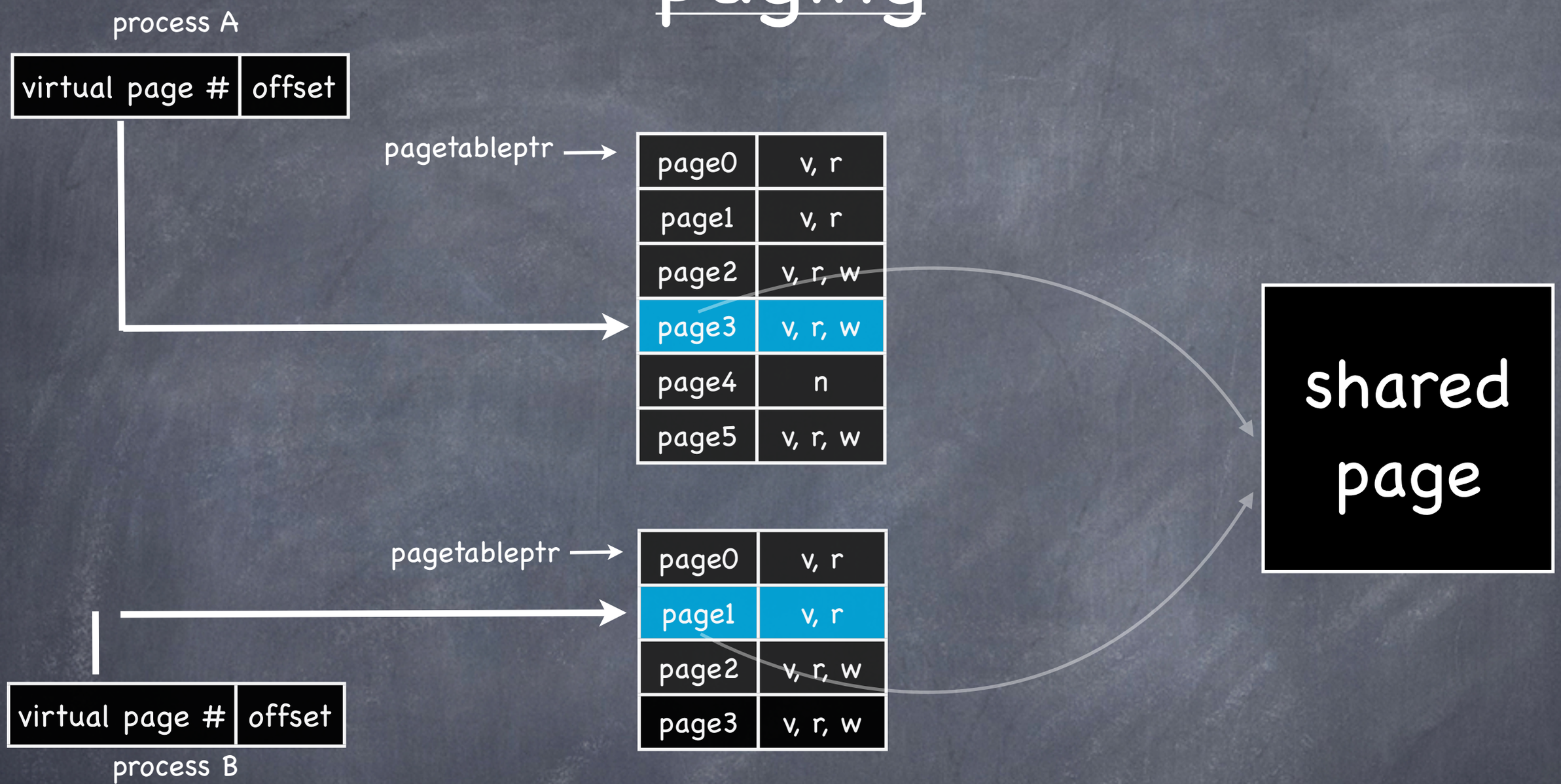
- there is a page table for each process
- page table resides in physical memory
- offset represents the size of a page;
  - for a 4K page, how many offset bits do we need? 12 bits
  - for a 4K page, for a 32 bit address space, how many page numbers are possible? 1m
  - why are we not checking limit for the offset? all pages are of same size!
  - can data structures be allocated that span more than a page? yes!
    - would it be contiguous in physical memory? not guaranteed!
  - why do we have a page table size? the page table grows ...
  - can stack/heap grow in this scheme? no! requires allocation of each page table entry

paging



- sharing pages:
  - process B can only read; however process A can read/write
  - note: virtual address of a physical address can be different across processes
- what do we need on a process context switch?

paging

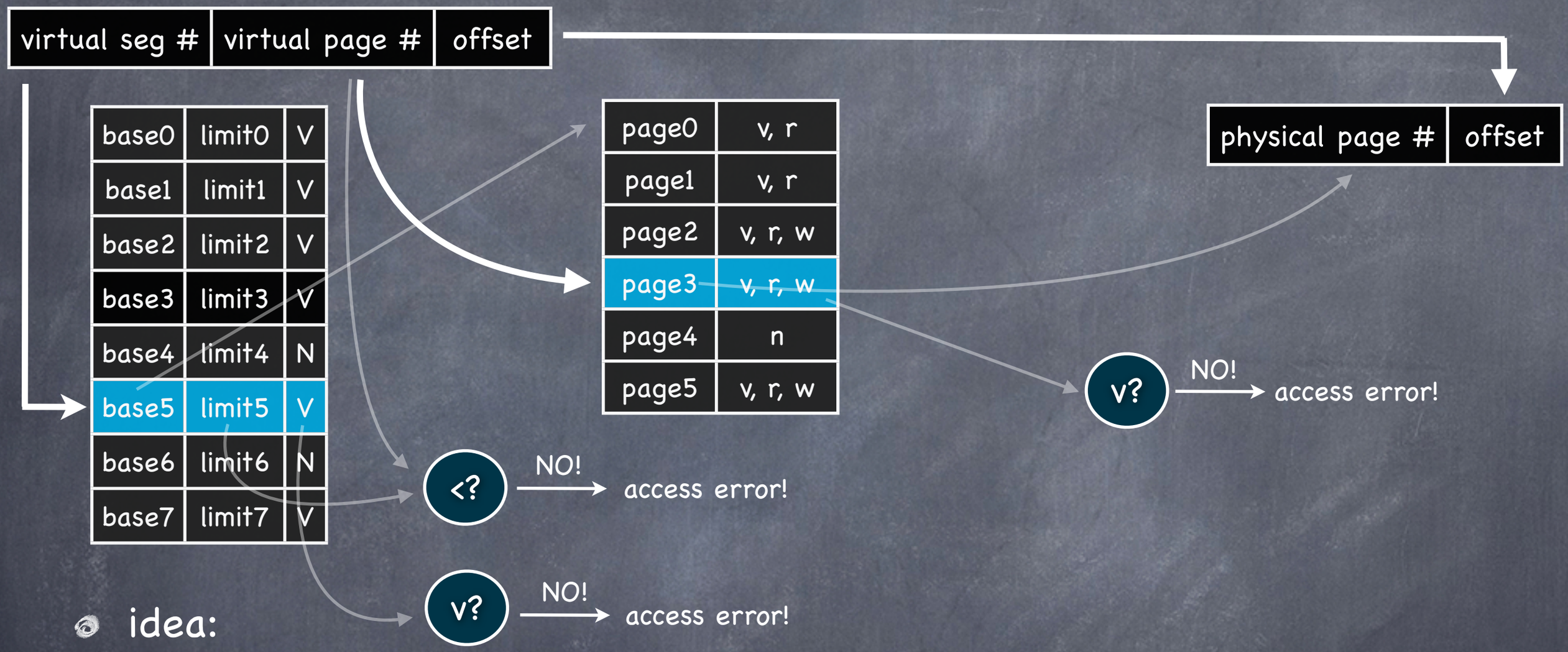


- sharing pages:
  - process B can only read; however process A can read/write
  - note: virtual address of a physical address can be different across processes
- what do we need on a process context switch?
  - page table pointer
  - page table size

