CPE 323 Introduction to Embedded Computer Systems: MSP430: Assembly Language and C

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Assembly Language and C

- How a high-level language uses low-level language features?
- C: Used in system programming, device drivers, …
- Use of addressing modes by compilers
- Parameter passing in assembly language
- Local storage

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C and the MSP430

- Compiler and the MSP430 instruction set
- C data types and implementation
- Storage classes
- Functions and parameters
- Pointers

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Compiling a C Program: Example #1

```
#include <msp430.h>

int main(void) {
      int i1, i2;
      unsigned int ui1;
      short int sint1;
      long int lint2;
      int a[4];          // int array, 4 elements
      // Stop watchdog timer to prevent time out reset
      WDTCTL = WDTPW + WDTHOLD;
      i1 = 2; i2 = -2;
      ui1=65535;
      sint1=127;
      lint2=128243;
      a[0]=20; a[1]=9;   //  a[20, 9, ...]
      return 0;
}
```

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Example #1 Compiler Generated List File
(TI Compiler, optimization: OFF, suppress debug symbols)

```
MSP430 Assembler PC v20.2.2 Mon Sep 21 09:17:08 2020

Copyright (c) 2003-2018 Texas Instruments Incorporated
CDataAllocationDemo.asm                                 PAGE    1

       1              ;******************************************************************************
       2              ;* MSP430 G3 C/C++ Codegen                                      PC v20.2.2.LTS *
       3              ;* Date/Time created: Mon Sep 21 09:17:08 2020                                 *
       4              ;******************************************************************************
       5                     .compiler_opts --abi=eabi --diag_wrap=off --hll_source=on --mem_model:code=small --mem_model:d
       6              ;      C:\ti\ccs1010\ccs\tools\compiler\ti-cgt-msp430_20.2.2.LTS\bin\acpia430.exe -@C:\\Users\\milenk
       7 000000              .sect   ".text:main"
       8                     .clink
       9                     .global main
      10              ;-------------------------------------------------------------------------
      11              ;  25 | int main(void) {
      12              ;  26 | int i1, i2;
      13              ;  27 | unsigned int ui1;
      14              ;  28 | short int sint1;
      15              ;  29 | long int lint2;
      16              ;  30 |  int a[4];
      17              ;  31 | // Stop watchdog timer to prevent time out reset
      18              ;-------------------------------------------------------------------------
      19
      20              ;******************************************************************************
      21              ;* FUNCTION NAME: main                                                        *
      22              ;*                                                                            *
      23              ;*   Regs Modified     : SP,SR,r12                                            *
      24              ;*   Regs Used         : SP,SR,r12                                            *
      25              ;*   Local Frame Size  : 0 Args + 20 Auto + 0 Save = 20 byte                  *
      26              ;******************************************************************************
      27 000000       main:
      28              ;* --------------------------------------------------------------------------*
      29 000000 8031          SUB.W     #20,SP                ; []
         000002 0014
      30              ;-------------------------------------------------------------------------
      31              ;  32 | WDTCTL = WDTPW + WDTHOLD;
      32              ;-------------------------------------------------------------------------
      33 000004 40B2          MOV.W     #23168,&WDTCTL+0      ; [] |32|
         000006 5A80
         000008 0000!
      34              ;-------------------------------------------------------------------------
      35              ;  33 | i1 = 2; i2 = -2;
      36              ;-------------------------------------------------------------------------
      37 00000a 43A1          MOV.W     #2,12(SP)             ; [] |33|
         00000c 000C
      38 00000e 40B1          MOV.W     #65534,14(SP)         ; [] |33|
         000010 FFFE
         000012 000E
      39              ;-------------------------------------------------------------------------
      40              ;  34 | ui1=65535;
      41              ;-------------------------------------------------------------------------
      42 000014 43B1          MOV.W     #65535,16(SP)         ; [] |34|
         000016 0010
      43              ;-------------------------------------------------------------------------
      44              ;  35 | sint1=127;
      45              ;-------------------------------------------------------------------------
      46 000018 40B1          MOV.W     #127,18(SP)           ; [] |35|
         00001a 007F
         00001c 0012

MSP430 Assembler PC v20.2.2 Mon Sep 21 09:17:08 2020

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```
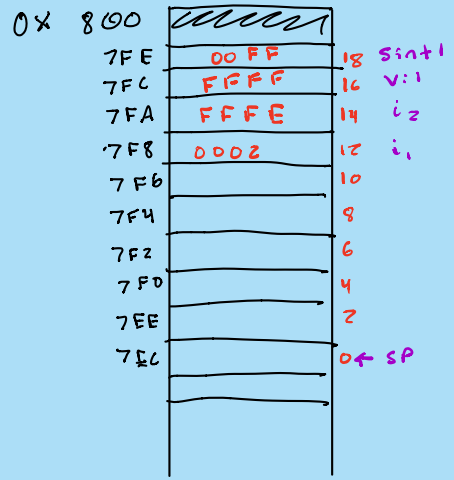

2x2=4
1x2=2
1x2=2
1x4=4
4x2=8
} 20 bytes



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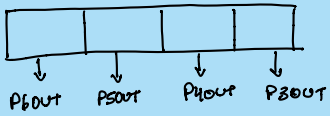
Example #1 Compiler Generated List File (TI Compiler, no optimization)

