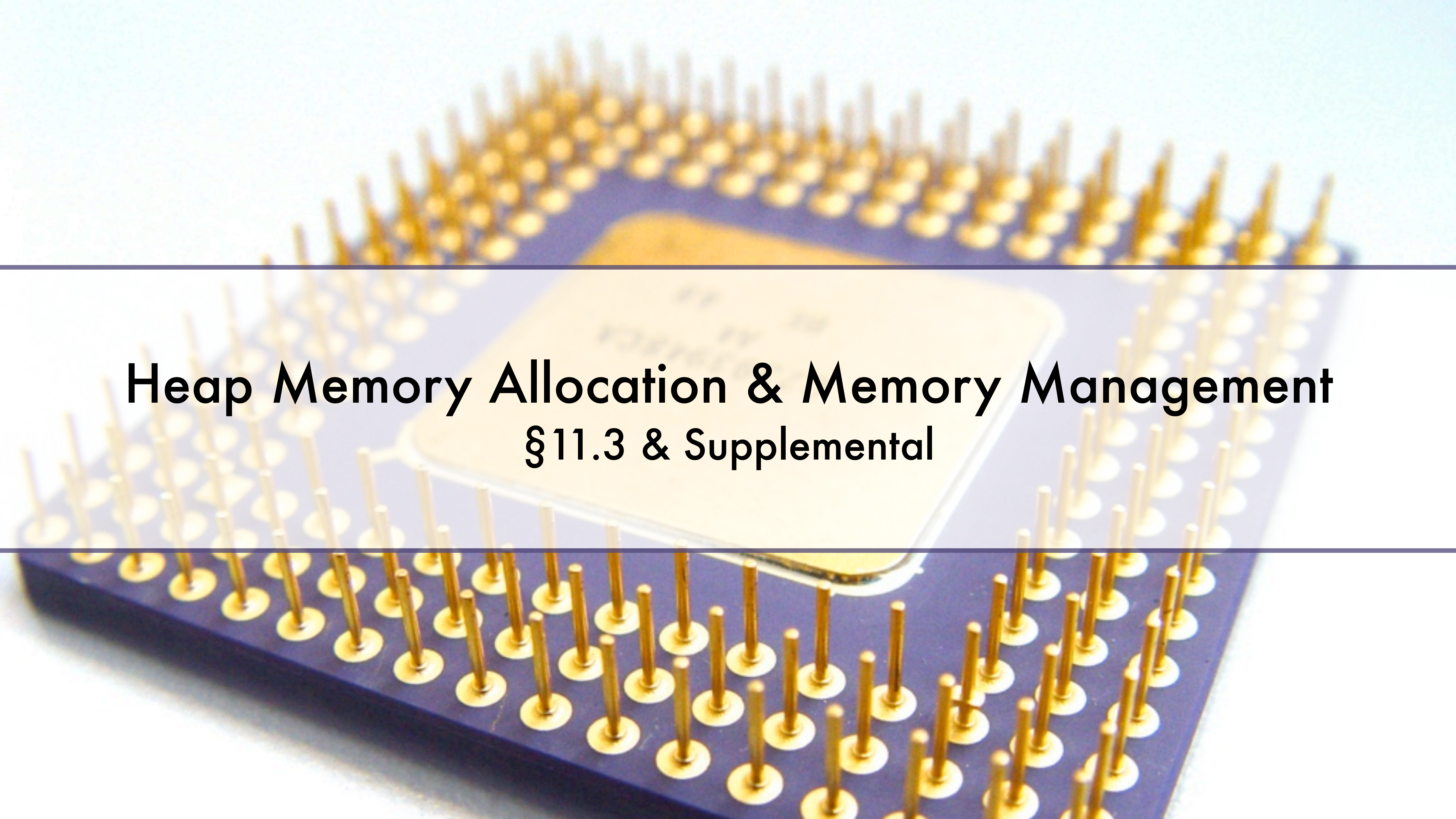
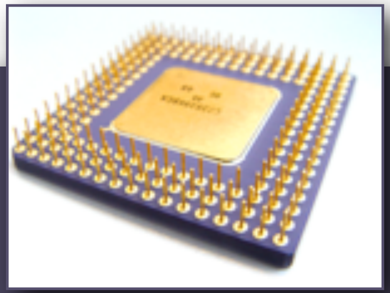


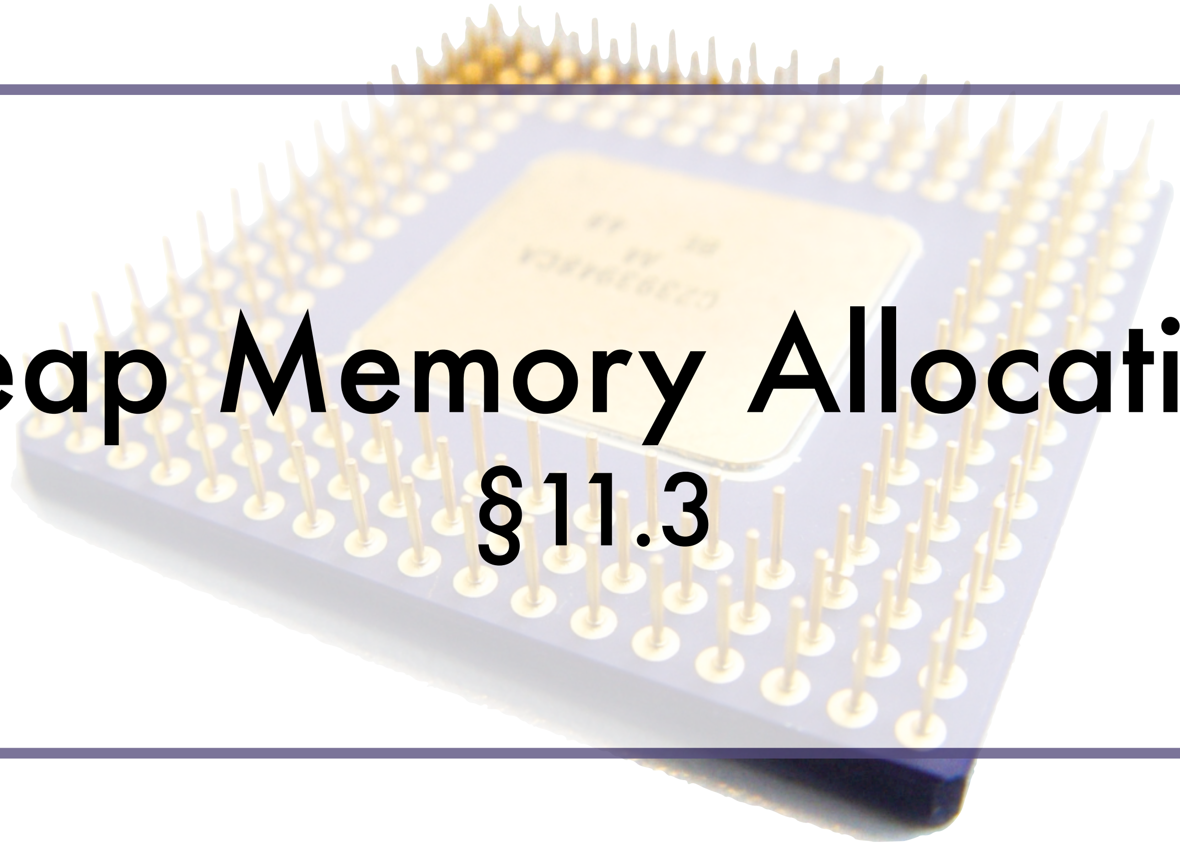
Heap Memory Allocation & Memory Management

§11.3 & Supplemental

Homework/Administrivia



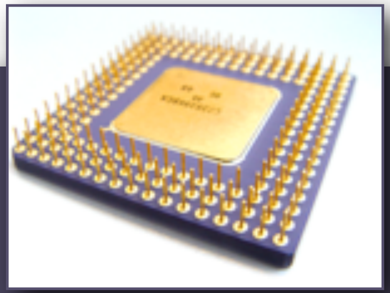
- **Floating Point:** You are only responsible for material from notes
  - Read §12.1–12.2 as necessary to understand that material; skip the parts we didn't cover
- **Read** §9.4.1–9.4.3 on two-dimensional arrays – *not covered in lecture*
- **Homework 6** – Due *this Sunday*, November 16, by 11:59 p.m. (sorry)
- **Exam 2 Bonus** next Friday, November 21, in class
  - Points possible: depends on your Exam 2 score. You can recover up to 30% of the points you missed. If you made ≥ 90%, it is worth 3 points.
    - Points possible = max(3, (100 – your score on Exam 2) × 0.3)
  - Score will be *added* to your Exam 2 score. If you don't take it, your Exam 2 score stays the same.
  - Topics: procedures/stack frames and memory operands
  - Only about half the length of a normal exam
  - Closed-book, closed-notes; no make-ups given after November 21 (only in advance)



Heap Memory Allocation

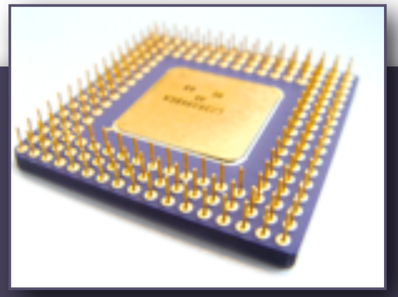
§11.3

Static vs. Dynamic Memory Allocation



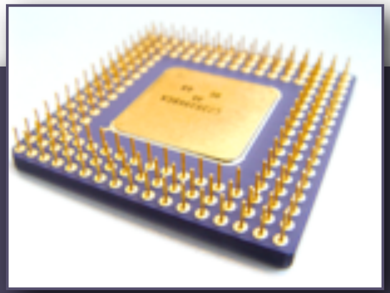
- **Statically allocated memory** is reserved when the program is compiled/assembled
  - Assembly: `.data` section (among others) is put directly into .exe file and loaded as-is
  - C++: global variables (among other things)
- **Dynamically allocated memory** is allocated while the program runs, as needed
  - C++/Java: `new Something()`
  - Assembly: need to call a Windows API function (HeapAlloc)
- Static allocations have a fixed size; dynamic allocation sizes are specified at runtime
- **Q.** Why is dynamically allocated memory necessary?

