pointer subterfuge

```
void f2b(void *arg, size_t len) {
    char buffer[100];
    long val = ...; /* assume on stack */
    long *ptr = ...; /* assume on stack */
    memcpy(buff, arg, len); /* overwrite ptr? */
    *ptr = val; /* arbitrary memory write! */
}
```

adapted from Pincus and Baker, Figure 2

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    char buffer[100];
    long val = ...; /* assume on stack */
    long *ptr = ...; /* assume on stack */
    memcpy(buff, arg, len); /* overwrite ptr? */
    *ptr = val; /* arbitrary memory write! */
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```

adapted from Pincus and Baker, Figure 2

arbitrary memory write

bunch of scenarios that lead to *single arbitrary memory write*

typical result: arbitrary code execution

how?

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overwrite existing machine code (insert jump?)
- problem: usually not writable

overwrite return address directly
- observation: don't care about stack canaries — skip them

overwrite other function pointer?

overwrite another data pointer — copy more?

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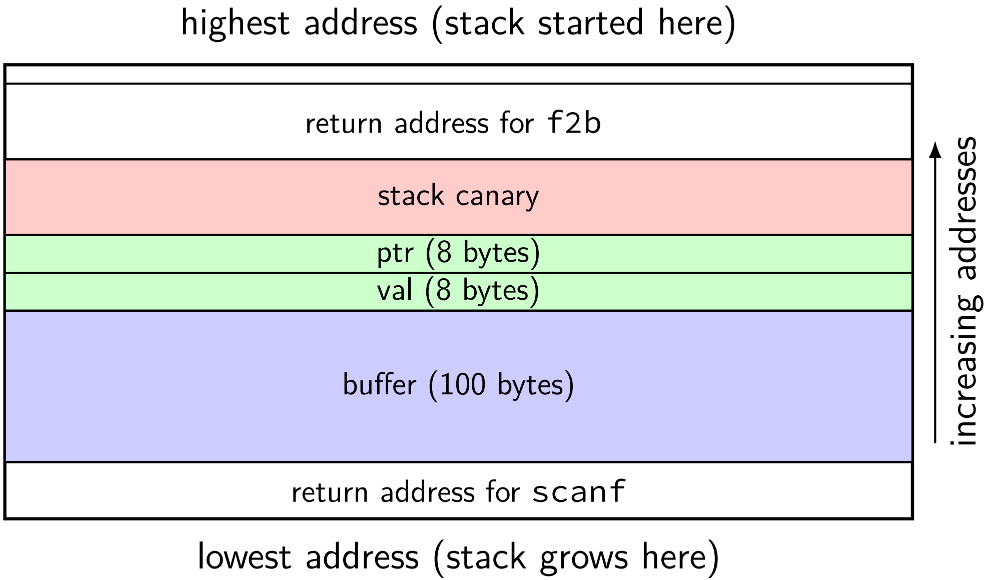
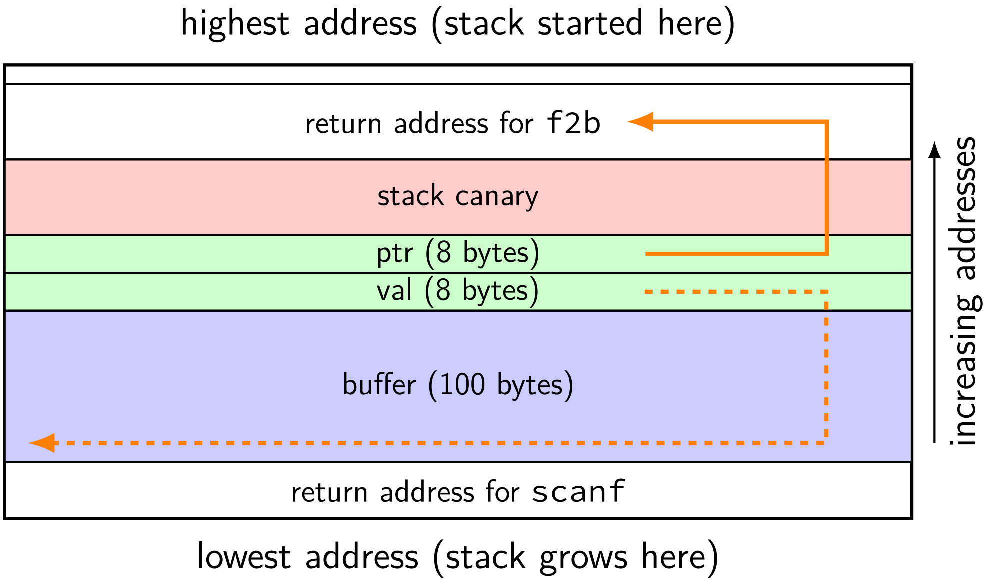
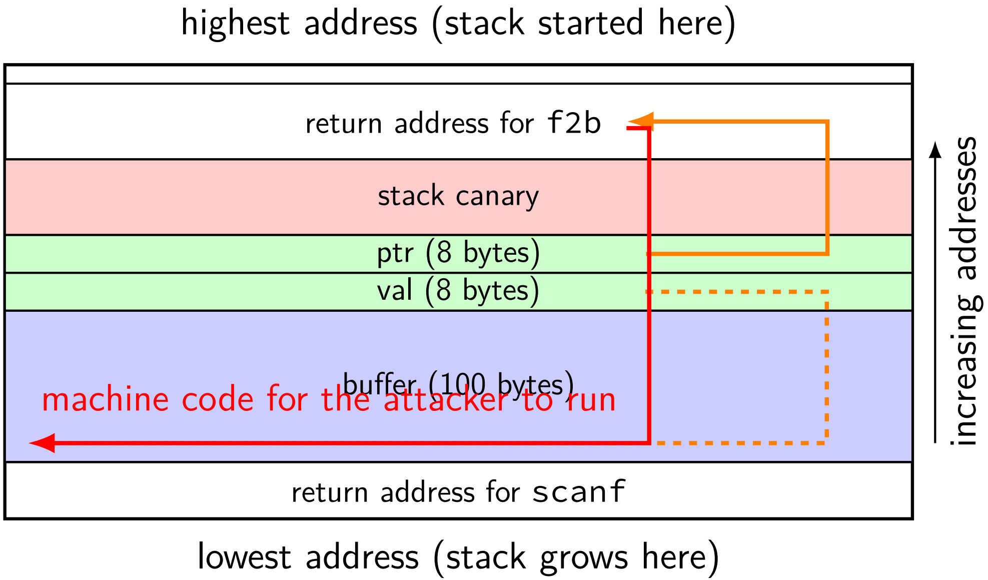
skipping the canary



skipping the canary



skipping the canary



exercise (1)

```
void vulnerable() {
    int *array;
    char buffer[100];
    if (!Allocate(&array))
        abort();
    gets(buffer);
    array[0] = atoi(buffer);
    ...
}
```

If return address is at 0x12345, where/how to place 0x12345 in input?

A. beginning, as ASCII base-10 number
B. beginning, as ASCII base-16 number
C. 100 bytes into buffer, as bytes
D. 104 bytes into buffer, as bytes
E. 120 bytes into buffer, as bytes
F. 136 bytes into buffer, as bytes
G. none of these

```
vulnerable:
    pushq %rbp
    pushq %rbx
    subq  $136, %rsp
    movq  %fs:40, %rax
    movq  %rax, 120(%rsp)
    xorl  %eax, %eax
    leaq  104(%rsp), %rdi
    call  Allocate
    testl %eax, %eax
    je    call_abort
    movq  %rsp, %rdi
    call  gets
    movq  104(%rsp), %rbp
    movl  $10, %edx
    movl  $0, %esi
    movq  %rsp, %rdi
    call  strtol
    movl  %eax, 0(%rbp)
    ...
```

exercise (2)

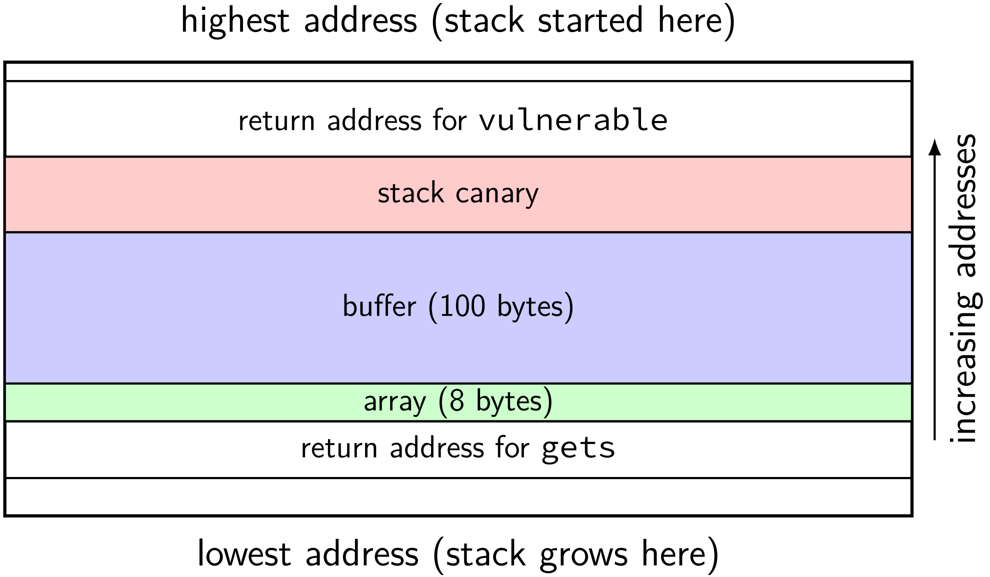
```
void vulnerable() {
    int *array;
    char buffer[100];
    if (!Allocate(&array))
        abort();
    gets(buffer);
    array[0] = atoi(buffer);
    ...
}
```

```
vulnerable:
    pushq %rbp
    pushq %rbx
    subq  $136, %rsp
    movq  %fs:40, %rax
    movq  %rax, 120(%rsp)
    xorl  %eax, %eax
    leaq  104(%rsp), %rdi
    call  Allocate
    testl %eax, %eax
    je    call_abort
    movq  %rsp, %rdi
    call  gets
    movq  104(%rsp), %rbp
    movl  $10, %edx
    movl  $0, %esi
    movq  %rsp, %rdi
    call  strtol
    movl  %eax, 0(%rbp)
    ...
```

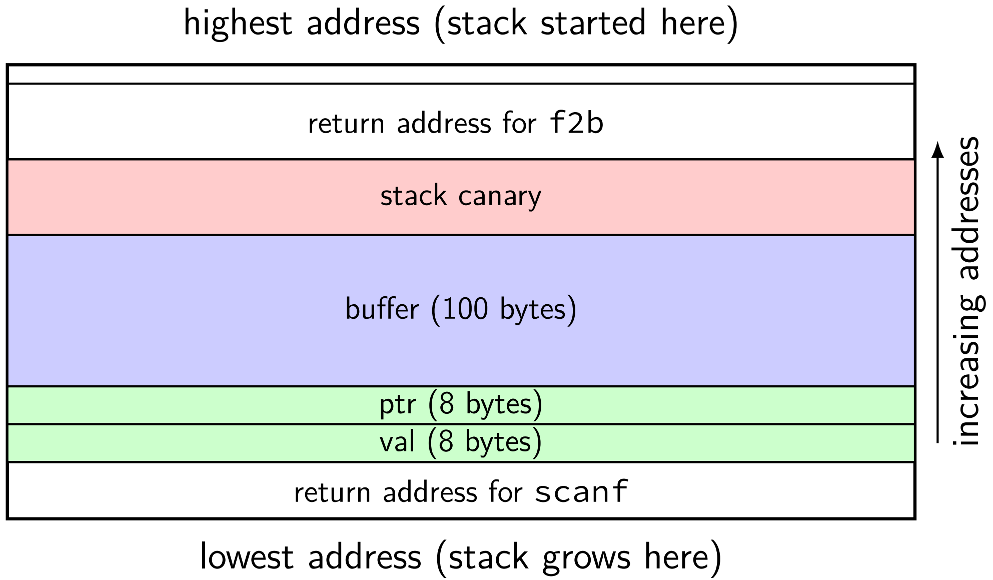
If we want to overwrite ret. addr. with 0x5678, where/how to place 0x5678 in input?

A. beginning, as ASCII base-10 number
B. beginning, as ASCII base-16 number
C. 100 bytes into buffer, as bytes
D. 104 bytes into buffer, as bytes
E. 120 bytes into buffer, as bytes
F. 136 bytes into buffer, as bytes
G. none of these

laying out stack to avoid subterfuge (1)

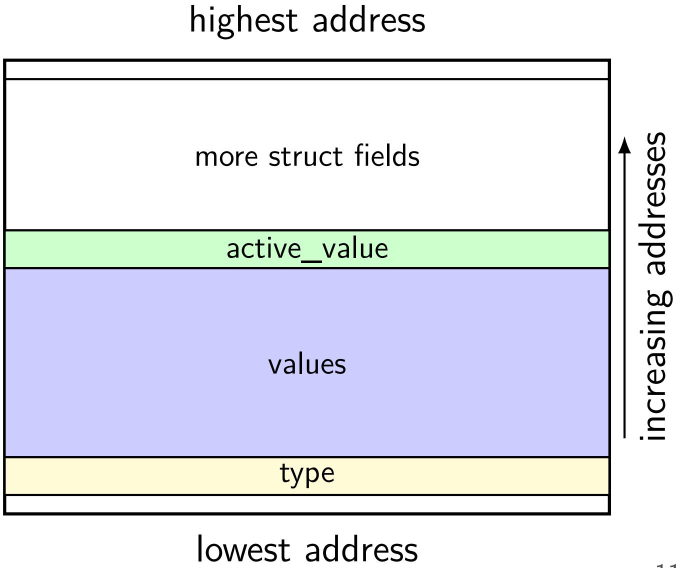

highest address (stack started here)
return address for vulnerable
stack canary
buffer (100 bytes)
array (8 bytes)
return address for gets
lowest address (stack grows here)
increasing addresses

laying out stack to avoid subterfuge (2)



other subterfuge cases (1)

