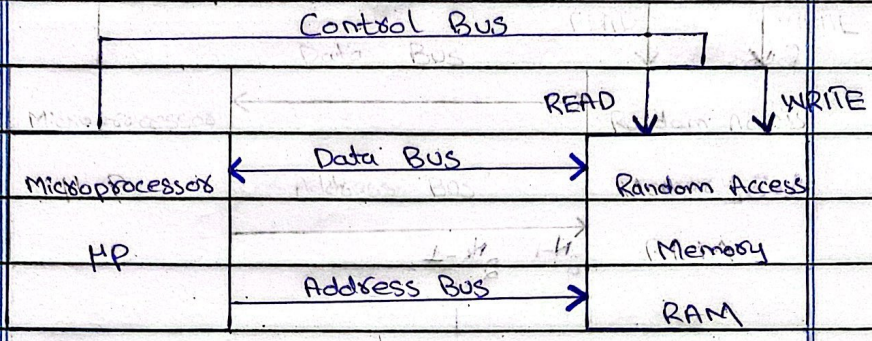
1.1 Computer System Design



Data Bus could be 8, 16, 32 or 64 bits. This bus is also bi-directional.

Address Bus could address 2^n, where n is number of address bits then 2^n gives total number of logical memory locations it can access.

1.2 Memory Operations

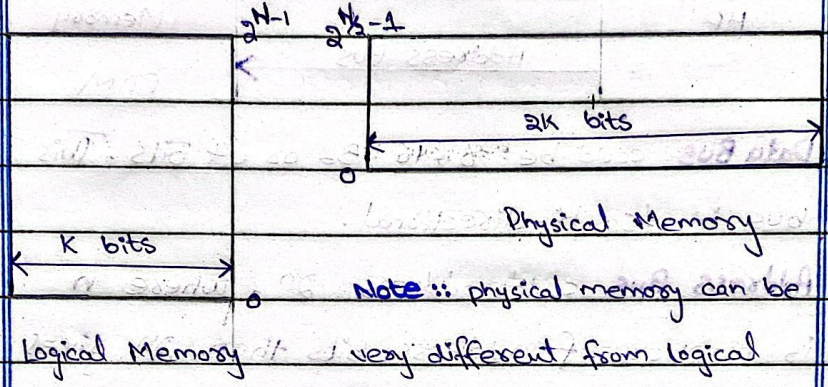
READ if you give high read control signal for a while with some address present in address bus than it will read data and place out on Data Bus towards processor.

WRITE if you give high on write control signal

than data present on Data Bus will be written on the location which address is in address Bus.

1.3

Logical Memory Maps



Note :: physical memory can be very different from logical memory but capacity is same.

Address can be of N bits. Range [0 – N-1]
This address could refer to 2^N locations.
In each address you could write K bits of data. So **Data Bus** size will be [0 – K-1]

Note :: This does not mean that physical address should be of K bits it could be 2K bits, but in that case physical memory have half locations.

As programmers you need not to concern about that physical memory but only logical memory for N bits address only read K bits. otherwise you will read carbage or write onto other saved data.

2.1 Processing

Program It is a passive entity that contains the set of code required to perform a certain task.

Process is a active instance of the program which is loaded into memory and executed by processor.

How does CPU turns a program into a Process?

Fetch → Decode → Execute

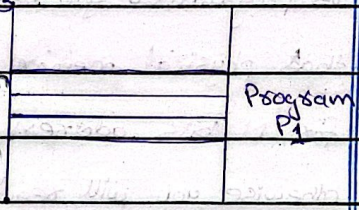
Load instruction from memory to CPU	Breaks down to Machine code	Run the Machine code

Old μP $F_1 D_1 E_1$ $F_2 D_2 E_2$ $F_3 D_3 E_3$ .....

New μP $F_1 D_1 E_1$

$F_2 D_2 E_2$

$F_3 D_3 E_3$ ...



Here program is stored in Memory a_1 to a_m. Suppose m instruction between address a_1 to a_m. The processor will fetch F, Decode D and Execute E each instructions. Modren microprocessor use pipeline where next fetch can be done as previous decodes in staircase mannar.

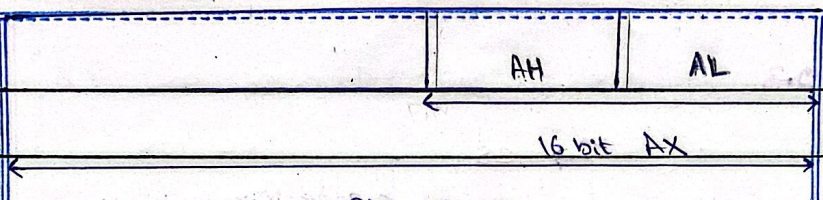
2.2

Registers

Data Register		Pointer/Index		Segments	
AX	Accumulator	IP	Instruction	CS	code segment
BX	Base	SI	Source Index	DS	Data segment
CX	Counter	DI	Destination Index	SS	Stack segment
DX	Data	SP	Stack Pointer	ES	Extra segment

Flags Zero, Carry, sign and overflow.

Add E before each for extended 32 bits.



Note You can not access upper 16 bits of EAX as register alone.

SP can only perform Last In First Out operations so we need another register to do random access that is **BP** (Base Pointer).

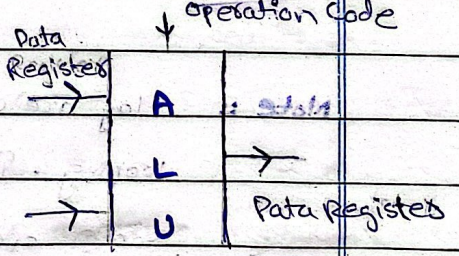
To do array Manipulation or char array/string we need **SI** and **DI**.

How they are used in processing?

Fetch

IP Instruction Pointer traces the line of code being executed and increases it by value **N** to fetch next instruction.

