Microprocessor Systems

Welcome!

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Office hours: M, W, Fr 10-12

TA(s): Greidi Ajalik

Lab: EME56 Times: Thursday 8AM – 1:30PM. I didn't pick them.

Lab is shared with EE214; their times are W 4-7PM, Th 5-8PM, and Fri 2-5PM.

Class Structure

Lab-centric!

- Eight lab projects plus a final project; projects implemented on the “Blackboard” by Real Digital. You must obtain your own board. The Blackboard:
  - Is based on a Xilinx ZYNQ chip with an ARM processor and an Artix FPGA;
  - Uses the free Vivado and/or SDK tool – SDK is a full-featured design environment that includes an assembler, compiler, debugger, and other tools;
  - Runs programs written in Assembly and/or C.
- Two mid-term tests and a final; Tests 50%, projects and homework 50%

Want to be successful? Commit!

EE234: Microprocessor Systems

Follows EE214. You should understand:

- Basic logic circuits, including AND, OR, NOT, NAND, NOR, XOR logic gates and combinational circuits built from them;
- Truth tables and logic expressions;
- Multiplexors, decoders, shifters, adders, ALUs, and other combinational logic blocks;
- Flip-flops, registers and counters;
- State machines and other sequential circuits;
- Basic programming techniques in C, C++ and/or Java

You should be comfortable using CAD tools for hardware and software design

Class Overview

Goals:

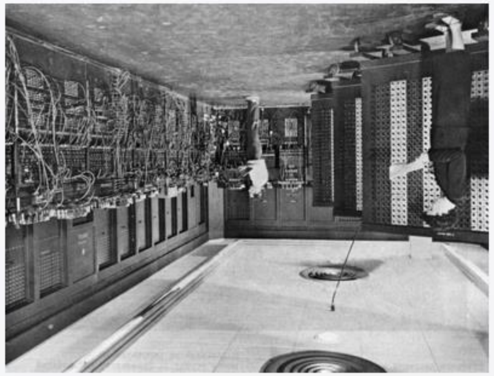
- Understand the general hardware architecture of processing circuits;
- Understand the general computing model;
- Understand the role and function of key peripherals;
- Be able to create low-level programs (assembly) and C programs to efficiently access and use on-chip resources;
- Be able to debug programs, and measure performance when needed;
- Understand the boot process, and how the compiler, assembler and linker produce executable files;
- Be generally excited about your prospects in this field

Background

Integrated Circuits and Processor Circuits

What is a processor?

A "processor" is the electronic circuitry within a computer that carries out the instructions of a computer program by performing the basic arithmetic, logical, control and input/output (I/O) operations specified by the instruction.



Eniac 1946-56
Artillery targeting

Univac 1 1951
Census Bureau

Univac 9000 1965-75
General Computing

IBM 360 Model 67 1967
General Computing

Cray XMP 1985

Apple 1 1976

VAX 1987

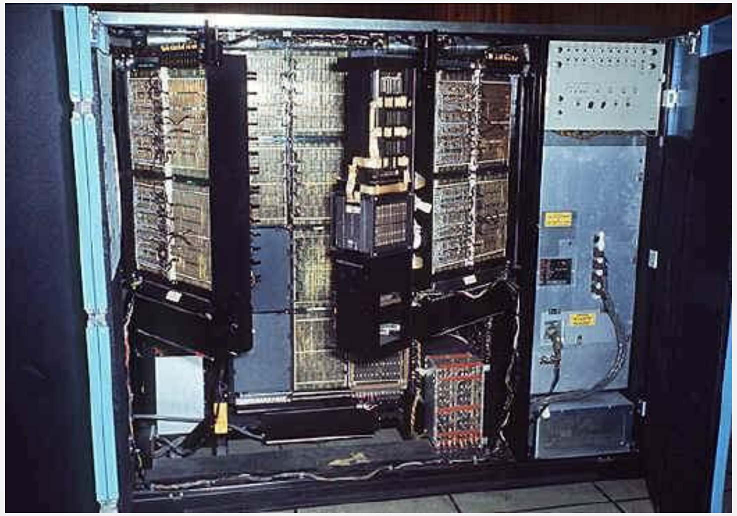
HP 9000 1990

Dell 1998

Mainframe (1960's)	10K adds/sec	Discrete
Minicomputer (1980's)	1M operations/sec	Discrete
Supercomputers (80s – 90s)	50MFlops-200MFlops	Discrete
Workstations (1990s)	10MFlops-50MFlops	Microprocessor
PCs (90s- Present)	10MFlops-500MFlops	Microprocessor

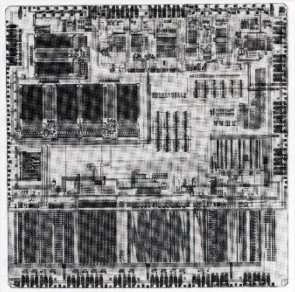
What is a microprocessor?

2m



Inside the IBM370 cabinet

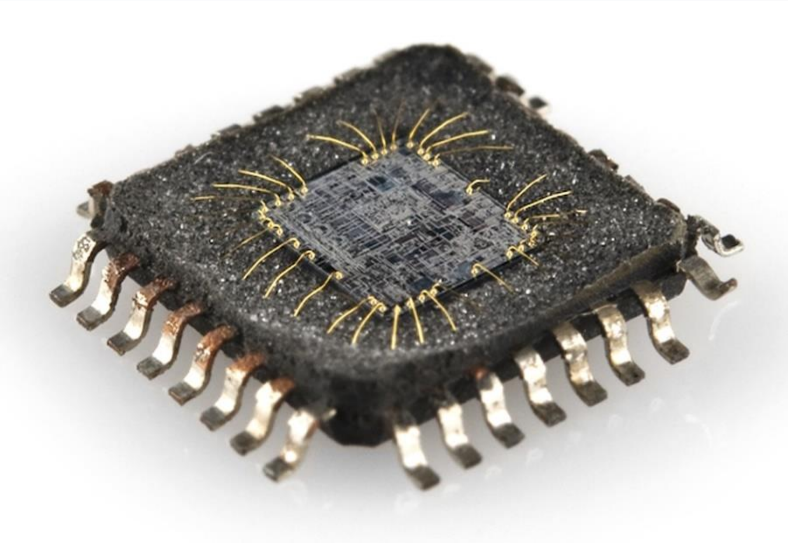
2mm



IBM370 chip

Transistors and Integrated Circuits

Integrated Circuits are collections of transistors, most typically FETs, manufactured on a single “chip” of semiconductor material, most typically silicon. Silicon is abundant, cheap, and has many desirable properties (very low cost, very reliable, relatively stable over time and temperature, non-toxic, low power, etc.)



