Introduction

CPE380/CS380, Spring 2026

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http://aggregate.org/hankd/

University of Kentucky

Course Overview

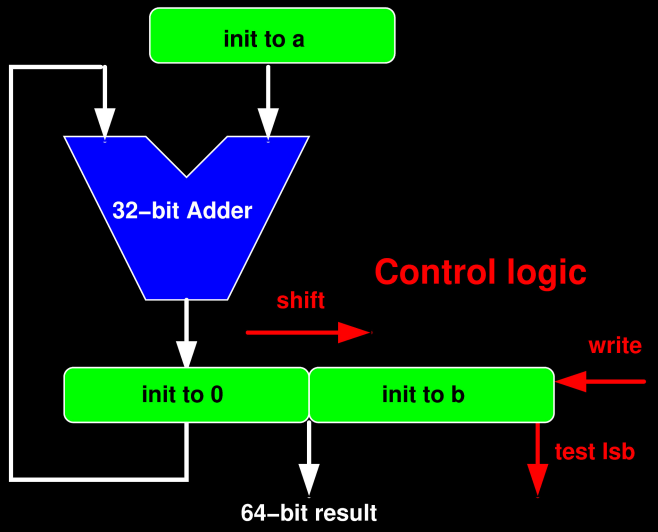
- You know how to write a simple program... from CS courses
- You know how to build simple combinatorial and sequential logic circuits from ECE courses (especially CPE282 or EE280/EE281)
- This course fills the gap between the two:
  - So you can better **specify & use** that stuff
  - So you can **create** the stuff in between
  - There will be implementations in Verilog

Verilog 32-bit Multiplier

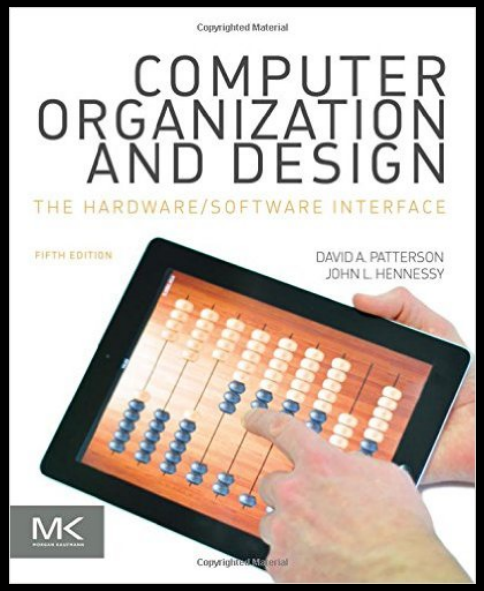
```
module mul(ready, c, a, b, reset, clk);

parameter BITS = 32;
input [BITS-1:0] a, b;
input reset, clk;
output reg [BITS*2-1:0] c;
output reg ready;
reg [BITS-1:0] d;
reg [BITS-1:0] state;
reg [BITS:0] sum;

always @(posedge clk or posedge reset) begin
  if (reset) begin
    ready <= 0;
    state <= 1;
    d <= a;
    c <= {{BITS{1'b0}}, b};
  end else begin
    if (state) begin
      sum = c[BITS*2-1:BITS] + d;
      c <= (c[0] ? {sum, c[BITS-1:1]} :
            (c >> 1));
      state <= {state[BITS-2:0], 1'b0};
    end else begin
      ready <= 1;
    end
  end
end
endmodule
```



Textbook



- The **OPTIONAL** text is: *Computer Organization & Design, 5th Edition: The Hardware/Software Interface* by Patterson & Hennessy
- You can use any MIPS edition from 2nd on… but for Spring 2026, we'll do some RISC-V
- We will not assign problems from the text
- Lots of additional materials online and presented in class… text is for reference only

Grading & Such

- One individual Verilog project, ~10%
- Three team projects, ~10% each
- Four homework assignments, ~10% each
- In-person final exam, ~20%
  (course grade limited to 1 letter above final)
- Material from lectures, the text as cited, canvas, or from the course URL:
  http://aggregate.org/CPE380/
- You are expected to **regularly attend class**
- I try not to curve much; always in your favor

Course Content

Lectures	Topic
1	Introduction
3	Verilog (individual project)
3	Multi-cycle machine (team project)
3	Machine & assembly languages (homework)
2	Single-cycle machine (team project)
3	Integer & float arithmetic (homework)
4	Pipelined machine (team project)
4	Memory hierarchy and I/O (homework)
3	Parallel processing and performance (homework)
1	*reserved for schedule slippage*
1	A simple compiler
1	Review for final exam

Schedule Notes

- Projects are deliberately pushed as early as possible to reduce time pressure
- Some topics may be given more or less time depending on how students are doing
- I will be presenting research at IS&T Electronic Imaging (EI26) conference, so we will not have regular class meetings 3/3 & 3/5

Me (and why I'm biased)

- Hank Dietz, ECE Professor and
  James F. Hardymon Chair in Networking
- Office: 203 Marksbury
- Research in parallel compilers & architectures:
  - Built 1st Linux PC cluster supercomputer
  - Antlr, AFNs, SWAR, FNNs, MOG, ...
  - Various awards & world records for best price/performance in supercomputing
- Lab: 108/108A Marksbury – I have **TOYS**!


KREQC
Kentucky's Rotationally Emulated Quantum Computer
SEE WHAT'S
Wildly Possible
Power Supply
Control Logic
KREQC
Wave Function Generator