paging

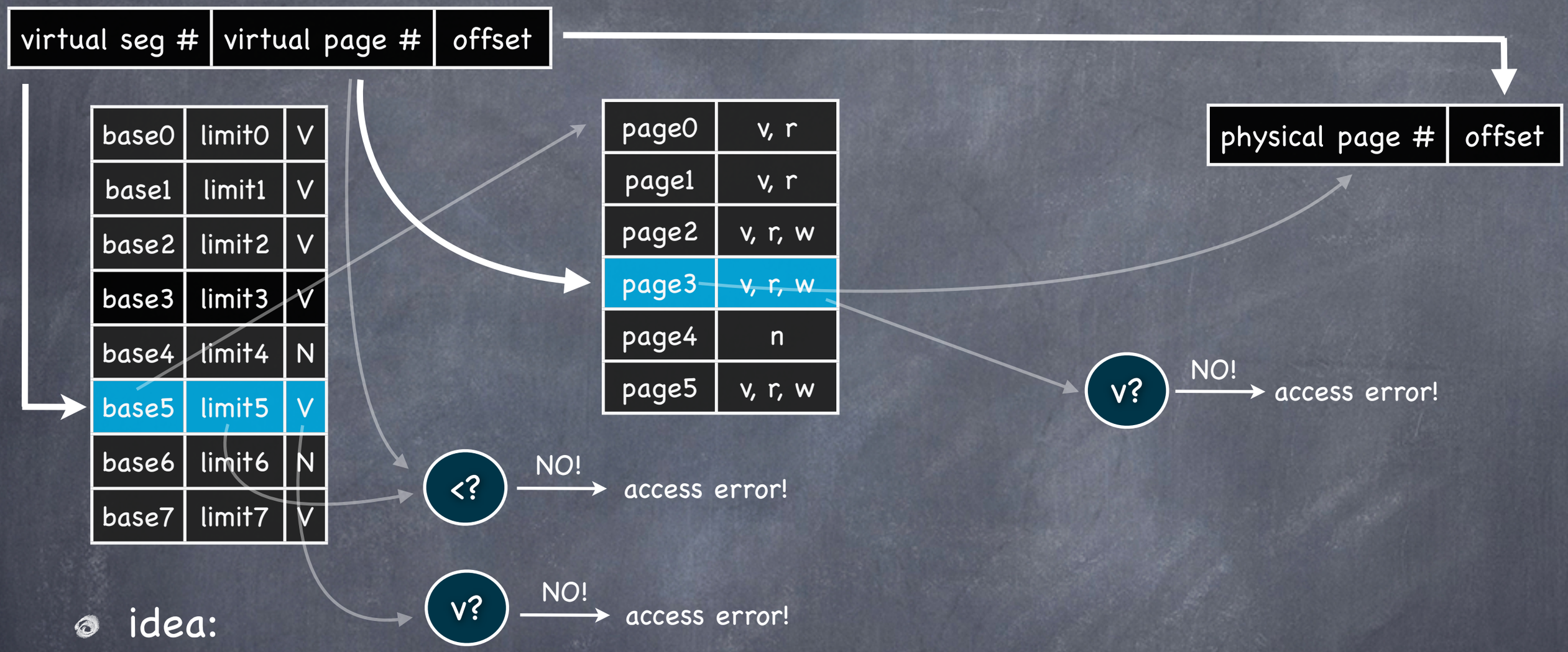
- issues:
  - cannot handle sparse address space
    - segmentation had this feature!
  - page tables reside in memory and they can get REALLY big!
    - it's possible to swap out individual pages to disk
    - would be nice to swap parts of page table to disk!

segmentation + paging



- idea:
  - create a multi-level translation
  - lowest-level is a page-table
  - higher-levels are segmented
- advantages:
  - whole segments can be shared!
  - can handle sparse address space
- what do we need on a process context switch?