Dynamic Allocations: Stack vs. Heap



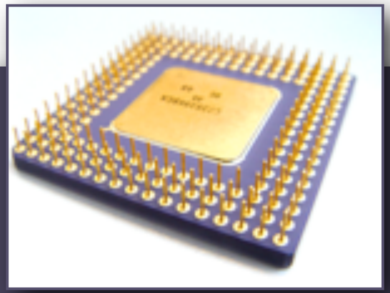
- In C++/Java:
  - Global variables are allocated statically
  - Local variables are allocated dynamically on the *stack* (remember `enter` *n*`,0`?)
  - Objects created using `new Something()` are allocated dynamically on the *heap*
- The runtime stack is a fixed size
  - In MASM, you can use a directive like `.stack 4096` to change it
  - If you try to push too much onto the stack/too many recursive calls, stack overflow
- The amount of heap memory is not fixed – ask Windows to give you more, and it will try
  - A **heap** is a memory pool for a specific process
    - Has nothing to do with heap data structures

How to Allocate Heap Memory



- Requires a sequence of two Windows API calls:
- 1. **`call GetProcessHeap`**
  - Returns (in EAX) a *handle* to the process's default heap
    - Processes can have several heaps. In subsequent calls, you'll need to tell Windows which heap your memory is coming from. This *handle* is just an integer that uniquely identifies this heap.
- 2. **`push`** *number of bytes to allocate*
  `push 0`
  `push` *the handle returned by GetProcessHeap*
  `call HeapAlloc`
  - Allocates the given number of bytes of memory
  - Returns (in EAX) the memory address of the allocated memory
- Both GetProcessHeap and HeapAlloc return 0 if an error occurs. *Check for this!*

On Garbage Collection

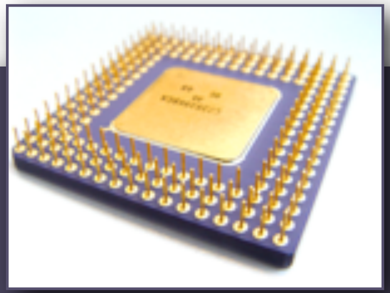


- In Java, memory is *garbage collected* – it is automatically freed when possible

```
public void foo() {
    System.out.println(new Object());    // An Object is allocated and displayed.
    System.out.println("Done!");         // Now, the garbage collector can delete the object,
                                         // since it's no longer needed.
}
```

- In C++, memory is **not** garbage collected
  - If you use `new`, you must also use `delete` to free that memory
- **Memory allocated using *HeapAlloc* is not garbage collected**
  - You must use *HeapFree* to free that memory

How to Free Heap Memory

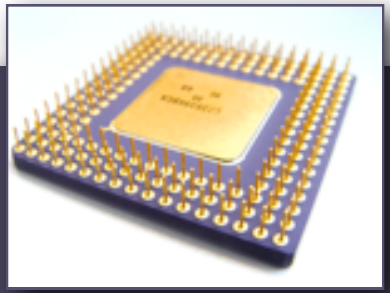


- **1.** **`call GetProcessHeap`**
  - Or if you already have a handle from a previous call, just use it

- **2.** **`push`** *the pointer returned by HeapAlloc*
  `push 0`
  `push` *the handle returned by GetProcessHeap*
  `call HeapFree`

- HeapFree returns 0 if an error occurs. *Check for this!*

Whiteboard Example



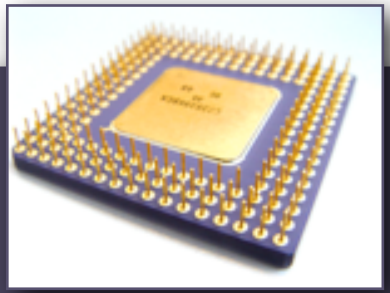
- The `exit` macro you have been using in your programs is actually shorthand for

```
push 0       ; This is your program's "exit code"
call ExitProcess
```

  - *ExitProcess* is a Windows API function that terminates a process
  - A nonzero exit code indicates that your program terminated due to an error

- **Q.** Write a program that:
  - Allocates 8 bytes of memory on the heap
  - Sets all 8 bytes to FFh
  - Frees the memory
  - Terminates with an exit code of 1 if an error occurs and 0 otherwise

Windows Dev Center



- HeapAlloc, HeapFree, ExitProcess, WriteConsole... all of these Windows API functions are documented in the Windows Dev Center
  - But you'll want a good book on Win32 programming if you begin to use these in real life...
  - Also, in real life, you would do Win32 programming in C or C++, not assembly language

