Computer Security

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COS 217

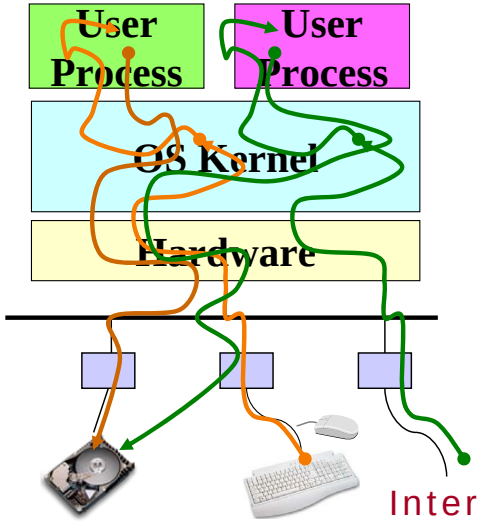
Interacting with the world

Keypress goes to OS kernel

OS looks up which window has "keyboard focus," routes to appropriate user process's stdin

User process does fprintf (asks OS to write to disk)

OS writes to disk



TCP packet goes to OS kernel

OS looks up which process is listening on that port, sends data to stdin

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OS writes to disk

Protection mechanisms

Keypress goes to OS kernel

OS looks up which window has "keyboard focus," routes to appropriate user process's stdin

User process does fprintf (asks OS to write to disk)

OS writes to disk

- Not to user process directly!
- Not to unauthorized user process!
- User process can't access disk directly!
- OS writes only to files that user process has privileges to open!

TCP packet goes to OS kernel

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User process does fprintf (asks OS to write to disk)

OS writes to disk

What prevents user process from directly accessing keyboard & disk?

- Input/output instructions are privileged instructions, attempting to execute them in unprivileged mode will result in trap to operating system
- Input/output device registers may be memory-mapped; virtual-memory system doesn't map those pages into user space
- Virtual-memory system prevents user process from modifying OS memory (can't fool OS into performing unauthorized services)
- Virtual-memory prevents user processes from modifying each others' memory (can't fool other process into writing bad data to its files on disk)

How attackers defeat protection

- Make the protection mechanism fail
  - (exploit bugs in protection software)
- Operate politely through the protection mechanism, manipulate semantics of application to obtain services
  - (exploit bad design of application)

A nice little program

```
% a.out
What is your name?
John Smith
Thank you, John Smith.
%
```

```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```


Why did this program crash?

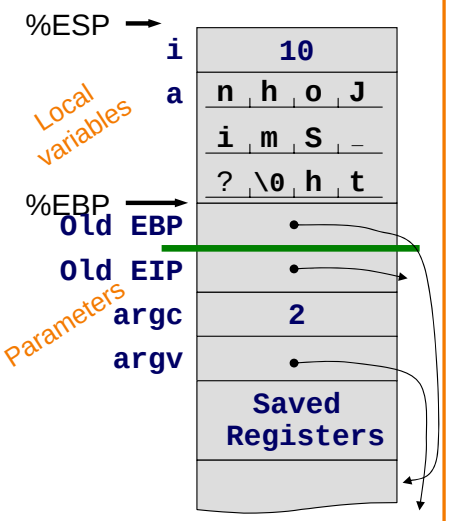
```
% a.out
What is your name?
adsli57asdkhj5jklds;ahj5;klsaduj5klysdukl5aujksd5ukals;5uj;akukla
Segmentation fault
%
```

```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```


Stack frame layout

```
% a.out
What is your name?
John Smith
Thank you, John Smith.
%
```