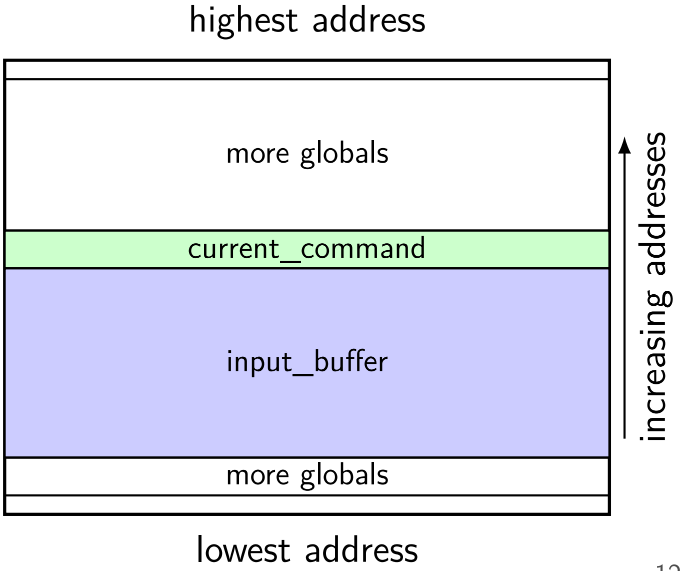
```
struct Command {
  CommandType type;
  int values[MAX_VALUES];
  int *active_value;
  ...
};
```



other subterfuge cases (2)

```
Command *current_command;
char input_buffer[4096];

void run_next_command() {
  if (!current_command) {
    current_command =
        getNext();
  }
  current_command-> ...
  ...
}
```



beyond return addresses

pointer subterfuge let us overwrite anything

my example: showed return address

but return address is tricky to locate exactly

but there are usually *much easier options!*

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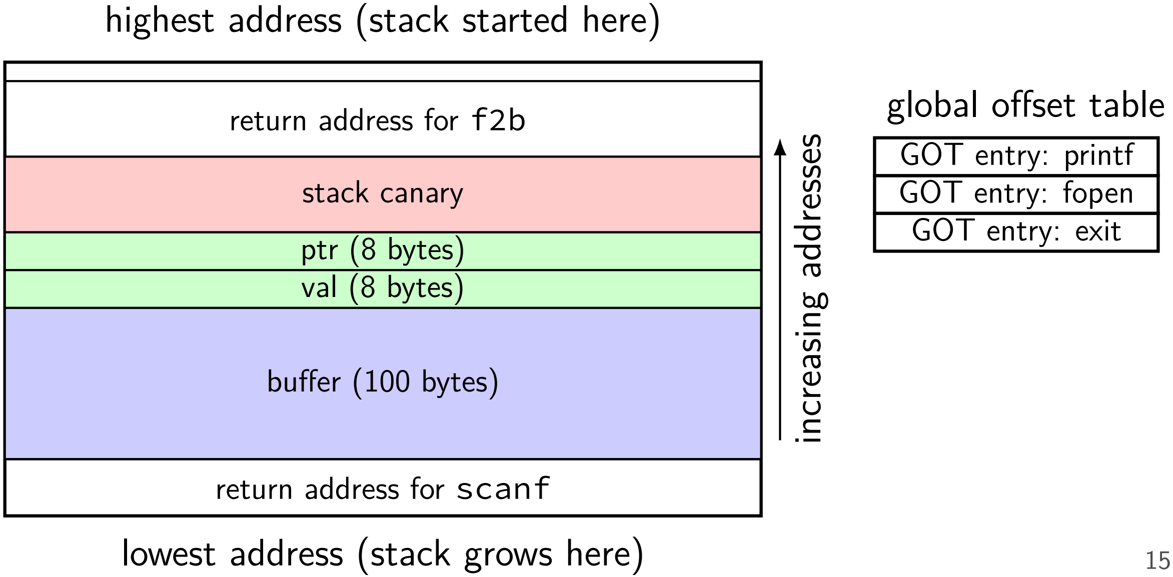
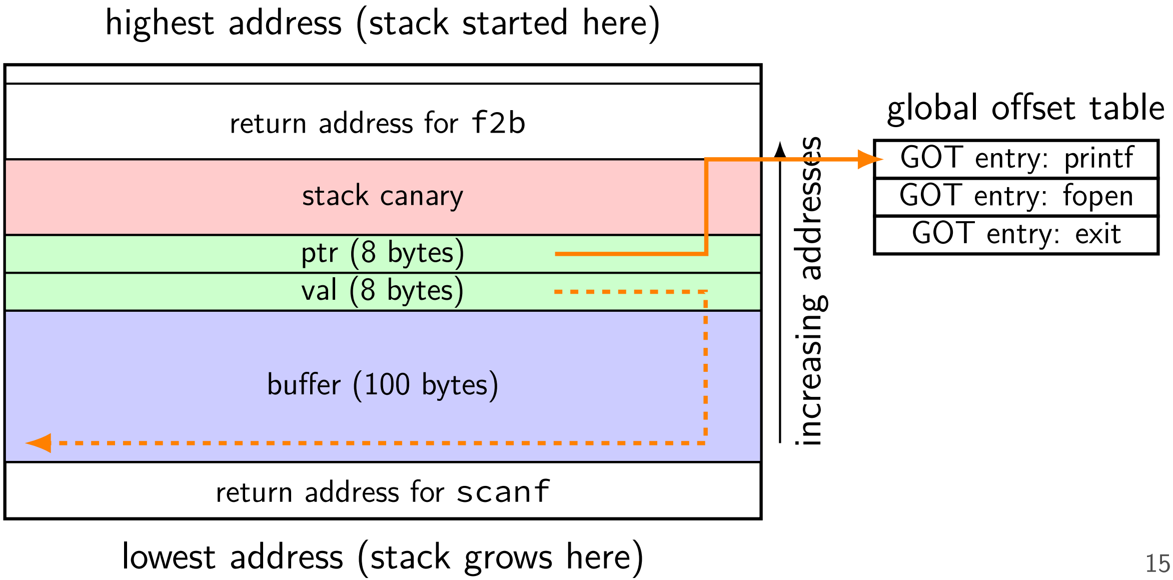
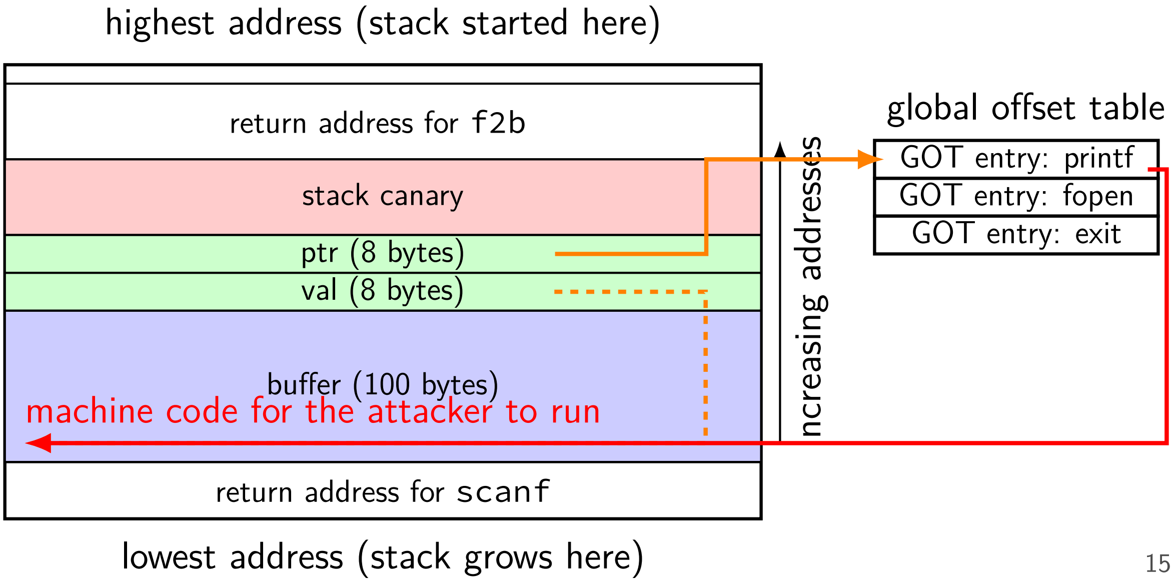
attacking the GOT



attacking the GOT



attacking the GOT



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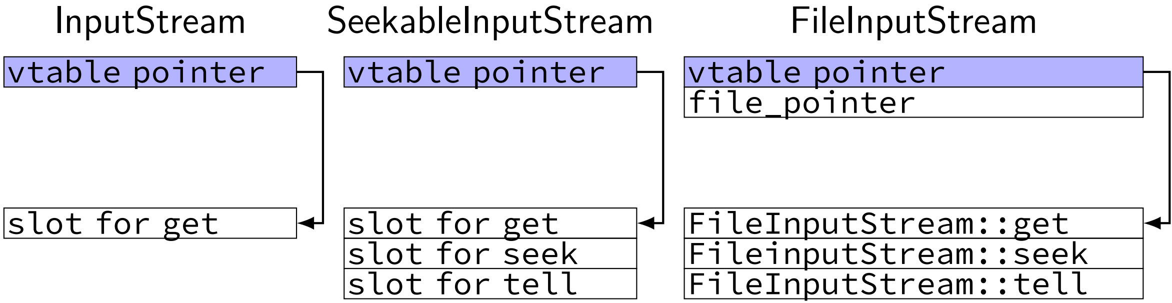
C++ inheritence

```
class InputStream {
public:
    virtual int get() = 0;
    // Java: abstract int get();
    ...
};
class SeekableInputStream : public InputStream {
public:
    virtual void seek(int offset) = 0;
    virtual int tell() = 0;
};
class FileInputStream : public SeekableInputStream {
public:
    virtual int get();
    virtual void seek(int offset);
    virtual int tell();
    ...
};
```

C++ inheritence: approx memory layout



C++ implementation (pseudo-code)

```
struct InputStream_vtable {
    int (*get)(InputStream* this);
};

struct InputStream {
    InputStream_vtable *vtable;
};

...

    InputStream *s = ...;
    int c = (s->vtable->get)(s);
```

C++ implementation (pseudo-code)

```
struct SeekableInputStream_vtable {
    struct InputStream_vtable as_InputStream;
    void (*seek)(SeekableInputStream* this, int offset);
    int (*tell)(SeekableInputStream* this);
};

struct FileInputStream {
    SeekableInputStream_vtable *vtable;
    FILE *file_pointer;
};

...

    FileInputStream file_in = { the_FileInputStream_vtable,  ... };
    InputStream *s = (InputStream*) &file_in;
```

C++ implementation (pseudo-code)

```
SeekableInputStream_vtable the_FileInputStream_vtable = {
    &FileInputStream_get,
    &FileInputStream_seek,
    &FileInputStream_tell,
};

...

    FileInputStream file_in = { the_FileInputStream_vtable,  ... };
    InputStream *s = (InputStream*) &file_in;
```

calling virtual method

```
SeekableInputStream *in = ...;  // 8(%rsp)
in->get();
in->seek(10);
```

```
# in->get();
movq    8(%rsp), %rdi // rdi <- in
movq    (%rdi), %rax  // rax <- vtable
call    *(%rax)       // call vtable[0]

# in->seek(10);
movq    8(%rsp), %rdi // rdi <- in
movl    $10, %esi     // esi <- 10
movq    (%rdi), %rax  // rax <- vtable
call    *8(%rax)      // call vtable[1]
```

FileInputStream assembly (1)

```
_ZN15FileInputStreamC2Ev: // constructor
   # rdi == this
   movq    $_ZTV15FileInputStream+16, (%rdi)
   ...
   ret
# VTable for FileInputStream
_ZTV15FileInputStream:
    # offset (for multiple inheritence)
    .quad   0
    # info for typeid() operator
    .quad   _ZTI15FileInputStream
    # VTable pointer points here
    # FileInputStream::get
    .quad   _ZN15FileInputStream3getEv
    # FileInputStream::seek
    .quad   _ZN15FileInputStream4seekEi
    # FileInputStream::tell
    .quad   _ZN15FileInputStream4tellEv
```

attacking function pointer tables

option 1: overwrite table entry directly

- required/easy for Global Offset Table — fixed location
- usually not possible for VTables — read-only memory

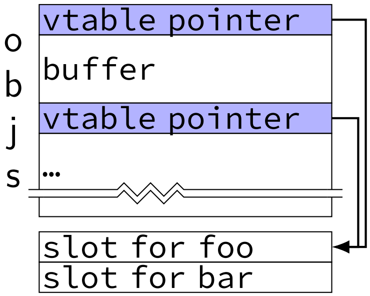
option 2: create table in buffer (big list of pointers to shellcode), point to buffer

- useful when table pointer next to buffer
- (e.g. C++ object on stack next to buffer)

option 3: find suitable pointer elsewhere

- e.g. point to wrong part of vtable to run different function

exercise



```
class VulnerableClass {
public:
    char buffer[100];
    virtual void foo();
    virtual void bar();
};
VulnerableClass objs[10];
```

Assume `gets(objs[0].buffer)` is run and eventually `ptr->foo()` will be run where `ptr == &objs[1]`.

input start: __________

input+50 bytes: __________

input+100 bytes: __________

A. shellcode
B. address of objs[0].buffer[0]
C. address of objs[0].buffer[50]
D. address of original vtable
E. address of objs[0]'s vtable
F. address of objs[1]'s vtable pointer

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overwrite another data pointer — copy more?

write to write

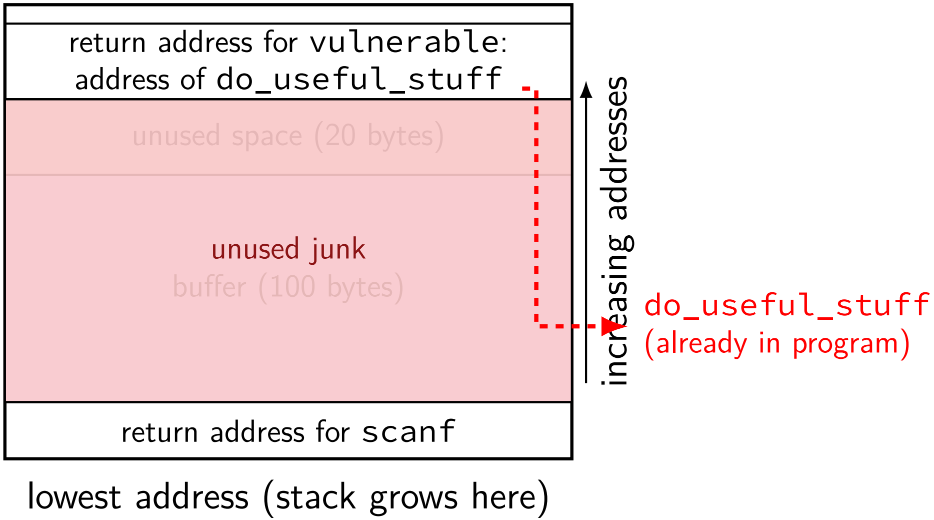
```
struct A {
    char name[100];
    long irrelevant;
    ...
    struct B* other_thing;
    ...
};
struct B {
    char name[100];
    ...
}
...
    gets(a_object->name);
    gets(a_object->other_thing->name);
...
```

so far overwrites

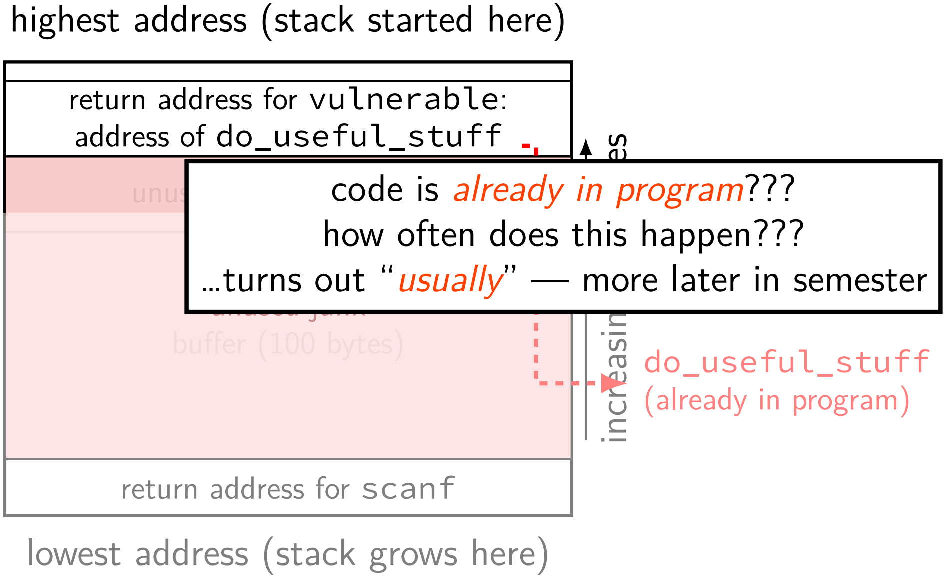
once we found a way to overwrite function pointer
easiest solution seems to be: direct to our code

...but alterante places to direct it to

return-to-somewhere



return-to-somewhere


highest address (stack started here)
return address for vulnerable:
address of do_useful_stuff
unus
unused junk
buffer (100 bytes)
increasing addresses
do_useful_stuff
(already in program)
return address for scanf
lowest address (stack grows here)

code is *already in program*???
how often does this happen???
...turns out "*usually*" — more later in semester

example: system()

```
NAME
       system - execute a shell command

SYNOPSIS
       #include <stdlib.h>

       int system(const char *command);
```

part of C standard library

in any program that dynamically links to libc

challenge: need to hope argument register (rdi) set usefully

locating system() Linux

```
$ ldd /bin/ls
        linux-vdso.so.1 (0x00002aaaaaade000)
        libselinux.so.1 => /lib/x86_64-linux-gnu/libselinux.so.1 (0x00002aaaaab3a000)
        libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00002aaaaab65000)
        libpcre2-8.so.0 => /usr/lib/x86_64-linux-gnu/libpcre2-8.so.0 (0x00002aaaaad57000)
        libdl.so.2 => /lib/x86_64-linux-gnu/libdl.so.2 (0x00002aaaaade7000)
        /lib64/ld-linux-x86-64.so.2 (0x00002aaaaaaab000)
        libpthread.so.0 => /lib/x86_64-linux-gnu/libpthread.so.0 (0x00002aaaaaded000)
$ objdump --dynamic-syms /lib/x86_64-linux-gnu/libc.so.6 | grep system
0000000000156a80 g    DF .text  0000000000000067  GLIBC_2.2.5 svcerr_systemerr
0000000000055410 g    DF .text  000000000000002d  GLIBC_PRIVATE __libc_system
0000000000055410  w   DF .text  000000000000002d  GLIBC_2.2.5 system
```

if address randomization disabled:
address should be 0x00002aaaaab650 + 0x55410

`ldd` — "what libraries does this load and where?"

similar tools for other OSes

case study (simplified)

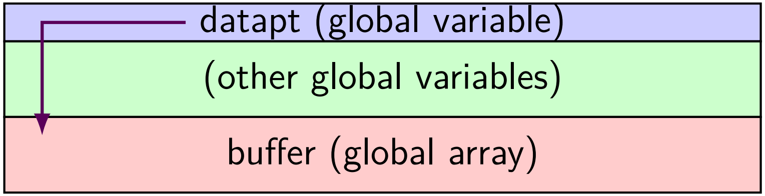
bug in NTPd (Network Time Protocol Daemon)

via Stephen Röttger, “Finding and exploiting ntpd vulnerabilities”
    `https://googleprojectzero.blogspot.com/2015/01/finding-and-exploiting-ntpd.html`

```
static void
ctl_putdata(
  const char *dp,
  unsigned int dlen,
  int bin   /* set to 1 when data is binary */
  ) {
    ...
    memmove((char *)datapt, dp, (unsigned)dlen);
    datapt += dlen;
    datalinelen += dlen;
```

the target

```
memmove((char *)datapt, dp, (unsigned)dlen);
```

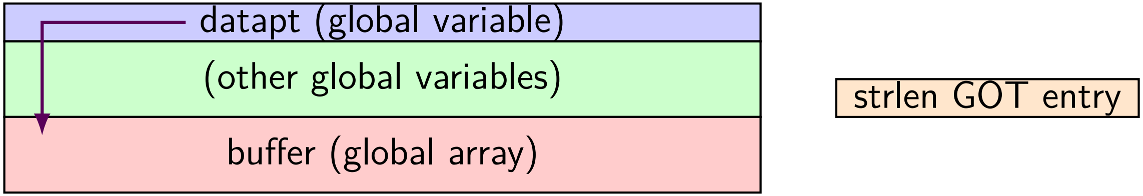


more context

```
memmove((char *)datapt, dp, (unsigned)dlen);
...
...
strlen(some_user_supplied_string)
/* calls strlen@plt
   looks up global offset table entry! */
```

the target

```
memmove((char *)datapt, dp, (unsigned)dlen);
```



overall exploit

overwrite `datapt` to point to strlen GOT entry

overwrite value of strlen GOT entry

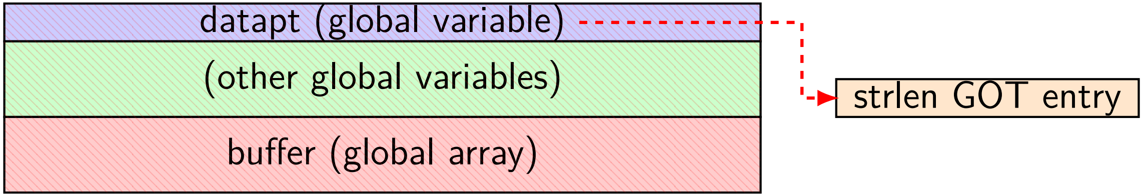
example target: `system` function

- executes command-line command specified by argument

supply string to provide argument to “`strlen`”

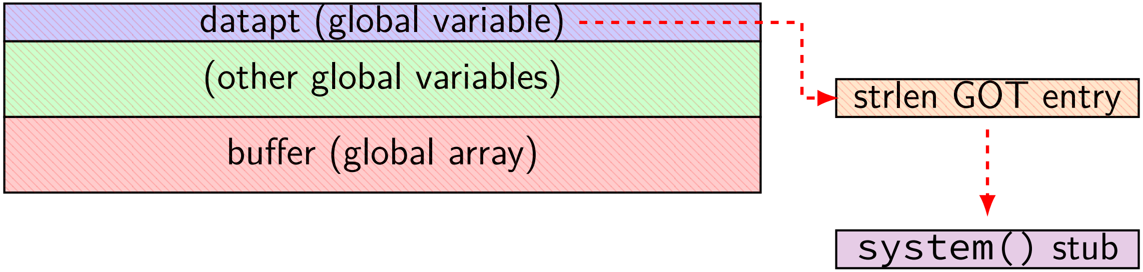
the target

```
memmove((char *)datapt, dp, (unsigned)dlen);
```



the target

```
memmove((char *)datapt, dp, (unsigned)dlen);
```



overall exploit: reality

real exploit was more complicated

needed to defeat more mitigations

needed to deal with not being able to write `\0`

actually tricky to send things that trigger buffer write
(meant to be local-only)

subterfuge exercise

```
struct Student {
    char email[128];
    struct Assignment *assignments[16];
    ...
};
struct Assignment {
    char submission_file[128];
    char regrade_request[1024];
    ...
};
void SetEmail(Student *s, char *new_email) { strcpy(s->email, new_email); }
void AddRegradeRequest(Student *s, int index, char *request) {
    strcpy(s->assignments[index]->regrade_request, request);
}
void vulnerable(char *STRING1, char *STRING2) {
    SetEmail(s, STRING1); AddRegradeRequest(s, 0, STRING2);
}
```

exercise: to set `0x1020304050` to `0xAABBCCDD`, what should STRING1, STRING2 be?

(assume 64-bit pointers, no padding in structs, little-endian)

subterfuge exercise solution

```
struct Student { char email[128]; struct Assignment *assignments[16]; ...  };
struct Assignment { char submission_file[128]; char regrade_request[1024]; ...  };
```

STRING1 (email) controls *what address to overwrite* (want `0x1020304050`)

- `&s->assignments[0] == &email[128]`
- make bytes 128–128+8 be pointer to fake assignment
- want fake assignment->`regrade_request` address to be 0x1020304050
- fake assignment address needs to be at 0x1020304050 - 128

STRING2 (regrade_reqest) controls *what value to set* (want `0xAABBCCDD`)

backup slides