Windows | Dev Center – Desktop

Dashboard Get started Design Develop Test

Desktop technologies Server and system API index Sample

- System Services
- Memory Management
- Memory Management Reference
- Memory Management Functions
  - AddSecureMemoryCacheCallback
  - AllocateUserPhysicalPages
  - AllocateUserPhysicalPagesNuma
  - BadMemoryCallbackRoutine
  - CopyMemory
  - CreateFileMapping
  - CreateFileMappingFromApp
  - CreateFileMappingNuma
  - CreateMemoryResourceNotification
  - DiscardVirtualMemory
  - FillMemory

HeapAlloc function

Allocates a block of memory from a heap. The allocated memory is not movable.

Syntax

C++

```
LPVOID WINAPI HeapAlloc(
  _In_  HANDLE hHeap,
  _In_  DWORD dwFlags,
  _In_  SIZE_T dwBytes
);
```

Parameters

hHeap [in]

- System Services
- Processes and Threads
- Process and Thread Reference
- Process and Thread Functions
  - AssignProcessToJobObject
  - AttachThreadInput
  - AvQuerySystemResponsiveness
  - AvRevertMmThreadCharacteristics
  - AvRtCreateThreadOrderingGroup
  - AvRtCreateThreadOrderingGroupEx
  - AvRtDeleteThreadOrderingGroup

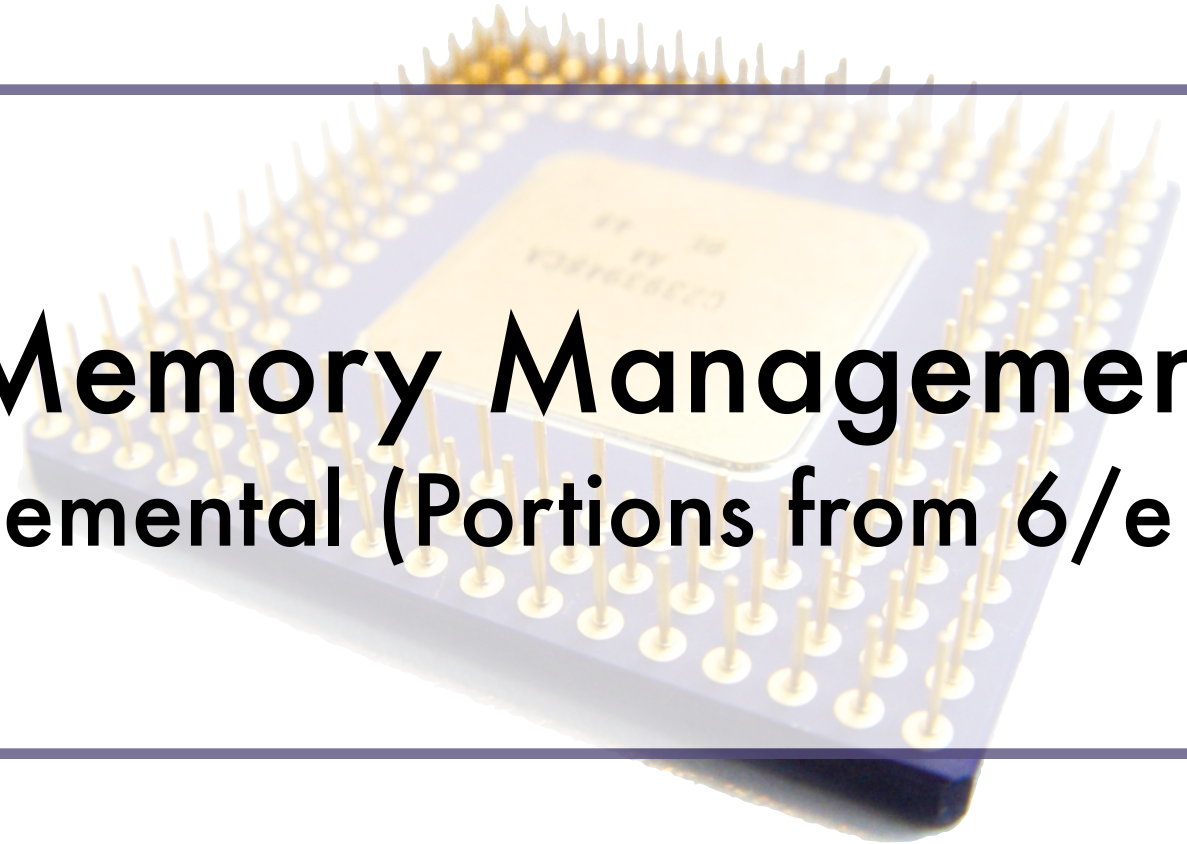
ExitProcess function

Ends the calling process and all its threads.

