Reverse Engineering
In Computer Applications

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Chapter 1

1. Introduction

1.1 About the Course and Notes

The sole purpose of these lecture notes is to provide an aid to the high school students attending the HSSP course "C-01B Reverse Engineering in Computer Applications" taught during Spring 2001 at the Massachusetts Institute of Technology. The information presented hereby is on an "as-is" basis and the author cannot be possibly held liable for damages caused or initiated using methods or techniques described (or mentioned) in these notes. The reader should make sure to obey copyright laws and international treaties. No responsibility is claimed regarding the reliability and accuracy of the material discussed throughout the lectures.

1.2 Definitions

Programming language is a program that allows us to write programs and be understood by a computer. **Application** is any compiled program that has been composed with the aid of a programming language.

Reverse Engineering (RE) is the decompilation of any application, regardless of the programming language that was used to create it, so that one can acquire its source code or any part of it.

The reverse engineer can re-use this code in his own programs or modify an existing (already compiled) program to perform in other ways. He can use the knowledge gained from RE to correct application programs, also known as bugs. But the most important is that one can get extremely useful ideas by observing how other programmers work and think, thus improve his skills and knowledge!

Here are just a few reasons that RE exists nowadays and its usage is increasing each year:

- Personal education
- Understand and work around (or fix) limitations and defects in tools
- Understand and work around (or fix) defects in third-party products.
- Make a product compatible with (able to work with) another product.
- Make a product compatible with (able to share data with) another product.
- To learn the principles that guided a competitor's design.
- Determine whether another company stole and reused some of source code.
- Determine whether a product is capable of living up to its advertised claims.

Not all actions performed can be considered “legal”. Hence, extreme caution must be taken, not to violate any copyright laws or other treaties. Usually each product comes with a copyright law or license agreement.

1.3 Typical Examples

What comes in our minds when we hear RE, is **cracking**. Cracking is as old as the programs themselves. To crack a program, means to trace and use a serial number or any other sort of registration information, required for the proper operation of a program. Therefore, if a shareware program (freely distributed, but with some inconveniences, like crippled functions, nag screens or limited capabilities) requires a valid registration information, a reverse engineer can provide that information by decompiling a particular part of the program.

Many times in the past, several software corporations have accused others for performing RE in their products and stealing technology and knowledge. RE is not limited to computer applications, the same happens with car, weapons, hi-fi components etc.

All major software developers do have knowledge of RE and they try to find programmers that are familiar with the concepts that will be taught during this class. RE are well paid, sometimes their salaries are double or even more, depending on the skills they have.

1.3.1 Hacking

Hackers are able to penetrate into public or private servers and modify some of their parameters. This may sound exotic and rather difficult, but it is basically based on REing the operating system and seeking for vulnerabilities.

Consider a server which is located at the web address http://www.hackme.com/. When we log on this server with ftp, telnet, http, or whatever else this server permits for its users, we can easily find out what operating system is running on this server. Then, we reverse engineer the security modules of this operating system and we look for exploits.

An example is for Windows servers. A hacker reversed the run32.dll module and discovered that the variable, which determines the number of open Command Prompts, is a byte (can vary from 0 to 255). Therefore, if he could open 257 command prompt windows, we would crash the system! This vulnerability has been cured long time ago. The cures come with the form of “patches” or brand new releases. Each time a patch is created, old vulnerabilities vanish and new ones appear. As long as someone can find and exploit system’s flaws like this, there’ll always be hacking.

1.3.2 Hiding Information from Public

Companies are hiding a lot of things: their mistakes, security vulnerabilities, privacy violations and trade secrets. Usually, if someone finds out how a product works by reverse engineering, the product will be less valuable. Companies think they have everything to lose with reverse engineering. This may be true, but the rest of the world has much to gain.

Take for example the CueCat barcode scanner from Digital Convergence, which Radio Shack, Forbes and Wired Magazine have been giving away. It scans small bar codes found in magazines and catalogs into your computer, then sends you to a Web site, which gives you more information. Linux programmers, ever eager to get a new device to work with the Linux operating system, took the thing apart.

They reverse engineered the encoding the device used and found out how it worked. This allowed them to write their own applications for the device. One of the better applications was one that allowed you to create a card catalog for your home library. By scanning in the ISBN barcodes on the back of your books the application is able to download information from Amazon.com and build a database. So here we have someone building something new by stitching together the CueCat, Linux and Amazon.

Digital Convergence didn't like this at all. It wanted to be in control of the Web site you went to when you swiped a barcode. The company didn't like the fact that other people could write software for the device it was giving away and that they didn't make any money from that. It also didn't like the fact that, in the process of reverse engineering the CueCat, programmers discovered that every one of them has a unique serial number. These programmers later found out and publicized that this serial number is tied into the customer information you give when you register your CueCat on the Digital Convergence Web site. The end result is Digital Convergence can record every barcode swipe you make along with your customer information.

Reverse engineering allowed people to truly understand what the product was doing. This wasn't at all clear from information that Digital Convergence originally gave out.

Many of the privacy risks we face today such as the unique computer identification numbers in Microsoft Office documents, the sneaky collection of data by Real Jukebox, or the use of Web bugs and cookies to track users were only discovered

by opening up the hood and seeing how things really work. Companies do not publish this kind of information publicly.

Sometimes they even disavow that they meant to design and build their products to work way it ends up working. People engaged in reverse engineering are a check on the ability of companies to invade our privacy without our knowledge. By going public with the information they uncover they are able to force companies to change what they are doing lest they face a consumer backlash.

Uncovering security vulnerabilities is another domain where reverse engineers are sorely needed. Whether by poor design, bad implementation, or inadequate testing, products ship with vulnerabilities that need to be corrected. No one wants bad security, except maybe criminals, but many companies are not willing to put in the time and energy required to ship products without even well known classes of problems. They use weak cryptography, they don't check for buffer overflows, and they use things like cookies insecurely. Reverse engineers, who publicly release information about flaws, force companies to fix them, and alert their customers in a timely manner.

The only way the public finds out about most privacy or security problems is from the free public disclosures of individuals and organizations. There are privacy watchdog groups and security information clearinghouses but without the reverse engineers who actually do the research we would never know where the problems are.

There are some trends in the computer industry now that could eliminate the benefits reverse engineering has to offer. The Digital Millennium Copyright Act (DMCA) was used by the Motion Pictures Association of America (MPAA) to successfully stop 2600 Magazine from publishing information about the flawed DVD content protection scheme. The information about the scheme, which a programmer uncovered by reverse engineering, was now contraband. It was illegal under the DMCA.

Think about that. There are now black boxes, whether in hardware or software, that are illegal to peek inside. You can pay for it and use it, but you are not allowed to

open up the hood. You cannot look to see if the box violates your privacy or has a security vulnerability that puts you at risk.

Companies that make hardware and software products love this property and are going to build their products so that they fall under the protection of the DMCA. :CueCat did this when they built their product. They added a trivial encoding scheme, which they call encryption, so that their bar code scanner was protected against reverse engineering by the DMCA. We can expect to see many more companies do this.

1.3.3 Cell Phones

Cell phones run software. Their menus, functionality, problems and features are all the result of the software, which is usually stored in memory modules. Since we have to deal with software programs we can perform RE on them and seek for undocumented features and/or problems.

Take for example the NOKIA 5210 cell phone. The manufacturer claims that the security code is unbreakable. Once set, only a hard reset can unlock the phone. Wrong! In any locked cell phone type "*3001#12345#". A secret menu will pop-up and display among all the other interesting stuff, your security code. This is what the customer service is using to retrieve your lost security code.

Cool! But how could someone discover this secret sequence of numbers? It would take practically infinite number of random attempts to find something like this. Simple. Dump the software in computer disks (dumping is a common used procedure, see arcade coin-ups and emulators). Then RE the software and you'll find plenty of "secret" codes.

1.3.4 Computer Applications

Consider the game MineSweeper; it's been shipping with every windows version, from 3.0 to windows ME and windows XP (the newest upcoming version, formerly

known as Whistler). So, it's been over 10 years now that people have been playing MineSweeper. It's a really simple game with not much functionality (and literally no bugs). We all know that to play the game, we go to Programs, then Accessories, then Games and click on MineSweeper (it's where it usually resides, if it has been installed).

What most people don't know, or if they do, they don't really care, is that MineSweeper consists of two program files (let aside the help files). These two files are in Windows installation directory (usually named \Windows or \Winnt) and are "Winmine.exe" and "Winmine.ini". We do know that the .exe file is the executable (or main program) and the .ini file holds the settings. Let's take a close look in the .ini file. It looks like this:

```
[Minesweeper]
Difficulty=1
Height=16
Width=16
Mines=40
Mark=1
Color=1
Xpos=80
Ypos=76
Time1=999
Time2=999
Time3=999
Name1=Anonymous
Name2=Anonymous
Name3=Anonymous
```

We do understand most of the fields and we can guess about the rest. Now let's add some lines:

```
Menu=1
Sound=3
```

The line menu=1 will cause Minesweeper's menu disappear. The other line will force the game to play a little song when you win (number 3 varies, experiment with higher numbers). Also, there is another setting named "Tick" but I haven't discovered what it does yet ☺.

So, why is that? Why these undocumented functions? Here are a few reasons:

- These functions are **buggy**. If we can't correct a bug, let's force it out of our program.
- **Documentation**. For everything you create, however simple it may be, you MUST document it. That may be more difficult than creating the program itself and more time consuming. Now, try to explain why you can remove the menus from minesweeper.
- **User Interface**. You should add an option under a configuration menu that says "hide menus" and then implement a way to reveal them in case we need them again and blah blah blah... Time consuming, need programming, we can't afford it!
- **Useless**. Yes, it may be useless and pointless. So hide it. It might take more time to remove it from the actual program, so just make sure that the user won't be able to access this feature.
- **Marketing**. For marketing purposes, we want to maintain the simplicity of our programs.

And all these tricks come from a simple and innocent program. Can you imagine what is hidden in the whole operating system?

1.4 Requirements

Although it may sound difficult in the beginning, RE is actually simple and much simpler than creating a program. When one is programming, he has to invent, think and create. On the other hand, when decompiling a program, the engineer is just reading the programmer's thoughts and he tries to make sense out of them.

No programming experience is required. However, if programming experience exists, it will significantly help students to gain a better understanding of the subject. What is necessary for the needs of this class, if a general knowledge of any Windows Operating System (from version 3.0 to windows 2000, it really does not matter). Also, an Internet connection and an email account will prove valuable since a great deal of teaching material will be distributed via the Internet.

1.5 Scope

Our major goal will be the ability to RE any computer application and to be able to partially understand what happens in a program. Everyone should be able to perform RE techniques and achieve certain simple tasks. In particular we will focus on:

- The ins and outs of a computer
- How the OS (Operating System) works
- Analyze an executable file
- Assembly and Disassembling
- Commercial and Freeware Tools for RE
- Advanced techniques for RE

1.6 Ethics

Most commercial programs (if not all), are protected by copyright laws that prevent unauthorized usage, duplication or reproduction of the packages (including hard copies). This does NOT apply for reverse engineering the compiled code of these programs. In other words, one cannot possibly prevent users from reversing his program since there is no “regular” or “consistent” way to reverse a program.

For example, if one wants to make a copy of a program, then all he has to do is follow the instruction provided (officially) in his Operating System’s user manual, in the section titled “Copying files”. Also, he can use a program without paying it in whole.

Consider the case where you buy a program and you install it in your PC, in your friends' PCs and in your work's PC. The license usually is for a sole installation and not for multiple (although you can of course buy additional licenses). This is highly illegal!

But there are no manuals around that can tell you how to reverse engineer a program. The reason is that something generic is impossible. There are no recipes to RE a program (as we'll realize in the next few lectures). One could claim that the amount of techniques requires to reverse all existing programs is equal to the amount of programs you have!

To determine better the ethics behind RE copyrighted programs, we can consider the following: for what purpose do we want to RE a program? If our goal is to obtain knowledge by monitoring the behavior and the routines that make a program run then it's absolutely right. Sometimes, we might want to correct an annoying feature of a program or a bug. That's also acceptable. We should refrain from using these techniques for direct violation of the copyright laws, i.e. registering illegally a program without paying for a nominal user license.

1.7 Miscellaneous Information

The following links lead to useful content regarding the structure of the class and may help the reader to get the most out of this class. Please note that neither these notes of the content that can be obtained by the following links are intended to substitute the lectures. They just provide further help for those interested more.

- Information on this course is hosted in the following web site: http://www.technologismiki.com/fotis/
- The course's home page URL is: http://www.technologismiki.com/fotis/courses/reca/
- To contact the author, please use the following email address: mailto:fotis@technologismiki.com

- Hackman hex editor and disassembler (can be downloaded for free): http://www.technologismiki.com/hackman/

Chapter 2

2. Programming Processors

2.1 Programming Languages

There are many ways to program a processor. In this book, we'll refer only to Intel and Intel compatible (Cyrix, AMD) processors. In general, there are three language generations. Today, the most popular generation is the third. The following table summarizes some of the various existing languages. (Machine code is zero generation language, since it is not a language!)

Table 1: Various Language split according to their generation status.

Generation	Language
First	Assembly
Second	Fortran, C, Basic, Pascal, Cobol
Third	Visual C++, Visual Basic, Delphi

To distinguish second and third generation languages, one can think of various ways. The common element between third generation languages is that they support Object Oriented Programming (OOP) and the usage of objects. This makes them extremely flexible and powerful, thus enabling programmers to create applications with an attractive graphic interface quickly and easily.

It can be said that according to table 1, assembly is a primitive language, therefore almost obsolete. That is not true. Assembly will exist as long as processors exist. It allows direct communication with the processor, which in turn allows direct communication with all peripherals. Imagine that we make a program in Fortran. When we finish composing the source code, we have to compile it, in other words to create an executable, so that the operating system can execute our program.

The **compiler** is the external program, which translates our comprehensive source code, written in any language (2nd or 3rd generation) into machine code. Each language uses (obviously) a different compiler, but all programs eventually are converted into executable files.

No matter which language is being used to create a program, we can always **disassemble** the executable file, i.e. convert the executable code into comprehensive assembly code. The only problem is that assembly is a rather difficult language and processor dependent; therefore we need to learn many processor specific instructions and, of course, become familiar with the concepts of the assembly programming language. In general, this is very difficult and requires a lot of time and practice. However, it is very easy to learn how to "read" certain parts of a disassembled code and extract the information needed, then convert it into another language (or leave it as assembly code).

The only exceptions to the above rules are Java (we can get the source code in Java) and Visual Basic versions 2 and 3 (which had the source code stored in the executable file, hence the extraction was a simple task).

Table 2 lists some of the programming languages in ascending order regarding the statements needed per function point. Nowadays, there is a tendency of creating languages that do many functions in the background and facilitate the programmer. Languages with more statements per function point are more difficult to learn and use.. Note the places of C++ and Visual Basic.

So, if a particular program is to be created using assembly, we'll need 53 times more statements per function point than creating this program in VBA. The only question now is, can we do everything with VBA? It would be foolish if someone interested in creating a graph used assembly of fortran77. However, if you intend to directly access and change the memory location of a variable, then you just can't do it with any other programming language but assembly.

Table 2: Number of statements per function point for several languages.

Language	Statements per function point
Assembly	320
C	125
Fortran77	110
Cobol	90
Smalltalk	80
Lisp	65
C++	50
Oracle (databases)	40
Visual Basic	30
Perl	25
VBA	6

2.2 Processor Arithmetic

The only thing that a computer processor can understand is the switch. And we are talking about the simplest type of a switch, with just two positions: on and off. When the switch is set to on (or true) we have the value 1. Otherwise, the switch is set to the off position (or false) and we get the value 0.

This notation is great since it's so easy to understand. But it introduces some not so obvious problems. Let's see how computer understands our numbers. Since it has only two symbols (1 and 0) to represent everything, we can't use another number system other than the binary. So, to convert a number from binary to decimal, we have to do the following:

$01101 = 0x2^4 + 1x2^3 + 1x2^2 + 0x2^1 + 1x2^0 = 13.$

Note that the exponent starts counting from 0 from right to left and increases in steps of 1 for every digit. This can be extent for virtually any number of digits.

Each of the switches is a bit. So, it's easy to understand what 16-bit or 32-bit is. For 16-bit operating systems (such as windows 3.11) the largest number that we can have is a 16 digit number with all its digits set to 1 which is 65535. Even for 32-bit operating systems (windows 9x, NT, 2000, Me) the largest number is (signed) 2147483647, which is still too small.

The trick is to use an exponent. For numbers greater than 2.14 billion i.e. 10x200, the processor uses the number 200 which occupies 8 bits and the other 8 bits are used for the rest of the number. The same trick is used to represent real numbers (with a floating point).

- 21.4 can be written as .21400 002, where the last three digits are the exponent of 10. $.214x10^{2}=21.4$
- $5.5x10^{199}$ can be written as .55000 200 (note that the floating point is not used, since the first digit is considered to be 0 -> 0.55000 200 so we can safely remove 0. from each of these numbers).

This notation does not directly apply to computers, since as we said before, computers understand only 0 and 1. So, in order to force a processor understand the number 0.3 we have to declare it as a division:

- $0.3=\frac{3}{10}=\frac{00000011}{00001010}->0.010891...$ and the processor is **unable** to compute an equivalent to 0.3!
- for $0.375=\frac{3}{8}=\frac{00000011}{00001000}->0.011$, there is no problem.

The result of this notation, is that PC can't perform accurately even the easiest additions! Consider the following:

Basic Listing

```
Dim i
Dim Sum
For i=1 to 100
      Sum=Sum+1
Next i
```

C/C++ Listing

```
Int main()
{
      int i;
      double sum;
      for (i=1;i<100;i++)
            sum=sum+1;
      return 0;
}
```

Fortran Listing

```
DO 50 I=1,100,1
SUM=SUM+1
50 CONTINUE
```

No matter which programming language is used, the result is the same: **not 100!!** In fact, it'll be a number very close to 100, like 99.99999283 and if we round the number (we expect an integer) we get 100.

It is very difficult for humans to use another numbering system other than decimal. However, there is one more system, the hexadecimal, which is very useful, since it is divided by 8. The number 8 is the magic PC number. The bits are divided by 8 (8, 16, 32 and 64). The different numbers that can be represented by an 8-bit number are 256 (divided by 8), with 16 bit, 65536 (again divided by 8), etc.

The **hexadecimal** numbering system has 16 symbols, from 0 to 9 and from A to F. A is equal to 10, B to 11 and F to 15. Therefore, the number:

98DC in decimal is $9x16^3+8x16^2+13x16^1+12x16^0=39132$

Hexadecimal numbers are represented usually by an ampersand in front of them (Basic) or by the 0x symbol (C/C++):

0x18 is a hexadecimal number equal to 1x16+18=24 while
18 is a decimal number equal to 0x12.

Table 3: Hexadecimal to decimal and vice versa from 0 to 255.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**A**	**B**	**C**	**F**	**E**	**F**
0	0	1	2	3	4	5	6	7	8	9	19	11	12	13	14	15
1	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
3	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
4	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
5	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
6	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
7	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
8	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
9	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
A	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175
B	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
C	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
D	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223
E	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239
F	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255

Ex: 0xD6=214 and 102=0x66

2.3 Memory Structure

It is very essential that the concept of memory is understood at this particular point. There are three types of computer memory: the temporary physical (also known as RAM), the temporary virtual (the virtual memory page file) and the permanent physical (or storage – Hard disk drive).