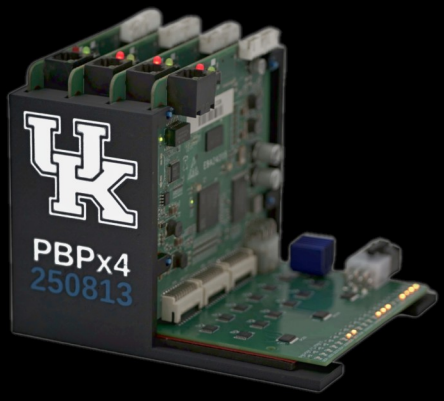

College of Engineering
Electrical & Computer Engineering


UK ECE

College of Engineering

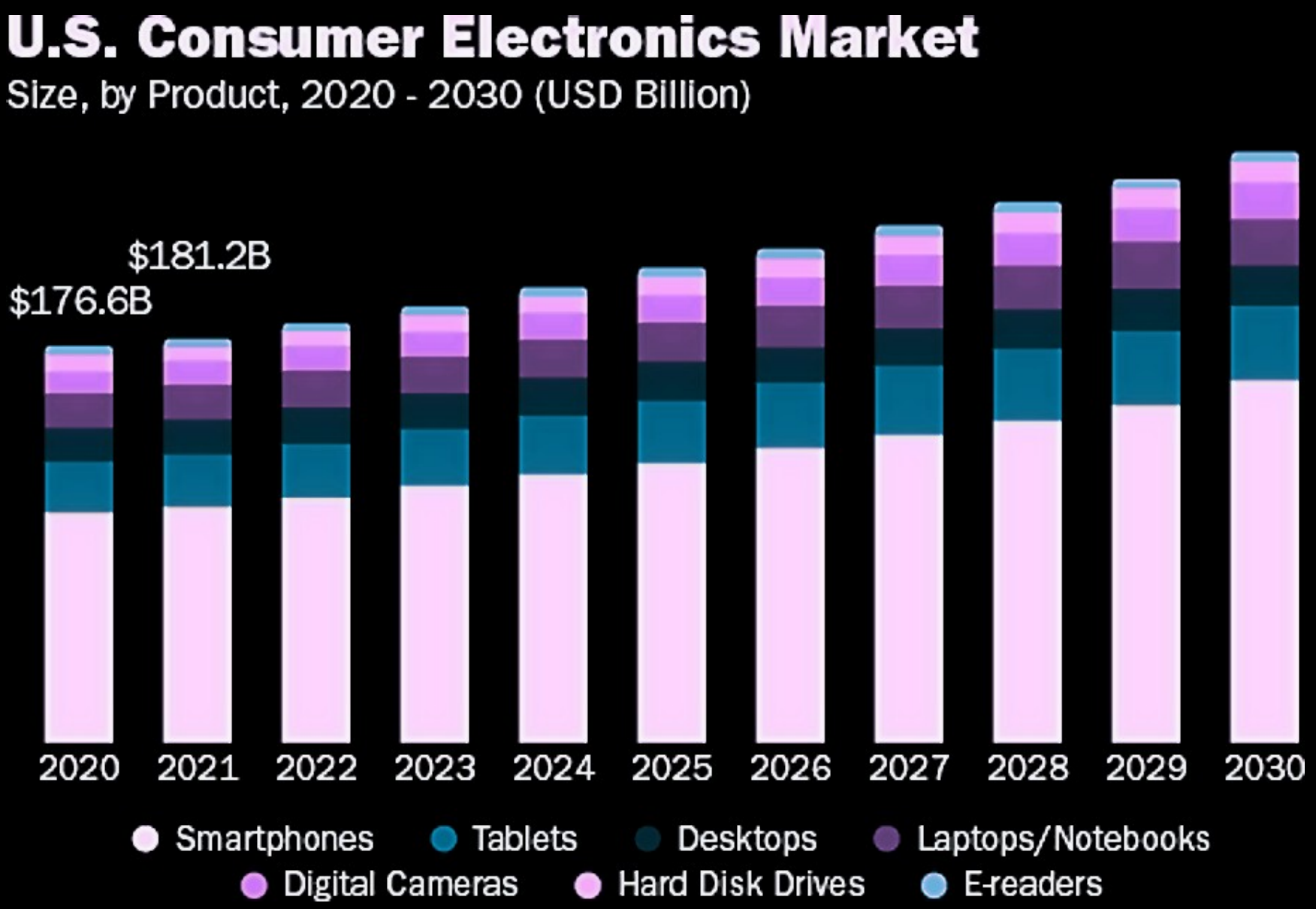
This cluster was Finally retired in Summer 2025!

