School of

Engineering and Computer Science

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Malware and Reverse Engineering

A Crash Course in x86 Disassembly

Chapters 4: "*Practical Malware Analysis: The Hands-on Guide to Dissecting Malicious Software*", Michael Sikorski and Andrew Honig, 2012

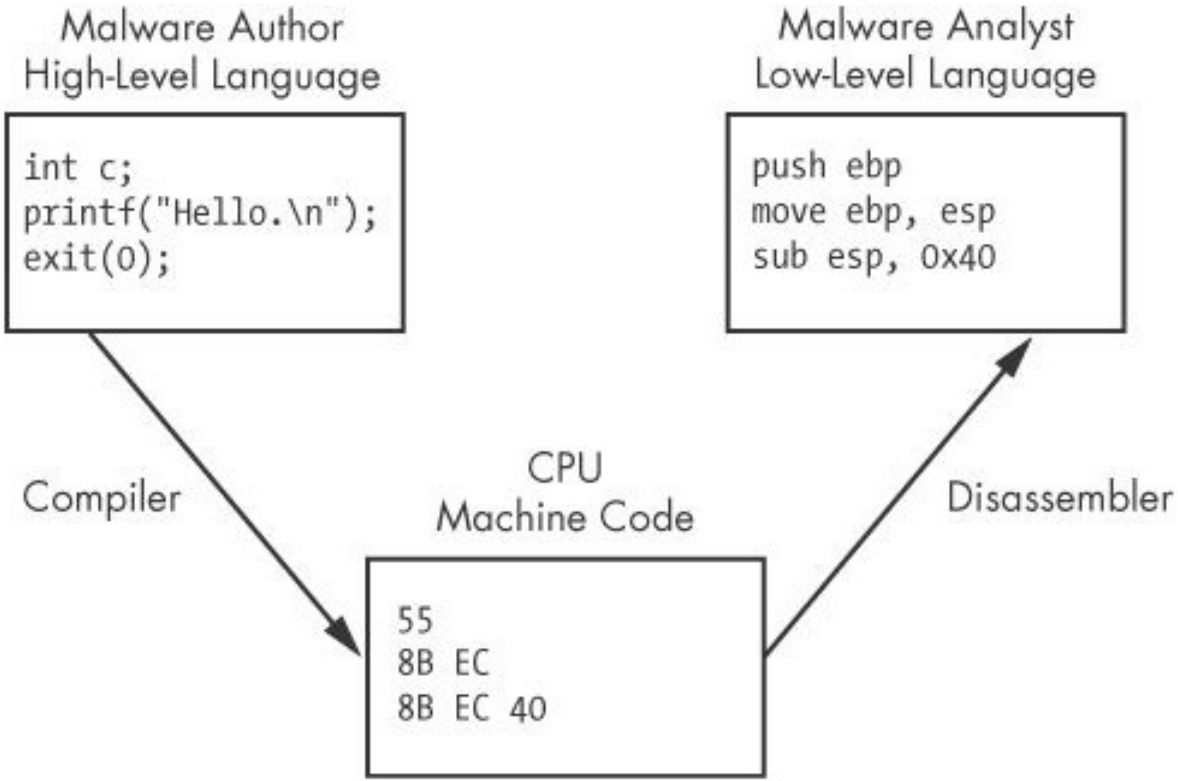
VICTORIA UNIVERSITY OF
WELLINGTON
TE HERENGA WAKA

Basic Techniques

- Basic static analysis
    - Looks at malware from the outside
- Basic dynamic analysis
    - Only shows you how the malware operates in one case
- Disassembly
    - View code of malware & figure out what it does

