CprE 288 – Introduction to Embedded Systems
(Syllabus & Course Overview)

Instructors:
Dr. Zhao Zhang (Sections A, B, C, D, E)
Dr. Phillip Jones (Sections F, G, J)

Overview of Today's Lecture

- Announcements
- Syllabus
  - Policies
  - Grading Scale
- Course Overview
  - Lab Hardware Introduction
  - Learning Objectives
  - Course Schedule
- Embedded Programming
  - Base Conversion
  - Processor Architectures

SYLLABUS

Syllabus | Homework Policy

- There will be weekly assignments
  - Short assignments to keep everyone active
- Individual assignments; work alone
- Typed homework answers are required
- Hand in a hard copy in class
- Occasionally, you may email your homework to your grading TA (increase TA workload)
- Late homework accepted within 3 days, 10% penalty per day
- Solutions will be posted three days after the due, then late homework won't be accepted

Syllabus | Laboratory Policy

- Lab attendance is <u>mandatory</u>
  - Automatically fail a lab with an unexcused absence
- Labs are partner activities for the purpose of **teamwork** (no exception)
- If you have to miss a lab, inform the instructor <u>prior</u> to the start of lab

- There are 9 labs and a lab project (Mars Rover)
  - Prelab, if given, is due in the beginning of the lab
  - Lab demo is due in the beginning of the next lab
- Lab is in Coover 2041
  - Check your lab section and time
  - No lab this week

Syllabus | Lecture Policy

- Lecture attendance strongly encouraged
  - Please review the lecture notes if not attending
  - Occasional absence is OK
  - Exams questions will reward those that participate in lecture activities
- Review sessions
  - The lecture before each exam

Syllabus | Exams

- Exam 1 – Thur 9/27 (the 6th week), 75 minutes
- Exam 2 – Thur 11/1 (the 11th week), 75 minutes
- Exam 3 – During Finals week, 75 minutes

This schedule is tentative

- Open notes (must be hard copies)
- Exams are accumulative, with a focus on new contents

Syllabus | Grading Scale

- Exams 45%
  - Exam 1: 15%
  - Exam 2: 15%
  - Exam 3: 15%
- Homework: 15%
- Laboratory Exercises: 25%
  - Nine laboratory exercises
- Laboratory Project: 15%

Syllabus | Academic Honesty

- Work independently on homework & exams
- Seek peer help to better your knowledge and skills rather than your grades
- This may be a hard course for those unfamiliar with C programming. Do not barrow code from others to get ahead.

- Good questions to ask:
  - "Could you explain how pointers work?"
  - "I don't understand this io_t struct. What is it?"
  - "Can you explain successive approximation?"

Syllabus | Academic Honesty

- Bad Question / Actions:
  - "Can you show me your answer for question 3?"
  - "Can you e-mail me your homework?"
  - "E-mail me your source code for taking a Sonar measurement"
  - "If I do homework question 1, will you do question 2 and then we can trade?"

Syllabus | Academic Honesty

- The following acts are considered a violation of the University's student conduct policy (not exclusively). Suspected offenders will be sent to the Dean of Students Office for investigation.
  - Sending or receiving any fragment of source code from another group, or from someone who previously took the class, is an offense.
  - Sending or receiving answers to homework assignments is an offense.
  - Copying answers from another person's exam is an offense.
- Those convicted of academic dishonest will receive at minimum a zero on the assignment, and may, at the discretion of the instruction, receive an F for the course.
- Policy: Anyone caught cheating will receive a lower grade than those who worked honestly through the course.

Syllabus | Website

- Take time to look at the course website:
  - http://class.ece.iastate.edu/cpre288
  - Shows list of supplementary books on Syllabus page

COURSE OVERVIEW

Course Overview| Summary

CprE 288 is:

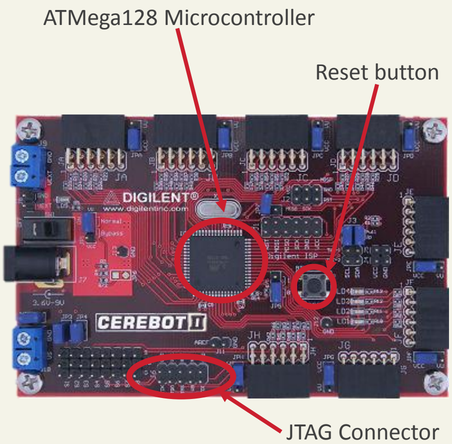
A class where students learn about embedded systems through writing C code for the VORTEX platform.

VORTEX is the codename for:

- Cerebot II
- ATmega128 microcontroller
- iRobot Create
- Attachments (stepper motor, servo, sonar, IR distance, LCD, etc.)

