

1. **Answer:**

a)

- Relative address is  $5499 = 5 \times 1024 + 379$ , i.e., virtual address is 5, 379
- Virtual address in binary is 0000 0001 01 01 0111 1011
- Map to frame number 2
- The physical address is 0000 10 01 0111 1011

b)

- Relative address is  $2221 = 2 \times 1024 + 173$ , i.e., virtual address is 2, 173
- Virtual address in binary is 0000 0000 10 00 1010 1101
- The page has not been loaded into memory yet, resulting in a page fault

2. **Answer:**a) A frame has the same size as a page,  $1 \text{ KB} = 2^{10}$  bytesb)  $2^{32}$  bytes = 4 GBc) The maximum number of pages in the virtual address space is  $2^{32} / 2^{10} = 2^{22}$ . There is one entry for each page. Therefore, there are  $2^{22}$  entries.

d)

- The 1<sup>st</sup> level page table size will be  $2^{22} \times 2^2$  bytes.
- The 1<sup>st</sup> level page table can be divided into  $(2^{24} \text{ bytes of page table}) / (2^{10} \text{ bytes/page}) = 2^{14}$  **pages**.
- The 2<sup>nd</sup> level page table size will be  $2^{14} \times 2^2 = 2^{16}$  bytes.
- The 2<sup>nd</sup> level page table can be further divided into  $(2^{16} \text{ bytes of page table}) / (2^{10} \text{ bytes/page}) = 2^6$  **pages**.
- The 3<sup>rd</sup> level page table size will be  $2^6 \times 2^2 = 2^8$  bytes, which can be fit into **one single page**.

Therefore, 3 levels of page tables are needed, with the size of 1 page, 64 ( $2^6$ ) pages, and 16,384 ( $2^{14}$ ) pages respectively.

3. **Answer:**a)  $2\text{K} \times 8 = 16\text{KB}$ b)  $16\text{K} \times 4 = 64\text{KB}$

4. **Answer:**

a) **OPT:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	2	2	2	2	2	2
	0	0	0	0	0	0	4	4	4	0	0	0
		1	1	1	3	3	3	3	3	3	3	3
F	F	F	F		F		F			F		

number of page faults = 7

b) **FIFO:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	4	4	4	0	0	0
	0	0	0	0	3	3	3	2	2	2	2	2
		1	1	1	1	0	0	0	3	3	3	3
F	F	F	F		F	F	F	F	F	F		

number of page faults = 10

c) **LRU:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7	7	7	2	2	2	2	4	4	4	0	0	0
	0	0	0	0	0	0	0	0	3	3	3	3
		1	1	1	3	3	3	2	2	2	2	2
F	F	F	F		F		F	F	F	F		

number of page faults = 9

d) **Clock:**

7	0	1	2	0	3	0	4	2	3	0	3	2
7*	7*	→7*	2*	2*	→2*	→2*	4*	4*	4*	→4	3*	3*
→	0*	0*	→0	→0*	0	0*	→0	2*	2*	2	→2	→2*
	→	1*	1	1	3*	3*	3	→3	→3*	0*	0*	0*
F	F	F	F		F		F	F		F	F	

number of page faults = 9

### Self-test

1. C
2. C
3. B
4. A
5. D
6. C