Proj 4x: Introduction to Hopper (20 pts.)

Purpose

Hopper is a disassembler and debugger that runs on Mac OS X or Linux, but not Windows. It has similar functionality to IDA Pro but costs 10x less. And the free version works on 64-bit executables.

What You Need

A 64-bit Ubuntu 14.04 machine, real or virtual. I recommend using the Ubuntu 14.04.03 machine I put on Mega, which already has Hopper installed. Here's the link to get my VM:

Ubuntu 14.04.03 with Hopper
Size: 2,198,435,208 bytes
SHA256(Ubuntux64-14.04.3-Hopper.7z)= 11d4cf7d54aca0b2c9d559f0ce16cdcfc2be4996491a2ddaab845d272fb2458e

Installing Hopper

If you use the VM I put on Mega, hopper is already installed. If you prefer to install it yourself, I did it this way. Note: the official Hopper repository for Ubuntu does not work (as of 11-23-15) due to an invalid signature.

I installed Ubuntu 14.04.03 x64 Desktop into a fresh VM. Then, in a Terminal window, I executed these commands:

```
sudo apt-get update

sudo apt-get upgrade -y

sudo apt-get dist-upgrade -y

sudo apt-get install build-essential -y

sudo apt-get install git subversion autoconf automake cmake libffi-dev libxml2-dev libgnutls-dev libicu-
dev libblocksruntime-dev libkqueue-dev libpthread-workqueue-dev autoconf libtool clang -y

cd /tmp

curl http://www.hopperapp.com/HopperWeb/downloads/hopperv3-3.11.2.deb > hopperv3-3.11.2.deb

sudo dpkg -i hopperv3-3.11.2.deb
```

Starting Ubuntu

Launch the Ubuntu VM in VMware Player or VMware Fusion.

Log in with these credentials:

- Username: **student**
- Password: **student**

Creating a Program to Debug

This is a simple vulnerable program we've used before.

In a Terminal window, execute this command:

```
nano pwd.c
```

Enter this code:

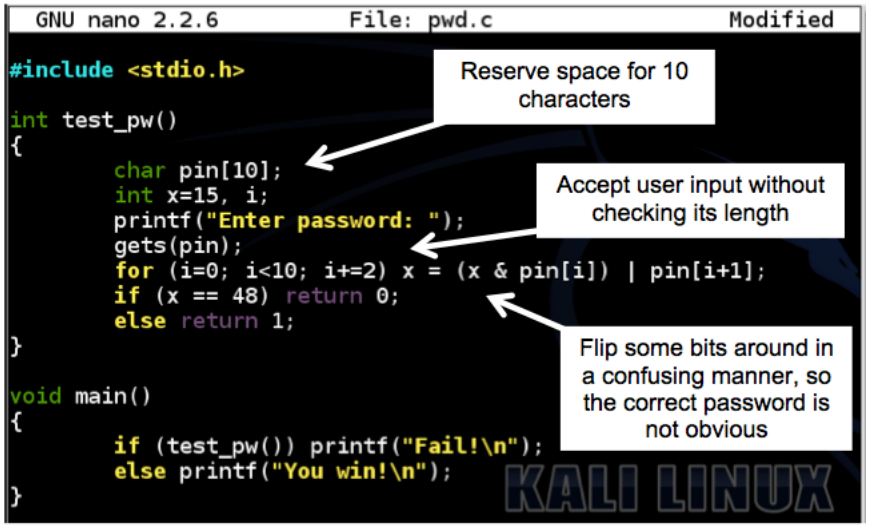
```
#include <stdio.h>

int test_pw()
{
        char pin[10];
        int x=15, i;
        printf("Enter password: ");
        gets(pin);
        for (i=0; i<10; i+=2) x = (x & pin[i]) | pin[i+1];
        if (x == 48) return 0;
        else return 1;
}

void main()
```

```
{
        if (test_pw()) printf("Fail!\n");
        else printf("You win!\n");
}
```

Your screen should look like this, with the explanatory boxes and arrows:



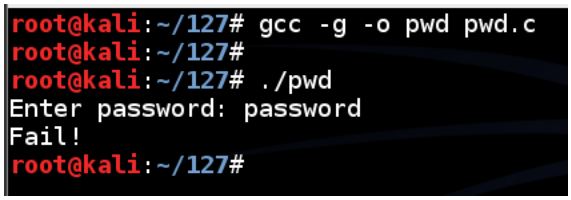
Save the file with **Ctrl+X**, **Y**, **Enter**.

Execute these commands to compile the code and run it:

```
gcc -g -o pwd pwd.c
./pwd
```

Enter a password of **password** and press Enter.

The program exits normally, wth the "Fail!" message, as shown below.



Starting Hopper

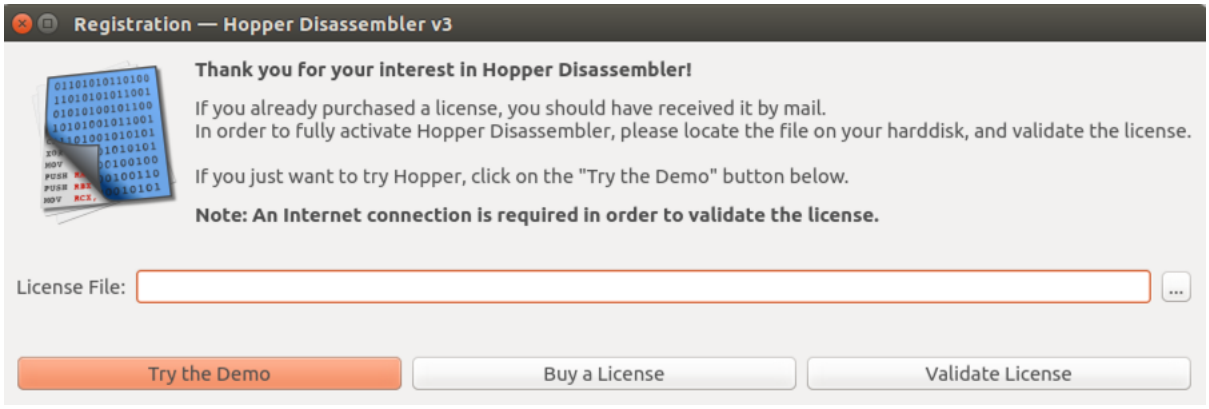
From the Ubuntu desktop, at the top left, click the square reddish **Search** button.

In the search field, type

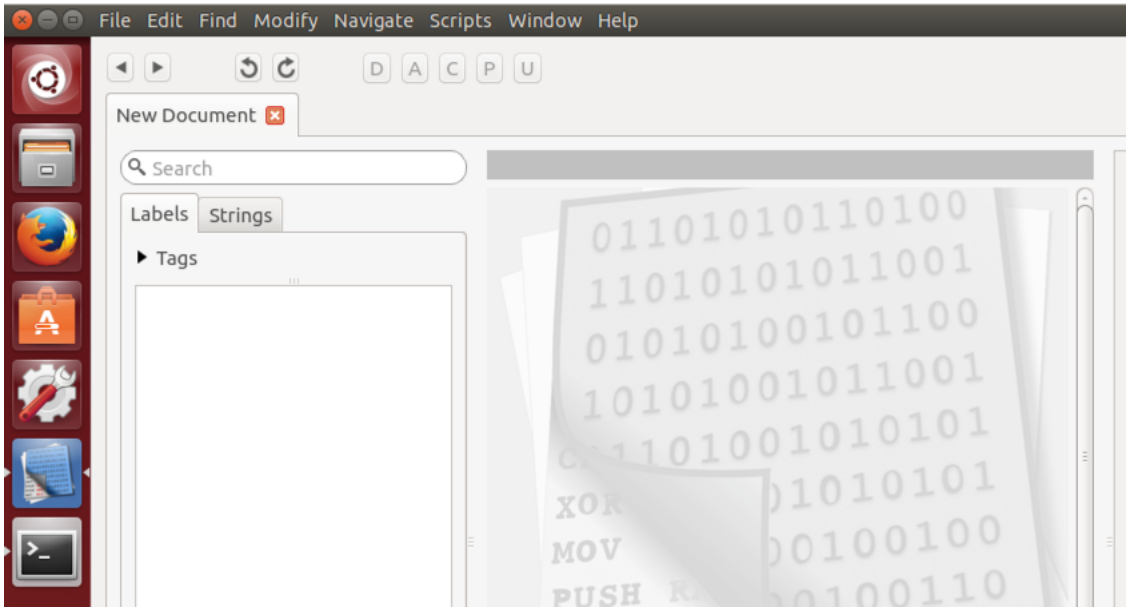
```
hopper
```

In the search results, click "**Hopper Disassembler v3**", as shown below.

