pointer subterfuge / memory protection

Changelog

15 March 2021 (after lecture): add URL for “finding and exploiting ntpd vulnerabilities” blog post; correct author name spelling

last time

integer overflow

stack canaries

information leaks

non-contiguous overwrites

format string exploits

- reading the stack
- %n — writing conversion specifier

pointer overwrite targets

- virtual function tables for inheritence

arbitrary memory write

bunch of scenarios that lead to single arbitrary memory write

- format exploits are one, but we'll find more!!

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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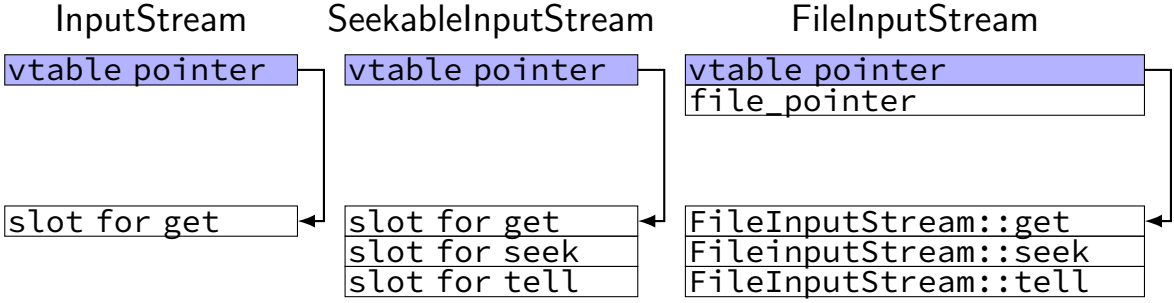
C++ inheritence

```
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 InputStream {
public:
    int get();
    void seek(int offset);
    int tell();
    ...
};
```