Execute

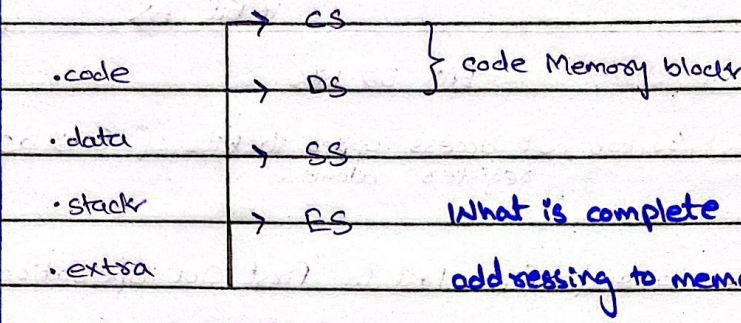


Note: Here **N** is operation code size. It can byte, word or Dword etc.

For different operation output goes in diff registers.

2.3

Segmentation



Memory

Code [CS : IP] is complete address to location memory blockr or instruction in code segment.

Data [DS : Bx, DI, SI] Address of Data

Stackr [SS : SP, BP] Address of stackr

Extra [PS : Bx, DI, SI] Address of destination data for string operations.

Note : Flag are used for branching and looping. These flags are set when some operation take place in Arithematic logic Unit and results are stored respective general purpose Registers.

3.1 BASIC Operations

To be very honest a computer is a dumb machine which could only perform three operations

LOAD ADD STORE (DLD)

Instruction set Intel 8086

Mnemonic ⟷ Syntax/Type Example

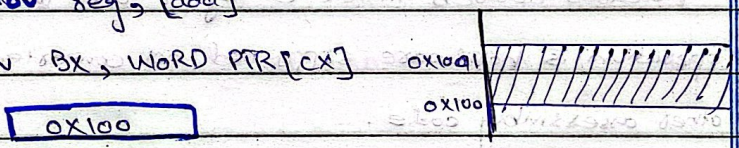
MOV reg, reg Reg Direct mov ax, bx

MOV reg, mem Immediate mov ax, 0x40

MOV mem, reg Direct mov 0x1330, ax

* MOV reg, [add]

Mov BX, WORD PTR [CX]



The whole shaded blocks will be moved to cx.

MOV BX, WORD PTR [CX+4] Reg Indirect + offset

MOVSX copy sign data low to high mov ecx, -16 movsx ax, ecx

MOVZX copy unsign data Registers mov ecx, 10 movzx ax, ecx

LAHF Load flags

SAHF Store flags

XCHG exchange used for swapping

Data Transfer Instructions

ALU Instructions

Unary operations

INC	reg/mem	inc ax.	
DEC	reg/mem	dec bx	
Neg	reg/mem	neg cx	
add	all	add ax, bx	Ans in ax
Sub	all	sub cx, bx	Ans in cx

i) **Note:** A high level language like C could generate more than 1 types of code for same program in Assessmbly but in assessmbly to machine there is one to one mapping.

ii) MOV Bx, WORD PTR [CX+4]

Increases address inside cx by 4 and this operation is hardware supported not converted to other assessmbly code.

iii) Add Ax, [Bx] This will add the location pointed by bx to value in ax.

iv) MOV Ax, Bx where Bx is 0x0000 then zero flag will be set to 1.

v) Clear Register XOR Ax, Ax

Ax will be zero and zero flag is set.

vi) **MUL** Multiplication where one register is set to AX as input and other can be of your choice and outputs in AX (lower bits) DX (high bits).

IMUL is used for sign multiplication

vii) **DIV** In Division dividend will be placed in AX and DX (lower bits in AX and upper in DX). Place divider in CX. The output will be in AX and DX. (AX → Quotient) (DX → Remainder)

IDIV for signed division.

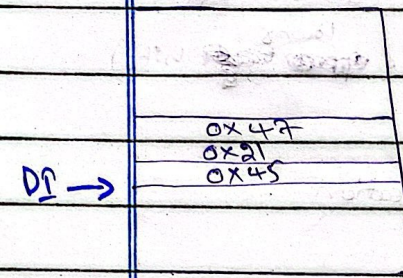
viii) **Division overflow** if a division does not produce a quotient that will not fit into the destination, a division overflow.

ix) **Compare** can be used for searching like find()

lets assume find pattern in string array / memory.

```
        Mov  AL, 0x21          // loading AL with search
        Mov  CX, 0x100         // 256 count in Cx
        Mov  DI, Address_Data
REPNE   Scasb                  // compare AL to [DI]
        CLD                    // clear Direction flag Auto inc
```

REPNE Repeat until not Equal or CX=0



// First it will compare AL value with value on address [DI] then decrease 1 byte then compare. on index 2 found.

So value of Ecx will be 255 as result/Data found after 1 iteration.

⇒ Cx is set to a number so that loop doesn't go infinite.

⇒ **CMPSB** can be used to compare two memory blocks of arrays in Ds or Es with **REPE** as above

⇒ **MOVS B/W/D** will copy all memory block from source to destination address Note here no flag will be affected so use **REP**. (Non Arithemtic OP)

3.2 Stack

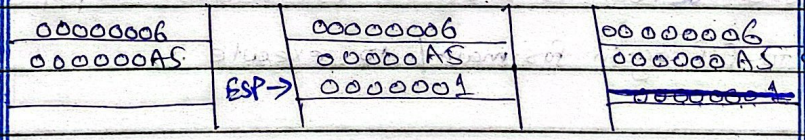
A stack pointer is used to deal Random Access Memory as stacks. ∴ ESP → RAM

Base of ESP comes from ESS [ESS: ESP]

Complete Stack Address

Push A push operation decreases the stack pointer by appropriate amount according size of operation and copies a value into the location in the stack refered by stack pointer **(ESP)**

Pop does the opposite and return value on top of stack



Note:: Pop [EBx] here data from stack segment pointed by ESP will be copied to Data segment pointed by EBx. So it is very important to specify how many bytes to read.

Pop WORD PTR [EBx] ∴ Reads 16 bits

Pop DWORD PTR [EBx]

EBP can be used for random access of stack.

MOV AX, WORD PTR [EBP-4]

[SS : EBP] ← Part of Extended Stack segment

Complete address.

