COS 217: Introduction to Programming Systems

The Assignment 6 'B' Attack

PRINCETON UNIVERSITY

A Program

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```


```
$ ./a.out
What is your name?
John Smith
Thank you, John Smith.
The answer to life, the universe, and everything is 42
```

A Reason Why People With Long Names Can't Have Nice Thir

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

```
$ ./a.out
What is your name?
Christopher Moretti
Thank you, Christopher Mor
tti.
The answer to life, the universe, and everything is 6911092
```

?

??? (!)

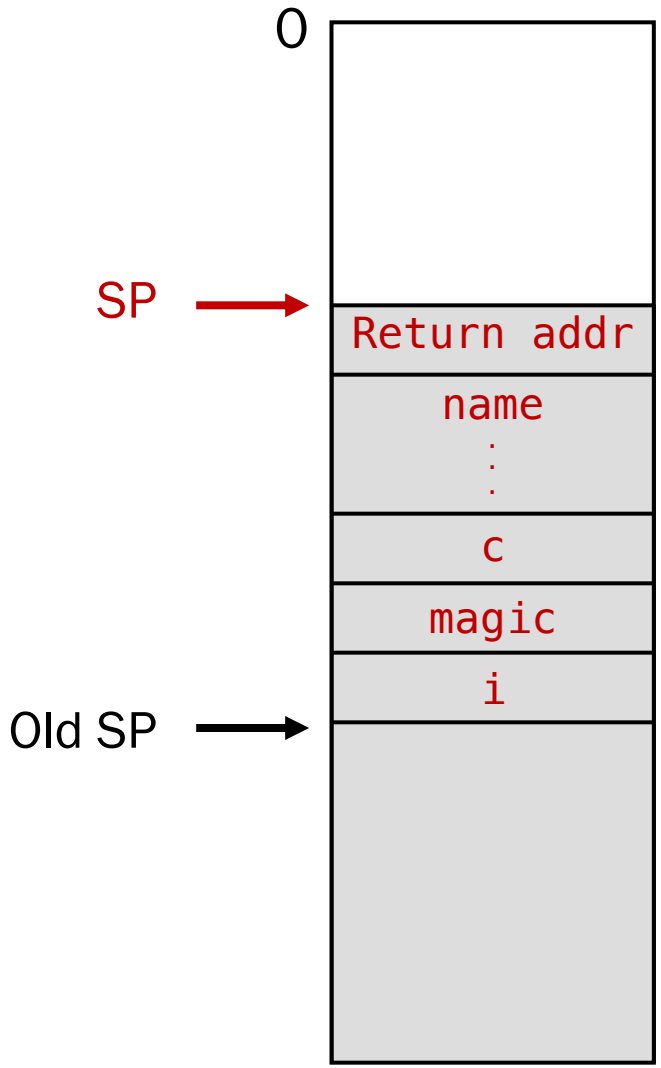
(depending on the area code, this might be an interesting phone number, but probably not one you should call for the answer to life, the universe, and everything)

Explanation: Stack Frame Layout

When there are too many characters, program carelessly writes beyond space "belonging" to name.

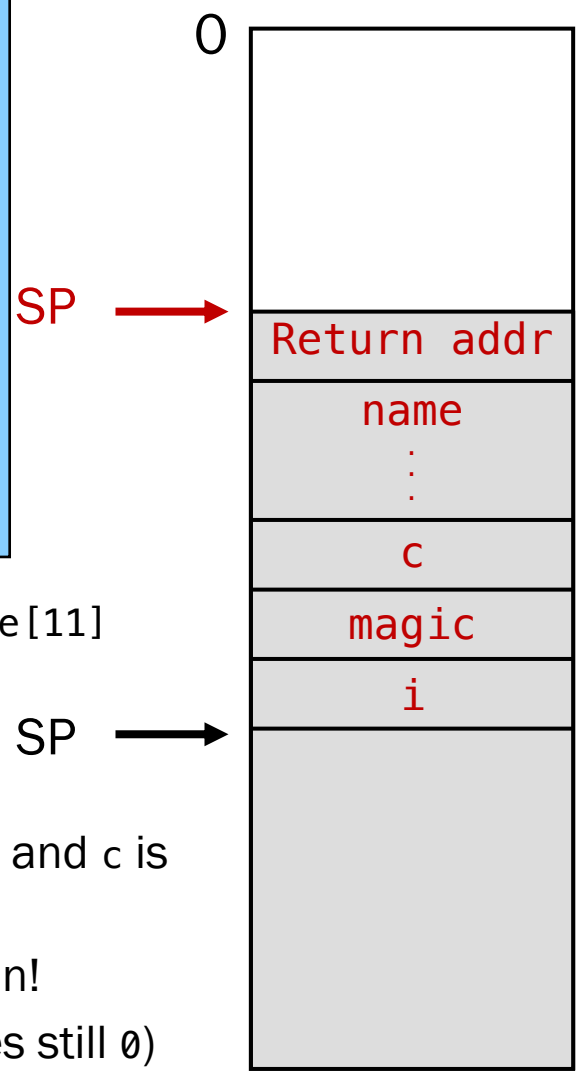
- Overwrites other variables
- This is a *buffer overrun*, or *stack smash*
- The program has a security bug!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```



Example Trace

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```



`Christopher`$_s$ (not `\0` terminated) in `name[0]`–`name[11]`
`Mor` in 3 padding bytes before `c`

Each letter from `getchar` overwrites `c` (it is also overwritten once by `name[i++] = c`, when `i` is 15 and `c` is '`e`') until `c` becomes '`\n`' and the loop ends.

First `t` overwrites `42` with `0x74` ('`t`') – little endian!

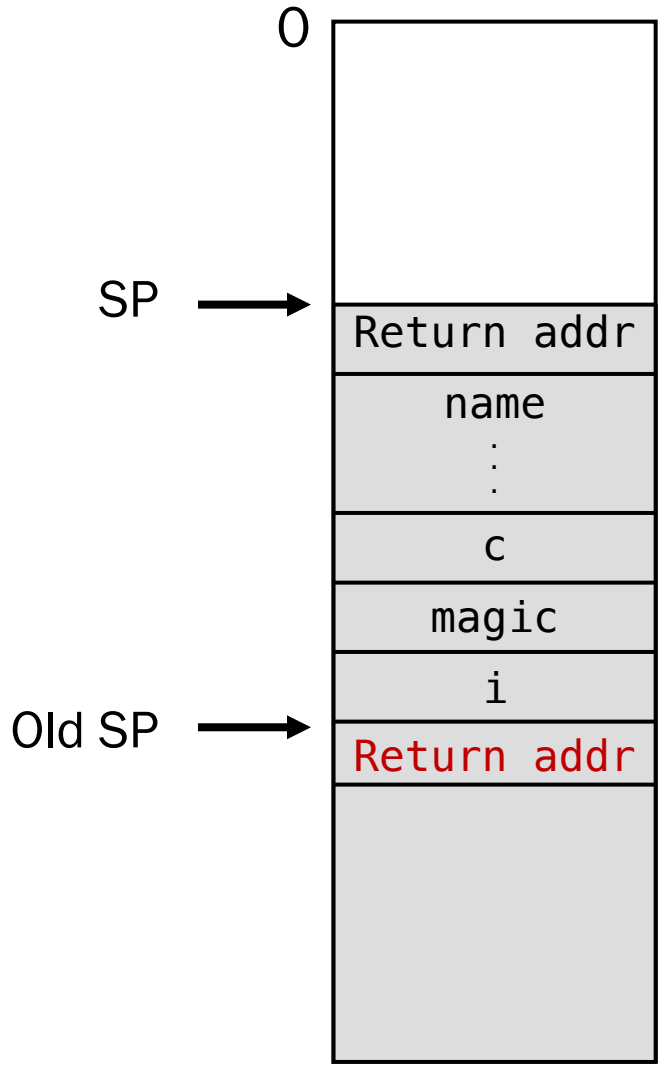
Second `t` makes `magic 29812` (2 high-order bytes still `0`)

Final `i` makes `magic 6911092` (1 high-order byte still `0`)

It Gets Worse...

Buffer overrun can overwrite return address of a previous stack frame!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

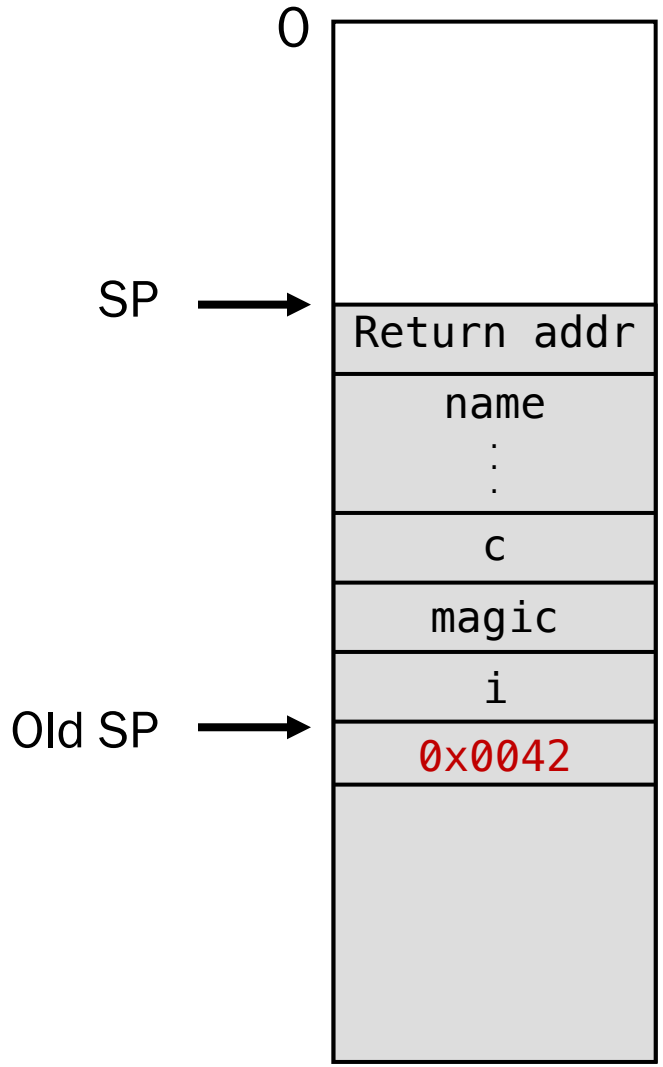


It Gets Worse...

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault,...

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

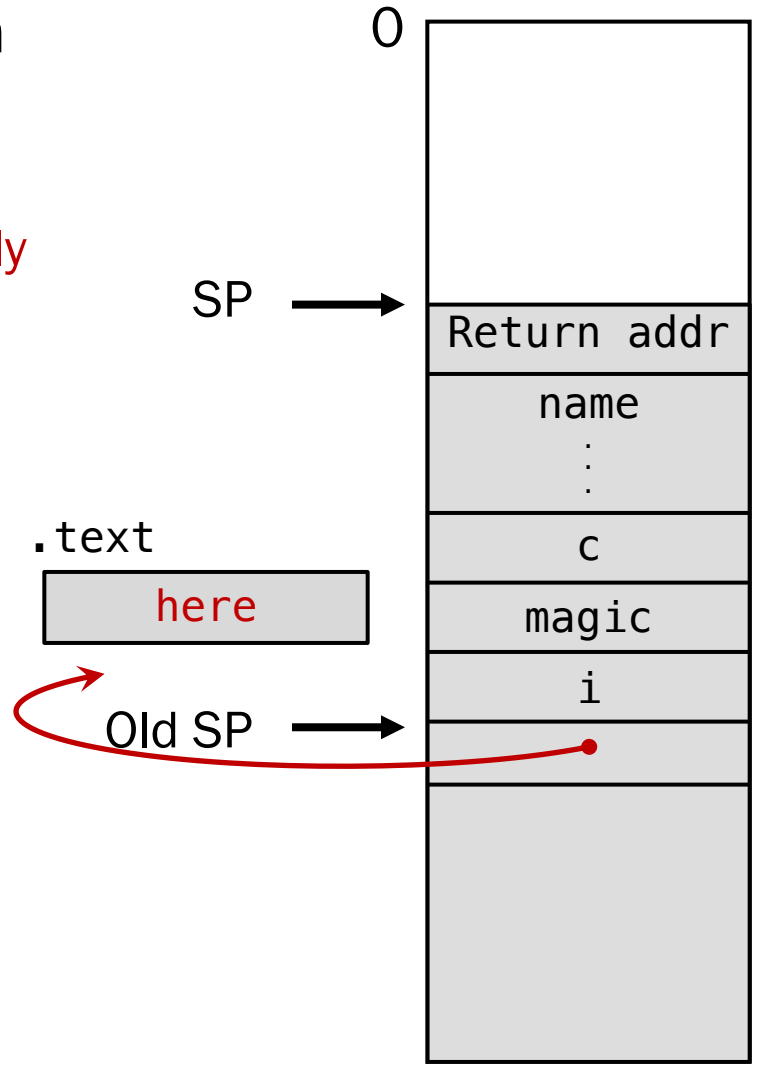


It Gets Much Worse...

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault, or it can cleverly cause unintended control flow!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```

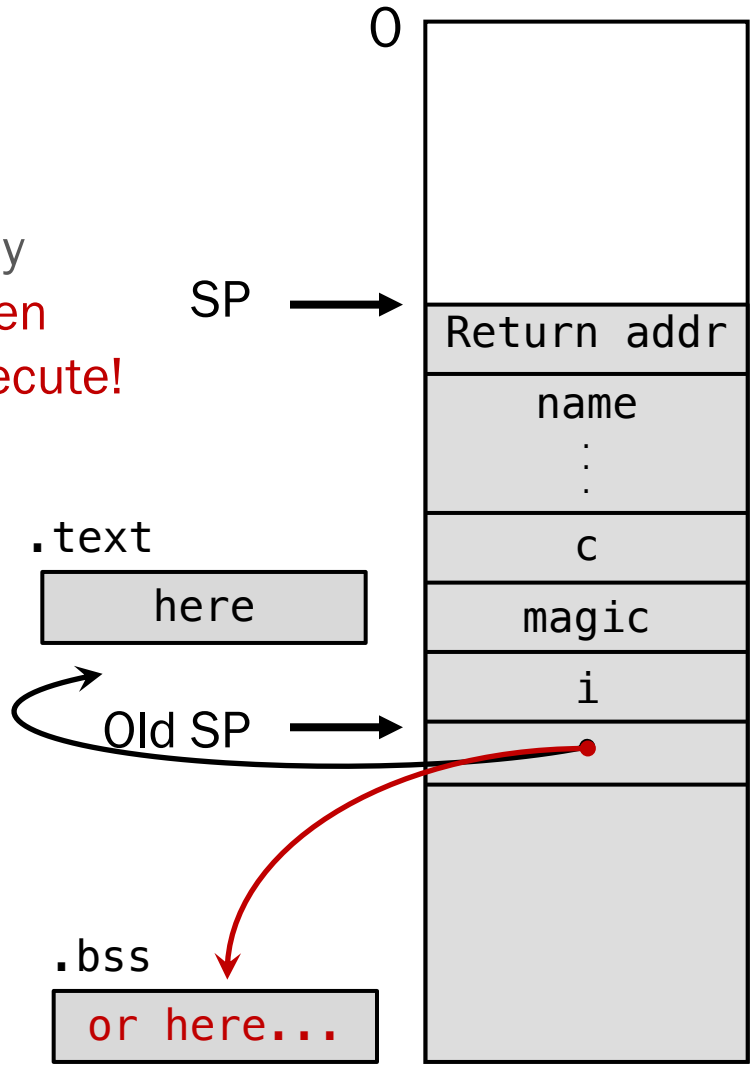


It Gets Much, Much Worse...

Buffer overrun can overwrite return address of a previous stack frame!

- Value can be an invalid address, leading to a segfault, or it can cleverly cause unintended control flow, or even cause arbitrary malicious code to execute!

```
#include <stdio.h>
int main(void)
{
   char name[12], c;
   int i = 0, magic = 42;
   printf("What is your name?\n");
   while ((c = getchar()) != '\n')
      name[i++] = c;
   name[i] = '\0';
   printf("Thank you, %s.\n", name);
   printf("The answer to life, the universe, "
          "and everything is %d\n", magic);
   return 0;
}
```



Defenses Against This Attack

Best: program in languages that make array-out-of-bounds impossible (Java, C#, ML, python, ...)

```
DESCRIPTION
       The  strcpy()  function  copies the string pointed to by src, including
       the terminating null byte ('\0'), to the buffer  pointed  to  by  dest.
       The  strings  may  not overlap, and the destination string dest must be
       large enough to receive the copy.  Beware  of  buffer  overruns!  (See
       BUGS.)

BUGS
       Never use gets().  Because it is impossible to tell without knowing the data in advance how many characters gets() will  read,  and
       because gets() will continue to store characters past the end of the buffer, it is extremely dangerous to use.  It has been used to
       break computer security.  Use fgets() instead.
```

None of these would have prevented the "Heartbleed" attack

If you must program in C: use discipline and software analysis tools to check bounds of array subscripts

Otherwise, stopgap security patches:

- Operating system randomizes initial stack pointer
- "No-execute" memory permission
- "Canaries" at end of stack frames

Assignment 6: Attack the “Grader” Program

```
enum {BUFSIZE = 48};
char grade = 'D';
char name[BUFSIZE];
…
int main(void) {
   mprotect(…);
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Bob
D is your grade.
Thank you, Bob.
$ ./grader
What is your name?
Andrew Appel
B is your grade.
Thank you, Andrew Appel.
```

Assignment 6 : Attack the “Grader” Program

```
/* Prompt for name and read it */
void getName() {
  printf("What is your name?\n");
  readString();
}
```

```
/* Read a string into name */
void readString() {
  char buf[BUFSIZE];
  int i = 0;
  int c;

  /* Read string into buf[] */
  for (;;) {
    c = fgetc(stdin);
    if (c == EOF || c == '\n')
      break;
    buf[i] = c;
    i++;
  }
  buf[i] = '\0';

  /* Copy buf[] to name[] */
  for (i = 0; i < BUFSIZE; i++)
    name[i] = buf[i];
}
```