In the "Registration" box, click "**Try the Demo**", as shown below.



Hopper opens. Move the mouse into the dark gray bar at the top, and the menu items will appear, starting with "File", "Edit", and "Find", as shown below.

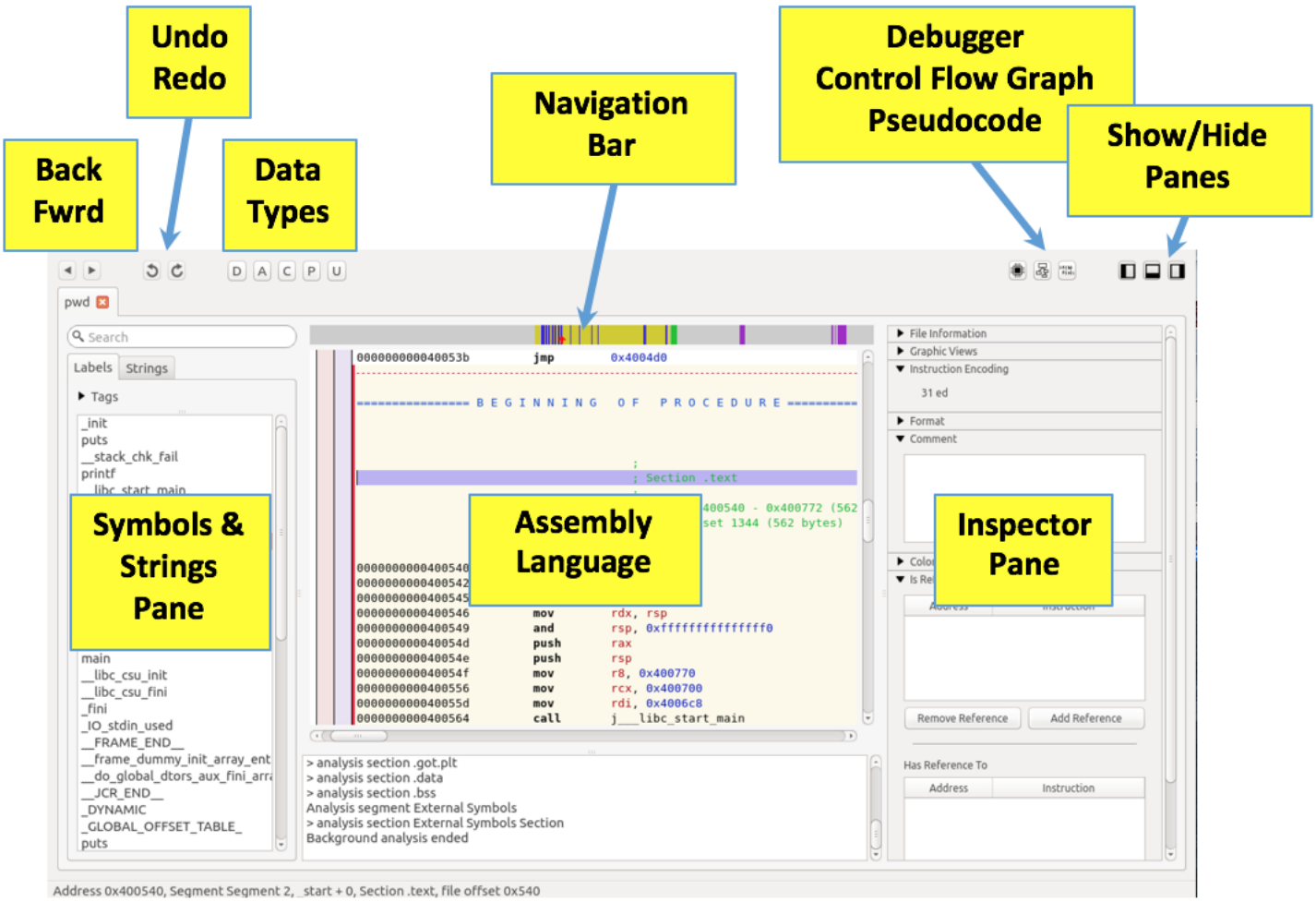


From the Hopper menu bar, click **File**, "**Read Executable to Disassemble...**".

Navigate to the **pwd** file you created above and double-click it.

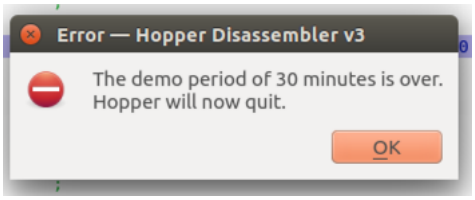
In the "Read Executable" box, click **OK**.

You see the Hopper main window, as shown below.



Restarting Hopper

Every 30 minuntes, Hopper will die, just to irritate you into paying $90, with the message shown below.



When this happens, do these things:

Click **OK**.

From the Ubuntu desktop, at the top left, click the square reddish **Search** button.

Click "**Hopper Disassembler v3**".

In the "Registration" box, click "**Try the Demo**".

From the Hopper menu bar, click **File**, "**Read Executable to Disassemble...**".

Navigate to the **pwd** file you created above and double-click it.

In the "Read Executable" box, click **OK**.

Pass 1: Assembly Code

We will make several passes through this program, seeing how Hopper helps us understand it.

The first pass looks at the code as a series of Assembly Language instructions. This is the most basic function of a disassembler.

Hiding the Inspector Pane

At the top right, click the rightmost of the three "**Show/Hide Panes**" buttons. This gives you more room to see the Assembly Language pane.

Hiding the "Symbols & Strings" Pane

At the top right, click the leftmost of the three "**Show/Hide Panes**" buttons. This allows the Assembly Language pane to use the entire window width.

Hiding the Message Pane

At the bottom, there is a pane containing messages from Hopper, like "analysis section .got.plt". Drag the top border of that section to the bottom.

