1 End-to-end Address Translation

Consider a simplified system with a TLB, an L1 d-cache, and the following properties

- The memory is byte addressable.
- Memory accesses are to **1-byte words** (not 4-byte words).
- Virtual addresses are 14 bits wide ($n = 14$).
- Physical addresses are 12 bits wide ($m = 12$).
- The page size is 64 bytes = 2^6.
- The TLB is 4-way set associative with 16 total entries.
- The L1 d-cache is physically addressed and direct mapped, with a 4-byte line size and 16 total sets.

In the following tables, **all numbers are given in hexadecimal**. The contents of the TLB and the page table for the first 16 page table entries (PTEs) are as follows:

TLB			
Index	Tag	PPN	Valid
0	03	–	0
	09	0D	1
	00	–	0
	07	02	1
1	03	2D	1
	02	–	0
	04	–	0
	0A	–	0
2	02	–	0
	08	–	0
	06	–	0
	03	–	0
3	07	–	0
	03	0D	1
	0A	34	1
	02	–	0

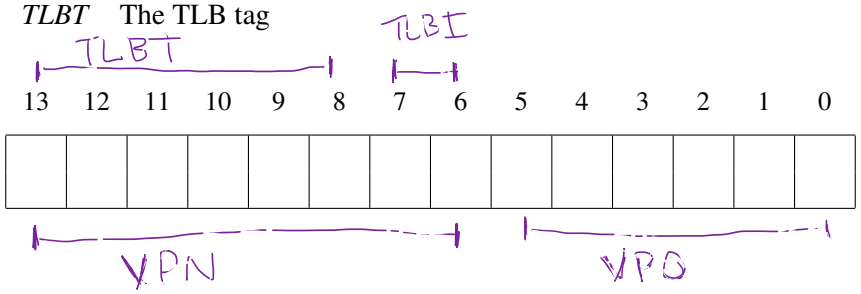
Page Table		
VPN	PPN	Valid
00	28	1
01	–	0
02	33	1
03	02	1
04	–	0
05	16	1
06	–	0
07	–	0
08	13	1
09	17	1
0A	09	1
0B	–	0
0C	–	0
0D	2D	1
0E	11	1
0F	0D	1

Cache						
Index	Tag	Valid	B0	B1	B2	B3
0	19	1	99	11	23	11
1	15	0	–	–	–	–
2	1B	1	00	02	04	08
3	36	0	–	–	–	–
4	32	1	43	6D	8F	09
5	0D	1	36	72	F0	1D
6	31	0	–	–	–	–
7	16	1	11	C2	DF	03
8	24	1	3A	00	51	89
9	2D	0	–	–	–	–
A	2D	1	93	15	DA	3B
B	0B	0	–	–	–	–
C	12	0	–	–	–	–
D	16	1	04	96	34	15
E	13	1	83	77	1B	D3
F	14	0	–	–	–	–

Answer the following questions using this information.

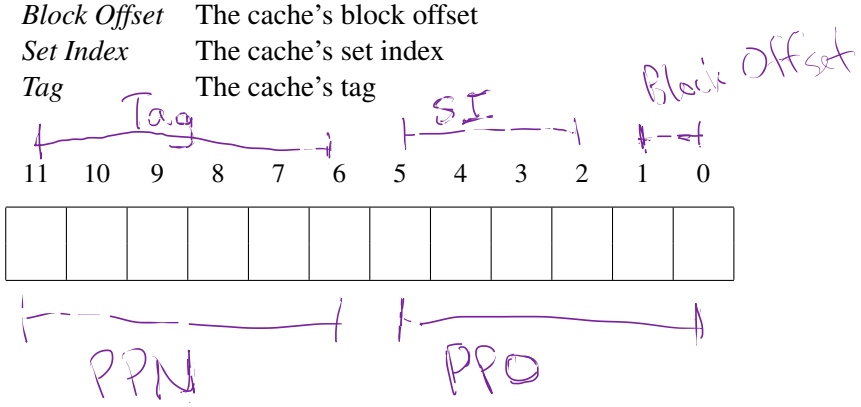
- The box below shows the format of a virtual address. Indicate (by labeling the diagram) the fields (if they exist) that would be used to determine the following: (If a field doesn't exist, don't draw it on the diagram.)

VPO	The virtual page offset
VPN	The virtual page number
TLBI	The TLB index
TLBT	The TLB tag



- The box below shows the format of a physical address. Indicate (by labeling the diagram) the fields that would be used to determine the following:

PPO	The physical page offset
PPN	The physical page number
Block Offset	The cache's block offset
Set Index	The cache's set index
Tag	The cache's tag

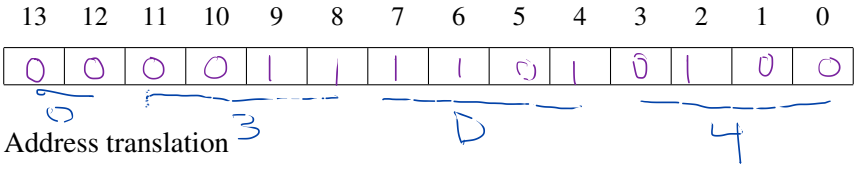


For the given virtual addresses (continued on the next page), indicate the TLB entry accessed and the physical address. Indicate whether the TLB misses and whether a page fault occurs.

If there is a page fault, enter "-" for "PPN" and leave part C blank.

Virtual address: `0x03D4`

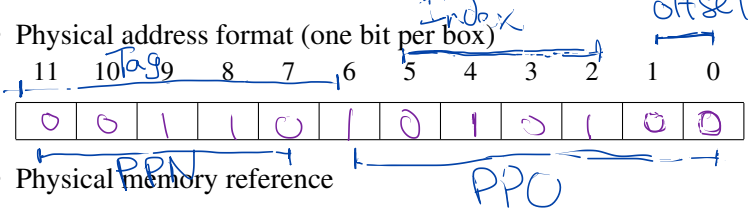
- Virtual address format (one bit per box)



- Address translation

Parameter	Value
VPN	0x 0F
VPO	0x 14
TLB Index	0x 03
TLB Tag	0x 03
TLB Hit? (Y/N)	Y
Page Fault? (Y/N)	N
PPN	0x 0D
PPO	0x 14

- Physical address format (one bit per box)



- Physical memory reference

Parameter	Value
Byte offset	0x0
Cache Index	0x 5
Cache Tag	0x 0D
Cache Hit? (Y/N)	Y
Cache byte returned	0x 36