C++ inheritence: 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;
```

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

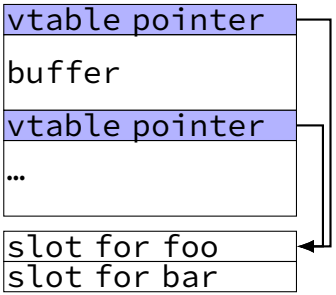
- useful when table pointer next to buffer
- (e.g. C++ object on stack next to buffer)

option 3: find suitable pointer elsewhere

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

exercise

objArray




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

if we can overflow `objArray[0].buffer` to change array[1]'s vtable pointer and know array[1].foo() will be called; finish the plan:

buffer[0]: _____

buffer[50]: _____

array[1]'s vtable pointer: _____

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

arbitrary memory write

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overwrite other function pointer?

overwrite another data pointer — copy more?

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

pointer subterfuge

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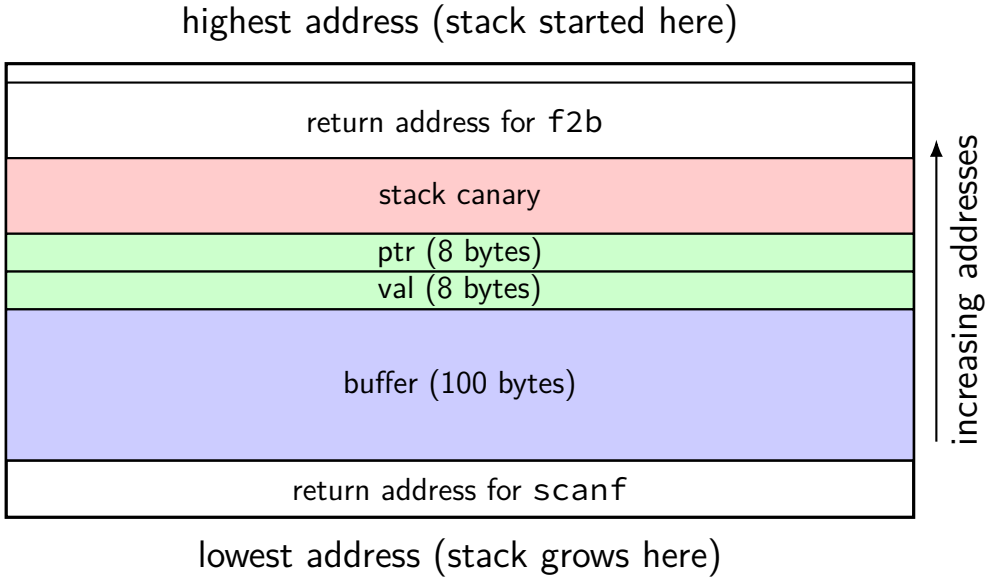
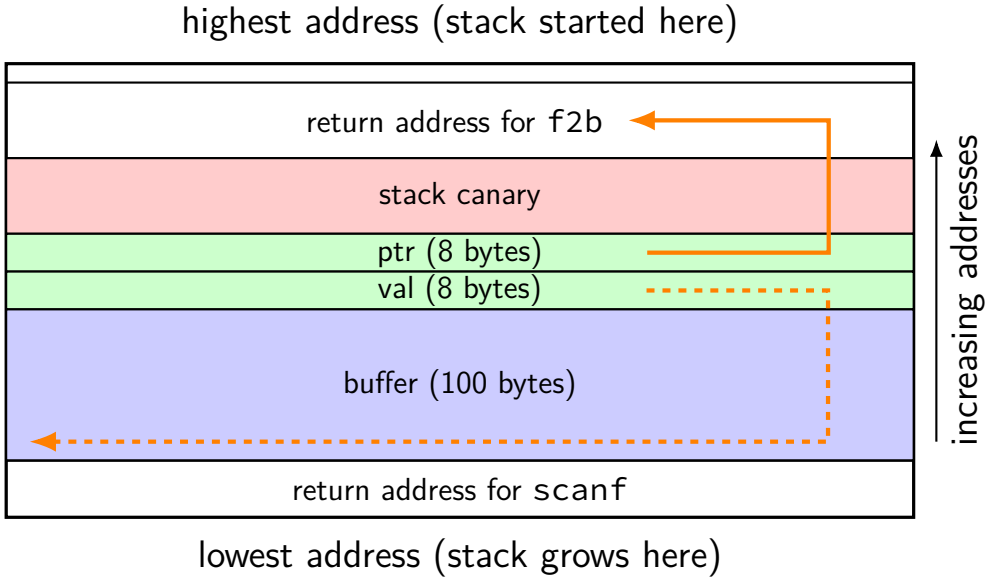
adapted from Pincus and Baker, Figure 2

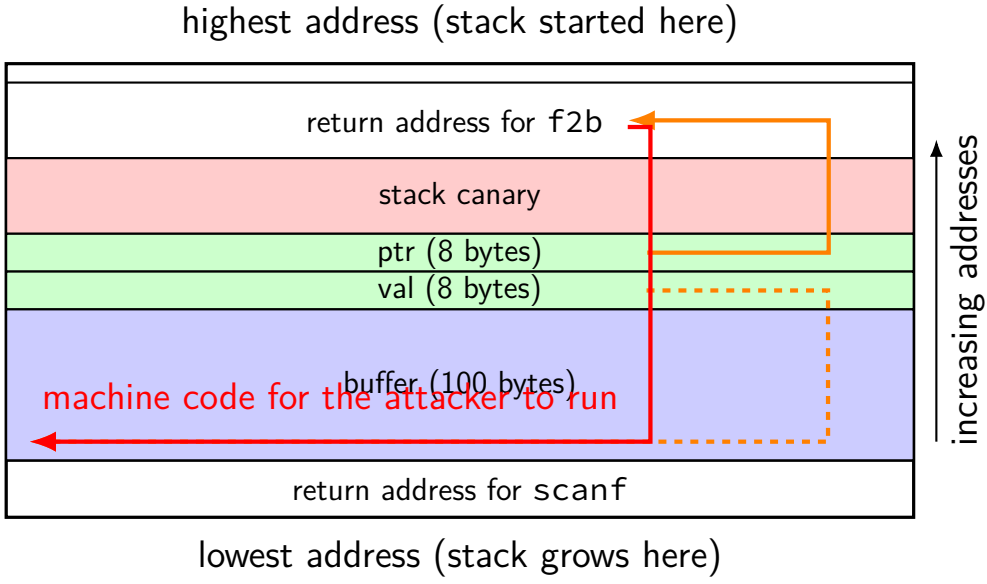
skipping the canary



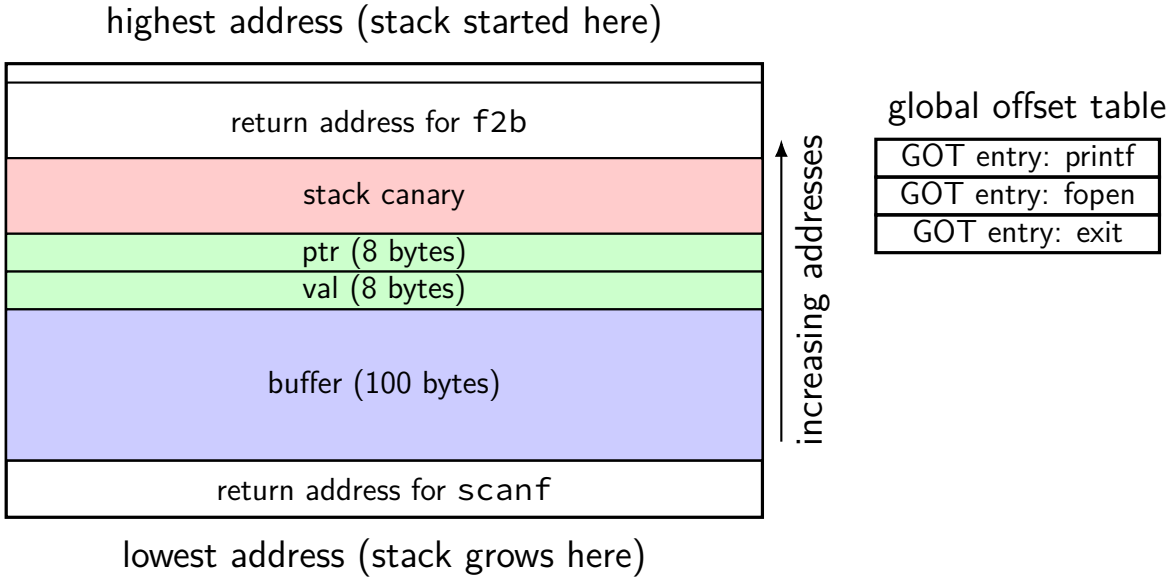
skipping the canary



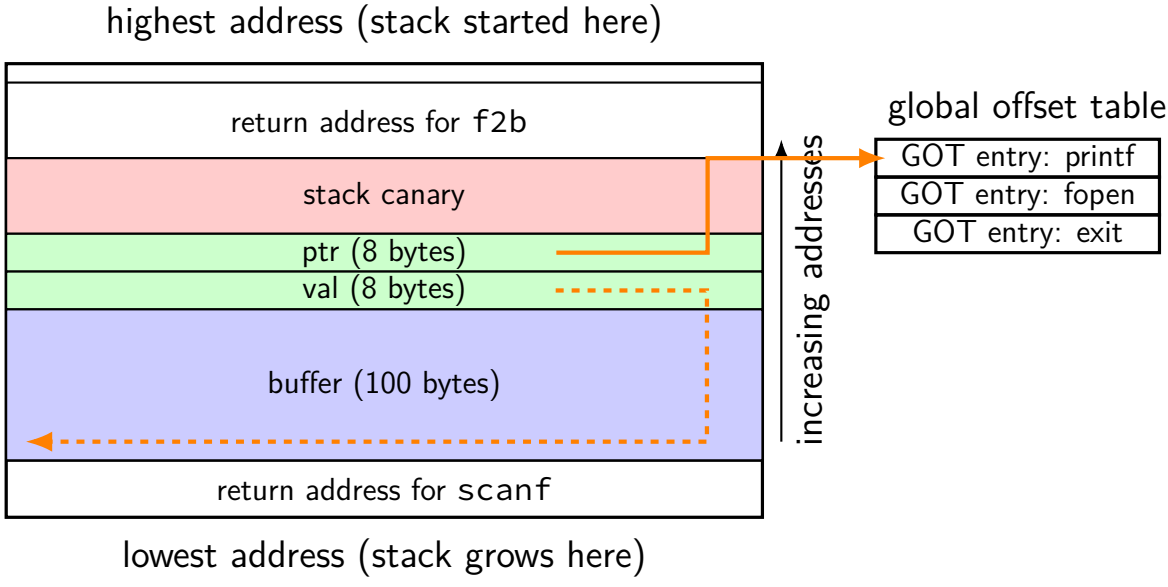
skipping the canary



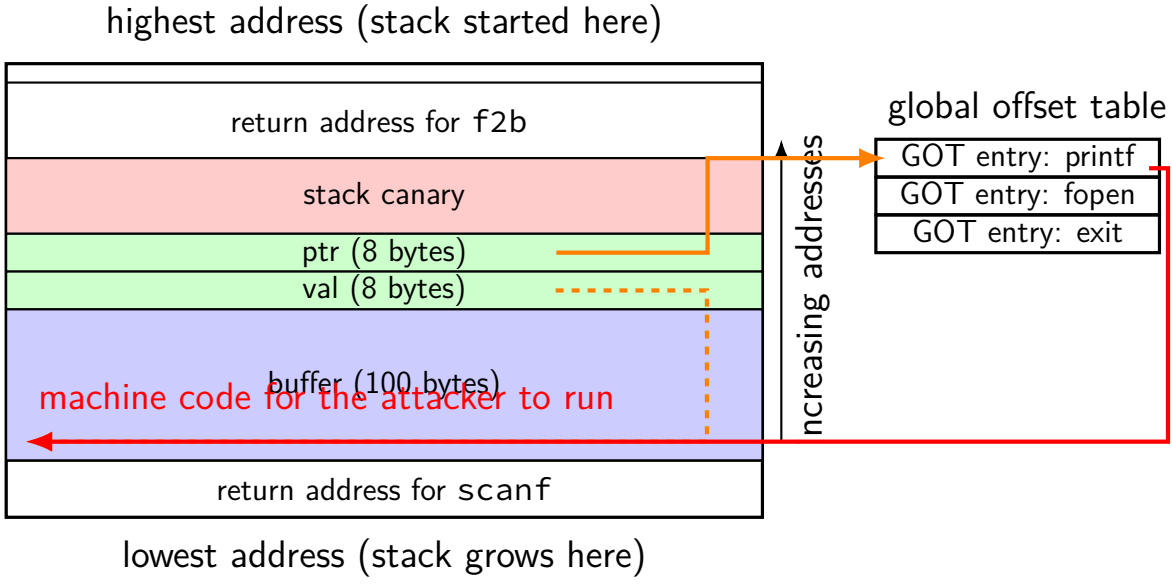