```
CDataAllocationDemo.asm                                                 PAGE    2

      47              ;-----------------------------------------------------------------------
      48              ;  36 | lint2=128243;                  | uw | lw |     0x 8 00
      49              ;-----------------------------------------------------------------------
      50 00001e 40B1            MOV.W     #62707,8(SP)            ; [] |36|
         000020 F4F3
         000022 0008
      51 000024 4391            MOV.W     #1,10(SP)               ; [] |36|
         000026 000A
      52              ;-----------------------------------------------------------------------
      53              ;  37 | a[0]=20; a[1]=9;
      54              ;-----------------------------------------------------------------------
      55 000028 40B1            MOV.W     #20,0(SP)               ; [] |37|
         00002a 0014
         00002c 0000
      56 00002e 40B1            MOV.W     #9,2(SP)                ; [] |37|
         000030 0009
         000032 0002
      57              ;-----------------------------------------------------------------------
      58              ;  38 | return 0;
      59              ;-----------------------------------------------------------------------
      60 000034 430C            MOV.W     #0,r12                  ; [] |38|
      61 000036 5031            ADD.W     #20,SP // nospace on stack ; []
         000038 0014                                 // add more space ?
      62 00003a 4130            RET       ; []
      63                      ; []
      64              ;*****************************************************************************
      65              ;* UNDEFINED EXTERNAL REFERENCES                                             *
      66              ;*****************************************************************************
      67                      .global WDTCTL
      68
      69              ;*****************************************************************************
      70              ;* BUILD ATTRIBUTES                                                          *
      71              ;*****************************************************************************
      72                      .battr "TI", Tag_File, 1, Tag_LPM_INFO(1)
      73                      .battr "TI", Tag_File, 1,
Tag_PORTS_INIT_INFO("012345678901ABCDEFGHIJ00000000000111110000000000
      74                      .battr "TI", Tag_File, 1, Tag_LEA_INFO(1)
      75                      .battr "TI", Tag_File, 1, Tag_HW_MPY32_INFO(2)
      76                      .battr "TI", Tag_File, 1, Tag_HW_MPY_ISR_INFO(1)
      77                      .battr "TI", Tag_File, 1, Tag_HW_MPY_INLINE_INFO(1)
      78                      .battr "mspabi", Tag_File, 1, Tag_enum_size(3)

No Assembly Errors, No Assembly Warnings
```

Example #2: demoC2ASM.c

```
#include <msp430.h>

int main(void) {
    WDTCTL = WDTPW | WDTHOLD;// stop watchdog timer

    unsigned int i = 0; // switches to unsigned long int
    unsigned char ch;
    unsigned long int sum = 0;

    for(i=0; i<10; i++) sum += i;
    P3OUT = (unsigned char) sum;
    P4OUT = (unsigned char) (sum >> 8);

    ch=P1IN;
    switch(ch) {
      case 0: P2OUT=0x01; break;
      case 1: P2OUT=0x02; break;
      default: P2OUT=0x80;
    }

    return 0;
}
```



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Example #2: List File (1)