So a processor can access its available temporary or permanent memory each time an instruction is executed. Hard disk drive can be considered as a huge RAM that is permanent, in terms of not getting wiped out when the system is reset. However the contents that are stored can be altered or wiped out without restrictions of any kind. In addition to this, modern motherboards come with EEPROM chipsets that provided ROM to the user. In these chips, the BIOS program is stored. Of course, EEPROM's contents can be changed sometimes (with some special instructions) and that makes them behave more than storage rather than physical memory unit.

Each time an application is loaded, it occupies some space in the available memory. If there is not enough available memory, then the application cannot be loaded. With the term application, we refer to any executable program (from the operating system to the device drivers). What may cause some confusion is the term "memory". Why shouldn't consider only the physical memory (usually 64 or 128 MB) as the only available memory source. Windows (and the other operating systems) have invented tricks to significantly increase the available physical memory, by taking advantage of some free hard disk space.

This is done via the virtual memory system. A file is created, named WIN386.SWP (which usually resides in the root directory) and is used as an extension to the existing physical memory. Physical memory can be considered as a hard disk with super fast access, where the OS can store and access variables and code. Therefore, when our physical memory is full and the OS uses the hard disk drive, we can experience delays in program execution (hard disk drive is much slower than the

physical memory) and hard disk activity without doing anything (some processes are active in the background even if we are not using our computer).

TIP: It is possible to determine the size of the available virtual memory through the control panel. Setting it 2.5 times the available physical and fixed to that size will increase our computer's performance.

2.3.1 Variables

The operating system and the applications use internally and between them, variables. These variables differ in content and type. They can be numbers (single, integer, double, float, etc), strings (single characters, long strings), Booleans and user-defined types. The point is that they contain different (in general) values and refer to different things.

These variables are stored in memory that is allocated to an application. Windows allocate 2 GB memory to any application. There is no erratum here; it's 2 GB although no application occupies that much space. The operating system automatically allocates enough space for these variables and is able to relocate them on demand. For example, an integer occupies 4 bytes while a long occupies 8 bytes and a char only 1.

We are particularly interested in variables, since all operations involve the usage of variables. In assembly, registers are used instead of variables; the logic remains however the same. Imagine the comparison routine. In most programming languages it is a statement like this:

```
[C++] IF (A==B) <do something>
          else <do something else>

[Basic] IF A=B then <do something> else <do something else>
```

In the above examples, A and B are variables. They may or may not be of the same type. Each language defines acceptable operations (i.e. compare integer with long).

2.3.2 Unicode Strings

In Win32 systems, strings (for reasons that are out of the course's scope) have changed internal format. With the term "internal format", we refer to the way the Operating System handles them. Throughout these notes, we'll be dealing with Unicode strings unless specifically told otherwise.

All ASCII searches for strings should be made with Unicode search option turned on in the hex editor (when this is available). The difference between ANSI and Unicode strings is that a null character (00) is inserted after each character. Therefore the string "ABC", which in hex is "585960", will be treated as "580059006000".

2.3.3 Pointers

If we define a variable A and we assign the value 5 to it, then we can be sure that each time we ask about the value of this variable, this will be 5, unless we change it. What we can't be sure of is the memory location of this variable. Take for example this piece of memory:

```
####################****################################
   ^           ^          ^          ^          ^
   0x4990      0x49A0     0x49B0     0x49C0     0x49D0
```

If we assume that the variable A is an integer, we can be sure that it'll occupy 4 bytes in the physical memory (RAM or virtual memory). Suppose that we could "see" (yes, it is possible) when in memory this variable resides. If we have 128 MB of Ram and variable A is somewhere in there, we can have a row of # as illustrated above,

where each # would represent a byte. At the address 0x49A4 is where we find the variable the first time we attempt to search for it.

Now, if we terminate the program, run it again and set the variable A equal to 5 as we did before and seek its location inside the physical memory, we'll discover that the location is completely different! The operating system obviously has used this location, which was free after the termination of the program, for another purpose and now it has allocated another memory space for our application and for this variable!

Why do we need to know the location in memory of a variable any time we run a program? Because, this way it is possible to overwrite this value we something else on the fly! Imagine playing Quake II. You are losing, since the available energy is 12. There is a variable that holds the energy. If you could only find that location where 12 is, you can switch to your debugger (Quake II stalls) and change this value to 150, then go back in the arena and kill 'em all!

We use pointers to retrieve the location in memory of a variable. Pointers exist in all major programming languages, either documented or undocumented. In C++ we use funny symbols like & in front of a variable to get its address. In Visual Basic we use the undocumented function VarPtr to get the pointer of a variable.

Chapter 3

3. Windows Anatomy

3.1 Windows API

Windows are revolutionary in personal computers. They brought multitasking and multiprocessing in our personal computers. We are now able to surf the Internet, listen to MP3 and use a word processor at the same time! Before this, there was the dark age of DOS (Disk Operating System), which was single tasking. One could run only one program at the time (ok, there were some TSR programs, but that's another story). So if you wanted to play a game and then write a document, you should terminate the game and run the word processor. There were many limitations of course in the hardware devices that were supported, Internet capabilities, available memory to programs, etc.

Windows brought the user close to the PC. And they did this by introducing an open architecture to the developers. Windows programmers have now common guidelines on how to create their programs. In DOS, each program had (if it had) a different user interface. Some used mouse, some didn't. Anyway, the similarities were few if any. Now with windows, no matter what application we are using, we expect certain features to exist and behave as expected. Consider the caption bar of any window, the click buttons, the check boxes etc.

Therefore, the user can easily control any windows application. But how is it possible that a programmer can use the same type of buttons (sometimes with slight variations)? Windows come with the API (Application Programming Interface), which consists of hundreds of functions, available to any windows program. Most of the API functions are coded in DLL (Dynamic Link Libraries) and the programmer can use them if he links his program to these DLLs.

The only problem is that, API changes since Windows change. New functions are introduced, bugs are fixed, old function become obsolete. For that reason, a program that worked well with Windows 95, may not work well or at all with Windows ME. API changes are available in three ways:

- Windows upgrades (i.e. Win 95 to Win 2000)
- Windows updates (i.e. Win 95 to Win 95b)
- Service packs (i.e. Win 2000 to Win 2000 sp1)

Detailed information about the API can be found in Microsoft Platform SDK web site (http://www.microsoft.com/msdownload/platformsdk/setuplauncher.asp). There you can download for free and use the latest edition of the platform SDK which includes detailed description of all the documented API functions (there are also undocumented API functions, reserved for Microsoft's reference only ☹)

Why are we interested in Windows API? Because all programs use some functions of the windows API. Each time a button is clicked, text is retrieved from a text box or a window is moved, a certain API function is executed. With the debugger we can set trap and intercept program's execution that lies between these functions, as we'll see later.

3.2 File System

In the beginning there was FAT (also known as FAT16). FAT was the file system used by DOS, Windows 3.x and Windows 95 first edition. Windows 95 second edition, Windows 98 and Windows 2000 can use FAT32 and FAT16. Windows NT4 and Windows 2000 can use NTFS (NT File System).

FAT stands for File Allocation Table. It resides in the hard disk and contains information that is used by the operating system to determine where in the hard disk is a particular file. A file can start at a location, then be interrupted and restart at another

location. A file like this is fragmented and when we defragment the hard disk, we join all the pieces of fragmented files like this.

To access (read or write) the hard drive (or the floppy disk, CD-Rom, DVD), a programmer has to resolve to windows API and perform this access via the operating system. However, certain operations (formatting illegally sectors, unmarking bad clusters, etc) require direct access. This is rather simple with assembly, under Win9x and Windows ME, VWIN32.VXD driver must be used or the equivalent direct access API under Windows NT and Windows 2000.

3.3 File Anatomy

Each file, no matter its contents, has a purpose. It may be an executable file, a media file (image, cursor, icon, sound, midi, etc), a text file, an application specific file (like Corel Draw file, Excel document, Powerpoint Presentation, etc) or anything else the user and programmer may want and need.

It is important and necessary that the Operating System is aware with which application it should process a certain file. The concept of file extensions (the part of the filename which comes after the fullstop) has been created to assist the OS and the users to identify a file. Consider the filename “mykids.jpg”. The extension jpg informs us that we should expect a JPEG image file, which should be processed by an image viewer/editor.

What happens if we change this extension from jpg to bmp? Sure they are both image files, but the operating system will *think* that this is a jpg file. It’s up to the application to understand that this file is not a bitmap, but a JPEG. Also, consider the following: the two files logo.sys, logos.sys and logow.sys are image files (the startup and shutdown logo screens in windows) and have the same extension with msdos.sys which is a text file. Still clever programs like ACDSee can identify that logo.sys is an image file, while msdos.sys is not. So there **has** to be something more.

Most of the files come with a header (apart from plain ASCII files). The header is a small part that resides in the beginning of the file and contains information regarding its contents. For example, every executable starts with MZ (Old DOS format) and contains a small loader that can operate in DOS. Thus, if we try to execute a windows file under DOS, an error message will appear, indicating “This program cannot be run in DOS mode” and inform the user that he should run the program in Windows.

3.3.1 File Header

The format of an operating system's executable file is in many ways a mirror of the operating system s built-in assumptions and behaviors. Although studying the ins and outs of an executable file format isn't something that usually appears high on most programmers' list of things to do, a great deal of useful knowledge about the operating system can be gleaned from doing this. Dynamic linking, loader behavior, and memory management are just three examples of operating system specifics that can be inferred by studying the executable format.

To understand how the Windows 9x, NT, 2000 or ME kernel works, you need to understand the PE format: It's that simple. And of course we **do** need to understand these kernels since we are going to be involved in reversing them!

It's common knowledge that Windows NT (the first of the Win32 operating systems) has a VAX VMS and UNIX heritage. Many of the key NT developers designed and coded for those platforms before coming to Microsoft. When it came time to design NT, it was only natural that they tried to minimize their bootstrap time by using previously written and tested tools. The executable and object module format that these tools produced and worked with is called **COFF** (Common Object File Format).

The relatively old (in computer years) nature of COFF can be seen in the fact that certain fields in the files are specified in octal format. The COFF format by itself was a good starting point, but needed to be extended to meet all the needs of a modern operating system such as Windows NT or Windows 95. The result of this updating is the

PE (remember, this stands for Portable Executable) format. It's called portable because all the implementations of NT on various platforms (Intel 386, MIPS, Alpha, Power PC, and so on) use the same executable format. Sure, there are differences in things such as the binary encoding of CPU instructions. You can't run a MIPS compiled PE executable on an Intel system. However, the important thing is that the operating system loader and programming tools don't have to be completely rewritten for each new CPU that arrives on the scene.

The strength of Microsoft's commitment to get Windows NT up and running quickly is evidenced by the fact that it abandoned existing Microsoft 32-bit tools and file formats. Virtual device drivers written for Windows 3.x were using a different 32-bit file layout (the LE format) long before NT appeared on the scene. In a testimonial to the "if it ain't broke, don't fix it" nature of Windows, Windows 95 uses both the PE format and the LE format. This allowed Microsoft to use existing Windows 3.x code in a big way.

Although it's reasonable to expect a completely new operating system (Windows NT, that is) to have a completely different executable format, it's a different story when it comes to object module (.OBJ and LIB) formats. Before Visual C++ 32-bit edition 1.0, all Microsoft compilers used the Intel OMF (Object Module Format) specification. The Microsoft compilers for Win32 implementations produce COFF format OBJ files. Some Microsoft competitors such as Borland have chosen to forego the COFF format OBJs and stick with the Intel OMF format. The result of this is that companies producing OBJs or LIBs for use with multiple compilers will need to go back to distributing separate versions of their products for different compilers (if they weren't already).

Those of you who like to read conspiracy into Microsoft's actions might see the decision to change OBJ formats as evidence of Microsoft trying to hinder its competitors. To claim true Microsoft "compatibility" down to the OBJ level, other vendors will need to convert all their 32-bit tools over to the COFF OBJ and LIB formats. In short, the OBJ and LIB file format can be viewed as yet another example of Microsoft abandoning existing standards in favor of something that suits it better.

3.3.2 Into PE Format

The PE format is documented (in the loosest sense of the word) in the WINNT. H header file, along with certain structure definitions for COFF format OBJs. (I'll be using the field names from WINNT. H later in the chapter.) About midway through WINNT.H is a section titled "Image Format." This section of the file starts out with small tidbits from the old familiar DOS MZ format and NE format headers before moving into the newer PE information. WINNT. H provides definitions of the raw data structures used by PE files, but contains only the barest hint of useful comments to explain what the structures and flags mean. The author of the header file for the PE format is certainly a believer in long, descriptive names, along with deeply nested structures and macros. When coding with WINNT. H, it's not uncommon to have expressions like this:

```
pNTHeader->OptionalHeader.DataDirectory[IMAGE_DIRECTORY_ENTRY_DEBUG].VirtualAddress;
```

Besides just reading about what PE files are composed of, you'll also want to dump out some PE files to see for yourself the concepts presented here. If you use Microsoft tools for Win32 development, the DUMPBIN program from Visual C++ and the Win32 SDK can dissect and output PE files and COFF OBJ/LIB files in human-readable form. DUMPBIN even has a nifty option to disassemble the code sections in the file it's taking apart. In light of Microsoft's claims that you're not allowed to disassemble its products, it's pretty interesting that it would provide a tool that makes it so easy to disassemble its programs and DLLs. If the ability to disassemble EXEs and OBJs wasn't useful, why would Microsoft have bothered to add this feature to DUMPBIN? It sure sounds like another case of "Do as we say, not as we do."

We'll use the term module to mean the code, data, and resources of an executable file or DLL that has been loaded into memory. Besides code and data that your program uses directly, a module is also composed of the supporting data used by Windows to determine where the code and data is located in memory.

In Win16, the supporting data structures are in the module database (the segment referred to by an HMODULE). In Win32, this information is kept in the PE header (the IMAGE_NT_HEADERS structure), which we'll explain in detail shortly.

The most important thing to know about PE files is that the executable file on disk is very similar to what the module will look like after Windows has loaded it. That's because the Windows loader doesn't need to work extremely hard to create a process from the disk file. Rather, the loader can take it easy and use Win32 memory mapped files to load the appropriate pieces of the PE file into a program's address space. To use a construction analogy, a PE file is like a prefabricated house: There are relatively few pieces, and each piece can be snapped into place with just a small amount of work. And, just as it's fairly easy to hook up the electricity and water connections in a prefab house, it's also a simple matter to wire a PE file up to the rest of the world (that is, connect it to its DLLs, and so on).

This same ease of loading applies to DLLs as well. Once an .EXE or .DLL module has been loaded, Windows can effectively treat it like any other memory-mapped file. This is in marked contrast to the situation in 16-bit Windows. The 16-bit NE file loader reads in portions of the file and creates separate data structures to represent the module in memory. When a code or data segment needs to be loaded, the loader has to allocate a new segment from the global heap, find where the raw data is stored in the executable file, seek to that location, read in the raw data, and apply any applicable fix-ups. In addition, each 16-bit module is responsible for remembering all the selectors it's currently using, whether the segment has been discarded, and so on.

For Win32, however, all the memory used by the module for code, data, resources, import tables, export tables, and other things is in one contiguous range of linear address space. All you need to know in this situation is the address where the loader mapped the executable file into memory. You can then easily find all the various pieces of the module by following pointers stored as part of the image.

Another idea you should be acquainted with before we start is the Relative Virtual Address, or RVA. Many fields in PE files are specified in terms of RVAs. An RVA is simply the offset of some item, relative to where the file is memory mapped to. For example, let's say the Windows loader mapped a PE file into memory starting at address 0x400000 in the virtual address space. If a certain table in the image starts at address 0x401464, the table's RVA is 0x1464:

(virtual address 0x401464)- (base address 0x400000) = RVA 0x1464

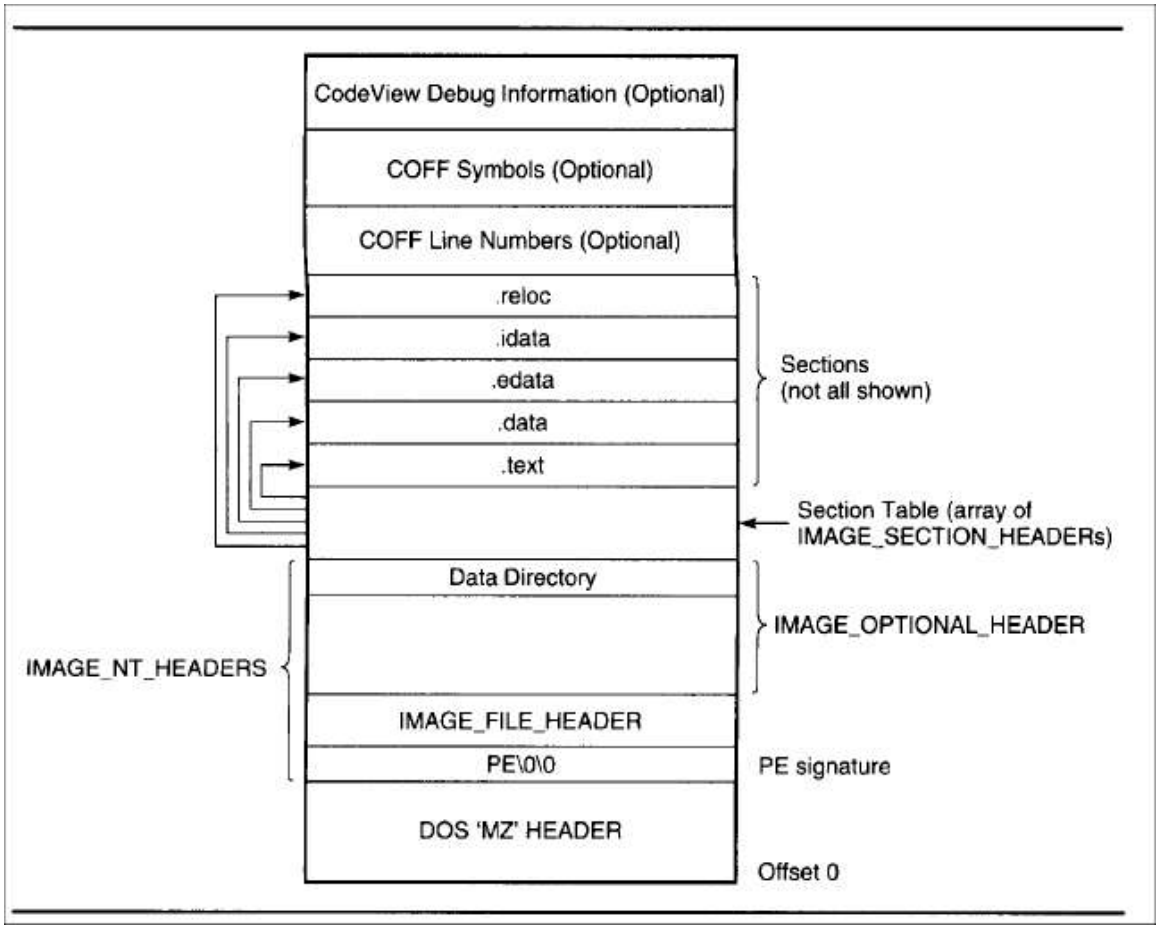
To convert an RVA into a usable pointer to memory, simply add the RVA to the base address where the module was loaded into. The term base address is another important concept to remember. A base address describes the starting address of a memory mapped EXE or DLL. For convenience, Windows NT and Windows 95 use the base address of a module as the module's instance handle (HINSTANCE). In Win32, calling the base address of a module an HINSTANCE is somewhat confusing, because the term instance handle comes from 16-bit Windows.

