EEL4744

Menu

- Elements of Microcomputer
- Components of a Microcontroller
- Microprocessor Applications
- Autonomous Mobile Agents
- History of the Microprocessor
- Instruction Set Processors
- GCPU
- Other Embedded Computer Systems

1

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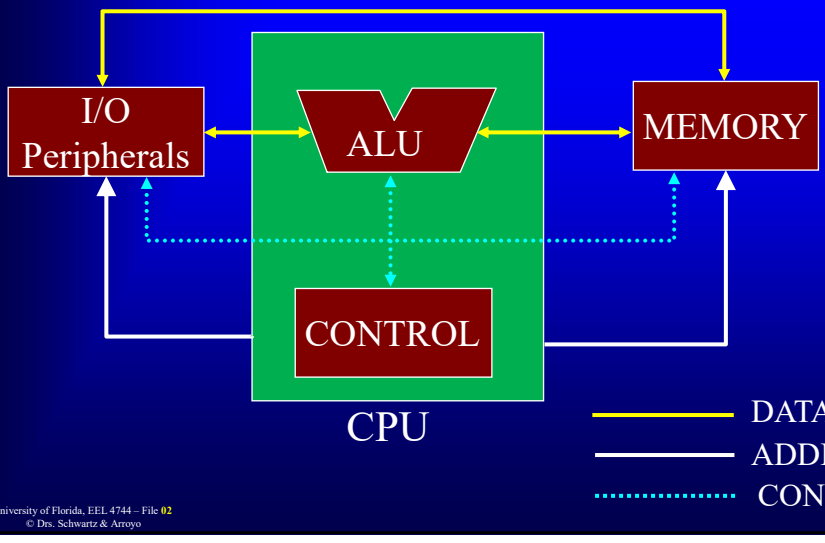
Computer Functional Block Diagram



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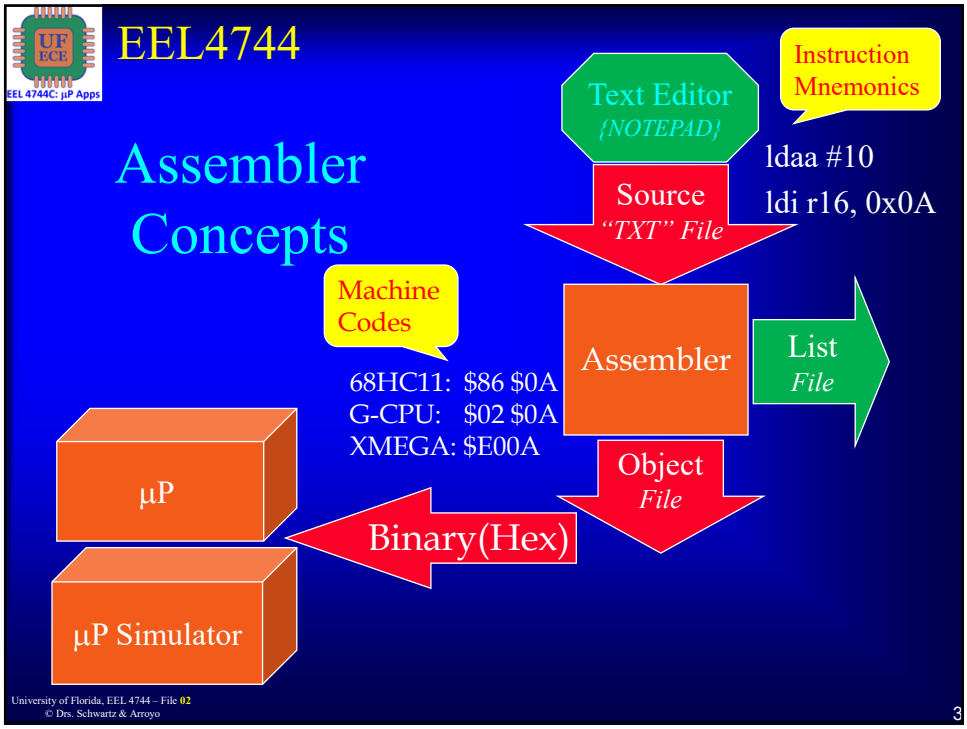
EEL4744
EEL 4744C: µP Apps
Assembler Concepts
Text Editor
{NOTEPAD}
Instruction Mnemonics
ldaa #10
ldi r16, 0x0A
Source
"TXT" File
Machine Codes
68HC11: $86 $0A
G-CPU: $02 $0A
XMEGA: $E00A
Assembler
List
File
Object
File
Binary(Hex)
µP
µP Simulator
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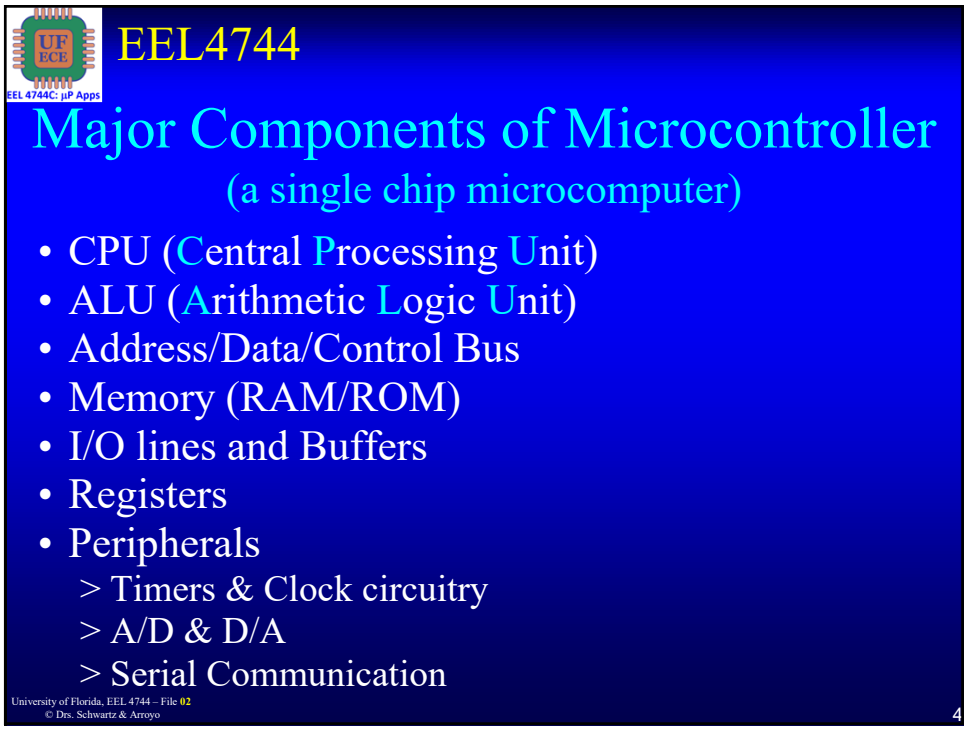
3

3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EEL 4744C: µP Apps
Major Components of Microcontroller
(a single chip microcomputer)
• CPU (Central Processing Unit)
• ALU (Arithmetic Logic Unit)
• Address/Data/Control Bus
• Memory (RAM/ROM)
• I/O lines and Buffers
• Registers
• Peripherals
> Timers & Clock circuitry
> A/D & D/A
> Serial Communication
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Microprocessor Applications

- Cars (> 100 per most cars!)
  - > Engine, Pollution controls, Safety systems (anti-lock brakes, backup cameras, traction control, keyless entry), Instrument panels, etc. [Tesla's Model 3 has well over 1000 µPs]
- Portable Devices
  - > Cell phones, DAD/NAD, Multi-meters, etc.
- Peripheral Computer Devices
  - > Keyboard, Tablets, Printers, etc.
- Others: Microwave ovens, Security Systems, TVs, etc.
- Autonomous Mobile Agents
- IoT (Internet of Things)
  - > Smart watches, smart thermostats, smart door locks, smart refrigerators, smart security systems, smart voice assistants (e.g., Amazon Echo, Google Home [Alexa], Apple HomePod [Siri])

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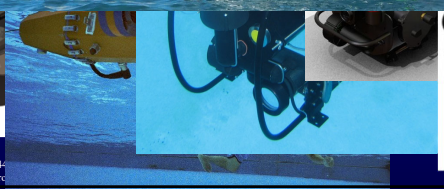
Autonomous Mobile Agents

- Later in the semester I'll show you many of the robots that we have built in MIL since 1994
  - > Ma
  - > So

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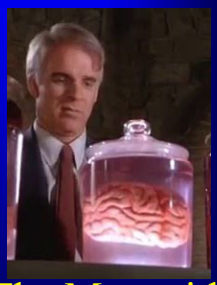
Microprocessor (μP) History

- When we say μP, we are talking about the brains of the computer
  - > But of course a brain without significant memory or a body is not very useful.
  - > Most of a computer are all the other components necessary to communicate with and challenge the brain.