```
MSP430 Assembler PC v20.2.2 Mon Sep 21 09:19:40 2020

      1              ;*******************************************************************************
      2              ;* MSP430 G3 C/C++ Codegen                                          PC v20.2.2.LTS
    *
      3              ;* Date/Time created: Mon Sep 21 09:19:40 2020                                  *
      4              ;*******************************************************************************
      5                      .compiler_opts --abi=eabi --diag_wrap=off --hll_source=on --
    mem_model:code=small --mem_model:d
      6              ;       C:\ti\ccs1010\ccs\tools\compiler\ti-cgt-msp430_20.2.2.LTS\bin\opt430.exe
    C:\\Users\\milenka\\A
      7 000000               .sect   ".text:main"
      8                      .clink
      9                      .global main
     10              ;-------------------------------------------------------------------------
     11              ;   7 | int main(void) {
     12              ;-------------------------------------------------------------------------
     13
     14              ;*******************************************************************************
     15              ;* FUNCTION NAME: main                                                         *
     16              ;*                                                                             *
     17              ;*   Regs Modified     : SP,SR,r12,r13,r14,r15                                 *
     18              ;*   Regs Used         : SP,SR,r12,r13,r14,r15                                 *
     19              ;*   Local Frame Size  : 0 Args + 0 Auto + 0 Save = 0 byte                     *
     20              ;*******************************************************************************
     21 000000        main:
     22              ;* ---------------------------------------------------------------------------*
     23              ;-------------------------------------------------------------------------
     24              ;   8 | WDTCTL = WDTPW | WDTHOLD;       // stop watchdog timer
     25              ;  10 | unsigned int i = 0;
     26              ;  11 | unsigned char ch;
     27              ;-------------------------------------------------------------------------
     28 000000 40B2          MOV.W     #23168,&WDTCTL+0      ; [] |8|
        000002 5A80
        000004 0000!
```

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Example #2: List File (2)

```
29              ;----------------------------------------------------------------------
30              ;  12 | unsigned long int sum = 0;
31              ;----------------------------------------------------------------------
32 000006 430F          MOV.W     #0,r15                ; [] |12|
33 000008 430D          MOV.W     #0,r13                ; [] |12|
34              ;----------------------------------------------------------------------
35              ;  14 | for(i=0; i<10; i++) sum += i;
36              ;----------------------------------------------------------------------
37 00000a 430E          MOV.W     #0,r14                ; [] |14|
38 00000c 903E          CMP.W     #10,r14               ; [] |14|
   00000e 000A
39 000010 2C06          JHS       $C$L2                 ; [] |14|
40                                                    ; [] |14|
41              ;* --------------------------------------------------------------------------*
42              ;*   BEGIN LOOP $C$L1
43              ;*
44              ;*   Loop source line                 : 14
45              ;*   Loop closing brace source line   : 14
46              ;*   Known Minimum Trip Count         : 1
47              ;*   Known Maximum Trip Count         : 4294967295
48              ;*   Known Max Trip Count Factor      : 1
49              ;* --------------------------------------------------------------------------*
50 000012       $C$L1:
51 000012 5E0F          ADD.W     r14,r15               ; [] |14|
52 000014 630D          ADDC.W    #0,r13                ; [] |14|
53 000016 531E          ADD.W     #1,r14                ; [] |14|
54 000018 903E          CMP.W     #10,r14               ; [] |14|
   00001a 000A
55 00001c 2BFA          JLO       $C$L1                 ; [] |14|
56                                                    ; [] |14|
57              ;* --------------------------------------------------------------------------*
58 00001e       $C$L2:
59              ;----------------------------------------------------------------------
60              ;  15 | P3OUT = (unsigned char) sum;
61              ;----------------------------------------------------------------------
62 00001e 4FC2          MOV.B     r15,&PBOUT_L+0        ; [] |15|
   000020 0000!
```

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Example #2: List File (3)

```
63              ;---------------------------------------------------------------------
64              ;  16 | P4OUT = (unsigned char) (sum >> 8);
65              ;---------------------------------------------------------------------
66 000022 108F          SWPB      r15                   ; [] |16|
67 000024 4FC2          MOV.B     r15,&PBOUT_H+0        ; [] |16|
   000026 0000!
68              ;---------------------------------------------------------------------
69              ;  18 | ch=P1IN;
70              ;---------------------------------------------------------------------
71 000028 425F          MOV.B     &PAIN_L+0,r15         ; [] |18|
   00002a 0000!
72              ;---------------------------------------------------------------------
73              ;  19 | switch(ch) {
74              ;  20 |   case 0: P2OUT=0x01; break;
75              ;  21 |   case 1: P2OUT=0x02; break;
76              ;---------------------------------------------------------------------
77 00002c 4F4F          MOV.B     r15,r15               ; [] |19|
78 00002e 930F          TST.W     r15                   ; [] |19|
79 000030 2409          JEQ       $C$L4                 ; [] |19|
80                                                    ; [] |19|
81              ;* ---------------------------------------------------------------------------*
82 000032 831F          SUB.W     #1,r15                ; [] |19|
83 000034 2404          JEQ       $C$L3                 ; [] |19|
84                                                    ; [] |19|
85              ;* ---------------------------------------------------------------------------*
86              ;---------------------------------------------------------------------
87              ;  22 | default: P2OUT=0x80;
88              ;---------------------------------------------------------------------
89 000036 40F2          MOV.B     #128,&PAOUT_H+0       ; [] |22|
   000038 0080
   00003a 0000!
90 00003c 3C05          JMP       $C$L5                 ; [] |23|
91                                                    ; [] |23|
```

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Example #2: List (4)