Each copy of an application in Winl6 gets its own separate data segment (and an associated global handle) that distinguishes it from other copies of the application; hence the term, instance handle. In Win32, applications don't need to be distinguished from one another because they don't share the same address space. Still, the term HINSTANCE persists to keep at least the appearance of continuity between Winl6 and Win32. What's important for Win32 is that you can call GetModuleHandle() for any DLL that your process uses, and get a pointer that you can use to access the module's components. By components, we refer to its imported and exported functions, its relocations, its code and data sections, and so on.

Another concept to be familiar with when investigating PE files and COFF OBJs is the section. A section in a PE file or COFF OBJ file is roughly equivalent to a segment or the resources in a 16-bit NE file. Sections contain either code or data. Some sections contain code or data that your program declared and uses directly, while other data sections are created for you by the linker and librarian, and contain information vital to

the operating system. In some of Microsoft's descriptions of the PE format, sections are also referred to as objects. This term has so many possibly conflicting meanings, however, that I'll stick to calling the code and data areas sections.

Before jumping into the details of the PE file, examine the figure below, which shows the overall layout of a PE file.



3.3.3 The PE Header

The first stop on our tour of the PE format is the PE header. Like all other Microsoft executable file formats, the PE file has a collection of fields at a known (or easy-to-find) location that define what the rest of the file looks like. The PE header contains vital pieces of information such as the location and size of the code and data

areas, what operating system the file is intended to be used with, and the initial stack size.

As with other executable formats from Microsoft, the PE header isn't at the very beginning of the file. Instead, the first few hundred bytes of the typical PE file are taken up by the DOS stub. This stub is a minimal DOS program that prints out something to the effect of "This program cannot be run in DOS mode." The intent is that if you run a Win32 program in an environment that doesn't support Win32, you'll get an informative (and frustrating) error message. When the Win32 loader memory maps a PE file, the first byte of the file mapping corresponds to the first byte of the DOS stub. That's right. With every Win32 program you start up, you get a complimentary DOS program loaded for free! (In Win16, the DOS stub isn't loaded into memory.)

As in other Microsoft executable formats, you find the real header by looking up its starting offset, which is stored in the DOS header. The WINNT.H file includes a structure definition for the DOS stub header that makes it very easy to look up where the PE header starts. The e_lfanew field is a relative offset (or RVA, if you prefer) to the actual PE header. To get a pointer to the PE header in memory, just add the field's value to the image base:

```
// Ignoring typecasts and pointer conversions for clarity...
pNTHeader = dosHeader + dosHeader->e_lfanew;
```

Once you have a pointer to the main PE header, the real fun begins. The main PE header is a structure of type IMAGE_NT_HEADERS, defined in WINNT. H. The IMAGE_NT_HEADERS structure in memory is what Windows 95 uses as its in-memory module database. Each loaded EXE or DLL in Windows 95 is represented by an IMAGE_NT_HEADERS structure. This structure is composed of a DWORD and two substructures, and is laid out as follows:

```
DWORD Signature;
IMAGE_FILE_HEADER FileHeader;
IMAGE_OPTIONAL_HEADER OptionalHeader;
```

The Signature field viewed as ASCII text is PE\0\0 (PE followed by two 0 bytes). If the e_lfanew field in the DOS header pointed to an NE signature at this location instead of a PE signature, you'd be working with a Win16 NE file. Likewise, an LE in the signature field would indicate a Virtual Device Driver (VxD) file. An LX here would be the mark of a file for Windows 95's arch rival, OS/2.

3.3.3.1 Image File Header

Following the PE signature DWORD in the PE header is a structure of type IMAGE_FILE_HEADER. The fields of this structure contain only the most basic information about the file. The structure appears to be unmodified from its original COFF implementations. Besides being part of the PE header, it also appears at the very beginning of the COFF OBJs produced by the Microsoft Win32 compilers. The fields of the IMAGE_FILE_HEADER follow.

WORD Machine

The CPU that this file is intended for. The following CPU IDs are defined:

CPU	Code
Intel I386	0x14C
Intel i860	0x14D
MIPS R3000	0x162
MIPS R4000	0x166
DEC Alpha AXP	0x184
Power PC	0x1F0 (little endian)
Motorola 68000	0x268
PA RISC	0x290

WORD NumberOfSections

The number of sections included in the EXE or OBJ.

DWORD TimeDateStamp

The time and date that the linker (or compiler for an OBJ file) produced this file. This field holds the number of seconds since December 31, 1969, at 4:00 P.M.

DWORD PointerToSymbolTable

The file offset of the COFF symbol table. This field is used only in OBJ files and PE files with COFF debug information. PE files support multiple debug formats, so debuggers should refer to the IMAGE_DIRECTORY_ENTRY_DEBUG entry in the data directory (defined later).

DWORD NumberOfSymbols

The number of symbols in the COFF symbol table. See the preceding field.

WORD SizeOfOptionalHeader

The size of an optional header that can follow this structure. In executables, it is the size of the IMAGE_OPTIONAL_HEADER structure that follows this structure. In OBJs, Microsoft says this field is supposed to always be 0. However, in dumping out the KERNEL32.LIB import library, there's an OBJ in there with a nonzero value in this field, so take their advice with a grain of salt.

WORD Characteristics

Flags that contain useful information about the file. Some important fields are described here (other fields are defined in WINNT. H):

Flag	Comment
0x0001	There are no relocations in this file.
0x0002	File is an executable image (that is, not a OBJ or LIB).
0x2000	File is a dynamic link library, not a program.

3.3.3.2 Image Optional Header

The third component of the PE header is a structure of type IMAGE_OPTIONAL_HEADER. For PE files, this portion certainly isn't optional. The COFF format allows individual implementations to define a structure of additional information beyond the standard IMAGE_FILE_HEADER. The fields in the IMAGE_OPTIONAL_HEADER are what the PE designers felt was critical information beyond the basic information in the IMAGE_FILE_HEADER.

All the fields of the IMAGE_OPTIONAL_HEADERS aren't necessarily critical for you to know. The more important ones are the ImageBase and the Subsystem fields. If you want, you can skim over or skip the following description of the fields.

WORD Magic

A signature WORD that identifies the state of the image file. The following values are defined:

Flag	Desciption
0x0107	A ROM Image
0x010B	A normal executable file (most files contain this value)

BYTE MajorL ink erVersion
BYTE MinorLinkerVersion

The version of the linker that produced this file. The numbers should be displayed as decimal values, rather than as hex. A typical linker version is 2.23.

DWORD SizeOfCode

The combined and rounded-up size of all the code sections. Usually, most files have only one code section, so this field typically matches the size of the .text section.

DWORD SizeOfinitializedData

This is supposedly the total size of all the sections that are composed of initialized data (not including code segments.) However, it doesn't seem to be consistent with the size of the initialized data sections in the file.

DWORD SizeOfUninitializedData

The size of the sections that the loader commits space for in the virtual address space, but that don't take up any space in the disk file. These sections don't need to have specific values at program startup, hence the term uninitialized *data.* Uninitialized data usually goes into a section called.

DWORD AddressOfEntry

The address where the image begins execution. This is an RVA, and usually can be found in the .text section. This field is valid for both EXEs and DLLs.

DWORD BaseOfCode

The RVA where the file's code sections begin. The code sections typically come before the data sections, and after the PE header in memory. This RVA is usually 0x1000 in Microsoft Link produced EXEs. Borland's TLINK32 typically has a value of 0x10000 in this field because it defaults to aligning objects on 64K boundaries, rather than 4K like the Microsoft linker.

DWORD BaseOfData

The RVA where the file's data sections begin. The data sections typically come last in memory, after the PE header and the code sections.

DWORD ImageBase

When the linker creates an executable, it assumes that the file will be memory mapped to a specific location in memory. That address is stored in this field. Assuming a load address allows linker optimizations to take place. If the file really is memory mapped to that address by the loader, the code doesn't need any patching before it can

be run. I'll talk more about this in the discussion of the base relocations. In NT 3.1 executables, the default image base was 0x10000.

For DLLs, the default was 0x400000. In Windows 95, the address 0x10000 can't be used to load 32-bit EXEs because it lies within a linear address region that's shared by all processes. Therefore, in Windows NT 3.5, Microsoft changed the default base address for Win32 Executables to 0x400000.

Older programs that were linked assuming a base address of 0x10000 will take longer to load under Windows 95 because the loader needs to apply the base relocations. I'll describe base relocations in detail later.

DWORD SectionAlignment

When mapped into memory, each section is guaranteed to start at a virtual address that's a multiple of this value. For paging reasons, the minimum section alignment is 0x1000, which is what the Microsoft linker uses by default. Borland C++'s TLINK defaults to 0x10000 (64KB).

DWORD FileAlignment

In the PE file, the raw data that comprises each section is guaranteed to start at a multiple of this value. The default value is 0x200 bytes, probably to ensure that sections always start at the beginning of a disk sector (which are also 0x200 bytes in length).

This field is equivalent to the segment/resource alignment size in NE files. Unlike NE files, PE files typically don't have hundreds of sections, so the space wasted by aligning the file sections is usually very small.

WORD Subsystem

The type of subsystem that this executable uses for its user interface. WINNT. H defines the following values:

Subsystem	Value	Comment
Native	1	Doesn't require a subsystem (for example, a device driver)
Windows_GUI	2	Runs in the Windows GUI subsystem
Windows_GUI	3	Runs in Windows character subsystem (console application)
OS2_GUI	5	Runs in the OS/2 character subsystem (OS/2 1.x only)
POSIX_GUI	7	Runs in the Posix character subsystem

WORD DllCharacteristics (marked as obsolete in NT 3.5)

A set of flags indicating which circumstances a DLL's initialization function (for example, DllMain()) will be called for. This value appears to always be set to 0, yet the operating system still calls the DLL initialization function for all four events. The following values are defined:

Value	Explanation
1	Call when DLL is first loaded into a process's address space
2	Call when a thread terminates
4	Call when a thread starts up
8	Call when DLL exits

DWORD SizeOfStackReserve

The amount of virtual memory to reserve for the initial thread's stack. Not all of this memory is committed, however (see the next field). This field defaults to 0x100000 (1MB). If you specify 0 as the stack size to CreateThread(), the resulting thread will also have a stack of this same size.

DWORD SizeOfStackCommit

The amount of memory that's initially committed for the initial thread's stack. This field defaults to 0x1000 bytes (1 page) in Microsoft Linkers, while TLINK32 sets it to 0x2000 bytes (2 pages).

DWORD SizeOfHeapReserve

The amount of virtual memory to reserve for the initial process heap. This heap's handle can be obtained by calling GetProcessHeap(). Not all of this memory is committed (see the next field).

DWORD SizeOfHeapCommit

The amount of memory initially committed in the process heap. The linker defaults to putting 0x1000 bytes in this field.

DWORD LoaderFlags (marked as obsolete in NT 3.5)

From WINNT. H, these appear to be fields related to debugging support. I've never seen an executable with either of these bits enabled, nor is it clear how to get the linker to set them. The following values are defined:

Value	Possible(!) Explanation
1	Invoke a breakpoint instruction before starting the process
2	Invoke a debugger on the process after it's been loaded

DWORD NumberOfRvaAndSizes

The number of entries in the DataDirectory array (see the following field description). This value is always set to 16 by the current tools.

IMAGE_DATA_DIRECTORY DataDirectory[IMAGE_NUMBEROF_DIRECTORY_ENTRIES]

An array of IMAGEDATA_DIRECTORY structures. The initial array elements contain the starting RVA and sizes of important portions of the executable file. Some elements at the end of the array are currently unused. The first element of the array is always the address and size of the exported function table (if present). The second array entry is the address and size of the imported function table, and so on. For a complete list of defined array entries, see the IMAGE_DIRECTORY_ENTRY_xxx #define's in WINNT. H.

The intent of this array is to allow the loader to quickly find a particular section of the image (for example, the imported function table), without needing to iterate through each of the image's sections, comparing names as it goes along.

Most array entries describe an entire section's data. However, the IMAGE_DIRECTORY_ENTRY_DEBUG element encompasses only a small portion of the bytes in the .rdata section. There's more information on this in "The .rdata section" portion of this chapter.

3.3.4 Section Table

Between the PE header and the raw data for the image's sections lies the section table. The section table contains information about each section in the image. The sections in the image are sorted by their starting address rather than alphabetically.

At this point, it would be worthwhile to clarify what a section is. In an NE file, your program's code and data are stored in distinct segments in the file. Part of an NE header is an array of structures, one for each segment your program uses. Each structure in the array contains information about one segment. The stored information includes the segment's type (code or data), its size, and its location elsewhere in the file. In a PE file, the section table is analogous to the segment table in the NE file.

Unlike an NE file segment table though, a PE section table doesn't store a selector value for each code or data chunk. Instead, each section table entry stores an address where the file's raw data has been mapped into memory. Although sections are analogous to 32-bit segments, they really aren't individual segments. Instead, a section simply corresponds to a memory range in a process's virtual address space.

Another way in which PE files diverge from NE files is how they manage the supporting data that your program doesn't use, but that the operating system does. Two examples are the list of DLLs that the executable uses and the location of the fix-up table. In an NE file, resources aren't considered to be segments.

Even though they have selectors assigned to them, information about resources isn't stored in the NE header's segment table. Instead, resources are relegated to a separate table toward the end of the NE header. Information about imported and exported functions also doesn't warrant its own segment, but is instead crammed into the confines of the NE header.

The story with PE files is different. Anything that might be considered vital code or data is stored in a full-fledged section. Thus, information about imported functions is stored in its own section, as is the table of functions that the module exports. The same is true for the relocation data. Any code or data that might be needed by either the program or the operating system gets its own section.

Immediately following the PE header in memory is an array of IMAGE_SECTION_HEADERs. The number of elements in this array is given in the PE header (the IMAGE NT HEADER.FileHeader.NumberOfSections field). The PEDUMP program outputs the section table and all of the section's fields and attributes.

```
01 .text VirtSize: 00005AFA VirtAddr: 00001000
raw data offs: 00000400 raw data size: 00005C00
relocation offs: 00000000 relocations: 00000000
line # offs: 00009220 line #'s: 0000020C
characteristics: 60000020
CODE MEM_EXECUTE MEM_READ

02 .bss VirtSize: 00001438 VirtAddr: 00007000
raw data offs: 00000000 raw data size: 00001600
relocation offs: 00000000 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: C0000080
UNINITIALIZED_DATA MEM_READ MEM_WRITE

03 .rdata VirtSize: 0000015C VirtAddr: 00009000
```

```
raw data offs: 00006000 raw data size: 00000200
relocation offs: 00000000 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: 40000040
INITIALIZED_DATA MEM_READ

04 .data VirtSize: 0000239C VirtAddr: 0000A000
raw data offs: 00006200 raw data size: 00002400
relocation offs: 00000000 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: C0000048
INITIALIZED_DATA MEM_READ MEM_WRITE

05 .idata VirtSize: 0000033E VirtAddr: 0000D000
raw data offs: 00008600 raw data size: 00000400
relocation offs: 00000000 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: C0000040
INITIALIZED DATA MEN_READ MEM_WRITE

06 .reloc VirtSize: 000006CE VirtAddr: 0000E000
raw data offs: 00008A00 raw data size: 00000800
relocation offs: 00000000 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: 42000040
INITIALIZED DATA MEM_DISCARDABLE MEM_READ

07 .drectve PhysAddr: 00000000 VirtAddr: 00000000
raw data offs: 000000DC raw data size: 00000026
relocation offs: 00000000 relocations: 00000000
line # offs: 00000080 line #'s: 00000000
characteristics: 00100A00
LNK_INFO LNK_REMOVE

08 .debug$S PhysAddr: 00000026 VirtAddr: 00000000
```

```
raw data offs: 00000102 raw data size: 000016D0
relocation offs: 000017D2 relocations: 00000032
line # offs: 00000080 line #'s: 00000000
characteristics: 42100048
INITIALIZED_DATA MEM_DISCARDABLE MEM_READ

09 .data PhysAddr: 000016F6 VirtAddr: 00000000
raw data offs: 000019C6 raw data size: 00000D87
relocation offs: 0000274P relocations: 00000045
line # offs: 00000000 line #'s: 00000000
characteristics: C0480048
INITIALIZED_DATA MEM_READ MEM_WRITE

10 .text PhysAddr: 0000247D VirtAddr: 00000000
raw data offs: 000029FF raw data size: 000010DA
relocation offs: 00003AD9 relocations: 000000E9
line # offs: 000043F3 line #'s: 000000D9
characteristics: 60500020
CODE MEM_EXECUTE MEM_READ

85 .debug$T PhysAddr: 00003557 VirtAddr: 00000000
raw data offs: 00004909 raw data size: 00000030
relocation offs: 00000008 relocations: 00000000
line # offs: 00000000 line #'s: 00000000
characteristics: 42]00048
INITIALIZED_DATA MEM_DISCARDABLE MEM_READ
```

Each IMAGE_SECTION_HEADER is a complete database of information about one section in the EXE or OBJ file, and has the following format:

BYTE Name[IMAGE_SIZEOF_SHORT_NAME]

This is an 8-byte ANSI name (not Unicode) that names the section. Most section names start with a . (a period; for example, .text), but this is *not* a requirement, in spite

of what some PE documentation would have you believe. You can name your own sections with either the segment directive in assembly language, or with #pragma data_seg and #pragma code_seg in the Microsoft C/C++ compiler. (Borland C++ users should use #pragma codeseg.) It's important to note that if the section name takes up the full 8 bytes, there is no NULL terminator byte. (TDUMP from Borland C++ 4.0x overlooked this fact, and would spew forth garbage on certain PE EXEs.) If you're a printf() devotee, you can use "%.8s" to avoid having to copy the name string to another buffer to null terminate it.

```
union {
DWORD PhysicalAddress
DWORD VirtualSize
} Misc;
```

This field has different meanings, depending on whether it occurs in an EXE or an OBJ. In an EXE, it holds the virtual size of the code or data section. This is the size before rounding up to the nearest file-alignment multiple. The SizeOfRawData field later on in the structure holds this rounded-up value. Interestingly, Borland's TLINK32 reverses the meaning of this field and the SizeOfRawData field, and appears to be the correct linker. For OBJ files, this field indicates the physical address of the section. The first section starts at address 0. To find the physical address of the next section, add the SizeOfRawData value to the physical address of the current section.

DWORD VirtualAddress

In EXEs, this field holds the RVA for where the loader should map the section to. To calculate the real starting address of a given section in memory, add the base address of the image to the section's VirtualAddress stored in this field. With Microsoft tools, the first section defaults to an RVA of 0xl000. In OBJs, this field is meaningless and is set to 0.

DWORD SizeOfRawData

In EXEs, this field contains the size of the section after it's been rounded up to the file-alignment size. For example, assume a file-alignment size of 0x200. If the

VirtualSize field says that the section is 0x35A bytes in length, this field will say that the section is 0x400 bytes long. In OBJs, this field contains the exact size of the section emitted by the compiler or assembler. In other words, for OBJs, it's equivalent to the VirtualSize field in EXEs.

DWORD PointerToRawData

This is the file-based offset to where the raw data for the section can be found. If you memory map a PE or COFF file yourself (rather than letting the operating system load it), this field is more important than the VirtualAddress field. That's because in this situation you'll have a completely linear mapping of the entire file, so you'll find the data for the sections at this offset rather than at the RVA specified in the VirtualAddress field.