attacking the GOT



attacking the GOT

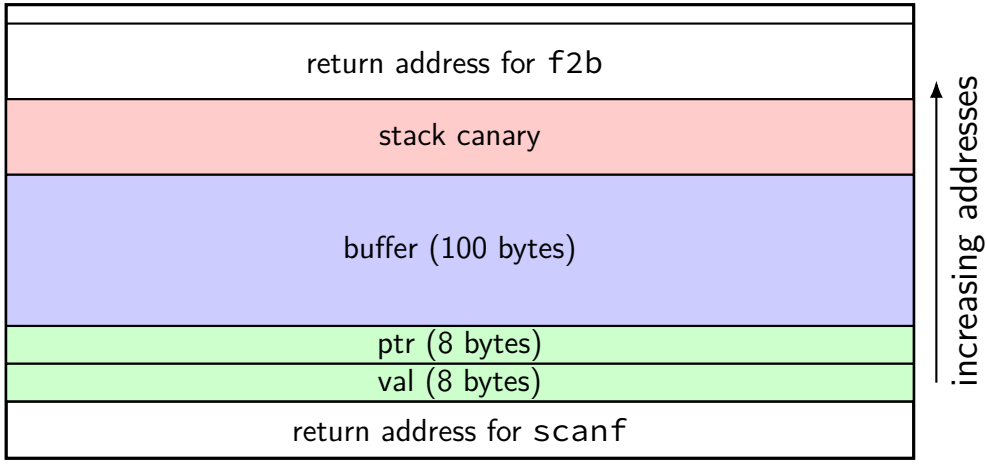


attacking the GOT



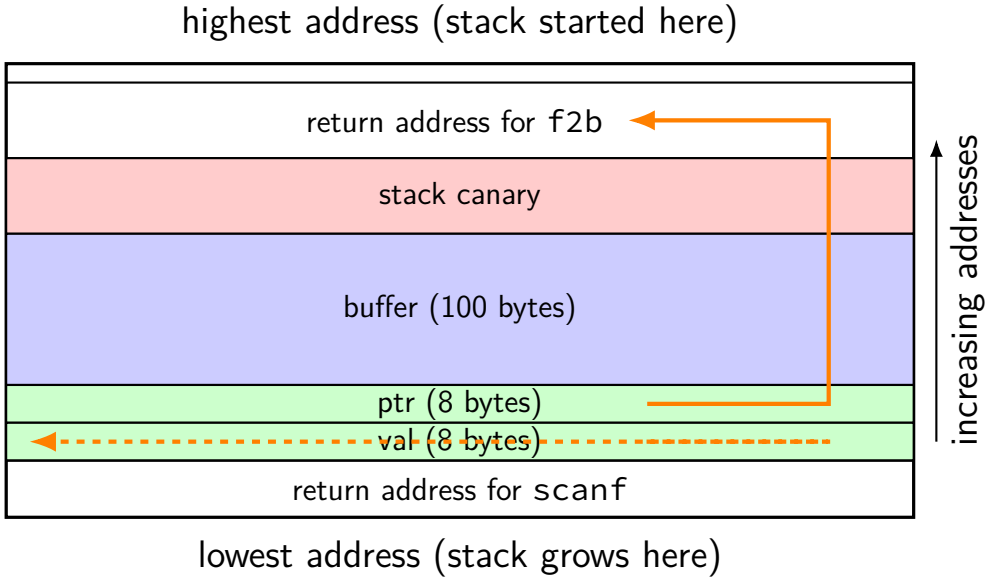
laying out stack to avoid subterfuge

highest address (stack started here)

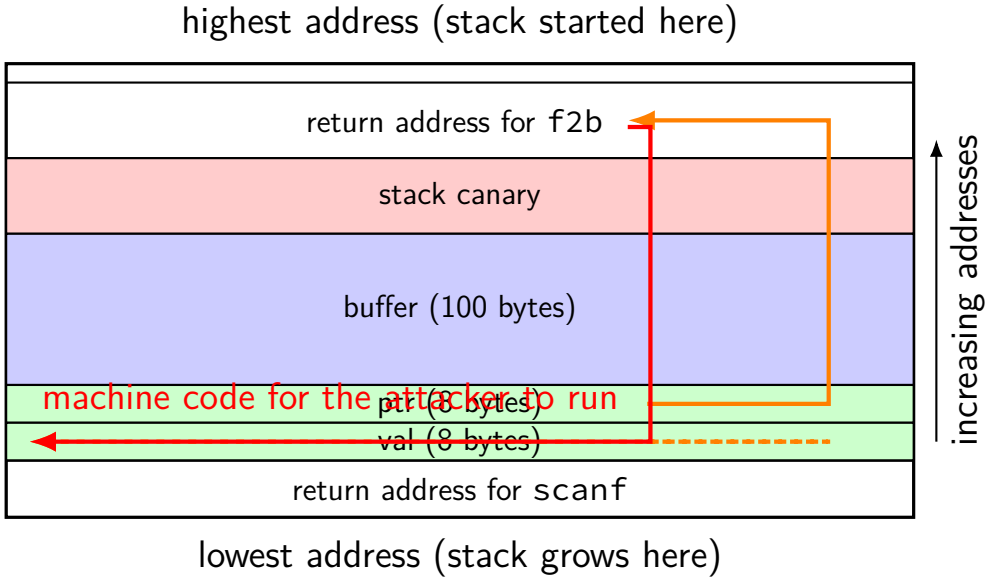


lowest address (stack grows here)

laying out stack to avoid subterfuge

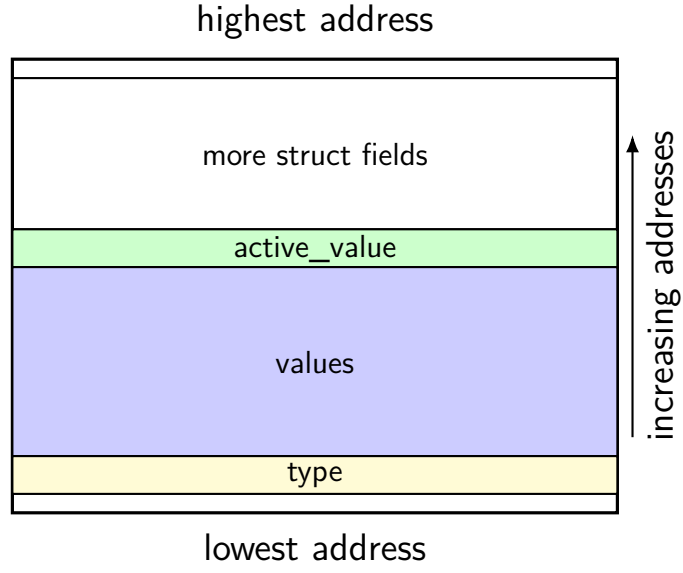


laying out stack to avoid subterfuge



other subterfuge cases (1)

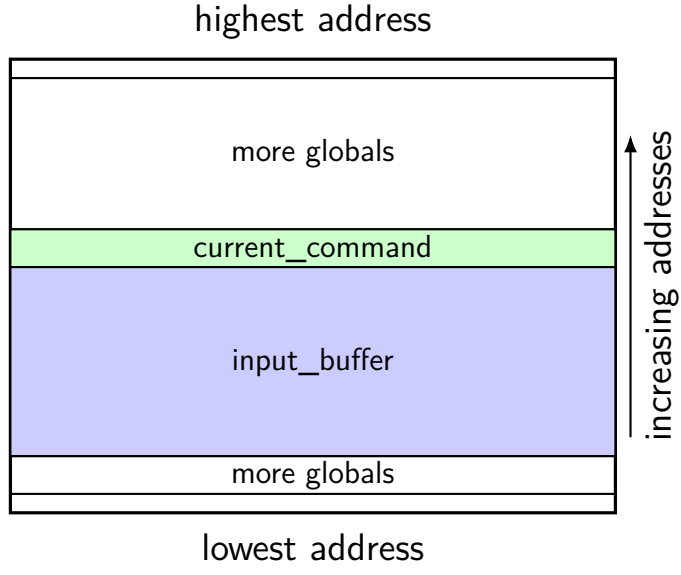
```
struct Command {
  CommandType type;
  int values[MAX_VALUES];
  int *active_value;
  ...
};
```



other subterfuge cases (2)

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