segmentation + paging



- idea:
  - create a multi-level translation
  - lowest-level is a page-table
  - higher-levels are segmented
- advantages:
  - whole segments can be shared!
  - can handle sparse address space
- what do we need on a process context switch?
  - highest level segment table

segmentation + paging

process A

virtual seg #	virtual page #	offset

base0	limit0	V
base1	limit1	V
base2	limit2	V
base3	limit3	V
base4	limit4	N
base5	limit5	V
base6	limit6	N
base7	limit7	V

page0	v, r
page1	v, r
page2	v, r, w
page3	v, r, w
page4	n
page5	v, r, w

shared segment

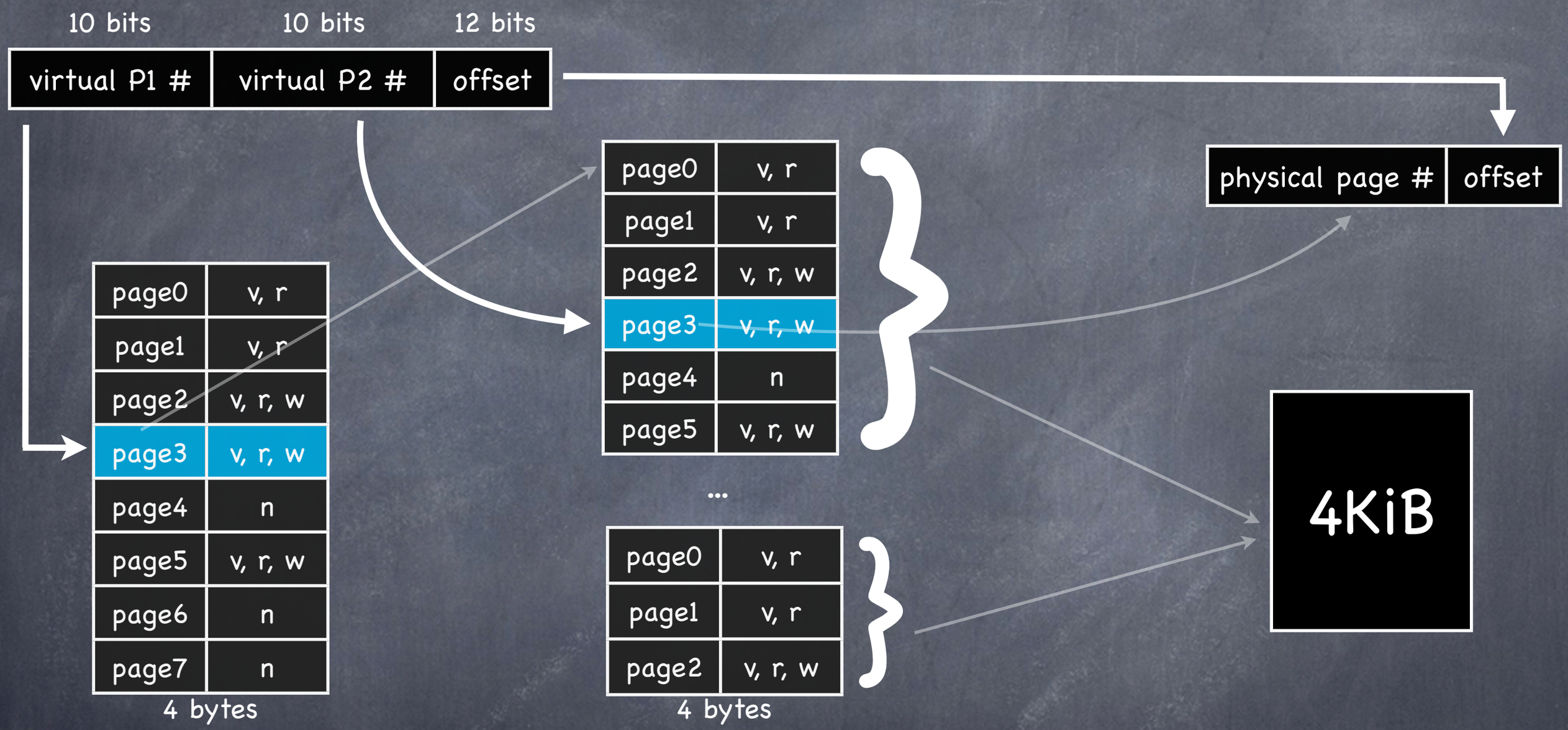
base0	limit0	V
base1	limit1	V
base2	limit2	V
base3	limit3	V
base4	limit4	N
base5	limit5	V
base6	limit6	N
base7	limit7	V

virtual seg #	virtual page #	offset

process B

- sharing:
  - whole segments can be shared!
  - individual pages can be shared as well!