Syntax

C++

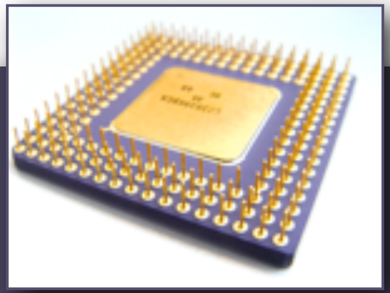
```
VOID WINAPI ExitProcess(
  _In_  UINT uExitCode
);
```



Memory Management

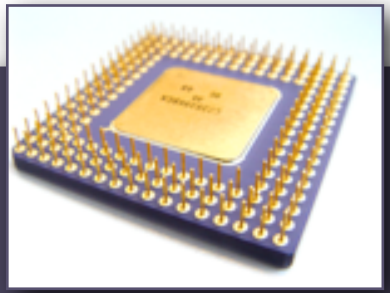
Supplemental (Portions from 6/e §2.3)

Real vs. Protected Mode



- Recall from a couple of months ago:
  - x86 processors can run in **real-address mode** or **protected mode**
  - Processors boot in real-address mode
    - For backward compatibility with the original 8086
  - MS-DOS used real-address mode
  - Windows, Linux, Mac OS X switch the processor to protected mode at startup

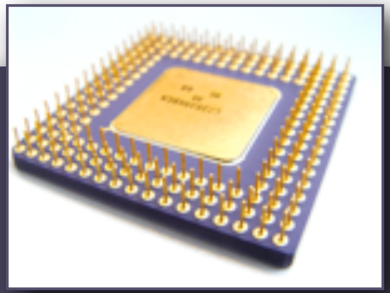
Memory Addresses



- *Surprise...* not all memory addresses correspond to RAM storage!
  - E.g., in real-address mode:
    - ROM BIOS (Basic Input-Output System) starts at address F0000h
    - Video memory starts at address A0000h
  - Hardware can be *memory-mapped*
    - Hardware devices connected to the address/data bus
    - Intercept requests to read/write certain addresses
  - BIOS can provide a (partial) *memory map*
    - E.g., identifies addresses corresponding to available RAM

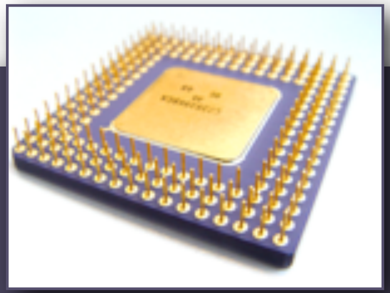
http://wiki.osdev.org/Detecting_Memory_(x86), http://www.uruk.org/orig-grub/mem64mb.html

Real-Address Mode (1)



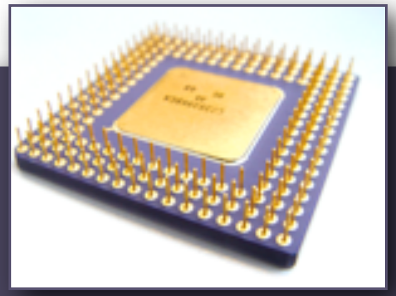
- **Real-address mode** (backward-compatible with the 8086)
  - Not designed for multitasking
    - Only one running program
  - 20-bit memory addresses
    - 00000h through FFFFFh
    - So only 1 MB of memory can be addressed
  - Programs can access any memory address
    - Including addresses corresponding to memory-mapped hardware
  - MS-DOS used real-address mode

Real-Address Mode (2)



- **Problem:** 8086 processor had 20-bit memory addresses but only 16-bit registers
- **Solution:** *Segmented memory*
  - Segment register holds 16-bit *segment* value,
16-bit general-purpose register holds 16-bit *offset* value
    - Segment-offset address written as *segment*:*offset*
    - Recall: segment registers are CS, DS, ES, FS, GS
  - The actual *(linear* or *absolute)* memory address is *segment* × 10h + *offset*
  - 08F1:0100 corresponds to the linear address 09010h
  - 07FF:1020 also corresponds to linear 09010h

Protected Mode (1)



- **Protected mode**
  - Designed for multitasking
    - OS has more privileges than application programs (four *privilege rings*)
  - 32-bit memory addresses
    - 00000000h through FFFFFFFFh
    - So 4 GB of memory can be addressed
  - Each process is assigned its own area of memory
  - One process cannot access another process's memory
  - Applications cannot access memory-mapped hardware