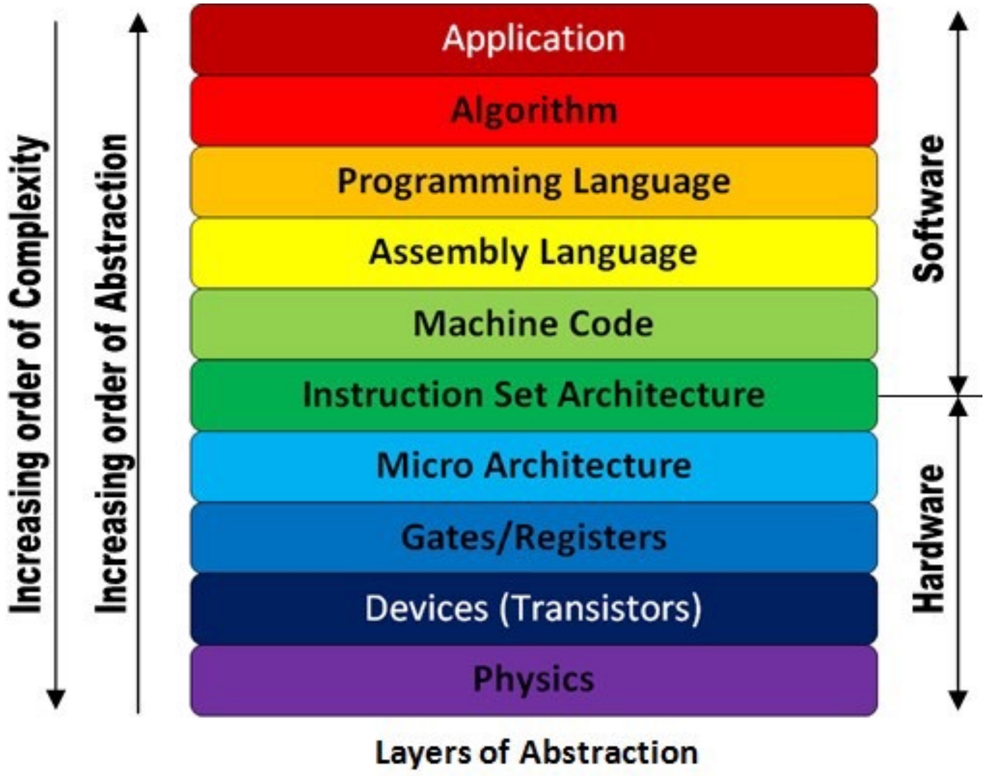
LEVELS OF ABSTRACTION

Code-level Example



Six Levels of Abstraction

- Hardware
- Microcode
- Machine code
- Low-level languages
- High-level languages
- Interpreted languages



Hardware, Microcode and Machine Code

- Hardware
  - Digital circuits
  - XOR, AND, OR, NOT gates
  - Cannot be easily manipulated by software
- Microcode
  - Also called firmware
  - Only operates on specific hardware it was designed for
  - Not usually important for malware analysis
- Machine Code
  - Tell the processor to do something
  - Created when a program written in a high-level language is compiled

Languages

- Low-level
  - Human-readable version of processor's instruction set
  - Assembly language
    - PUSH, POP, NOP, MOV, JMP ...
  - Disassembler generates assembly language
  - This is the highest level language that can be reliably recovered from malware when source code is unavailable
- High-level
  - Most programmers use these
  - C, C++, etc.
  - Converted to machine code by a compiler

Languages (cont.)

- Interpreted
  - Highest level
  - Java, C#, Perl, .NET, Python
  - Code is not compiled into machine code
  - It is translated into **bytecode**
    - An intermediate representation
    - Independent of hardware and OS
    - Bytecode executes in an **interpreter**, which translates bytecode into machine language on the fly at runtime
    - Ex: Java Virtual Machine

REVERSE ENGINEERING

Disassembly

- Malware on a disk is in **binary** form at the **machine code** level
- **Disassembly** converts the binary form to **assembly language**
- IDA Pro is the most popular disassembler