3.3 Sub Routines

A procedure is a named block of code defined with in PROC and ENDP directives.

CALL instruction loades function add to EIP before that push current add to stack poluted by ESP. instruction

when return is executed ESP address is pop to EIP again for main / to execute.

★ This branching helps to reuse code without rewriting it.

Note :: All directive or mnemoic are hadrware supposted and they are not broken much simpler they are executed on hardware level.

4.1 C to Assembly (MSVC x86)

C

```
#include <stdio.h>

int main() {

   printf("Hello World");

   return 0;
}
```

Assembly

```
--- CandASM01.cpp ---

#include <stdio.h>

int main() {

00311870  push      ebp
00311871  mov       ebp,esp
00311873  sub       esp,0C0h
00311879  push      ebx
0031187A  push      esi
0031187B  push      edi
0031187C  mov       edi,ebp
0031187E  xor       ecx,ecx
00311880  mov       eax,0CCCCCCCCh
00311885  rep stos    dword ptr es:[edi]
00311887          mov                                   ecx,offset
_43D8056B_CandASM01@cpp (031C008h)
0031188C                                                call
@__CheckForDebuggerJustMyCode@4 (031132Ah)

   printf("Hello World");
00311891  push      offset string "Hello World" (0317B30h)
00311896  call      _printf (03110D2h)
0031189B  add       esp,4

   return 0;
0031189E  xor       eax,eax
}

003118A0  pop       edi
003118A1  pop       esi
003118A2  pop       ebx
003118A3  add       esp,0C0h
003118A9  cmp       ebp,esp
003118AB  call      __RTC_CheckEsp (031124Eh)
003118B0  mov       esp,ebp
003118B2  pop       ebp
003118B3  ret

--- No source file---
```

When you look at a simple "Hello, World!" program, you'll notice that it translates into a large amount of assembly code. Additionally, it's important to note that even after the main function, the code continues to run and includes a ret statement in **.asm.**

After the C program ends, the operating system typically manages any remaining cleanup tasks, deallocating resources used by the program and reclaiming memory. The specific operations shown in the assembly code snippet ensure that the function cleans up its own stack frame and returns control properly to the calling function or the operating system.

```
#include <iostream>

int main() {

   int a = 5; int b = 3;
   int result = 0;
```

```
include <iostream>

int main() {
004124E0  push      ebp
004124E1  mov       ebp,esp
004124E3  sub       esp,0ECh
```

```
    __asm {
        mov eax, a      ; load a
        mov ebx, b      ; load b
        xor ecx, ecx    ; clear ecx

    loop_start:
        test ebx, ebx   ; check ebx
        jz loop_end     ; if zero, end loop
        add ecx, eax    ; accumulate result
        dec ebx         ; decrement ebx
        jmp loop_start  ; repeat loop

    loop_end:
        mov result, ecx  ; store result
    }

    std::cout << a << " * " << b << " = " << result <<
    std::endl;

    return 0;
}
```

```
004124E9  push      ebx
004124EA  push      esi
004124EB  push      edi
004124EC  lea       edi,[ebp-2Ch]
004124EF  mov       ecx,0Bh
004124F4  mov       eax,0CCCCCCCCh
004124F9  rep stos  dword ptr es:[edi]
004124FB  mov       eax,dword ptr [__security_cookie
(041C004h)]
00412500  xor       eax,ebp
00412502  mov       dword ptr [ebp-4],eax

    int a = 5; int b = 3;
00412505  mov       dword ptr [a],5
0041250C  mov       dword ptr [b],3
    int result = 0;
00412513  mov       dword ptr [result],0

    __asm {
        mov eax, a;     load a
0041251A  mov       eax,dword ptr [a]
        mov ebx, b;     load b
0041251D  mov       ebx,dword ptr [b]
        xor ecx, ecx;   clear ecx
00412520  xor       ecx,ecx

        loop_start :
        test ebx, ebx;      check ebx
00412522  test      ebx,ebx
            jz loop_end;    if zero, end loop
00412524  je        loop_end (041252Bh)
            add ecx, eax;   accumulate result
00412526  add       ecx,eax
            dec ebx;        decrement ebx
00412528  dec       ebx
            jmp loop_start; repeat loop
00412529  jmp       main+42h (0412522h)

            loop_end :
        mov result, ecx;    store result
0041252B  mov       dword ptr [result],ecx
    }

    std::cout << a << " * " << b << " = " << result << std::endl;
0041252E  mov       esi,esp
00412530          push                                offset
std::endl<char,std::char_traits<char> > (041103Ch)
00412535  mov       edi,esp
00412537  mov       eax,dword ptr [result]
0041253A  push      eax
0041253B  push      offset string " = " (0419B30h)
00412540  mov       ebx,esp
00412542  mov       ecx,dword ptr [b]
00412545  push      ecx
00412546  push      offset string " * " (0419B34h)
0041254B  mov       eax,esp
0041254D  mov       edx,dword ptr [a]
00412550  push      edx
00412551  mov             ecx,dword ptr [__imp_std::cout
(041D0D8h)]
00412557  mov       dword ptr [ebp-0ECh],eax
0041255D          call                              dword ptr
[__imp_std::basic_ostream<char,std::char_traits<char>
>::operator<< (041D0A0h)]
```

```
00412563  mov       ecx,dword ptr [ebp-0ECh]
00412569  cmp       ecx,esp
0041256B  call      __RTC_CheckEsp (04112A3h)
00412570  push      eax
00412571  call      std::operator<<<std::char_traits<char>
> (04111B8h)
00412576  add       esp,8
00412579  mov       ecx,eax
0041257B        call                                dword     ptr
[__imp_std::basic_ostream<char,std::char_traits<char>
>::operator<< (041D0A0h)]
00412581  cmp       ebx,esp
00412583  call      __RTC_CheckEsp (04112A3h)
00412588  push      eax
00412589  call      std::operator<<<std::char_traits<char>
> (04111B8h)
0041258E  add       esp,8
00412591  mov       ecx,eax
00412593        call                                dword     ptr
[__imp_std::basic_ostream<char,std::char_traits<char>
>::operator<< (041D0A0h)]
00412599  cmp       edi,esp
0041259B  call      __RTC_CheckEsp (04112A3h)
004125A0  mov       ecx,eax
004125A2        call                                dword     ptr
[__imp_std::basic_ostream<char,std::char_traits<char>
>::operator<< (041D0A4h)]
004125A8  cmp       esi,esp
004125AA  call      __RTC_CheckEsp (04112A3h)
    return 0;
004125AF  xor       eax,eax
}

004125B1  pop       edi
004125B2  pop       esi
004125B3  pop       ebx
004125B4  mov       ecx,dword ptr [ebp-4]
004125B7  xor       ecx,ebp
004125B9    call            @__security_check_cookie@4
(041118Bh)
004125BE  add       esp,0ECh
004125C4  cmp       ebp,esp
004125C6  call      __RTC_CheckEsp (04112A3h)
004125CB  mov       esp,ebp
004125CD  pop       ebp
004125CE  ret
```