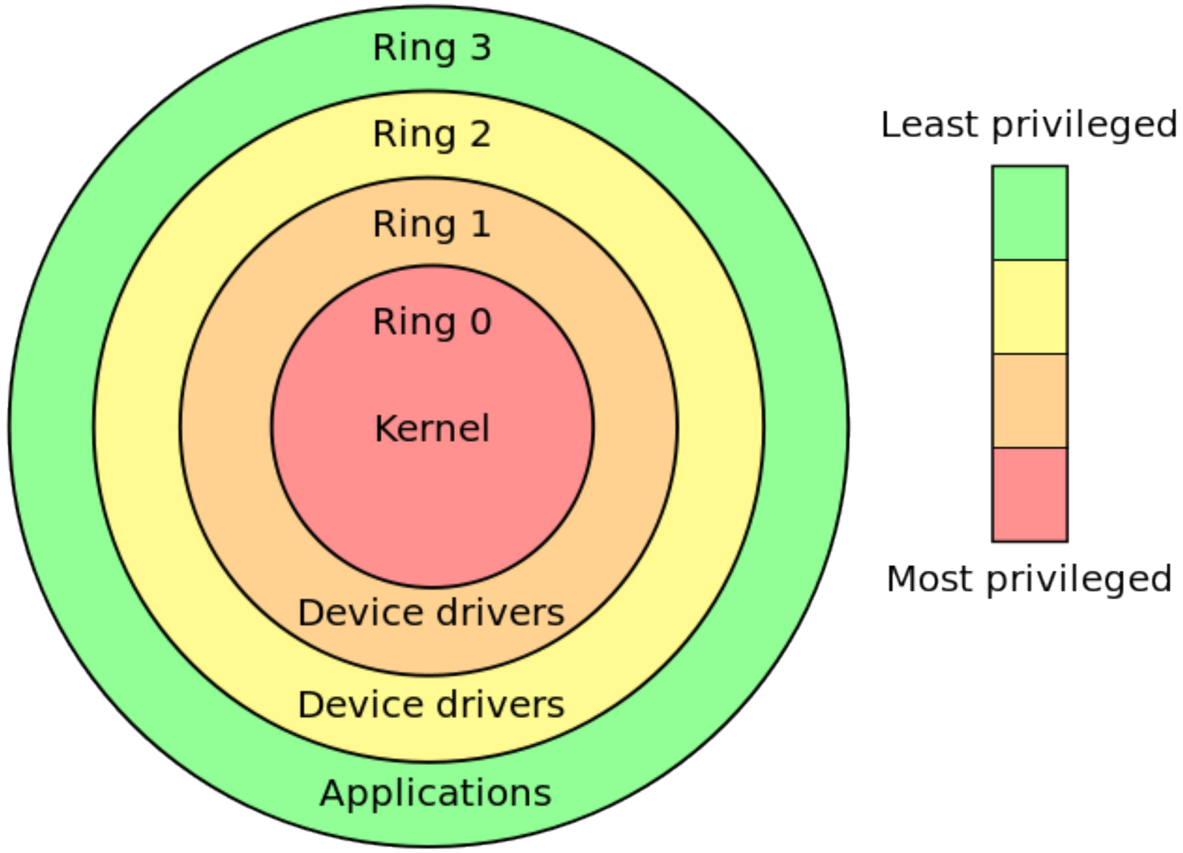
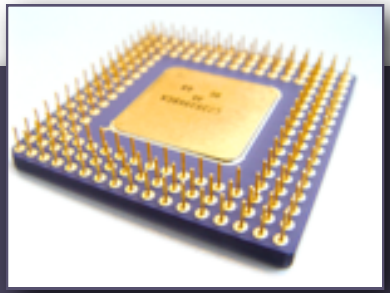