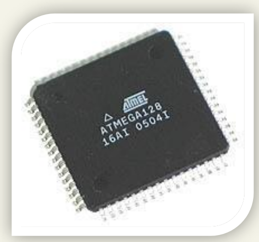
Course Overview | Cerebot II

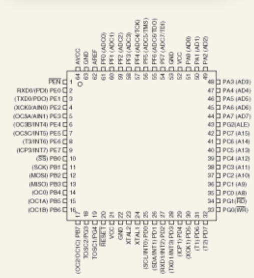
- Digilent's Cerebot II
  - "Break-out" board for the microcontroller
  - Microcontroller is an ATmega128 (not the usual ATmega64)
  - Main difference between the two is more memory



Course Overview | ATmega128

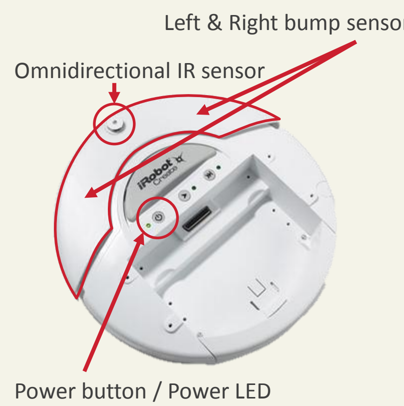
- MCU (Microcontroller unit)
- Manufactured by Atmel
- Clock speed
  - 16 MHz processor
- Memory
  - 4 KB of EEPROM (for long term storage)
  - 4 KB of SRAM (data memory)
  - 128 KB of Flash (program memory)
- Lots of features
  - Timers, Input Capture, PWM, ADC, SPI, UART, etc





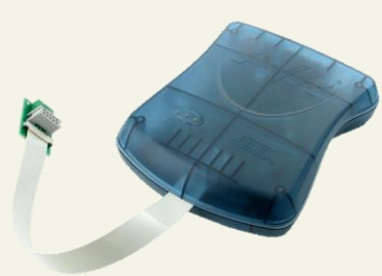
Course Overview | iRobot Create

- List of Sensors
  - Omnidirectional IR sensor
  - Left & Right bump sensors
  - Four cliff sensors along the front
  - Wall sensor
  - All three wheels have drop sensors
- 2 wheels for movement
- Students program the MCU on the Cerebot II
  - Communication between the MCU and iRobot Create occurs over serial
  - We will use an API called *Open Interface* to communicate



Course Overview | JTAG MKII

- AT JTAG ICE MKII
  - JTAG = Joint Test Action Group
  - Interface between Cerebot II board and the computer
  - Enables debugging of many of Atmel's AVR MCUs (microcontroller unit)
  - Lab TA's will stress how fragile this can be. So use with care.



Course Overview

- Hardware is not cheap! (This isn't just an Arduino)
- iRobot Create
  - $129
- Cerebot II
  - $39.95
- AT JTAG ICE MKII
  - $299
- Making a cool robot
  - Priceless

Course Overview| Learning Objective

- Learn to read datasheets/manuals in order to develop practical applications
- Learn basic hardware and software debugging
- Be able to program and design applications for embedded systems
- Gain experience programming in C for the Atmega128
- Understand basic computing concepts such as:
  - Interrupts
  - Interrupt Service Routines (ISR)
  - I/O subsystems
  - How processors work, registers, program memory, etc
- Understand the Atmel processor architecture
- Understand how C is converted to assembly code

Course Overview | Schedule

Three general phases:

Exam 1: (C-programming, Micro-controller basics)

- *Weeks 1-5*
  - Overview of course and lab hardware
  - Review of C programming
  - Special function registers
  - iRobot Create overview
  - Interrupt handling (ISR)

Exam 2: (Peripherals)

- Weeks 6-10
  - Timers
  - Serial (USART)
  - Distance sensors (IR & Sonar)
  - Analog to Digital Conversion (ADC)
  - Input Capture
  - Output Compare and Pulse Width Modulation (PWM)

Exam 3: (Assembly)

- *Weeks 11-15*
  - Start of Lab Project
  - AVR Assembly programming

EMBEDDED SYSTEMS

What are Embedded Systems?

- Examples:
  - Programmable thermostats
  - GPS Asset tracking
  - Remote controls
  - iRobot Create

What are Embedded Systems?

