CO2017 — Surgery 5, Memory Management 2017–18

2018–05–18; R1335

Questions

Q1—Variable partition direct memory addressing

At a given moment, a *variable partition direct memory system* has gaps in memory of the following sizes, in the order given:

15K 30K 25K 20K 40K

A process of size 18K is to be loaded. Which hole size would be selected, using

1. a *best fit* policy

2. a *first fit* policy

3. a *worst fit* policy

Q2—Virtual Memory page replacement

Consider a Virtual Memory system with 20 pages, numbered 0 to 19, and with 5 page frames available, lettered A to E (to help distinguish frames from virtual pages). Initially all page frames are **empty**.

Suppose that page requests arrive in the following order:

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

1. Using a *Not Recently Used* (NRU) page replacement algorithm how many page faults would occur? Which pages would be loaded into which page frames at each step?

2. Using a *First In First Out* (FIFO) page replacement algorithm how many page faults would occur? Which pages would be loaded into which page frames at each step?

3. Using a *First In First Out with 2nd chance* (FIFO, 2nd chance) page replacement algorithm how many page faults would occur? Which pages would be loaded into which page frames at each step?

4. Using a *Least Recently Used* (LRU) page replacement algorithm, how many page faults would occur? Which pages would be loaded into which page frames at each step?

5. Using a **Clock Replacement** page replacement algorithm, how many page faults would occur? Which pages would be loaded into which page frames at each step?

Model Answers to CO2017 Surgery 4

Q1

1. 20K
2. 30K
3. 40K

Q2

In these solutions, the columns A to E represent the contents of each page frame, and each row represents what happens when another page reference is made. The "next" column shows the page that will be referenced next. The rest of the row shows the updated state of the page frames and associated data that results from the page reference. In some cases the changes required are split over 2 lines for clarity (grouped together using background shading).

In exam conditions, when adding a new row of page frame statuses to the table, unchanged values can be omitted. For clarity, complete rows are shown in these solutions.

Newly loaded page frames (the results of a page fault) are indicated in bold here. When handwriting solutions, you could distinguish these values by underling, or by circling the new values.

Since the first few page faults are always into **empty** page frames, these are combined into a single row in the answers given here.

1. Not Recently Used (NRU)

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

Use ⊠ or □ to indicate "recently used" (referenced) or not. Pages newly loaded after a page fault are shown in bold.

In cases where the page fault results in a **reset of all** "recently used" flags, it is shown as **two rows** in the table for clarity. You would not need to do this under exam conditions, although you should note that such a reset has occurred.

next	A	B	C	D	E	
	1⊠	**2**⊠	**11**⊠	**6**⊠	**9**⊠	
5	1□	2□	11□	6□	9□	reset ref bits
5	**5**⊠	2□	11□	6□	9□	
11	5⊠	2□	11⊠	6□	9□	
2	5⊠	2⊠	11⊠	6□	9□	
3	5⊠	2⊠	11⊠	**3**⊠	9□	
15	5⊠1	2⊠	11⊠	3⊠	**15**⊠	
14	5□	2□	11□	3□	15□	reset ref bits
14	**14**⊠	2□	11□	3□	15□	
2	14⊠	2⊠	11□	3□	15□	
11	14⊠	2⊠	11⊠	3□	15□	
1	14⊠	2⊠	11⊠	**1**⊠	15□	
6	14⊠	2⊠	11⊠	1⊠	**6**⊠	
17	14□	2□	11□	1□	6□	reset ref bits
17	**17**⊠	2□	11□	1□	6□	
2	17⊠	2⊠	11□	1□	6□	

5 initial + 7 subsequent page faults

2. First In First Out (FIFO)

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

Use subscript to indicate position in queue — lowest number is at the queue head, so is the frame that will be evicted.

Newly loaded page frames are shown in bold.

The "frame queue" column shows the state of the FIFO queue explicitly immediately **after** the frames are in the state shown on the row. The next page fault will evict the frame at the head of the queue. The contents of this column are equivalent to the subscript notation. You would not need to produce both formats under exam conditions.