Image Source: http://en.wikipedia.org/wiki/File:Priv_rings.svg

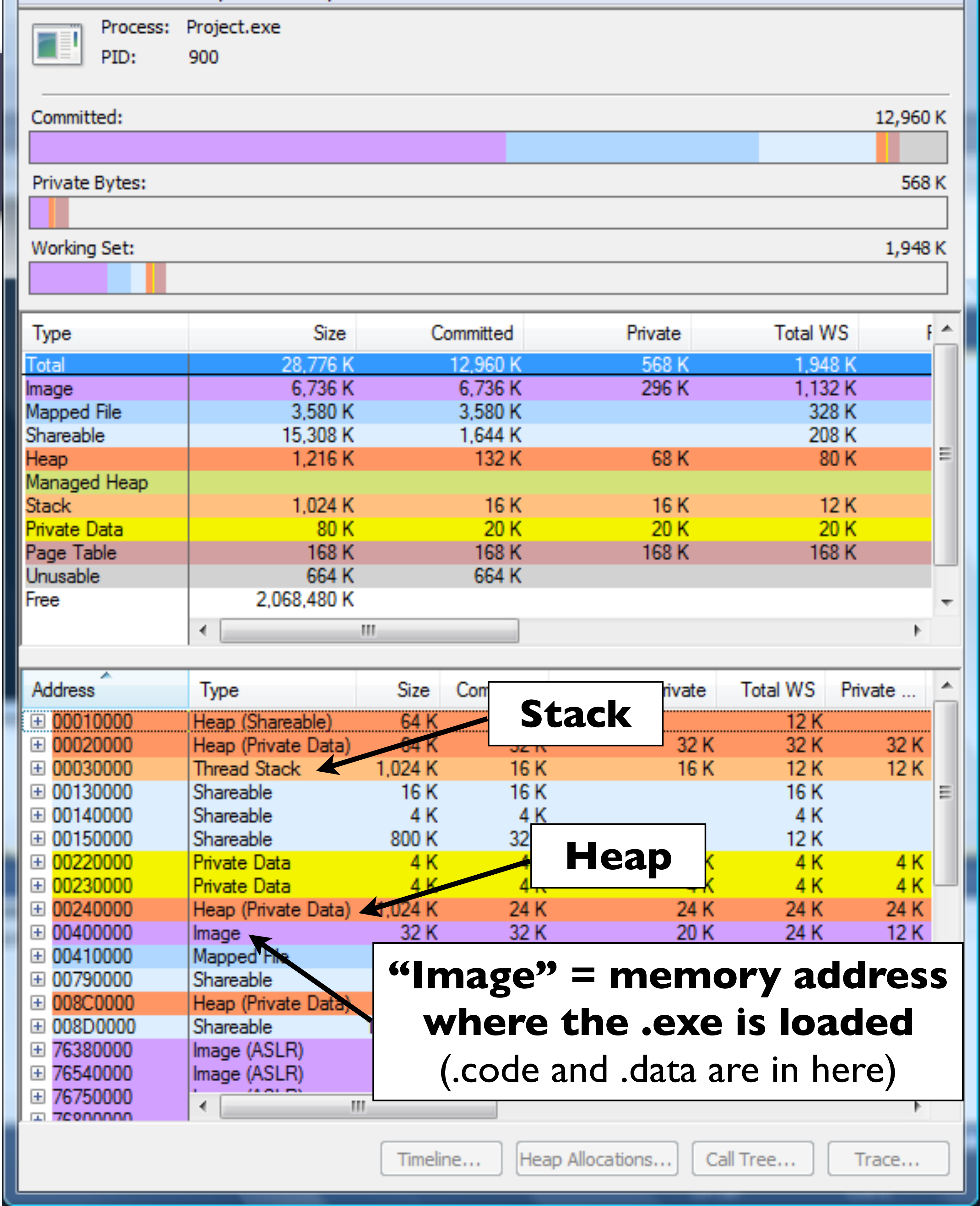
Protected Mode (2)

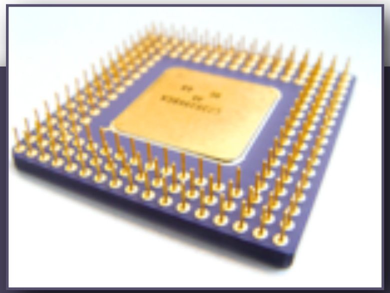


- In (32-bit) protected mode, there are 32-bit memory addresses and 32-bit registers
- Modern operating systems use the **flat** segmentation model
  - Essentially, every segment starts at memory address 00000000h
  - So, 32-bit memory addresses exactly correspond to a linear address
  - This is why `mov eax, OFFSET foo` puts the memory address of `foo` into EAX:
    - The value stored into EAX is the number of bytes from the start of the data segment to `foo`
    - But the data segment starts at memory address 00000000h
    - So the offset *is* the linear memory address!
- In protected mode, segment registers used for a different purpose
  - Unless you're writing an operating system, you can basically ignore them

Address Space

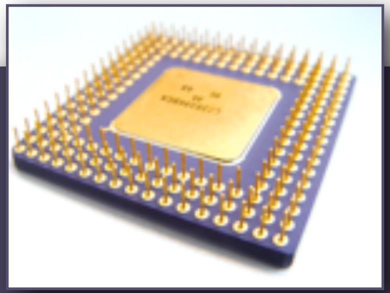
- Recall:
  - Executables (.exe files) contain data and text sections corresponding to `.data` and `.code` sections of an assembly language program
  - To run a program, the operating system loads the executable (.exe file) into memory and sets EIP to point to the first instruction; it also does other things, like reserve memory for the stack
  - Memory addresses are 32 bits; each memory address corresponds to one byte of memory
  - Think of memory as a giant, 4 GB array of bytes, indexed 00000000h through FFFFFFFFh
- VMMap (from www.sysinternals.com) can display the address space of a running process





- Does it seem weird that your .data section is almost *always* at memory address 00405000h? Like, that memory address is *always* available for your program to use?

Protected Mode – Virtual Memory (1)