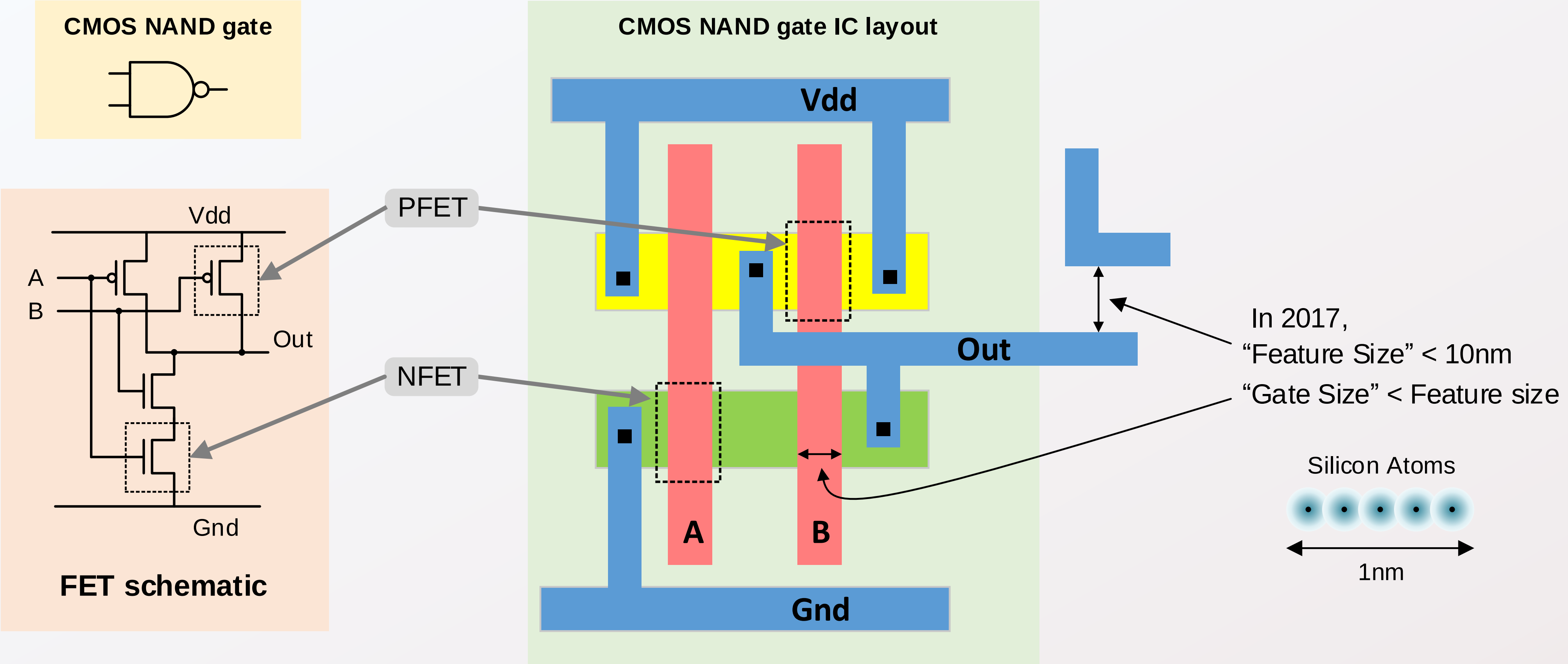
ICs range from simple digital devices, to precision analog components like amplifiers, to complex “systems on chip”. More than 500 billion IC’s are manufactured every year.

ICs are used in phones, TVs, radios, meters, toys, white goods, computers, tools – in virtually all electronics products

Processors are *Integrated Circuits* built from FETs in CMOS configurations. Processors are widely used in telecommunications, computing devices, tools, appliance, etc. More than 20 billion processors will be manufactured in 2018.

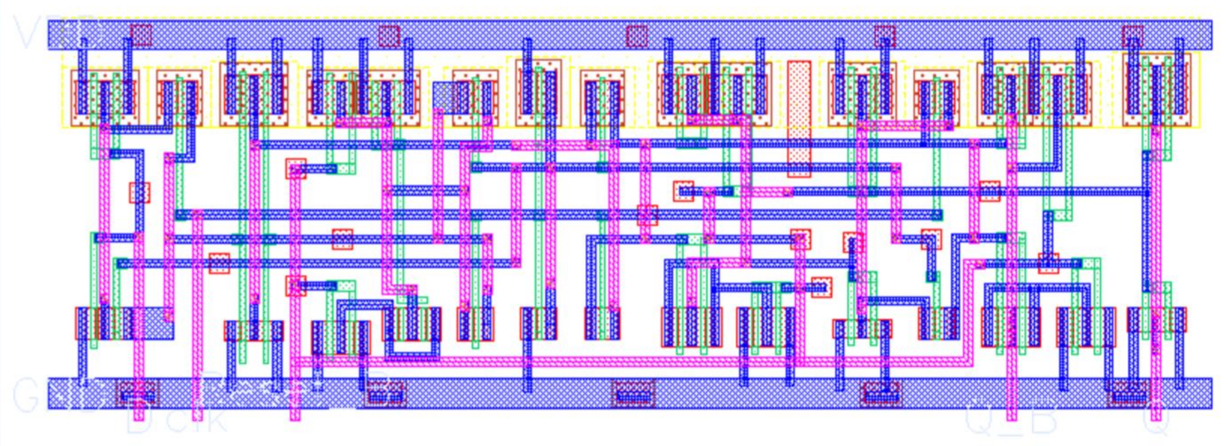
Photo from https://learn.sparkfun.com/tutorials/integrated-circuits - good short read!

CMOS circuits



- Polysilicon (conductor)
- Metal (conductor)
- Diffusion area
- Diffusion area
- Via (a connection between structures)

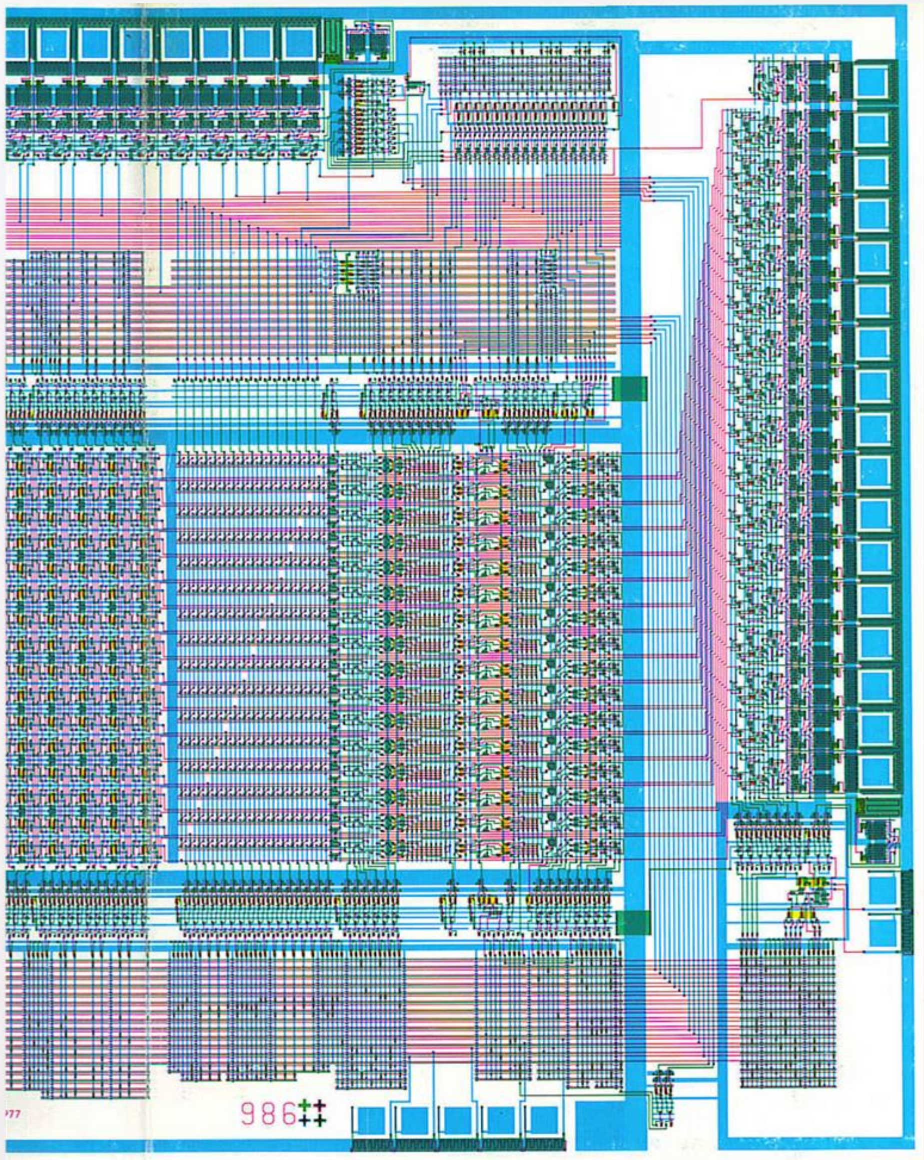
CMOS circuit examples



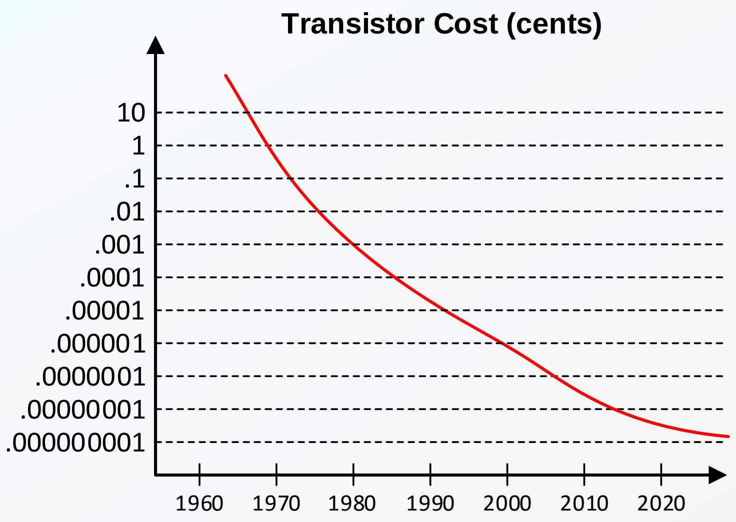
D flip-flop – about 50 transistors

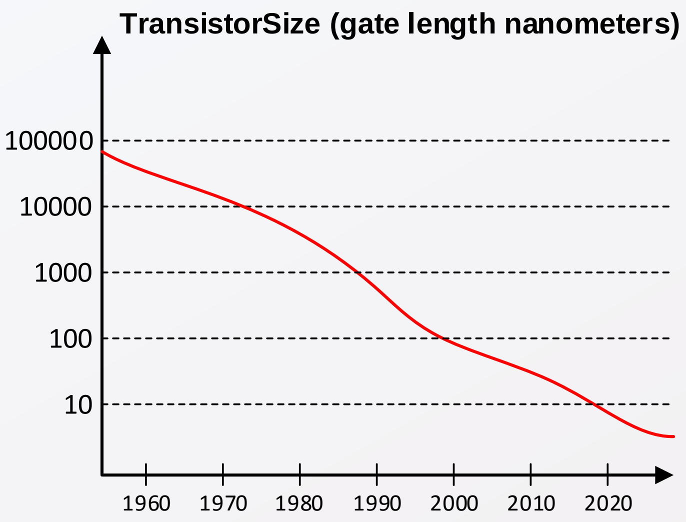
Partial processor (about 2000 transistors shown) ->

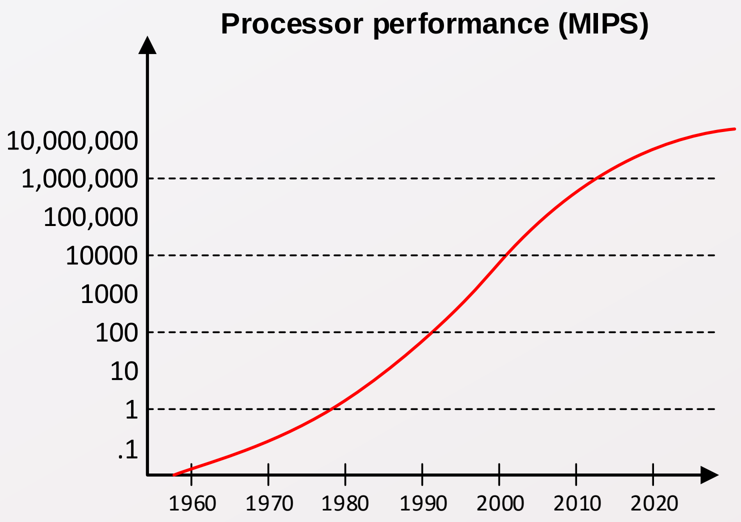
Imagine 10 million circuits like this ->
That’s the number of transistors on today’s largest processors (20,000,000,000 and counting!)

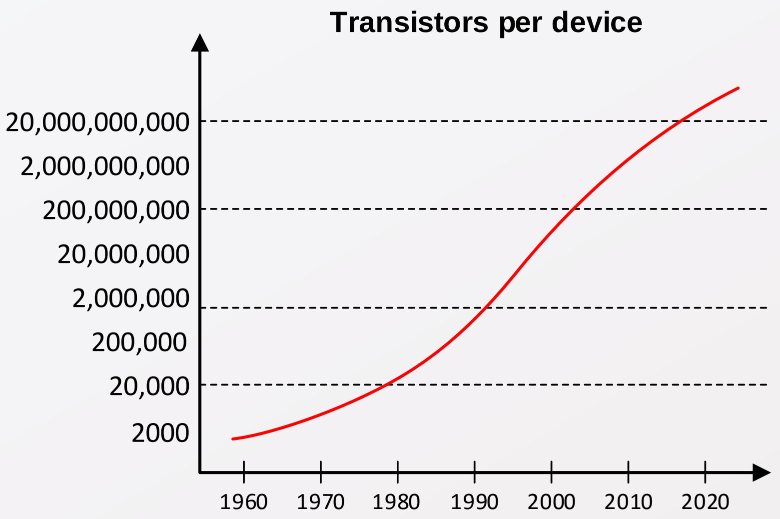


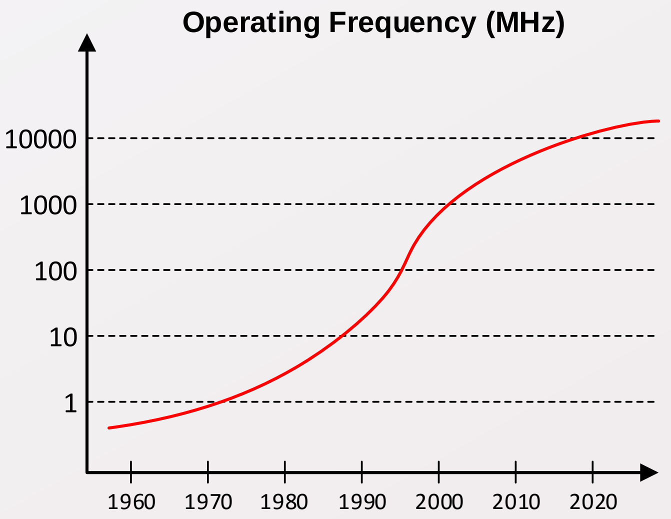
Transistor Economies

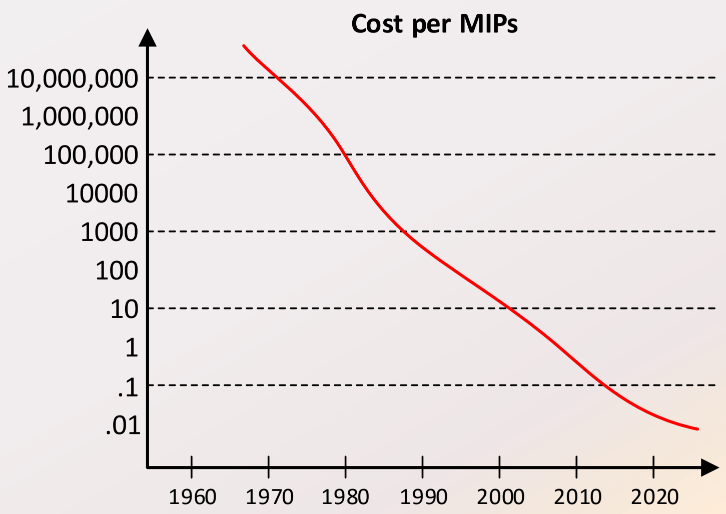












If transistors were ping-pong balls…

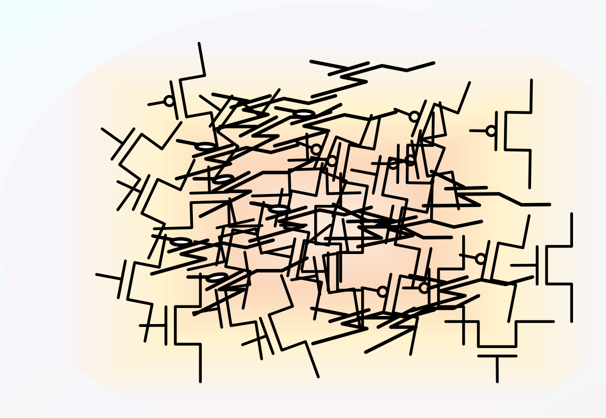
- In 1980, we could fill a suitcase (Intel 8080 - 3500 transistors)
- In 1990, we could fill two Greyhound buses (Pentium - 3.1M transistors)
- In 2005, we could fill a large high-school gym (Core2 Duo - 300M transistors)
- In 2015, a multi-story office building (Core i7 - 3.2B transistors)
- In 2017, a football stadium (AMD Epyc - 20B transistors)

We are approaching 500 billion instructions per second on a single processor IC; 100 MIPS on processors that cost less than $5; 10 MIPS on processors costing less than 50 cents.

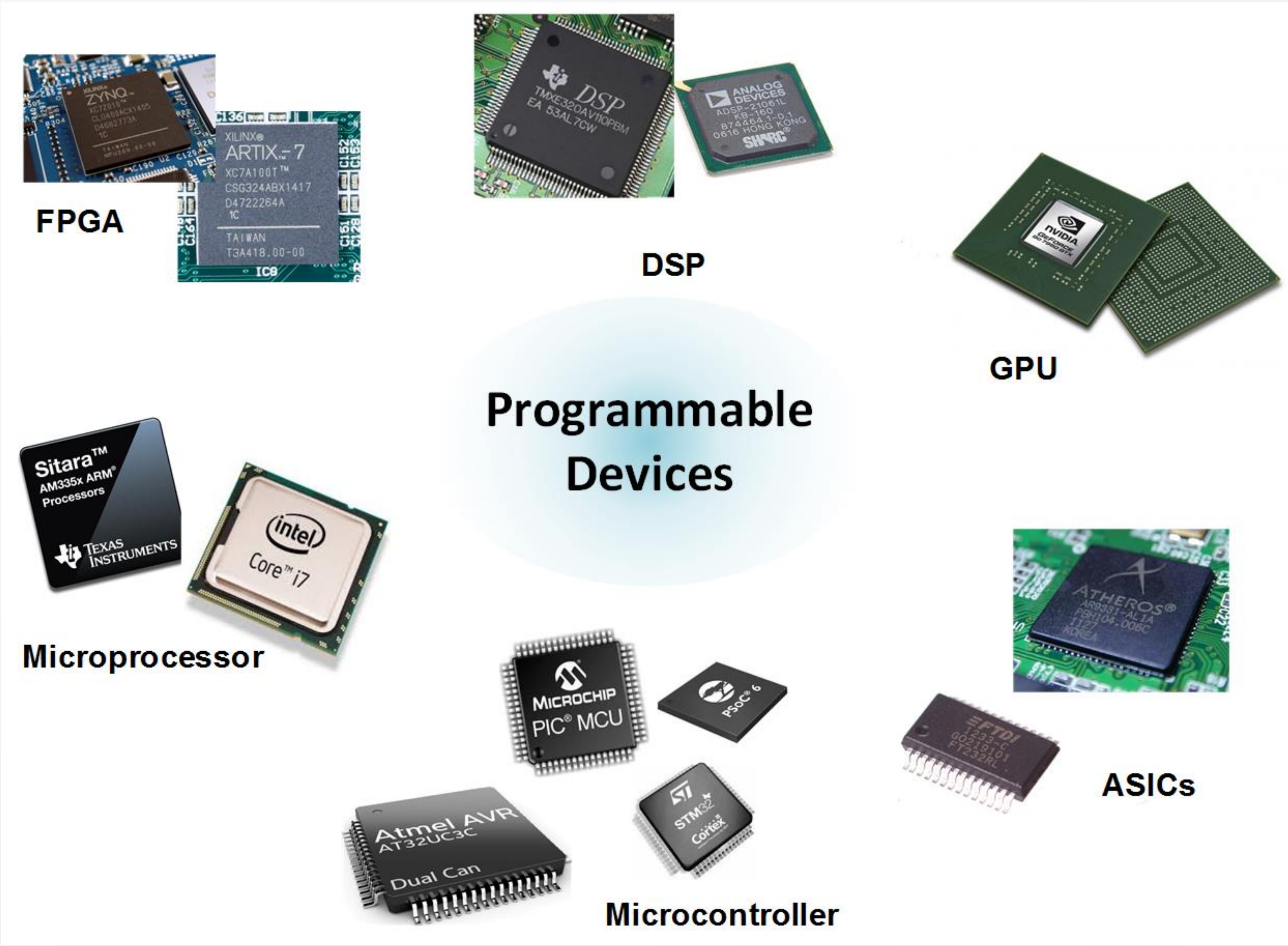
But, we are near the limits for transistor size, speed, and power.

Today’s challenge is to use the devices we can build efficiently and effectively, and that, to a large extent, means… *good use and programming of processor circuits*.

We can take a bunch of transistors…



…and make a variety of “processors”



Any number of low-cost, mass produced transistors can be assembled into a wide array of CMOS devices. Processors are currently some of the most widely used devices. Why?

ICs that qualify as "Processors"

FPGA: "Field Programmable Gate Array" – user programmable circuits that can be configured to be a processor, MP3 decoder, data acquisition device, etc. Can be reconfigured any number of times. Good for prototyping smaller production volumes (less than 20K-50K per year), and special/high-performance needs.

DSP: "Digital Signal Processor" – contains fast, wide multipliers, adders and high-speed memory. Ideal for real-time filtering/processing of acquired signals.

GPU: "Graphics Processing Unit" – contains large array of special-purpose DSP-like processors and wide, fast I/O busses for moving and processing lots of graphics data.

ASIC: "Application Specific Integrated Circuit" – targeted design to solve particular problems very efficiently (bus control, signal acquisition, system "glue"). Generally not useful for off-target applications.

Microprocessor: General-purpose, typically higher performance computing device that can execute a sequence of arithmetic or logical instructions on externally supplied data. Can execute general programs stored in external memory.

Microcontroller: A smaller microprocessor surrounded by commonly used peripherals like RAM, ROM, port controllers, A/Ds, etc.

Comparisons

	FPGA/SoC	DSP	Microprocessor	Microcontroller	GPU	ASIC
Development environment	FPGA: VHDL, Verilog, SystemC Processor: C, C++, Assembly, Java	C, C++	C, C++, Java	C, Assembly	C, C++	APIs
Unit Cost	Very high	High	High	Low - Very low	High	Moderate
Annual sales	Moderate	Moderate-Low	Moderate-High	Very high	Moderate	Moderate
Applications	Telecommunications, automotive, test and measurement, education	Phones, TVs, radios, other signal acquisition; speech recognition, image processing	General purpose computing (desktops, laptops, tablets, phones)	Specific controllers and embedded applications like white goods, automotive, toys, gadgets	PC-based graphics cards, especially for VR and gaming	Digital systems with special needs: USB, radios, lots of diverse inputs
Strengths	Programmable hardware; good for field upgrades and prototyping	Fast filtering algorithms on real-time signals	High throughput general processor	Low cost, small footprint for targeted applications	Very high throughput for graphics computing	Best solution for special-purpose applications
Some Manufacturers	Xilinx, Altera (Intel), Microsemi	Texas Instruments, Analog Devices	Intel, AMD, TI, ST, NXP	Xilinx, Altera, TI, ST, On, Microchip, Cypress,	Nvidia, AMD (ATI), Imagination,	FTDI, Atheros, Expressif, NXP

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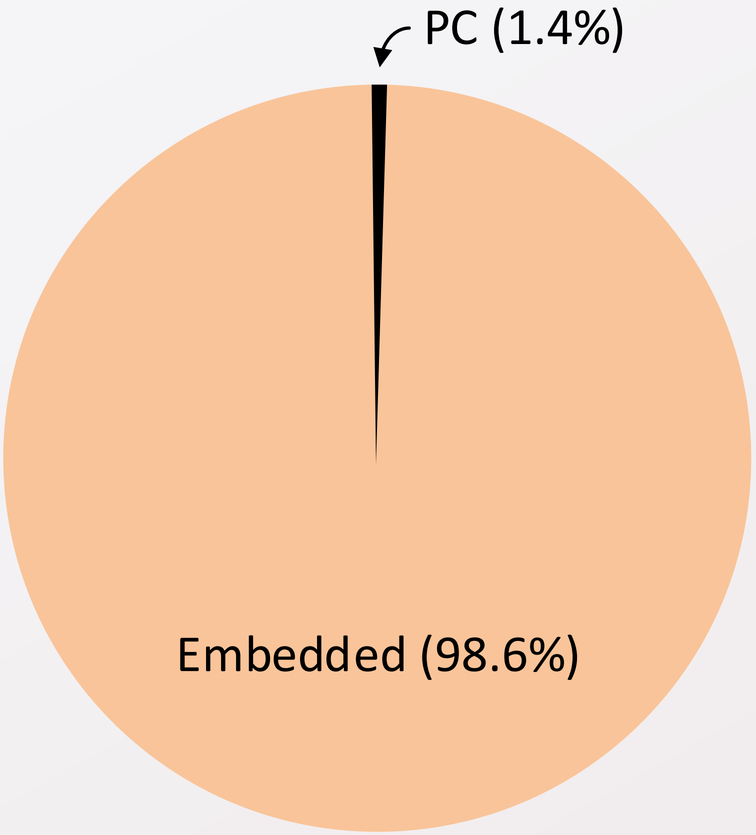
Where are processors used?

2017 PC sales (worldwide): ~300 million

2017 Embedded Processors (worldwide): ~22 billion



Number of processors sold 2016

Microprocessors are a large fraction of all semiconductor sales.

Worldwide Revenue Ranking for Top 25 Semiconductor Suppliers in 2015 (Billions of US Dollars)

2014 Rank	2015 Rank	Company Name	2014 Revenue($)	2015 Revenue($)	Revenue Percent Change	Revenue Percent of Total	Revenue Cumulative Percent
1	1	Intel	49.96	51.42	2.9%	14.8%	14.8%
2	2	Samsung Electronics	37.09	40.16	8.3%	11.6%	26.4%
4	3	SK Hynix	16.11	16.50	2.4%	4.8%	31.1%
3	4	Qualcomm	19.29	16.50	-14.5%	4.8%	35.9%
5	5	Micron Technology	16.11	14.08	-12.6%	4.1%	39.9%
6	6	Texas Instruments	12.25	12.26	0.1%	3.5%	43.5%
15	7	NXP	5.48	9.72	77.3%	2.8%	46.3%
7	8	Toshiba	10.23	8.83	-13.7%	2.5%	48.8%
8	9	Broadcom	8.40	8.41	0.2%	2.4%	51.2%
9	10	STMicroelectronics	7.40	6.90	-6.8%	2.0%	53.2%
14	11	Avago Technologies	5.65	6.89	22.0%	2.0%	55.2%
13	12	Infineon Technologies	5.94	6.81	14.8%	2.0%	57.2%
10	13	MediaTek	7.02	6.65	-5.2%	1.9%	59.1%
23	14	Apple	2.99	6.06	103.0%	1.7%	60.8%
11	15	Renesas Electronics Corporation	6.82	5.69	-16.4%	1.6%	62.5%
17	16	Sony	5.05	5.34	5.7%	1.5%	64.0%
12	17	SanDisk	6.26	4.98	-20.5%	1.4%	65.4%
19	18	nVidia	4.11	4.40	7.0%	1.3%	66.7%
16	19	Advanced Micro Devices (AMD)	5.39	3.92	-27.3%	1.1%	67.8%
21	20	ON Semiconductor	3.52	3.48	-1.0%	1.0%	68.8%
22	21	Analog Devices	3.09	3.43	11.0%	1.0%	69.8%
26	22	Skyworks Solutions	2.55	3.25	27.5%	0.9%	70.8%
24	23	HiSilicon Technologies	2.65	3.12	17.8%	0.9%	71.6%
20	24	Marvell Technology Group	3.71	2.86	-22.9%	0.8%	72.5%
25	25	ROHM Semiconductor	2.61	2.44	-6.4%	0.7%	73.2%
		All Others	104.60	93.15	-10.9%	26.8%	
		Total Semiconductor	**354.28**	**347.27**	**-2.0%**	**100.0%**	

Source: IHS

Leading MPU Suppliers ($M)

2013 Rank	Company	2012	2013	Percent Change	Marketshare	Main Product Lines
1	Intel	36,892	36,325	-2%	62.0%	x86 PC, tablet, and server MPUs
2	Qualcomm	5,322	6,884	29%	11.7%	ARM mobile app processors
3	Samsung (+Apple)*	4,249	4,850	14%	8.3%	ARM mobile app processors
4	AMD	3,605	2,831	-21%	4.8%	x86 MPUs for PCs and servers
5	Freescale	1,070	1,247	17%	2.1%	ARM and embedded MPUs
6	TI	565	485	-14%	0.8%	ARM and embedded MPUs
7	MediaTek	325	415	28%	0.7%	ARM mobile app processors
8	Nvidia	764	398	-48%	0.7%	ARM mobile app processors
9	Spreadtrum	265	375	42%	0.6%	ARM mobile app processors
10	Broadcom	345	356	3%	0.6%	ARM mobile app processors

Source: IC Insights

*Includes Apple's custom processors made by Samsung's foundry business

Leading MCU Suppliers ($M)

2016 Rank	Company	2015	2016	% Change	% Marketshare
1	**NXP***	1,350	2,914	116%	19%
2	**Renesas**	2,560	2,458	-4%	16%
3	**Microchip****	1,355	2,027	50%	14%
4	**Samsung**	2,170	1,866	-14%	12%
5	**ST**	1,514	1,573	4%	10%
6	**Infineon**	1,060	1,106	4%	7%
7	**Texas Instruments**	820	835	2%	6%
8	**Cypress*****	540	622	15%	4%

*Acquired Freescale in December 2015.

**Purchased Atmel in April 2016.

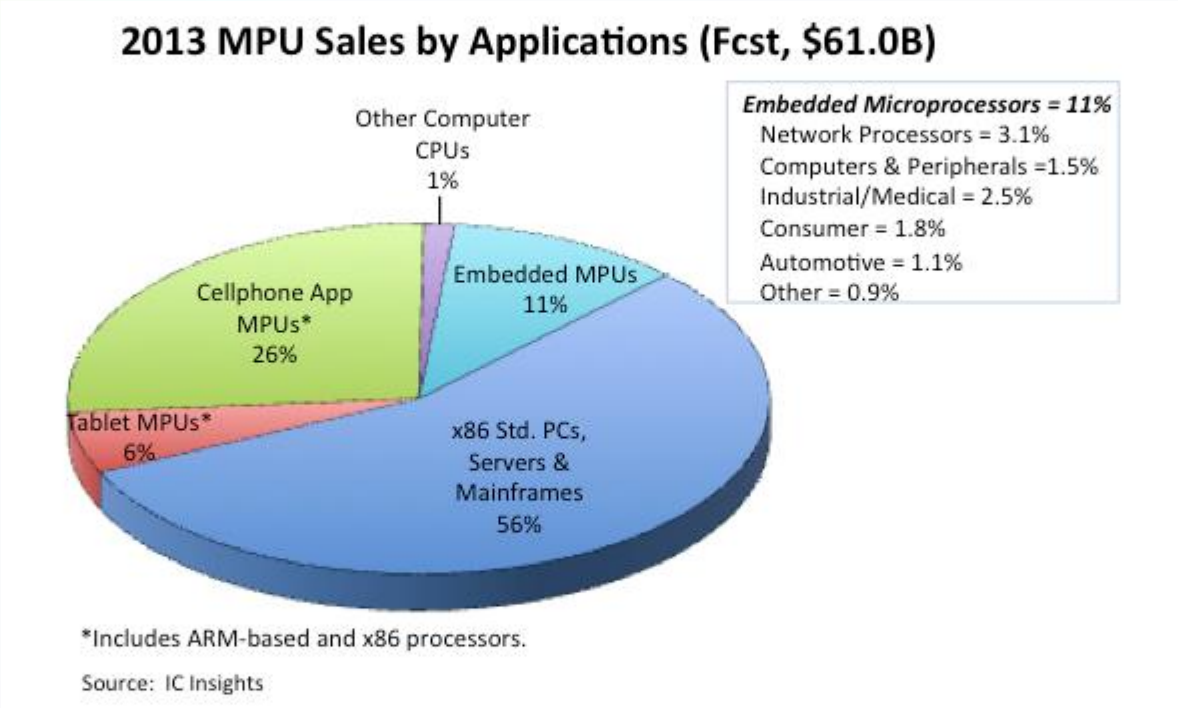
***Includes full year of sales from Spansion acquisition in March 2015.

Source: IC Insights, company reports

8-bit MCUs: 20 cents to $5; up to 25MIPs

32-bit MCUs: 80 cents to $25; up to 1000+ MIPs

	2012	2013	2014	2015	2016	2017	CAGR
Total Semiconductor	325,367	339,666	361,612	385,052	395,974	413,602	4.9%
Microcontroller (MCU)	16,008	16,202	17,211	18,799	19,307	20,480	5.1%
4 bit MCU	154	159	161	157	145	133	-2.8%
8 bit MCU	6,057	6,565	6,936	7,532	7,768	8,259	6.4%
16 bit MCU	4,021	3,611	3,765	4,060	4,053	4,019	0.0%
32 bit MCU	5,776	5,868	6,349	7,050	7,341	8,069	6.9%



MCU Applications:

Couldn't find good market segment data, but they're everywhere!

The Blackboard

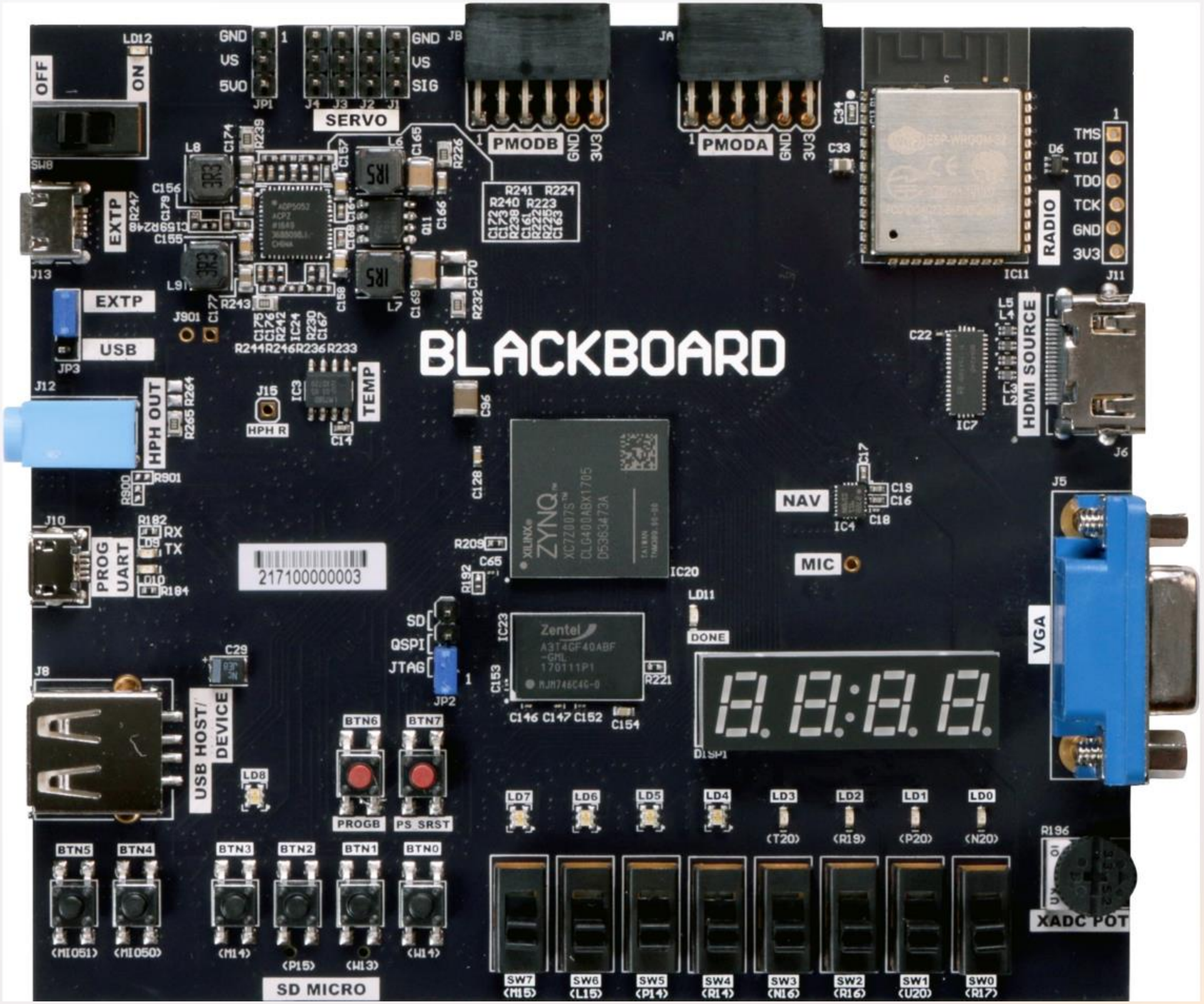
Designed by some of the world’s top engineers specifically for, well, ***you***.

