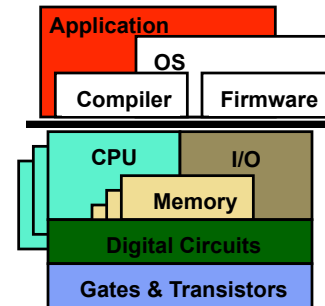


# CIS 371

## Computer Organization and Design

### Unit 15: Putting It All Together: Anatomy of the XBox 360 Game Console

## This Unit: Putting It All Together



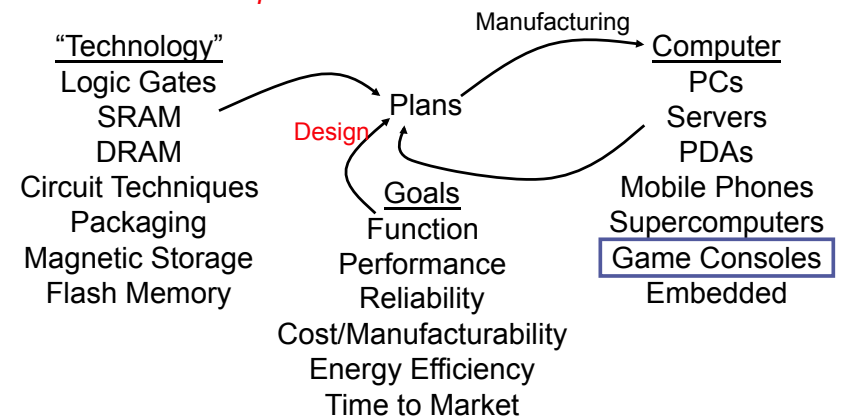
- Anatomy of a game console
  - Microsoft XBox 360
- Focus mostly on CPU chip
- Briefly talk about system
  - Graphics processing unit (GPU)
  - I/O and other devices

## Sources

- **Application-customized CPU design: The Microsoft Xbox 360 CPU story**, Brown, IBM, Dec 2005
  - <http://www-128.ibm.com/developerworks/power/library/pa-fpfxbox/>
- **XBox 360 System Architecture**, Andrews & Baker, IEEE Micro, March/April 2006
- Microprocessor Report
  - **IBM Speeds Xbox 360 to Market**, Krewell, Oct 31, 2005
  - **Powering Next-Gen Game Consoles**, Krewell, July 18, 2005

## What is Computer Architecture?

The role of a *computer* architect:



## Microsoft Xbox Game Console History

- Xbox
  - First game console by Microsoft, released in 2001, \$299
  - Glorified PC
    - 733 Mhz x86 Intel CPU, 64MB DRAM, NVIDIA GPU (graphics)
    - Ran modified version of Windows OS
  - ~25 million sold
- Xbox 360
  - Second generation, released in 2005, \$299-\$399
  - All-new custom hardware
    - 3.2 Ghz PowerPC IBM processor (custom design for Xbox 360)
    - ATI graphics chip (custom design for Xbox 360)
  - 50+ million sold

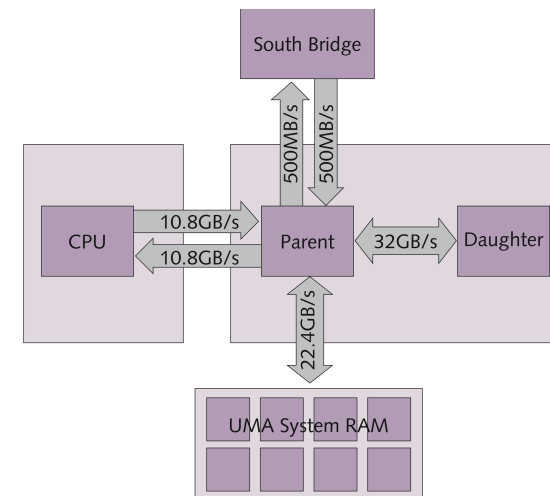
## Microsoft Turns to IBM for Xbox 360

- Microsoft is mostly a software company
  - Turned to IBM & ATI for Xbox 360 design
  - Sony & Nintendo also turned to IBM (for PS3 & Wii, respectively)
- Design principles of Xbox 360 [Andrews & Baker]
  - Value for 5-7 years
    - → big performance increase over last generation
  - Support anti-aliased high-definition video (720\*1280\*4 @ 30+ fps)
    - → extremely high pixel fill rate (goal: 100+ million pixels/s)
  - Flexible to suit dynamic range of games
    - → balance hardware, homogenous resources
  - Programmability (easy to program)
    - → listened to software developers

