Virtual Memory: Mechanics of Page Faults
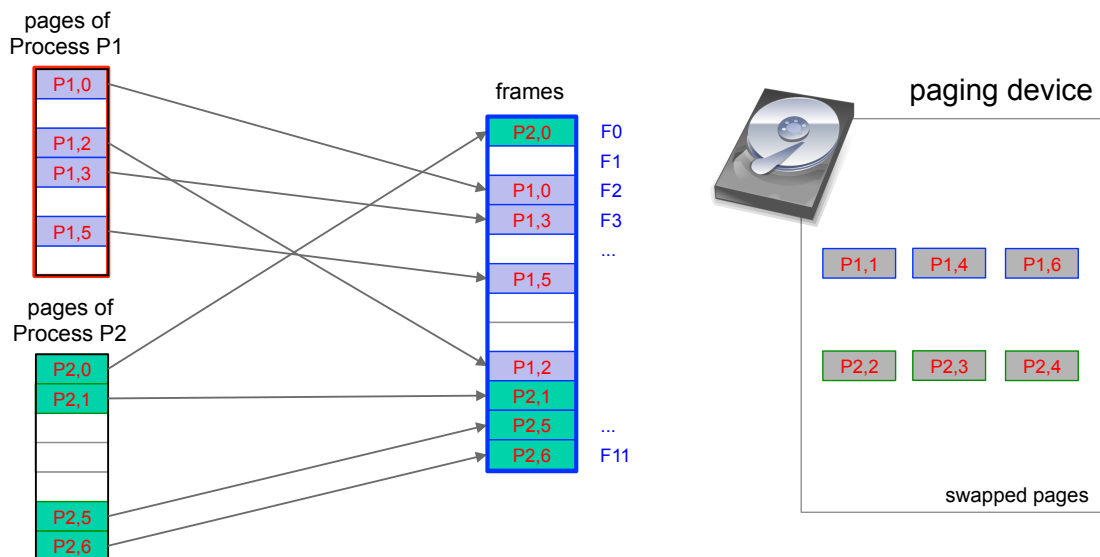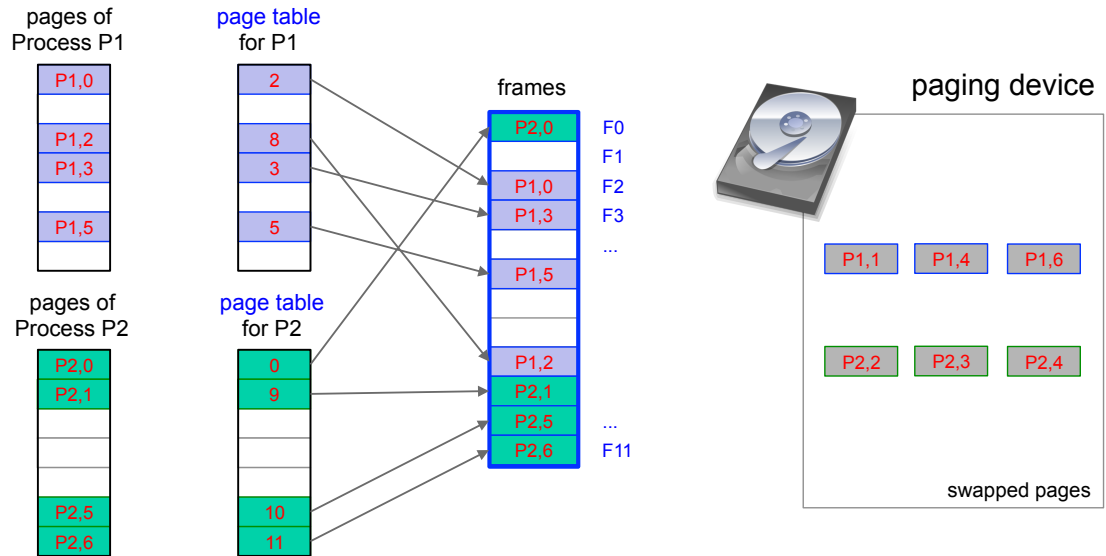
- Recap: Page-level on-demand Swapping – "Paging"