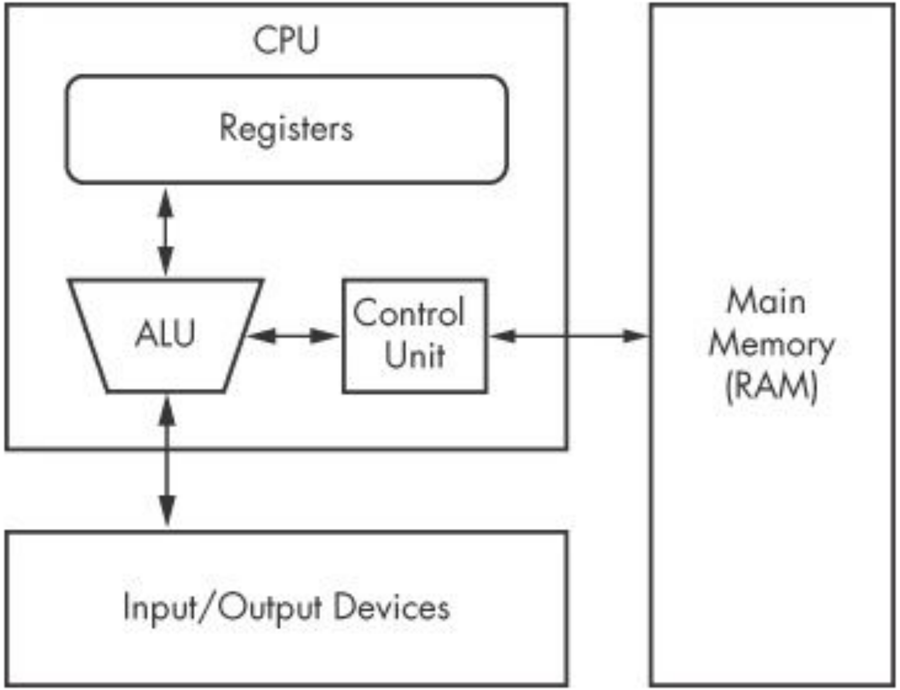
Assembly Language

- Different versions for each type of processor
- x86 – 32-bit Intel (most common)
- x64 – 64-bit Intel
- SPARC, PowerPC, MIPS, ARM – others
- Windows runs on x86 or x64
- x64 machines can run x86 programs
- Most malware is designed for x86

THE X86 ARCHITECTURE

Von Neumann Architecture

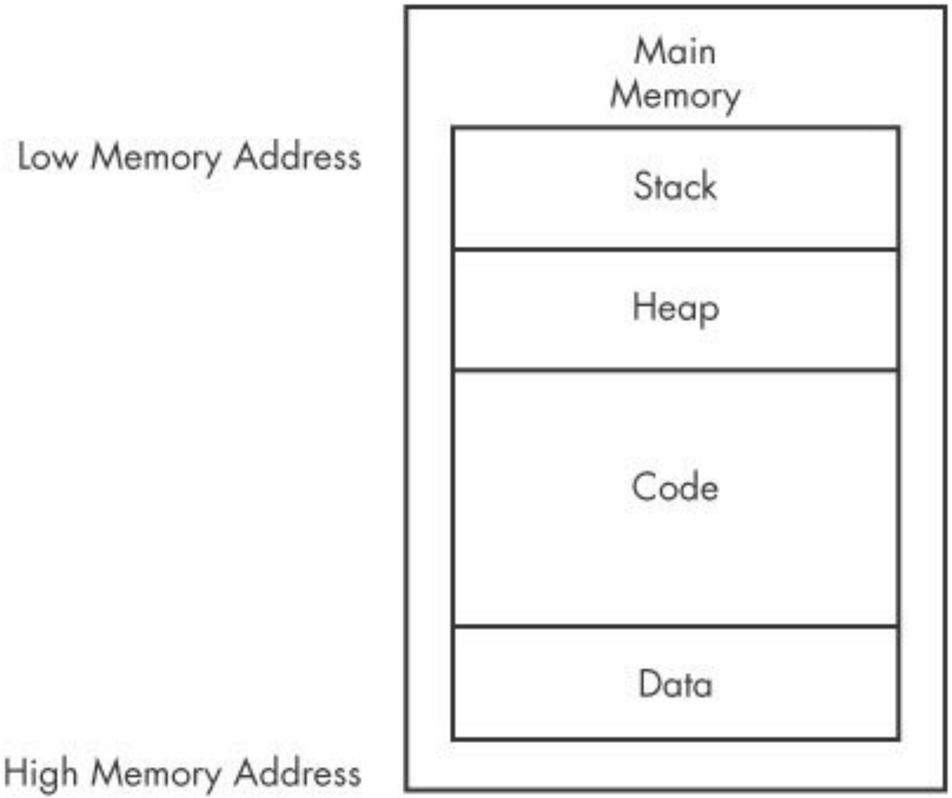
- **CPU** (Central Processing Unit) executes code
- **RAM** stores all data and code
- **I/O** system interfaces with the hard disk, keyboard, monitor, etc.