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



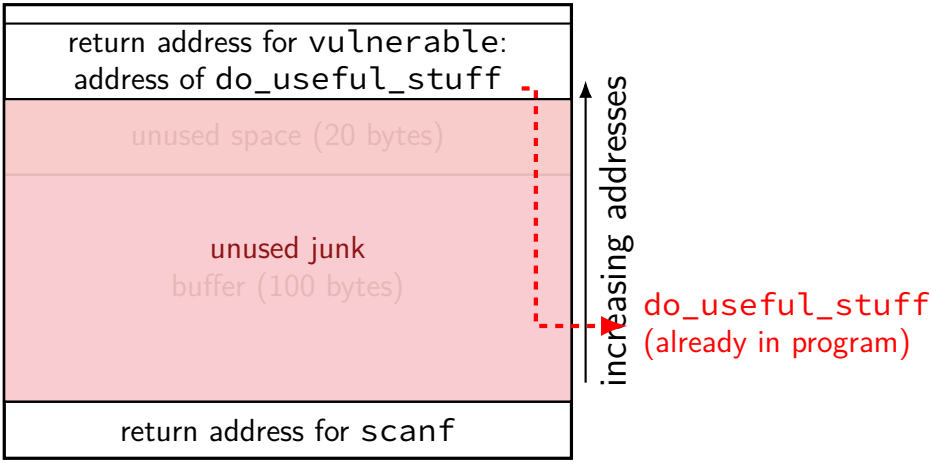
so far overwrites

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

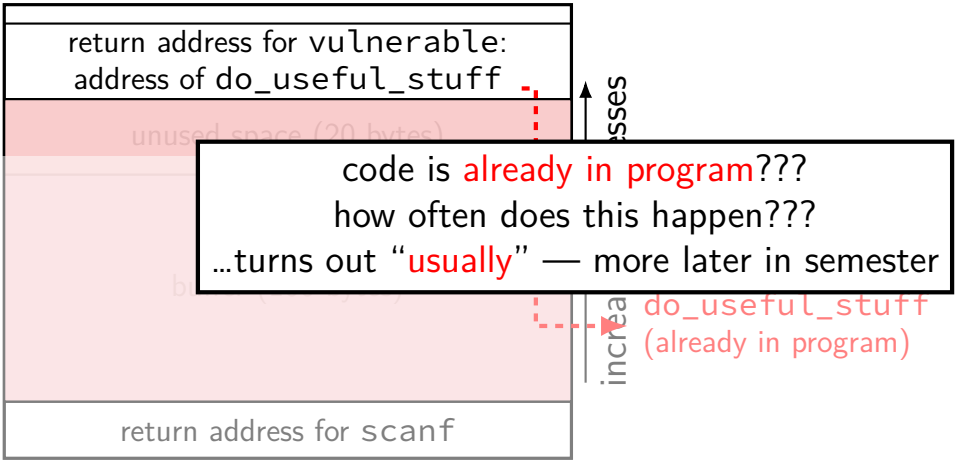
highest address (stack started here)



lowest address (stack grows here)

return-to-somewhere

highest address (stack started here)



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

lowest address (stack grows here)

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)

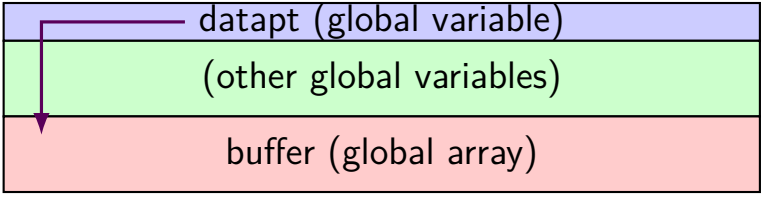
bug in NTPd (Network Time Protocol Daemon)

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);
```