Electrical & Computer Engineering



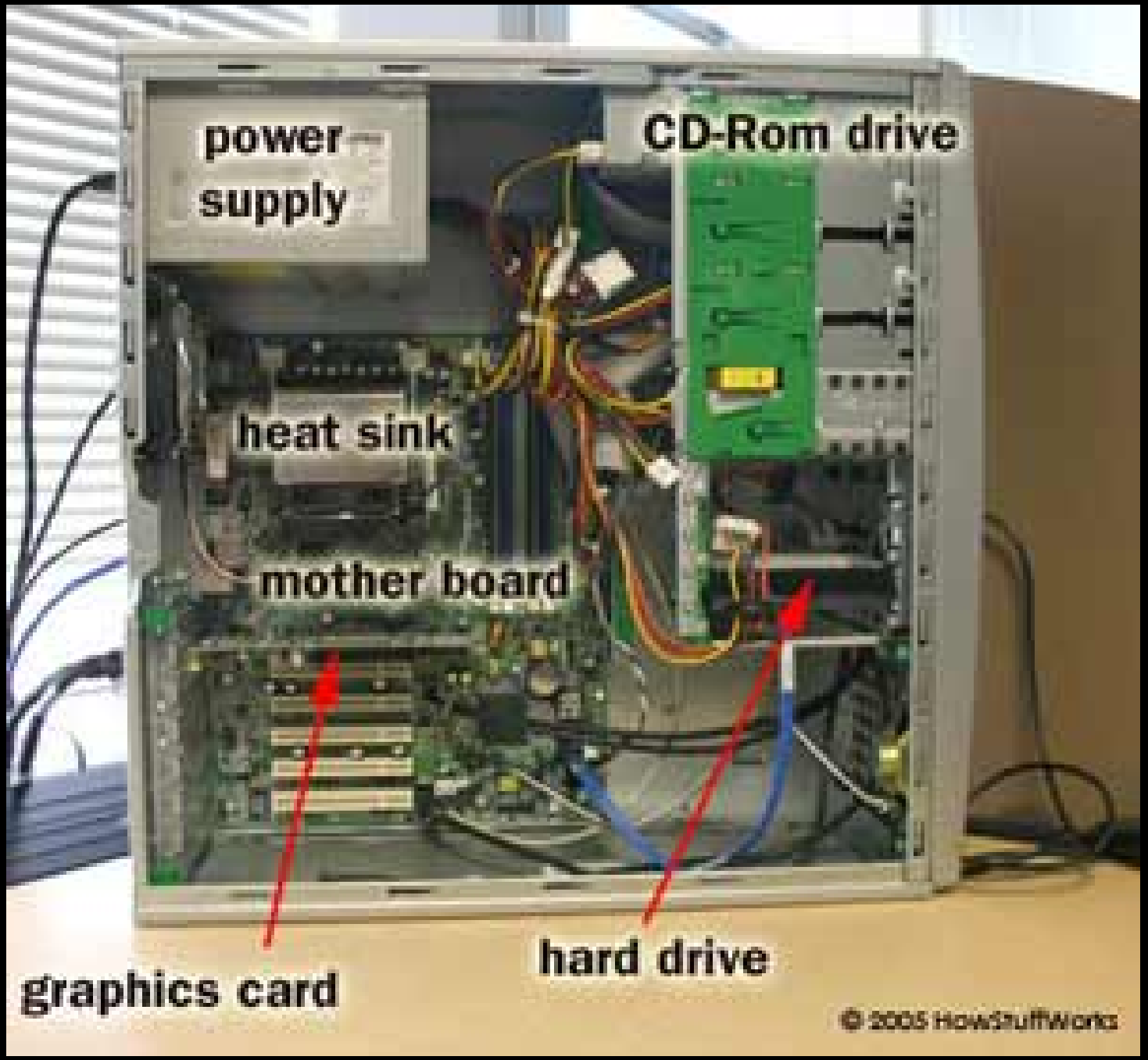
Let's Talk About Computers

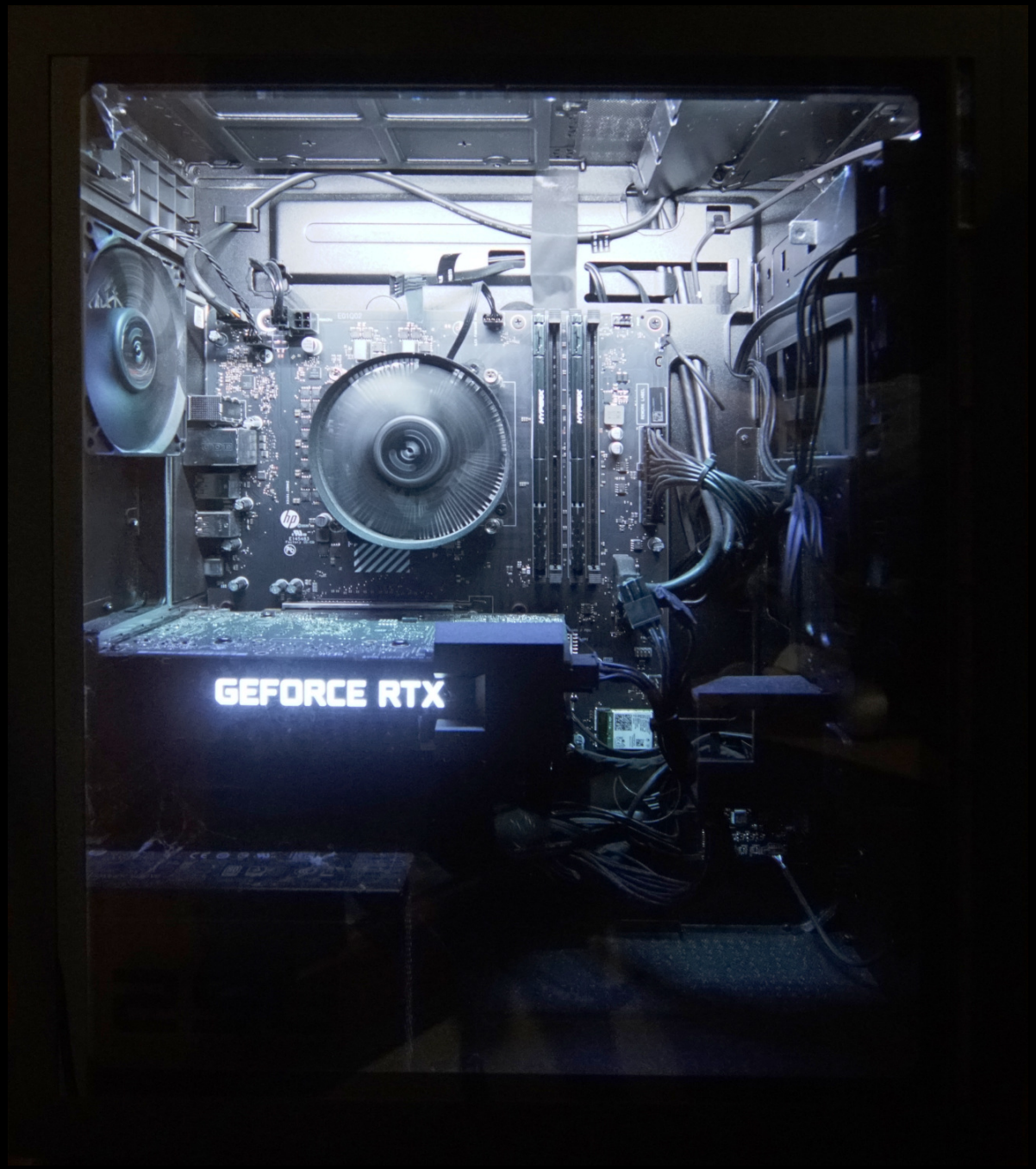
- Embedded computers, IoT (Internet of Things)
- Personal Mobile Devices (PMDs)...
  usually “smart phones” and tablets
- Personal Computers (PCs)
- Servers
- Supercomputers
- Clusters, Farms, Grids, and Clouds
  (Warehouse Scale Computers – WSC,
  Software as a Service – SaaS)