As you can observe, inline assembly is slightly modified to ensure compatibility, such as using dword ptr when converting int to 32-bit. The compiler does not alter its operations when generating assembly for the entire C program.

*However, it's important to note that this implementation of **MUL** is significantly slower than the original **MUL** in assembly because the latter is hardware-implemented, whereas this is a software approach.*

4.2 Pointer Arithmetic (MSVC x86)

```
#include <stdio.h>

int main() {

    char* a = 0;
```

```
...
    char* a = 0;
00651795  mov       dword ptr [a],0
    int* b = 0;
0065179C  mov       dword ptr [b],0
```

```
    int* b = 0;

    a++;
    b++;

    return 0;
}
```

```
    a++;
006517A3  mov         eax,dword ptr [a]
006517A6  add         eax,1
006517A9  mov         dword ptr [a],eax
    b++;
006517AC  mov         eax,dword ptr [b]
006517AF  add         eax,4
006517B2  mov         dword ptr [b],eax

    return 0;
006517B5  xor         eax,eax
...
```

char occupies 1 byte in memory, so each subsequent char is placed immediately after the previous one. On the other hand, an int occupies 4 bytes, so each subsequent int is placed 4 bytes after the previous one in consecutive memory locations.

```
#include <stdio.h>

int main() {

    const char* testString = "Hello, world!";
    int len;

    __asm {
        mov esi, testString
        xor ecx, ecx

        loop_start:
            cmp byte ptr[esi + ecx], 0
            je loop_end
            inc ecx
            jmp loop_start

        loop_end:
            mov len, ecx
    }

    printf("The length of the string is: %d\n", len);

    return 0;
}
```

```
...
    __asm {
        mov esi, testString
008A189C  mov         esi,dword ptr [testString]
        xor ecx, ecx
008A189F  xor         ecx,ecx

        loop_start:
            cmp byte ptr[esi + ecx], 0
008A18A1  cmp         byte ptr [esi+ecx],0
            je loop_end
008A18A5  je          loop_end (08A18AAh)
            inc ecx
008A18A7  inc         ecx
            jmp loop_start
008A18A8  jmp         main+31h (08A18A1h)

        loop_end:
            mov len, ecx
008A18AA  mov         dword ptr [len],ecx
    }
...
```

```
#include <stdio.h>

int main() {

    const char* testString = "Hello, world!";
    int length = 0;

    while (testString[length] != '\0') {
        length++;
    }

    printf("The length of the string is: %d\n", length);

    return 0;
}
```

```
...
    const char* testString = "Hello, world!";
00541895   mov           dword ptr [testString],offset string
"Hello, world!" (0547B30h)
    int length = 0;
0054189C  mov         dword ptr [length],0

    while (testString[length] != '\0') {
005418A3  mov         eax,dword ptr [testString]
005418A6  add         eax,dword ptr [length]
005418A9  movsx       ecx,byte ptr [eax]
005418AC  test        ecx,ecx
005418AE  je          __$EncStackInitStart+3Fh (05418BBh)
        length++;
005418B0  mov         eax,dword ptr [length]
005418B3  add         eax,1
005418B6  mov         dword ptr [length],eax
    }
005418B9     jmp                  __$EncStackInitStart+27h
```

```
(05418A3h)

    printf("The length of the string is: %d\n", length);
005418BB  mov         eax,dword ptr [length]
005418BE  push        eax
005418BF  push        offset string "The length of the string
is: %d@"... (0547B40h)
005418C4  call        _printf (05410D2h)
005418C9  add         esp,8
...
```

It's notable that MSVC generates code that is often more logically correct than what an average person might write, even correcting inline assembly code where necessary.

Note: Don't use ***length;*** it is reserved word inline-assembly.

```
#include <stdio.h>

int main() {

    int a = 10, b = 3;
    int c, d;

    c = a / b;
    d = a % b;

    return 0;
}
```

```
...
    int a = 10, b = 3;
007A1795  mov         dword ptr [a],0Ah
007A179C  mov         dword ptr [b],3
    int c, d;
    c = a / b;
007A17A3  mov         eax,dword ptr [a]
007A17A6  cdq
007A17A7  idiv        dword ptr [b]
007A17AA  mov         dword ptr [c],eax
    d = a % b;
007A17AD  mov         eax,dword ptr [a]
007A17B0  cdq
007A17B1  idiv        dword ptr [b]
007A17B4  mov         dword ptr [d],edx
...
```

There is no assembly after compiling on declaration,
Additionally, the same code is compiled twice, as highlighted in red, because the compiling is Not Intelligent.

```
#include <stdio.h>

int main() {

    int a = 10, b = 3;
    int c, d;

    __asm {
        mov   eax, dword ptr[a]
        cdq
        idiv    dword ptr[b]
        mov   dword ptr[c], eax
        mov   dword ptr[d], edx
    }

    printf("Quotient :: %d \t Remainder :: %d", c, d);

    return 0;
}
```

cdq ; Convert doubleword in %eax to quadword in %edx:%eax
https://docs.oracle.open.solaris