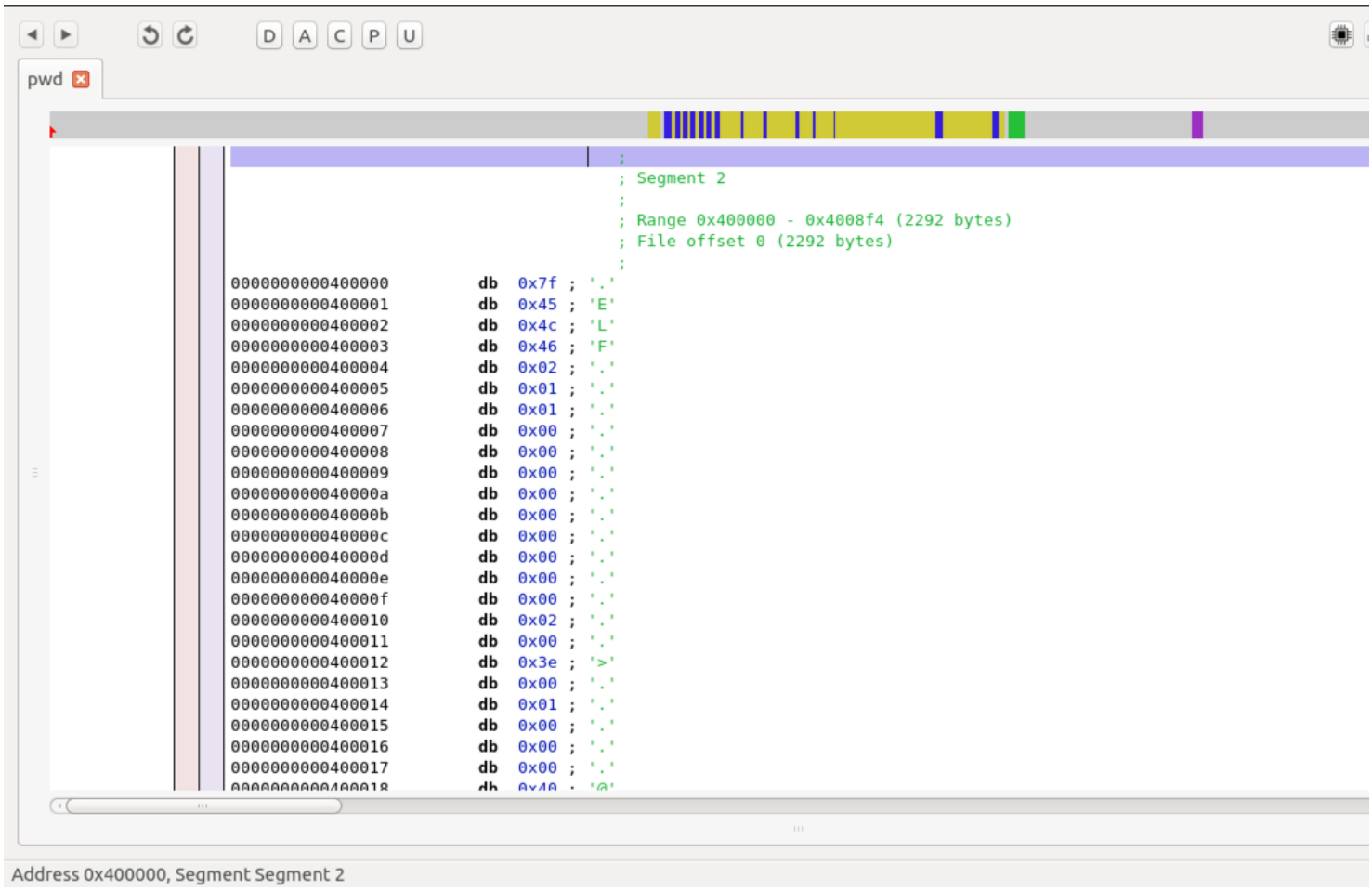
Now, finally, the whole window is available for assembly code, as shown below.

On the right edge, drag the scroll bar to the top. Click the very first line to select it.

The Navigation Bar

At the top center, there's a colored bar with a little red arrow. This is a linear graph of the entire file, and the red arrow indicates your current position.

The red arrow in the Navigation Bar is now at the left edge, as shown below.

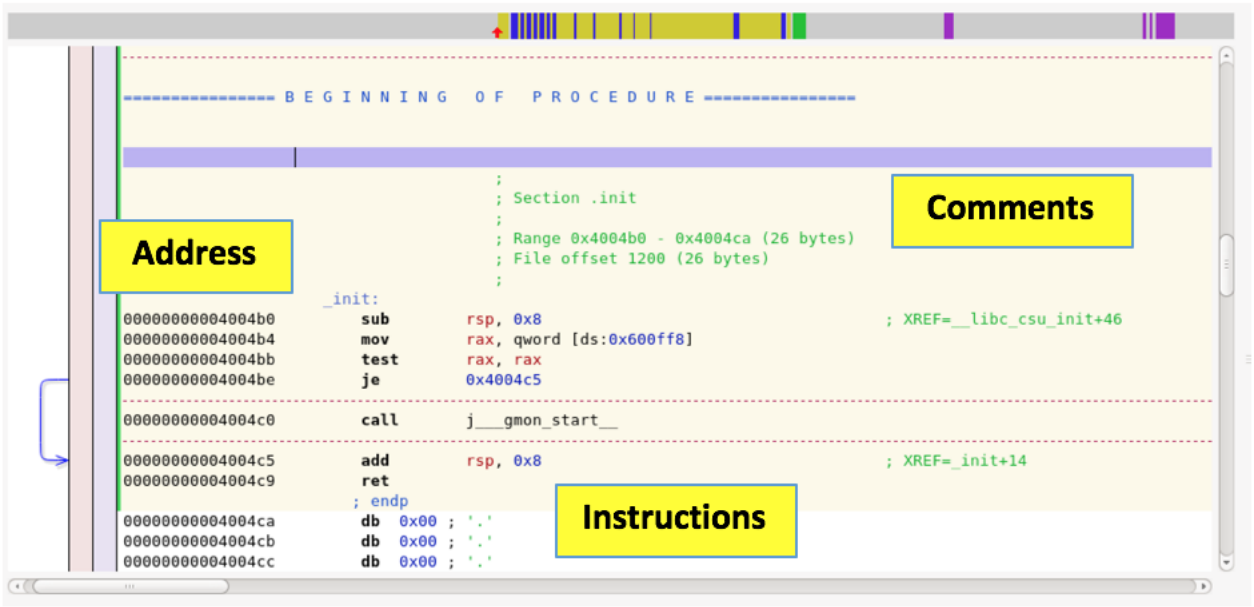


In the Navigation bar, drag the little red arrow to the first yellow stripe.

Code appears, with a yellow-shaded background behind it, as shown below.

Notice these sections:

- **Address:** in hexadecimal, 64 bits long
- **Comments:** Added by Hopper to make the code easier to understand
- **Instructions:** in assembly language