DWORD PointerToRelocations

In OBJs, this is the file-based offset to the relocation information for this section. The relocation information for each OBJ section immediately follows the raw data for that section. In EXEs, this field (and the subsequent field) are meaningless, and are set to 0.

When the linker creates the EXE, it resolves most of the fix-ups, leaving only base address relocations and imported functions to be resolved at load time. The information about base relocations and imported functions is kept in the base relocation and imported functions sections, so there's no need for an EXE to have per-section relocation data following the raw section data.

DWORD PointerToLinenumbers

The file-based offset of the line number table. A line number table correlates source-file line numbers to the addresses where the code generated for a given line can be found. In modern debug formats like the CodeView format, line number information is stored as part of the debug information. In the COFF debug format, however, the line number information is conceptually distinct from the symbolic name/type information. Usually, only code sections (for example, .text or CODE) have line numbers. In EXE files,

the line numbers are collected toward the end of the file, after the raw data for the sections.

In OBJ files, the line number table for a section comes after the raw section data and the relocation table for that section. I'll discuss the format of line number tables in "The COFF Debug Information" section later in the chapter.

WORD NumberOfRelocations

The number of relocations in the relocation table for this section (the PointerToRelocations field listed previously). This field appears to be used only in OBJ files.

WORD NumberOfLinenumbers

The number of line numbers in the line number table for this section (the PointerToLinenumbers field listed previously).

DWORD Characteristics

What most programmers call *flags,* the COFF/PE format refers to as *characteristics.* This field is a set of flags that indicate the section's attributes (code/data, readable, writeable, and so on). For a complete list of all possible section attributes, see the IMAGE_SCN_XXX XXX #defines in WINNT. H.

Flag Usage

It's interesting to note what's missing from the information stored for each section. First, notice there's no indication of any PRELOAD attributes. The NE file format lets you specify a PRELOAD attribute for segments that should be loaded immediately at module load time. The OS/2 2.0 LX format has something similar, allowing you to specify that up to 8 pages should be preloaded. The PE format, on the other hand, has nothing like this. Based on this, we have to assume that Microsoft is confident in the performance of the demand-paged loading of their Win32 implementations. Also missing from the PE format is an intermediate page lookup table.

COFF flags	Explanation
0x00000020	Section contains code. Usually set in conjunction with the executable flag.
0x00000040	This section contains initialized data. Almost all sections except executable and the .bss section have this flag set.
0x00000080	This section contains uninitialized data (for example, the .bss section).
0x00000200	This section contains comments or some other type of information. A typical use of this section is the .drectve section emitted by the compiler, which contains commands for the linker.
0x00000800	This section's contents shouldn't be put in the final EXE file. This section is used by the compiler/assembler lo pass information to the linker
0x02000000	This section can be discarded, since it's not needed by the process once it's been loaded. The most common discardable section is the base relocations section (.reloc).
0x10000000	This section is shareable. When used with a DLL, the data in this section is shared among all processes using the DLL. The default is for data sections to be nonshared, meaning that each process using a DLL gets ils own separate copy of this section's data. In more technical terms, a shared section tells the memory manager to set the page mappings for this section so that all processes using the DLL refer to the same physical page in memory. To make a section shareable, use the SHARED attribute at link time. For example: LINK/SECTION:MYDATA, RWS ... tells the linker that the section called MYDATA should be readable, write able, and shared. By default, Borland C++ DLL data segments have the shared attribute.
0x20000000	This section is executable. This flag is usually set whenever the Contains Code flag (0x00000020) is set.
0x40000000	This section is readable. This flag is almost always set for sections in EXE flies.
0x80000000	The section is writeable. If this flag isn't set in an EXE's section, the loader should mark the memory-mapped pages as read-only or execute-only. Typical sections with this attribute are .data and .bss.

The equivalent of an IMAGE_SECTION_HEADER in the OS/2 LX format doesn't point directly to where the code or data for a section can be found in the file. Instead, an OS/2 LX file contains a page lookup table that specifies attributes and the location in the file of specific ranges of pages within a section.

The PE format dispenses with all that and guarantees that a section's data will be stored contiguously in the file. Of the two formats, the LX method may allow more flexibility, but the PE style is significantly simpler and easier to work with. Having written file dumpers and disassemblers for both formats, I can personally vouch for this!

Another welcome change in the PE format from the older NE format is that the locations of items are stored as simple DWORD offsets. In the NE format, the location of almost everything was stored as a sector value. To find the real file offset, you need to first look up the alignment unit size in the NE header, and convert it to a sector size (typically, 16 or 512 bytes). You then need to multiply the sector size by the specified sector offset to get an actual file offset.

If by chance something isn't stored as a sector offset in an NE file, it's probably stored as an offset relative to the NE header. Since the NE header isn't at the beginning of the file, you need to drag around the file offset of the NE header in your code. In contrast, PE files specify the location of various items by using simple offsets relative to where the file was memory mapped to. All in all, the PE format is much easier to work with than the NE, LX, or LE formats (assuming you can use memory mapped files).

3.3.5 Commonly Encountered Sections

Now that we've got an overall picture of what sections are and how they're located, we can discuss more about the common sections we'll find in EXE and OBJ files. Although this list of sections is by no means complete, it does include the sections you encounter every day (even if you're not aware of it). The sections are presented in order of their importance and by how frequently they're likely to be encountered.

The .text section

The .text section is where all general-purpose code emitted by the compiler or assembler ends up. Since PE files run in 32-bit mode and aren't restricted to 16-bit segments, there's no reason to break up the code from separate source files into separate sections. Instead, the linker concatenates all the .text sections from the various OBJs into one big .text section in the EXE.

If you use Borland C++ the compiler emits its code to a segment named CODE. Thus, PE files produced with Borland C++ have a section named CODE, rather than a .text section. I was surprised to find out that there was additional code in the .text section beyond what I created with the compiler or used from the runtime libraries. In a PE file, when you call a function in another module (for example, GetMessage() in USER32.DLL), the CALL instruction emitted by the compiler doesn't transfer control directly to the function in the DLL. Instead, the call instruction transfers control to a JMP DWORD PTR [XXXXXXXX] instruction that's also in the .text section. The JMP instruction jumps to an address stored in a DWORD in the .idata section. This .idata section DWORD contains the real address of the operating system function entry point.

After contemplating this for awhile, I came to understand why calls to DLLs are implemented this way. By funneling all calls to a given DLL function through one location, there's no longer any need for the loader to patch every instruction that calls a DLL. All the PE loader has to do is put the correct address of the target function into the DWORD in the .idata section. No CALL instructions need to be patched.

This is markedly different from NE files, where each segment contains a list of fixups that need to be applied to the segment. If the segment calls a given DLL function 20 times, the loader must copy the function's address into that segment 20 times. The downside to the PE method is that you can't initialize a variable with the true address of a DLL function. For example, you'd think that something like:

```
FARPROC pfnGetMessage = GetMessage;
```

would put the address of GetMessage into the variable pfnGetMessage. In Win16, this works, but in Win32 it doesn't. In Win32, the variable pfnGetMessage ends up holding the address of the JMP DWORD PTR [XXXXXXXX] thunk in the .text section that I mentioned earlier. If we wanted to call through the function pointer, things would work as we'd expect. If we want to read the bytes at the beginning of GetMessage(), however, we're out of luck (unless we do additional work to follow the .idata "pointer" ourselves).

After Visual C++ 2.0 was released; it introduced a new twist to calling imported functions. If we look in the system header files from Visual C++ 2.0 (for example, WINBASE.H), we'll see a difference from the Visual C++ 1.0 headers. In Visual C++ 2.0, the operating system function prototypes in the system DLLs include a __declspec(dllimport) as part of their definition. The __declspec(dllimport) turns out to have quite a useful effect when calling imported functions. When we call an imported function prototyped with __ declspec(dllimport), the compiler doesn't generate a call to a JMP DWORD PTR [XXXXXXXX] instruction elsewhere in the module. Instead, the compiler generates the function call as CALL DWORD PTR [XXXXXXXX].

The .data section

Just as .text is the default section for code, the .data section is where your initialized data goes. Initialized data consists of global and static variables that are initialized at compile time. It also includes string literals (for example, the string "Hello World" in a C/C++ program). The linker combines all the .data sections from the OBJ and LIB files into one .data section in the EXE. Local variables are located on a thread's stack and take no room in the .data or .bss sections.

The DATA section

Borland C++ uses the name DATA for its default data section. This is equivalent to the .data section for Microsoft's compiler (see the previous section, "The .data section").

The .bss section

The .bss section is where any uninitialized static and global variables are stored. The linker combines all the .bss sections in the OBJ and LIB files into one .bss section in the EXE. In the section table, the RawDataOffset field for the .bss section is set to 0, indicating that this section doesn't take up any space in the file. TLINK32 doesn't emit a .bss section. Instead, it extends the virtual size of the DATA section to account for uninitialized data.

The .CRT section

The .CRT section is another initialized data section used by the Microsoft C/C++ runtime libraries (hence the name .CRT). The data in this section is used for things such as calling the constructors of static C++ classes before main or WinMain is invoked.

The .rsrc section

The .rsrc section contains the resources for the module. In the early days of NT, the .RES file output of the 16-bit RC.EXE wasn't in a format that the Microsoft linker could understand. The CVTRES program converted these .RES files into a COFF format OBJ, placing the resource data into a .rsrc section within the OBJ. The linker could then treat the resource OBJ as just another OBJ to link in, which meant the linker didn't have to "know" anything special about resources. More recent linkers from Microsoft appear to be able to process the .RES files directly.

The section

The .idata section contains information about functions (and data) that the module imports from other DLLs. This section is equivalent to an NE file's module reference table. A key difference is that each function that a PE file imports is specifically listed in this section. To find the equivalent information in an NE file, you'd have to go digging through the relocations at the end of the raw data for each of the segments.

The .edata section

The .edata section is a list of the functions and data that the PE file exports for use by other modules. Its NE file equivalent is the combination of the entry table, the resident names table, and the nonresident names table. Unlike in Winl6, there's seldom

a reason to export anything from an EXE file, so you usually see only .edata sections in DLLs. The exception to this is EXEs produced by Borland C++, which always appear to export a function (__GetExceptDLLinfo) for internal use by the runtime library.

When using Microsoft tools, the data in the .edata section comes to the PE file via the .EXP file. Put another way, the linker doesn't generate this information on its own. Instead, it relies on the library manager (LIB32) to scan the OBJ files and create the .EXP file that the linker adds to its list of modules to link. Yes, that's right! Those pesky .EXP files are really just OBJ files with a different extension.

The .reloc section

The .reloc section holds a table of *base relocations.* A base relocation is an adjustment to an instruction or initialized variable value; an EXE or a DLL needs this adjustment if the loader couldn't load the file at the address where the linker assumed it would be. If the loader can load the image at the linker's preferred base address, the loader ignores the relocation information in this section.

If you want to take a chance and hope that the loader can always load the image at the assumed base address, you can use the/FIXED option to tell the linker to strip this information. Although this might save space in the executable file, it might also cause the executable to not work on other Win32 platforms. For example, let's say you built an EXE for NT and based the EXE at 0x10000. If you told the linker to strip the relocations, the EXE wouldn't run under Windows 95, where the address 0x10000 isn't available (the minimum load address in Windows 95 is 0x400000; that is, 4MB).

It's important to note that the JMP and CALL instructions generated by a compiler use offsets relative to the instructions, rather than actual offsets in the 32-bit fiat segment. If the image needs to be loaded somewhere other than the location the linker assumed was a base address, these instructions don't need to change, since they use relative addressing. As a result, there are not as many relocations as you might think. Relocations are usually needed only for instructions that use a 32-bit offset to some data. For example, let's say you had the following global variable declarations:

```
int i;
int *ptr = &i;
```

If the linker assumed an image base of 0x10000, the address of the variable i will end up containing something like 0x12004. At the memory used to hold the pointer ptr, the linker will have written out 0x12004, since that's the address of the variable i. If the loader (for whatever reason) decided to load the file at a base address of 0x70000, the address of i would then be 0x72004. However, the pre-initialized value of the ptr variable would then be incorrect because i is now 0x60000 bytes higher in memory.

This is where the relocation information comes into play. The .reloc section is a list of places in the image where the difference between the linker-assumed load address and the actual load address needs to be taken into account. I'll talk more about relocations in the "PE File Base Relocations" section.

The .tls section

When you use the compiler directive "__declspec(thread)", the data that you define doesn't go into either the .data or .bss sections. Rather, a copy of it ends up in the .tls section. The .tls section derives its name from the term *thread local storage,* and is related to the TlsAlloc() family of functions.

To briefly summarize thread local storage, think of it as a way to have global variables on a per-thread basis. That is, each thread can have its set of static data values, yet the code that uses the data does so without regard to which thread is executing. Consider a program that has several threads working on the same task, and thereby executing through the same code. If you declared a thread local storage variable, for instance:

```
__declspec (thread) int i = 0:
// This is a global variable declaration.
```

each thread would transparently have its own copy of the variable i. It's also possible to explicitly ask for and use thread local storage at run-time by using the TlsAlloc,

TlsSetValue, and TlsGetValue functions. In most cases, it's much easier to declare your data in your program with __declspec (thread) than it is to allocate memory on a per-thread basis and store a pointer to the memory in a TlsAlloc()'ed slot.

There's one unfortunate note that must be added about the .tls section and __declspec(thread) variables. In NT and Windows 95, this thread local storage mechanism won't work in a DLL if the DLL is loaded dynamically by LoadLibrary(). In an EXE or an implicitly loaded DLL, everything works fine. If you can't implicitly link to the DLL, but need per-thread data, you'll have to fall back to using TlsAlloc() and TlsGetValue() with dynamically allocated memory.

It's important to note that the actual per-thread memory blocks aren't stored in the .tls section at runtime. That is, when switching threads, the memory manager doesn't change the physical memory page that's mapped to the module's .tls section. Instead, the .tls section is merely the data used to initialize the actual per-thread data blocks. The initialization of per-thread data areas is a cooperative effort between the operating system and the compiler runtime libraries. This requires additional data - -the TLS directory - - that's stored in the .rdata section.

The .rdata section

The .rdata section is used for at least four things. First, in EXEs produced by Microsoft Link, the .rdata section holds the debug directory (there is no debug directory in OBJ files). In TLINK32 EXEs, the debug directory is in a section named .debug. The debug directory is an array of IMAGE_DEBUG_DIRECTORY structures. These structures hold information about the type, size, and location of the various types of debug information stored in the file. Three main types of debug information can appear: CodeView, COFF, and FPO.

The debug directory isn't necessarily found at the beginning of the .rdata section. Instead, to find the start of the debug directory, you have to use the RVA found in the seventh entry (IMAGE_DIRECTORY_ENTRY_DEBUG) of the data directory. (The

data directory is at the end of the PE header portion of the file.) To determine the number of entries in a Microsoft Link debug directory, divide the size of the debug directory (found in the size field of the data directory entry) by the size of an IMAGE_DEBUG_DIRECTORY structure.

In contrast, TLINK32 emits an actual count of the debug directories in the size field, not the total length in bytes. The second useful portion of an .rdata section is the description string. If you specified a DESCRIPTION entry in your program's .DEF file, the specified description string appears in the .rdata section. In the NE format, the description string is always the first entry of the nonresident names table. The description string is intended to hold a useful text string describing the file.

Unfortunately, I haven't discovered an easy way to find it. I've seen PE files that had the description string before the debug directory, and other files that had it after the debug directory. I'm not aware of any consistent method of finding the description string (or even to determine if it's present at all). A third use of the .rdata section is for GUIDs used in OLE programming.

The UUID.LIB import library contains a collection of 16-byte GUIDs that are used for things such as interface IDs. These GUIDs end up in the EXE or DLL's .rdata section. The final use of the .rdata section that I'm aware of is as a place to put the TLS (Thread Local Storage) directory. The TLS directory is a special data structure used by the compiler runtime library to transparently provide thread local storage for variables declared in program code.

under Specs: Portable Executable and Common Object File Format. Of primary interest in the TLS directory are pointers to the start and end of a copy of the data to be used to initialize each thread local storage block. An RVA for the TLS directory can be found in the IMAGE_DIRECTORY_ENTRY_TLS entry in the PE header's data directory. The actual data to be used for TLS block initialization is found in the .tls section (described earlier).

3.3.6 PE File Imports

Earlier, we saw how function calls to outside DLLs don't call the DLL directly. Instead, the CALL instruction goes to a JMP DWORD PTR [XXXXXXXX] instruction somewhere in the executable's .text section (or .icode section if you're using Borland C++ 4.0). Alternatively, if __ declspec(dllimport) was used in Visual C++, the function call becomes a "CALL DWORD PTR [XXXXXXXX]". In either case, the address that the JMP or CALL instruction looks up is stored in the .idata section. The JMP or CALL instruction transfers control to that address, which is the intended target address.

Before it's loaded into memory, the information stored in a PE file's .idata section contains the information necessary for the loader to determine the addresses of the target functions and patch them into the executable image. After the .idata section has been loaded, it contains pointers to the functions that the EXE/DLL imports. Note that all the arrays and structures I'm discussing in this section are contained in the .idata section.

The .idata section (or *import table,* as I prefer to call it) begins with an array of IMAGE_IMPORT_DESCRIPTOR's. There is one IMAGE_IMPORT_DESCRIPTOR for each DLL that the PE file implicitly links to. No count is kept to indicate the number of structures in this array. Instead, the last element of the array is indicated by a final IMAGE_IMPORT_DESCRIPTOR that has fields filled with NULLs. The format of an IMAGE_IMPORT_DESCRIPTOR is as follows:

```
DWORD Charachteristics/OriginalFirstThunk
```

This field is an offset (an RVA) to an array of DWORDs. Each of these DWORDs is actually an IMAGE_THUNK_DATA union. Each IMAGE_THUNK_DATA DWORD corresponds to one function imported by this EXE/DLL.

If you run the BIND utility, this array of DWORDS is left alone, whereas the FirstThunk DWORD array (described momentarily) is modified.

DWORD TimeDateStamp

The time/date stamp indicating when the file was built. This field normally contains 0. However, the Microsoft BIND utility updates this field with the time/date stamp of the DLL that this IMAGE_IMPORT_DESCRIPTOR refers to.

DWORD ForwarderChain

This field relates to forwarding, which involves one DLL forwarding references to one of its functions to another DLL. For example, in Windows NT, KERNEL32.DLL forwards some of its exported functions to NTDLL.DLL. An application may think it's calling a function in KERNEL32.DLL, but it actually ends up calling into NTDLL.DLL. This field contains an index into the FirstThunk array (described momentarily). The function indexed by this field will be forwarded to another DLL. Unfortunately, the format of how a function is forwarded is just barely described in the Microsoft documentation.

DWORD Name

This is an RVA to a null-terminated ASCII string containing the imported DLL's name (for example, KERNEL32.DLL or USER32.DLL).

PIMAGE_THUNK_DATA FirstThunk;

This field is an offset (an RVA) to an array of IMAGE_THUNK_DATA DWORDs. In most cases, the DWORD is interpreted as a pointer to an IMAGE_IMPORT_BY_NAME structure. However, it's also possible to import a function by ordinal value. The important parts of an IMAGE_IMPORT_DESCRIPTOR are the imported DLL name and the two arrays of IMAGE_THUNK_DATA DWORDs. Each IMAGE_THUNK_DATA DWORD corresponds to one imported function. In the EXE file, the two arrays (pointed to by the Characteristics and FirstThunk fields) run parallel to each other, and are terminated by a NULL pointer entry at the end of each array. Why are there two parallel arrays of pointers to the IMAGE_THUNK_DATA structures? The first array (the one pointed to by the Characteristics field) is left alone and is never modified. It's sometimes called the

hint-name table. The second array (pointed to by the FirstThunk field in the IMAGE_IMPORT_DESCRIPTOR) is overwritten by the PE loader. The loader iterates through each IMAGE_THUNK_DATA and finds the address of the function that it refers to. The loader then overwrites the IMAGE_THUNK_DATA DWORD with the address of the imported function.