- Role of Page Table

- Page Faults Step-by-Step: the "valid" Bit in Page Table

- Page Replacement

- The "dirty" Bit to minimize I/O write operations
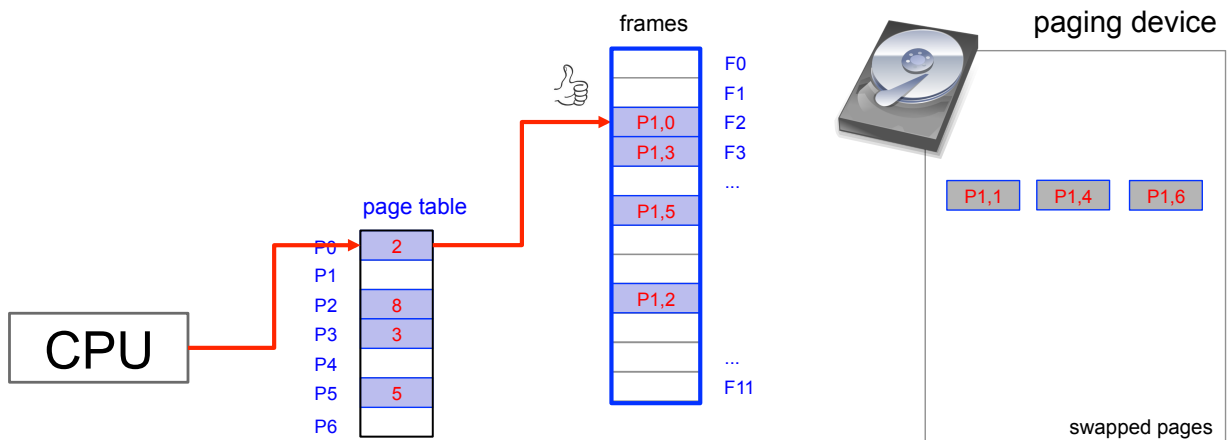
- The "use" Bit to identify recently-used pages

Recap: Page-Level on-Demand Swapping

pages of
Process P1

frames

paging device

Page Tables

pages of
Process P1

P1,0
P1,2
P1,3
P1,5

page table
for P1

2
8
3
5

frames

P2,0	F0
	F1
P1,0	F2
P1,3	F3
	...
P1,5	
P1,2	
P2,1	
P2,5	...
P2,6	F11

pages of
Process P2

P2,0
P2,1
P2,5
P2,6

page table
for P2

0
9
10
11

paging device

P1,1	P1,4	P1,6

P2,2	P2,3	P2,4

swapped pages

Memory Access without Page Fault

frames

	F0
	F1
P1,0	F2
P1,3	F3
	...
P1,5	
P1,2	
	...
	F11

page table

P0	2
P1	
P2	8
P3	3
P4	
P5	5
P6	

CPU

paging device

P1,1	P1,4	P1,6

swapped pages

Page Fault Step-by-Step: "valid" Bit

frame number

Present – "valid bit"
R/W – Read-only or Read-Write
U/S – user or kernel page
Reserved – do not use!
A – accessed, "use bit"
D – "dirty bit"
Reserved – do not use!
Avail – feel free to use these bits