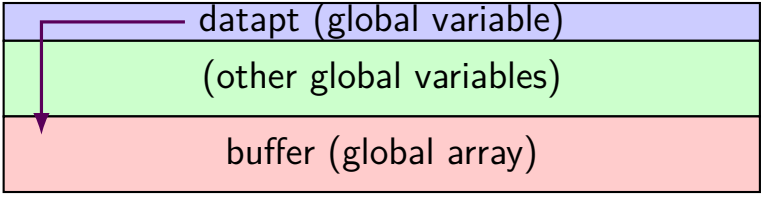


more context

```
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);
```



strlen GOT entry

overall exploit

overwrite `datapt` to point to strlen GOT entry

overwrite value of strlen GOT entry

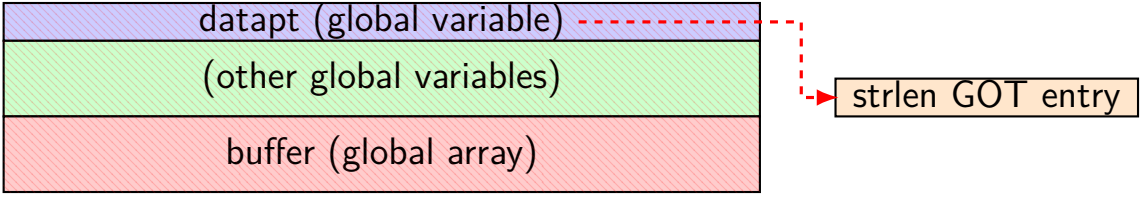
example target: `system` function

executes command-line command specified by argument

supply string to provide argument to "`strlen`"

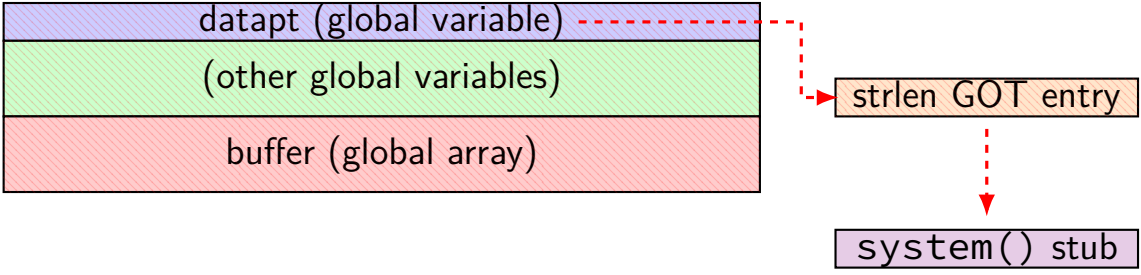
the target

```
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

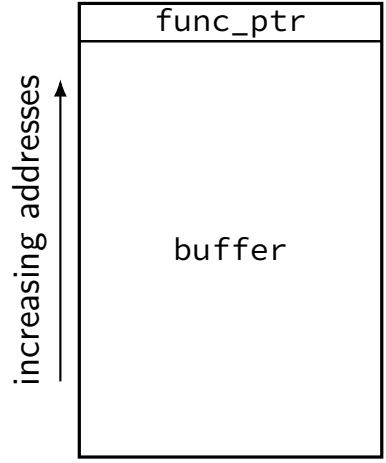
```
struct Student {
    char email[128];
    struct Assignment *assignments[16];
    ...
};
struct Assignment {
    char submission_file[128];
    char regrade_request[1024];
    ...
};
void SetEmail(Student *s, char *new_email) { strcpy(s->email, new_email); }
void AddRegradeRequest(Student *s, int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