Note in particular that when a page is re-referenced (so no page fault) (*e.g.* when page 11 is referenced on line 3 of the table), nothing is changed in the page queue.

next	A	B	C	D	E	frame queue
	1_1	2_2	11_3	6_4	9_5	[A B C D E]
5	5_6	2_2	11_3	6_4	9_5	[B C D E A]
11	5_6	2_2	11_3	6_4	9_5	[B C D E A]
2	5_6	2_2	11_3	6_4	9_5	[B C D E A]
3	5_6	3_7	11_3	6_4	9_5	[C D E A B]
15	5_6	3_7	15_8	6_4	9_5	[D E A B C]
14	5_6	3_7	15_8	14_9	9_5	[E A B C D]
2	5_6	3_7	15_8	14_9	2_{10}	[A B C D E]
11	11_{11}	3_7	15_8	14_9	2_{10}	[B C D E A]
1	11_{11}	1_{12}	15_8	14_9	2_{10}	[C D E A B]
6	11_{11}	1_{12}	6_{13}	14_9	2_{10}	[D E A B C]
17	11_{11}	1_{12}	6_{13}	17_{14}	2_{10}	[E A B C D]
2	11_{11}	1_{12}	6_{13}	17_{14}	2_{10}	[E A B C D]

5 initial + 9 subsequent page faults

3. FIFO with 2nd chance

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

Use subscript to indicate position in queue, and ⊠ or □ to indicate when a page has been referenced or not. The lowest number is at the queue head, so is the frame that will be evicted, unless it has been referenced, in which case it is marked un-referenced and moved to the back of the queue.

Newly loaded page frames are shown in bold.

The "frame queue" column shows the FIFO queue of page frames explicitly, together with the "recently used" state of each frame. The next page fault will evict the frame at the head of the queue unless it is marked referenced. The contents of this column are equivalent to the subscript notation. You would not need to produce both formats under exam conditions.

In cases where the page fault first requires adjustment of the FIFO queue to move "2nd chance" frames to the back, it is shown in the table as 2 rows. (You can combine both rows if you want to under exam conditions.)

Note how when a page is referenced without causing a page fault (*e.g.* when 11 is referenced on line 4 of the table), the **order** of the FIFO queue is not changed.

next	A	B	C	D	E	frame queue	
	$\mathbf{1_1}$⊠	$\mathbf{2_2}$⊠	$\mathbf{11_3}$⊠	$\mathbf{6_4}$⊠	$\mathbf{9_5}$⊠	[A⊠B⊠C⊠D⊠E⊠]	
5	1_1□	2_2□	11_3□	6_4□	9_5□	[A□B□C□D□E□]	unmark all frames
5	$\mathbf{5_6}$⊠	2_2□	11_3□	6_4□	9_5□	[B□C□D□E□A⊠]	
11	5_6⊠	2_2□	11_3⊠	6_4□	9_5□	[B□C⊠D□E□A⊠]	
2	5_6⊠	2_2⊠	11_3⊠	6_4□	9_5□	[B⊠C⊠D□E□A⊠]	
3	5_6⊠	2_7□	11_8□	6_4□	9_5□	[D□E□A⊠B□C□]	ref'd frames to back of queue
3	5_6⊠	2_7□	11_8□	$\mathbf{3_9}$⊠	9_5□	[E□A⊠B□C□D⊠]	
15	5_6⊠	2_7□	11_8□	3_9⊠	$\mathbf{15_{10}}$⊠	[A⊠B□C□D⊠E⊠]	
14	5_{11}□	2_7□	11_8□	3_9⊠	15_{10}⊠	[B□C□D⊠E⊠A□]	ref'd frames to back of queue
14	5_{11}□	$\mathbf{14_{12}}$⊠	11_8□	3_9⊠	15_{10}⊠	[C□D⊠E⊠A□B⊠]	
2	5_{11}□	14_{12}⊠	$\mathbf{2_{13}}$⊠	3_9⊠	15_{10}⊠	[D⊠E⊠A□B⊠C⊠]	
11	5_{11}□	14_{12}⊠	2_{13}⊠	3_{14}□	15_{15}□	[A□B⊠C⊠D□E□]	ref'd frames to back of queue
11	$\mathbf{11_{16}}$⊠	14_{12}⊠	2_{13}⊠	3_{14}□	15_{15}□	[B⊠C⊠D□E□A⊠]	
1	11_{16}⊠	14_{17}□	2_{18}□	3_{14}□	15_{15}□	[D□E□A⊠B□C□]	ref'd frames to back of queue
1	11_{16}⊠	14_{17}□	2_{18}□	$\mathbf{1_{19}}$⊠	15_{15}⊠	[E□A⊠B□C□D⊠]	
6	11_{16}⊠	14_{17}□	2_{18}□	1_{19}⊠	$\mathbf{6_{20}}$⊠	[A⊠B□C□D⊠E⊠]	
17	11_{21}□	14_{17}□	2_{18}□	1_{19}⊠	6_{20}⊠	[B□C□D⊠E⊠A□]	ref'd frames to back of queue
17	11_{21}□	$\mathbf{17_{22}}$⊠	2_{18}□	1_{19}⊠	6_{20}⊠	[C□D⊠E⊠A□B⊠]	
2	11_{21}□	17_{22}⊠	2_{18}⊠	1_{19}⊠	6_{20}⊠	[C⊠D⊠E⊠A□B⊠]	