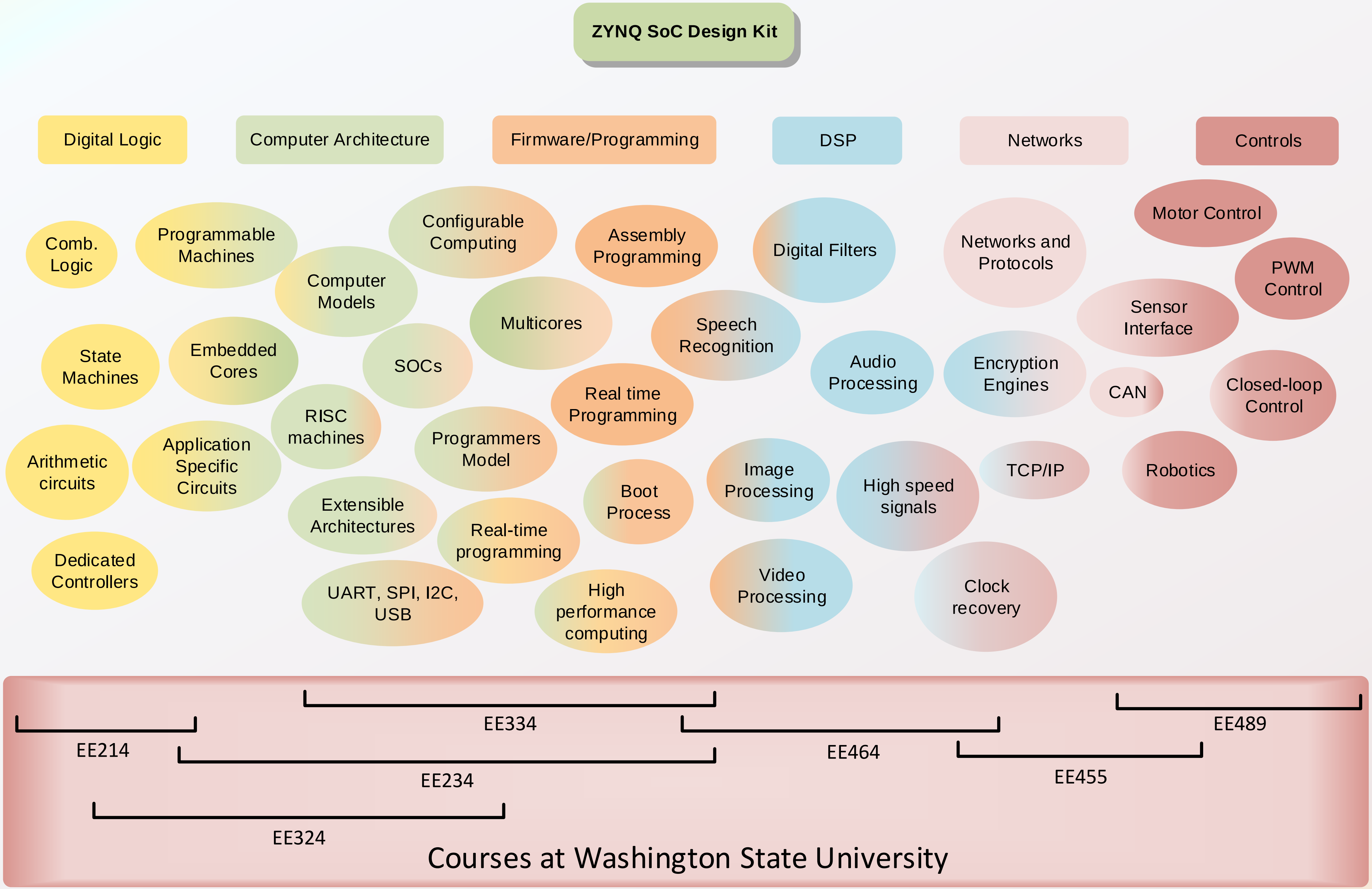
Based on Xilinx’s ZYNQ device, it includes world’s most popular embedded processor (ARM) and the best available CAD/CAS tools.

It also includes an integral FPGA.

We will program in assembly and C. We will learn about the CPU, it’s required ecosystem components, how to program it, and how to use a variety of typical peripheral devices.

This is going to be fun. Seriously.




ZYNQ SoC Design Kit
Digital Logic
Computer Architecture
Firmware/Programming
DSP
Networks
Controls
Comb. Logic
Programmable Machines
Configurable Computing
Assembly Programming
Digital Filters
Networks and Protocols
Motor Control
PWM Control
Computer Models
Multicores
Speech Recognition
Sensor Interface
State Machines
Embedded Cores
SOCs
Audio Processing
Encryption Engines
CAN
Closed-loop Control
RISC machines
Real time Programming
Programmers Model
Arithmetic circuits
Application Specific Circuits
Image Processing
High speed signals
TCP/IP
Robotics
Extensible Architectures
Boot Process
Real-time programming
Dedicated Controllers
UART, SPI, I2C, USB
High performance computing
Video Processing
Clock recovery
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EE455
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Courses at Washington State University