In Intelligent Compiling, the compiler is well aware of the task being performed and optimizes the code to save computing power by reducing the number of operations executed. For instance, when training a neural network, this optimization can reduce millions of operations.

```
#include <stdio.h>

int main() {

    int a, b, c, d;
```

```
...
    int a, b, c, d;
    int x = 10, y = 5;
00EB1795  mov         dword ptr [x],0Ah
00EB179C  mov         dword ptr [y],5
```

```
    int x = 10, y = 5;

    a = x + y;
    b = x - y;
    c = x * y;
    d = x / y;

    return 0;
}
```

```
    a = x + y;
00EB17A3  mov         eax,dword ptr [x]
00EB17A6  add         eax,dword ptr [y]
00EB17A9  mov         dword ptr [a],eax
    b = x - y;
00EB17AC  mov         eax,dword ptr [x]
00EB17AF  sub         eax,dword ptr [y]
00EB17B2  mov         dword ptr [b],eax
    c = x * y;
00EB17B5  mov         eax,dword ptr [x]
00EB17B8  imul        eax,dword ptr [y]
00EB17BC  mov         dword ptr [c],eax
    d = x / y;
00EB17BF  mov         eax,dword ptr [x]
00EB17C2  cdq
00EB17C3  idiv        dword ptr [y]
00EB17C6  mov         dword ptr [d],eax
...
```

```
#include <stdio.h>

int main() {

    int a, b, c, d;

    int x = 10, y = 5;

    __asm {

        mov         eax, dword ptr[x]

        add         eax, dword ptr[y]
        mov         dword ptr[a], eax

        sub         eax, dword ptr[y]
        mov         dword ptr[b], eax

        imul        eax, dword ptr[y]
        mov         dword ptr[c], eax

        cdq
        idiv        dword ptr[y]
        mov         dword ptr[d], eax

    }

    printf("Add :: %d Sub :: %d Mul :: %d Div :: %d",
    a, b, c, d);

    return 0;
}
```

In custom assembly, the repetitive instructions for all four arithmetic operations and optimizes them to a single **mov** instruction in custom assembly, significantly reducing the number of operations.

Using -02 -O3 optimization can sometimes lead to larger code size and slower performance due to increased instruction cache misses and aggressive inlining.

```
#include <stdio.h>

int two() {
    return 2;
}
```

-O2 Flag gcc 14.1

```
two:
        mov     eax, 2
        ret
```

```
int main() {
   int t = two();
   return 0;
}
```

```
main:
        xor     eax, eax
        ret
```

```
#include <stdio.h>

int two() {
   return 2;
}

int main() {
   int t = two();
   printf("%d",t);
   return 0;
}
```

-O2 Flag gcc 14.1

```
two:
        mov     eax, 2
        ret
.LC0:
        .string "%d"
main:
        sub     rsp, 8
        mov     esi, 2
        mov     edi, OFFSET FLAT:.LC0
        xor     eax, eax
        call    printf
        xor     eax, eax
        add     rsp, 8
        ret
```

5.1

Compiling C

Source Code → Preprocessed file → Assembly file → object file → Executable

Preprocessing

Preprocess handle directives like #include #define etc. Also expands all marcos and including contents into one file.

File Extension (.i) file

Command GCC gcc -E source.c -o source.i

Note:: The error of redefination comes here.

Compiling / Assembling

Converts preprocessed file into assembly code.

File Extension (.s) file (.asm) Windows

Command GCC gcc -S source.i -o source.s

objecting

The assembler converts assembly code to machine code and generates an object file.

File Extension (.o)

command GCC gcc -c source.s -o source.o

Note:: Static linked libraries are copied into final executable while dynamic link libraries are called while execution.

Linking

Linkers take one or more objects and combine them into single executable. It resolves references between objects and include libraries.

file Type (None) Unix (.exe) Windows

Command GCC gcc source.o -o executable

Note:: DLL or Dynamic Linked libraries and static are to be specified as command line argument while executing file production

gcc main -L/path/to/lib -llibname -o main.o

∴ Before linking the defination of any function used doesn't even matter only declaration is require in corresponding .h file (Not found linker Error)

CALL ① Push Return addr to stack } Control transfer
② Load EIP Function Address } from main to fn

RET ① Pop Return addr of main to EIP

This means implicitly the stack changes for program to execute properly. (ESP changes)

5.2 C to Assembly with Stack

```
int main() {

    int arr[] = { 2, 3, 7, 6, 7 };
    int length = sizeof(arr) / sizeof(arr[0]);

    printf("Starting the assembly function...\n");
    int result = add_func(length, arr);
    printf("Result: %d\n", result);

    return 0;
}
```

To optimize your C code for accumulating an integer array, consider custom optimizations that suit your specific problem. While GCC may generate large code with many operations, you can tailor the optimizations yourself to use minimal memory and cpu.

Simplicity is key in AI tasks since they already demand significant computation and memory. Keeping things straightforward helps manage these challenges

Generate assembly for C code
using **GCC** no Optimization

```
add_func:
        push    rbp
        mov     rbp, rsp
        mov     DWORD PTR [rbp-20], edi
        mov     QWORD PTR [rbp-32], rsi
        mov     DWORD PTR [rbp-4], 0
        mov     DWORD PTR [rbp-8], 0
        jmp     .L2
.L3:
        mov     eax, DWORD PTR [rbp-8]
        cdqe
        lea     rdx, [0+rax*4]
        mov     rax, QWORD PTR [rbp-32]
        add     rax, rdx
        mov     eax, DWORD PTR [rax]
        add     DWORD PTR [rbp-4], eax
        add     DWORD PTR [rbp-8], 1
.L2:
        mov     eax, DWORD PTR [rbp-8]
        cmp     eax, DWORD PTR [rbp-20]
        jl      .L3
        mov     eax, DWORD PTR [rbp-4]
        pop     rbp
        ret

add_func ENDP
END
```

Custom Assembly in **add.asm**

```
 .model flat, STDCALL

.code
add_func PROC C

    ; Save the base pointer
    push ebp
    mov ebp, esp

    ; Load the length of the array into ECX
    mov ecx, [ebp+8]

    ; Load the pointer to the array into ESI
    mov esi, [ebp+12]

    ; Initialize EAX to 0
    xor eax, eax

loop_label:

    ; Add the current element to EAX
    add eax, [esi]

    ; Increment the pointer to the next element
    add esi, 4

    ; Loop until ECX is 0
    loop loop_label

    ; Restore the base pointer
    pop ebp
    ret

add_func ENDP
END
```

In assembly language, parameters are accessed using the stack pointer relative to **EBP** with a positive offset **[EBP + N]**, while local variables are accessed with a negative offset **[EBP - N]**. Integer values are returned through the EAX register, and global variables are accessed directly by their memory address.