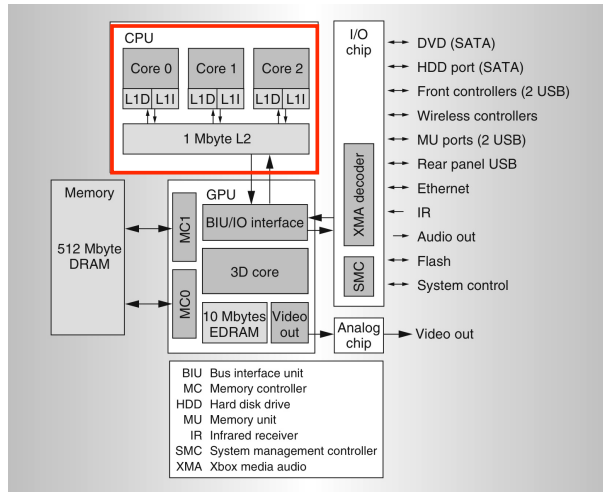
## More on Games Workload

- Graphics, graphics, graphics
  - Special highly-parallel graphics processing unit (GPU)
  - Much like on PCs today
- But general-purpose, too
  - "The high-level game code is generally a database management problem, with plenty of object-oriented code and pointer manipulation. Such a workload needs a large L2 and high integer performance." [Andrews & Baker]
- Wanted only a modest number of modest, fast cores
  - Not one big core
  - Not dozens of small cores (leave that to the GPU)
  - Quote from Seymour Cray

## Xbox 360 System from 30,000 Feet



## XBox 360 System



CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006] 9

## XBox 360 "Xenon" Processor

- ISA: 64-bit PowerPC chip
  - RISC ISA
    - Like MIPS, but with condition codes
  - Fixed-length 32-bit instructions
  - 32 64-bit general purpose registers (GPRs)
- ISA Extended with VMX-128 operations
  - **128 registers, 128-bits each**
  - Packed "vector" operations
  - Example: four 32-bit floating point numbers
    - One instruction:  $VR1 * VR2 \rightarrow VR3$
    - Four single-precision operations
    - Also supports conversion to Microsoft DirectX data formats
  - Similar to AltiVec (and Intel's MMX, SSE, SSE2, etc.)
  - Works great for 3D graphics kernels and compression

CIS 371 (Martin): Xbox 360

10

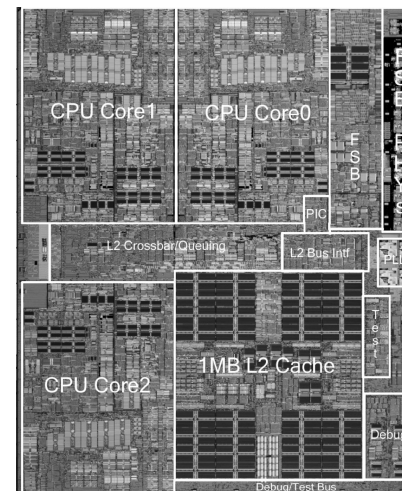
## XBox 360 "Xenon" Processor

- Peak performance:  $\sim 75$  gigaflops
  - Gigaflop = 1 billion floating points operations per second
- Pipelined superscalar processor
  - 3.2 Ghz operation
  - Superscalar: two-way issue
  - VMX-128 instructions (four single-precision operations at a time)
  - Hardware multithreading: two threads per processor
  - Three processor cores per chip
- Result:
  - $3.2 * 2 * 4 * 3 = \sim 77$  gigaflops