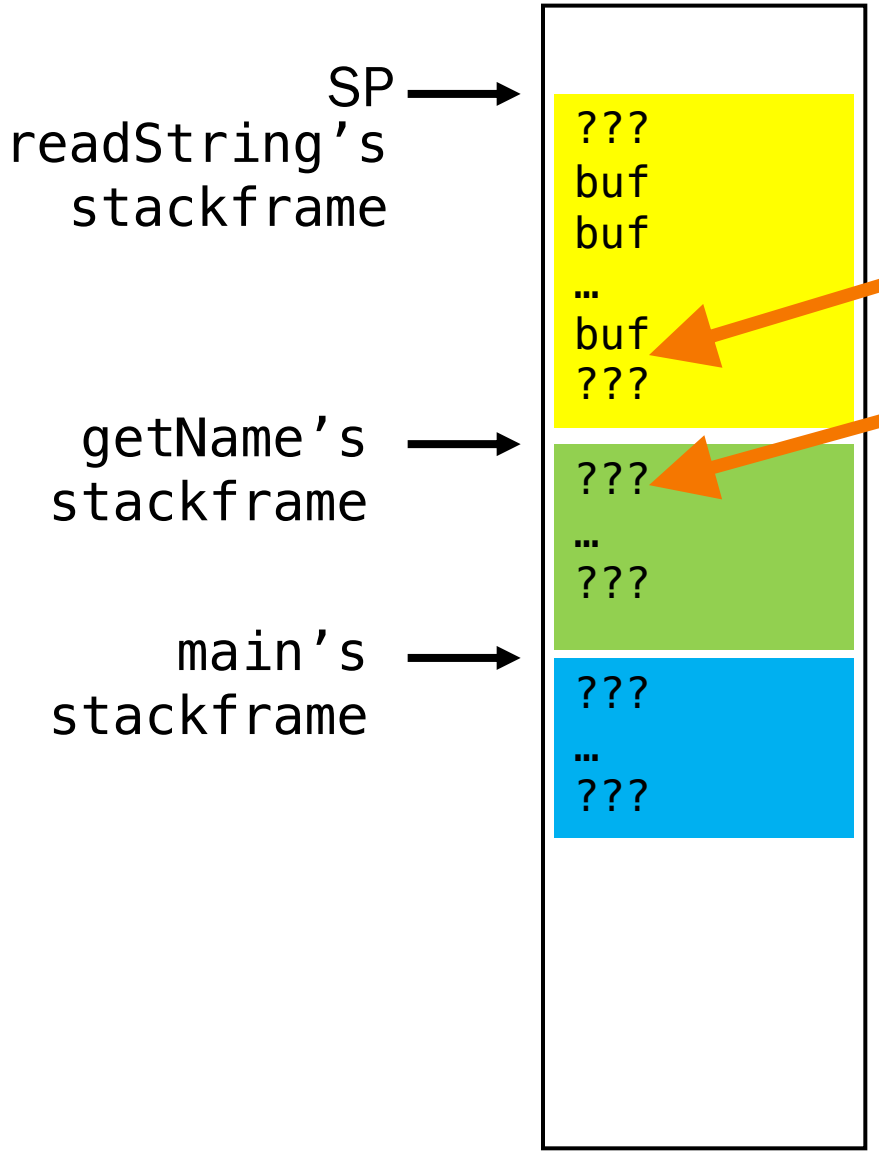
Unchecked write to buffer!

Assignment 6: Attack the “Grader” Program

```
int main(void) {
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Bob\0(#@&$%*#&(*^!@%*!!(&#$%(@*
B is your grade.
Thank you, Bob.
```

Memory Map of STACK Section



Keep writing past end of buf

Get to getName's stackframe

What's there?

getName's saved x30! (somewhere on stack)

Overwrite it!