- Example:
  - Mars Sojourner Rover (1997)
    - ~25 pounds
    - 25 x 19 x 12 inches
  - 8-bit Intel 80C85
    - 100 KHz Clock speed

Embedded Programming

- Key factors in embedded systems
  - Code speed – timing constraints, limited processor
  - Code size – Limited memory size
  - Energy – portability means less battery consumption
- Programming Methods

– Machine Code	0001 1101 1100
– Low Level Languages	Assembly
– High Level Languages	C, C++, Java
– Application Level Languages	VBA, Access, scripting

Embedded Programming

- Programming Methods
  (from lowest level of abstraction to highest level of abstraction)

– Machine Code	
– Low Level Languages	Assembly
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Embedded Programming

- Why use C for embedded systems?
  - Designed to expose machine details for efficiency
  - Borrows features of contemporary high level programming languages
  - Easier to manage large embedded projects
- Why use assembly?
  - Pros: High speed, low code size, low energy
  - Cons: Low programmer productivity

Methods for Representing Data

- Bit
  - 1 (True)
  - 0 (False)
- Nibble (less commonly used)
  - 4 bits
- Byte
  - 8 bits
- Word
  - 16 bits
- Double Word
  - 32 bits

Methods for Representing Data

- Three of the most common forms of notation
  - Decimal (base 10) 0123456789
  - Hexadecimal (base 16) 0123456789ABCDEF
  - Binary (base 2) 01
- Another less common form is octal (base 8)
- Converting between forms
  - When converting binary to hexadecimal, every group of 4 bits (nibble) represents a hexadecimal digit
  - Examples:

Binary	Hexadecimal
0010	2
0100	4
1010	A

Base Conversion

- Methods to convert between bases
  - Use a calculator or the internet
    - TI 89
    - Microsoft's Calculator in Programmer mode
    - Google
      - Example searches:
      - 128 in binary
      - 0b0010 in hex
      - 0x03ef in decimal
    - Wolfram Alpha
      - Example searches:
      - All Google queries
      - 0xef32
      - 0b0101
  - Compute by hand
    - Every EE/CprE engineer should know how to change base

Base Conversion (by hand)

- Base n to base 10

Problem: Convert 0b01001011 to base 10

Solution:
Label each column and add.

2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128's	64's	32's	16's	8's	4's	2's	1's
0	1	0	0	1	0	1	1

64 + 8 + 2 + 1 = 75

- Examples will be demonstrated on the white board

Base Conversion (by hand)

- Base 10 to base n

Problem: Convert 175 to base 16

Solution:
Create a table of the columns in a base 16 number and subtract from the original number:

16^1	16^0
16's	1's
A	

175 – 160 = 15

16^1	16^0
16's	1's
A	F

0xAF

- Examples will be demonstrated on the white board

Base Conversion

- Syntax in C (for AVR Studio)
  - Computers understand binary
  - The following lines of code are all the same (the complier does not care what base the programmer uses):

```
char x = 2 + 1;
char x = 0b10 + 1;
char x = 0x2 + 1;
char x = 0x02 + 0x01;
```


Components of a Computer

- Central Processing Unit
  - Interprets and carries out all the instructions contained in software
- Memory
  - Used to store instructions and data
  - Random Access Memory (RAM)
  - Read Only Memory (ROM)
- Input/Output
  - Used to communicate with the outside world

How Processor Works

Machine instruction: Tell computer what to do in a single step

- A bundle of binary bits with certain formats
- Only asks for simple operations
- Assembly: textual notations of machine program

Example in C:

x = a + b;

Execution steps at assembly/machine level:

R1 $\leftarrow$ a

R2 $\leftarrow$ b

R3 $\leftarrow$ R1+R2

x $\leftarrow$ R3

A compiler does the translation between C code and machine code!

Microprocessor

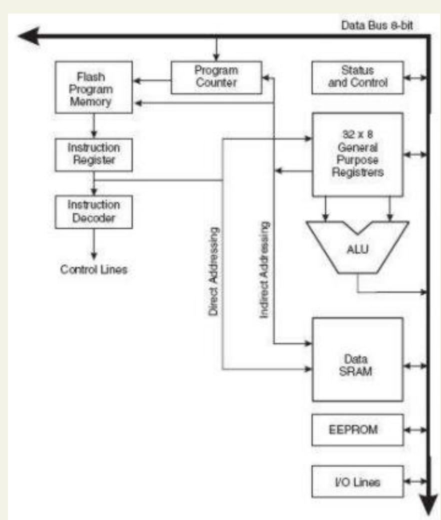
- A single chip that contains a whole CPU
- Examples:
  - Intel P4 or AMD Athlon in desktops/notebooks
  - ARM processor in Apple iPod
  - Has the ability to fetch and execute instructions stored in memory
- Has the ability to access external memory, external I/O and other peripherals

Processor Architecture

- von Neumann Architecture
  - Single data area that stores both program memory and data memory
- Harvard Architecture
  - Separate memories, one for data and one for program instructions
- RISC Architecture (Reduced Instruction Set Computing)
  - Reasoning: reduced number of instructions will increase simplicity and lead to faster processors, fewer transistors, and less power.