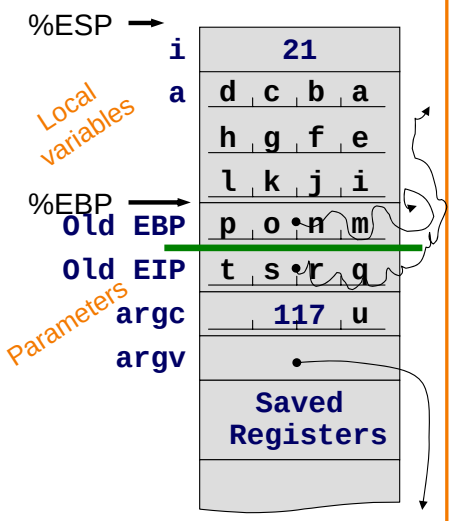
```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```



Buffer overrun

```
% a.out
What is your name?
abcdefghijklmnopqrstu
Segmentation fault
%
```

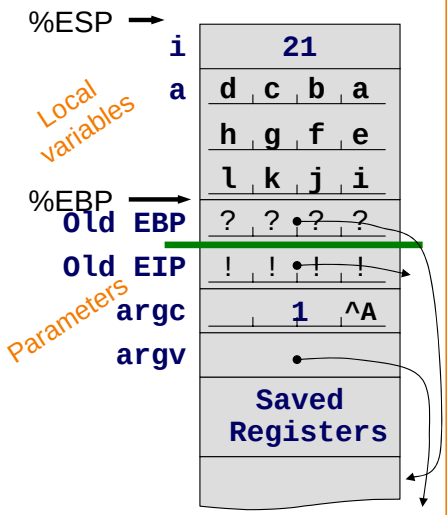
```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```



Innocuous? buffer overrun

```
% a.out
What is your name?
abcdefghijkl????!!!!^A
%
```

```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```

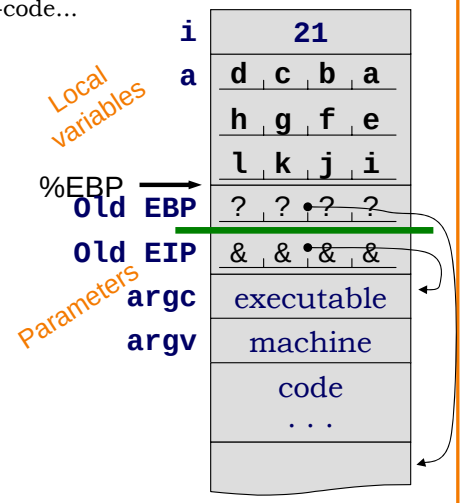


Cleverly malicious?
Maliciously clever?

Buffer overrun

```
% a.out
What is your name?
abcdefghijkl????&&&&executable-machine-code...
How may I serve you, master?
%
```