Futurama
https://youtu.be/FNEH-M2qmlg



The Man with Two Brains
https://youtu.be/YT0CScFzp1o

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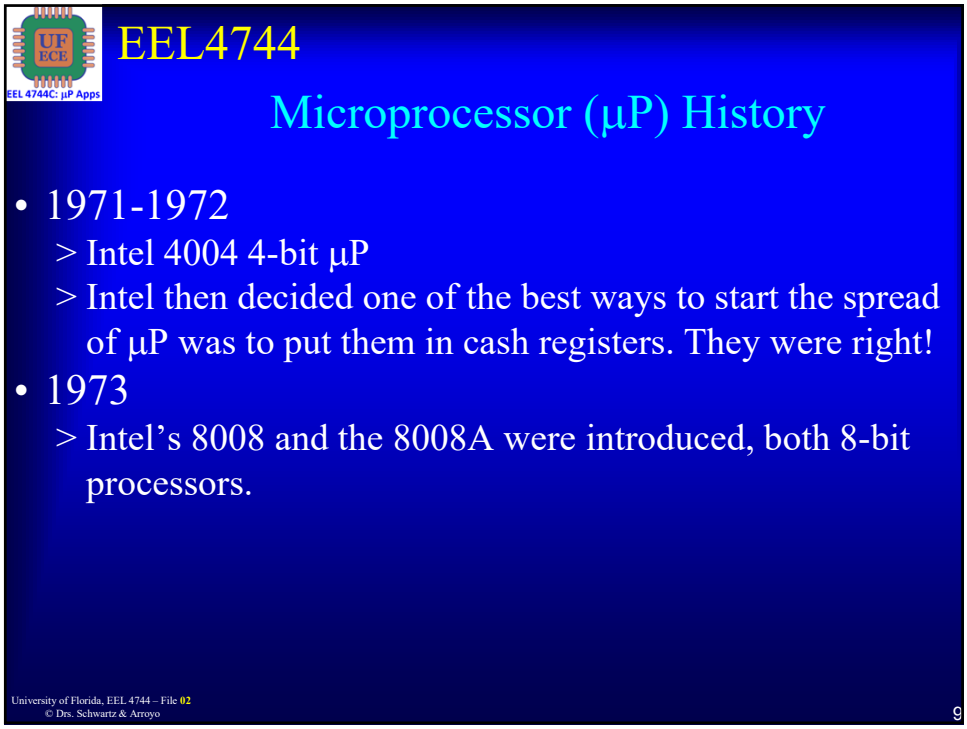
Microprocessor (μP) History

- 1968
  - > Attempted the first single chip computer (Viatron)
- 1969
  - > Intel got into the act developing calculators for BusiCom
- 1970
  - > HP calculator $300.
  - > 12KB of Magnetic Core Memory cost about $5,000 in 1973; this is about $30,000 in 2023 dollars.