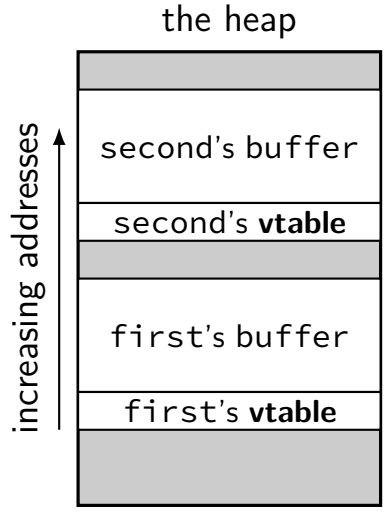
easy heap overflows

```
struct foo {
    char buffer[100];
    void (*func_ptr)(void);
};
```



heap overflow: adjacent allocations

```
class V {
  char buffer[100];
public:
  virtual void ...;
  ...
};
...
V *first = new V(...);
V *second = new V(...);
strcpy(first->buffer,
       attacker_controlled);
```



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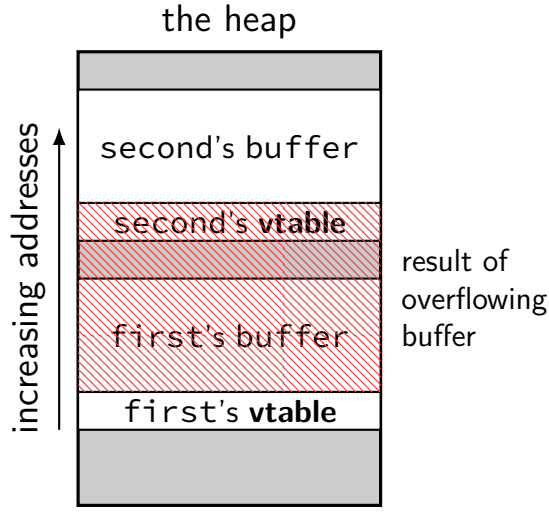


heap structure

where does malloc, free, new, delete, etc. keep info?

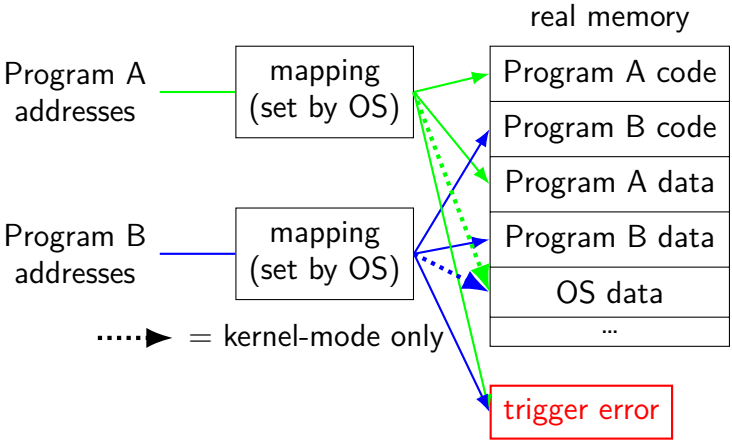
often in data structures next to objects on the heap

special case of adjacent heap objects problem

topic for later

recall(?): virtual memory

illuision of dedicated memory



the mapping (set by OS)

program address range	read?	write?	real address
0x0000 --- 0x0FFF	no	no	---
0x1000 --- 0x1FFF	no	no	---
…			
0x40 0000 --- 0x40 0FFF	yes	no	0x...
0x40 1000 --- 0x40 1FFF	yes	no	0x...
0x40 2000 --- 0x40 2FFF	yes	no	0x...
…			
0x60 0000 --- 0x60 0FFF	yes	yes	0x...
0x60 1000 --- 0x60 1FFF	yes	yes	0x...
…			
0x7FFF FF00 0000 — 0x7FFF FF00 0FFF	yes	yes	0x...
0x7FFF FF00 1000 — 0x7FFF FF00 1FFF	yes	yes	0x...
…			

Virtual Memory

modern hardware-supported memory protection mechanism

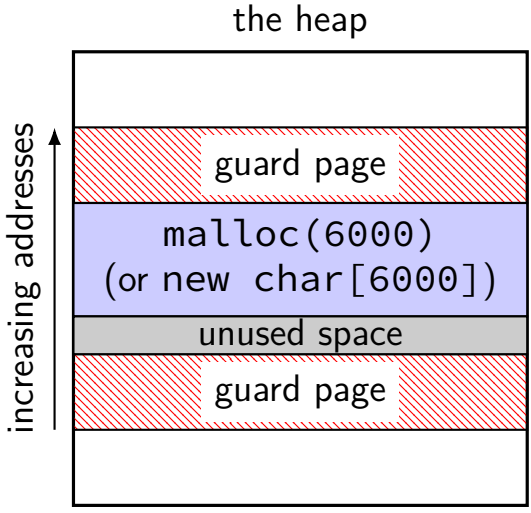
via table: OS decides what memory program sees