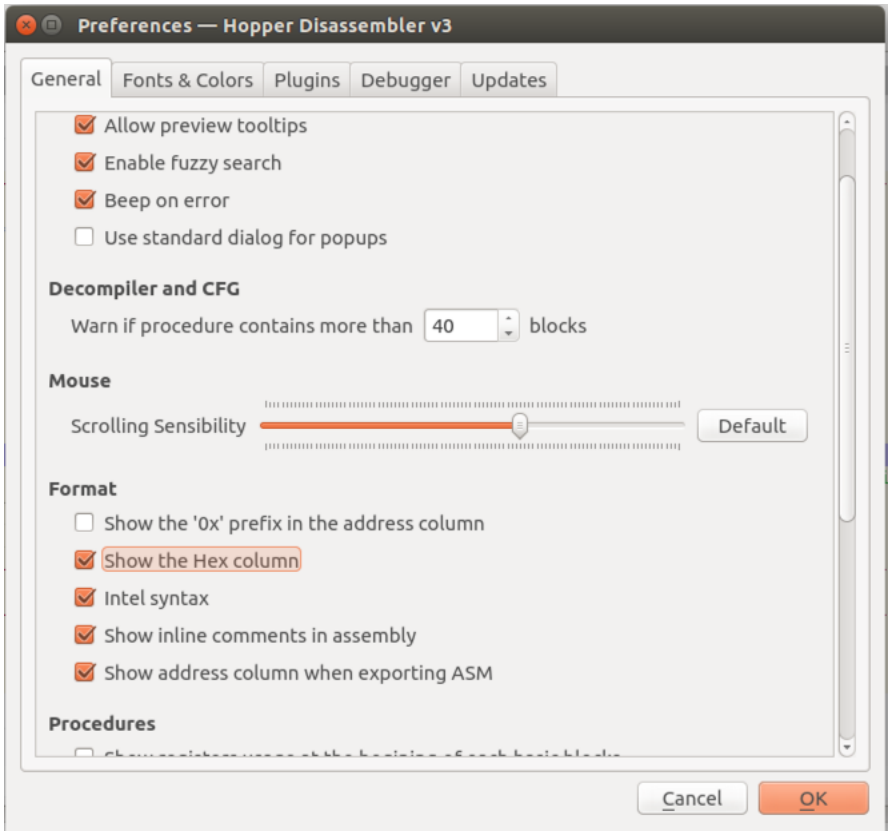


Displaying the Hex Column

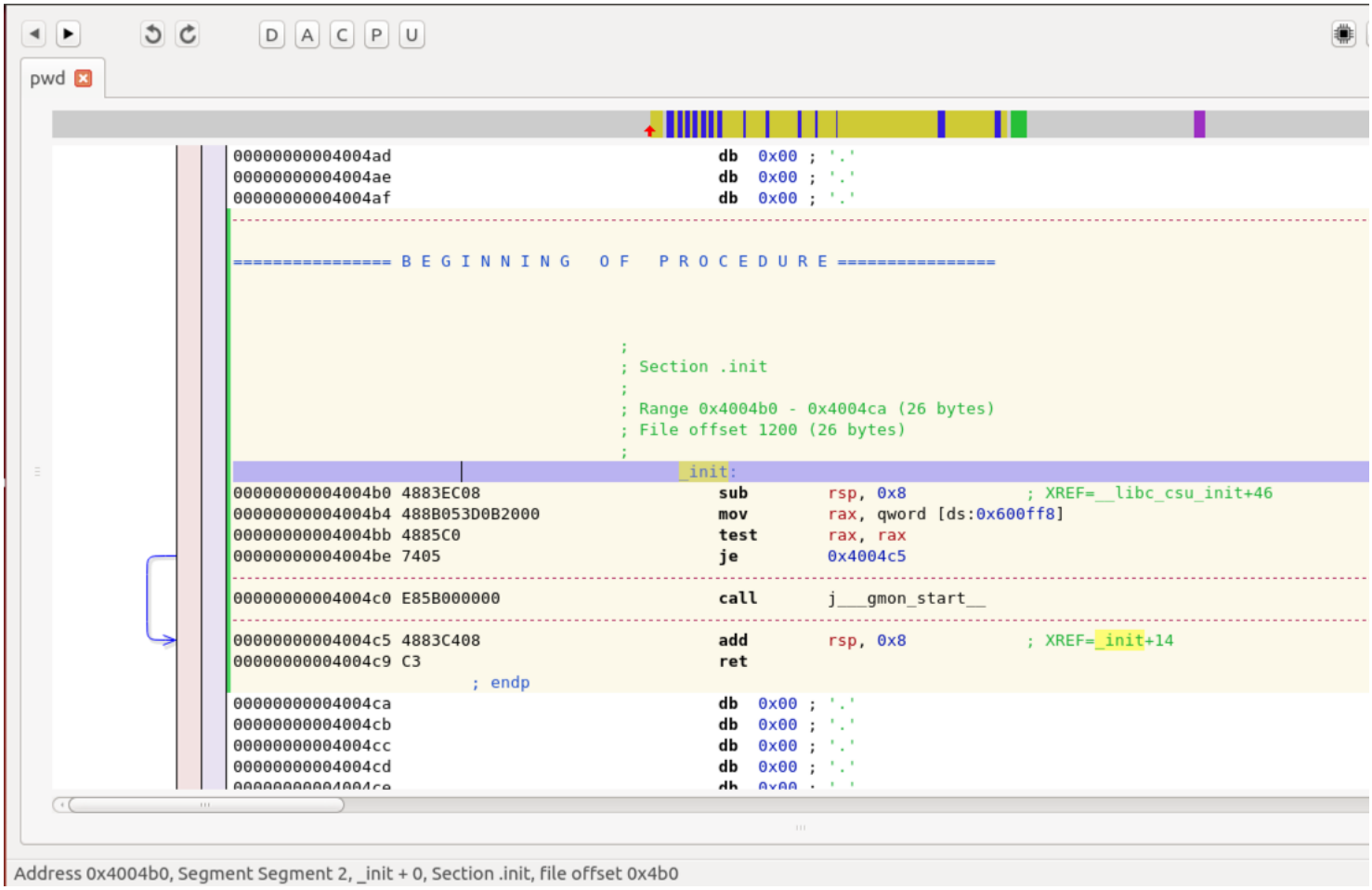
One important thing that is missing from the Hopper display is the instructions in their raw hexadecimal form. To show them, from the Hopper menu bar, click **Window**, **Preferences**.

In the Preferences box, click "**Show the hex column**", as shown below.

Click **OK**.



Now the hexadecimal version of each assembly instruction is visible, as shown below.



Color Codes in Hopper

Hopper assigns each byte of a file into one of these five categories, each coded with a color:

- **Data** *(purple)*: a constant, like an array of integers
- **ASCII** *(green)*: a NULL terminated C string
- **Code** *(blue)*: an instruction
- **Procedure** *(yellow)*: Part of a method that has been successfully reconstructed by Hopper
- **Undefined** *(grey)*: an area not yet explored by Hopper

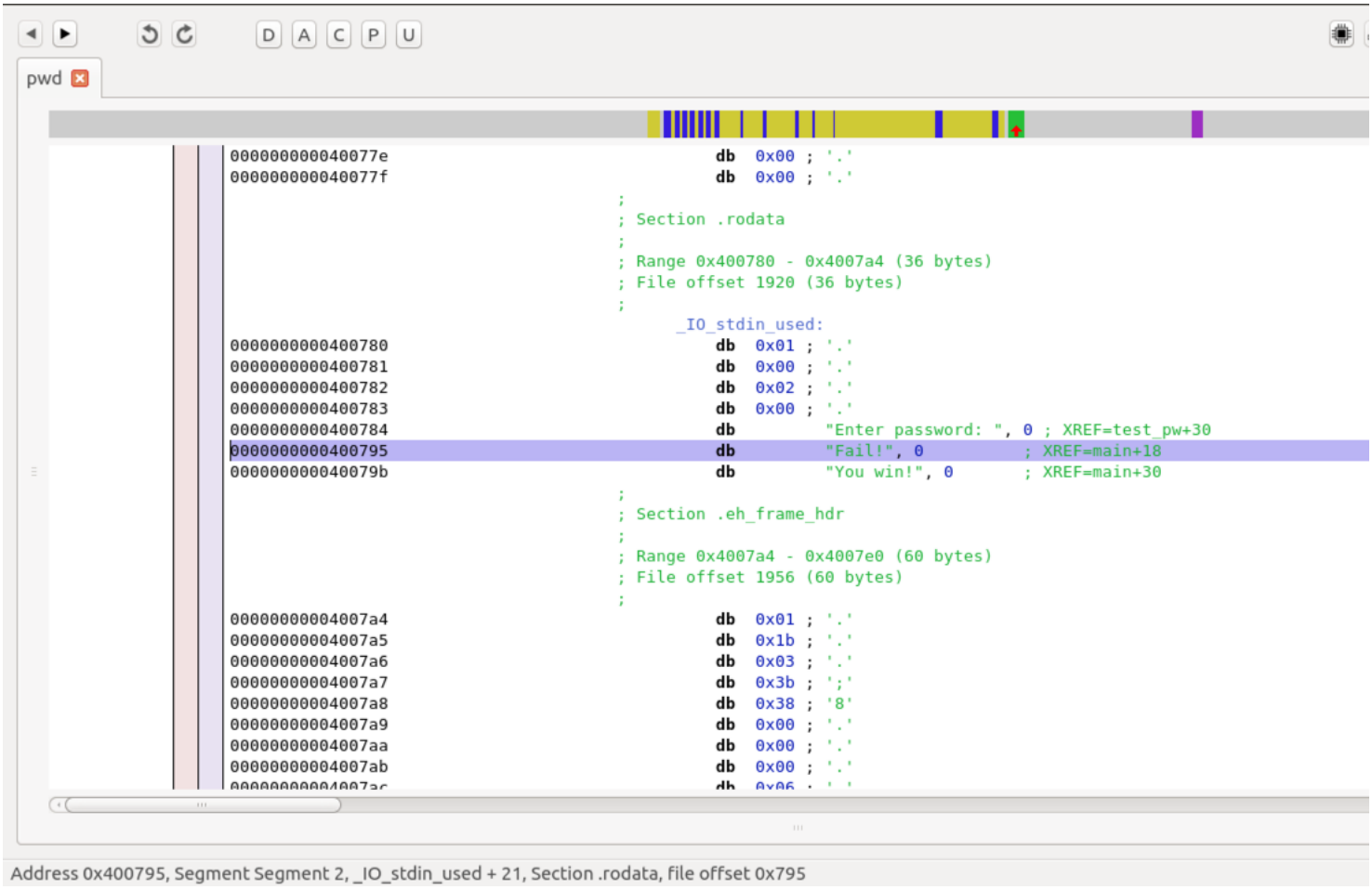
The yellow-shaded region of assembly language in the image above is a "Procedure" -- code Hopper was able to understand.

