

Paging: Smaller Tables

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- 1 With a linear page table, you need a single register to locate the page table, assuming that hardware does the lookup upon a TLB miss. How many registers do you need to locate a two-level page table? A three-level table?**

Only one. Only a reference to the page directory is needed in addition to the virtual address, since every level of the page table contains enough information to construct a reference to the next level down.

- 2 Use the simulator to perform translations given random seeds 0, 1, and 2. How many memory references are needed to perform each lookup?**

If all entries are valid, three memory references are needed for a lookup: one in the page directory, one in the page table, and one at the physical address

2.1

VA 611c

Upper five bits: 11000 = 0d24 (page directory entry) Pde contents: 0xa1 = 0b10100001. Valid bit set. Page frame number: 0100001 = 0d33

Next five bits: 01000 = 0d8 (page table entry) Pte contents: 0xb5 = 0b10110101. Valid bit set. Physical frame number: 0b0110101 = 0d53

Last five bits: 11100 = 0d28 (offset)

Physical address: 0x6bc Physical address contents: 0x08

VA 3da8

Upper five bits: 01111 = 0d15 (page directory entry) Pde contents: 0xd6 = 0b11010110. Valid bit set. Page frame number: 0b1010110 = 0d86
Next five bits: 01101 = 0d13 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault

VA 17f5

Upper five bits: 00101 = 0d5 (page directory entry) Pde contents: 0xd4 = 0b11010100 Valid bit set. Page frame number: 1010100 = 0d84
Next five bits: 11111 = 0d31 (page table entry) Pte contents: 0xce = 0b11001110.
Valid bit set. Physical frame number: 0b1001110 = 0d78
Last five bits: 10101 = 0d21 (offset)

Physical address: 0x9d5 Physical address contents: 0x1c

VA 7f6c

Upper five bits: 11111 = 0d31 (page directory entry) Pde contents: 0xff = 0b11111111. Valid bit set. Page frame number: 1111111 = 0d127
Next five bits: 11011 = 0d27 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

VA 0bad

Upper five bits: 00010 = 0d2 (page directory entry) Pde contents: 0xe0 = 0b11100000. Valid bit set. Page frame number: 1100000 = 0d96
Next five bits: 11101 = 0d29 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

VA 6d60

Upper five bits: 11011 = 0d27 (page directory entry) Pde contents: 0xc2 = 0b11000010. Valid bit set. Page frame number: 1000010 = 0d66
Next five bits: 01011 = 0d11 (page table entry) Pte contents: 0xf7 = 0d01111111.
Valid bit not set. Fault.

VA 2a5b

Upper five bits: 01010 = 0d10 (page directory entry) Pde contents: 0xd5 = 0b11010101. Valid bit set. Page frame number: 1010101 = 0d85
Next five bits: 10010 = 0d18 (page table entry) Pte contents: 0x7f = 0d01111111.
Valid bit not set. Fault.

VA 4c5e

Upper five bits: 10011 = 0d19 (page directory entry) Pde contents: 0xf8 = 0b11111000 Valid bit set. Page frame number: 1111000 = 0d120
Next five bits: 00010 = 0d2 (page table entry) Pte contents: 0x7f = 0d01111111.
Valid bit not set. Fault.

VA 2592

Upper five bits: 01001 = 0d9 (page directory entry) Pde contents: 0x9e =

0b10011110. Valid bit set. Page frame number: 0011110 = 0d30
Next five bits: 01100 = 0d12 (page table entry) Pte contents: 0xbd = 0b10111101.
Valid bit set. Physical frame number: 0b0111101 = 0d61
Last five bits: 10010 = 0d18 (offset)

Physical address: 0x7b2 Physical address contents: 0x1b

VA 3e99

Upper five bits: 01111 = 0d15 (page directory entry) Pde contents: 0xd6 = 0b11010110. Valid bit set. Page frame number: 1010110 = 0d86
Next five bits: 10100 = 0d20 (page table entry) Pde contents: 0xca = 0b11001010
Valid bit set. Physical frame number: 0b1001010 = 0d74
Last five bits: 11001 = 0d25 (offset)