8


EEL4744
Microprocessor (µP) History
• 1971-1972
> Intel 4004 4-bit µP
> Intel then decided one of the best ways to start the spread of µP was to put them in cash registers. They were right!
• 1973
> Intel's 8008 and the 8008A were introduced, both 8-bit processors.
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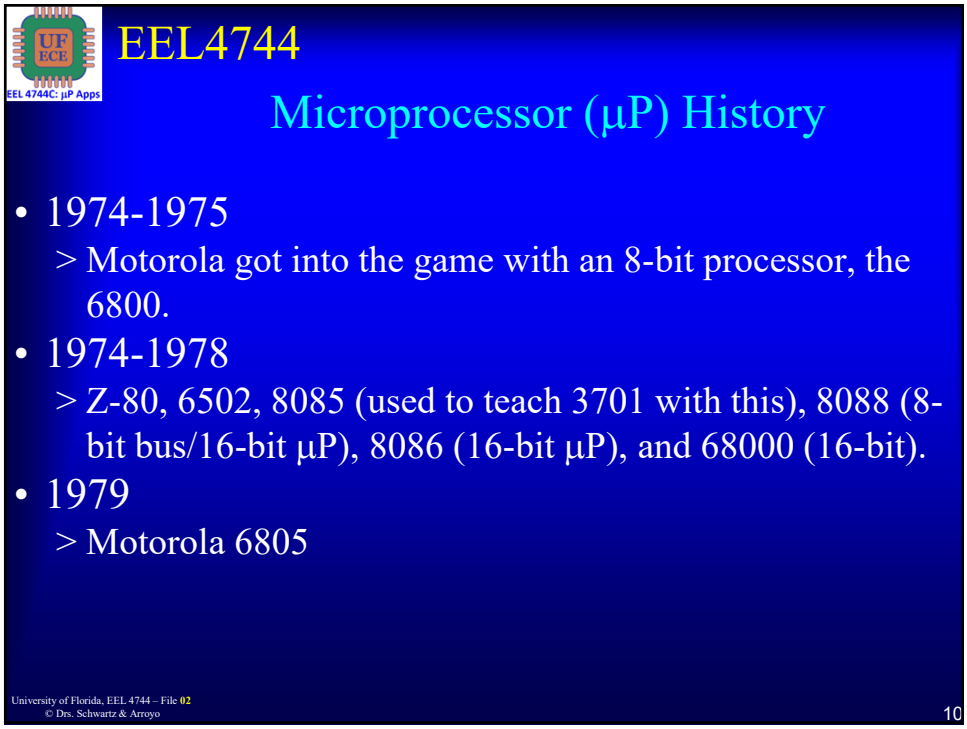
EEL4744
Microprocessor (µP) History
• 1974-1975
> Motorola got into the game with an 8-bit processor, the 6800.
• 1974-1978
> Z-80, 6502, 8085 (used to teach 3701 with this), 8088 (8-bit bus/16-bit µP), 8086 (16-bit µP), and 68000 (16-bit).
• 1979
> Motorola 6805
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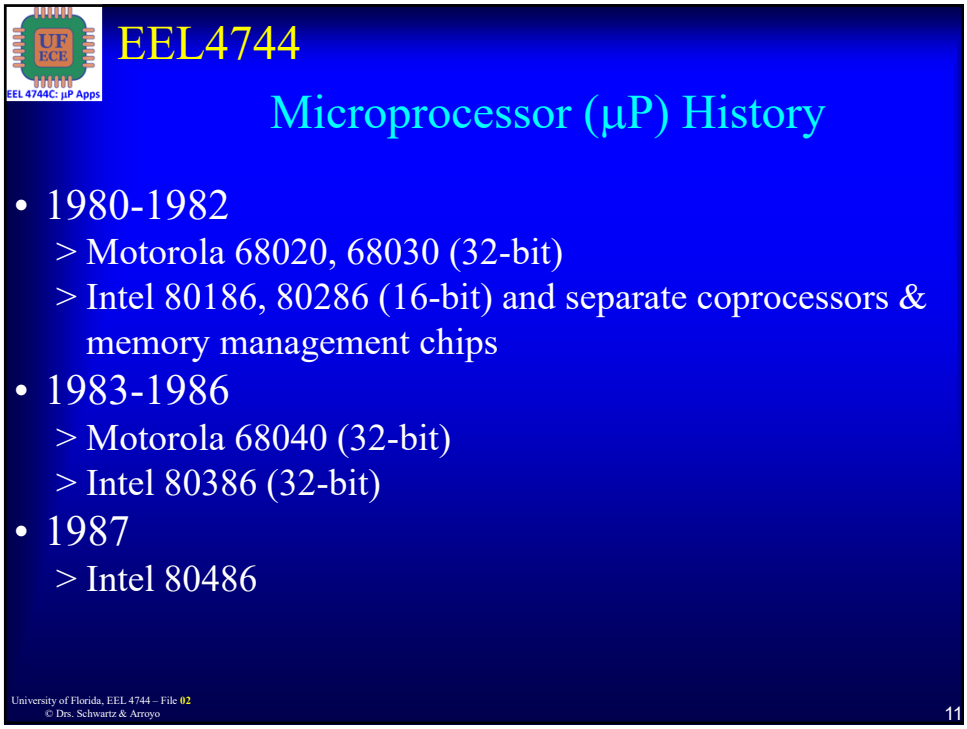
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Microprocessor (µP) History
• 1980-1982
> Motorola 68020, 68030 (32-bit)
> Intel 80186, 80286 (16-bit) and separate coprocessors & memory management chips
• 1983-1986
> Motorola 68040 (32-bit)
> Intel 80386 (32-bit)
• 1987
> Intel 80486
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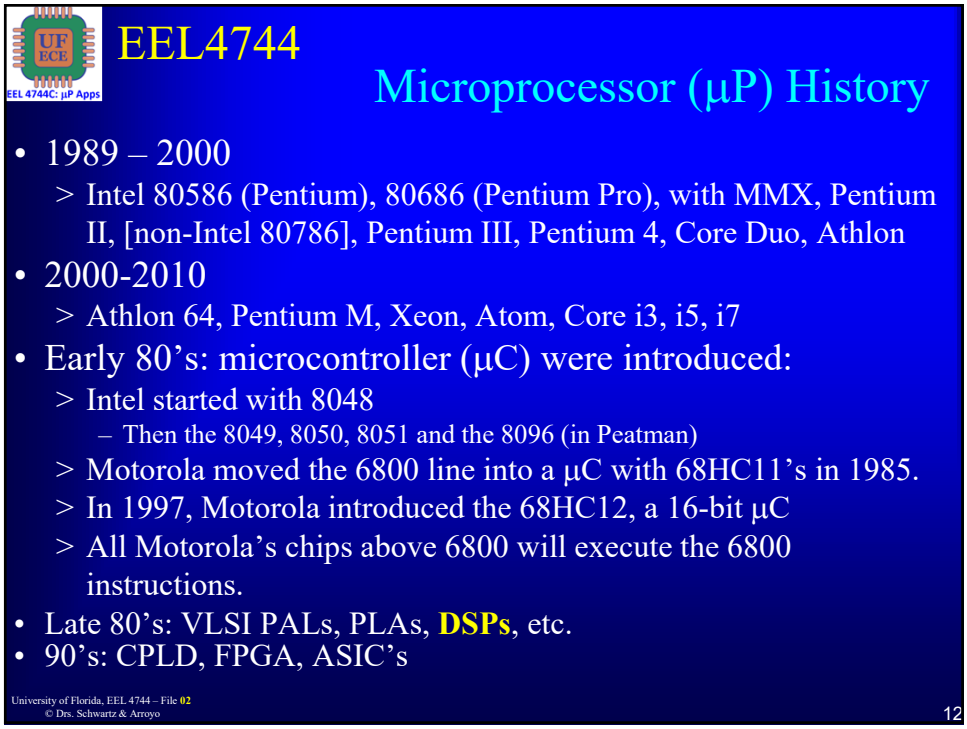
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Microprocessor (µP) History
• 1989 – 2000
> Intel 80586 (Pentium), 80686 (Pentium Pro), with MMX, Pentium II, [non-Intel 80786], Pentium III, Pentium 4, Core Duo, Athlon
• 2000-2010
> Athlon 64, Pentium M, Xeon, Atom, Core i3, i5, i7
• Early 80's: microcontroller (µC) were introduced:
> Intel started with 8048
– Then the 8049, 8050, 8051 and the 8096 (in Peatman)
> Motorola moved the 6800 line into a µC with 68HC11's in 1985.
> In 1997, Motorola introduced the 68HC12, a 16-bit µC
> All Motorola's chips above 6800 will execute the 6800 instructions.
• Late 80's: VLSI PALs, PLAs, DSPs, etc.
• 90's: CPLD, FPGA, ASIC's
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Microprocessor (µP) History

- During all this growth, the costs of µP (and µC) remains relatively constant, but the functionality grew
  - > Now we have **real-time** control, fast and low power chips
  - > µP's are entire computers on a chip
  - > µC's are µP's with RAM, ROM, I/O (plus interface logic and control module), timers, A/D, D/A, etc.
  - > µP's and µC's have built-in extensibility, i.e., can expand their function with additional chips for more: RAM, ROM, Ports (I/O lines)