CPU Components

- **Control unit**
  - Fetches instructions from RAM using a **register** named the **instruction pointer**
- **Registers**
  - Data storage within the CPU
  - Faster than RAM
- **ALU (Arithmetic Logic Unit)**
  - Executes an instruction and places results in registers or RAM

Main Memory (RAM)



Data and Code

- Data
  - Values placed in RAM when a program loads
  - Sometimes these values are called **static**
    - They may not change while the program is running
  - Sometimes these values are called **global**
    - Available to any part of the program
- Code
  - Instructions for the CPU
  - Controls what the program does

Heap and Stack

- Heap
  - **Dynamic memory**
  - Changes frequently during program execution
  - Program creates (allocates) new values, and eliminates (frees) them when they are no longer needed
- Stack
  - Local variables and parameters for functions
  - Helps programs flow

Instructions

- **Mnemonic** followed by **operands**
- **mov ecx 0x42**
  - Move into Extended C register the value 42 (hex)
- **mov ecx** is 0xB9 in hexadecimal
- The value 42 is 0x4200000000
- In binary, this instruction is

  0xB942000000

Assembly Language Instructions

- We're using the **Intel** format
  - **AT&T format** reverses the source and destination positions

Mnemonic	Destination operand	Source operand
`mov`	`ecx`	`0x42`

Endianness

- ***Big***-Endian
  - Most significant byte first
  - 0x42 as a 64-bit value would be 0x00000042
- ***Little***-Endian
  - Least significant byte first
  - 0x42 as a 64-bit value would be 0x42000000
- Network data uses big-endian
  - 127.0.0.1, or in hex, 7F 00 00 01
  - Sent over the network as 0x7F000001
  - Stored in RAM as 0x0100007F
- x86 programs use little-endian

Operands

- **Immediate**
  - Fixed values like 0x42
- **Register**
  - eax, ebx, ecx, and so on
- **Memory address**
  - Denoted with brackets, like [eax]

Registers

- The x86 registers

General registers	Segment registers	Status register	Instruction pointer
EAX (AX, AH, AL)	CS	EFLAGS	EIP
EBX (BX, BH, BL)	SS		
ECX (CX, CH, CL)	DS		
EDX (DX, DH, DL)	ES		
EBP (BP)	FS		
ESP (SP)	GS		
ESI (SI)			

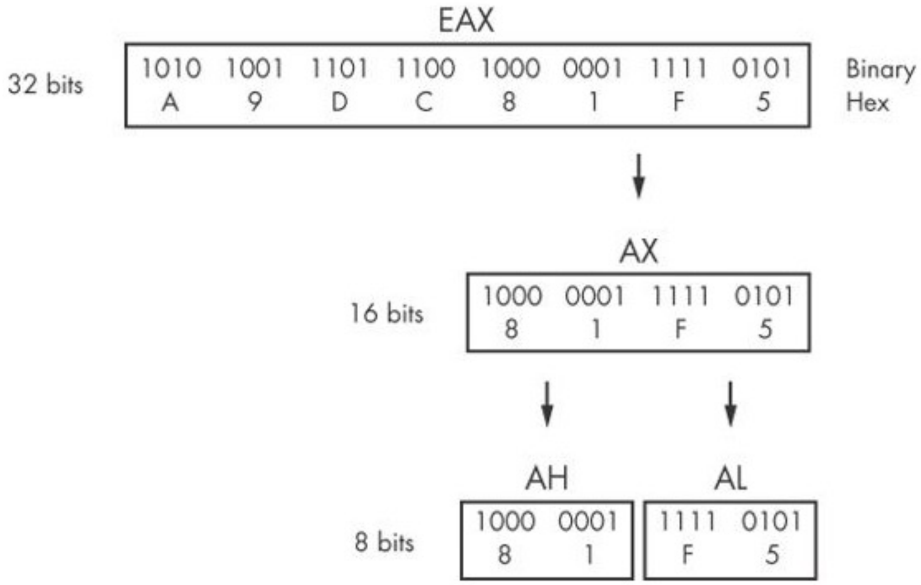
Registers (cont.)