Custom Printf

```
#include <stdio.h>
```

Include irvine32.inc

```
#ifdef __cplusplus
extern "C" {
#endif

   // Declare the assembly function
   extern int add_func(int length, int* arr);

   // Declare the assembly function
   extern int printf_func(const char* String, ...);

#ifdef __cplusplus
}
#endif

int main() {

   int arr[] = { 2, 3, 7, 6, 7, -5, 6, 9 };
   int length = sizeof(arr) / sizeof(arr[0]);

   int result = add_func(length, arr);
      printf_func(" %d Printfed from Custome Printf \n
Result: %d\n",1,result);

   return 0;
}
```

```
.code
printf_func PROC C
   ; Save the base pointer
   push ebp
   mov ebp, esp

   ; Load the format string into ESI
   add ebp, 8
   mov esi, [ebp]

print_loop:
   ; Load the byte at ESI into AL
   mov al, [esi]

   ; Check for null terminator
   cmp al, 0
   je print_done

   ; Check for '%'
   cmp al, '%'
   je check_next_char

   ; sys_write for one character
   call WriteChar

   inc esi          ; move to the next character
   jmp print_loop     ; repeat the loop

check_next_char:
   inc esi          ; move to the next character
   mov al, [esi]
   cmp al, 'd'
   je print_int

   ; unknown format specifier, ignore it
   jmp print_loop

print_int:
   ; load the integer from the stack
   add ebp, 4
   mov eax, [ebp]
   call WriteInt

   ; move to the next character
   inc esi
   jmp print_loop

print_done:
   ; Restore the base pointer
   pop ebp
   ret

printf_func ENDP
END
```

5.3

Context Switching Problems

push ebp ⋮ ⋮ pop ebp	save current stack frame, allowing function to use ebp for parameters or local variables. Then atlast restore it for smooth transaction back to main or calling function.
RET N	Perform task of RET pop address main and put in EIP. In RET N it adds immediate value to ESP. Hence clean up stack upto N Bytes.
SUB ESP, 0x40	This will move ESP pointer to 64 bytes behind which can be used for storing local variable.

Note: This sub ESP could result in overriding memory of other system and could result in system crash. Avoid this as much as you can as I have not got it my programmes as examples.

6.1 Recursion & Assembly

C

```
unsigned long long factorial_recursive(int n) {
    if (n == 0 || n == 1) {
        return 1; // Base case
    }
    else {
        return n * factorial_recursive(n - 1); // Recursive call
    }
}
```

```
Recursive Factorial of 63 = 1585267068834414592
Time taken: 5455058 nanoseconds
```

Assembly

```
factorial_recursive:
        push    rbp
        mov     rbp, rsp
        push    rbx
        sub     rsp, 24
        mov     DWORD PTR [rbp-20], edi
        cmp     DWORD PTR [rbp-20], 0
        je      .L2
        cmp     DWORD PTR [rbp-20], 1
        jne     .L3
.L2:
        mov     eax, 1
        jmp     .L4
.L3:
        mov     eax, DWORD PTR [rbp-20]
        movsx   rbx, eax
        mov     eax, DWORD PTR [rbp-20]
        sub     eax, 1
        mov     edi, eax
        call    factorial_recursive
        imul    rax, rbx
.L4:
        mov     rbx, QWORD PTR [rbp-8]
        leave
        ret
```

```
unsigned long long factorial_iterative(int n) {
    unsigned long long result = 1;
    for (int i = 2; i <= n; i++) {
        result *= i;
    }
    return result;
}
```

```
Iterative Factorial of 63 = 1585267068834414592
Time taken: 2978189 nanoseconds
```

```
factorial_iterative:
        push    rbp
        mov     rbp, rsp
        mov     DWORD PTR [rbp-20], edi
        mov     QWORD PTR [rbp-8], 1
        mov     DWORD PTR [rbp-12], 2
        jmp     .L2
.L3:
        mov     eax, DWORD PTR [rbp-12]
        cdqe
        mov     rdx, QWORD PTR [rbp-8]
        imul    rax, rdx
        mov     QWORD PTR [rbp-8], rax
        add     DWORD PTR [rbp-12], 1
.L2:
        mov     eax, DWORD PTR [rbp-12]
        cmp     eax, DWORD PTR [rbp-20]
        jle     .L3
        mov     rax, QWORD PTR [rbp-8]
        pop     rbp
        ret
```

1. Function Call Overhead

- Pushing registers onto the stack
- Saving the current instruction pointer
- Jumping to the function
- Returning from the function
- Popping registers from the stack

2. Stack Overflow Risk

Deep recursion can lead to stack overflow errors, causing the program to crash.

These are the reasons why Recursion can be inefficient when computing factorials.