frames

	F0
	F1
P1,0	F2
P1,3	F3
	...
P1,5	
P1,2	
	...
	F11

paging device

P1,1	P1,4	P1,6

swapped pages

page table

P0	2	v
P1		i
P2	8	v
P3	3	v
P4		i
P5	5	v
P6		i

CPU

?!
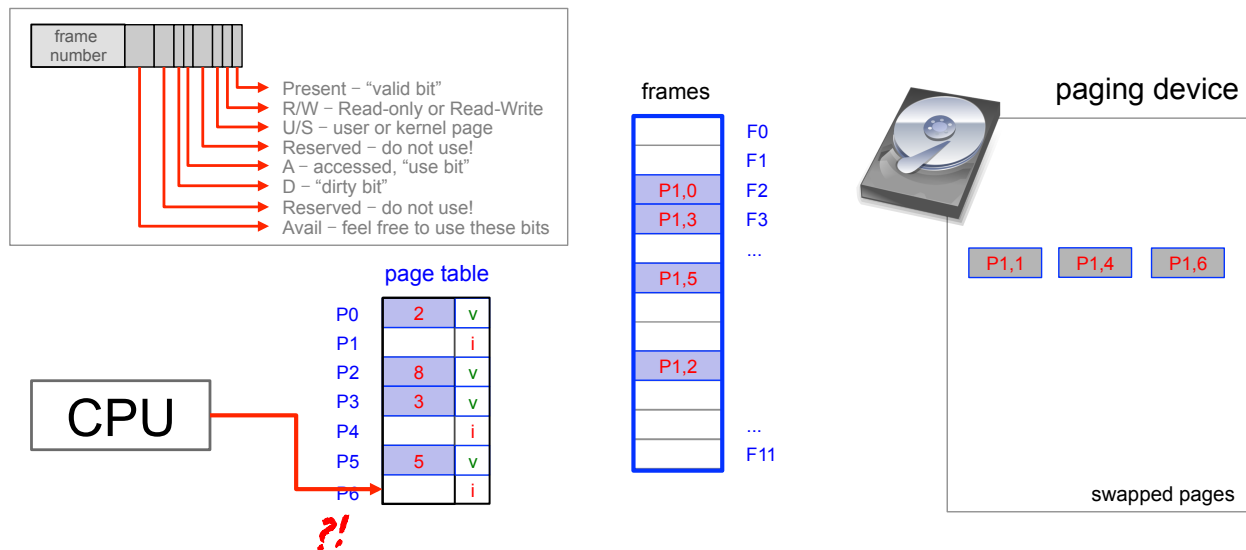
Step-by-Step Page Fault: Page Fault Exception

OS

locate missing page on paging device

return from page fault exception!

page fault exception!

frames

	F0
	F1
P1,0	F2
P1,3	F3
	...
P1,5	
P1,2	
P1,6	...
	F11

P1,1	P1,4	P1,6

load page into memory

swapped pages

page table

P0	2	v
P1		i
P2	8	v
P3	3	v
P4		i
P5	5	v
P6	10	v

CPU

update page table entry
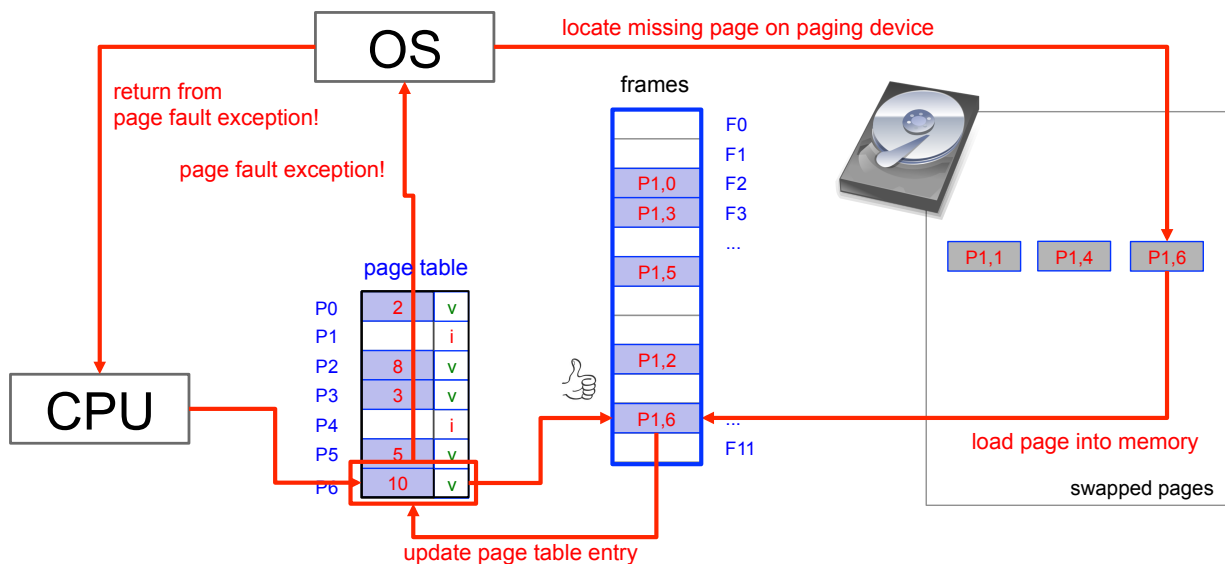
What if all Frames are Used? (Frame/Victim Selection)

OS

locate missing page on paging device

frames

page fault exception!

