Two-Level Scheme for 32-bit Address

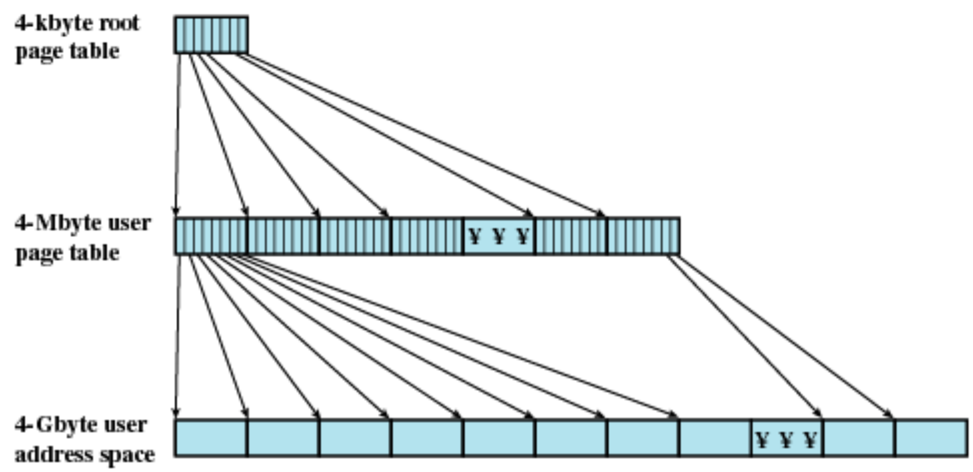


Figure 8.4 A Two-Level Hierarchical Page Table

Page Tables

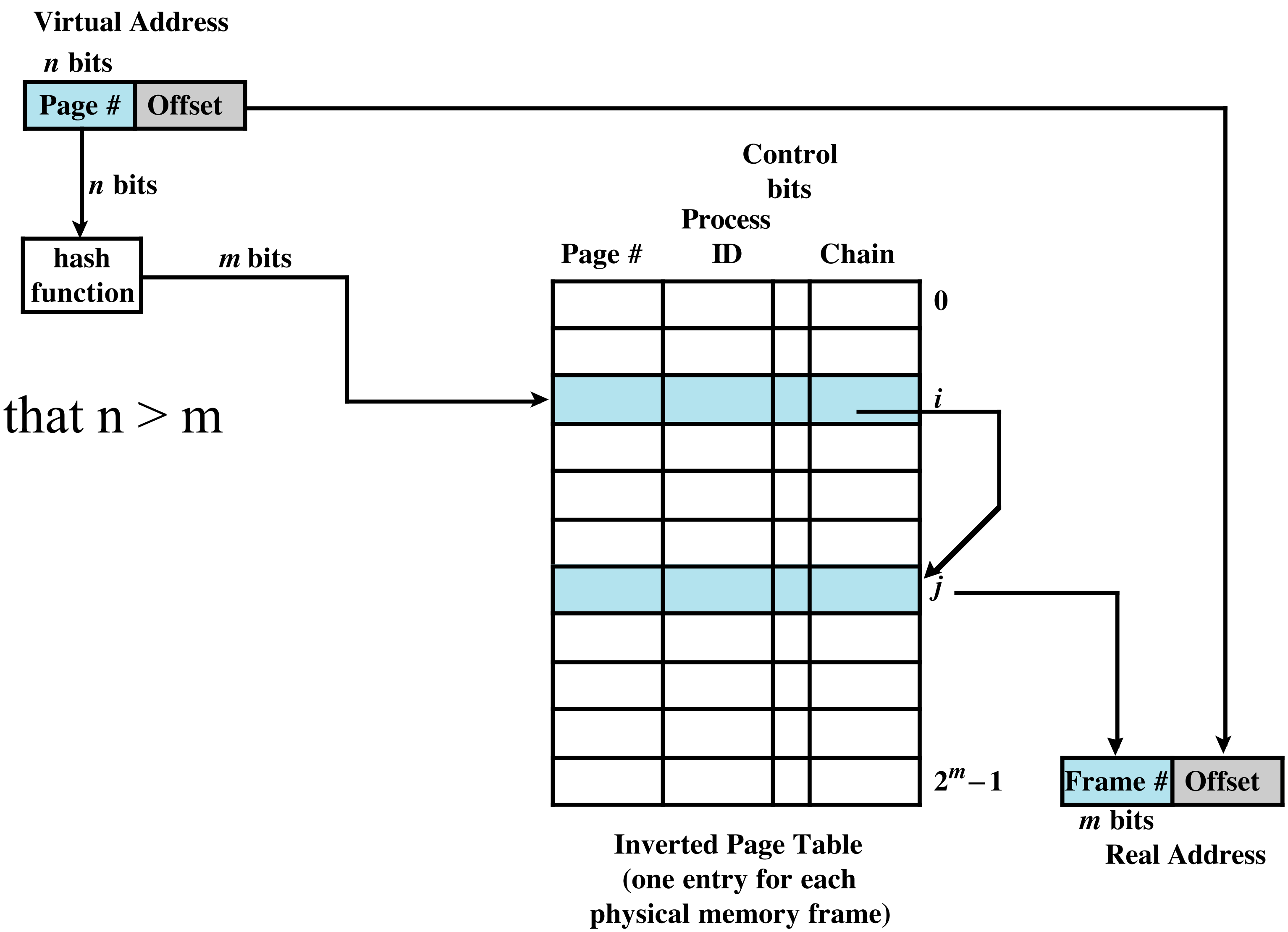
- The entire page table may take up too much main memory
- Page tables are also stored in virtual memory
- When a process is running, part of its page table is in main memory