The regions with a white background above and below the yellow-shaded region are "Code" regions--they appear to be assembly instructions, but Hopper isn't sure what they are for.

Viewing ASCII Strings

In the Navigation bar, drag the little red arrow into the green bar.

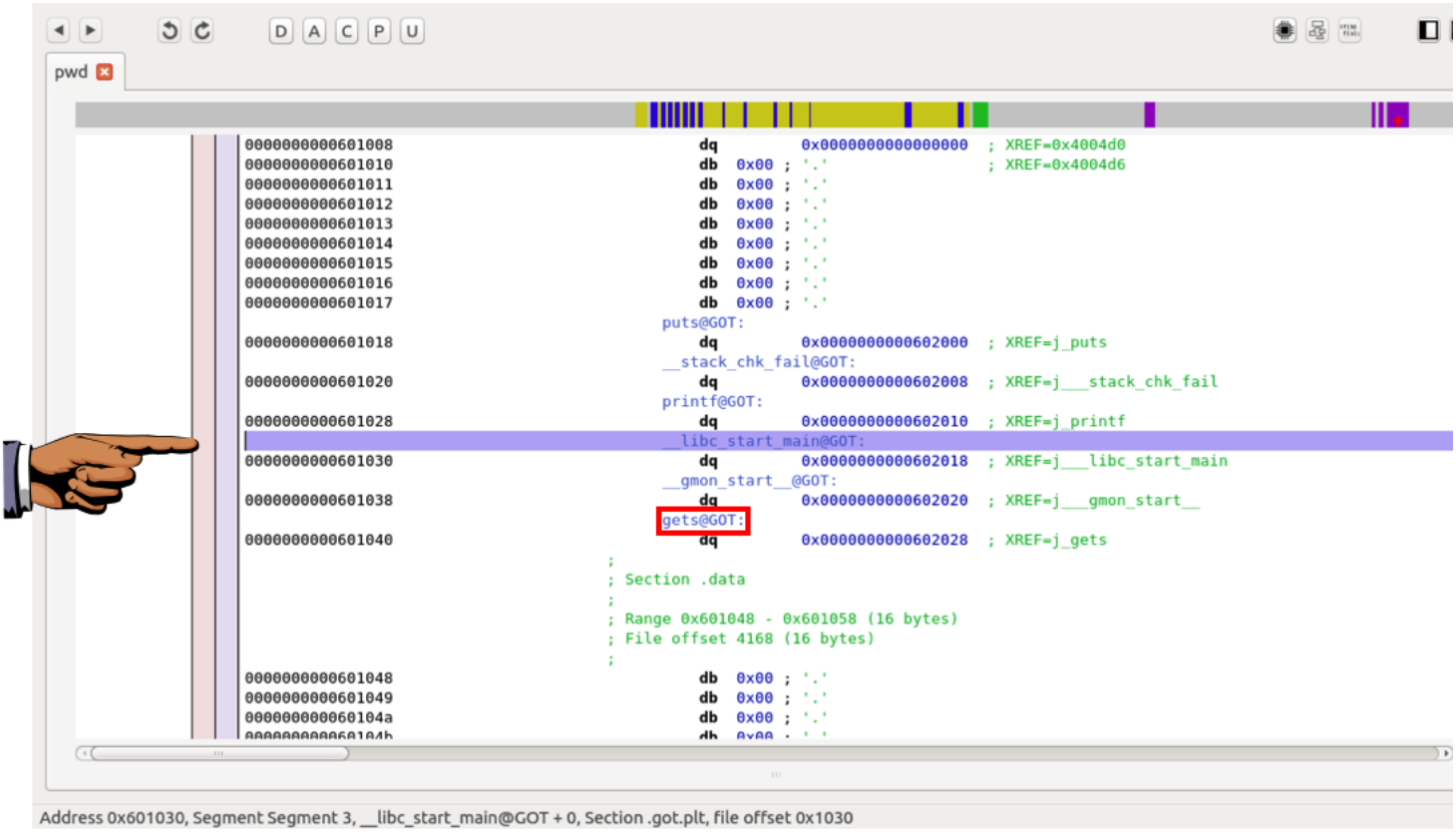
This section contains string constants, such as "**Enter password**" and "**Fail!**", as shown below.



Viewing Data

In the Navigation bar, drag the little red arrow into the purple bar at the far right, as shown below.

This section contains the Global Offset Table, which we have used before in exploitation, as shown below.



Saving a Screen Image

Make sure **puts@GOT** is visible, as shown above.

Press the **PrintScrn** key to copy the whole desktop to the clipboard.

YOU MUST SUBMIT A FULL-SCREEN IMAGE FOR FULL CREDIT!

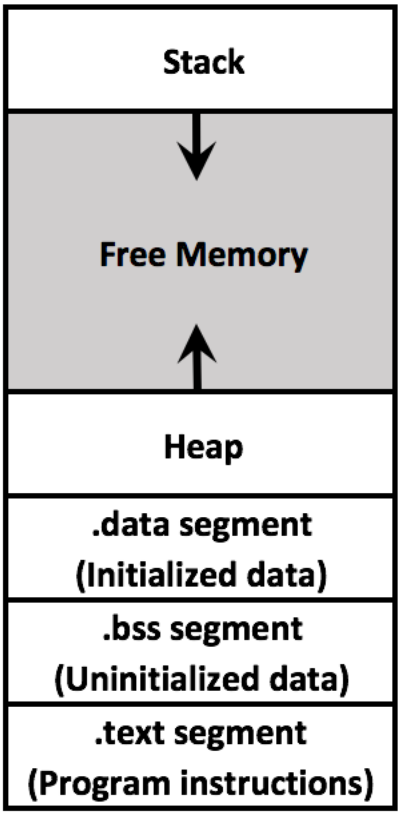
Paste the image into Paint.

Save the document with the filename "**YOUR NAME Proj 4xa**", replacing "YOUR NAME" with your real name.

Pass 2: Segments, Sections, Symbols, & Strings

Memory Layout

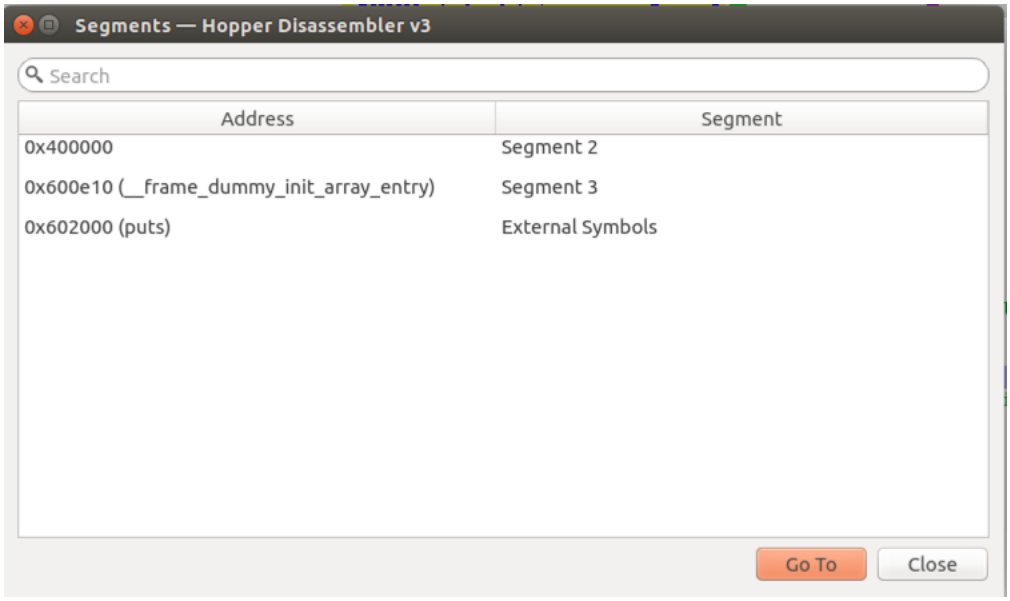
Here are the main sections of memory used by a Linux executable:



Navigating by Segments

From the Hopper menu bar, click **Navigate**, "**Show Segment List**".

A "Segments" window appears, as shown below.

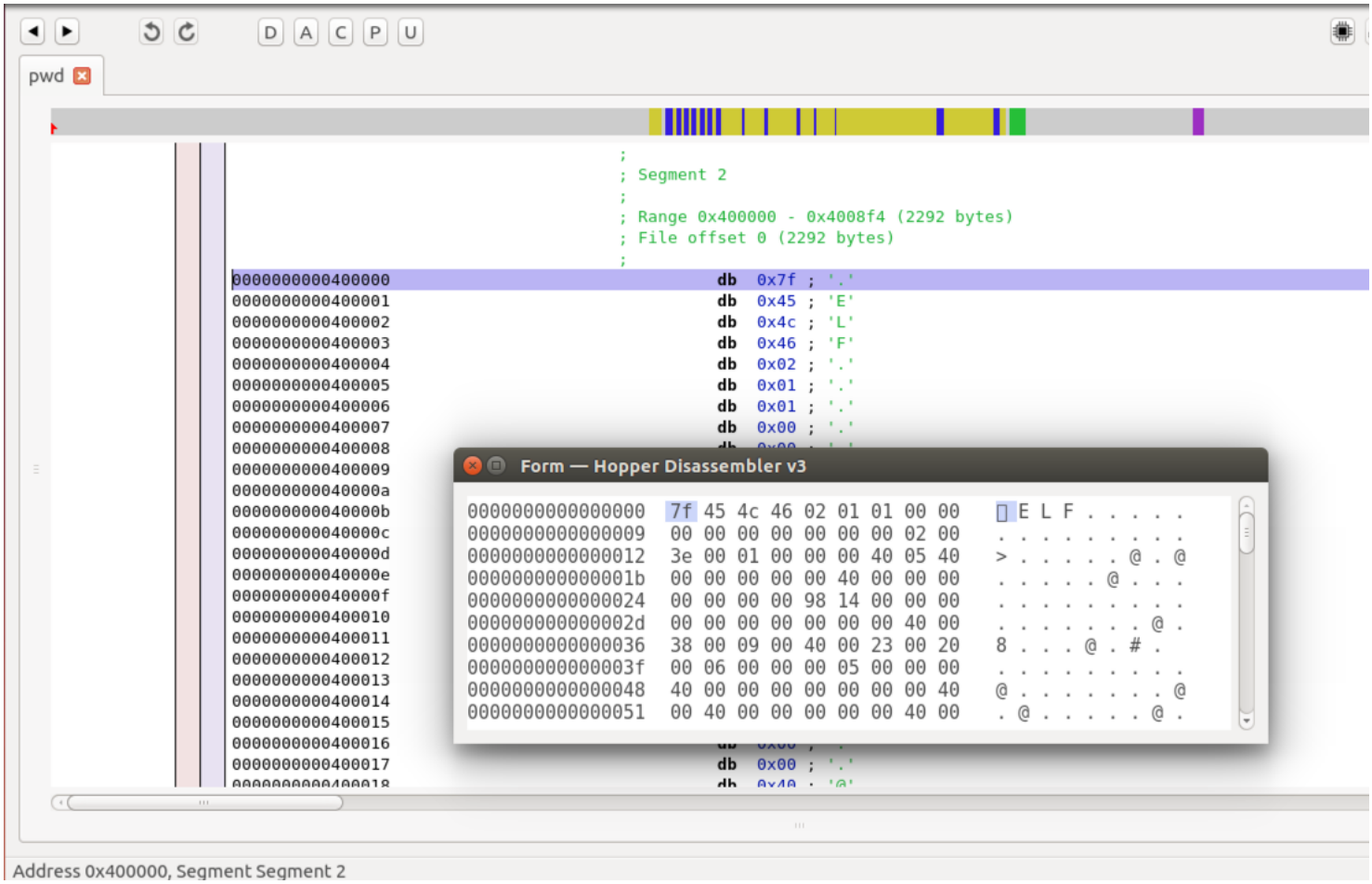


This isn't much use for understanding program flow, but you can see the start of the program in memory.

In the Segments box, click **0x400000** and click the "**Go To**" button.

A series of bytes appears, beginning with ".ELF", as shown below.

To see the code in a more readable view, click **Windows**, "**Show Hexadecimal Editor**".



Close the "Form" window (the Hexadecimal Editor).

Navigating by Sections

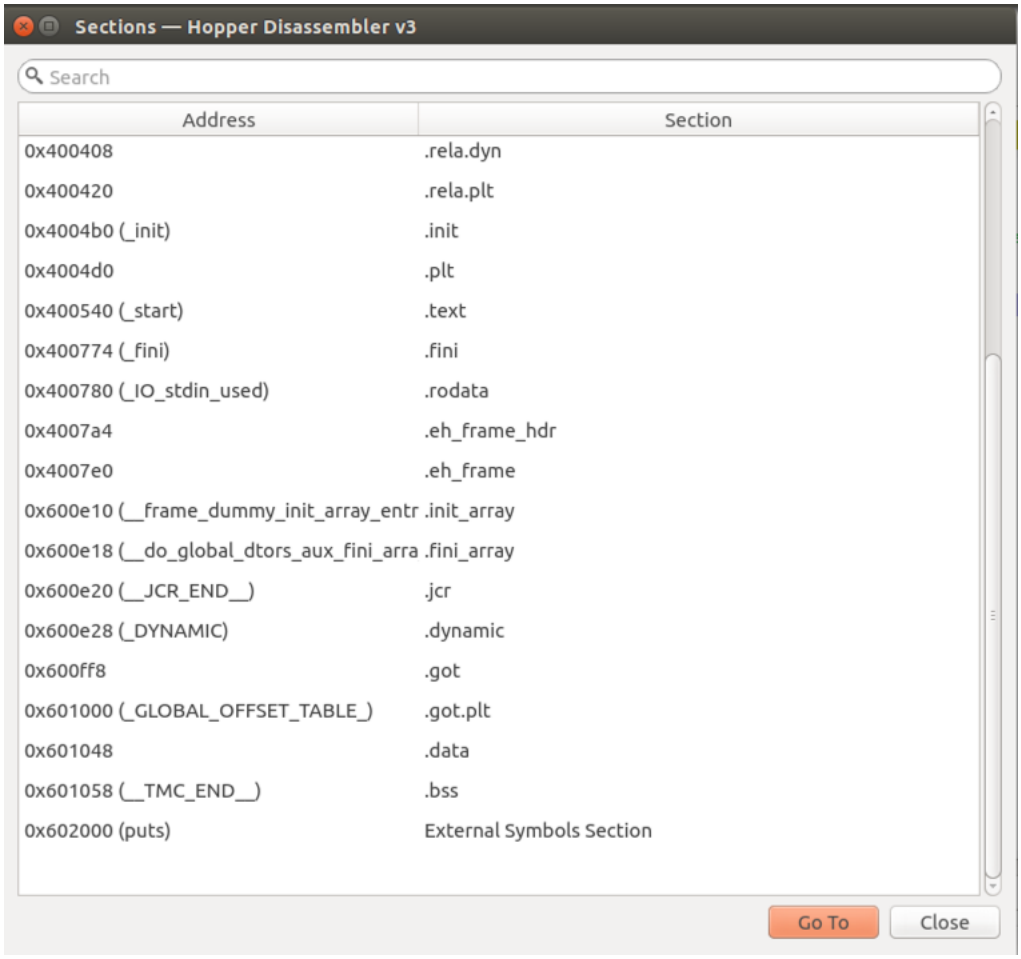
From the Hopper menu bar, click **Navigate**, "**Show Section List**".