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of Transistors in µPs

Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

Our World in Data

Transistor count

50,000,000,000

50 billion

10,000,000,000

5,000,000,000

1,000,000,000

500,000,000

http://en.wikipedia.org/wiki/Moore%27s_law

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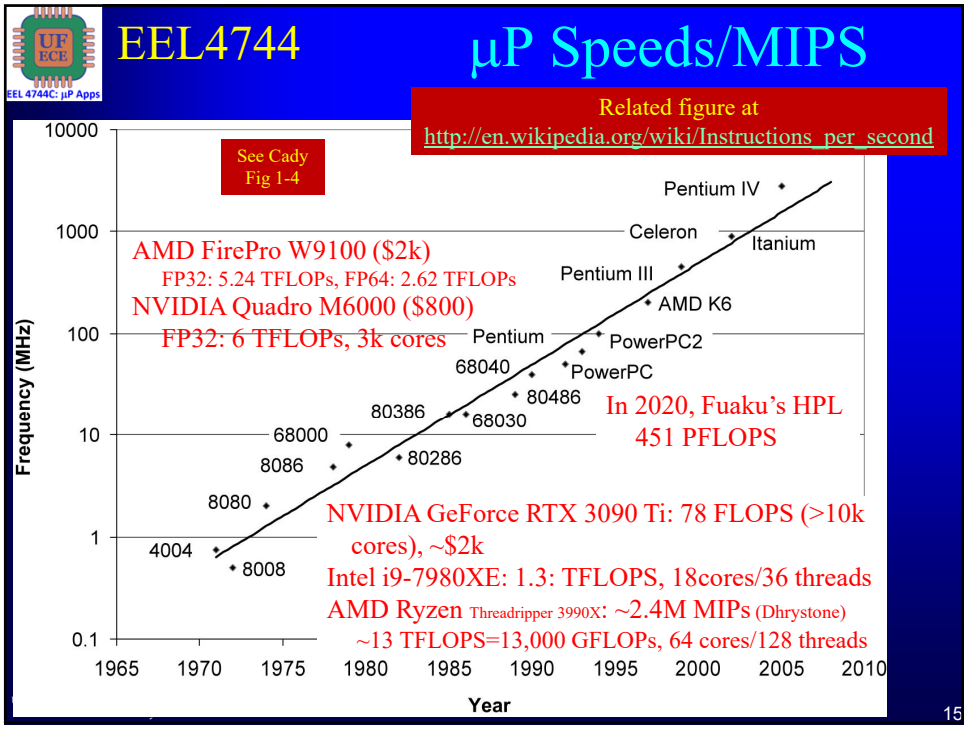
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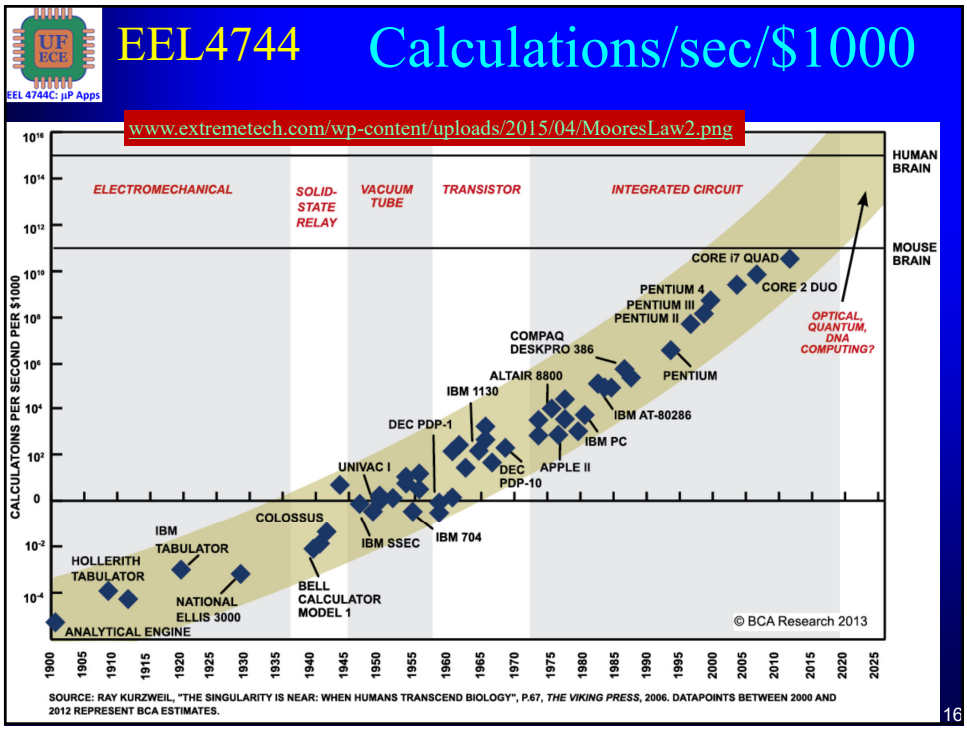
µP Speeds/MIPS
EEL 4744C: µP Apps
Related figure at
http://en.wikipedia.org/wiki/Instructions_per_second
See Cady
Fig 1-4
AMD FirePro W9100 ($2k)
FP32: 5.24 TFLOPs, FP64: 2.62 TFLOPs
NVIDIA Quadro M6000 ($800)
FP32: 6 TFLOPs, 3k cores
In 2020, Fuaku's HPL
451 PFLOPS
NVIDIA GeForce RTX 3090 Ti: 78 FLOPS (>10k cores), ~$2k
Intel i9-7980XE: 1.3: TFLOPS, 18cores/36 threads
AMD Ryzen Threadripper 3990X: ~2.4M MIPs (Dhrystone)
~13 TFLOPS=13,000 GFLOPs, 64 cores/128 threads
Frequency (MHz)
Year
10000
1000
100
10
1
0.1
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
4004
8008
8080
8086
8086
80286
80386
68030
68040
80486
Pentium
PowerPC
PowerPC2
Pentium III
Celeron
Pentium IV
Itanium
AMD K6
15

15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Calculations/sec/$1000
EEL 4744C: µP Apps
www.extremetech.com/wp-content/uploads/2015/04/MooresLaw2.png
CALCULATOINS PER SECOND PER $1000
ELECTROMECHANICAL
SOLID-STATE RELAY
VACUUM TUBE
TRANSISTOR
INTEGRATED CIRCUIT
HUMAN BRAIN
MOUSE BRAIN
OPTICAL, QUANTUM, DNA COMPUTING?
ANALYTICAL ENGINE
HOLLERITH TABULATOR
IBM TABULATOR
NATIONAL ELLIS 3000
COLOSSUS
BELL CALCULATOR MODEL 1
UNIVAC I
IBM SSEC
IBM 704
DEC PDP-1
IBM 1130
DEC PDP-10
APPLE II
ALTAIR 8800
COMPAQ DESKPRO 386
IBM PC
IBM AT-80286
PENTIUM
PENTIUM II
PENTIUM III
PENTIUM 4
CORE 2 DUO
CORE i7 QUAD
© BCA Research 2013
SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, THE VIKING PRESS, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.
16

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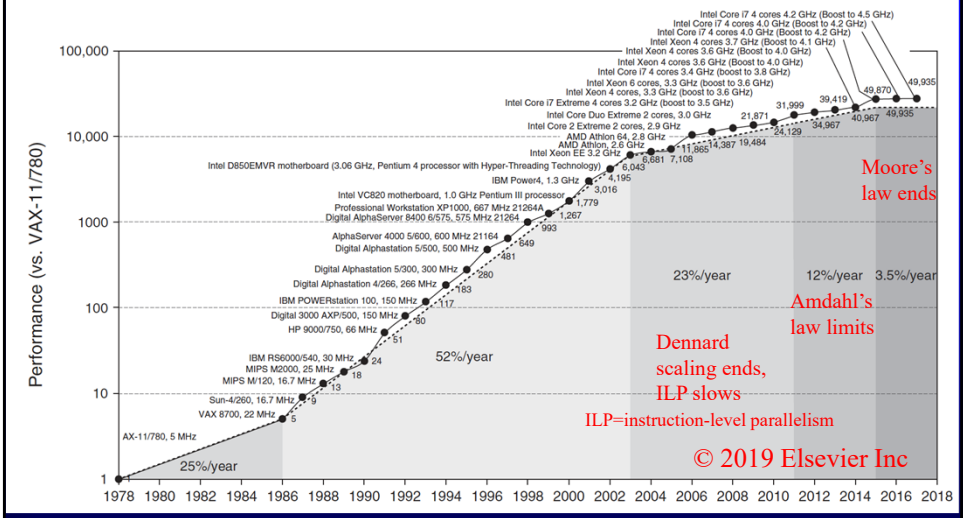
Performance Increases Slowing Down



Performance relative to the VAX 11/780 as measured by the SPEC integer benchmarks.

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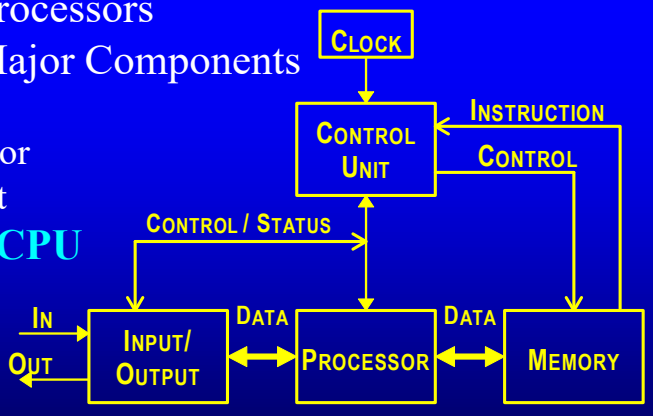
Instruction Set Processors

- Instruction Processors
- Functional/Major Components
  - > The Clock
  - > The Processor
  - > Control Unit
- **Example: GCPU**