```
 92                ;* ---------------------------------------------------------------------------*
 93 00003e          $C$L3:
 94 00003e 43E2              MOV.B     #2,&PAOUT_H+0         ; [] |21|
    000040 0000!
 95 000042 3C02              JMP       $C$L5                 ; [] |21|
 96                                                          ; [] |21|
 97                ;* ---------------------------------------------------------------------------*
 98 000044          $C$L4:
 99 000044 43D2              MOV.B     #1,&PAOUT_H+0         ; [] |20|
    000046 0000!
100                ;* ---------------------------------------------------------------------------*
101 000048          $C$L5:
102                ;-----------------------------------------------------------------------
103                ;  25 | return 0;
104                ;-----------------------------------------------------------------------
105 000048 430C             MOV.W     #0,r12                ; [] |25|
106 00004a 4130             RET       ; []
107                       ; []
108                ;*****************************************************************************
109                ;* UNDEFINED EXTERNAL REFERENCES                                             *
110                ;*****************************************************************************
111                       .global PAIN_L
112                       .global PAOUT_H
113                       .global PBOUT_L
114                       .global PBOUT_H
115                       .global WDTCTL
116
117                ;*****************************************************************************
118                ;* BUILD ATTRIBUTES                                                          *
119                ;*****************************************************************************
120                       .battr "TI", Tag_File, 1, Tag_LPM_INFO(1)
121                       .battr "TI", Tag_File, 1,
```


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Example #2: List File (5)

```
Tag_PORTS_INIT_INFO("012345678901ABCDEFGHIJ00000000000011111000000000
     122                    .battr "TI", Tag_File, 1, Tag_LEA_INFO(1)
     123                    .battr "TI", Tag_File, 1, Tag_HW_MPY32_INFO(2)
     124                    .battr "TI", Tag_File, 1, Tag_HW_MPY_ISR_INFO(1)
     125                    .battr "TI", Tag_File, 1, Tag_HW_MPY_INLINE_INFO(1)
     126                    .battr "mspabi", Tag_File, 1, Tag_enum_size(3)

No Assembly Errors, No Assembly Warnings
MSP430 Assembler PC v20.2.2 Mon Sep 21 09:19:40 2020
LABEL                                VALUE       DEFN    REF

$C$L1                           000012+        51     55
$C$L2                           00001e+        62     39
$C$L3                           00003e+        94     83
$C$L4                           000044+        99     79
$C$L5                           000048+       105     90     95
.MSP430                         000001          0
.MSP4619                        000000          0
.msp430                         000001          0
.msp4619                        000000          0
PAIN_L                                REF               71    111
PAOUT_H                               REF               89     94     99    112
PBOUT_H                               REF               67    114
PBOUT_L                               REF               62    113
WDTCTL                                REF               28    115
__TI_ASSEMBLER_VERSION__        13134d2          0
__TI_EABI__                     000001           0
main                            000000+        28      9
```


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C Data Types

Data type	Size	Range	Alignment
bool	8 bits	0 to 1	1
char	8 bits	to 255	1
signed char	8 bits	-128 to 127	1
unsigned char	8 bits	0 to 255	1
signed short	16 bits	-32768 to 32767	2
unsigned short	16 bits	0 to 65535	2
signed int	16 bits	-32768 to 32767	2
unsigned int	16 bits	0 to 65535	2
signed long	32 bits	-2^{31} to $2^{31}-1$	2
unsigned long	32 bits	0 to $2^{32}-1$	2
signed long long	64 bits	-2^{63} to $2^{63}-1$	2
unsigned long long	64 bits	0 to $2^{64}-1$	2
float	32 bits		2
double	32 bits		2 (*)
double	64 bits		

① any address in space.

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C Data Types, cont'd

- Local variables
  - Defined inside a function
  - Cannot be accessed from outside the function
  - Normally lost when a return from the function is made
- Global variables
  - Defined outside a function
  - Can be accessed both from inside and outside the function
- Variables defined in a block exist only within that block

```
int i; /*global variable, visible to everything from this point*/
void function_1(void) /*A function with no parameters*/
   {
      int k; /*Integer k is local to function_1*/
         {
            int q; /*Integer q exists only in this block*/
            int j; /*Integer j is local and not the same as j in main*/
         }
   }
void main(void)
   {
      int j; /*Integer j is local to this block within function main*/
   } /*This is the point at which integer j ceases to exist*/
```

Storage Class Specifiers

- **`auto`** -> Default
  - Variable is no longer required once a block has been left; Default
- **`register`**
  - Ask compiler to allocate the variable to a register
  - Also is automatic
  - Cannot be accessed by means of pointers
- **`static`** will stay alive when you leave function
  - Allows local variable to retain its value when a block is reentered
  - Initialized only once, by the compiler!
- **`extern`**
  - Indicates that the variable is defined outside the block
  - The same global variable can be defined in more than one module

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Storage Class Modifiers

- **`volatile`**
  - To define variables that can be changed externally
  - Compiler will not put them in registers
  - Think about Status Registers ! peripherals
- **`const`**
  - Variable may not be changed during the execution of a program
  - Cannot be changed unintentionally,
    but CAN be changed externally
    (as a result of an I/O, or OS operations external to the C program)
- Type conversion
  - In C, done either automatically or explicitly (casting)

Compiling a C Program: Example #3