Inverted Page Table

- Alternative to (multi-level) page table
  - Used on PowerPC, UltraSPARC, and IA-64 architecture
  - One entry in table for each physical memory frame
  - Page number portion of a virtual address is mapped to a hash value
  - Fixed proportion of real memory is required for the tables regardless of the number of processes

Inverted Page Table

- Page table entries:
  - Page number
  - Process identifier
  - Control bits
  - Chain pointer



Note that n > m

Figure 8.6 Inverted Page Table Structure

Translation Lookaside Buffer

- Each virtual memory reference can cause two physical memory accesses
  - One to fetch the page table
  - One to fetch the data
- To overcome this problem a high-speed cache is set up for page table entries
  - Called Translation Lookaside Buffer (TLB)

Translation Lookaside Buffer

- Contains page table entries that have been most recently used

Translation Lookaside Buffer

- Given a virtual address, processor examines the TLB
- If page table entry is present (TLB hit), the frame number is retrieved and the real address is formed
- If page table entry is not found in the TLB (TLB miss), the page number is used to index the process page table

Translation Lookaside Buffer

- First checks if page is already in main memory
  - If not in main memory a page fault is issued
- The TLB is updated to include the new page entry

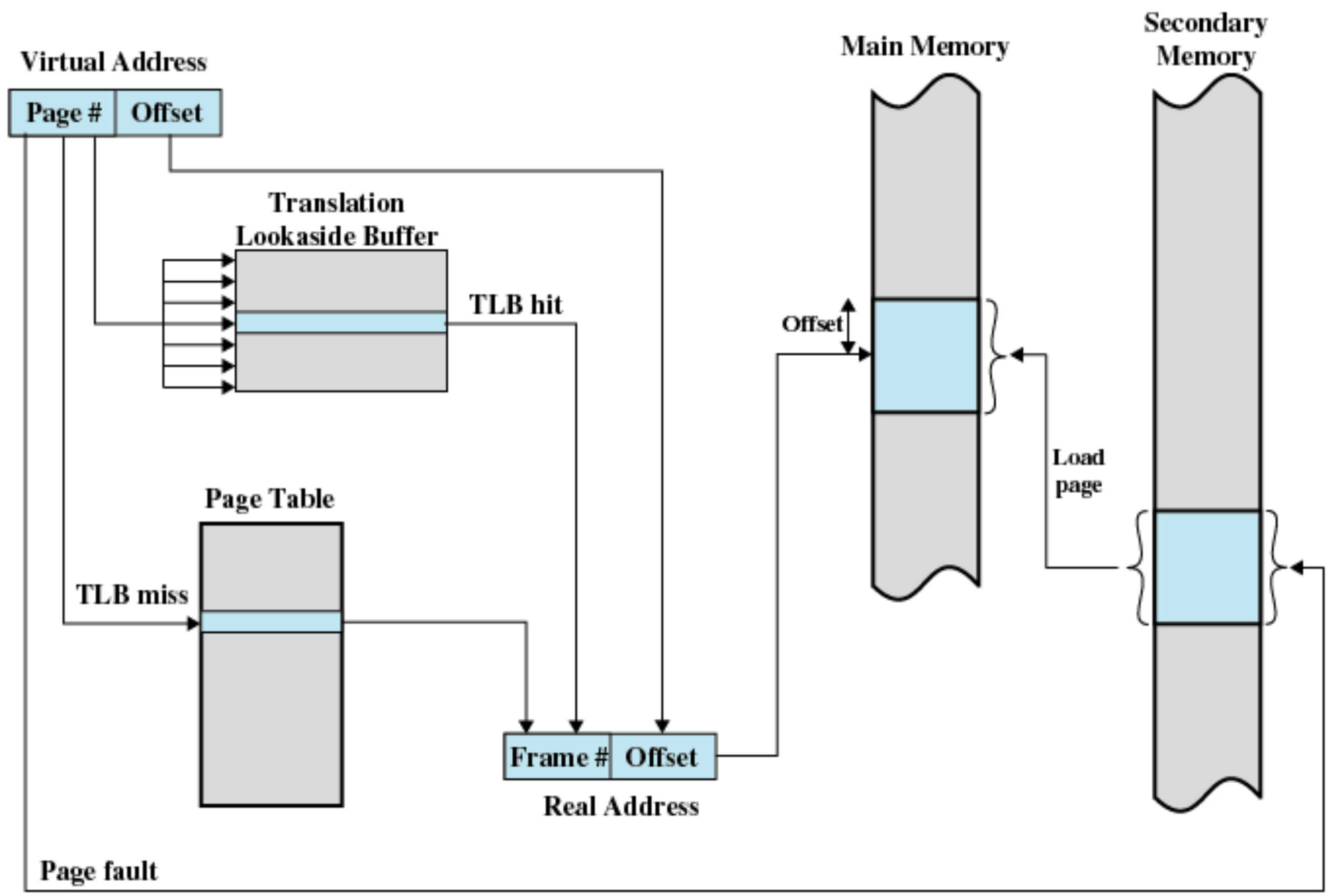


Figure 8.7 Use of a Translation Lookaside Buffer

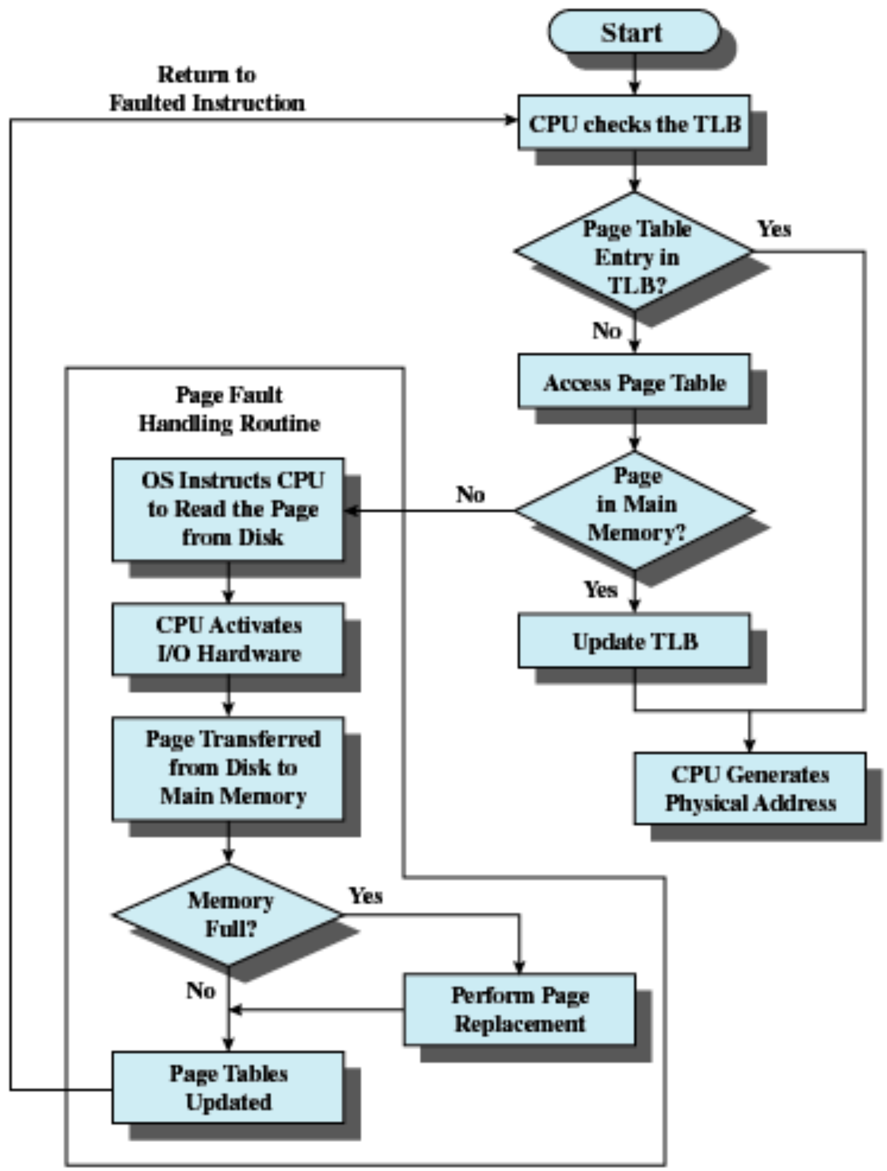


Figure 8.8 Operation of Paging and Translation Lookaside Buffer (TLB) [FURH87]