- **General** registers
  - Used by the CPU during execution
- **Segment** registers
  - Used to track sections of memory
- **Status flags**
  - Used to make decisions
- **Instruction pointer**
  - Address of next instruction to execute

Size of Registers

- General registers are all 32 bits in size
  - Can be referenced as either 32bits (edx) or 16 bits (dx)

- Four registers (eax, ebx, ecx, edx) can also be referenced as 8-bit values
  - AL is lowest 8 bits
  - AH is higher 8 bits



General Registers

- Typically **store data** or **memory addresses**
- Normally interchangeable
- Some instructions reference **specific registers**
- Multiplication and division use EAX and EDX
- **Conventions**
  - **Compilers** use registers in **consistent ways**
  - EAX contains the return value for function calls

Flags

- EFLAGS is a status register
- 32 bits in size
- Each bit is a flag
- SET (1) or Cleared (0)

Important Flags

- **ZF** Zero flag
  - Set when the result of an operation is zero
- **CF** Carry flag
  - Set when result is too large or small for destination
- **SF** Sign Flag
  - Set when result is negative, or when most significant bit is set after arithmetic
- **TF** Trap Flag
  - Used for debugging—if set, processor executes only one instruction at a time

EIP (Extended Instruction Pointer)

- Contains the memory address of the next instruction to be executed
- If EIP contains wrong data, the CPU will fetch non-legitimate instructions and crash
- Buffer overflows target EIP

SIMPLE INSTRUCTIONS

Simple Instructions

- **mov destination, source**
  - Moves data from one location to another

- We use Intel format with destination first

- Remember indirect addressing
  - [ebx] means the memory location pointed to by EBX

`mov` Instruction Examples

Instruction	Description
`mov eax, ebx`	Copies the contents of EBX into the EAX register
`mov eax, 0x42`	Copies the value 0x42 into the EAX register
`mov eax, [0x4037C4]`	Copies the 4 bytes at the memory location 0x4037C4 into the EAX register
`mov eax, [ebx]`	Copies the 4 bytes at the memory location specified by the EBX register into the EAX register
`mov eax, [ebx+esi*4]`	Copies the 4 bytes at the memory location specified by the result of the equation `ebx+esi*4` into the EAX register

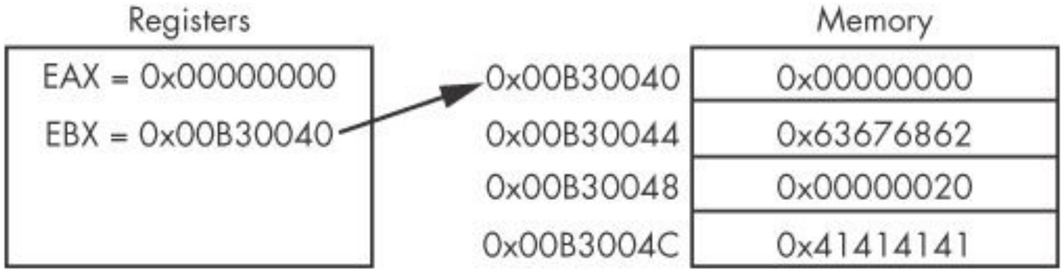
Load Effective Address (*lea*)

- lea destination, source
  - lea eax, [ebx+8]
  - Puts ebx + 8 into eax

- Compare
  - mov eax, [ebx+8]
  - Moves the data at location ebx+8 into eax

EBX Register Used to Access Memory

- EAX and EBX values (left)
- Information contained in memory (right)
- EBX is set to 0xB30040
- Value at 0xB30048 is 0x20
- `mov eax, [ebx+8]`
  - Puts 0x20 into EAX
- `lea eax, [ebx+8]`
  - Puts 0xB30048 into EAX



Arithmetic

- **sub** Subtracts
- **add** Adds
- **inc** Increments
- **dec** Decrements
- **mul** Multiplies
- **div** Divides

NOP

- Does nothing
- 0x90
- Commonly used as a **NOP Sled**
- Allows attackers to run code even if they are imprecise about jumping to it