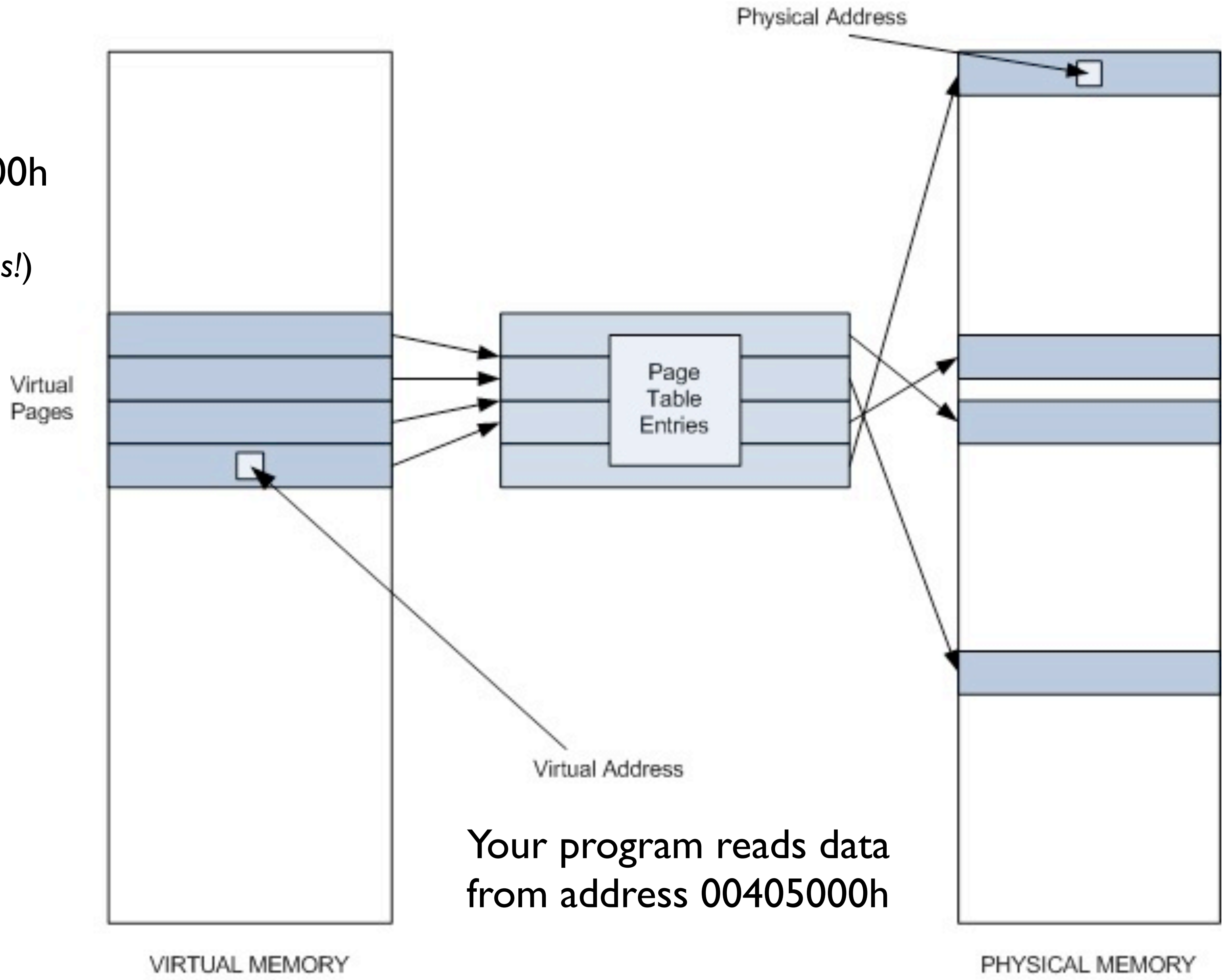


- In the flat memory model, 32-bit addresses correspond exactly to a linear address, but...
- **The memory addresses you use in your assembly language program (like 00405000h) are *virtual* memory addresses! The *physical* address—where you'll find the data in RAM—is completely different.**
- Modern operating systems use *virtual memory* or *paging*
  - A *page table* is used to determine how linear addresses are mapped to physical addresses
    - Memory is divided into 4KB blocks called *pages*
  - Pages can be temporarily stored on disk; that memory can then be used by another process
    - Gives the illusion that the computer has more memory than the amount of physical RAM installed

Protected Mode – Virtual Memory (2)

Windows tells you
your .data section is at
memory address 00405000h

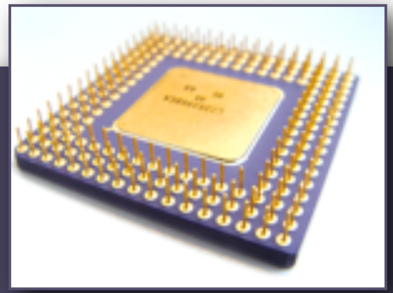
(That's actually a *virtual address!*)



Your program reads data
from address 00405000h

Windows maintains a *page table*, which is used to figure out the *physical* memory location in RAM where the data is actually stored

Virtual Address Space



- In Windows 32-bit operating systems...
- Each process (running program) has its own 32-bit virtual address space
  - Each process has 4 GB of virtual memory
- The bottom 2 GB is **user-mode space**
  - Addresses 00000000h–7FFFFFFFh
  - Your executable is loaded at address 00400000h
  - Data, stack, and heap are all in this address range
  - Code from EXEs and DLLs is marked read-only (why?)
- The top 2 GB is **system space** (or **kernel space**)
  - Addresses 80000000h–FFFFFFFFh
  - OS code is here; your program cannot read/write this space