F0
F1
P1,0 F2
P1,3 F3
...

P1,5

P1,1   P1,4   P1,6

page table

P0	2	v
P1		i
P2		i
P3	3	v
P4		i
P5	5	v
P6		i

update page table entry of victim

CPU

select a victim

P1,2

load page into memory

...
F11

P1,2   evict the victim

swapped pages
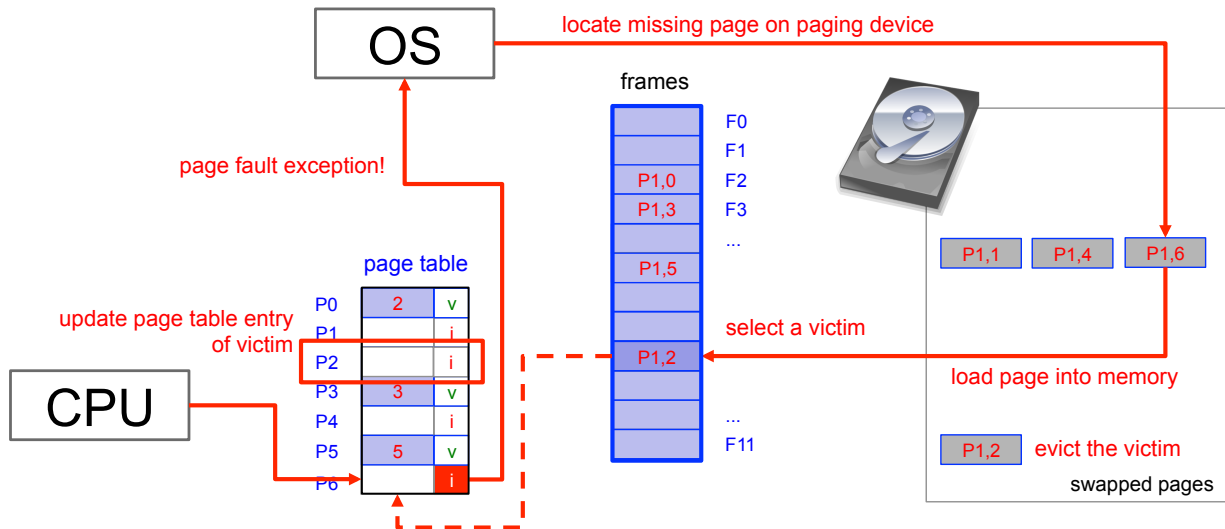
Minimizing I/O Writes with "Dirty" Bit

frame number

Present – "valid bit"
R/W – Read-only or Read-Write
U/S – user or kernel page
Reserved – do not use!
A – accessed, "use bit"
D – "dirty bit"
Reserved – do not use!
Avail – feel free to use these bits

frames

F0
F1
P1,0 F2
P1,3 F3
...

P1,5

P1,1   P1,4   P1,6

read

page table

P0	2	v	
P1		i	-
P2	8	v	D
P3	3	v	
P4		i	-
P5	5	v	D
P6		i	-

CPU

P1,2

load page into memory

write

?!