ATmega128 Processor Architecture

- 8 bit processor
  - size of bus is 8 bits
  - size of registers is 8 bits
- Harvard architecture
- RISC architecture
- 133 instructions



HISTORY OF MICROPROCESSORS

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History of Microprocessors

- 1950s - The beginning of the digital era and electronic computing
- 1969 – Intel is a small startup company in Santa Clara with 12 employees
  - Fairchild, Motorola are large semiconductor companies
  - HP and Busicom make calculators
- 1971 – Intel makes first microprocessor the 4-bit 4004 series for Busicom calculators (~100 KHz)
- 1972 – Intel makes the 8008 series, an 8-bit microprocessor,
  - ATARI is a startup company
  - Creates a gaming console and releases PONG

History of Microprocessors

- 1974 – the first real useful 8-bit microprocessor is released by Intel – the 8080
  - Motorola introduces the 6800 series
  - Zilog has the Z80
- 1975 – GM and Ford begin to put microcontrollers in cars
  - Many cars today have over 100 microcontrollers
  - TI gets into the microprocessor business with calculators and digital watches
- 1977 – Apple II is released using MOS 6502 (similar to motorola 6800). Apple II dominated from 1977 to 1983
- 1978 – Intel introduces the first 16-bit processor, the 8086
  - Motorola follows with the 68000 which is ultimately used in the first Apple Macintosh

History of Microprocessors

- 1981 – IBM enters the PC making market and uses the Intel 8088 – proliferation of the home computer
- 1982-1985 – Intel introduces the 32-bit 80286 (4 MHz)and 80386
- 1989 – 80486 is being used in PC's, able to run Microsoft Windows
- 1992 – Apple, IBM and Motorola begin to make PowerMac and PowerPC's using Motorola chips
- 1993 – Pentium chip is released (60 MHz)
- 2000 – Intel Pentium 4 chip is released (1.3 GHz)
- 2001 – IBM Power 4 chip, first commercial (non-embeded) multicore (2 cores, 1.3 GHz).
- 2011 – Intel E7-8870, 10 cores (2.8 GHz).

MICROCONTROLLER OVERVIEW

Microcontroller

- Essentially a microprocessor with on-chip memories and I/O devices
- Designed for specific functions
- All in one solution - Reduction in chip count
- Reduced power consumption
- Reduced cost
- Examples
  - MC68332, MC68HC11, PPC555, Atmel family (e.g. Atmega128)
- More details of components later
  - A/D converters, temperature sensors, communications, timing circuits, many others

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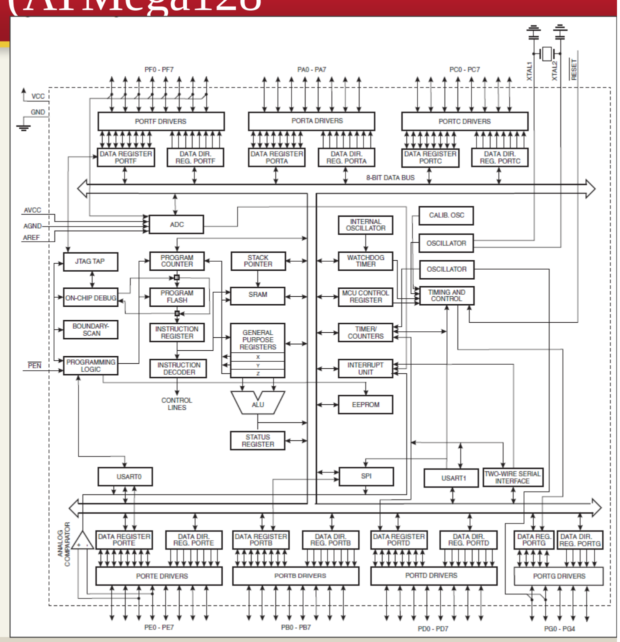
Microcontroller (ATMega128

- On-chip memory
  - Instruction
  - Data
- Microprocessor
  - 8-bit
- I/O modules
  - ADC (Analog to Digital Converters)
  - Timers/Counters
    - Many uses
  - USARTs
  - Multi-Purpose Ports
  - A-G



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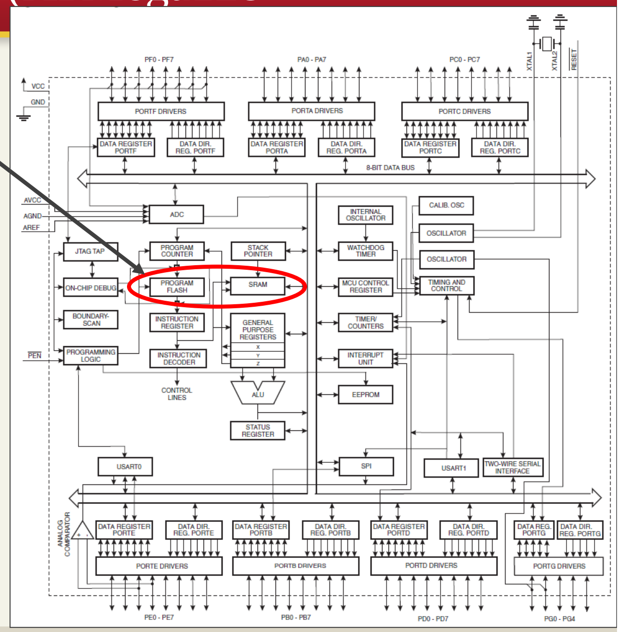

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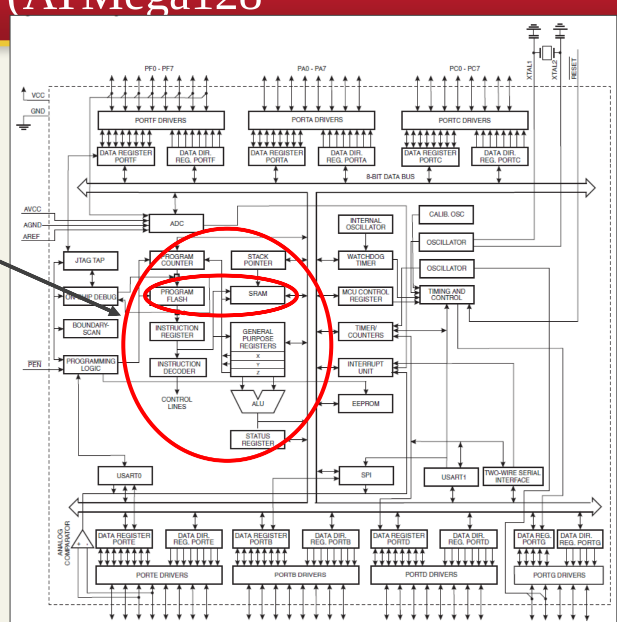

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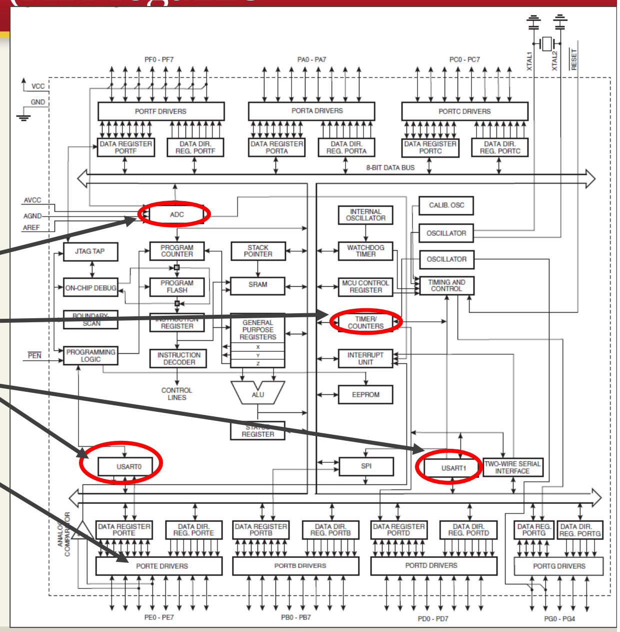

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Why Study Microcontrollers

This course may serve for several purposes:

- Build useful applications
- Practice programming and debugging skills
- Understand computer internals

It paves the way to learning computer design, operating systems, compilers, embedded systems, security and other topics.

- Microcontrollers have everything in a typical computer: CPU, memory and I/O.

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LAB 1 QUICK OVERVIEW

Lab 1: Introduction to the Platform

Purpose: Introduction to the AVR Studio 5 and VORTEX Platform

- AVR Studio 5: The integrated development environment (IDE) for Atmel AVR platforms
- VORTEX: An integrated hardware platform of iRobot Create and Cerebot II microcontroller board

AVR Studio 5

An IDE from Atmel for AVR platforms

- Source code editing
- Compiling building
- Download binary to boards
- Debug
- Simulation