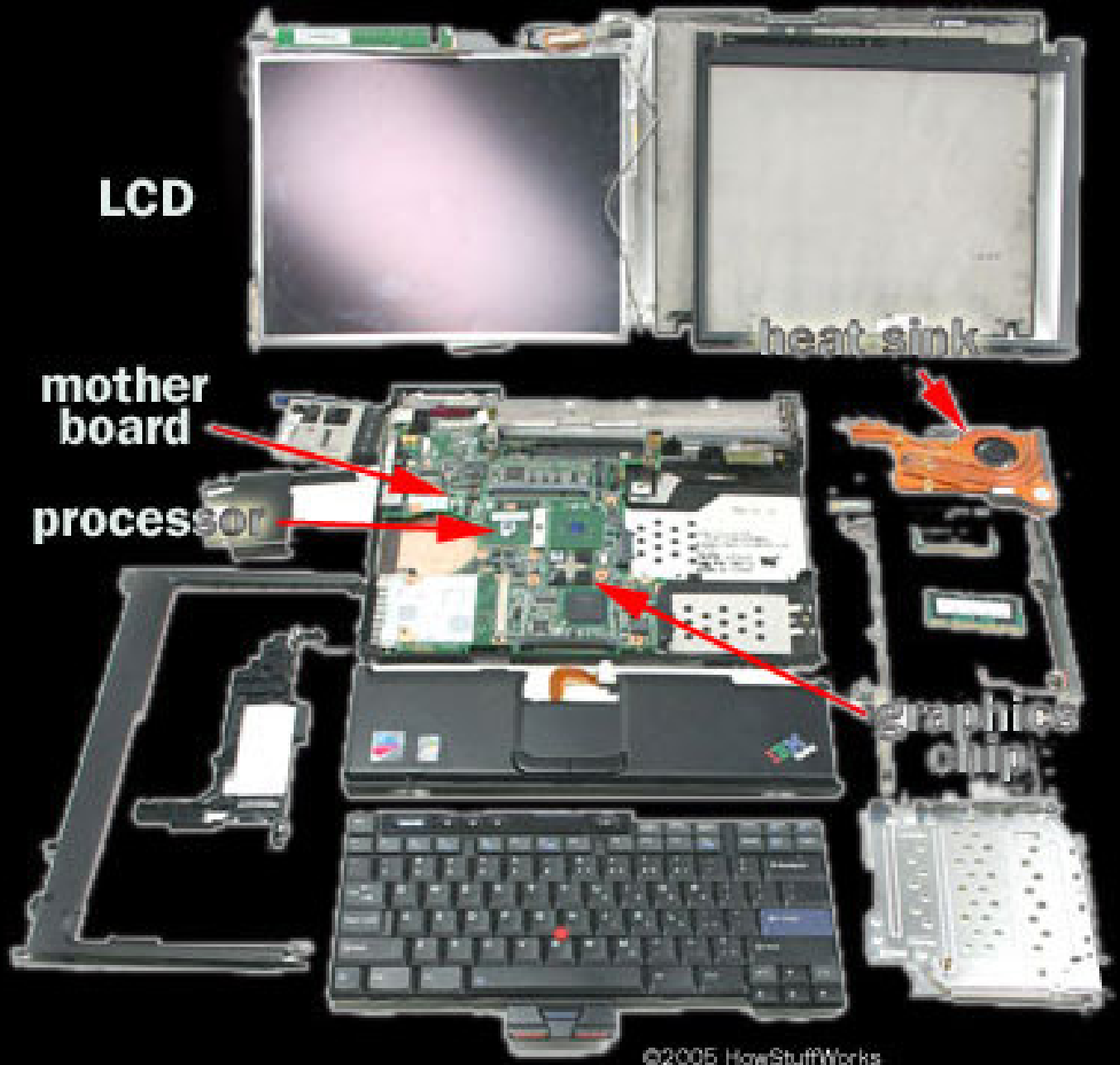


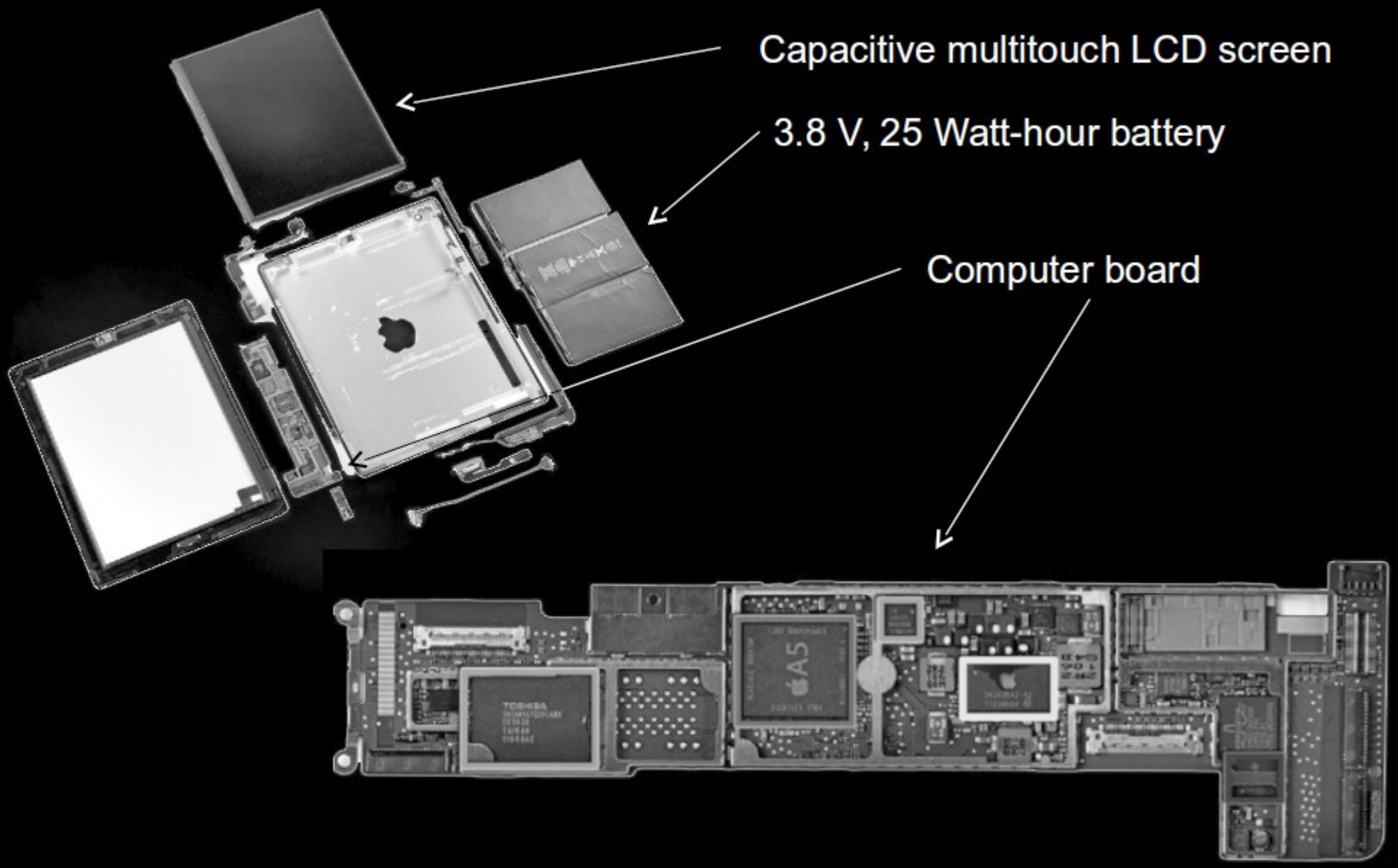
https://www.grandviewresearch.com/industry-analysis/personal-consumer-electronics-market

What's Inside?

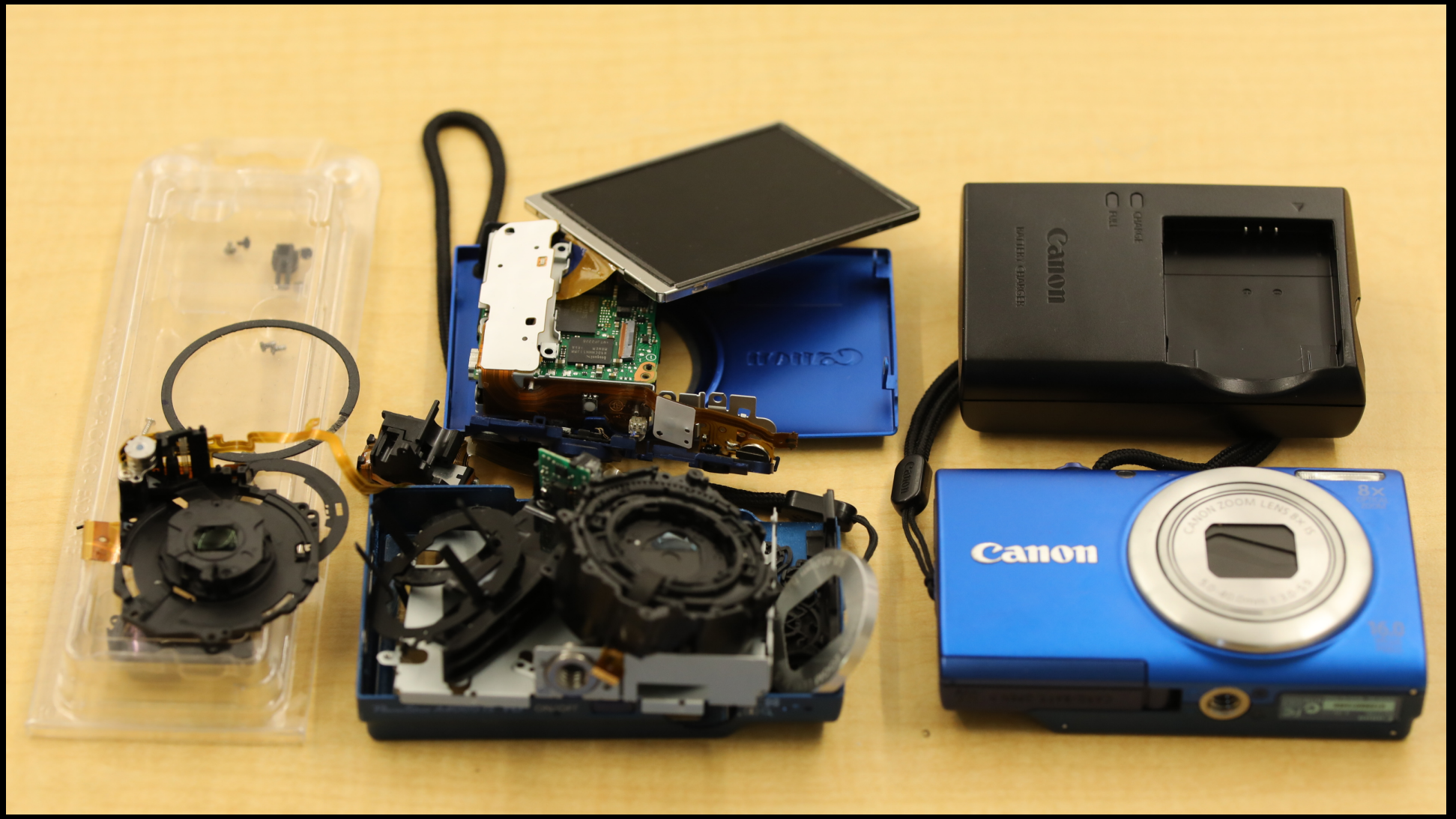

power supply
CD-Rom drive
heat sink
mother board
graphics card
hard drive
© 2005 HowStuffWorks