6.2 C & Assembly Subroutines

At assembly level there are some hardware accelerators which will run in linear time as they are implemented in hardware itself. If we use these in assembly then we can boost our computational power and reduce time.

```
%%writefile str_len.asm                    ; returns length of given pointer to string
section .text
global str_len

str_len:

    mov edi, [esp+4]  ; Load pointer to string

    mov ecx, -1         ; Set loop counter to -1
    xor al, al          ; Clear al register
    repne scasb         ; Scan string for null terminator
    mov eax, ecx        ; Move negative length to eax

    neg eax             ; Convert to positive length
    dec eax             ; Adjust for null terminator
    ret                 ; Return length in eax
```

The **SCASB** instruction in x86 assembly compares the byte in AL with the byte pointed to by EDI (or ESI) and adjusts the index based on the Direction Flag. With **REPNE**, **SCASB** scans the string, continuing until a match is found or ECX reaches zero.

```
%%writefile str_cmp.asm                    ; Compare both string where difference found returns address
section .text
global str_cmp

str_cmp:
    mov edi, [esp+4]    ; Load pointer to string 1
    mov esi, [esp+8]    ; Load pointer to string 2

    CLD                 ; Clear direction flags for string ops

    mov ecx, -1         ; Initialize loop counter to -1

    repz cmpsb          ; Compare bytes in both strings until ECX is 0

    jne found_difference  ; If not equal, jump to difference handling

    xor eax, eax        ; If equal, return 0 in EAX
    ret

Found_difference:

    ; Return index of first mismatch
    mov eax, ecx      ; Move loop counter to EAX
    neg eax         ; Convert to positive index
    dec eax         ; Adjust for 0-based indexing
     ret
```

The **repz** prefix in x86 assembly repeats a string operation (like **cmpsb** or **scasb**) while the zero flag (ZF) is set and ECX is non-zero. The **cmpsb** instruction compares bytes at ESI and EDI, adjusting these registers based on the Direction Flag (DF).

```
%%writefile mem_set.asm                    ; Initialize all memory location to Null
```

```
section .text
global mem_set

mem_set:

   CLD                    ; clear direction flags

   mov edi, [esp+4]    ; Load array pointer into EDI
   mov ecx, [esp+8]    ; Load array length into ECX

   xor al, al              ; Set AL to 0 (null value)

   rep stosb               ; Fill array with null values
   ret
```

The **stosb** instruction stores the value in AL into the memory location pointed to by EDI (or RDI), then adjusts EDI based on the Direction Flag (DF). The rep prefix repeats a string operation (like **stosb**) for a count specified by ECX, continuing until ECX reaches zero.

```
%%writefile mem_cpy.asm                    ; copy contents from one memory to other
section .text
global mem_cpy

mem_cpy:
   CLD             ; clear direction flags

   mov edi, [esp+4]   ; Load string pointers into EDI and ESI
   mov esi, [esp+8]
   mov ecx, [esp+12]  ; N bytes to copy

   rep movsb         ; Compare bytes in both strings
   ret
```

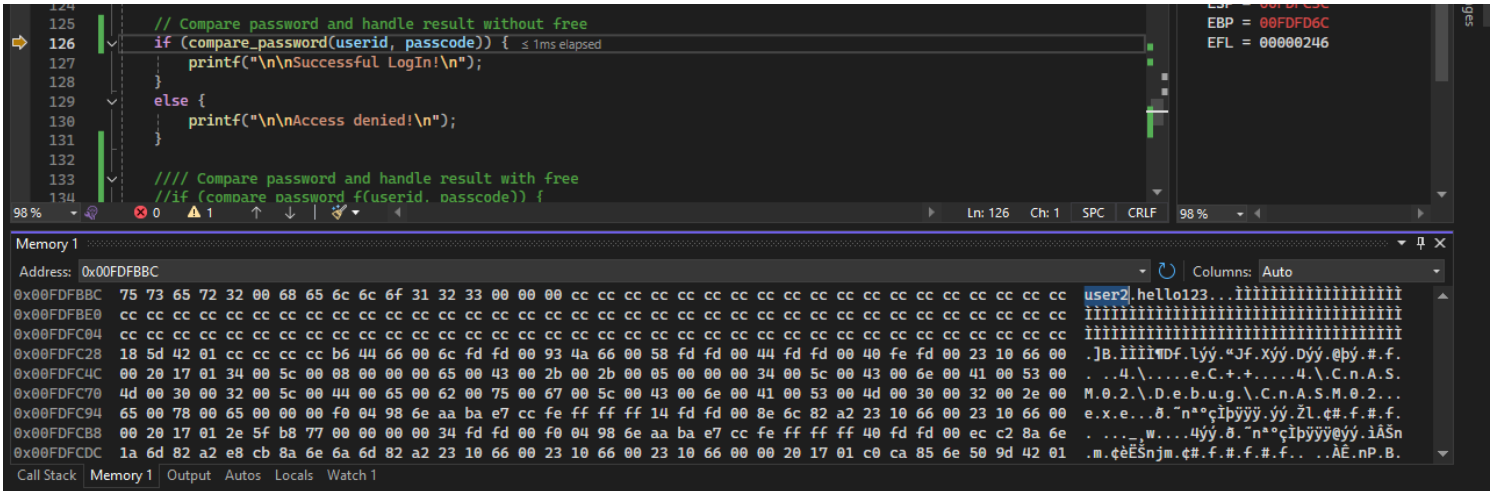
The **movsb** instruction in x86 assembly moves a byte from the memory location pointed to by ESI (or RSI in 64-bit) to the memory location pointed to by EDI (or RDI in 64-bit). After the byte is moved, ESI and EDI are either incremented or decremented based on the state of the direction flag (**DF**).