5 initial + 9 subsequent page faults

4. Least Recently Used (LRU)

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

Subscript indicates time of last reference. When a page fault occurs, evict the page with lowest number. Make sure to update the time of reference when a non-page fault occurs (*e.g.* when page 11 is referenced on line 3 of the table).

next	A	B	C	D	E
	$\mathbf{1_1}$	$\mathbf{2_2}$	$\mathbf{11_3}$	$\mathbf{6_4}$	$\mathbf{9_5}$
5	$\mathbf{5_6}$	2_2	11_3	6_4	9_5
11	5_6	2_2	$11_\mathbf{7}$	6_4	9_5
2	5_6	$2_\mathbf{8}$	11_7	6_4	9_5
3	5_6	2_8	11_7	$\mathbf{3_9}$	9_5
15	5_6	2_8	11_7	3_9	$\mathbf{15_{10}}$
14	$\mathbf{14_{11}}$	2_8	11_7	3_9	15_{10}
2	14_{11}	$2_\mathbf{12}$	11_7	3_9	15_{10}
11	14_{11}	2_{12}	$11_\mathbf{13}$	3_9	15_{10}
1	14_{11}	2_{12}	11_{13}	$\mathbf{1_{14}}$	15_{10}
6	14_{11}	2_{12}	11_{13}	1_{14}	$\mathbf{6_{15}}$
17	$\mathbf{17_{16}}$	2_{12}	11_{13}	1_{14}	6_{15}
2	17_{16}	$2_\mathbf{17}$	11_{13}	1_{14}	6_{15}

5 initial + 7 subsequent page faults

5. Clock replacement

$$1, 2, 11, 6, 9, 5, 11, 2, 3, 15, 14, 2, 11, 1, 6, 17, 2$$

The "clock hand" column shows the position of the clock hand immediately **after** the frames are in the state shown on the row. "Ticks" are the steps forward made by the clock hand to get to the new position (so 5 ticks is a complete revolution of the clock).

In cases where a page fault results in a complete revolution of the clock, it is shown in the table as two rows. (You may combine these into a single row under exam conditions if you want.)

Note that in cases where a page reference does not result in a page fault (*e.g.* where page 11 is referenced on line 4 of the table), the clock hand does not move at all.

next	A	B	C	D	E	clock hand	
	1⊠	**2**⊠	**11**⊠	**6**⊠	**9**⊠	A	
5	1□	2□	11□	6□	9□	A	5 ticks
5	**5**⊠	2□	11□	6□	9□	B	1 tick
11	5⊠	2□	11⊠	6□	9□	B	
2	5⊠	2⊠	11⊠	6□	9□	B	
3	5⊠	2□	11□	**3**⊠	9□	E	3 ticks
15	5⊠	2□	11□	3⊠	**15**⊠	A	1 tick
14	5□	**14**⊠	11□	3⊠	15⊠	C	2 ticks
2	5□	14⊠	**2**⊠	3⊠	15⊠	D	1 tick
11	**11**⊠	14⊠	2⊠	3□	15□	B	3 ticks
1	11⊠	14□	2□	**1**⊠	15□	E	3 ticks
6	11⊠	14□	2□	1⊠	**6**⊠	A	1 tick
17	11□	**17**⊠	2□	1⊠	6⊠	C	2 ticks
2	11□	17⊠	2⊠	1⊠	6⊠	C	

5 initial + 9 subsequent page faults

Comparison of Clock and FIFO+2nd chance: If you look carefully you will see that the Clock and FIFO+2nd chance algorithms have identical behaviour in terms of the order that pages are replaced. If you look at the head of the FIFO queue at each point, you will see that it is the same as the "hand" of the clock algorithm, and the number of "ticks" is how far you advance along the queue at each stage.

Clock and FIFO+2nd chance are simply different implementations of the same algorithm. In practice it is usually simpler/cheaper/faster to implement the clock algorithm.