Making Address Translation Fast

• Page tables are stored in main memory.
• Memory access requires two accesses:
  – Access to obtain the physical address from page table
  – Access to get data or instruction from main memory
• This two access approach needs improvement.
Translation-Lookaside Buffer (TLB)

• A special cache that keeps track of recently used translations.
• The TLB corresponds to that little piece of memo paper we typically use to record the location of a set of books from the card catalog.
• The size of TLB is typically 16 – 512 entries.
TLB Operation (1)

• On every reference, the tags (virtual page numbers) in the TLB are searched.
• If it is a hit in TLB, the physical page number is used to form the address, and the reference bit is turned on.
• If the processor is performing a write, a dirty bit is turned on.
TLB Operation (2)

• If a miss in the TLB occurs, the page table is searched:
  – If it is a hit in the page table, the page exists in the physical memory and the TLB is updated.
  – If it is a miss, the page does not exist in the main memory and a page fault exception is evoked.
virtual address

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Page NO  Page offset

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Tag

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Valid bit/Tag

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physical page address

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TLB

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If TLB miss

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Page Table

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valid bit/pdf physical page address

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Page Number  Page offset

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If page table miss, a page fault occurs.
Redundant Arrays of Inexpensive Disks (RAID)

• In the late 1980s, the high performance storage of choice was large, expensive disks.
• Recently, the design choice was shifted to use of many small disks to improve the performance.
RAID

- In order to cope with disk failures, disk redundancy was added.
- The cost of extra redundancy is more affordable for small disks.
- RAID --- (1) improved performance by parallel data loading, (2) improved reliability by disk redundancy.
RAID-0: No redundancy, just striping

- Popularly used because RAID-0 is left to the operator to set when creating a storage system.
RAID-1: Mirroring

- Uses twice as many disks as does in RAID-0.
- Whenever data is written to one disk, that data is also written to a redundant disk.
- If a disk fails, the system reads the mirror disk.
- Hot swap is possible.
- Most expensive.
RAID-2: Error Detecting/Correcting Code

- Single error correction, two-bit error detection requires bit distance of 3.
- Rarely used.
RAID-3: Bit-interleaved Parity

- When one disk fails, lost disk is recovered by the bits in the P disk.
RAID-3 drawback

- Requires read access of all disks.
RAID-4: Block Interleaved Parity

- No need to access D1, D2, and D3. Involve only two disks.
RAID-4: Block Interleaved Parity, Drawback

- The parity disk must be accessed on every write.
RAID-5: Distributed Block Interleaved Parity

- Parity data is distributed to all disks. (widely used)
RAID-6: P+Q Redundancy

• Allows recovery from a second disk failure.

\[
P = D_0 \oplus D_1 \oplus D_2 \oplus D_3
\]

\[
Q = g^0 D_0 \oplus g^1 D_1 \oplus g^2 D_2 \oplus g^3 D_3
\]

\(g : Galois\_Field\)
Nested RAID Levels
RAID-10: Striping of Mirroring
RAID-01: Mirroring of Striping
RAID-51: Mirroring of Distributed Block Interleaved Parity
RAID-101: ?