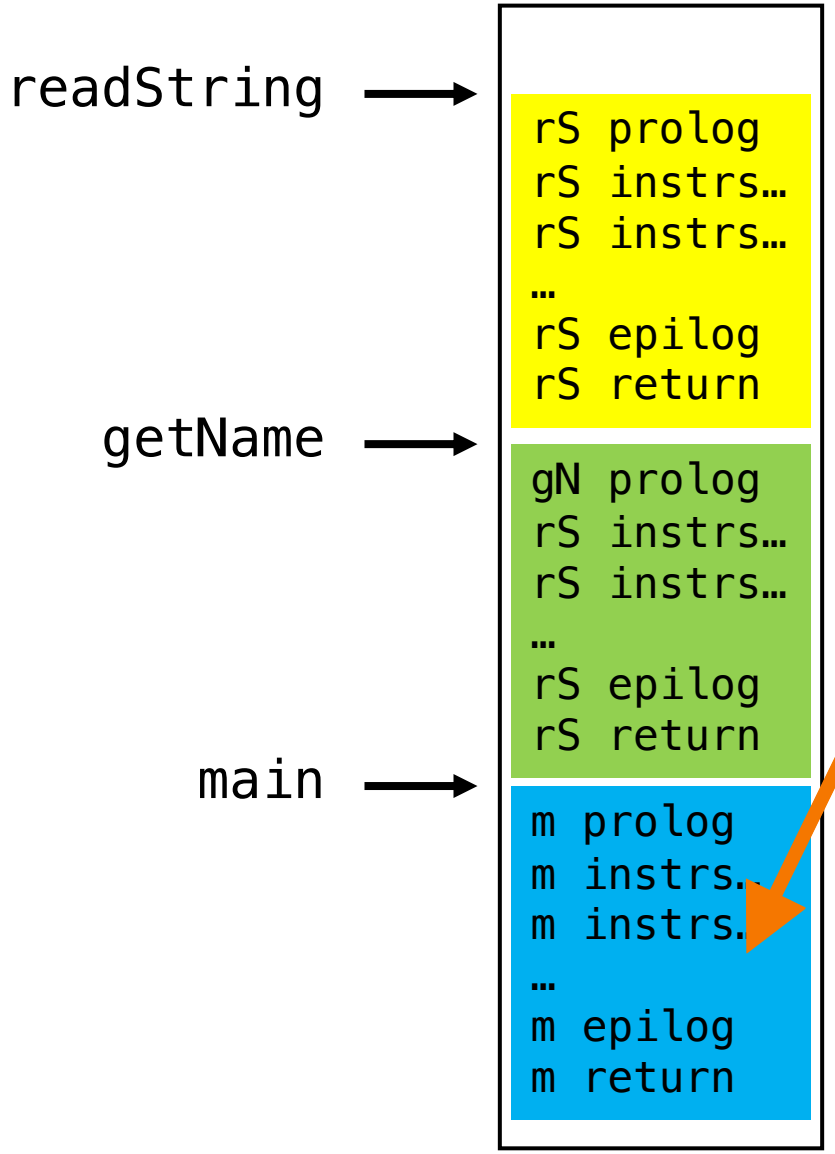
With what?

Assignment 6: Attack the “Grader” Program

```
int main(void) {
   getname();
   if (strcmp(name, "Andrew Appel") == 0)
      grade = 'B';
   printf("%c is your grade.\n", grade);
   printf("Thank you, %s.\n", name);
   return 0;
}
```

```
$ ./grader
What is your name?
Bob\0(#@&$%*#&(*^!@%*!!(&#$%(@*
B is your grade.
Thank you, Bob.
```

Memory Map of TEXT Section




```
…
checkappel:
    if (strcmp(name, "Andrew Appel") != 0)
        goto afterb
    grade = 'B' ← HERE!
afterb:
    print …
…
```

Construct Your Exploit String (`createdataB.c`)

1. Your name.
   - After all, the `grader` program's last line of output must be: `"Thank you, [your name]."`
2. A null byte.
   - Otherwise the `grader` program's last line of output will be corrupted.
3. Filler to overrun until `x30`.
   - Presumably more null bytes are easiest, but easter eggs are fine.
4. The address of `grade = 'B'`.

1. Open the file `dataB` and write your name into that file (e.g. with `fprintf`)
2. See "Writing Binary Data" precept handout. `'\0'` is just a single byte of binary data.
4. The address is a little-endian two's complement `unsigned long`.

Summary

- This lecture:
  - Buffer overrun attacks in general
  - Assignment 6 “B Attack” principles of operation
- Next precept:
  - Assignment 6 “B Attack” recap
  - Memory map using gdb
  - Writing binary data
- Final 2 lectures:
  - Assignment 6 “A Attack” overview
  - Machine language details needed for “A Attack”
  - *Finally* finishing the 4-stage build process: the Linker!
- Final precept:
  - MiniAssembler and ”A Attack” details