A "Sections" window appears, as shown below.

This has several familiar items in it:

- **_init** : prepares to start the program
- **_start** : (**.text** section) More preparation to launch the program
- **_GLOBAL_OFFSET_TABLE** : (**.got.plt** section) pointers to library functions, which we have exploited in the past

Note that the Stack and the Heap aren't shown--those sections won't exist until we run the program. So far, we have been performing *static analysis*--looking at "dead code".



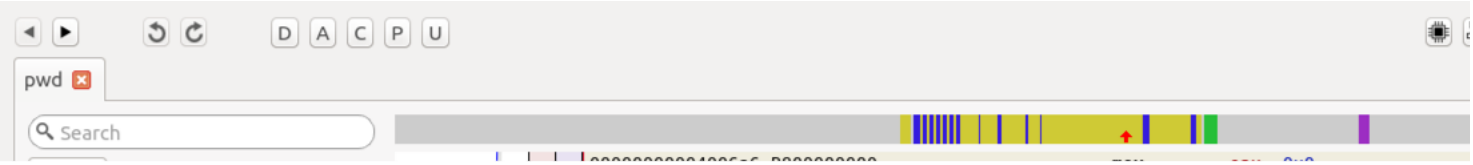
Close the "Sections" window.

Using Symbols

At the top right, click the leftmost of the three "**Show/Hide Panes**" buttons. This shows the "**Symbols & Strings**" pane, as shown below.

On the left side, a list of friendly Labels appears.

In the left pane, click **main**. The assembly code for the main() routine appears, as shown below.



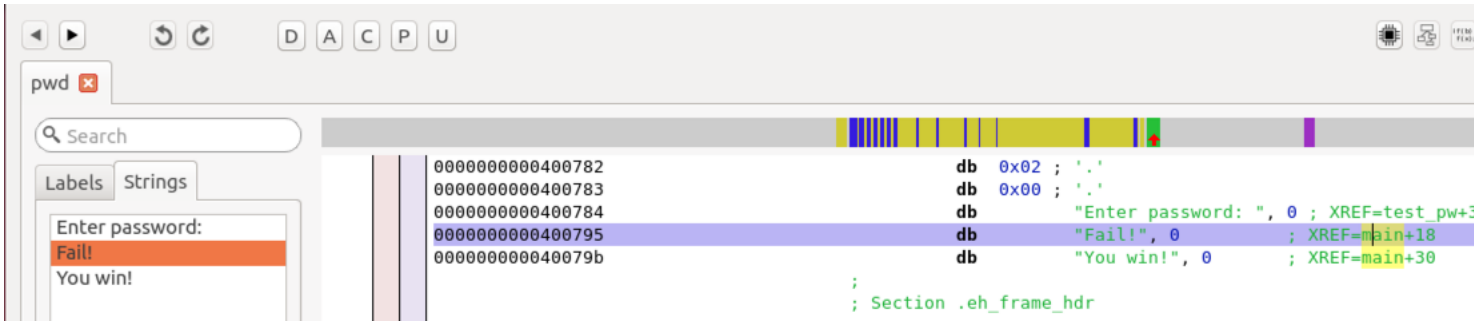
In the left pane, click **test_pw**. The assembly code for the test_pw() routine appears, as shown below.

Using Strings

In the left pane, click the **Strings** tab.

Click **Fail!**.

The right pane shows the ASCII string "Fail!", as shown below.

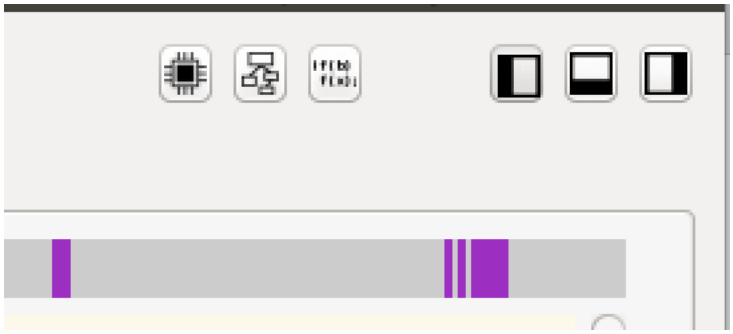


Suppose we want to trick the code into accepting any password, and not printing "Fail!". We'd like to see the code that uses the string "Fail!".

In the right pane, to the right of the word "Fail!", there is a comment beginning with **XREF=**. Double-click the "**main+18** text. The code appear in main() that prints "Fail!", as shown below.

Control Flow Graph

At the top right of Hopper, click the "**Control Flow Graph**" button, as shown below.



The Control Flow Graph appears, as shown below.

It shows that **main** calls a subroutine named **test_pw**, then tests the return value, and jumps to one of two **puts** calls to print messages.

The Control Flow Graph is pretty, but it doesn't show which choice prints "Win!" and which prints "Fail!".

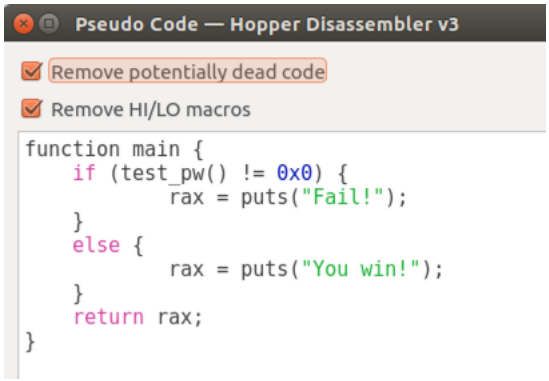
Close the Control Flow Graph.

Pseudocode

At the top right of Hopper, click the **Pseudocode** button, as shown above.

The Pseudocode window appears, containing code written in a C-like language, as shown below.

This is much easier to read! It shows that the program prints "You win!" when test_pw returns zero.



Close the Pseudocode window.

Understanding the Assembly Code

Now the assembly code is easier to understand. Starting at address **4006d1**, the code calls **test_pw**. It then uses **test** to see if the return value is zero. If it is, it jumps to location **4006e6** and prints "You Win!". Otherwise it doesn't jump, and prints "Fail!".

So a simple way to make the program accept any password is to fill the bytes outlined in green below with NOPs.

Saving a Screen Image

Make sure the hex codes starting with **BF95** and ending with **EB0A** are visible, as shown above.

Press the **PrintScrn** key to copy the whole desktop to the clipboard.

YOU MUST SUBMIT A FULL-SCREEN IMAGE FOR FULL CREDIT!

Paste the image into Paint.

Save the document with the filename "**YOUR NAME Proj 4xb**", replacing "YOUR NAME" with your real name.

Exiting Hopper

The paid version of Hopper lets you modify code and save the modified version, but not the free demo version.

Close Hopper.

Modifying the Executable

In a Terminal window, execute this command to install hexedit:

```
apt-get install hexedit -y
```

Enter the password **student** when you are prompted to.

In a Terminal window, execute these commands to copy the **pwd** executable to a new file named **pwd2**, and open it in the hexedit hex editor:

```
cp pwd pwd2

hexedit pwd2
```

The binary opens in hexedit, as shown below.

The first four characters are **.ELF**, shown on the right side in ASCII.

In hexedit, press **Ctrl+S**.

Enter this "hexa string":

```
BF95
```

Press **Enter**.