Earlier, we mentioned that CALLs to DLL functions go through a "JMP DWORD PTR [XXXXXXXX]" thunk. The [XXXXXXXX] portion of the thunk refers to one of the entries in the FirstThunk array. Since the array of IMAGE_THUNK_DATAs that's overwritten by the loader eventually holds the addresses of all the imported functions, it's called the "Import Address Table."

Since the import address table is usually in a writeable section, it's relatively easy to intercept calls that an EXE or a DLL makes to another DLL. You simply patch the appropriate import address table entry to point to the desired interception function. There's no need to modify any code in either the caller or callee images. This capability can be very useful.

It's interesting to note that in Microsoft-produced PE files, the import table isn't wholly synthesized by the linker. Instead, all the pieces necessary to call a function in another DLL reside in an import library. When you link a DLL, the library manager (LIB.EXE) scans the OBJ files being linked and creates an import library. This import library is different from the import libraries used by 16-bit NE file linkers. The import library that the 32-bit LIB produces has a .text section and several .idata$ sections. The .text section in the import library contains the JMP DWORD PTR [XXXXXXXX] thunk that I mentioned earlier. That thunk has a name stored for it in the OBJ's symbol table. The name of the symbol is identical to the name of the function being exported by the DLL (for example, _DispatchMessage@4).

One of the .idata$ sections in the import library contains the DWORD that the thunk dereferences through. Another of the .idata$ sections has a space for the "hint ordinal" followed by the imported function's name. These two fields make up an

IMAGE_IMPORT_BY_NAME structure. When you later link a PE file that uses the import library, the import library's sections are added to the list of sections from your OBJs that the linker needs to process. Since the thunk in the import library has the same name as the function being imported, the linker thinks the thunk is really the imported function, and fixes up calls to the imported function to point at the thunk. The thunk in the import library is essentially seen as the imported function.

Besides providing the code portion of an imported function thunk, the import library provides the pieces of the PE file's .idata section (or import table). These pieces come from the various .idata$ sections that librarian put into the import library. In short, the linker doesn't really know the differences between imported functions and functions that appear in a different OBJ file. The linker just follows its preset rules for building and combining sections, and everything falls into place naturally.

3.3.7 PE File Exports

The opposite of importing a function is exporting a function for use by EXEs or other DLLs. APE file stores information about its exported functions in the .edata section. Generally, Microsoft LINK-produced PE EXE files don't export anything, so they don't have an .edata section. TLINK32 EXEs, on the other hand, usually export one symbol, so they do have an .edata section. Most DLLs export functions and have an .edata section. The primary components of an .edata section (a.k.a. the export table) are tables of function names, entry point addresses, and export ordinal values.

In an NE file, the equivalents of an export table are the entry table, the resident names table, and the nonresident names table. In the NE file, these tables are stored as part of the NE header rather than in segments or resources. At the beginning of an .edata section is an IMAGE_EXPORT_DIRECTORY structure. This structure is immediately followed by the data pointed to by fields in the IMAGE_EXPORT_DIRECTORY structure. An IMAGE_EXPORT_DIRECTORY looks like this:

DWORD Characteristics

This field appears to be unused and is always set to 0.

DWORD TimeDateStamp

The time/date stamp indicating when this file was created.

WORD MajorVersion

WORD MinorVersion

These fields appear to be unused and are set to 0.

DWORD Name

The RVA of an ASCIIZ string with the name of this DLL (for example, MYDLL.DLL).

DWORD Base

The starting export ordinal number for functions exported by this module. For example, if the file exported functions with ordinal values of 10, 11 and 12, this field would contain 10.

DWORD NumberOfFunctions

The number of elements in the AddressOfFunctions array. This value is also the number of functions exported by this module. Usually this value is the same as the NumberOfNames field (see the next description), but they can be different.

DWORD NumberOfNames

The number of elements in the AddressOfNames array. This value contains the number of functions exported by name, which usually (but not always) matches the total number of exported functions.

PDWORD *AddressOfFunctions

This field is an RVA and points to an array of function addresses. The function addresses are the entry-point RVAs for each exported function in this module.

PDWORD *AddressOfNames

This field is an RVA and points to an array of string pointers. The strings contain the names of the functions exported by name from this module.

PWORD *NumberOfNameOrdinals

This field is an RVA, and points to an array of WORDs. The WORDs are essentially the export ordinals of all the functions exported by name from this module. However, don't forget to add the starting ordinal number specified in the Base field (described a few fields back). The layout of the export table is somewhat odd. As I mentioned earlier, the requirements for exporting a function are an address and an export ordinal.

Optionally, if you export the function by name, there will be a function name. You'd think that the designers of the PE format would have put all three of these items into a structure and then have an array of these structures. Instead, you have to look up the various pieces in three separate arrays. The most important of the arrays pointed to by the IMAGE_EXPORT_DIRECTORY is the array pointed to by the AddressOfFunctions field. This is an array of DWORDs, each DWORD containing the address (RVA) of an imported function. The export ordinal for each exported function corresponds to its position in the array. For instance (assuming ordinals start at 1), the address of the function with export ordinal 1 would have its address in the first element of the array. The function with export ordinal 2 would have its address in the second element of the array, and so on.

There are two important things to remember about the AddressOf-Functions array. First, the export ordinal needs to be biased by the value in the Base field of the IMAGE_EXPORT_DIRECTORY. If the Base field contains the value 10, then the first

DWORD in the AddressOfFunctions array corresponds to export ordinal 10, the second entry to export ordinal 11, and so forth.

The other thing to remember is that the export ordinals can have gaps. Let's say that you explicitly export two functions in a DLL, with ordinal values 1 and 3. Even though you exported only two functions, the AddressOfFunctions array has to contain three elements. Any entries in the array that don't correspond to an exported function contain the value 0.

When the Win32 loader fixes up a call to a function that's imported by ordinal, it has very little work to do. The loader simply uses the function's ordinal value as an index into the target module's AddressOfFunctions array. Of course, the loader also has to take into account that the lowest export ordinal may not be 1, and must adjust its indexing appropriately.

More often than not, Win32 EXEs and DLLs import functions by name rather than by ordinal. This is where the other two arrays pointed to in the IMAGE_EXPORT_DIRECTORY structure come into play. The AddressOfNames and AddressOfNameOrdinals arrays exist to allow the loader to quickly find the export ordinal corresponding to a given function name. The AddressOfNames and AddressOfNameOrdinals arrays both A d d r e s s O f N a m e O r d i n a l s contain the same number of elements (given by the NumberOfNames field of the IMAGE_EXPORT_DIRECTORY). The AddressOfNames array is an array of pointers to function names, and the AddressOfNameOrdinals array is an array of indexes into the AddressOfFunctions array.

Let's see how the Win32 loader would fix up a call to a function that's imported by name. First, the loader would search the strings pointed to in the AddressOfNames array. Let's say it finds the string it's looking for in the third element. Next, the loader would use the index it found to look up the corresponding element in the AddressOfNameOrdinals array (in this case, the third element). This array is just a collection of WORDs, with each WORD acting as an index into the AddressOfFunctions

array. The final step is to take the value in the AddressOfNameOrdinals array and use it as an index into the AddressOfFunctions array.

Incidentally, if you dump out the exports from the system DLLs (for example, KERNEL32.DLL and USER32.DLL), you'll see that in many cases two functions differ only by one character at the end of the name, for instance, CreateWindowExA and CreateWindowExW. This is how Unicode support is implemented "transparently." The functions that end with A are the ASCII (or ANSI) compatible functions; those ending in W are the Unicode version of the function. In your code, you don't explicitly specify which function to call. Instead, the appropriate function is selected in WINDOWS.H with preprocessor #ifdefs. The following excerpt from the NT WINDOWS.H is an example of how this works:

```
#ifdef UNICODE
#define DefWindowProc DefWindowProcW
#else
#define DefWindowProc DefWindowProcA
#endif                          //                          !UNICODE
```

Chapter 4

4. Basic Concepts of Assembly

4.1 Registers

You can consider a register as a variable inside the CPU (Central Processing Unit). That depicts registers so close. There are several registers exist in PC:

AX, BX, CX, DX, CS, DS, ES, SS, SP, BP, SI, DI, Flags, and **IP**

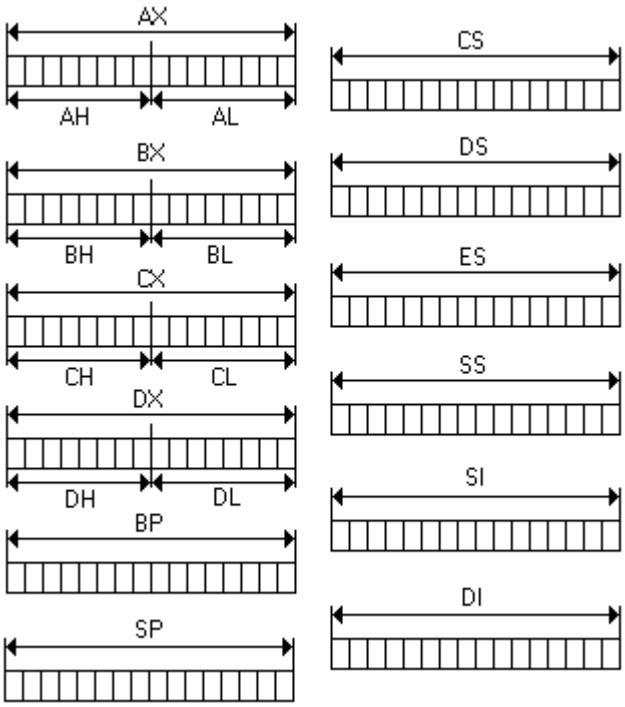
They are all 16-bits. You can treat it as if they are word (or unsigned integer) variables. However, each register has its own use.

- AX, BX, CX, and DX are **general purpose registers**. They can be assigned to any value you want. Of course you need to adjust it into your need.
    - AX is usually called **accumulator register**, or just accumulator. Most of arithmetical operations are done with AX. Sometimes other general purpose registers can also be involved in arithmetical operation, such as DX.
    - The register BX is usually called **base register**. The common use is to do array operations. BX is usually worked with other registers, most notably SP to point to stacks.
    - The register CX is commonly called **counter register**. This register is used for counter purposes. That's why our PC can do looping.
    - DX register is the **data register**. It is usually for reserving data value.
- The registers CS, DS, ES, and SS are called **segment registers**. You may not fiddle with these registers. You can only use them in the correct ways only.
    - CS is called **code segment register**. It points to the segment of the running program. We may NOT modify CS directly.

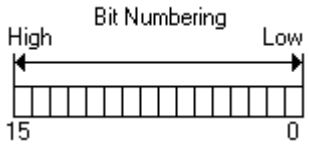
  - DS is called **data segment register**. It points to the segment of the data used by the running program. You can point this to anywhere you want as long as it contains the desired data.
  - ES is called **extra segment register**. It is usually used with DI and doing pointers things. The couple DS:SI and ES:DI are commonly used to do string operations.
  - SS is called **stack segment register**. It points to stack segment.
- The register SI and DI are called **index registers**. These registers are usually used to process arrays or strings.
  - SI is called **source index** and DI is **destination index**. As the name follows, SI is always pointed to the source array and DI is always pointed to the destination. This is usually used to move a block of data, such as records (or structures) and arrays. These registers are commonly coupled with DS and ES.
- The register BP, SP, and IP are called **pointer registers**.
  - BP is **base pointer**, SP is **stack pointer**, and IP is **instruction pointer**. Usually BP is used for preserving space to use local variables. SP is used to point the current stack. Although SP can be modified easily, you must be cautious. It's because doing the wrong thing with this register could cause your program to crash. IP denotes the current pointer of the running program. It is always coupled with CS and it is NOT modifiable. So, the couple of CS:IP is a pointer pointing to the current instruction of running program. You cannot access CS or IP directly.
- The **flag** register is used to store the current status of the processor. It holds the value of which the programmers may need to access. This involves detecting whether the last arithmetic holds zero result or may be overflow. You can only modify flag from stack.

The general registers AX, BX, CX, and DX are 16-bit. However, they are composed from two smaller registers. For example: AX. **The high 8-bit** is called AH, and **the low 8-bit** is called AL. Both AH and AL can be accessed directly. However,

since they altogether embodied AX, modifying AH is modifying the high 8-bit of AX. Modifying AL is modifying the low 8-bit of AX.



Bit numbering of a register begins from the lower part. The lowest bit is numbered as bit 0, the highest bit is numbered as bit 15. So, there are 16 bits. Therefore, AL occupy bit 0 to bit 7 of AX, AH occupy bit 8 to bit 15 of AX.



Note that x386 processors introduce extended registers. Most of the registers, except segment registers are enhanced into 32-bit. So, we have extended registers EAX, EBX, ECX, and so on. AX is only the low 16-bit (bit 0 to 15) of EAX. BX is only the low 16-bit (bit 0 to 15) of EBX and so on. There is no special direct access to the upper 16-bit (bit 16 to 31) in extended register. Segment registers are not extended. There are no ECS, or EDS or so.

4.2 Flag

Flag is actually 16-bit register that contains processor status. Intel doesn't provide a direct access to it; it is accessed via stack (Via POPF and PUSHF). However, for some reason you can then access flag using the assembly instruction SAHF and LAHF for just some flag attributes. You can access each flag attribute by using bitwise AND operation since each status is mostly represented by just 1 bit. Here's the flag layout:

- C denotes carry flag (bit 0). It is turned to 1 whenever the last arithmetical operation, such as adding and subtracting, has “carry” or “borrow,” otherwise 0. DOS often uses this to indicate errors.
- P denotes parity flag (bit 2). Rarely used. It will set to 1 if the last operation (any operation) results even number of bit 1. It is usually used in communication things.
- A denotes auxiliary flag (bit 4). Rarely used. It is set in Binary Coded Decimal (BCD) operations.
- Z denotes zero flag (bit 6). Usually used to detect whether the last operation (any operation) holds zero result.
- S denotes sign flag (bit 7). It is often used to detect whether the last operation holds negative result. It is set to 1 if the highest bit (bit 7 in bytes, or bit 15 in words) of the last operation is 1.
- T denotes trap flag (bit 8). It is only used in debuggers to turn on the step-by-step feature.
- I denotes interrupt flag (bit 9). It is used to toggle the interrupt enable or not. If the bit is set (= 1), then the interrupts are enabled, otherwise disabled. The default is on.
- D denotes interrupt flag (bit 10). It is used for directions of string operations. If the bit is set, then all string operations are done backward. Otherwise, forward. The default is forward (= 0).

- O denotes the overflow flag (bit 11). It is used to detect whether the last arithmetic operation result has overflowed or not. If the bit is set, then it has been an overflow.
- IOPL denotes the I/O Privilege Level flag (bit 12 to 13). It is used to denote the privilege level of the running programs. It is rarely used in real mode programming. This flag exists in 286 or better CPUs.
- N denotes the Nested Task flag (bit 14) this flag is exist on 286 or better CPU. This is to detect whether it has been multiple task (or exceptions) occur. Rarely used in practical programming.
- Upon the most often used flag is O, D, I, S, Z, and C.

386 or better CPUs has enhanced the flag into 32-bit. The logic however remains the same. We won't get involved in the 32-bit flag system, since it would be far out of our scope.

4.3 Memory

Of course the program's code (code) is placed in the memory. The memory is actually numbered as the address, starting from 0, 1, 2, until everything has been mapped. To address data in the memory, CPU uses registers. Originally, CPU only has 16-bit registers, so the maximum amount of memory that can be addressed is 2^{16} = 65536 (64K). However, after XT arrives, the memory is extended to 1 MB. That is 16 times bigger than the original.

Unfortunately, the CPU still has 16 bit registers which is, in fact, cannot handle all the memory. Engineers had to get around with this and the technique called **segmentation** was invented. That means the memory is divided virtually into several areas called **segment**.

Upon the arrival of segmentation, the segment registers appeared in order to corporate the idea. The segment registers are 16 bit, too. The idea of the segmentation

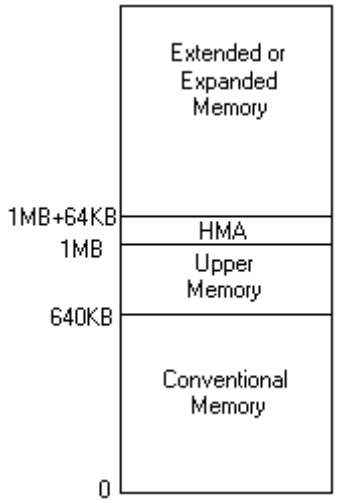
is NOT dividing 1 MB into 16 exact parts. This means that segment registers are only allowed to have the value of 0 to 15, and this only uses 4 bits.

If the segment number is 0, then we can access the memory 0 to 65536. Segment number 1 allows us to access memory number 16 to 65552. Segment 2 from 32 to 65568, and so on **with the increment of 16**. It is obvious that all 1 MB of the memory is addressable. Why did they do that? It is for the sake of the operating system memory management stuff. DOS aligns the executed code to the nearest 16 bytes alignment.

The memory access must be done in a pair of register. The first is the segment register and next is any register, usually BX, DX, SI or DI. The register pair usually written like this: ES:DI with a colon between them. The pair is called the **segment:offset** pair. So, ES:DI means that the segment part is addressed by ES, and the offset part is addressed by DI.

If the ES contains 0, and DI is 5, means that we access the memory 5. If ES:DI = 0001:0005 then it actually access the actual address 21 (1 * 16 + 5 = 21). Remember the interleaving mentioned above. So, 0000:0021 and 0001:0005 is actually the same address. How could the processor do that? The register pair segment:offset contains the **logical address**. The actual address or the **absolute address** needs to be calculated from the logical address. Since the increment of the interleaving is 16, then we need to multiply the segment value with 16 first, then add it with the offset part.

Usually programmers refer the memory 0 to 640 KB as the **low memory**. Sometimes it is called **conventional memory**. The area above the first 640 KB up to 1 MB is called **upper memory**. Then the 64KB after the border of 1 MB is called **high memory area (HMA)**. Above this point it is either **extended** or **expanded memory**.



Nowadays, the difference between extended memory and expanded memory is not too clear. It fully depends on the driver. `HIMEM.SYS` provide access to extended memory. `EMM386.EXE`, `QEMM`, `386MAX`, or so provides the access to expanded memory. Programmers usually prefer expanded memory to extended, because operations made in the expanded memory are faster.

4.4 Stacks

When the OS loads the program code into memory, a specific amount of memory is reserved in order to make the program run as expected. Each program memory mode behaves differently. However, there is one thing: there must be a room for the code itself, then there must be room for data, and the last thing is there must be room for the **stack**.

The stack is like a temporary area to store things needed in the near future (while the program is running). It is mainly used to pass the parameter value to procedures or functions. Sometimes, it also acts as temporary space for allocating local variables. Hence, the role of the stack is very important.