Von Neumann (aka Princeton) Architecture

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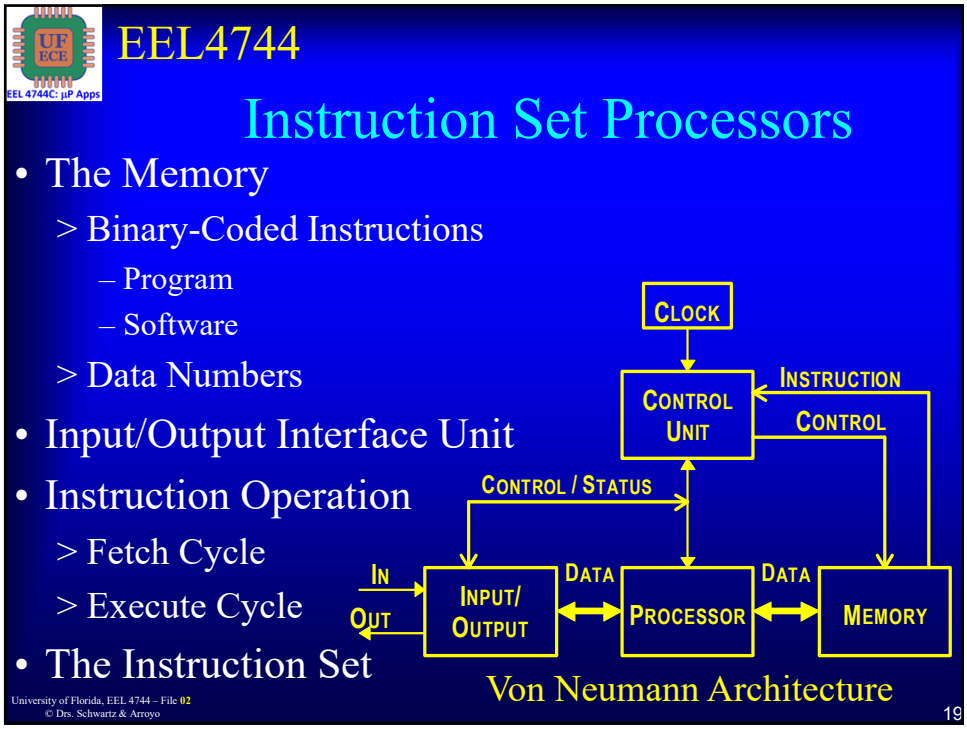
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Instruction Set Processors
• The Memory
> Binary-Coded Instructions
– Program
– Software
> Data Numbers
• Input/Output Interface Unit
• Instruction Operation
> Fetch Cycle
> Execute Cycle
• The Instruction Set
CLOCK
CONTROL UNIT
INSTRUCTION
CONTROL
CONTROL / STATUS
IN
OUT
INPUT/ OUTPUT
DATA
PROCESSOR
DATA
MEMORY
Von Neumann Architecture
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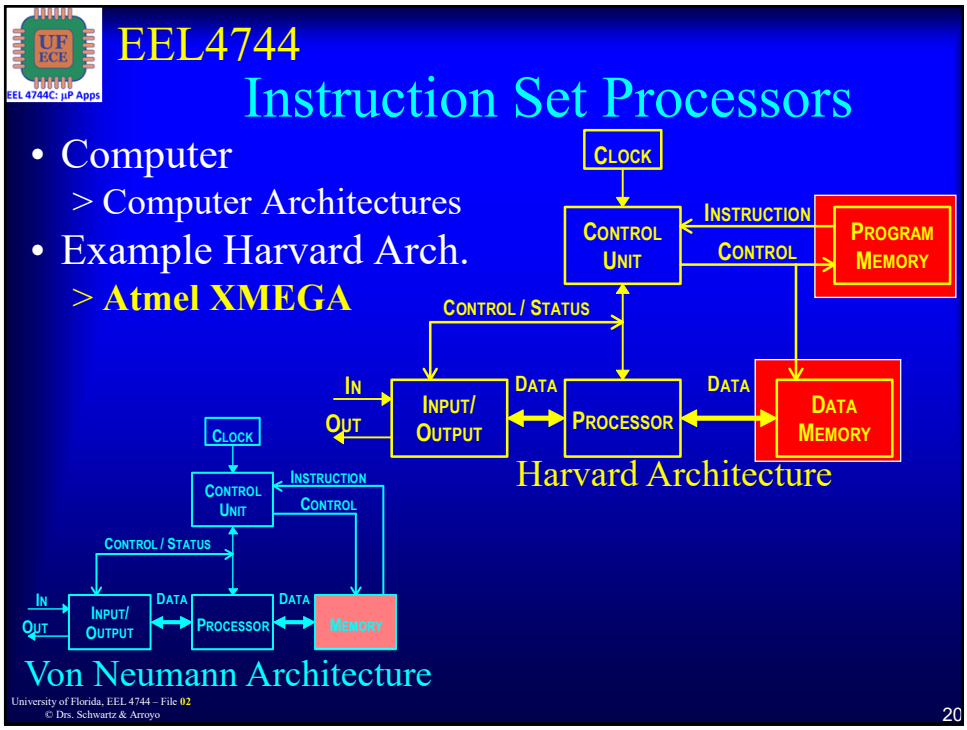
EEL4744
Instruction Set Processors
• Computer
> Computer Architectures
• Example Harvard Arch.
> Atmel XMEGA
CLOCK
CONTROL UNIT
INSTRUCTION
CONTROL
PROGRAM MEMORY
CONTROL / STATUS
IN
OUT
INPUT/ OUTPUT
DATA
PROCESSOR
DATA
DATA MEMORY
Harvard Architecture
CLOCK
CONTROL UNIT
INSTRUCTION
CONTROL
CONTROL / STATUS
IN
OUT
INPUT/ OUTPUT
DATA
PROCESSOR
DATA
Von Neumann Architecture
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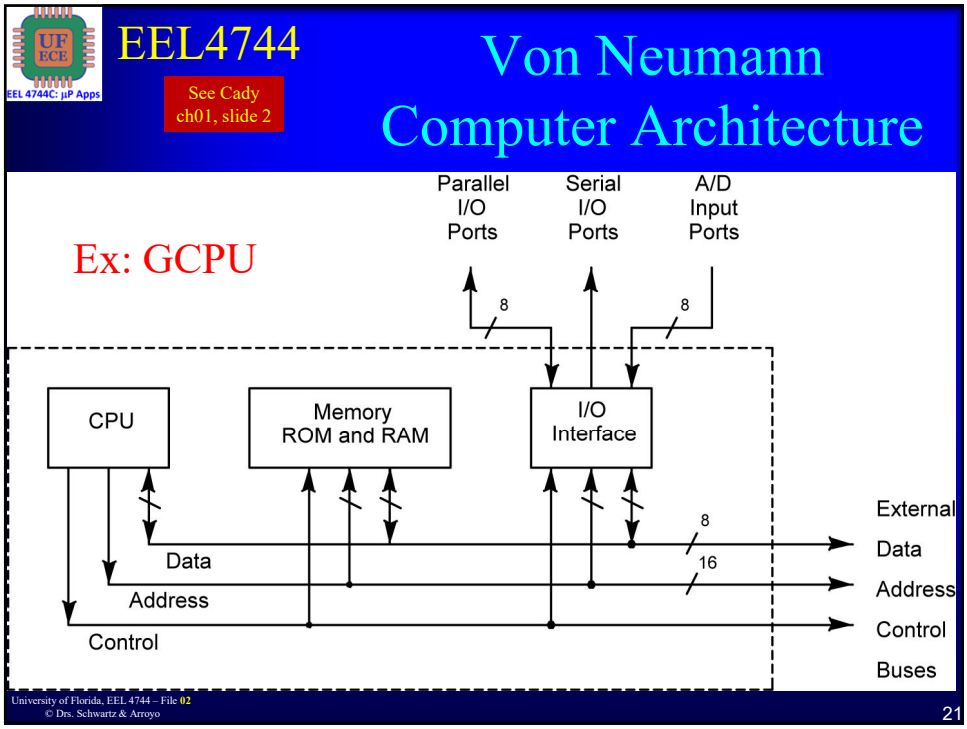
EEL4744
EEL 4744C: µP Apps
See Cady ch01, slide 2
Von Neumann Computer Architecture
Ex: GCPU
Parallel I/O Ports
Serial I/O Ports
A/D Input Ports
8
8
CPU
Memory ROM and RAM
I/O Interface
8
16
Data
Address
Control
External Data
Address
Control
Buses
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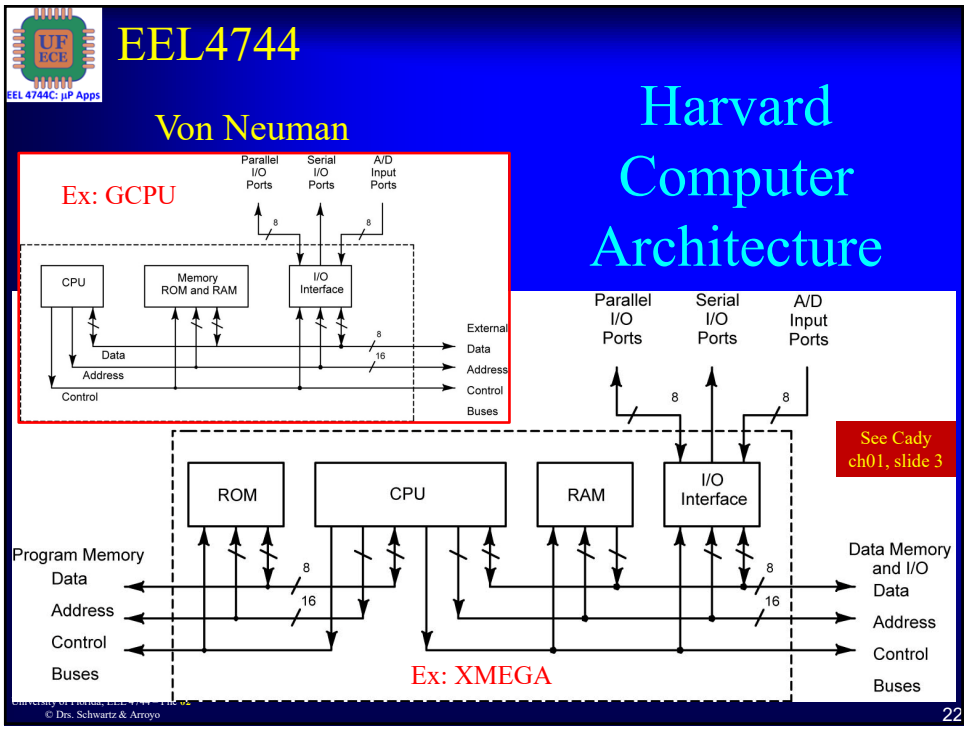
EEL4744
EEL 4744C: µP Apps
Von Neuman
Ex: GCPU
Parallel I/O Ports
Serial I/O Ports
A/D Input Ports
CPU
Memory ROM and RAM
I/O Interface
Data
Address
Control
External Data
Address
Control
Buses
Harvard Computer Architecture
Parallel I/O Ports
Serial I/O Ports
A/D Input Ports
8
8
See Cady ch01, slide 3
ROM
CPU
RAM
I/O Interface
Program Memory
Data
Address
Control
Buses
8
16
Data Memory and I/O
Data
Address
Control
Buses
Ex: XMEGA
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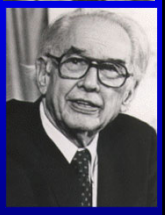
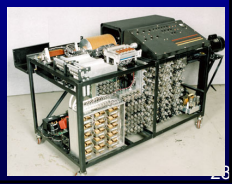
Atansoff - Berry Computer (ABC)

