x86 Page Table

• In x86:
  – Pages are 4 KB in size
  – Virtual Addresses are 32-bits
  – Each PTE is 4 B in size

• How large is the Page Table for each process?
Multi-Level Page Table

• **Solution**: Create multiple levels of tables to look up a physical memory address.
Multi-Level Page Tables

- Each virtual address can now be divided into \((n+1)\) different pieces for an \((n)\) level page table.
  
  - **Example:** Two Level Page Table:
    - First Level Page Number
    - Second Level Page Number
    - Page Offset
• Given
  – 32-bit Virtual Addresses
  – 4 KB Pages
  – 12-bit First Level Page Table Number

• What are the components of the address: 0x48503423
• Given
  – 32-bit Virtual Addresses
  – 64 KB Pages
  – 8-bit First Level Page Table Number

• What are the components of the address: 0x48503423
• Given
  – 32-bit Virtual Addresses
  – 4 KB Pages
  – 4 B page table entries

• If every-level page table fits into a single page:
  – How many levels are in the page table?
  – How many bits is the index of each level?
• Given:
  – Each PTE is 16 B
  – The pointer to top-level of the page table is 0x1000.
  – *: “PTE Contents” shows the contents of the memory if it was read as a PTE, and only shows the address field of the PTE.

• Q: On system with a single-level page table and 256 B pages:
  – What is the physical address of the virtual address 0x241?
• **Given:**
  
  – Each PTE is 16 B
  – The pointer to top-level of the page table is **0x1000**.
  – *: “PTE Contents” shows the contents of the memory if it was read as a PTE, and only shows the address field of the PTE.

• **Q:** On system with a two-level page table where the index of each level is 4-bits:
  
  – What is the physical address of the virtual address **0x1234**?
Fragmentation

• Throughout all of memory, we have **completely unused space** that we call fragmentation.
  
  – **Internal Fragmentation**: Allocated memory that is never used by the algorithm.
    • Ex: Buddy system using 32 B for a 18 B request
    • *Not the same thing as overhead!*

  – **External Fragmentation**: Unallocated memory, but too small to be useful.
    • Ex: A best-fit for a 72 B request may be 75 B.
      – The remaining 3 B is a very small hole, effectively useless.
Thrashing

- **Thrashing** occurs when a computer's virtual memory subsystem is in a constant state of paging, rapidly exchanging data in memory for data on disk.
Regions of Virtual Memory /process:

Strategies to manage the heap:

Two ways to map virtual memory to physical:

Virtual address components:

Contents of a PTE:

Page eviction strategies:

Vocab: