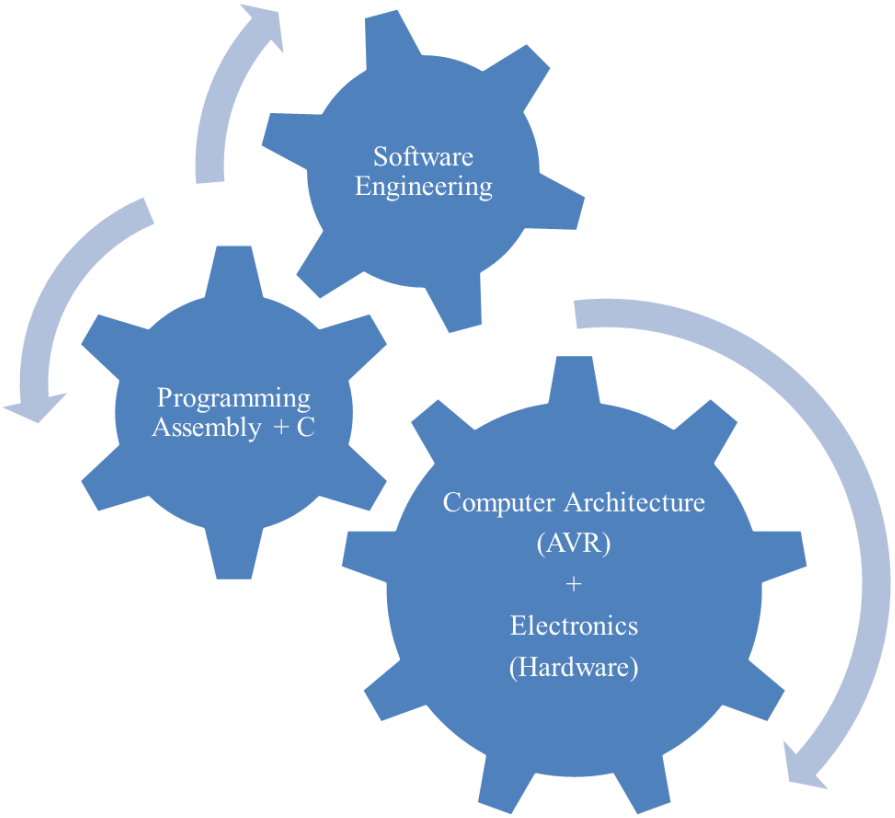
NCS 362: Embedded Systems



- ~~Software Engineering.~~
- C Programming

Assignment no. 3

kindly read the following paper [Software Engineering for Space Exploration]. In short, one paper only (2 pages), write an essay mention your opinion about the topic.

Notes:

- you will deliver your report on Monday (at lecture time).
- you can work in a group but the group is only two students.
- you may need to read more - paper references or external resources.
- at lecture time, there will be a discussion regarding the topic, be ready to present the topic and discuss it.

Introduction to C Programming

- Compiler is system software converts a high-level language program (human readable format) into object code (machine readable format).
  gcc, visual studio.
- Assembler is system software converts an assembly language program (human readable format) into object code (machine readable format).
- Linker builds software system by connecting (linking) software components.
- Loader places the object code in memory. In an embedded system, the loader programs object code into flash ROM.
- Debugger is a set of hardware and software tools we use to verify system is operating correctly. The two important aspects of a good debugger are control and observability.

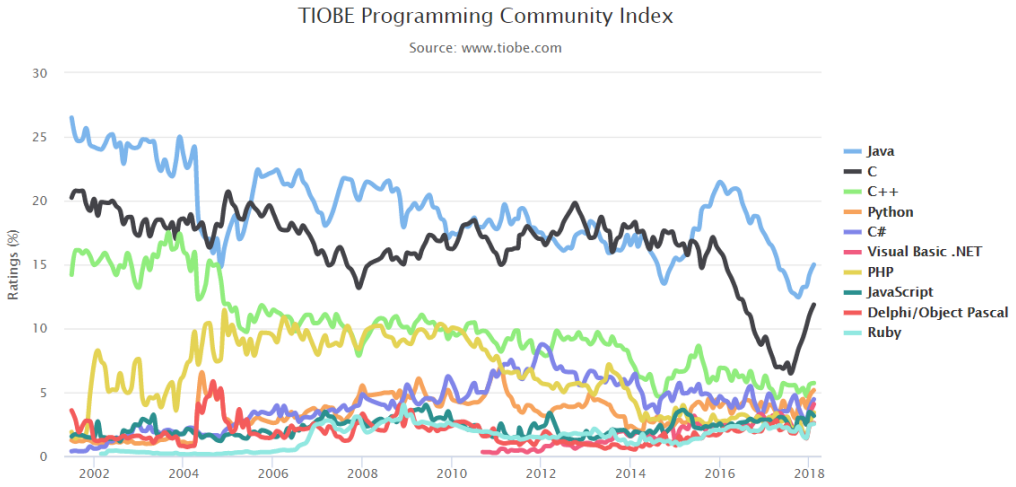
C code (**z = x+y;**) →
Assembly code (**ADD R2,R1,R0**) →
Machine code (**0xEB010200**)

Introduction to C Programming – What?

- C is a general-purpose programming language initially developed by Dennis Ritchie between 1969 and 1973 while at AT&T Bell Labs.
- In most programming languages the column position and line number affect the meaning. On the contrary, C is a free field language. Except for preprocessor lines (that begin with #), spaces, tabs and line breaks have the same meaning.
- C was invented to write an operating system - UNIX.
- C is a successor of B language.
- The language was formalized in 1988 by the American National Standard Institute (ANSI).
- Today's most popular Linux OS and RDBMS MySQL have been written in C.

Introduction to C Programming – Why ?

- Why C language ?
  - last ten years, ranked one or two - high-level languages. (popular)
  - C is the most common language for embedded systems. It is not tied to any particular hardware or system.
  - C is efficient programing language.
  - C is high/mid level language.



Introduction to C Programming – Why ?

- Why C language ?

	Energy
(c) C	1.00
(c) Rust	1.03
(c) C++	1.34
(c) Ada	1.70
(v) Java	1.98
(c) Pascal	2.14
(c) Chapel	2.18
(v) Lisp	2.27
(c) Ocaml	2.40
(c) Fortran	2.52
(c) Swift	2.79
(c) Haskell	3.10
(v) C#	3.14
(c) Go	3.23
(i) Dart	3.83
(v) F#	4.13
(i) JavaScript	4.45
(v) Racket	7.91
(i) TypeScript	21.50
(i) Hack	24.02
(i) PHP	29.30
(v) Erlang	42.23
(i) Lua	45.98
(i) Jruby	46.54
(i) Ruby	69.91
(i) Python	75.88
(i) Perl	79.58

	Time
(c) C	1.00
(c) Rust	1.04
(c) C++	1.56
(c) Ada	1.85
(v) Java	1.89
(c) Chapel	2.14
(c) Go	2.83
(c) Pascal	3.02
(c) Ocaml	3.09
(v) C#	3.14
(v) Lisp	3.40
(c) Haskell	3.55
(c) Swift	4.20
(c) Fortran	4.20
(v) F#	6.30
(i) JavaScript	6.52
(i) Dart	6.67
(v) Racket	11.27
(i) Hack	26.99
(i) PHP	27.64
(v) Erlang	36.71
(i) Jruby	43.44
(i) TypeScript	46.20
(i) Ruby	59.34
(i) Perl	65.79
(i) Python	71.90
(i) Lua	82.91

	Mb
(c) Pascal	1.00
(c) Go	1.05
(c) C	1.17
(c) Fortran	1.24
(c) C++	1.34
(c) Ada	1.47
(c) Rust	1.54
(v) Lisp	1.92
(c) Haskell	2.45
(i) PHP	2.57
(c) Swift	2.71
(i) Python	2.80
(c) Ocaml	2.82
(v) C#	2.85
(i) Hack	3.34
(v) Racket	3.52
(i) Ruby	3.97
(c) Chapel	4.00
(v) F#	4.25
(i) JavaScript	4.59
(i) TypeScript	4.69
(v) Java	6.01
(i) Perl	6.62
(i) Lua	6.72
(v) Erlang	7.20
(i) Dart	8.64
(i) Jruby	19.84

Introduction to C Programming – Why ?

- C is much more flexible than other high-level programming languages:
  - C is a structured language.
  - C is a relatively small language.
  - C has very loose data typing.
  - C easily supports low-level bit-wise data manipulation.
  - C is sometimes referred to as a "high-level assembly language".

- When compared to assembly language programming:
  - Code written in C can be more reliable.
  - Code written in C can be more scalable.
  - Code written in C can be more portable between different platforms.
  - Code written in C can be easier to maintain.
  - Code written in C can be more productive.

Embedded C Programming !

Main characteristics of an Embedded programming environment:

- Limited ROM.
- Limited RAM.
- Limited stack space.
- Hardware oriented programming.
- Critical timing (Interrupt Service Routines, tasks, …).
- Many different pointer kinds (far / near / rom / uni / paged / …).
- Special keywords and tokens (@, interrupt, tiny, …).

Introduction to C Programming – How ?

- Variables and Data Types.
- Operators and Hardware Manipulation.
- Program Flow Control.
- Advanced Types, Constants and Expressions.
- Arrays and Pointer Basics.
- Functions.
- Structures and Unions.
- Arrays of Pointers.
- Declarations.
- Preprocessor.

Introduction to C Programming– Program

- C Program is divided into four sections.
- Every C program has a main, and execution begins at the top of this main.

```
//**** 0. Documentation Section
//  This program calculates the area of square shaped rooms
//  Author: Ramesh Yerraballi & Jon Valvano
//  Date: 6/28/2013
//
// 1. Pre-processor Directives Section
#include <stdio.h>  // Diamond braces for sys lib: Standard I/O
#include "uart.h"   // Quotes for user lib: UART lib
#define SIZE 10 // SIZE is found as a token, it is replaced with the 10
// 2. Global Declarations section
// 3. Subroutines Section
// MAIN: Mandatory routine for a C program to be executable
int main(void) {
  UART_Init();  // call subroutine to initialize the uart
  printf("This program calculates areas of square-shaped rooms\n");
}
```

Introduction to C Programming – Keywords

Standard ANSI C recognizes the following keywords			
auto	double	int	struct
break	else	long	switch
case	enum	register	typedef
char	extern	return	union
const	float	short	unsigned
continue	for	signed	void
default	goto	sizeof	volatile
do	if	static	while

__asm Specify a function is written in assembly code

C Programming / Basic Syntax

- A C program consists of various tokens and a token is either a keyword, an identifier, a constant, a string literal, or a symbol.
- Comments are like helping text in your C program and they are ignored by the compiler. /* This is a comment */
- A C identifier is a name used to identify a variable, function, or any other user-defined item.
- A C identifier starts with a letter A to Z, a to z, or an underscore '_' followed by zero or more letters, underscores, and digits (0 to 9).
- C does not allow punctuation characters such as @, $, and % within identifiers.
- C is a case-sensitive programming language.

C Programming / Punctuation

- Punctuation marks (semicolons, colons, commas, apostrophes, quotation marks, braces, brackets, and parentheses)

Punctuation	*Meaning*
;	End of statement
:	Defines a label
,	Separates elements of a list
( )	Start and end of a parameter list
{ }	Start and stop of a compound statement
[ ]	Start and stop of a array index
" "	Start and stop of a string
' '	Start and stop of a character constant

C Programming / Storage Classes

- A storage class defines the scope (visibility) and life-time of variables and/or functions within a C.

Storage Class	Description
auto	auto storage class is the default storage class for all local variables.
register	register storage class is used to define local variables that should be stored in a register instead of RAM
static	static storage class instructs the compiler to keep a local variable in existence during the life-time of the program instead of creating and destroying it each time it comes into and goes out of scope.
extern	extern storage class is used to give a reference of a global variable that is visible to ALL the program files.

C Programming / Variables and Expressions

- Local variables contain temporary information that is accessible only within a narrow scope.
- In C, local variable must be declared immediately after a brace { that begins a compound statement. Unlike globals, which are said to be static, locals are created dynamically when their block is entered, and they cease to exist when control leaves the block.
- Although two global variables cannot use the same name, a local variable of one block can use the same name as a local variable in another block.
- Constants refer to fixed values that the program may not alter during its execution.
- Constants can be of any of the basic data types like an integer constant.
- Void represents the absence of type.

C Programming / Variables and Expressions

Data type	Precision	Range
unsigned char	8-bit unsigned	0 to +255
signed char	8-bit signed	-128 to +127
unsigned int	compiler-dependent – 16 or 32 bits	
int	compiler-dependent– 16 or 32 bits	
unsigned short	16-bit unsigned	0 to +65535
short	16-bit signed	-32768 to +32767
unsigned long	unsigned 32-bit	0 to 4294967295L
long	signed 32-bit	-2147483648L to 2147483647L

C Programming / Variables and Expressions

```
int main(void) {
  unsigned long side; // room wall meters
  unsigned long area; // size squared meters
  UART_Init();        // call subroutine to initialize the uart
  side = 3;
  area = side*side;
  printf("\nArea of the room with side of %ld m is %ld sqr
m\n",side,area);
}
```

C Programming / Operators

- An operator is a symbol that tells the compiler to perform specific mathematical or logical functions.

- C language is rich in built-in operators and provides the following types of operators :

  - Arithmetic Operators
  - Relational Operators
  - Logical Operators
  - Bitwise Operators
  - Assignment Operators
  - Misc Operators

C Programming / Arithmetic Operators

Operation	Description	Example
+	Adds two operands.	A + B = 30
−	Subtracts second operand from the first.	A − B = -10
*	Multiplies both operands.	A * B = 200
/	Divides numerator by de-numerator.	B / A = 2
%	Modulus Operator and remainder of after an integer division.	B % A = 0
++	Increment operator increases the integer value by one.	A++ = 11
--	Decrement operator decreases the integer value by one.	A-- = 9

Given that **A** holds 10 and **B** holds 20

C Programming / Relational Operators

Operation	Description	Example
==	Checks if the values of two operands are equal. If yes, then the condition becomes true.	(A == B) is not true.
!=	Checks if the values of two operands are not equal. If the values are not equal, then the condition becomes true.	(A != B) is true.
>	Checks if the value of left operand is greater than the value of right operand. If yes, then the condition becomes true.	(A > B) is not true.
<	Checks if the value of left operand is less than the value of right operand. If yes, then the condition becomes true.	(A < B) is true.
>=	Checks if the value of left operand is greater than or equal to the value of right operand. If yes, then the condition becomes true.	(A >= B) is not true.
<=	Checks if the value of left operand is less than or equal to the value of right operand. If yes, then the condition becomes true.	(A <= B) is true.

Given that **A** holds 10 and **B** holds 20

C Programming / Logical Operators

Operation	Description	Example
&&	Called Logical AND operator. If both the operands are non-zero, then the condition becomes true.	(A && B) is true.
||	Called Logical OR Operator. If any of the two operands is non-zero, then the condition becomes true.	(A || B) is true.
!	Called Logical NOT Operator. It is used to reverse the logical state of its operand. If a condition is true, then Logical NOT operator will make it false.	!(A && B) is false.

Given that **A** holds 10 and **B** holds 20

C Programming / Bitwise Operators

Operation	Description	Example
&	Binary AND Operator copies a bit to the result if it exists in both operands.	(A & B) = 12, i.e., 0000 1100
|	Binary OR Operator copies a bit if it exists in either operand.	(A | B) = 61, i.e., 0011 1101
^	Binary XOR Operator copies the bit if it is set in one operand but not both.	(A ^ B) = 49, i.e., 0011 0001
~	Binary Ones Complement Operator is unary and has the effect of 'flipping' bits.	(~A) = -61, i.e., 1100 0011
<<	Binary Left Shift Operator. The left operands value is moved left by the number of bits specified by the right operand.	A << 2 = 240 i.e., 1111 0000
>>	Binary Right Shift Operator. The left operands value is moved right by the number of bits specified by the right operand.	A >> 2 = 15 i.e., 0000 1111

Given that **A** = 0011_1100 (60) and **B** = 0000_1101(13)

C Programming / Assignment Operators

Operation	Description	Example
=	Simple assignment operator. Assigns values from right side operands to left side operand	C = A + B assigns the value of A + B to C
+=	Add AND assignment operator. It adds the right operand to the left operand and assign the result to the left operand.	C += A is equivalent to C = C + A
-=	Subtract AND assignment operator. It subtracts the right operand from the left operand and assigns the result to the left operand.	C -= A is equivalent to C = C - A
*=	Multiply AND assignment operator. It multiplies the right operand with the left operand and assigns the result to the left operand.	C *= A is equivalent to C = C * A
/=	Divide AND assignment operator. It divides the left operand with the right operand and assigns the result to the left operand.	C /= A is equivalent to C = C / A
%=	Modulus AND assignment operator. It takes modulus using two operands and assigns the result to the left operand.	C %= A is equivalent to C = C % A

C Programming / Assignment Operators

Operation	Description	Example
<<=	Left shift AND assignment operator.	C <<= 2 is same as C = C << 2
>>=	Right shift AND assignment operator.	C >>= 2 is same as C = C >> 2
&=	Bitwise AND assignment operator.	C &= 2 is same as C = C & 2
^=	Bitwise exclusive OR and assignment operator.	C ^= 2 is same as C = C ^ 2
|=	Bitwise inclusive OR and assignment operator.	C |= 2 is same as C = C | 2

C Programming / Misc Operators

Operation	Description	Example
sizeof()	Returns the size of a variable.	Sizeof (a), where a is integer, will return 4.
&	Returns the address of a variable.	&a; returns the actual address of the variable.
*	Pointer to a variable.	*a;
? :	Conditional Expression.	If Condition is true ? then value X : otherwise value Y

C Programming / Precedence - Priority

Precedence	*Operators*	*Associativity*
highest	**() [] . -> ++(postfix) --(prefix)**	left to right
	++(prefix) --(prefix) !~ sizeof (type) +(unary) -(unary) &(address) *(dereference)	right to left
	*** / %**	left to right
	+ -	left to right
	<< >>	left to right
	< <= > >=	left to right
	== !=	left to right
	&	left to right
	^	left to right
	|	left to right
	&&	left to right
	||	left to right
	? :	right to left
	= += -= *= /= %= <<= >>= |= &= ^=	right to left
lowest	**,**	left to right

C Programming / Operators

```
void main(void)
        {
        long x,y,z;
           x=1; y=2;
           z = x+4*y;
           x++;
           y--;
           x = y<<2;
           z = y>>2;
           y += 2;
        }
```

What is the value of x, y and z ?

C Programming / Operators

```
void main(void)
        {
        long x,y,z;     // Three local variables
           x=1; y=2;    // set the values of x and y
           z = x+4*y;  // arithmetic operation   z = 1+8 = 9
           x++;         // same as x=x+1;        x = 2
           y--;        // same as y=y-1;       y = 1
           x = y<<2;    // left shift same as x=4*y; x = 4
           z = y>>2;    // right shift same as x=y/4;      y = 1
           y += 2;      // same as y=y+2;        y =3
        }
```