- John Atansoff and Clifford Berry are recognized as having created the **first** electronic digital computing device in 19**37**
  - > Atansoff graduated from the **University of Florida** (with an **EE** degree) in 19**25** (0x25 = 37)
- The ABC concepts were borrowed, without permission, to build ENIAC in the 1940s
  - > A 1973 lawsuit established that Atanasoff was indeed the "**father of the digital computer**"
  - > "It was at an evening of **scotch and 100 mph car rides**," John Atanasoff told reporters, "when the concept came, for an electronically operated machine, that would use **base-two** (**binary**) numbers instead of the traditional base-10 numbers, condensers for memory, and a regenerative process to preclude loss of memory from electrical failure."





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Why Assembly Language?

- Why should you learn assembly language?
  - > Sometimes, assembly is the best solution for a particular program where efficiency (speed or storage) matter!
  - > See http://techcrunch.com/2014/01/04/snappylabs/
- We will start the course using assembly language and then migrate to C
  - > There is **no expectation** that you know how to program in C today

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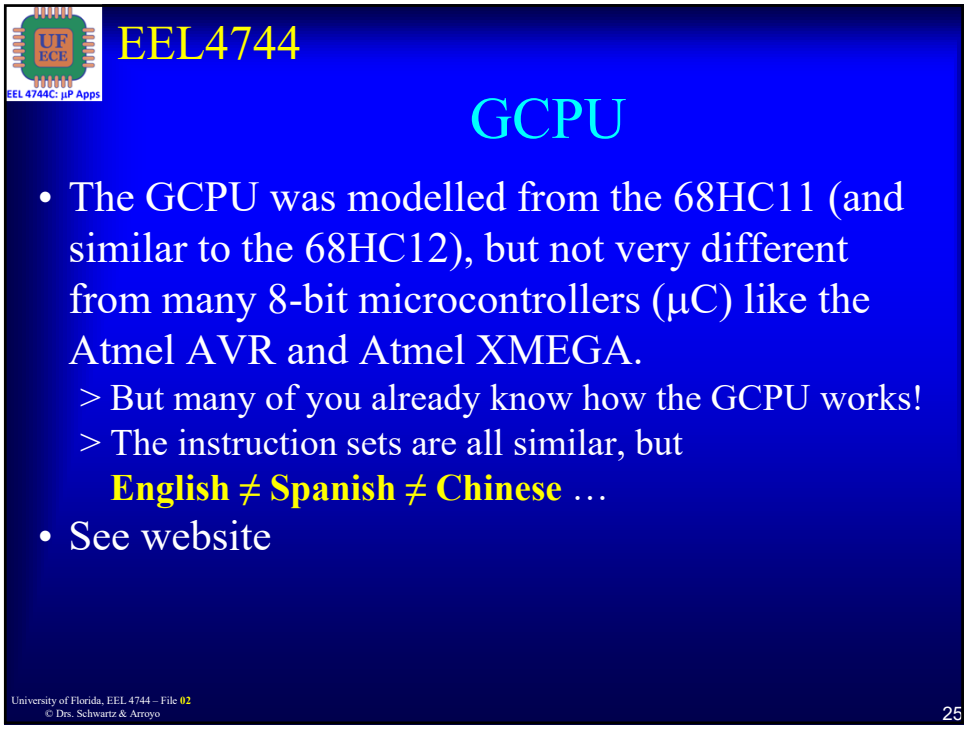
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GCPU
• The GCPU was modelled from the 68HC11 (and similar to the 68HC12), but not very different from many 8-bit microcontrollers (μC) like the Atmel AVR and Atmel XMEGA.
> But many of you already know how the GCPU works!
> The instruction sets are all similar, but
English ≠ Spanish ≠ Chinese …
• See website
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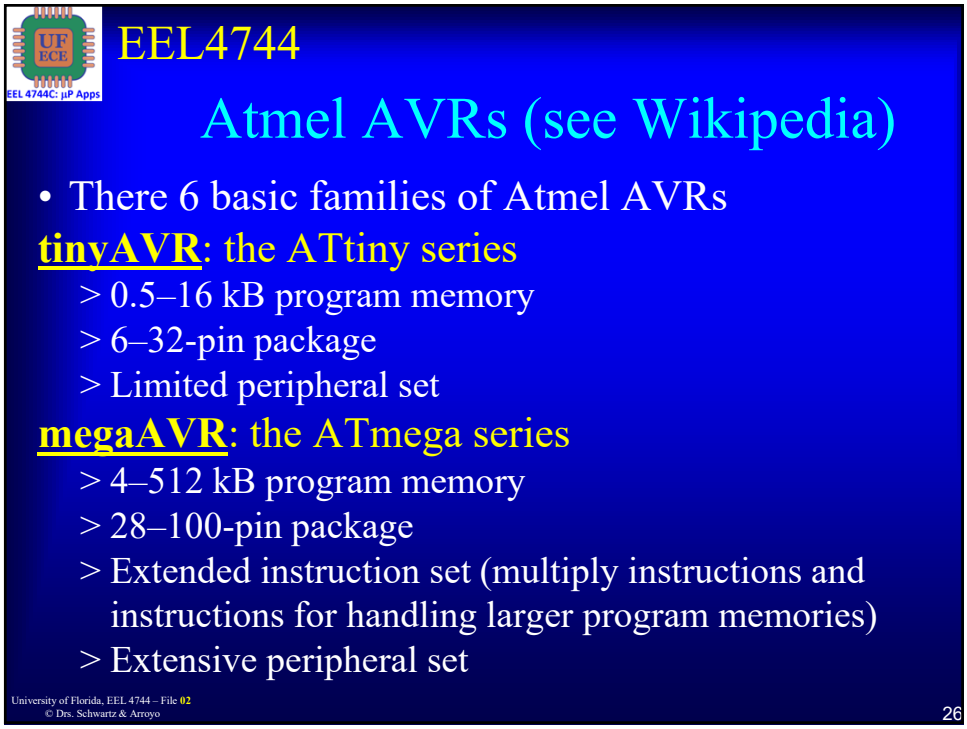
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Atmel AVRs (see Wikipedia)
• There 6 basic families of Atmel AVRs
tinyAVR: the ATtiny series
> 0.5–16 kB program memory
> 6–32-pin package
> Limited peripheral set
megaAVR: the ATmega series
> 4–512 kB program memory
> 28–100-pin package
> Extended instruction set (multiply instructions and instructions for handling larger program memories)
> Extensive peripheral set