...
F11

P1,2   evict the victim

swapped pages
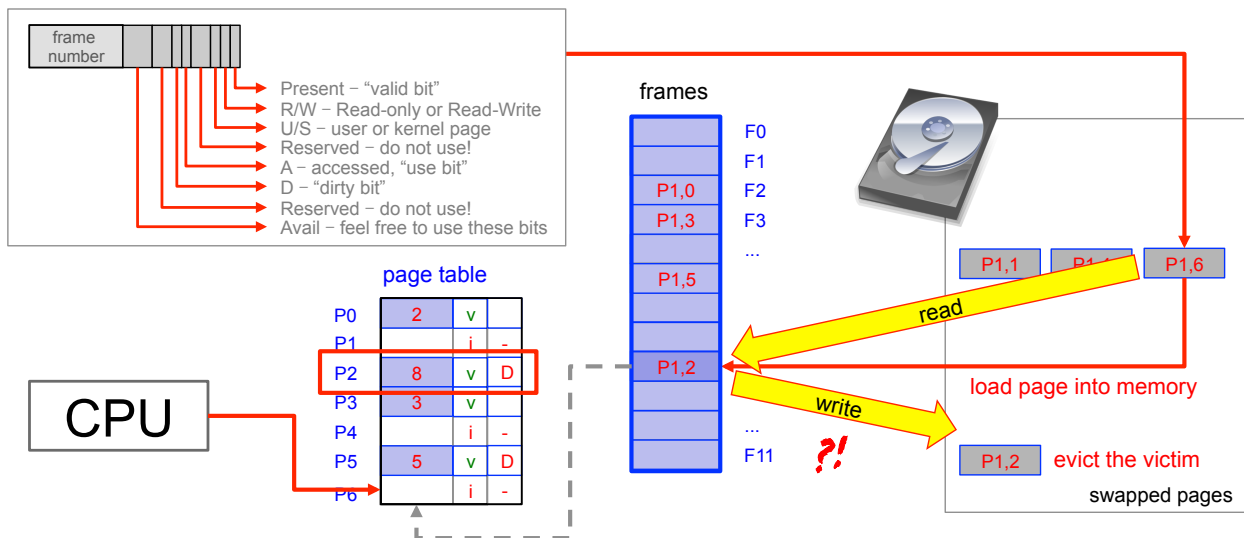
Victim Selection with the "Use" Bit

frame
number

Present – "valid bit"
R/W – Read-only or Read-Write
U/S – user or kernel page
Reserved – do not use!
A – accessed, "use bit"
D – "dirty bit"
Reserved – do not use!
Avail – feel free to use these bits

frames

F0
F1
F2
F3
...

F11

select a victim

?!

swapped pages

| P1,1 | P1,4 | P1,6 |

page table

P0	2	v		1
P1		i	-	-
P2	8	v	D	1
P3	3	v		0
P4		i	-	-
P5	5	v	D	1
P6		i	-	-

CPU

P1,0
P1,3

P1,5

P1,2
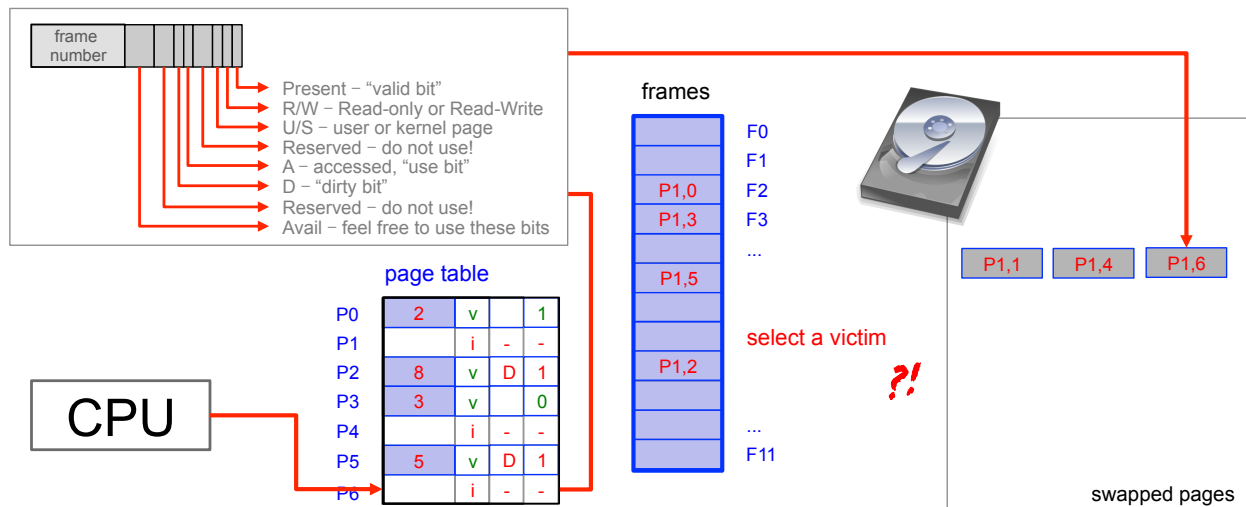
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- Page Faults Step-by-Step

- "valid" Bit in Page Table

- Page Replacement

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- "use" Bit to identify recently-used pages