The cursor moves to location 6DA, as shown below.

Carefully type **90** over twelve bytes, as shown below.

To save the file, press **Ctrl+X**, **Y**, **Enter**.

In a Terminal window, execute this command to run the file:

```
./pwd2
```

Enter any password, such as **YOURNAME**. You win, as shown below.

```
student@ubuntu:~/Documents$ ./pwd2
Enter password: YOURNAME
You win!
student@ubuntu:~/Documents$
```

Pass 3: Debugging

Hopper provides a graphical interface to the gdb debugger. We'll use that next.

Starting the Hopper Debugger

From the Ubuntu desktop, at the top left, click the square reddish **Search** button.

In the search field, type

```
hopper
```

In the search results, click "**Hopper Debugger v3**", as shown below.

A box appears, saying "Server is running..." as shown below.

Leave this box open.

Starting Hopper

From the Ubuntu desktop, at the top left, click the square reddish **Search** button. In the search results, click "**Hopper Disassembler v3**"

In the "Registration" box, click "**Try the Demo**".

Hopper opens. From the Hopper menu bar, click **File**, "**Read Executable to Disassemble...**".

Navigate to the **pwd** file you created above and double-click it.

In the "Read Executable" box, click **OK**.

Setting a Breakpoint

Before opening the debugger, we'll set a breakpoint in Hopper.

In the "Symbols & Strings" pane, on the **Tags** tab, click **main**.

In the right pane, in the reddish vertical stripe, next to the first instruction in main, click the mouse. A red dot appears, showing that this is now a breakpoint, as shown below.

Starting the Debugger

At the top right of Hopper, click the **Debugger** button, as shown below.

A GDB window appears, as shown below.

The most useful buttons are labelled below.

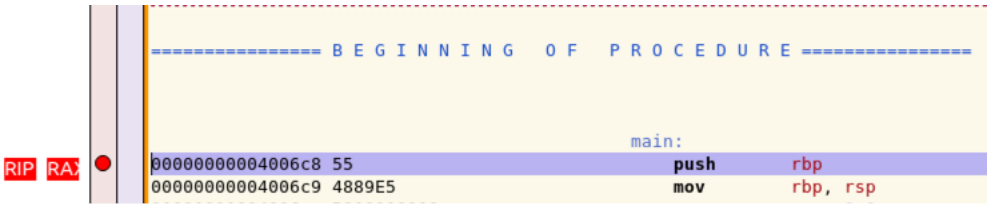
Starting the Program

In the GDB window, click the **Continue** button.

The program launches, and stops at your breakpoint.

The disassembler window labels the breakpoint with a red **RIP** marker, indicating that the Instruction Pointer is here, as shown below.

It also labels this line with a red **RAX**.



The GDB window shows the current contents of the processor's registers.

As shown below, both RIP and RAX have the same value--the address of the breakpoint.

Troubleshooting

If you make any sort of mistake using the debugger, you cannot easily close it and restart it.

Instead, you must use command-line utilities to kill all hopper processes, as explained in the "Exiting the Debugger" section at the end of these instructions.

Using "Step into"

In the GDB window, click the "**Step into**" button.

In the lower left of the window, the "Callstack" pane now shows a location of }**main + 0x1**", as shown below.

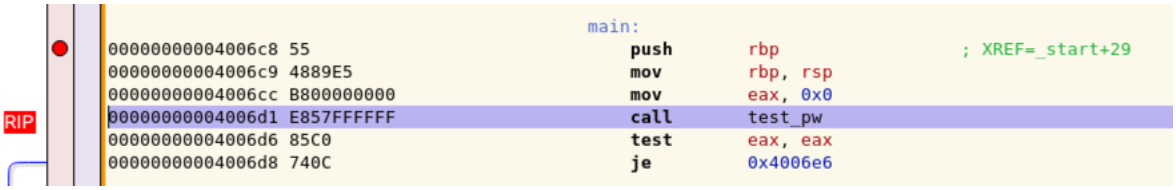
The Disassembler window also shows that the program has moved forward one instruction, as shown below.

The red **RIP** has moved down one line, and the red **RAX** still points to the first command in main(), as shown below.

In the GDB window, click the "**Step into**" button twice more.

In the lower left of the window, the "Callstack" pane now shows a location of }**main + 0x9**", as shown below.

The Disassembler window now shows that we are at the "**call test_pw**" instruction, as shown below.



In the GDB window, click the "**Step into**" button once more.

In the lower left of the window, the "Callstack" pane now shows two lines: we are still in **main**, but also in the subroutine **test_pw**, called by **main**, as shown below.

This is the meaning of "Step into" -- it executes only a single instruction, even if that instruction is a **call** and enters a new subroutine.

The Disassembler window now shows that we are inside the "**call test_pw**" function, as shown below.

In the GDB window, click the "**Step into**" button nine more times.

The Disassembler window shows that we about to call the **j_printf** function, as shown below.

In the GDB window, click the "**Step into**" button once more.

In the lower left of the window, the "Callstack" pane now shows three lines: we are still in **main**, and in the subroutine **test_pw**, but we are also in the subroutine **j_printf**, as shown below.

The Disassembler window now shows that we are inside the "**j_printf**" function, as shown below.

Using "Step out"

We are about to enter the Global Offset Table and then enter the C library.

We aren't interested in debugging the C library--we want to debug the C code we wrote. So it doesn't make sense to keep on using "Step in".

What we really want to do is "Step out", to get back to **test_pw**. In the GDB window, click the "**Step out**" button once.

In the lower left of the window, the "Callstack" pane now shows only two lines again: **main**, and **test_pw**, as shown below.

Using "Step over"

This is the level we want to stay at, inside the code we wrote.

To stay at this level, we use the "Step over" button.

In the GDB window, click the "**Step over**" button three times.

In the lower left of the window, the "Callstack" pane now shows two lines, but they are grayed out, as shown below.

The Disassembler window no longer shows which instruction we are on, as shown below.

What has happened? We have stepped over the **j_gets** function, and the program is waiting for user input from inside that function.

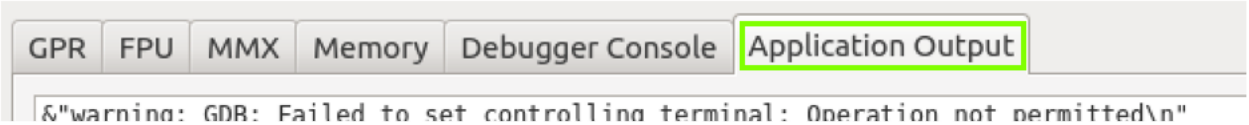
Interacting with the Console

In the GDB window, click the "**Application Output**" tab.

Here you see a warning message, followed by the "**Enter password:**", prompt, as shown below.

In the bar at the bottom, type in your name (not the literal text "YOURNAME", as shown below) and press **Enter**.

Your name appears inside the window, as shown below.



Saving a Screen Image

Make sure **YOURNAME** and "**Application Output**" are visible, as shown above.

Press the **PrintScrn** key to copy the whole desktop to the clipboard.

YOU MUST SUBMIT A FULL-SCREEN IMAGE FOR FULL CREDIT!

Paste the image into Paint.

Save the document with the filename "**YOUR NAME Proj 4xc**", replacing "YOUR NAME" with your real name.

Exiting the Debugger

The clean way to exit is to first click the square **Stop** button in the debugger, then click the red **X** in the top left to close the debugger window, and then close the Hopper disassembler.

If that process fails (and it often does), do this:

In a Terminal window, execute this command:

```
ps aux | grep hopper
```

Now use the **kill** command to kill each process, one by one, by process ID number, as shown below.

Turning in your Project

Email the images to **cnit.126sam@gmail.com** with the subject line: **Proj 4x from YOUR NAME**

Sources

Hopper Tutorial

The Hopper Disassembler

Binary Patching, The Brute Force of Reverse Engineering with IDA and Hopper (And a Hex Editor).

Data segment (Wikipedia)

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