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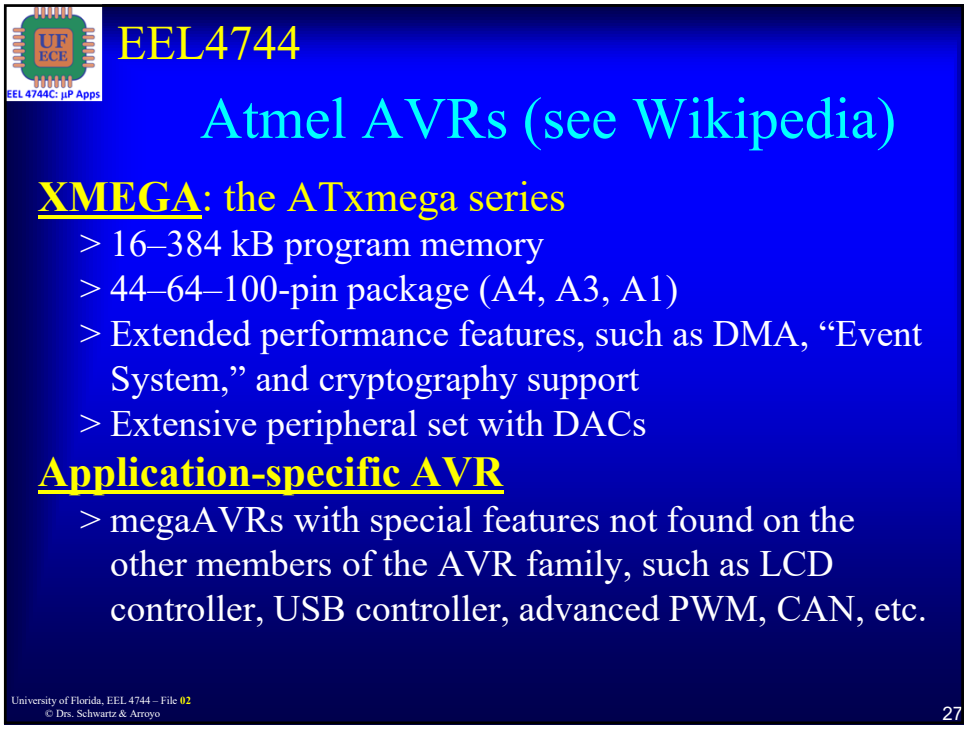
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Atmel AVRs (see Wikipedia)
XMEGA: the ATxmega series
> 16–384 kB program memory
> 44–64–100-pin package (A4, A3, A1)
> Extended performance features, such as DMA, "Event System," and cryptography support
> Extensive peripheral set with DACs
Application-specific AVR
> megaAVRs with special features not found on the other members of the AVR family, such as LCD controller, USB controller, advanced PWM, CAN, etc.
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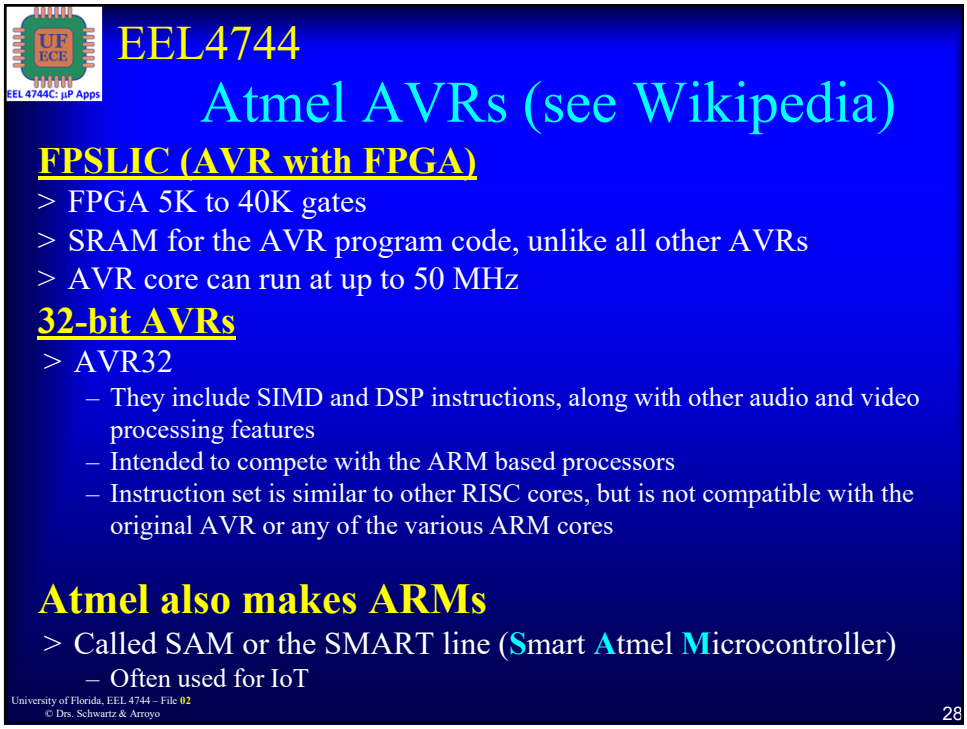
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Atmel AVRs (see Wikipedia)
FPSLIC (AVR with FPGA)
> FPGA 5K to 40K gates
> SRAM for the AVR program code, unlike all other AVRs
> AVR core can run at up to 50 MHz
32-bit AVRs
> AVR32
– They include SIMD and DSP instructions, along with other audio and video processing features
– Intended to compete with the ARM based processors
– Instruction set is similar to other RISC cores, but is not compatible with the original AVR or any of the various ARM cores
Atmel also makes ARMs
> Called SAM or the SMART line (Smart Atmel Microcontroller)
– Often used for IoT
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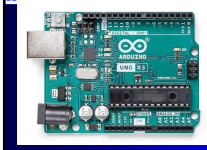
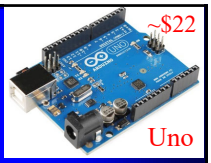
The Arduino Revolution

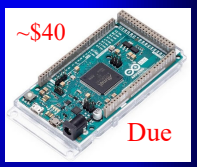


$23
Uno Rev3



~$22
Uno

- **Arduino** is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible (i.e., for the hobbyist [non-engineer]).
  - > The hardware consists of a simple **open source hardware** board designed around an 8-bit Atmel AVR microcontroller, though a new model has been designed around a 32-bit Atmel ARM (i.e., the Arduino Duo).
  - > The software consists of a standard programming language compiler and a boot loader that executes on the microcontroller.
  - > See http://www.arduino.cc/ . Prices from $22 to $100.



~$40
Due

- **Arduido Shields** can be plugged on top of the Arduino PCB, extending its capabilities.
- **Arduido Sketches** is the name used for simple programs.