It works exactly as the stack in linked list! The last item pushed into stack is going to be popped first. LIFO (Last In First Out) concept works here. At this moment,

you don't have to know how stack works in depth. The main thing is that you know that stack here uses the LIFO concept, but it is **NOT a linked list**.

Adjusting stacks, involves reserving as much memory as needed for stack. If you use many parameters in your procedure or functions, you need to reserve bigger stack. Usually 2 KB or 4 KB is enough for many programs. However, if you use a lot of local variables, you need to reserve more.

4.5 Interrupts

The Interrupt is like its name: it interrupts. Basically, it interrupts processes. Upon the request of an interrupt, the processor usually **stores only the CS:IP and flag** state of the running program, then it goes to the interrupt routine. After processing the interrupt, the processor restores all states stored and resumes the program execution. There are three kinds of interrupts: hardware (other than CPU) interrupts, software interrupts, and CPU-generated interrupts.

Hardware interrupts occur if one of the hardware devices inside the computer requires immediate processing. Delaying the process could cause unpredictable, or even, catastrophic effects. Keyboard interrupt is one example. If you press a key in your keyboard, you generate an interrupt. Keyboard chips notify the processor that they have a character to send. Can you imagine if the processor ignores the request and go on? Your key is never processed!

Software interrupts occur if the running program requests the program to be interrupted and do something else. It is usually like waiting the user input from keyboard, or may be request the graphic driver to initialize itself to graphic screen.

CPU-generated interrupts occurs if the processor knows that is something wrong with the running code. It is usually directed for crash protection. If your program contains instructions that processor doesn't know, the processor interrupts your program. It also happens if you divide a number with 0 (divide by zero error).

Interrupts have a lot of uses and in general, they ease the programmers' lives, since they handle certain priority events, like changing into graphic screen, waiting for a key, accessing files, disks and so on are done through interrupts.

Chapter 5

5. Assembly Commands

In this chapter, we'll discuss several technical details of the most important assembly commands for the reverse engineer. Note, that this information has been taken from Hackman Disassembler. For a complete and up-to-date assembly instructions reference, please use Hackman Disassembler. The commands follow in no particular order.

5.1 CMP: Compare Two Operands

5.1.1 Description

Compares the first source operand with the second source operand and sets the status flags in the EFLAGS (refers to the extended Flags, for a brief description of how flags work, please review 4.2) register according to the results. The comparison is performed by subtracting the second operand from the first operand and then setting the status flags in the same manner as the SUB instruction. When an immediate value is used as an operand, it is sign-extended to the length of the first operand.

The CMP instruction is typically used in conjunction with a conditional jump (Jcc), condition move (CMOVcc), or SETcc instruction. The condition codes used by the Jcc, CMOVcc, and SETcc instructions are based on the results of a CMP instruction.

5.1.2 Operation

Below, there is a pseudo code fragment to demonstrate how the CPU behaves upon the execution of a CMP command:

```
temp -> SRC1 - SignExtend(SRC2);
```

ModifyStatusFlags; (* Modify status flags in the same manner as the SUB instruction*)
The SUB instruction is described later in this chapter.

5.1.3 Opcode Instruction Description

3C ib CMP AL, imm8 Compare imm8 with AL
3D iw CMP AX, imm16 Compare imm16 with AX
3D id CMP EAX, imm32 Compare imm32 with EAX
80 /7 ib CMP r/m8, imm8 Compare imm8 with r/m8
81 /7 iw CMP r/m16, imm16 Compare imm16 with r/m16
81 /7 id CMP r/m32,imm32 Compare imm32 with r/m32
83 /7 ib CMP r/m16,imm8 Compare imm8 with r/m16
83 /7 ib CMP r/m32,imm8 Compare imm8 with r/m32
38 / r CMP r/m8,r8 Compare r8 with r/m8
39 / r CMP r/m16,r16 Compare r16 with r/m16
39 / r CMP r/m32,r32 Compare r32 with r/m32
3A / r CMP r8,r/m8 Compare r/m8 with r8
3B / r CMP r16,r/m16 Compare r/m16 with r16
3B / r CMP r32,r/m32 Compare r/m32 with r32

5.2 J cc: Jump if Condition Is Met

5.2.1 Description

Checks the state of one or more of the status flags in the EFLAGS register (CF, OF, PF, SF, and ZF) and, if the flags are in the specified state (condition), performs a jump to the target instruction specified by the destination operand. A condition code (cc) is associated with each instruction to indicate the condition being tested for. If the condition is not satisfied, the jump is not performed and execution continues with the instruction following the Jcc instruction.

The target instruction is specified with a relative offset (a signed offset relative to the current value of the instruction pointer in the EIP register). A relative offset (rel8, rel16, or rel32) is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed, 8-bit or 32-bit immediate value, which is added to the instruction pointer. Instruction coding is most efficient for offsets of –128 to +127. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s, resulting in a maximum instruction pointer size of 16 bits.

The conditions for each Jcc mnemonic are given in the “Description” column of the table on the preceding page. The terms “less” and “greater” are used for comparisons of signed integers and the terms “above” and “below” are used for unsigned integers.

Because a particular state of the status flags can sometimes be interpreted in two ways, two mnemonics are defined for some opcodes. For example, the JA (jump if above) instruction and the JNBE (jump if not below or equal) instruction are alternate mnemonics for the opcode 77H. The Jcc instruction does not support far jumps (jumps to other code segments). When the target for the conditional jump is in a different segment, use the opposite condition from the condition being tested for the Jcc instruction, and then access the target with an unconditional far jump (JMP instruction) to the other segment. For example, the following conditional far jump is illegal:

```
JZ FARLABEL;
```

To accomplish this far jump, use the following two instructions:

```
JNZ BEYOND;
JMP FARLABEL;
BEYOND:
```

The JECXZ and JCXZ instructions differ from the other Jcc instructions because they do not check the status flags. Instead they check the contents of the ECX and CX

registers, respectively, for 0. Either the CX or ECX register is chosen according to the address-size attribute. These instructions are useful at the beginning of a conditional loop that terminates with a conditional loop instruction (such as LOOPNE). They prevent entering the loop when the ECX or CX register is equal to 0, which would cause the loop to execute 2 32 or 64K times, respectively, instead of zero times. All conditional jumps are converted to code fetches of one or two cache lines, regardless of jump address or cacheability.

5.2.2 Operation

Below, there is a pseudo code fragment to demonstrate how the CPU behaves upon the execution of a J xx command:

```
IF condition
THEN
EIP ¬ EIP + SignExtend(DEST);
IF OperandSize = 16
THEN
EIP ¬ EIP AND 0000FFFFH;
FI;
FI;
```

5.2.3 Opcode Instruction Description

77 cb JA rel8 Jump short if above (CF=0 and ZF=0)

73 cb JAE rel8 Jump short if above or equal (CF=0)

72 cb JB rel8 Jump short if below (CF=1)

76 cb JBE rel8 Jump short if below or equal (CF=1 or ZF=1)

72 cb JC rel8 Jump short if carry (CF=1)

E3 cb JCXZ rel8 Jump short if CX register is 0

E3 cb JECXZ rel8 Jump short if ECX register is 0

74 cb JE rel8 Jump short if equal (ZF=1)

7F cb JG rel8 Jump short if greater (ZF=0 and SF=OF)

7D cb JGE rel8 Jump short if greater or equal (SF=OF)

7C cb JL rel8 Jump short if less (SF<>OF)

7E cb JLE rel8 Jump short if less or equal (ZF=1 or SF<>OF)

76 cb JNA rel8 Jump short if not above (CF=1 or ZF=1)

72 cb JNAE rel8 Jump short if not above or equal (CF=1)

73 cb JNB rel8 Jump short if not below (CF=0)

77 cb JNBE rel8 Jump short if not below or equal (CF=0 and ZF=0)

73 cb JNC rel8 Jump short if not carry (CF=0)

75 cb JNE rel8 Jump short if not equal (ZF=0)

7E cb JNG rel8 Jump short if not greater (ZF=1 or SF<>OF)

7C cb JNGE rel8 Jump short if not greater or equal (SF<>OF)

7D cb JNL rel8 Jump short if not less (SF=OF)

7F cb JNLE rel8 Jump short if not less or equal (ZF=0 and SF=OF)

71 cb JNO rel8 Jump short if not overflow (OF=0)

7B cb JNP rel8 Jump short if not parity (PF=0)

79 cb JNS rel8 Jump short if not sign (SF=0)

75 cb JNZ rel8 Jump short if not zero (ZF=0)

70 cb JO rel8 Jump short if overflow (OF=1)

7A cb JP rel8 Jump short if parity (PF=1)

7A cb JPE rel8 Jump short if parity even (PF=1)

7B cb JPO rel8 Jump short if parity odd (PF=0)

78 cb JS rel8 Jump short if sign (SF=1)

74 cb JZ rel8 Jump short if zero (ZF = 1)

0F 87 cw/cd JA rel16/32 Jump near if above (CF=0 and ZF=0)

0F 83 cw/cd JAE rel16/32 Jump near if above or equal (CF=0)

0F 82 cw/cd JB rel16/32 Jump near if below (CF=1)

0F 86 cw/cd JBE rel16/32 Jump near if below or equal (CF=1 or ZF=1)

0F 82 cw/cd JC rel16/32 Jump near if carry (CF=1)

0F 84 cw/cd JE rel16/32 Jump near if equal (ZF=1)

0F 84 cw/cd JZ rel16/32 Jump near if 0 (ZF=1)

0F 8F cw/cd JG rel16/32 Jump near if greater (ZF=0 and SF=OF)

0F 8D cw/cd JGE rel16/32 Jump near if greater or equal (SF=OF)

0F 8C cw/cd JL rel16/32 Jump near if less (SF<>OF)

0F 8E cw/cd JLE rel16/32 Jump near if less or equal (ZF=1 or SF<>OF)

0F 86 cw/cd JNA rel16/32 Jump near if not above (CF=1 or ZF=1)

0F 82 cw/cd JNAE rel16/32 Jump near if not above or equal (CF=1)

0F 83 cw/cd JNB rel16/32 Jump near if not below (CF=0)

0F 87 cw/cd JNBE rel16/32 Jump near if not below or equal (CF=0 and ZF=0)

0F 83 cw/cd JNC rel16/32 Jump near if not carry (CF=0)

0F 85 cw/cd JNE rel16/32 Jump near if not equal (ZF=0)

0F 8E cw/cd JNG rel16/32 Jump near if not greater (ZF=1 or SF<>OF)

0F 8C cw/cd JNGE rel16/32 Jump near if not greater or equal (SF<>OF)

0F 8D cw/cd JNL rel16/32 Jump near if not less (SF=OF)

0F 8F cw/cd JNLE rel16/32 Jump near if not less or equal (ZF=0 and SF=OF)

0F 81 cw/cd JNO rel16/32 Jump near if not overflow (OF=0)

0F 8B cw/cd JNP rel16/32 Jump near if not parity (PF=0)

0F 89 cw/cd JNS rel16/32 Jump near if not sign (SF=0)

0F 85 cw/cd JNZ rel16/32 Jump near if not zero (ZF=0)

0F 80 cw/cd JO rel16/32 Jump near if overflow (OF=1)

0F 8A cw/cd JP rel16/32 Jump near if parity (PF=1)

0F 8A cw/cd JPE rel16/32 Jump near if parity even (PF=1)

0F 8B cw/cd JPO rel16/32 Jump near if parity odd (PF=0)

0F 88 cw/cd JS rel16/32 Jump near if sign (SF=1)

0F 84 cw/cd JZ rel16/32 Jump near if 0 (ZF=1)

5.3 PUSH: Push Word or Doubleword Onto the Stack

5.3.1 Description

Decrements the stack pointer and then stores the source operand on the top of the stack. The address-size attribute of the stack segment determines the stack pointer size (16 bits or 32 bits), and the operand-size attribute of the current code segment determines the amount the stack pointer is decremented (2 bytes or 4 bytes). For

example, if these address- and operand-size attributes are 32, the 32-bit ESP register (stack pointer) is decremented by 4 and, if they are 16, the 16-bit SP register is decremented by 2.(The B flag in the stack segment's segment descriptor determines the stack's address-size attribute, and the D flag in the current code segment's segment descriptor, along with prefixes, determines the operand-size attribute and also the address-size attribute of the source operand.) Pushing a 16-bit operand when the stack address-size attribute is 32 can result in a misaligned the stack pointer (that is, the stack pointer is not aligned on a doubleword boundary).

The PUSH ESP instruction pushes the value of the ESP register as it existed before the instruction was executed. Thus, if a PUSH instruction uses a memory operand in which the ESP register is used as a base register for computing the operand address, the effective address of the operand is computed before the ESP register is decremented. In the real-address mode, if the ESP or SP register is 1 when the PUSH instruction is executed, the processor shuts down due to a lack of stack space. No exception is generated to indicate this condition.

Intel Architecture Compatibility

For Intel Architecture processors from the Intel 286 on, the PUSH ESP instruction pushes the value of the ESP register as it existed before the instruction was executed. (This is also true in the real-address and virtual-8086 modes.) For the Intel 8086 processor, the PUSH SP instruction pushes the new value of the SP register (that is the value after it has been decremented by 2).

5.3.2 Operation

Below, there is a pseudo code fragment to demonstrate how the CPU behaves upon the execution of a PUSH command:

```
IF StackAddrSize = 32
THEN
```

```
IF OperandSize = 32
THEN
ESP ¬ ESP - 4;
SS:ESP ¬ SRC; (* push doubleword *)
ELSE (* OperandSize = 16*)
ESP ¬ ESP - 2;
SS:ESP ¬ SRC; (* push word *)
FI;
ELSE (* StackAddrSize = 16*)
IF OperandSize = 16
THEN
SP ¬ SP - 2;
SS:SP ¬ SRC; (* push word *)
ELSE (* OperandSize = 32*)
SP ¬ SP - 4;
SS:SP ¬ SRC; (* push doubleword *)
FI;
FI;
```

5.3.3 Opcode Instruction Description

```
FF /6 PUSH r/m16 Push r/m16
FF /6 PUSH r/m32 Push r/m32
50+ rw PUSH r16 Push r16
50+ rd PUSH r32 Push r32
6A PUSH imm8 Push imm8
68 PUSH imm16 Push imm16
68 PUSH imm32 Push imm32
0E PUSH CS Push CS
16 PUSH SS Push SS
1E PUSH DS Push DS
06 PUSH ES Push ES
```

0F A0 PUSH FS Push FS

0F A8 PUSH GS Push GS

5.4 POP: Pop a Value from the Stack

5.4.1 Description

Loads the value from the top of the stack to the location specified with the destination operand and then increments the stack pointer. The destination operand can be a general-purpose register, memory location, or segment register.

The address-size attribute of the stack segment determines the stack pointer size (16 bits or 32 bits—the source address size), and the operand-size attribute of the current code segment determines the amount the stack pointer is incremented (2 bytes or 4 bytes). For example, if these address- and operand-size attributes are 32, the 32-bit ESP register (stack pointer) is incremented by 4 and, if they are 16, the 16-bit SP register is incremented by 2.

The B flag in the stack segment's segment descriptor determines the stack's address-size attribute, and the D flag in the current code segment's segment descriptor, along with prefixes, determines the operand-size attribute and also the address-size attribute of the destination operand.

If the destination operand is one of the segment registers DS, ES, FS, GS, or SS, the value loaded into the register must be a valid segment selector. In protected mode, popping a segment selector into a segment register automatically causes the descriptor information associated with that segment selector to be loaded into the hidden (shadow) part of the segment register and causes the selector and the descriptor information to be validated (see the "Operation" section).

A null value (0000-0003) may be popped into the DS, ES, FS, or GS register without causing a general protection fault. However, any subsequent attempt to

reference a segment whose corresponding segment register is loaded with a null value causes a general protection exception (#GP). In this situation, no memory reference occurs and the saved value of the segment register is null. The POP instruction cannot pop a value into the CS register. To load the CS register from the stack, use the RET instruction.

If the ESP register is used as a base register for addressing a destination operand in memory, the POP instruction computes the effective address of the operand after it increments the ESP register.

The POP ESP instruction increments the stack pointer (ESP) before data at the old top of stack is written into the destination.

A POP SS instruction inhibits all interrupts, including the NMI interrupt, until after execution of the next instruction. This action allows sequential execution of POP SS and MOV ESP, EBP instructions without the danger of having an invalid stack during an interrupt 1. However, use of the LSS instruction is the preferred method of loading the SS and ESP registers.

5.4.2 Operation

Below, there is a pseudo code fragment to demonstrate how the CPU behaves upon the execution of a POP command:

```
IF StackAddrSize = 32
THEN
IF OperandSize = 32
THEN
DEST ¬ SS:ESP; (* copy a doubleword *)
ESP ¬ ESP + 4;
ELSE (* OperandSize = 16*)
DEST ¬ SS:ESP; (* copy a word *)
```

```
ESP ¬ ESP + 2;
FI;
ELSE (* StackAddrSize = 16* )
IF OperandSize = 16
THEN
DEST ¬ SS:SP; (* copy a word *)
SP ¬ SP + 2;
ELSE (* OperandSize = 32 *)
DEST ¬ SS:SP; (* copy a doubleword *)
SP ¬ SP + 4;
FI;
FI;
```

Loading a segment register while in protected mode results in special checks and actions, as described in the following listing. These checks are performed on the segment selector and the segment descriptor it points to.

```
IF SS is loaded;
THEN
IF segment selector is null
THEN #GP(0);
FI;
IF segment selector index is outside descriptor table limits
OR segment selector's RPL ¹ CPL
OR segment is not a writable data segment
OR DPL ¹ CPL
THEN #GP(selector);
FI;
IF segment not marked present
THEN #SS(selector);
ELSE
SS ¬ segment selector;
```

```
SS ¬ segment descriptor;
FI;
FI;
IF DS, ES, FS or GS is loaded with non-null selector;
THEN
IF segment selector index is outside descriptor table limits
OR segment is not a data or readable code segment
OR ((segment is a data or nonconforming code segment)
AND (both RPL and CPL > DPL))
THEN #GP(selector);
IF segment not marked present
THEN #NP(selector);
ELSE
SegmentRegister ¬ segment selector;
SegmentRegister ¬ segment descriptor;
FI;
FI;
IF DS, ES, FS or GS is loaded with a null selector;
THEN
SegmentRegister ¬ segment selector;
SegmentRegister ¬ segment descriptor;
FI;
```

NOTE: in a sequence of instructions that individually delay interrupts past the following instruction, only the first instruction in the sequence is guaranteed to delay the interrupt, but subsequent interrupt-delaying instructions may not delay the interrupt. Thus, in the following instruction sequence:

```
STI
POP SS
POP ESP
```

Interrupts may be recognized before the POP ESP executes, because STI also delays interrupts for one instruction.

5.4.3 Opcode Instruction Description

8F /0 POP m16 Pop top of stack into m16; increment stack pointer
8F /0 POP m32 Pop top of stack into m32; increment stack pointer
58+ rw POP r16 Pop top of stack into r16; increment stack pointer
58+ rd POP r32 Pop top of stack into r32; increment stack pointer
1F POP DS Pop top of stack into DS; increment stack pointer
07 POP ES Pop top of stack into ES; increment stack pointer
17 POP SS Pop top of stack into SS; increment stack pointer
0F A1 POP FS Pop top of stack into FS; increment stack pointer
0F A9 POP GS Pop top of stack into GS; increment stack pointer

5.5 AND: Logical AND

5.5.1 Description

Performs a bitwise AND operation on the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. (However, two memory operands cannot be used in one instruction.) Each bit of the result of the AND instruction is a 1 if both corresponding bits of the operands are 1; otherwise, it becomes a 0.