GEFORCE RTX

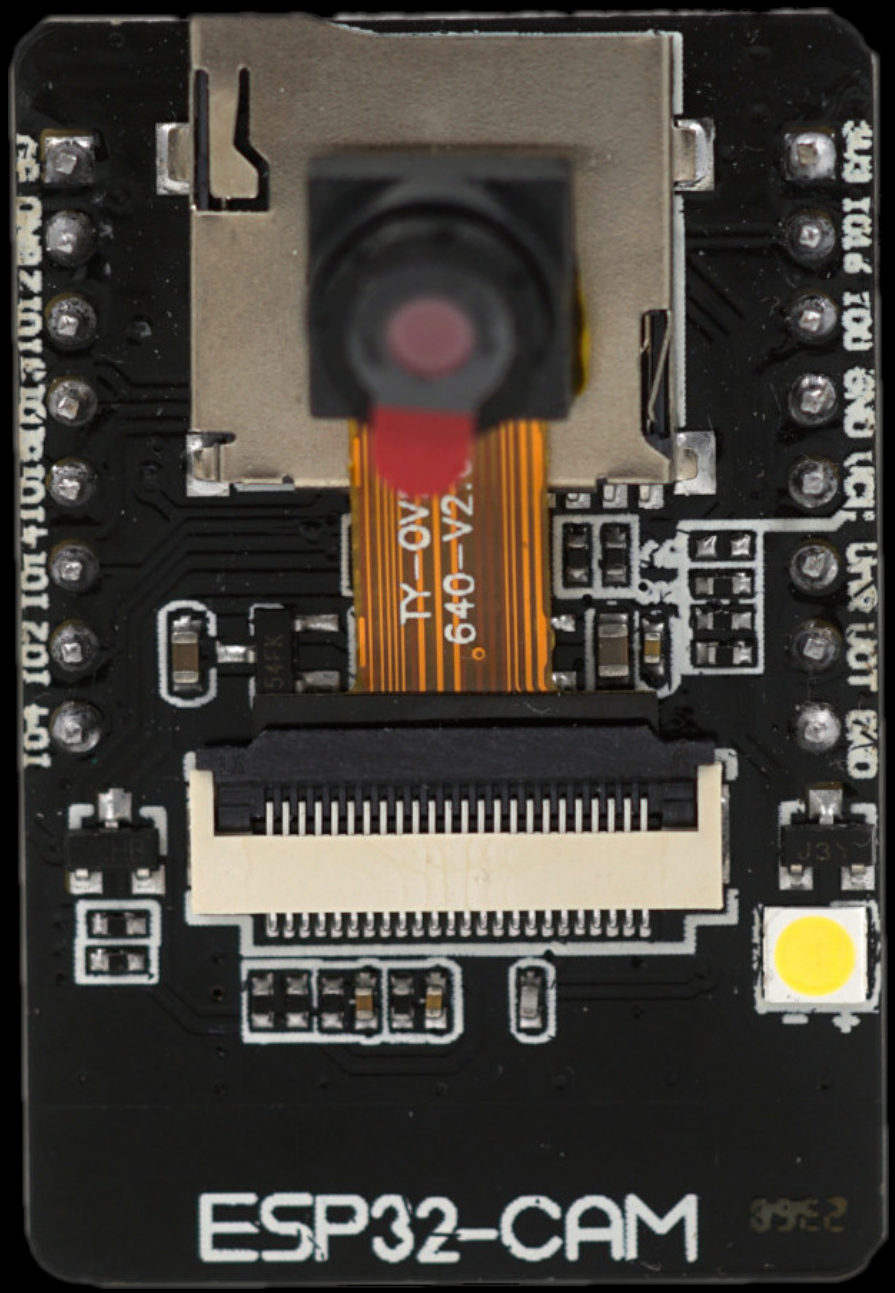

LCD
heat sink
mother board
processor
graphics chip
©2005 HowStuffWorks

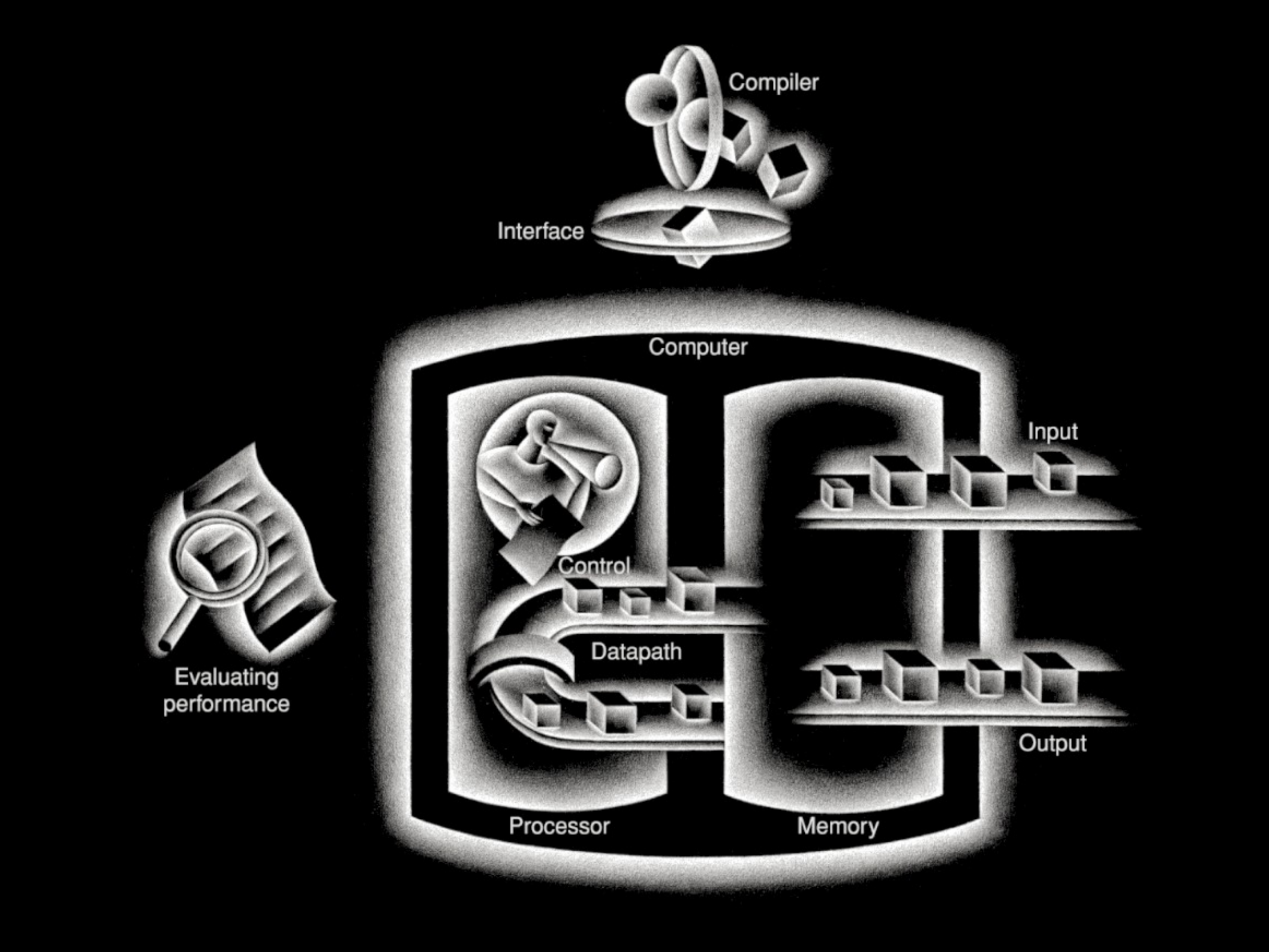

Capacitive multitouch LCD screen
3.8 V, 25 Watt-hour battery
Computer board
A5
TOSHIBA