```
int main(void) {
      volatile int i1, i2;
      volatile unsigned int ui1;
      volatile short int sint1;
      volatile long int lint2;
      volatile int a[4];
      // Stop watchdog timer to prevent time out reset
      WDTCTL = WDTPW + WDTHOLD;
      i1 = 2; i2 = -2;
      ui1=65535;
      sint1=127;
      lint2=128243;
      a[0]=20; a[1]=9;
      return 0;
}
```

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Example #3 Compiler Generated List File (no optimization)

DC8 → Constants

```
C:\Documents and Settings\Aleksandar\My Documents\Work\teaching\cpe323-
    08F\tutorial\test_dtypes.c
      1          #include "io430.h"
   \                                     In  segment DATA16_AN, at 0x120
   \   union <unnamed> volatile __data16 _A_WDTCTL
   \                     _A_WDTCTL:
   \   000000                DS8 2 Allocate Storage

   \                                     In  segment CODE, align 2
      2          int main( void ) {
   \                     main:
   \   000000   31801400      SUB.W   #0x14, SP
      3            volatile int i1, i2;
      4            volatile unsigned int ui1;
      5            volatile short int sint1;
      6            volatile long int lint2;
      7            volatile int a[4];
      8            // Stop watchdog timer to prevent time out reset
      9            WDTCTL = WDTPW + WDTHOLD;
   \   000004   B240805A2001 MOV.W   #0x5a80, &0x120
     10            i1 = 2; i2 = -2;
   \   00000A   A1430000      MOV.W   #0x2, 0(SP)
   \   00000E   B140FEFF0200 MOV.W   #0xfffe, 0x2(SP)
     11            ui1=65535;
   \   000014   B1430400      MOV.W   #0xffff, 0x4(SP)
     12            sint1=127;
   \   000018   B1407F000600 MOV.W   #0x7f, 0x6(SP)
     13            lint2=128243;
   \   00001E   B140F3F40800 MOV.W   #0xf4f3, 0x8(SP)
   \   000024   91430A00      MOV.W   #0x1, 0xa(SP)
```


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Example #3 Compiler Generated List File (no optimization)

```
14            a[0]=20; a[1]=9;
   \   000028   B14014000C00 MOV.W   #0x14, 0xc(SP)
   \   00002E   B14009000E00 MOV.W   #0x9, 0xe(SP)
     15             return 0;
   \   000034   0C43         MOV.W   #0x0, R12
   \   000036   31501400     ADD.W   #0x14, SP
   \   00003A   3041         RET
   \   00003C                REQUIRE _A_WDTCTL
     16          }
Maximum stack usage in bytes:

     Function CSTACK
     -------- ------
     main         22


   Segment part sizes:

     Function/Label Bytes
     -------------- -----
     _A_WDTCTL          2
     main              60


 60 bytes in segment CODE
  2 bytes in segment DATA16_AN

 60 bytes of CODE memory
  0 bytes of DATA memory (+ 2 bytes shared)

Errors: none
Warnings: none
```


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Example #4: Factorial

```
#include "stdio.h"
#include "io430.h"

int fact(int n);

int main(void) {

  int n = 5;

  int nf;

  nf = fact(n);

  printf("n=%d, nf=%d\n", n, nf);

  return 0;
}

int fact(int n) {

  if(n>1) return n*fact(n-1);
  else return 1;
}
```

Example #4: Factorial, List File