5.5.2 Operation and Example

Pseudo code:
DEST ¬ DEST AND SRC;

Example:

Consider the integers 58 and 167. Below is illustrated the result of the operation 58 AND 167. Note that the same skeptic can be extended in 32, 64 or more bit numbers.

1. Convert number 58 into binary: 00111010
2. Convert number 167 into binary: 10100111
3. Align numbers vertically. If two bits at the same location have the value 1, the new number should also have the value 1 for the equivalent bit. Else, 0.

	00111010
AND	10100111
IS EQUAL	**00100010** which is 34.

5.5.3 Opcode Instruction Description

24 ib AND AL, imm8 AL AND imm8

25 iw AND AX, imm16 AX AND i mm16

25 id AND EAX, imm32 EAX AND imm32

80 /4 ib AND r/m8,imm8 r/m8 AND imm8

81 /4 iw AND r/m16,imm16 r/m16 AND imm16

81 /4 id AND r/m32,imm32 r/m32 AND imm32

83 /4 ib AND r/m16,imm8 r/m16 AND imm8 (sign-extended)

83 /4 ib AND r/m32,imm8 r/m32 AND imm8 (sign-extended)

20 /r AND r/m8,r8 r/m8 AND r8

21 / r AND r/m16,r16 r/m16 AND r16

21 / r AND r/m32,r32 r/m32 AND r32

22 / r AND r8,r/m8 r8 AND r/m8

23 / r AND r16,r/m16 r16 AND r/m16

23 / r AND r32,r/m32 r32 AND r/m32

5.6 NOT: One's Complement Negation

5.6.1 Description

Performs a bitwise NOT operation (each 1 is cleared to 0, and each 0 is set to 1) on the destination operand and stores the result in the destination operand location. The destination operand can be a register or a memory location.

5.6.2 Operation and Example

Pseudo code:
DEST ¬ NOT DEST;

Example:

Consider the integer 167. Below is illustrated the result of the operation NOT 167. Note that the same skeptic can be extended in 32, 64 or more bit numbers.

1. Convert number 167 into binary: 10100111
2. Reverse all bits (1 should be 0 and vice versa)

NOT 10100111
IS EQUAL **01011000** which is 88. (note, it is equal to 255-167)

5.6.3 Opcode Instruction Description

F6 /2 NOT r/m8 Reverse each bit of r/m8
F7 /2 NOT r/m16 Reverse each bit of r/m16
F7 /2 NOT r/m32 Reverse each bit of r/m32

5.7 OR: Logical Inclusive OR

5.7.1 Description

Performs a bitwise inclusive OR operation between the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. (However, two memory operands cannot be used in one instruction.) Each bit of the result of the OR instruction is 0 if both corresponding bits of the operands are 0; otherwise, each bit is 1.

5.7.2 Operation and Example

Pseudo code:
DEST ¬ DEST OR SRC;

Example:

Consider the integers 58 and 167. Below is illustrated the result of the operation 58 OR 167. Note that the same skeptic can be extended in 32, 64 or more bit numbers.

1. Convert number 58 into binary: 00111010
2. Convert number 167 into binary: 10100111
3. Align numbers vertically. If two bits at the same location have the value 0, the new number should also have the value 0 for the equivalent bit. Else, 1.

	00111010
OR	10100111
IS EQUAL	**10111111** which is 191.

5.7.3 Opcode Instruction Description

0C ib OR AL, imm8 AL OR imm8
0D iw OR AX, imm16 AX OR imm16
0D id OR EAX, imm32 EAX OR imm32
80 /1 ib OR r/m8,imm8 r/m8 OR imm8
81 /1 iw OR r/m16,imm16 r/m16 OR imm16
81 /1 id OR r/m32,imm32 r/m32 OR imm32
83 /1 ib OR r/m16,imm8 r/m16 OR imm8 (sign-extended)
83 /1 ib OR r/m32,imm8 r/m32 OR imm8 (sign-extended)
08 / r OR r/m8,r8 r/m8 OR r8
09 / r OR r/m16,r16 r/m16 OR r16
09 / r OR r/m32,r32 r/m32 OR r32
0A / r OR r8,r/m8 r8 OR r/m8
0B / r OR r16,r/m16 r16 OR r/m16
0B / r OR r32,r/m32 r32 OR r/m32

5.8 XOR: Logical Exclusive OR

5.8.1 Description

Performs a bitwise exclusive OR (XOR) operation on the destination (first) and source (second) operands and stores the result in the destination operand location. The source operand can be an immediate, a register, or a memory location; the destination operand can be a register or a memory location. (However, two memory operands cannot be used in one instruction.) Each bit of the result is 1 if the corresponding bits of the operands are different; each bit is 0 if the corresponding bits are the same.

5.8.2 Operation and Example

Pseudo code: DEST ¬ DEST XOR SRC;

Example:

Consider the integers 58 and 167. Below is illustrated the result of the operation 58 XOR 167. Note that the same skeptic can be extended in 32, 64 or more bit numbers.

4. Convert number 58 into binary: 00111010
5. Convert number 167 into binary: 10100111
6. Align numbers vertically. If two bits at the same location are the same, the result is 0 else 1.

	00111010
XOR	10100111
IS EQUAL	**10011101** which is 157.

5.8.3 Opcode Instruction Description

34 ib XOR AL, imm8 AL XOR imm8

35 iw XOR AX, imm16 AX XOR imm16

35 id XOR EAX, imm32 EAX XOR imm32

80 /6 ib XOR r/m8,imm8 r/m8 XOR imm8

81 /6 iw XOR r/m16,imm16 r/m16 XOR imm16

81 /6 id XOR r/m32,imm32 r/m32 XOR imm32

83 /6 ib XOR r/m16,imm8 r/m16 XOR imm8 (sign-extended)

83 /6 ib XOR r/m32,imm8 r/m32 XOR imm8 (sign-extended)

30 / r XOR r/m8,r8 r/m8 XOR r8

31 / r XOR r/m16,r16 r/m16 XOR r16

31 / r XOR r/m32,r32 r/m32 XOR r32

32 / r XOR r8,r/m8 r8 XOR r/m8

33 / r XOR r16,r/m16 r8 XOR r/m8

33 / r XOR r32,r/m32 r8 XOR r/m8

5.9 Other instructions

5.9.1 CALL: Call Procedure

Saves procedure linking information on the stack and branches to the procedure (called procedure) specified with the destination (target) operand. The target operand specifies the address of the first instruction in the called procedure. This operand can be an immediate value, a general-purpose register, or a memory location.

This instruction can be used to execute four different types of calls:

- Near call—A call to a procedure within the current code segment (the segment currently pointed to by the CS register), sometimes referred to as an intrasegment call.
- Far call—A call to a procedure located in a different segment than the current code segment, sometimes referred to as an intersegment call.
- Inter-privilege-level far call—A far call to a procedure in a segment at a different privilege level than that of the currently executing program or procedure.
- Task switch—A call to a procedure located in a different task.

The latter two call types (inter-privilege-level call and task switch) can only be executed in protected mode.

5.9.1.1 Near Call

When executing a near call, the processor pushes the value of the EIP register (which contains the offset of the instruction following the CALL instruction) onto the stack (for use later as a return-instruction pointer). The processor then branches to the address in the current code segment specified with the target operand.

The target operand specifies either an absolute offset in the code segment (that is an offset from the base of the code segment) or a relative offset (a signed displacement relative to the current value of the instruction pointer in the EIP register, which points to the instruction following the CALL instruction). The CS register is not changed on near calls.

For a near call, an absolute offset is specified indirectly in a general-purpose register or a memory location (r/m16 or r/m32). The operand-size attribute determines the size of the target operand (16 or 32 bits). Absolute offsets are loaded directly into the EIP register. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s, resulting in a maximum instruction pointer size of 16 bits. (When accessing an absolute offset indirectly using the stack pointer [ESP] as a base register, the base value used is the value of the ESP before the instruction executes.)

A relative offset (rel16 or rel32) is generally specified as a label in assembly code, but at the machine code level, it is encoded as a signed, 16- or 32-bit immediate value. This value is added to the value in the EIP register. As with absolute offsets, the operand-size attribute determines the size of the target operand (16 or 32 bits).

5.9.1.2 Far Calls in Real-Address or Virtual-8086 Mode

When executing a far call in real-address or virtual-8086 mode, the processor pushes the current value of both the CS and EIP registers onto the stack for use as a return-instruction pointer. The processor then performs a “far branch” to the code segment and offset specified with the target operand for the called procedure. Here the target operand specifies an absolute far address either directly with a pointer (ptr16:16 or ptr16:32) or indirectly with a memory location (m16:16 or m16:32).

With the pointer method, the segment and offset of the called procedure is encoded in the instruction, using a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address immediate. With the indirect method, the target operand

specifies a memory location that contains a 4-byte (16-bit operand size) or 6-byte (32-bit operand size) far address.

The operand-size attribute determines the size of the offset (16 or 32 bits) in the far address. The far address is loaded directly into the CS and EIP registers. If the operand-size attribute is 16, the upper two bytes of the EIP register are cleared to 0s.

5.9.1.3 Far Calls in Protected Mode

When the processor is operating in protected mode, the CALL instruction can be used to perform the following three types of far calls:

- Far call to the same privilege level.
- Far call to a different privilege level (inter-privilege level call).
- Task switch (far call to another task).

In protected mode, the processor always uses the segment selector part of the far address to access the corresponding descriptor in the GDT or LDT. The descriptor type (code segment, call gate, task gate, or TSS) and access rights determine the type of call operation to be performed. If the selected descriptor is for a code segment, a far call to a code segment at the same privilege level is performed.

If the selected code segment is at a different privilege level and the code segment is non-conforming, a general-protection exception is generated. A far call to the same privilege level in protected mode is very similar to one carried out in real-address or virtual-8086 mode. The target operand specifies an absolute far address either directly with a pointer (ptr16:16 or ptr16:32) or indirectly with a memory location (m16:16 or m16:32).

The operand-size attribute determines the size of the offset (16 or 32 bits) in the far address. The new code segment selector and its descriptor are loaded into CS register, and the offset from the instruction is loaded into the EIP register.

Note that a call gate (described in the next paragraph) can also be used to perform far call to a code segment at the same privilege level. Using this mechanism provides an extra level of indirection and is the preferred method of making calls between 16-bit and 32-bit code segments. When executing an inter-privilege-level far call, the code segment for the procedure being called must be accessed through a call gate.

The segment selector specified by the target operand identifies the call gate. Here again, the target operand can specify the call gate segment selector either directly with a pointer (ptr16:16 or ptr16:32) or indirectly with a memory location (m16:16 or m16:32). The processor obtains the segment selector for the new code segment and the new instruction pointer (offset) from the call gate descriptor.

The offset from the target operand is ignored when a call gate is used. On inter-privilege-level calls, the processor switches to the stack for the privilege level of the called procedure. The segment selector for the new stack segment is specified in the TSS for the currently running task. The branch to the new code segment occurs after the stack switch. (Note that when using a call gate to perform a far call to a segment at the same privilege level, no stack switch occurs.)

On the new stack, the processor pushes the segment selector and stack pointer for the calling procedure's stack, an (optional) set of parameters from the calling procedures stack, and the segment selector and instruction pointer for the calling procedure's code segment.

A value in the call gate descriptor determines how many parameters to copy to the new stack. Finally, the processor branches to the address of the procedure being called within the new code segment.

Executing a task switch with the CALL instruction is somewhat similar to executing a call through a call gate. Here the target operand specifies the segment selector of the task gate for the task being switched to (and the offset in the target operand is ignored.) The task gate in turn points to the TSS for the task, which contains the segment selectors for the task's code and stack segments.

The TSS also contains the EIP value for the next instruction that was to be executed before the task was suspended. This instruction pointer value is loaded into EIP register so that the task begins executing again at this next instruction. The CALL instruction can also specify the segment selector of the TSS directly, which eliminates the indirection of the task gate.

Note that when you execute at task switch with a CALL instruction, the nested task flag (NT) is set in the EFLAGS register and the new TSS's previous task link field is loaded with the old tasks TSS selector. Code is expected to suspend this nested task by executing an IRET instruction, which, because the NT flag is set, will automatically use the previous task link to return to the calling task. Switching tasks with the CALL instruction differs in this regard from the JMP instruction which does not set the NT flag and therefore does not expect an IRET instruction to suspend the task.

5.9.1.4 Mixing 16-Bit and 32-Bit Calls

When making far calls between 16-bit and 32-bit code segments, the calls should be made through a call gate. If the far call is from a 32-bit code segment to a 16-bit code segment, the call should be made from the first 64 KBytes of the 32-bit code segment. This is because the operand-size attribute of the instruction is set to 16, so only a 16-bit return address offset is saved.

Also, the call should be made using a 16-bit call gate so that 16-bit values will be pushed on the stack.

5.9.2 ADD: Add

Adds the first operand (destination operand) and the second operand (source operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, a register, or a memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The ADD instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a carry in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

5.9.3 SUB: Subtract

Subtracts the second operand (source operand) from the first operand (destination operand) and stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, register, or memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

The SUB instruction does not distinguish between signed or unsigned operands. Instead, the processor evaluates the result for both data types and sets the OF and CF flags to indicate a borrow in the signed or unsigned result, respectively. The SF flag indicates the sign of the signed result.

5.9.4 MUL: Unsigned Multiply

Performs an unsigned multiplication of the first operand (destination operand) and the second operand (source operand) and stores the result in the destination

operand. The destination operand is an implied operand located in register AL, AX or EAX (depending on the size of the operand); the source operand is located in a general-purpose register or a memory location.

The result is stored in register AX, register pair DX:AX, or register pair EDX:EAX (depending on the operand size), with the high-order bits of the product contained in register AH, DX, or EDX, respectively. If the high-order bits of the product are 0, the CF and OF flags are cleared; otherwise, the flags are set.

5.9.5 DIV: Unsigned Divide

Divides (unsigned) the value in the AX register, DX:AX register pair, or EDX:EAX register pair (dividend) by the source operand (divisor) and stores the result in the AX (AH:AL), DX:AX, or EDX:EAX registers. The source operand can be a general-purpose register or a memory location.

The action of this instruction depends on the operand size, as shown in the following table:

Operand Size	Dividend	Divisor	Quotient	Remainder
Word/byte	AX r/m8	AL	AH	255
Doubleword/word	DX:AX r/m16	AX	DX	65535
Quadword/doubleword	EDX:EAX r/m32	EAX	EDX	2^32 - 1

Non-integral results are truncated (chopped) towards 0. The remainder is always less than the divisor in magnitude. Overflow is indicated with the #DE (divide error) exception rather than with the CF flag.

5.9.6 MOV: Move

Copies the second operand (source operand) to the first operand (destination operand). The source operand can be an immediate value, general-purpose register,

segment register, or memory location; the destination register can be a general-purpose register, segment register, or memory location. Both operands must be the same size, which can be a byte, a word, or a doubleword.

The MOV instruction cannot be used to load the CS register. Attempting to do so results in an invalid opcode exception (#UD). To load the CS register, use the far JMP, CALL, or RET instruction.

If the destination operand is a segment register (DS, ES, FS, GS, or SS), the source operand must be a valid segment selector. In protected mode, moving a segment selector into a segment register automatically causes the segment descriptor information associated with that segment selector to be loaded into the hidden (shadow) part of the segment register. While loading this information, the segment selector and segment descriptor information is validated (see the “Operation” algorithm). The segment descriptor data is obtained from the GDT or LDT entry for the specified segment selector.

A null segment selector (values 0000-0003) can be loaded into the DS, ES, FS, and GS registers without causing a protection exception. However, any subsequent attempt to reference a segment whose corresponding segment register is loaded with a null value causes a general protection exception (#GP) and no memory reference occurs.

Loading the SS register with a MOV instruction inhibits all interrupts until after the execution of the next instruction. This operation allows a stack pointer to be loaded into the ESP register with the next instruction (MOV ESP, stack-pointer value) before an interrupt occurs 1 . The LSS instruction offers a more efficient method of loading the SS and ESP registers.

When operating in 32-bit mode and moving data between a segment register and a general-purpose register, the Intel Architecture 32-bit processors do not require the use of the 16-bit operand-size prefix (a byte with the value 66H) with this

instruction, but most assemblers will insert it if the standard form of the instruction is used (for example, MOV DS, AX). The processor will execute this instruction correctly, but it will usually require an extra clock. With most assemblers, using the instruction form MOV DS, EAX will avoid this unneeded 66H prefix.

When the processor executes the instruction with a 32-bit general-purpose register, it assumes that the 16 least-significant bits of the general-purpose register are the destination or source operand. If the register is a destination operand, the resulting value in the two high-order bytes of the register is implementation dependent. For the Pentium Pro processor, the two high-order bytes are filled with zeros; for earlier 32-bit Intel Architecture processors, the two high order bytes are undefined.

NOTE: In a sequence of instructions that individually delay interrupts past the following instruction, only the first instruction in the sequence is guaranteed to delay the interrupt, but subsequent interrupt-delaying instructions may not delay the interrupt. Thus, in the following instruction sequence:

```
STI
MOV SS, EAX
MOV ESP, EBP
```

Interrupts may be recognized before MOV ESP, EBP executes, because STI also delays interrupts for one instruction.

Chapter 6

6. SoftIce for Windows

Throughout the rest of the lectures notes, we'll be using SoftIce 4.0x debugger from Numega (http://www.numega.com). The main advantage of SoftIce is the ability to load before windows. This allows us to debug even Windows themselves. It also intercepts crashes and gives us helpful debugging information. However, since it is a kernel mode debugger, it lacks a nice graphic user interface, and peripheral support. That is, if i.e. you are using a laptop and have plugged in external devices through a dock station, you won't be able to use them. Get SoftIce and make sure that it is the right version for the operating system you have. Windows 9x have a different version than Windows NT/2000. Windows Me is not supported, although there is an article at Numega prompting you to download and install the DDK for Windows Me. (for more information see http://www.numega.com/support/knowledgebase/docs/1078.stm)

6.1 Installing SoftIce

Double click the single installation file. The standard installation process will initiate (InstallShield). Click Next. Read and agree with the license agreement! If you don't agree with the terms listed there, the setup will cease. The next dialog box requires you to enter the serial number of the product. The serial number is different for the two SoftIce versions (Win 9x and NT/2000). Click Next.

We'll leave the default installation directory as-is. If for some reason you want to alter the installation directory you may do so, but be warned that the absolute paths given in the rest of these notes have to point to the directory that you've used for the installation. Click Next.

Select all four installation options. You may want to skip demonstration files if you like (or help files and online books). A full installation will occupy approximately 13 MB of hard disk space. Click Next.

Unless you are completely sure about your graphic display and selecting it and testing it is successful, leave the default VGA adapter. Note that it is wise to press the Test button even if you leave the default VGA adapter checked. Monochrome card/monitor should be left unchecked, while the Universal Video Driver should remain checked. Click Next.

Do not select a mouse device yet; this can be done later. However, if you do select a mouse driver, please make sure that you make the right selection. Click Next. Now, the installation process requires permission to modify your autoexec.bat file. You should grant this permission by leaving the first option checked. SoftIce will insert a couple of important lines in your autoexec.bat file so that SoftIce can be loaded at startup.

Click Next twice. The installation will copy all necessary (and selected) files onto your disk. After this procedure is finished, you'll be prompted to register SoftIce. Select the last option (register later) and press Next.