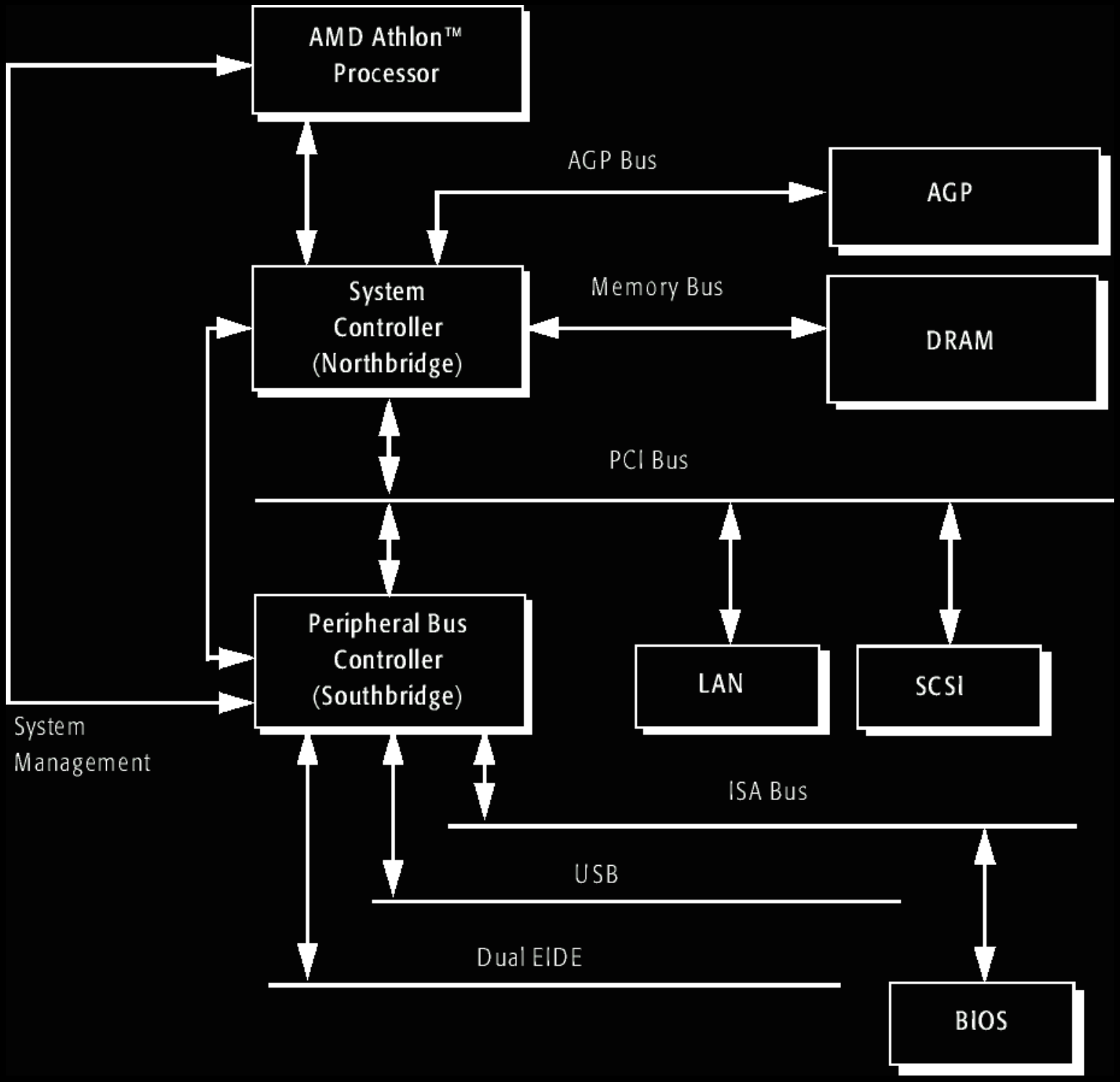

DIGIC 4


Canon
Canon
Canon
8×


FlashAir
W-02
Wireless LAN
10
SD HC
32 GB
TOSHIBA


ESP32-CAM


Compiler
Interface
Computer
Input
Control
Datapath
Output
Processor
Memory
Evaluating
performance

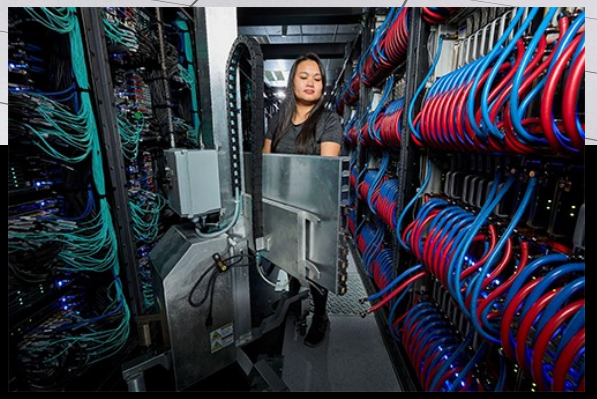

AMD Athlon™
Processor
AGP Bus
AGP
System
Controller
(Northbridge)
Memory Bus
DRAM
PCI Bus
Peripheral Bus
Controller
(Southbridge)
LAN
SCSI
System
Management
ISA Bus
USB
Dual EIDE
BIOS

Processor Terminology

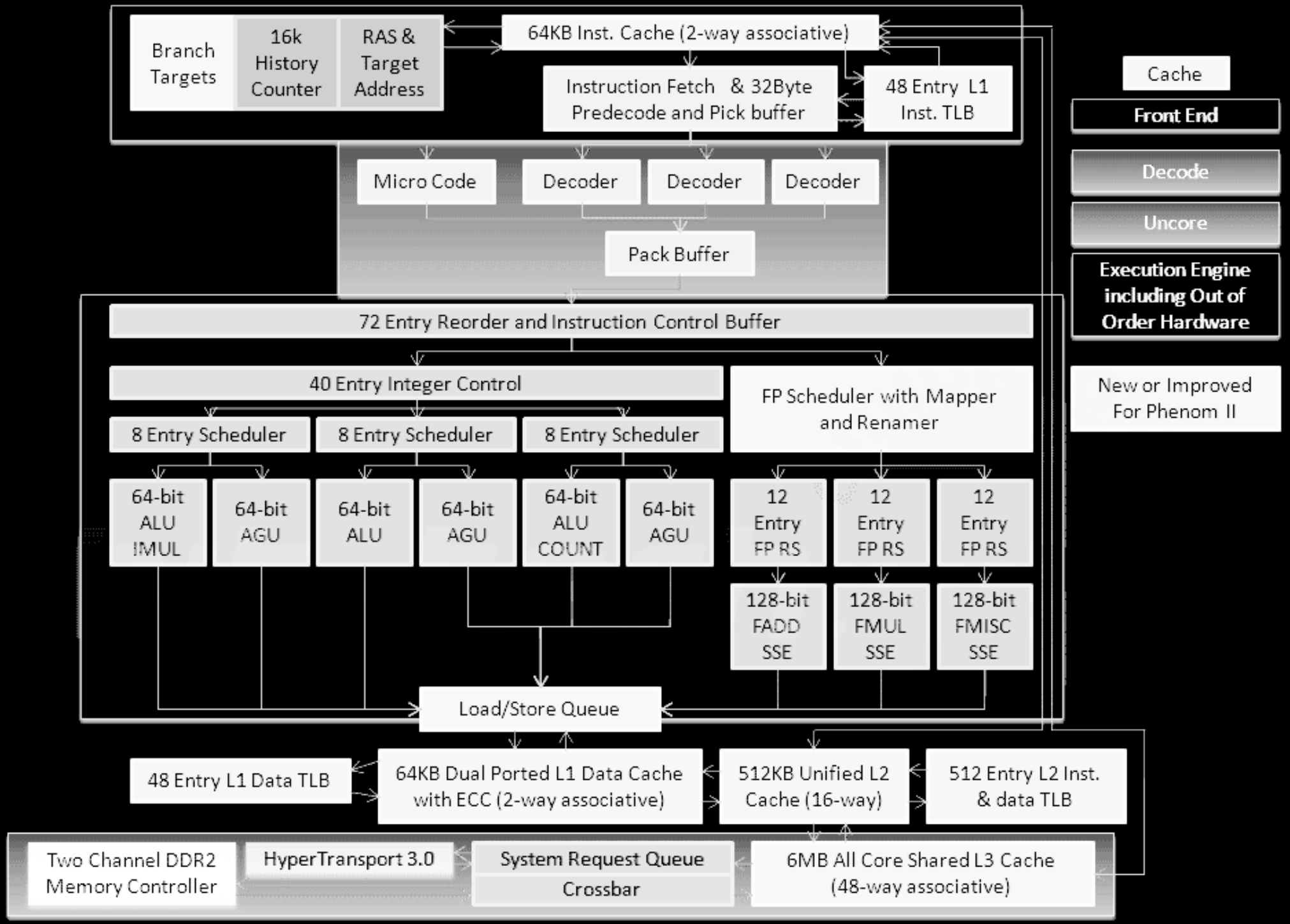
- CPU – Central Processing Unit
- PE, Core – Processing Element
- Processor – CPU or chip containing PEs
- "Computer Family" – same ISA
- x86, IA32, x64/AMD64 – Intel 386-based ISAs
- MIPS, ARM, RISC-V – other common ISAs
- DSP – Digital Signal Processor
- GPU – Graphics Processing Unit
- Tensor – Matrix support for neural networks
- Quantum – Combinatorial use of superposition