Physical address: 0x959 Physical address contents: 0x1e

2.2

VA 6c74

Upper five bits: 11011 = 0d27 (page directory entry) Pde contents: 0xa0 = 0b10100000 Valid bit set. Page frame number: 0100000 = 0d32
Next five bits: 00011 = 0d3 (page table entry) Pte contents: 0xe1 = 0b11100001
Valid bit set. Physical frame number: 0b1100001 = 0d97
Last five bits: 10100 = 0d20 (offset)

Physical address: 0xc34 Physical address contents: 0x06

VA 6b22

Upper five bits: 11010 = 0d26 (page directory entry) Pde contents: 0xd2 = 0b11010010 Valid bit set. Page frame number: 1010010 = 0d82
Next five bits: 11001 = 0d25 (page table entry) Pte contents: 0xc7 = 0b11000111
Valid bit set. Physical frame number: 0b1000111 = 0d71
Last five bits: 00010 = 0d2 (offset)

Physical address: 0x8e2 Physical address contents: 0x1a

VA 03df

Upper five bits: 00000 = 0d0 (page directory entry) Pde contents: 0xda = 0b11011010 Valid bit set. Page frame number: 1011010 = 0d90
Next five bits: 11110 = 0d30 (page table entry) Pte contents: 0x85 = 0b10000101
Valid bit set. Physical frame number: 0b0000101 = 0d5
Last five bits: 11111 = 0d31 (offset)

Physical address: 0xbf Physical address contents: 0x0f

VA 69dc

Upper five bits: 11010 = 0d26 (page directory entry) Pde contents: 0xd2 = 0b11010010 Valid bit set. Page frame number: 1010010 = 0d82
Next five bits: 01110 = 0d14 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

VA 317a

Upper five bits: 01100 = 0d12 (page directory entry) Pde contents: 0x98 = 0b10011000 Valid bit set. Page frame number: 0011000 = 0d24
Next five bits: 01011 = 0d11 (page table entry) Pte contents: 0xb5 = 0b10110101
Valid bit set. Physical frame number: 0b0110101 = 0d53
Last five bits: 11010 = 0d26 (offset)

Physical address: 0x6ba Physical address contents: 0x1e

VA 4546

Upper five bits: 10001 = 0d17 (page directory entry) Pde contents: 0xa1 = 0b10100001 Valid bit set. Page frame number: 0100001 = 0d33
Next five bits: 01010 = 0d10 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

VA 2c03

Upper five bits: 01011 = 0d11 (page directory entry) Pde contents: 0xc4 = 0b11000100 Valid bit set. Page frame number: 1000100 = 0d68
Next five bits: 00000 = 0d0 (page table entry) Pte contents: 0xd7 = 0b11010111.
Valid bit set. Physical frame number: 0b1010111 = 0d87
Last five bits: 00011 = 0d3 (offset)

Physical address: 0xae3 Physical address contents: 0x16

VA 7fd7

Upper five bits: 11111 = 0d31 (page directory entry) Pde contents: 0x92 = 0b10010010 Valid bit set. Page frame number: 0010010 = 0d18
Next five bits: 11110 = 0d30 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

VA 390e

Upper five bits: 01110 = 0d14 (page directory entry) Pde contents: 0x7f = 0b01111111 Valid bit not set. Fault.

VA 748b 11101 00100 01011

Upper five bits: 11101 = 0d29 (page directory entry) Pde contents: 0x80 = 0b10000000 Valid bit set. Page frame number: 0000000 = 0d0
Next five bits: 00100 = 0d4 (page table entry) Pte contents: 0x7f = 0b01111111.
Valid bit not set. Fault.

2.3 Skipped

3 Given your understanding of how cache memory works, how do you think memory references to the page table will behave in the cache? Will they lead to lots of cache hits (and thus fast access)? Or lots of misses?

Memory references to the page table will be very fast, since they are accessed so frequently. The page directory is accessed every time there is a memory reference (unless the virtual address translation is already cached), and although the virtual address translations are spread between the different page tables, there are only a relatively small number of them, so their addresses will very likely be cached.