```
#include <stdio.h>
int main(int argc, char **argv) {
  char buffer[30];  int i;
  printf("What is your name?\n");
  for (i=0; ; i++) {
    int c = getchar();
    if (c=='\n' || c ==EOF) break;
    a[i] = c;
  }
  a[i]='\0';
  printf("Thank you, %s.\n",a);
  return 0;
}
```



Buffer-overrun vulnerabilities

Keypress goes to OS kernel

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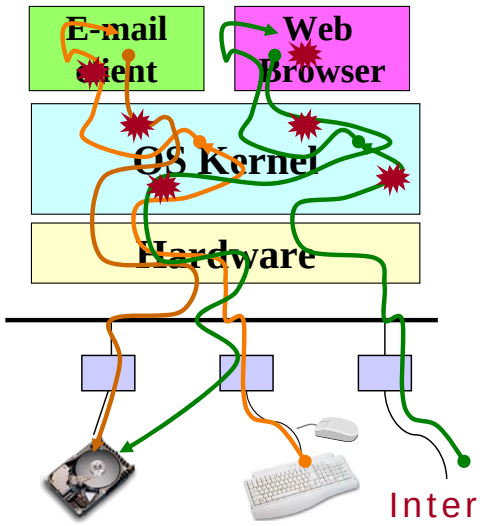
OS writes to disk



TCP packet goes to OS kernel

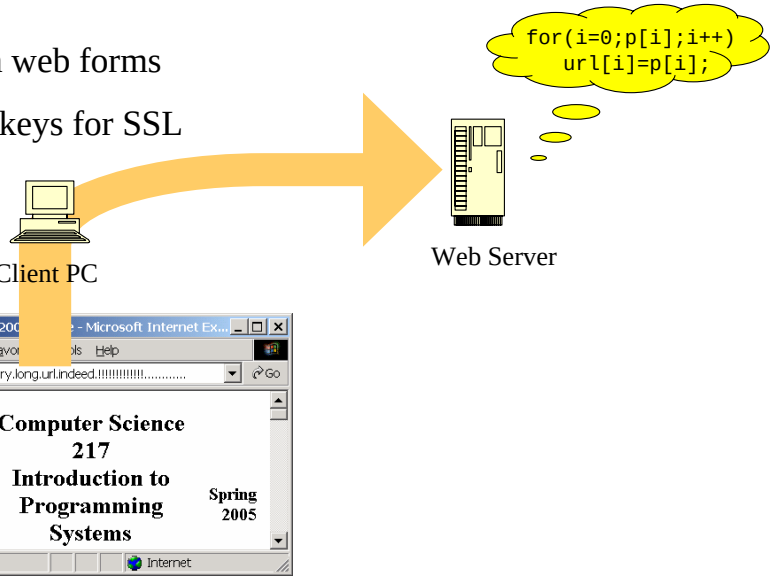
OS looks up which process is listening on that port, sends data to stdin

User process does fprintf (asks OS to write to disk)

OS writes to disk

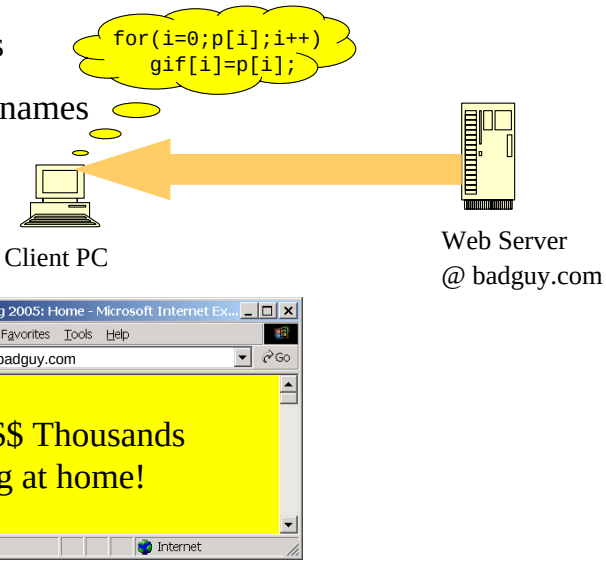
Attacking a web server

- URLs
- Input in web forms
- Crypto keys for SSL
- etc.

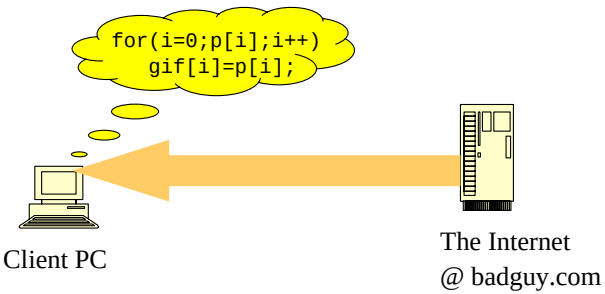


Attacking a web browser

- HTML keywords
- Images
- Image names
- URLs
- etc.



Attacking everything in sight



- E-mail client
- PDF viewer
- Operating-system kernel
- TCP/IP stack
- *Any* application that ever sees input directly from the outside

Your programming assignment

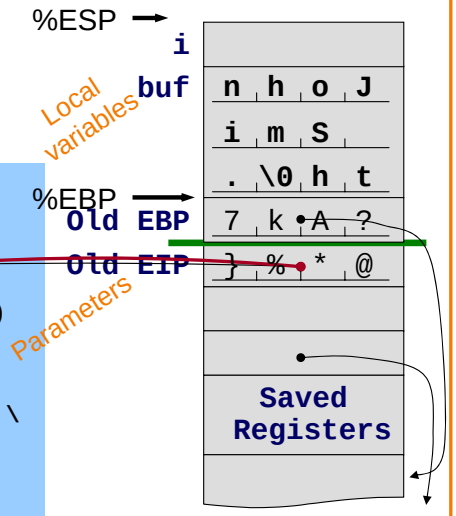
```
% a.out
What is your name?
John Smith
Thank you, John Smith.
I recommend that you get a grade of D on this assignment
%
```