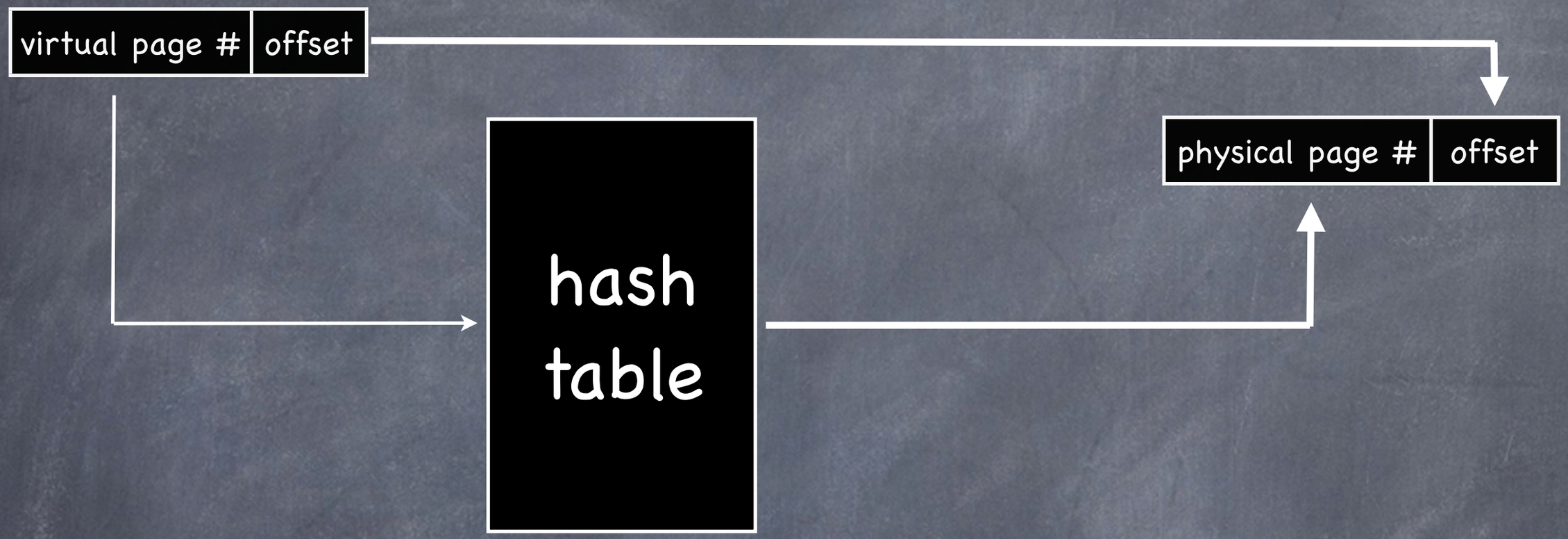
two-level page table



- all the levels of page table and pages themselves are 4K!
- allows to transparently swap out parts of the page table!

- issues:
  - two (or more) level lookups become expensive (use a TLB)

inverted page table



- page table size becomes independent of virtual address space
- becomes directly related to the amount of physical memory
- very attractive for 64-bit virtual address spaces

- issues:
  - complexity of managing a hash table in hardware

summary

- base-bound registers
  - complete process contiguously loaded in physical memory
  - external fragmentation, no inter-process sharing
- segmentation
  - part of a process can be loaded into memory
  - external fragmentation, large segments swapped to disk
- paging
  - no external fragmentation, flexible sharing
  - cannot handle sparse addresses, page tables can grow BIG!
- segmentation + paging
  - can handle sparse addresses
  - complete segments or individual pages can be shared
- two-level page tables
  - portion of the page-table can be swapped to disk
- inverted page tables
  - page-table size directly related to size of physical memory
  - complexity to manage hash table in hardware