```
    1           # include "stdio.h"
    2           #include "io430.h"
    4           int fact(int n);
\                                       In  segment CODE, align 2
    6           int main(void) {
\                       main:
\     000000    0A12          PUSH.W  R10
\     000002    0B12          PUSH.W  R11
    7
    8             int n = 5;
\     000004    3A400500      MOV.W   #0x5, R10
    9
   10             int nf;
   11
   12             nf = fact(n);
\     000008    0C4A          MOV.W   R10, R12
\     00000A    B012....      CALL    #fact
\     00000E    0B4C          MOV.W   R12, R11
   13
   14             printf("n=%d, nf=%d\n", n, nf);
\     000010    0B12          PUSH.W  R11
\     000012    0A12          PUSH.W  R10
\     000014    3C40....      MOV.W   #`?<Constant "n=%d, nf=%d\\n">`, R12
\     000018    B012....      CALL    #printf
   15
   16             return 0;
\     00001C    0C43          MOV.W   #0x0, R12
\     00001E    2152          ADD.W   #0x4, SP
\     000020    3B41          POP.W   R11
\     000022    3A41          POP.W   R10
\     000024    3041          RET
   17           }
```

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Example #4: Factorial, List File (cont'd)

```
  19          int fact(int n) {
\                     fact:
\   000000   0A12          PUSH.W  R10
\   000002   0A4C          MOV.W   R12, R10
  20
  21            if(n>1) return n*fact(n-1);
\   000004   2A93          CMP.W   #0x2, R10
\   000006   0E38          JL      ??fact_0
\   000008   0C4A          MOV.W   R10, R12
\   00000A   3C53          ADD.W   #0xffff, R12 //subtracting 1
\   00000C   B012....      CALL    #fact
\   000010   0212          PUSH.W  SR
\   000012   32C2          DINT
\   000014   824A3001      MOV.W   R10, &0x130
\   000018   824C3801      MOV.W   R12, &0x138
\   00001C   1C423A01      MOV.W   &0x13a, R12
\   000020   3241          POP.W   SR
\   000022   013C          JMP     ??fact_1
  22            else return 1;
\                     ??fact_0:
\   000024   1C43          MOV.W   #0x1, R12
\                     ??fact_1:
\   000026   3A41          POP.W   R10
\   000028   3041          RET
  23          }
\                                 In  segment DATA16_C, align 1, align-
 sorted
\                     `?<Constant "n=%d, nf=%d\\n">`:
\   000000   6E3D25642C20 DC8 "n=%d, nf=%d\012"
\            6E663D25640A
\            00
```


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Functions and Parameters

```
#include "io430.h"
void swapbyv(int a, int b);
void swapbyr(int *a, int *b);
int main( void )
{
  // Stop watchdog timer to prevent time out reset
  WDTCTL = WDTPW + WDTHOLD;
  int x = 5;
  int y = 6;
  // pass parameters by value
  swapbyv(x, y);
  // pass parameters by reference
  swapbyr(&x, &y);

  return 0;
}
```

```
void swapbyv(int a, int b) {
  int temp;
  temp = a;
  a = b;
  b = temp;
}

void swapbyr(int *a, int *b) {
  int temp;
  temp = *a;
  *a = *b;
  *b = temp;
}
```

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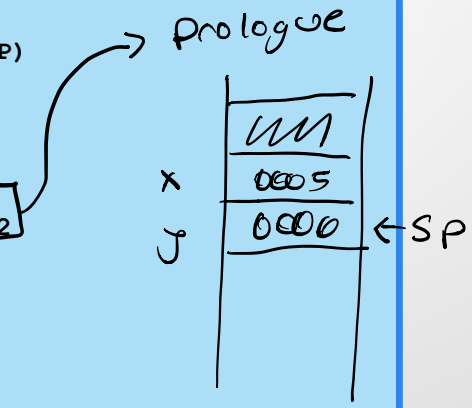
Functions and Parameters

```
8           int main( void )
  \                       main:
    9           {
  \   000000    2182          SUB.W   #0x4, SP
   10             // Stop watchdog timer to prevent time out reset
   11             WDTCTL = WDTPW + WDTHOLD;
  \   000002    B240805A2001  MOV.W   #0x5a80, &0x120
   12
   13             int x = 5;
  \   000008    B14005000200  MOV.W   #0x5, 0x2(SP)
   14             int y = 6;
  \   00000E    B14006000000  MOV.W   #0x6, 0(SP)

   19             swapbyv(x, y);
  \   000014    2D41          MOV.W   @SP, R13
  \   000016    1C410200      MOV.W   0x2(SP), R12
  \   00001A    B012....      CALL    #swapbyv

   24             swapbyr(&x, &y);
  \   00001E    0D41          MOV.W   SP, R13
  \   000020    0C41          MOV.W   SP, R12
  \   000022    2C53          ADD.W   #0x2, R12
  \   000024    B012....      CALL    #swapbyr

   29             return 0;
  \   000028    0C43          MOV.W   #0x0, R12
  \   00002A    2152          ADD.W   #0x4, SP
  \   00002C    3041          RET
  \   00002E                  REQUIRE _A_WDTCTL
   30           }
```



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Functions and Parameters