```
char grade = 'D';
int main(void) {
  printf("What is your name?\n");
  readString(Name);
  if (strcmp(Name,"Andrew Appel")==0)
      grade='B';
  printf("Thank you, %s.\n\
         I recommend that you get a grade of %c \
         on this assignment.\n", Name, grade);
  exit(0);
}
```

OK, that's a B...

```
% a.out
What is your name?
John Smith\0.?Ak7@*&%}
Thank you, John Smith.
I recommend ... a grade of B ...
%
```

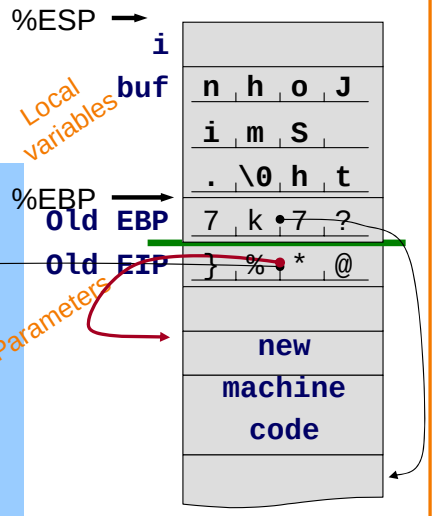
```
char grade = 'D';
int main(void) {
  printf("What is your name?\n");
  readString(Name);
  if (strcmp(Name,"Andrew Appel")==0)
      grade='B';
  printf("Thank you, %s.\n\
         I recommend ... grade of %c \
         ...nment.\n", Name, grade);
  exit(0);
}
```



How about an A?

```
% a.out
What is your name?
John Smith\0.?7k7@*&%}3k1n1l5018
Thank you, John Smith.
I recommend ... a grade of A ...
%
```

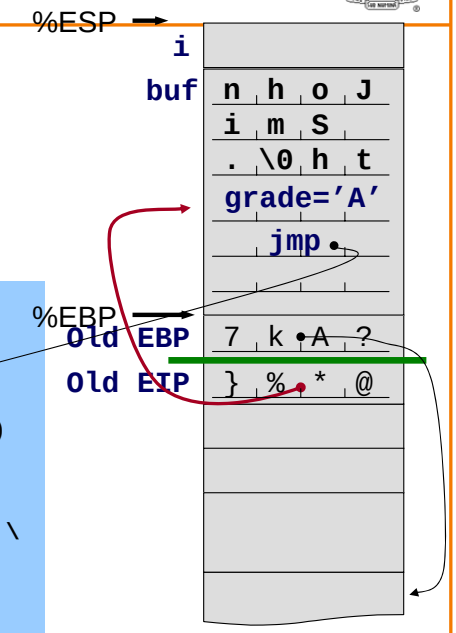
```
char grade = 'D';
int main(void) {
  printf("What is your name?\n");
  readString(Name);
  if (strcmp(Name,"Andrew Appel")==0)
      grade='B';
  printf("Thank you, %s.\n\
         I recommend ... grade of %c \
         ...nment.\n", Name, grade);
  exit(0);
}
```



A simpler solution

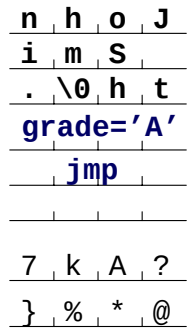
```
% a.out < getA
What is your name?
Thank you, John Smith.
I recommend ... a grade of A ...
%
```