The Stack

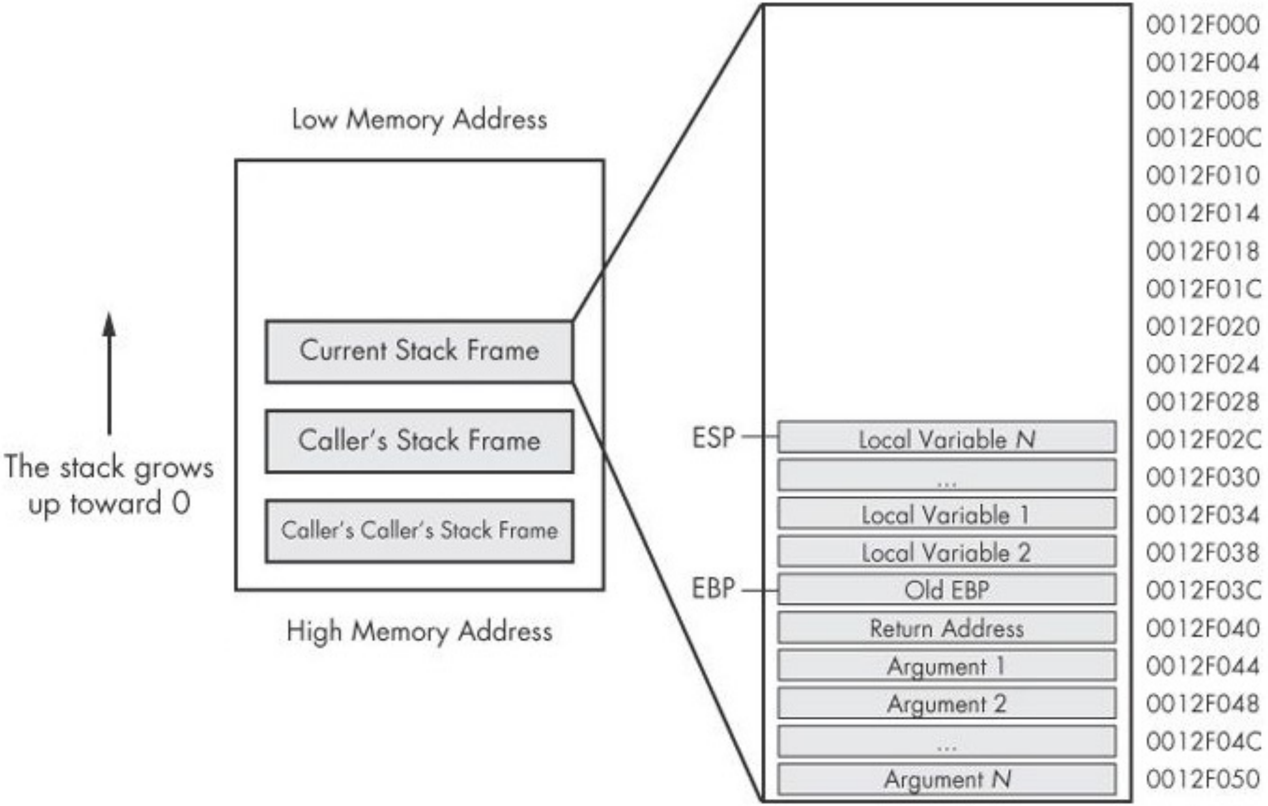
- Memory for functions, local variables, and flow control
- Last in, First out
- **ESP** (Extended Stack Pointer) – top of stack
- **EBP** (Extended Base Pointer) – bottom of stack
- **PUSH** puts data on the stack
- **POP** takes data off the stack
- **Other Stack Instructions**
  - To enter a function
    - Call or Enter
  - To exit a function
    - Leave or Ret

Function Calls

- Small programs that do one thing and return, like printf()
- ***Prologue***
  - Instructions at the start of a function that prepare stack and registers for the function to use
- ***Epilogue***
  - Instructions at the end of a function that restore the stack and registers to their state before the function was called

Stack Frames

- x86 stack layout



Conditionals and Brancing

- Conditional
  - test
    - Compares two values the way AND does, but does not alter them
    - `test eax, eax`
      - Sets Zero Flag if eax is zero
  - `cmp eax, ebx`
    - Sets Zero Flag if the arguments are equal
- Branching
  - jz loc
    - Jump to loc if the Zero Flag is set
  - jnz loc
    - Jump to loc if the Zero Flag is cleared

C Main Method

- Every C program has a main() function

- `int main(int argc, char** argv)`
    - **argc** contains the number of arguments on the command line
    - **argv** is a pointer to an array of names containing the arguments

Example

- cp foo bar
  - argc = 3
  - argv[0] = cp
  - argv[1] = foo
  - argv[2] = bar

END OF LECTURE. THANK YOU.