```
\                                   In  segment CODE,
 align 2
  32          void swapbyv(int a, int b) {
\                     swapbyv:
  33            int temp;
  34
  35            temp = a;
\   000000   0F4C          MOV.W   R12, R15
  36            a = b;
\   000002   0C4D          MOV.W   R13, R12
  37            b = temp;
\   000004   0D4F          MOV.W   R15, R13
  38           }
\   000006   3041          RET
  39

\                                   In  segment CODE,
 align 2
  40          void swapbyr(int *a, int *b) {
\                     swapbyr:
  41            int temp;
  42
  43            temp = *a;
\   000000   2F4C          MOV.W   @R12, R15
  44            *a = *b;
\   000002   AC4D0000      MOV.W   @R13, 0(R12)
  45            *b = temp;
\   000006   8D4F0000      MOV.W   R15, 0(R13)
  46           }
\   00000A   3041          RET
```

```
Maximum stack usage in bytes:

     Function      CSTACK
     --------      ------
     main              6
       -> swapbyv      6
       -> swapbyr      6
     swapbyr           2
     swapbyv           2


   Segment part sizes:

     Function/Label Bytes
     -------------- -----
     _A_WDTCTL          2
     main              46
     swapbyv            8
     swapbyr           12


 66 bytes in segment CODE
  2 bytes in segment DATA16_AN

 66 bytes of CODE memory
  0 bytes of DATA memory (+ 2 bytes
    shared)
```


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Pointers and C

```
#include "io430.h"
#include "stdio.h"
int main( void ) {
int x = 5;  // an integer x
  int *p_x;   // a pointer to int
  int y1;     // an integer y1 (uninitialized)
  long int y2, y3; // long integers y2, y3
  long int *p_y2;  // a pointer to long integer
  char mya[20] = "hello world, cpe323!";    // character array
  char *p_mya;     // pointer to character
  WDTCTL = WDTPW + WDTHOLD; // stop WDT
  p_x = &x;        // p_x points to x
  y1 = 10 + x;     // new value to y1
  y2 = -1;
  p_y2 = &y2;      // pointer p_y2 points to y2
  y3 = 10 + *p_y2;
  p_mya = mya;     // p_mya points to array mya
  p_mya = p_mya + 3;
  // display addresses and variables in terminal i/o
  printf("a.x=%x, x=%x\n", &x, x);
  printf("a.p_x=%x, p_x=%x\n", &p_x, p_x);
  printf("a.y1=%x, y1=%x\n", &y1, y1);
  printf("a.y2=%x, y2=%lx\n", &y2, y2);
  printf("a.y3=%x, y3=%lx\n", &y3, y3);
  printf("a.p_y2=%x, p_y2=%x\n", &p_y2, p_y2);
  printf("a.mya=%x, mya=%s\n", &mya, mya);
  printf("a.p_mya=%x, p_mya=%x\n", &p_mya, p_mya);
  return 0;
}
```

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Pointers and C, cont'd

```
    1          #include "io430.h"
\                                     In  segment DATA16_AN, at 0x120
\    union <unnamed> volatile __data16 _A_WDTCTL
\                       _A_WDTCTL:
\    000000                 DS8 2
    2          #include "stdio.h"
    3
\                                     In  segment CODE, align 2
    4          int main(void) {
\                              main:
\    000000   31802600      SUB.W   #0x26, SP
    5            // Stop watchdog timer to prevent time out reset
    6            WDTCTL = WDTPW + WDTHOLD;
\    000004   B240805A2001 MOV.W   #0x5a80, &0x120
    7            int x = 5;  // an integer x
\    00000A   B14005000000 MOV.W   #0x5, 0(SP)
    8            int *p_x;   // a pointer to int
    9            int y1;     // an integer y1 (uninitialized)
   10            long int y2, y3; // long integers y2, y3
   11            long int *p_y2;  // a pointer to long integer
   12            char mya[20] = "hello world, cpe323!";    // character array
\    000010   0C41          MOV.W   SP, R12
\    000012   3C501200      ADD.W   #0x12, R12
\    000016   3E40....      MOV.W   #`?<Constant "hello world, cpe323!">`, R14
\    00001A   3D401400      MOV.W   #0x14, R13
\    00001E   B012....      CALL    #?CopyMemoryBytes
   13            char *p_mya;     // pointer to character
   14
   15            p_x = &x;        // p_x points to x
\    000022   0F41          MOV.W   SP, R15
\    000024   814F0800      MOV.W   R15, 0x8(SP)
```


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Pointers and C, cont'd