CIS 371 (Martin): Xbox 360

11

## XBox 360 "Xenon" Chip (IBM)

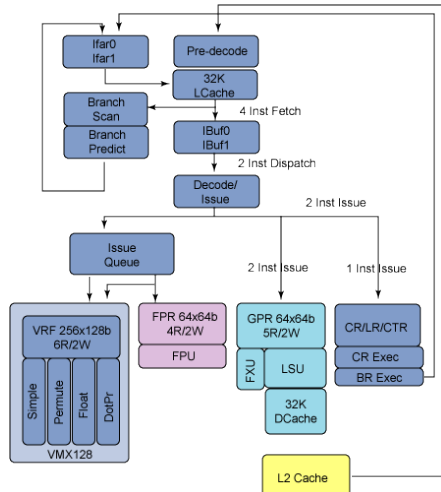


- 165 million transistors
  - IBM's 90nm process
- Three cores
  - 3.2 Ghz
  - Two-way superscalar
  - Two-way multithreaded
- Shared 1MB cache

CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006] 12

## "Xenon" Processor Pipeline



- Four-instruction fetch
- Two-instruction "dispatch"
- Five functional units
- "VMX128" execution "decoupled" from other units
  - 14-cycle VMX dot-product
- Branch predictor:
  - "4K" G-share predictor
  - Unclear if 4KB or 4K 2-bit counters
  - Per thread

CIS 371 (Martin): Xbox 360

[Brown, IBM, Dec 2005]

13

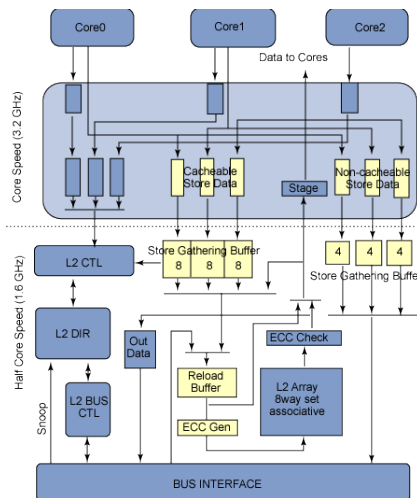
## XBox 360 Memory Hierarchy

- 128B cache blocks throughout
- 32KB 2-way set-associative instruction cache (per core)
- 32KB 4-way set-associative data cache (per core)
  - Write-through, lots of store buffering
  - Parity
- 1MB 8-way set-associative second-level cache (per chip)
  - Special "skip L2" prefetch instruction
  - MESI cache coherence
  - Error Correcting Codes (ECC)
- 512MB GDDR3 DRAM, dual memory controllers
  - Total of 22.4 GB/s of memory bandwidth
- Direct path to GPU

CIS 371 (Martin): Xbox 360

14

## Xenon Multicore Interconnect

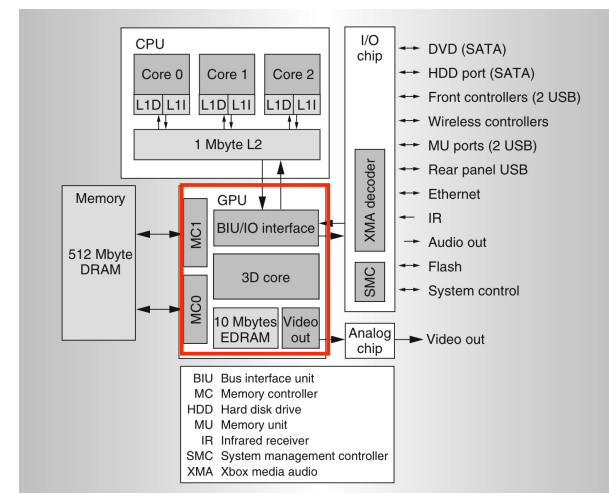


CIS 371 (Martin): Xbox 360

[Brown, IBM, Dec 2005]