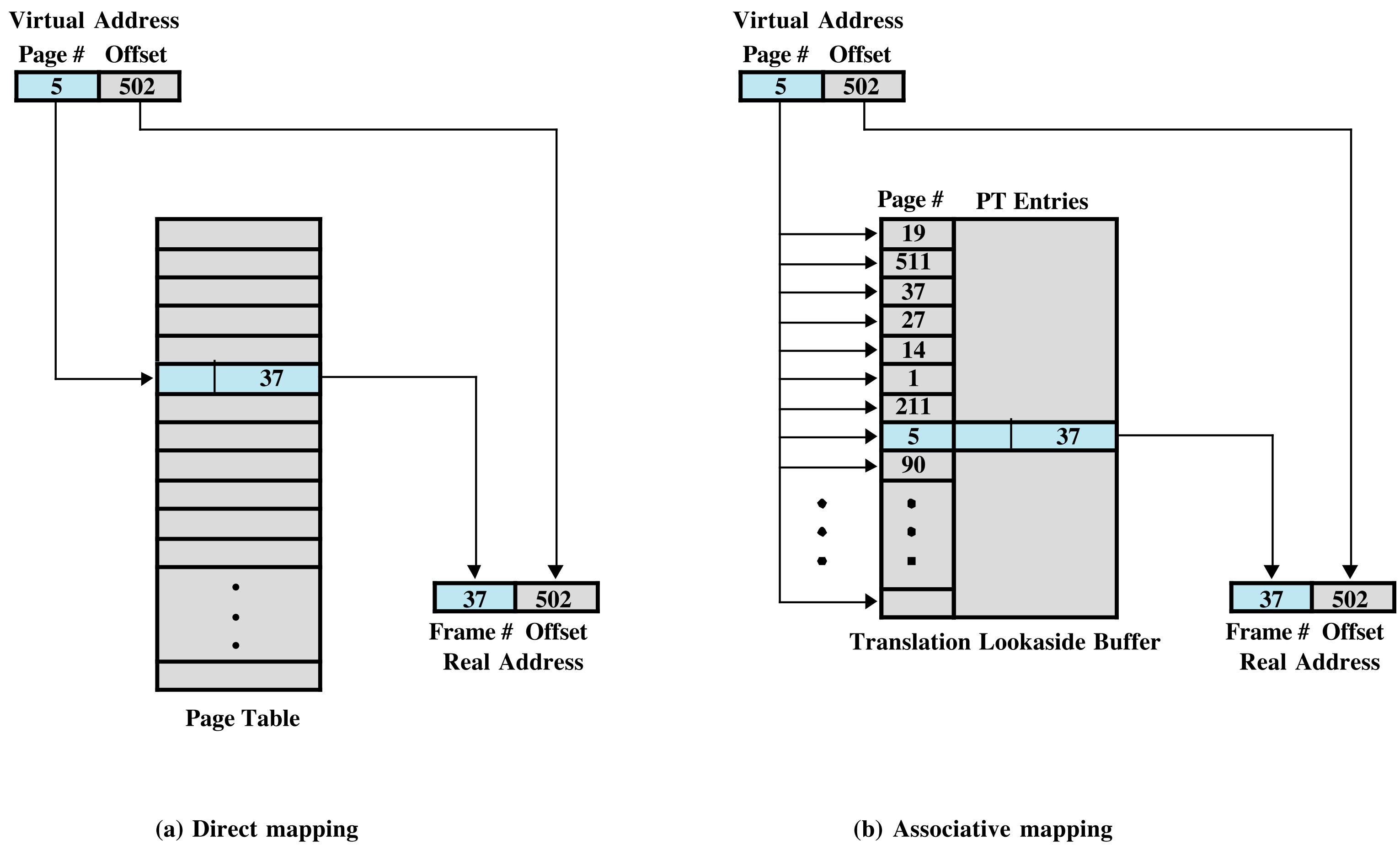


Figure 8.9 Direct Versus Associative Lookup for Page Table Entries

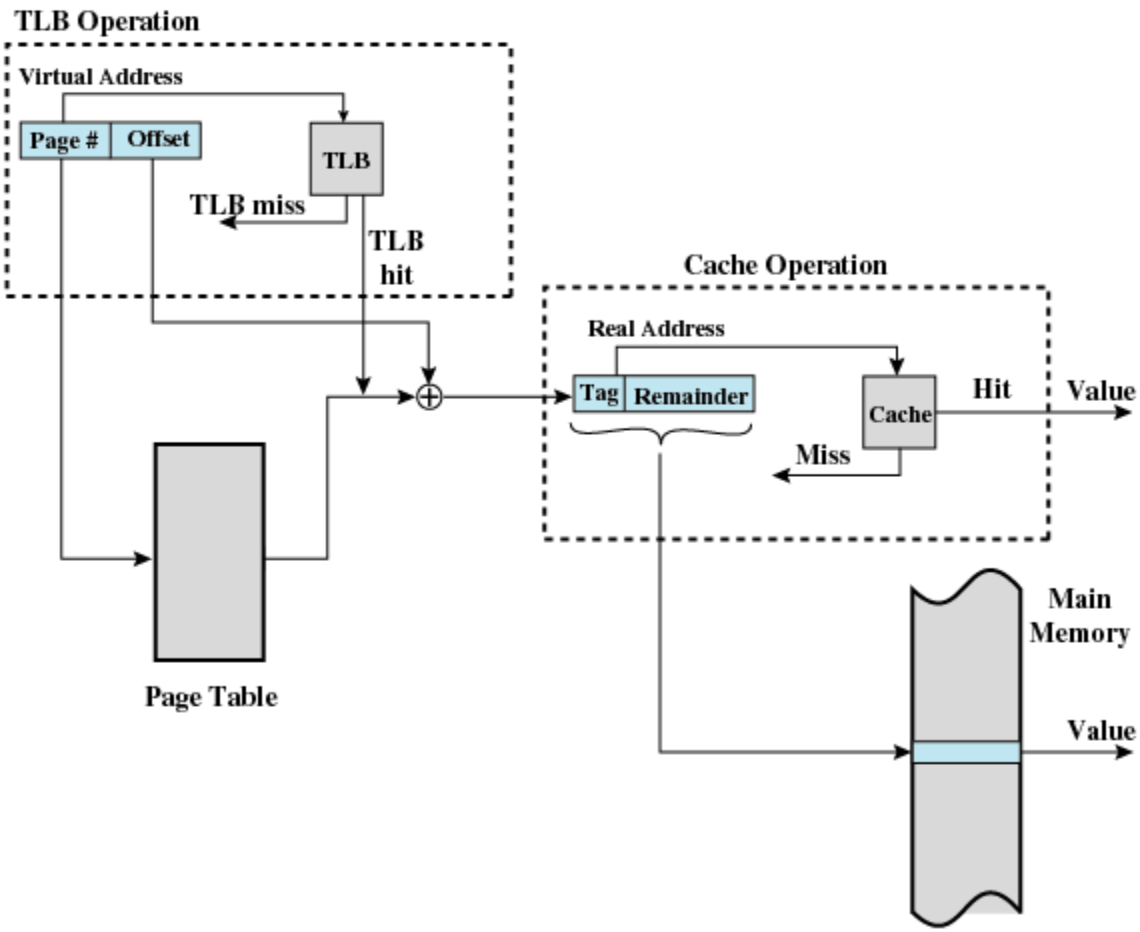


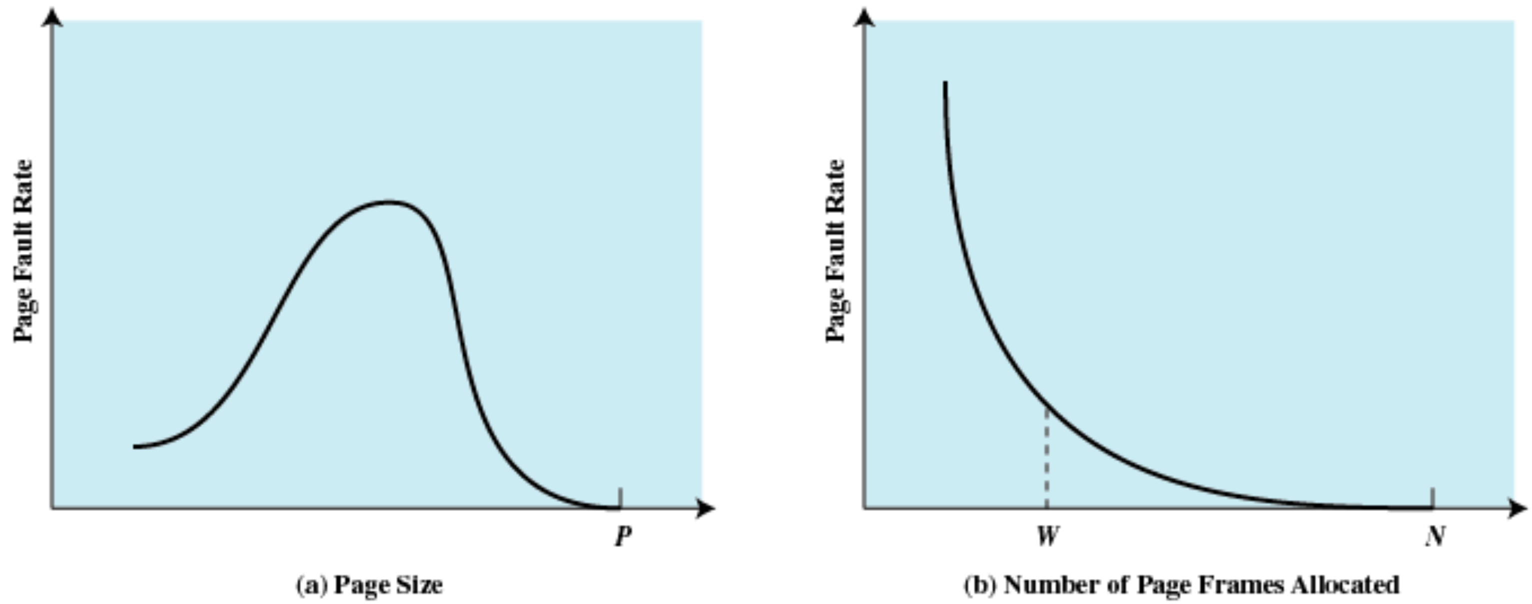
Figure 8.10 Translation Lookaside Buffer and Cache Operation

Page Size - A Tradeoff Space

- Smaller page size, less amount of internal fragmentation
- Smaller page size, more pages required per process
- More pages per process means larger page tables
- Larger page tables means large portion of page tables in virtual memory
- Secondary memory is designed to efficiently transfer large blocks of data so a large page size is better

Page Size

- Small page size, large number of pages will be found in main memory
- As time goes on during execution, the pages in memory will all contain portions of the process near recent references. Page faults low.
- Increased page size causes pages to contain locations further from any recent reference.



P = size of entire process
W = working set size
N = total number of pages in process

Figure 8.11 Typical Paging Behavior of a Program

Example Page Sizes

Table 8.2 Example Page Sizes

Computer	Page Size
Atlas	512 48-bit words
Honeywell-Multics	1024 36-bit word
IBM 370/XA and 370/ESA	4 Kbytes
VAX family	512 bytes
IBM AS/400	512 bytes
DEC Alpha	8 Kbytes
MIPS	4 kbyes to 16 Mbytes
UltraSPARC	8 Kbytes to 4 Mbytes
Pentium	4 Kbytes or 4 Mbytes
PowerPc	4 Kbytes
Itanium	4 Kbytes to 256 Mbytes