```
  16            y1 = 10 + x;     // new value to y1
\   000028   2F41          MOV.W   @SP, R15
\   00002A   3F500A00      ADD.W   #0xa, R15
\   00002E   814F0600      MOV.W   R15, 0x6(SP)
  17            y2 = -1;
\   000032   B1430A00      MOV.W   #0xffff, 0xa(SP)
\   000036   B1430C00      MOV.W   #0xffff, 0xc(SP)
  18            p_y2 = &y2;      // pointer p_y2 points to y2
\   00003A   0F41          MOV.W   SP, R15
\   00003C   3F500A00      ADD.W   #0xa, R15
\   000040   814F0400      MOV.W   R15, 0x4(SP)
  19            y3 = 10 + *p_y2;
\   000044   1F410400      MOV.W   0x4(SP), R15
\   000048   2E4F          MOV.W   @R15, R14
\   00004A   1F4F0200      MOV.W   0x2(R15), R15
\   00004E   3E500A00      ADD.W   #0xa, R14
\   000052   0F63          ADDC.W  #0x0, R15
\   000054   814E0E00      MOV.W   R14, 0xe(SP)
\   000058   814F1000      MOV.W   R15, 0x10(SP)
  20            p_mya = mya;     // p_mya points to array mya
\   00005C   0F41          MOV.W   SP, R15
\   00005E   3F501200      ADD.W   #0x12, R15
\   000062   814F0200      MOV.W   R15, 0x2(SP)
  21            p_mya = p_mya + 3;
\   000066   B15003000200 ADD.W   #0x3, 0x2(SP)
```


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Example #5: Pointers and Pointer Arithmetic

Consider the following C program.
Assume that the register SP at the beginning points to 0x0A00.
Assume all variables are allocated on the stack, and in the order as they appear in the program (a, b, c, mych, pli, pi).
ASCII code for character '0' is 48 (0x30).

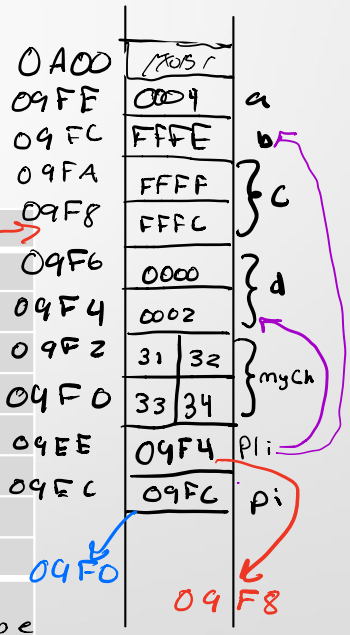
First element @ lowest address

```
1   int main( void )  {
2     volatile int a = 4, b = -2;
3     volatile long int c = -4, d = 2;
4     volatile char mych = {'4', '3', '2', '1'};
5     volatile long int *pli = &d; // Var is pointer, to type long int
6     volatile int *pi = &b;
7     pli = pli + 1;
8     pi = pi - 6;
9     *pi = a + *pi;
10  }
```

FFFF FFFC

Pointer Arithmetic 09F8 1x4
09FC - 6x2 09F0 (34)

pi



Line 7: pli++; //next object in sequence of that type

1x4

line 8: pi = pi - 6 → 6x2=12

Line 9: *pi = a + *pc;

3334
+ 0004
→ 3338

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Example #5 (cont'd)

#	Question?	Value/Address
1	The number of bytes allocated on the stack for the variables declared in line 2. Volatile int a=4, b=-2	4 bytes
2	The number of bytes allocated on the stack for the character array declared in line 4. Volatile char mych = {'4','3','2','1'}	4 bytes
3	The number of bytes allocated on the stack for all variables declared in lines 2-6.	20 bytes
4	Value of mych[0] after initialization performed in line 4.	'4' or 34
5	Address of variable b (&b).	09FC
7	Value of pli at the moment after the statement in line 5 is executed.	09F4
8	Value of pli at the moment after the statement in line 7 is executed.	09F8
9	Value of pi at the moment after the statement in line 8 is executed.	09F0
10	Value of mych[0] at the moment after the statement in line 9 is executed.	0x38 '8'

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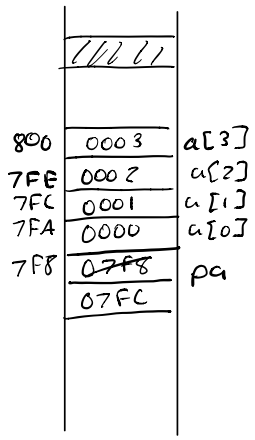
- Volatile int a[4] = { 0, 1, 2, 3 }
  Volatile int *pa;
  pa = a; //address of A
  pa = pa + 2; // 0x07F8 + 2x2 = 0x07FC



Char myCh[5] = { 0, 1, 2, 'A', '3' };