15

## XBox 360 System

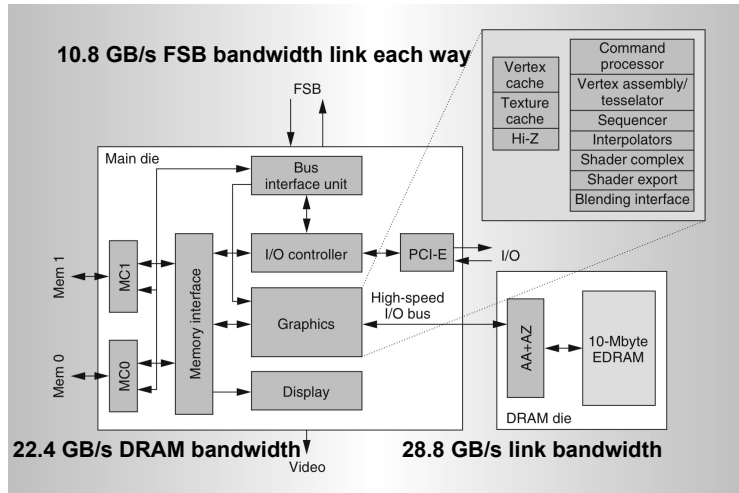


CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006]

16

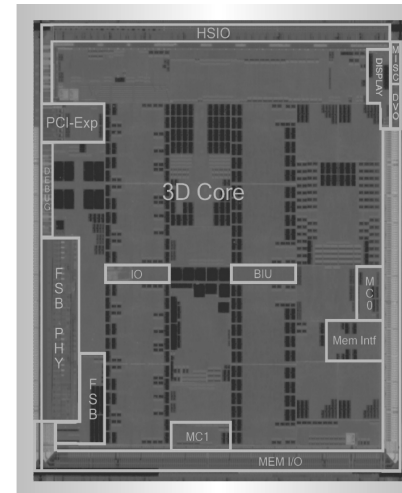
## XBox Graphics Subsystem



CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006] 17

## Graphics "Parent" Die (ATI)

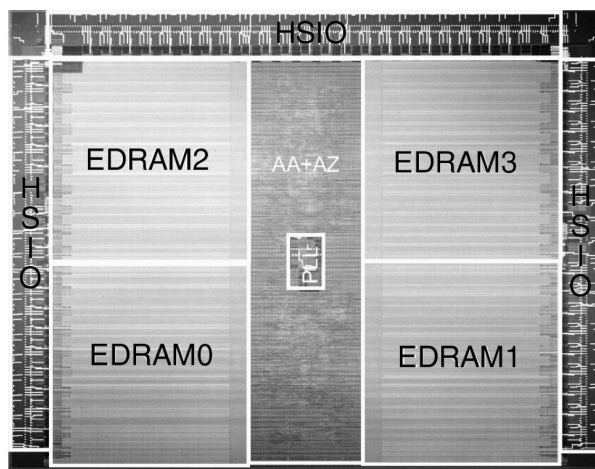


- 232 million transistors
- 500 Mhz
- 48 unified shader ALUs
  - Mini-cores for graphics

CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006] 18

## GPU "daughter" die (NEC)



- 100 million transistors
- 10MB eDRAM
  - "Embedded"
- NEC Electronics
- Anti-aliasing
  - Render at 4x resolution, then sample
- Z-buffering
  - Track the "depth" of pixels
- 256GB/s internal bandwidth

CIS 371 (Martin): Xbox 360

[Andrews & Baker, IEEE Micro, Mar/Apr 2006] 19

## Putting It All Together

- Unit 0: Abstraction and design goals
- Unit 1: ISAs
- Unit 2/3: Digital logic & single-cycle datapath
- Unit 4: Arithmetic
- Unit 5/7: Pipelining & performance
- Unit 8/9: Caches & virtual memory
- Unit 10: Superscalar
- Unit 11: Static & Dynamic Scheduling
- Unit 12: Multicore
- Guest lecture: GPUs
- Unit 13/14: Vectors/Power

CIS 371 (Martin): Xbox 360

20