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The Arduino Family

ENTRY LEVEL	UNO, LEONARDO, 101, ESPLORA, MICRO, NANO, MINI, MKR2UNO ADAPTER, STARTER KIT
ENHANCED FEATURES	MEGA, ZERO, DUE, MEGA ADK, M0, M0 PRO, MKR ZERO, MOTOR SHIELD, USB HOST SHIELD, PROTO SHIELD, MKR PROTO SHIELD, 4 RELAYS SHIELD, MEGA PROTO SHIELD, MKR RELAY PROTO SHIELD, MKR CAN SHIELD, MKR 485 SHIELD, MKR MEM SHIELD, MKR CONNECTOR CARRIER, ISP, USB2SERIAL MICRO, USB2SERIAL CONVERTER
INTERNET OF THINGS	YÚN, ETHERNET, TIAN, INDUSTRIAL 101, LEONARDO ETH, MKR FOX 1200, MKR WAN 1300, MKR GSM 1400, MKR WiFi 1010, UNO Wifi REV2, MKR NB 1500, MKR VIDOR 4000, MKR1000, YUN MINI, YÚN SHIELD, WIRELESS SD SHIELD, WIRELESS PROTO SHIELD, ETHERNET SHIELD V2, GSM SHIELD V2, MKR ETH SHIELD, MKR IoT BUNDLE
EDUCATION	CTC 101, ENGINEERING KIT
WEARABLE	GEMMA, LILYPAD ARDUINO USB, LILYPAD ARDUINO MAIN BOARD, LILYPAD ARDUINO SIMPLE, LILYPAD ARDUINO SIMPLE SNAP

https://www.arduino.cc/en/Main/Products

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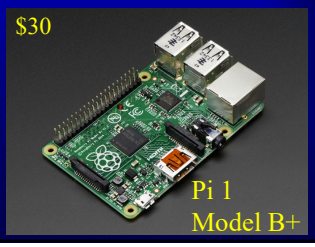
Raspberry Pi

- Similar to the Arduino family of PCBs, the Raspberry Pi family is based around a single board computer https://www.raspberrypi.org
  - > Instead of an 8-bit microcontroller on the early Arduinos, the Raspberry Pis are built around **ARM** processors and can run Linux (as well as …)
- RP is an entry-level single board computer with
  - > USB keyboard and mouse inputs, Ethernet port, SD card slot
  - > TV port, PC monitor port
  - > Audio ports, LEDs, GPIO
  - > OS: Linux (3 varieties) + others



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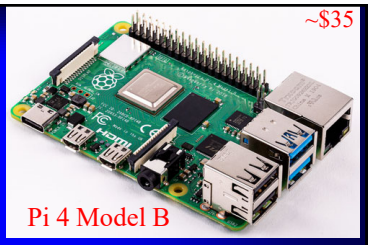
Raspberry Pi



- **CPU:** 4× ARM Cortex-A72, 1.5GHz
- **GPU:** OpenGL ES 3.0 Graphics
- **RAM:** 1GB, 2GB, or 4GB LPDDR4-3200
- **Networking:** Gigabit Ethernet, 2.4/5.0GHz 802.11ac wireless
- **Bluetooth:** Bluetooth 5.0 (Bluetooth Low Energy)
- **Storage:** microSD
- **GPIO:** 40-pin header
- **Ports:** 2x HDMI, 2× display, 2× CSI camera, 4=pole stereo audio & composite video, 2× USB 3.0, 2× USB 2.0,
- **Plus:** 5V DC via USB-C, Power over Ethernet (POE)

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TI LaunchPads

- MSP430/MSP432 LaunchPad Development Kits
  - > Like Arduino shields, TI LaunchPads have an assortment of **BoosterPacks** including
    - – Sensor Hub
    - – LCD
    - – RFID
    - – Touch Screen
    - – Capacitive Touch
    - – Wi-Fi
    - – Etc.

Select either image for link

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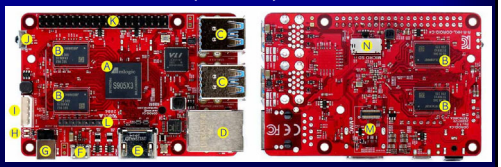
ODROID

www.hardkernel.com

- Although the ODROID is less well known then the Raspberry Pi, it is nominally more powerful
- New versions of ODROID are available every year, usually for around between $50 and $100
  - > ODROID N2 is available now ($65)
    - – More details on next page
  - > ODROID-H2 will be available soon ($110)
    - – x86
  - > ODROID-C4 (pictured) is now available for $50



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ODROID-N2

- Amlogic S922X (4x Cortex-A73 @ 1.8GHz, 2x Cortex-A53 @ 1.9GHz); Mali-G52 GPU with 6x 846MHz EEs
- 2GB or 4GB DDR4 32-bit RAM
- eMMC socket with upto 128GB
- MicroSD slot
- 8MB SPI flash
- Gigabit Ethernet port; up to 1Gbps
- HDMI 2.1 port for up to 4K@60Hz
- Composite video jack with stereo line-out and 384Khz/32bit audio DAC
- 4x USB 3.0 host ports
- 40-pin GPIO header (25x GPIO, 2x i2C, 2x ADC, 6x PWM, SPI, UART, SPDIF, various power signals, etc.)
- 7.5-20V DC jack; 12V/2A adapter
  - > 1.8W (idle) to 5.5W (stress)

$65

ODROID-N2

www.ameridroid.com

www.hardkernel.com

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OOTB Robotics

- µPAD: XMEGA128A1U
- Additional supporting PCBs
  - > Backpacks
    - – Switch/LED
    - – Analog
    - – Robotics (with new IMU starting this semester)
  - > Memory Base

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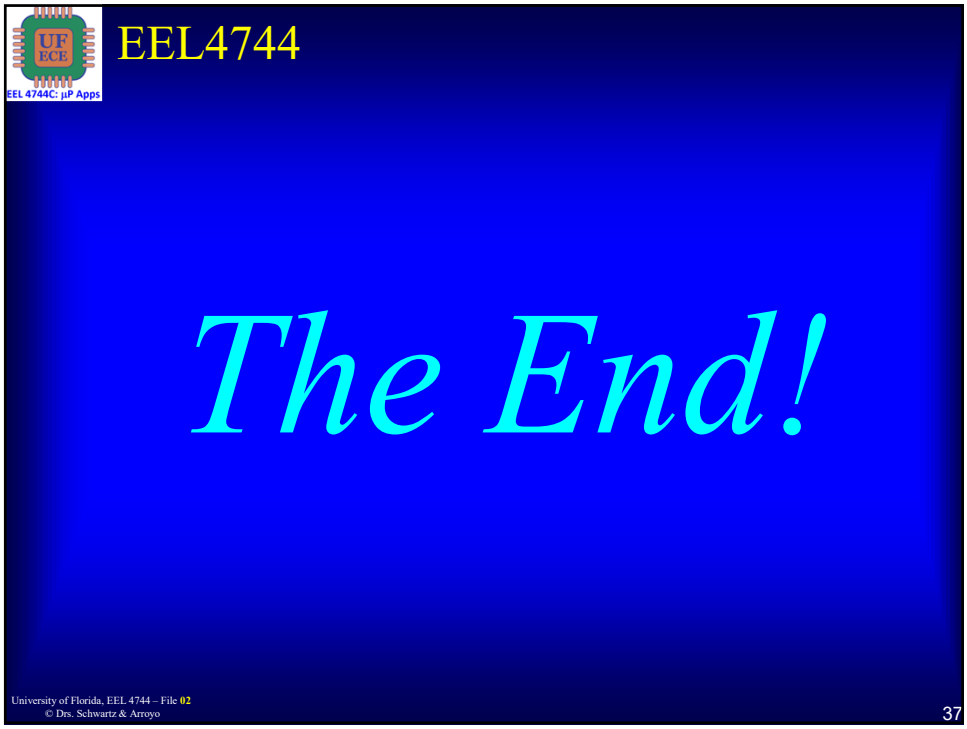
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EEL 4744C: µP Apps
The End!
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