Complexity is Increasing!

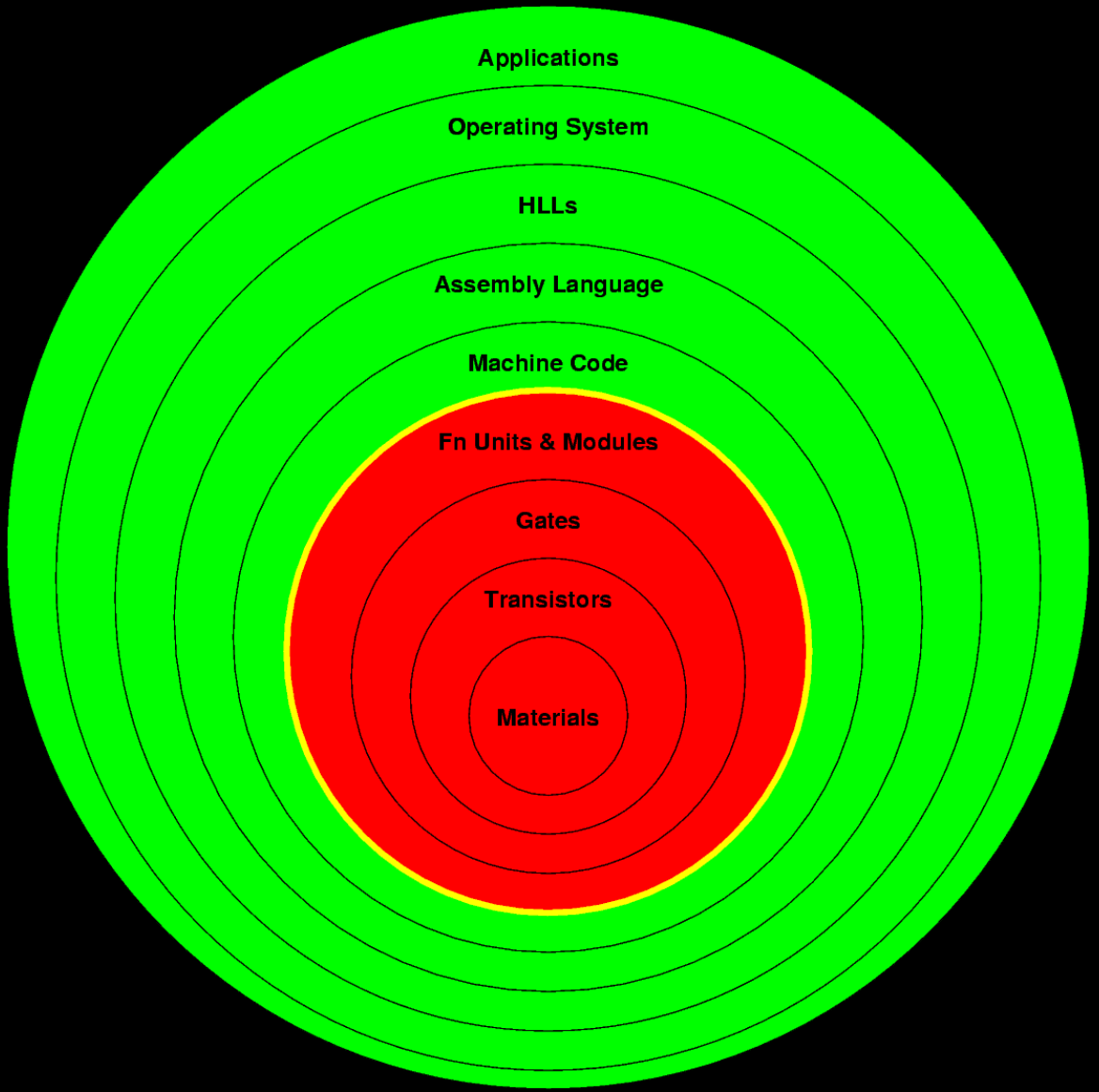
- Lots of things you use every day have **BILLIONS** of components!
- You don't live long enough to know it all



El Capitan supercomputer:
11,039,616 cores, 2.821 Exaflop/s
Cost approx. $600M, 29.7 MW power


Branch Targets
16k History Counter
RAS & Target Address
64KB Inst. Cache (2-way associative)
Instruction Fetch & 32Byte Predecode and Pick buffer
48 Entry L1 Inst. TLB
Micro Code
Decoder
Decoder
Decoder
Pack Buffer
72 Entry Reorder and Instruction Control Buffer
40 Entry Integer Control
8 Entry Scheduler
8 Entry Scheduler
8 Entry Scheduler
FP Scheduler with Mapper and Renamer
64-bit ALU IMUL
64-bit AGU
64-bit ALU
64-bit AGU
64-bit ALU COUNT
64-bit AGU
12 Entry FP RS
12 Entry FP RS
12 Entry FP RS
128-bit FADD SSE
128-bit FMUL SSE
128-bit FMISC SSE
Load/Store Queue
48 Entry L1 Data TLB
64KB Dual Ported L1 Data Cache with ECC (2-way associative)
512KB Unified L2 Cache (16-way)
512 Entry L2 Inst. & data TLB
Two Channel DDR2 Memory Controller
HyperTransport 3.0
System Request Queue
Crossbar
6MB All Core Shared L3 Cache (48-way associative)
Cache
Front End
Decode
Uncore
Execution Engine including Out of Order Hardware
New or Improved For Phenom II

Abstraction “Onion”