```
char grade = 'D';
int main(void) {
  printf("What is your name?\n");
  readString(Name);
  if (strcmp(Name,"Andrew Appel")==0)
      grade='B';
  printf("Thank you, %s.\n\
         I recommend ... grade of %c \
         ...nment.\n", Name, grade);
  exit(0);
}
```



The file getA

```
% a.out < getA
What is your name?
Thank you, John Smith.
I recommend ... a grade of A ...
%
```



getA:

```
John Smith\0.movl 'A',grade; jmp wherever0000?Ak7@*%}
```

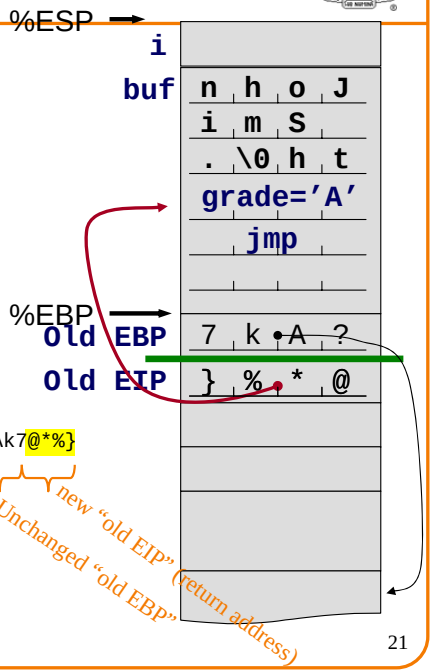
New machine code

Size of buffer

Unchanged "old EBP"

new "old EIP" (return address)

What value to use for new return address?



- Computers are deterministic
- Operating system initializes stack pointer to predictable value
- Stack grows deterministic amount from process entry to call of **readString**

getA:

```
John Smith\0.movl 'A',grade; jmp wherever0000?Ak7@*%}
```

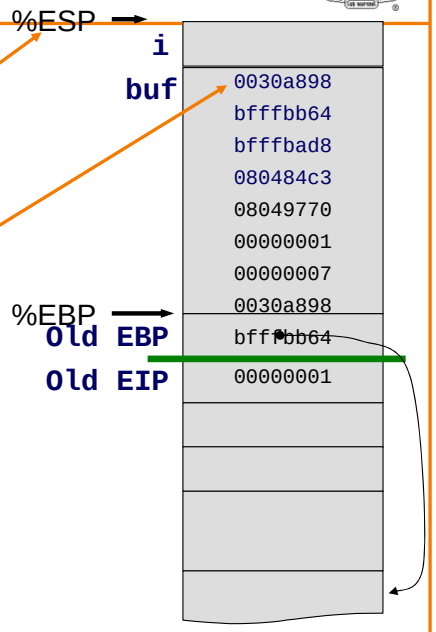
New machine code

Size of buffer

new "old EIP" (return address)

Unchanged "old EBP"

Use gdb to find out




```
% gdb a.out
GNU gdb Red Hat Linux
Copyright 2004 Free Software Foundation
(gdb) break readString
Breakpoint 1 at 0x804843d
(gdb) run
Starting program: a.out
(no debugging symbols found)...
What is your name?
Breakpoint 1, 0x0804843d in readString ()
(gdb) x/10x $esp
0xbfffbab0:     0x0030a898      0xbfffbb64
                0xbfffbad8      0x080484c3
0xbfffbac0:     0x08049770      0x00000001
                0x00000007      0x0030a898
0xbfffbad0:     0xbfffbb64      0x00000001
(gdb)
```


Defenses against this attack

- Best: program in languages that make array-out-of-bounds impossible (Java, C#, ML, ...)
- Good: use discipline in C programming always to check bounds of array subscripts
- Better than nothing: Operating system randomizes initial stack pointer
  - How to attack it:

```
John Smith\0.....nop;nop;nop;nop;...;nop;do_bad_things;exit(0)
```

Can jump anywhere in here, so don't have to know exact value of stack pointer

Defenses against this attack

- Best: program in languages that make array-out-of-bounds impossible (Java, C#, ML, ...)
- Good: use discipline in C programming always to check bounds of array subscripts
- Better than nothing: Operating system randomizes initial stack pointer
  - How to attack it:

```
John Smith\0.....nop;nop;nop;nop;...;nop;do_bad_things;exit(0)
```

For this assignment, you don't need such a fancy attack.

The hello.c program copies the buffer to the global bss data space (into the **Name** array) so you can just jump there, don't have to know the stack height.

Defenses against this attack

- Best: program in languages that make array-out-of-bounds impossible (Java, C#, ML, ...)
- Good: use discipline in C programming always to check bounds of array subscripts
- Better than nothing: Operating system randomizes initial stack pointer
- Better than nothing: Prohibit execution of machine code from the stack and data segments
  - Problem 1: backward compatibility
  - Problem 2: need VM hardware with "exec/noexec" bit on a page by page basis; x86/Pentium family lacks this
  - Amazing hack solution: use obsolete "segment registers" left over from 80286.

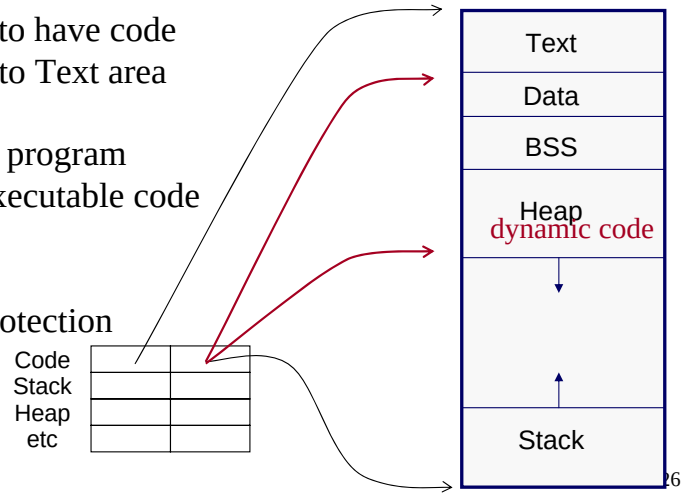
Segment register defense

- In normal (modern) usage, all segment registers point to entire range of addressable memory, `0` to `0xffffffff`

• Amazing hack is to have code segment point just to Text area

• Problem: what if program wishes to create executable code on the fly?

• Solution: undo protection



At your service...

- For your convenience in this programming assignment, we have turned off the segment-register defense

```
char grade = 'D';
int main(void) {
    mprotect(((unsigned)Name) & 0xfffff000,1,
             PROT_READ | PROT_WRITE | PROT_EXEC);
printf("What is your name?\n");
  readString(Name);
  if (strcmp(Name,"Andrew Appel")==0)
      grade='B';
  printf("Thank you, %s.\n\
         I recommend ... grade of %c \
         ...nment.\n", Name, grade);
  exit(0);
}
```


How to get started

To succeed on this programming assignment,

- Use **gdb** to map out where things are
  - Stack frame of "readString"
  - Stack frame of "main" underneath it
  - Global data area containing "grade" and "Name"
  - Machine code for "main"

  Take notes of all these things, by address.
- Write a little assembly-language program
  - Set the "grade" variable to 'A'; jump to wherever
  - Assemble it, maybe even link it into a copy of hello.c, and examine what it looks like using gdb
- Prepare your attack data
  - I found it helpful to write a C program to print out the data string
  - useful functions: printf, putchar, putw

Start early

- Use **gdb** to map out where things are
  - Stack frame of “readString”
  - Stack frame of “main” underneath it
  - Global data area containing “grade” and “Name”
  - Machine code for “main”

  Take notes of all these things, by address.

If possible, get this part done by the time your Weds/Thurs precept meets this week. Feel free to work jointly with another student on this part. Bring your notes with you to precept.