C
Declarations

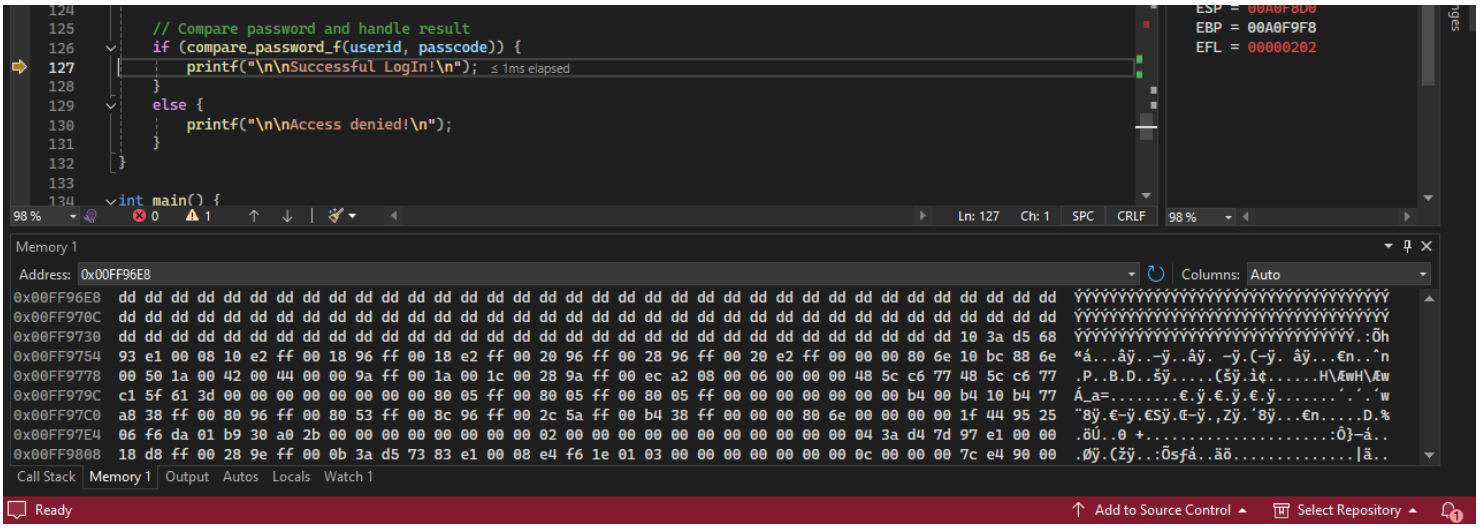
```
// Declare the str_len function, which calculates the length of a string
extern "C" int str_len(const char *str);  // Returns the length of the input string

// Declare the str_cmp function, which compares two strings
extern "C" int str_cmp(const char *str1, const char *str2);  // Returns 0 if equal, non-zero if not equal

// Declare the mem_set function, which sets a block of memory to a specific value
extern "C" void mem_set(const char *destination, int N);  // Sets N bytes of memory at destination to 0

// Declare the mem_cpy function, which copies a block of memory from one location to another
extern "C" void mem_cpy(const char *destination, const char *source, int N);  // Copies N bytes from source to destination
```

6.3 Local Variables in Subroutines

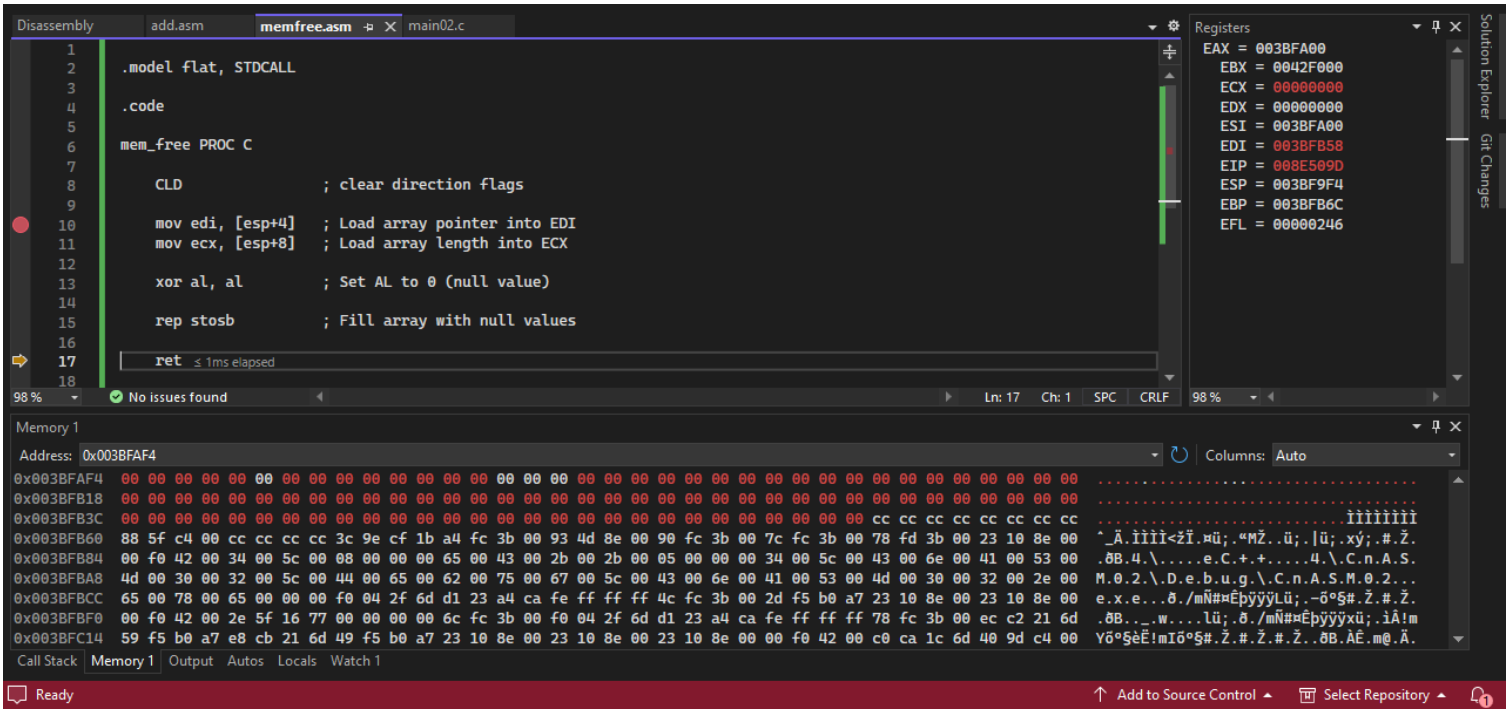
In continuous running applications, functions should clear their local variables before exiting to prevent security vulnerabilities. This practice helps avoid data leaks and ensures sensitive information isn't left in memory. Consistently clearing memory enhances both security and stability of the application.



Login system vulnerability: User credentials remain in memory after login function exits, leaving sensitive data exposed if not properly cleared.



Freeing dynamic memory ensures sensitive info is erased, protecting against unauthorized access or memory dumping.



If you prefer not to use dynamic memory, you can use memfree (previously known as memset method) to clear the memory space. This helps improve security by ensuring sensitive data is erased.