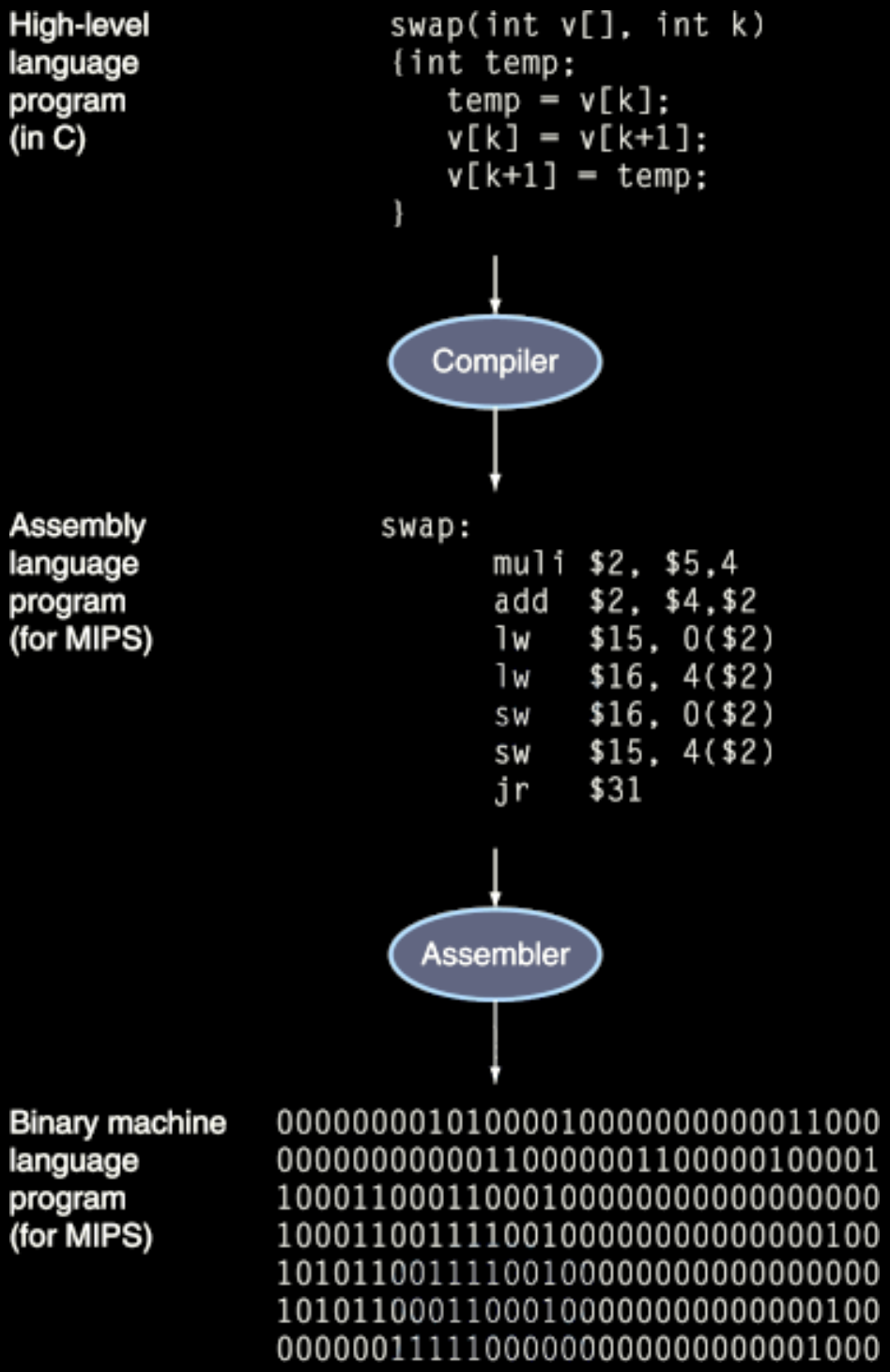


Software Layers

- Applications...
- Operating Systems (OS)...
- High-Level Languages (HLLs)
  Aka, High Order Languages (HOLs)
  - Designed for humans to write & read
  - Modularity
  - Abstract data types, type checking
  - Assignment statements
  - Control constructs
  - I/O statements

Instruction Set Architecture

- ISA defines HW/SW interface
- Assembly Language
  - Operations match hardware abilities
  - Relatively simple & limited operations
  - Mnemonic (human readable?)
- Machine Language
  - Bit patterns – 0s and 1s
  - Actually executed by the hardware


High-level language program (in C)
swap(int v[], int k)
{int temp;
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;
}
Compiler
Assembly language program (for MIPS)
swap:
muli $2, $5,4
add $2, $4,$2
lw $15, 0($2)
lw $16, 4($2)
sw $16, 0($2)
sw $15, 4($2)
jr $31
Assembler
Binary machine language program (for MIPS)
00000000101000010000000000011000
00000000000011000000110000100001
10001100011000100000000000000000
10001100111100100000000000000100
10101100111100100000000000000000
10101100011000100000000000000100
00000011111000000000000000001000

Hardware Layers

- Function-block organization
- Gates & Digital Logic (CPE282 stuff)
- Transistors
  - Used as bi-level (saturated) devices
  - Amplifiers, not just on/off switches
- Materials & Integrated Circuits
  - Implementation of transistors, etc.
  - Analog properties

Who Does What?

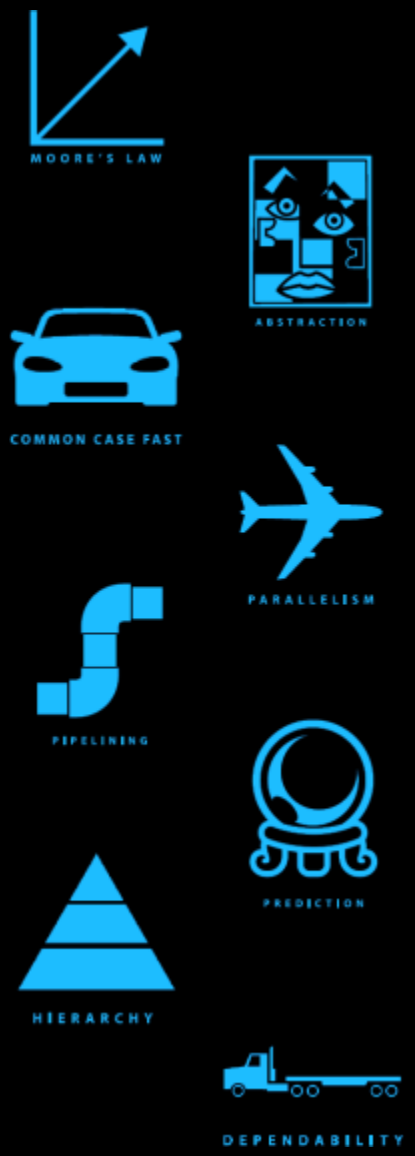
- Instruction Set Design, by *Architect*
  - Machine & Assembly Languages
  - "**Computer Architecture**"
  - **Instruction Set Architecture** / Processor
- Computer Hardware Design, by *Engineer*
  - Logic Design & Machine Implementation
  - "**Processor Architecture**"
  - "Computer Organization"

How To Use Layers

- Things are too complex to “know everything”
- Need to know only layers adjacent
  - Makes design complexity reasonable
  - Makes things reusable
- Can tunnel to lower layers
  - For efficiency
  - For special capabilities

8 Great Ideas

- Design for Moore's Law
- Abstraction
- Make the common case fast
- Pipelining
- Parallelism
- Prediction
- Hierarchy of memories
- Dependability via redundancy



SI Terminology Of Scale

1000^1	kilo	k	1000^-1	milli	m
1000^2	mega	M	1000^-2	micro	u
1000^3	giga	G	1000^-3	nano	n
1000^4	tera	T	1000^-4	pico	p
1000^5	peta	P	1000^-5	femto	f
1000^6	exa	E			

- 1000^x vs. 1024^x
- 1 Byte (B) is 8-10 bits (b), 4 bits in a Nybble
- Hertz (Hz) is frequency (vs. period)

Conclusion

- LOTS of stuff to know about...
  focus of this course is the basic stuff around the ISA and its implementation
- A lot of computer system design is about how to build efficient systems despite incredibly high and rapidly increasing system complexity
- Look at the history references on the WWW:
  not to memorize who, what, when, & where,
  but to ***see trends***...