A message might appear prompting you to install Adobe Acrobat reader. If you don't have this program, you'll need it in order to read SoftIce's manual. However, since you are reading these lecture notes you have it, therefore you will skip this message by pressing OK. You have to restart your system.

Note that the startup process will be different now. Windows loader starts SoftIce (so does ntldr for windows NT/2000). When your windows startup, press CTRL+D to test your installation. If everything was successful, SoftIce window will pop-up and your Windows will freeze. Press CTRL+D to dismiss SoftIce and proceed to the next section to configure it properly.

6.2 Configuring SoftIce

Go to your programs and you'll see a new program group named Numega SoftIce. Inside it, you'll find two setup options, one for your display adapter and one for your mouse. You can change the mouse setup if it doesn't work, but do not mess with the display adapter settings if it works. SoftIce will appear in a small window. We'll see how to change this later.

You also have 4 help files, a standard html read me file, a help file and two adobe pdf books. All are very helpful especially if you run into unexpected problems. Finally there is an application named Numega SoftIce Loader. This does not load SoftIce, it's name might be confusing. It edits with a graphic interface the initialization (.ini) file used to store SoftIce's settings.

Find a file called winice.dat located in the SoftIce installation directory, which should be C:\program files\Numega\softice95. Open it with notepad. This file holds the customization settings that SoftIce reads each time it starts.

6.2.1 Resizing Panels

Open SoftIce (press CTRL+D). Type **lines**. On the bottom line, you'll see a help line, explaining you what this command does. Press space once. You'll then see what parameters the lines command accepts. I've used 60. Experiment with all the numbers you see. Then, if you want to make your changes final (remain the same each time SoftIce is running), go to notepad, where the winice.dat file is, and save this setting:

INIT="X;" is replaced by **INIT="lines 60;"**

Save your changes in notepad. In order to change the number of columns in the window, the process is the same, but the command used is **width**. So, type width and SoftIce will tell you what width does. Press space and you'll get the range of settings

you can use. I've used 80. The setting you have to put in winice.dat file is "width=80;" like you did with the lines command, so you'll have:

INIT="lines 60;width=80;"

6.2.2 Panels

SoftIce has a lot of panels, which are all configurable. That is, you can hide or unhide each one of them and of course resize them, with or without the help of your mouse. We'll be using the keyboard commands just in case your mouse is not working.

Command	Explanation
WC [number]	If no number is specified, it toggles the code window. If a number is present, it sets the code window lines equal to that number. (Recommended: 25, it's a **very** important window!)
WR	Toggles the registers window, which is on the top part of the window. It is recommended that the registers' window is always on.
WD [number]	Number behaves as in WC command. This toggles the data window, which can be used as a hex editor. You may want to close this window and free up some space.
WF	Toggles the floating stack pointers window. We won't use this window.
WL	Toggles the locals window. We won't use this window.
WS	Toggles the stack window. We won't use this window much.
WW	Toggles the watch window. Set wathes with the watch <address> command. This is very useful and we will need it in the future but not in present.

To make all changes permanent, store the settings in winice.dat file. Here's what I am using:

INIT="lines 60;code on;wd 13;wc 25;wr;ww 6; faults off;"

6.2.3 Other Useful Settings

The **code** command toggles on and off the code column in the disassembly window. The code window is the second column from left to right and has the opcodes of the functions that are disassembled. If it is off, then there are only three columns instead of four.

It is convenient to set **faults off** by default. This will force SoftIce not to pop-up every time a windows application crashes. Besides, we don't want to debug everything! It is necessary to set faults on when we debug our own applications since in case of a fault, SoftIce won't pop up when faults are set to off.

If CTRL+D is not convenient for you, you can always use the **altkey** command to change it. The syntax is ALTKEY (CTRL or ALT) key. For example, altkey alt F will replace CTRL+D shortcut with ALT+F.

You probably have noticed by now that the up and down cursors are used to navigate through the previous commands in the command panel. Also, note that entering **cls** will allow you to clear SoftIce's panel. Set mouse x, sets the mouse speed from 0 (slowest) to 3 (fastest).

All these settings (and more) can be saved in winice.dat file, so that they'll be restored each time SoftIce is initialized:

```
INIT="lines 60;code on;wd 13;wc 25;ww 6;wl;dex 1 ss:esp;faults off;"
INIT="altkey ctrl d;watch es:di;watch eax;watch *es:di;set mouse 3;cls;X;"
```

6.2.4 SoftIce Window

Since everything freezes, it's not that easy to take a snapshot of SoftIce's window. There is a way though, freeze something in the background, pop up SoftIce

and close it. SoftIce will remain on the frozen window, since painting is unavailable for frozen applications. Then, you can probably take a snapshot of your screen (or maybe not, since SoftIce uses a different display driver)

```
+--------------------------------------------------------------------------+
| EAX=...     This is the registers window, activate it                    |
| EDI=...     by typing wr                                                 |
+--------------------------------------------------------------------------+
| es:di=...   This is the watch window, activate it by typing ww.  To watch|
|             something, type watch bla, eg watch eax                      |
+--------------------------------------------------------------------------+
| xxxx:yyyyyyyy 01 02 03 04 05 06 07 08-09 10 11 12 13 14 15 16 ..............|
| xxxx:yyyyyyyy 01 02 03 04 05 06 07 08-09 10 11 12 13 14 15 16 ..............|
|                                                                          |
| This is the data window, activate it by typing wd.  It is here that you can |
| see what's stored in memory.                                             |
+--------------------------------------------------------------------------+
| 0028:C000A010  7902              JNS     C000A014                (JUMP  )|
| 0028:C000A012  33C0              XOR     EAX,EAX                         |
| 0028:C000A014  83E81F            SUB     EAX,1F                          |
|                                                                          |
| This is the code window, where the assembly commands the target is executing |
| are displayed.  Activate this window by typing wc.                       |
+--------------------------------------------------------------------------+
|:< type your commands here >                                              |
|                                                                          |
| Well this is where you type your commands                                |
+--------------------------------------------------------------------------+
```

6.2.5 Symbols

Symbols, are DLL functions that are imported in SoftIce, so the program know what parameters are taken as arguments and what is returned (if something is returned). Symbols are located in the winice.dat file, at the end of the file with a semicolon in front of them, which is like a remark. Removing these semicolons is required in order to import the symbols and breakpoint them.

```
;EXP=c:\windows\system\kernel32.dll
;EXP=c:\windows\system\user32.dll
;EXP=c:\windows\system\gdi32.dll
```

```
;EXP=c:\windows\system\comdlg32.dll
;EXP=c:\windows\system\shell32.dll
;EXP=c:\windows\system\advapi32.dll
;EXP=c:\windows\system\shell232.dll
;EXP=c:\windows\system\comctl32.dll
....
```

Please note that although it would be nice to breakpoint all modules (windows modules and program dlls), that's impossible since they would occupy too much resources. So, we'll just breakpoint some of the most "popular" modules like kernel32.dll, user32.dll, comdlg32.dll and advapi32.dll. You can of course breakpoint all of the default entries in the SoftIce winice.dat module.

There is also another point you need to take care of, the path of the modules. It has to be an absolute path. So, if your windows installation directory is C:\WINNT, probably kernel32.dll resides in C:\Winnt\system32\kernel32.dll. If you are unsure, then you can use the Search for Files function to search for the modules you need to breakpoint.

6.3 Breakpoints

In the following table, all common breakpoint related commands are listed. Of course, there are many more shortcuts and commands related to breakpoints. You are advised to consult SoftIce manuals for more information on how to work with breakpoints. Before you try to use breakpoint, make sure that you've been through 6.2.5 paragraph and you completely understand what are symbols and in which dynamic link library the function you wish to breakpoint resides.

Since the names of the functions are not available in Windows, you should download Platform SDK from Microsoft web site (http://www.microsoft.com) which contains all the names of the (documented) functions, the DLL in which they reside and

information on their usage. You are not required to do so, but it will help you if you are interested in RE.

Use the **bpx** command to set breakpoint on execution. This command takes as its only argument the function name. On execution means that SoftIce will pop up when this command is called. Then, you can easily navigate to the caller function. Note that in order to set a breakpoint, you must have the symbols imported (see 6.2.5 for information on how to breakpoint symbols). If you do not know the name of the function you wish to set a breakpoint on, then consult the Microsoft platform SDK for an up-to-date list. Some functions are operating system specific.

All the breakpoints are stored in the breakpoint list. To view items in the breakpoint list, type **bl** in the command line. The first column indicates the breakpoint index, which starts counting from 0. Therefore, the second index will be 1, the third 2 and so on. The index is very useful when we want to edit the breakpoint. We edit an existing breakpoint with the instruction **bpe <index>**. Consider the following example:

bpx getdlgitemtexta

- Here we set a breakpoint on execution of the function “getdlgitemtexta”. Softice needs the symbols of the user32.dll module, since this function is a part of the user32.dll module.

bl

- We get the breakpoint list. Note that SoftIce starts listing breakpoints with their indices (00), type (BPX = on execution) and module!function name, i.e. USER32.DLL!GetDlgItemTextA. SoftIce automatically recognizes that this function belongs to user32.dll. If it can’t find an appropriate module, then you have to either edit winice.dat (see 6.2.5) or use another function name.

bpe 0

- We decide that this breakpoint is not correct, so we want to edit it. SoftIce will put us in an edit mode, with the current breakpoint’s value in memory 0.

bpx getdlgitemtextw

- This will replace getdlgitemtexta with getdlgitemtextw. To verify changes, all we have to do is use bl.

To remove all or some of the breakpoints that we've set, we have to use **bc** command (breakpoint clear). If a star (*) is used as an argument, all breakpoints will be cleared. Else, we must indicate the number of the breakpoint we wish to remove (use bl to retrieve the number).

Occasionally, we may find that all breakpoints in memory are not that useful. Therefore, we might want to disable some or all of them without erasing them. If we erase them, we should type them back in the next time we would like to use them. If we disable them, all that is needed is to enable them.

For this purpose, we are going to use **bd** and **be** commands that take the same arguments with bc. If a star (*) is used, all breakpoint will be disabled or enabled respectively, otherwise the breakpoint that corresponds to the index used will be disabled or enabled. Note that when we list the breakpoints (bl), disabled breakpoints are listed with a * after their indices.

Command	**Explanation**
bpx <name>	This command sets a breakpoint on execution. You can't set the same breakpoint twice. An error will appear (duplicate breakpoint).
Bl	Lists all breakpoint
bpe <index>	Edit a breakpoint that you've already defined. To see what is the index of the breakpoint you are interested in, use bl.
bc * or <index>	Clear one or all breakpoints.
bd * or <index>	Disables one or all breakpoints.
be * or <index>	Enabes one or all breakpoints.
bh	Breakpoint history, to easily navigate through your past actions.

Some times it's not enough to set breakpoints on execution only. SoftIce is extremely versatile and convenient in breakpointing other things and work in memory mode or hardware mode. That's why it's very useful when debugging device drivers or Windows.

- **Bmsg** breakpoints on windows messages
- **Bpint** breakpoints on interrupts
- **Bpio** breakpoints on i/o access
- **Bpm** breakpoints on memory access (can be bpm, bpmb, bpmd, bpmw)
- **Bpr** breakpoints on memory range (very, very useful), see also bprw.

Also, one can find useful the **bpt** (template) and **bstat** (statistics), but these commands are far away from the scope of these notes and won't be described or used.

6.3 Useful Functions

GetDlgTextItemA is invoked each time a string from a text box is retrieved. Therefore, we can rely on the fact that each time we enter something in a text box and the program tries to reach the data contained there, this function will be executed.

Hmemcpy is even more powerful than the previous, since this function will always be invoked. Consider the case where the programmer bypasses getdlgtextitema by using his own controls and methods. Since the string will be stored in a variable that resides in memory, hmemcpy will be invoked.

6.4 Navigation in SoftIce

After you've set a breakpoint and SoftIce popped up, all you need to find is who called that function that you've breakpointed. That is, the function resides in a module, whose symbols are imported in SoftIce (see 6.2.5). When SoftIce detects the function, it means that you are in the module that implements the function and of course you are not interested in it.

The first thing you have to do is move back to the caller. This is done by pressing **F11 (jump to caller)**. Then you can refer to the following table to start learning how to navigate through code.

Shortcut	Explanation
F3	Switch between various SoftIce panels if you need to.
F4	Shows program screen.
F7	Executes to the cursor.
F8	Executes a single step
F10	Steps over
F11	Jump to caller, goes to the function that invoked the breakpoint. Actually it is a “Go to” command.
F12	Returns from the procedure call.

For more information, please consult SoftIce manual. These keyboard shortcuts can be remapped. There are also command equivalents (i.e. F8 is command T).

Chapter 7

7. Hackman Editor

Hackman is a hex editor and disassembler (in the future, there'll also be an application level debugger under the same suite). Its purpose is to easily let you export and modify portions of the source code of any executable program. Of course, it may be used as a mere hex editor. In the following sections, a brief description of some interesting functions included in both Lite and Professional editions is available.

7.1 String Manipulation

With this function, you can search in both 16 and 32 bit files (windows 3.x and windows 32 – 9x, NT, 2000, Me) for strings. A string may be any label that appears as a menu or as a static or dynamic caption within a program. Take for example Windows Explorer.

Labels are the menu names (like File) but also some dynamic menus. Try to right click on an .exe file and on a .dll file. You'll notice that some menus change in the pop up menu that appears and some always exist (like Properties, Delete and Rename). Static menus are called those that always appear, Dynamic are called the menus that may or may not appear. If you try to delete a file, a dialog box appears asking for your confirmation. The text on that dialog box is also a string resource.

Almost every application has string resources. The first step in searching for them is to identify if the program is 16 or 32 bit. The difference between them is that the 32-bit programs use Unicode strings. This is illustrated below:

- Label "Text" is equal to 5465787400 in standard ANSI (16-bit)
- Label "Text" is equal to 5400650078007400000 in Unicode

The difference is that between every two letters, a null character (00) appears. All you have to do is check the Unicode search each time you want to find a string. (The find command is in Edit -> Find). Hackman will automatically treat any string as **ANSI** if this option is not checked and as **Unicode** if it is checked.

Once you find the string you want to alter, bear this in mind: you can replace it with any string of an equal or lower length but you can't easily insert characters. Say for example that the string "Text" must be replaced with "Test". If 32-bit, check Unicode search and find it. Then go on "x" and type "s". Press the Save button or from the Write menu select the Write submenu to save changes.

Now, let's say that you want to trim this label. Instead of "Text" you need the label "ext". Go on T and type e, then x and then t. Move to the hex part, on the number 74 and type 00. This will trim your 4-letter word to a 3-letter word:

- "Text" is initially 54006500780074000000
- Target "ext" will be 65007800740000000000

In the case where we deal with 16-bit files, all we have to do it replace the hex value of the character we need to trim with 00. The whole process can be further simplified if we just place a null terminator (00) in any character and ignore the remaining:

- "Text" is initially 54006500780074000000
- 65000000740065000000 will display "e" since after "e" we have a null.

You have to be very careful when you deal with menus and other strings that support **accelerators**. An accelerator is used as a keyboard shortcut, combined with Alt. Take for example windows explorer. While holding Alt down, press H and then A. The about box will pop up. The letter that corresponds to a menu, button or other active

element appears with an underscore. Notice the little underline below the letter H in windows explorer menu.

There is a trick to place an accelerator in resources, even if an accelerator does not exist. Or you can erase one if it does already exist! The accelerator appears with an ampersand (&) character just before the letter. For example Help will appear as &Help and Format with “o” underlined will be F&ormat. Replacing F&ormat with &Format will replace the accelerator “o” with “f”.

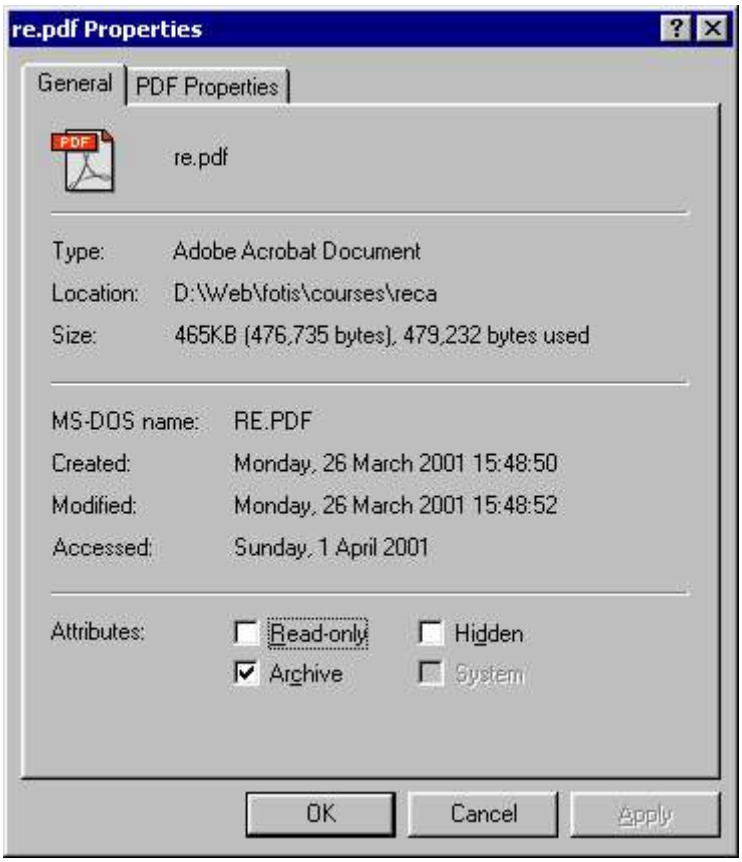
7.2 Version Stamp

Version stamps usually exist in executable files and dynamic link libraries. To view the version stamp of a file (OS specific), all you have to do is right click it, then select Properties and click on the version tab. If the version tab does not exist, then there is no version stamp.

To change the version stamp is easy; go to Write menu, the Special and then go to Version Changer. If the file you've opened has a version stamp, the plugin (Version Changer) will automatically let you edit (with the lower or equal law) the version strings. This could also be done manually, search for the strings and replace them, but this way is much faster.

7.3 Date Stamp

Date stamps usually exist for every file. Although creation date and time and last modification date and time are logically manipulated, the last access time is not. And this happens because when you right click a file and select properties, you actually access it and therefore, the stamp changes again. You can change the date stamp of any file with Hackman. Just open the file in Hackman (it is called logged file), go to Write, then Special and then select Modify dates.



7.4 Icon Resources

To extract icon resources from a file, use the Icon Xtractor (From the Write menu select Icon Xtract). To replace an icon in a file, extract first the icon you want to replace. Then, open it in Hackman (the extracted file) and select a part of it (double click for selection, let's say 15-16 bytes). Press Copy. Go to the target file and press Find. The paste the bytes onto the find text box.

You'll find the source code of the icon in the target file. It should be 766 bytes long, if unsure, check the length of the extracted file. Overwrite this information (delete it and then use insert file to insert a new icon in the target file).

7.5 Other Tools

Other useful tools included in Hackman package:

- **Automatic patch**: make any changes you want, then use the Make Patch command under execute menu to create a patch program.
- **Disassembler**: no description needed!
- **Decrypt/Encrypt**: strong (up to 128 bit) cryptography routines
- **Export**: export and filter part or the whole source code in Java, C++, Text, HTML, Quickbasic and other popular formats. Commands are available for both the clipboard (Copy As) and a file buffer (File|Export selection as).
- **Online libraries**: press F1 or from Help menu select books online.