- whether it's read-only or not

granularity of pages — typically 4KB

not in table — segfault (OS gets control)

malloc/new guard pages



guard pages

deliberate holes

accessing — segfualt

call to OS to allocate (not very fast)

likely to ‘waste’ memory

- guard around object? minimum 4KB object

guard pages for malloc/new

can implement malloc/new by placing guard pages around allocations

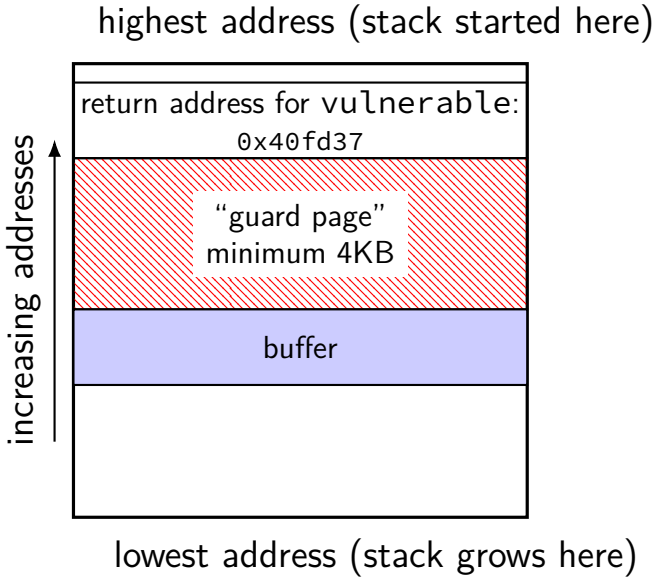
- commonly done by real malloc/new's for large allocations

problem: minimum actual allocation 4KB

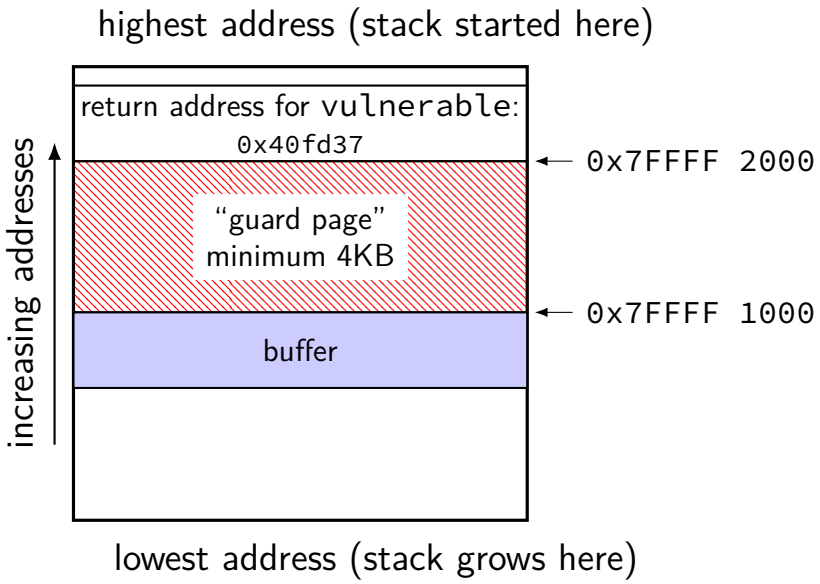
problem: substantially slower

example: "Electric Fence" allocator for Linux (early 1990s)

stack canary alternative

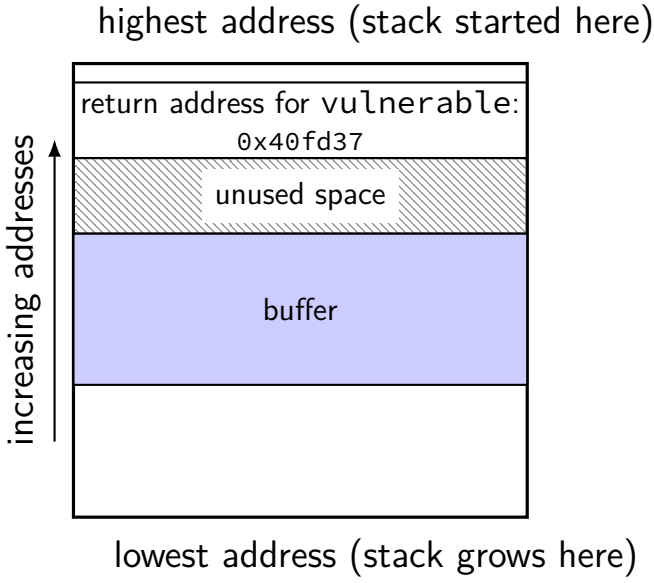


stack canary alternative

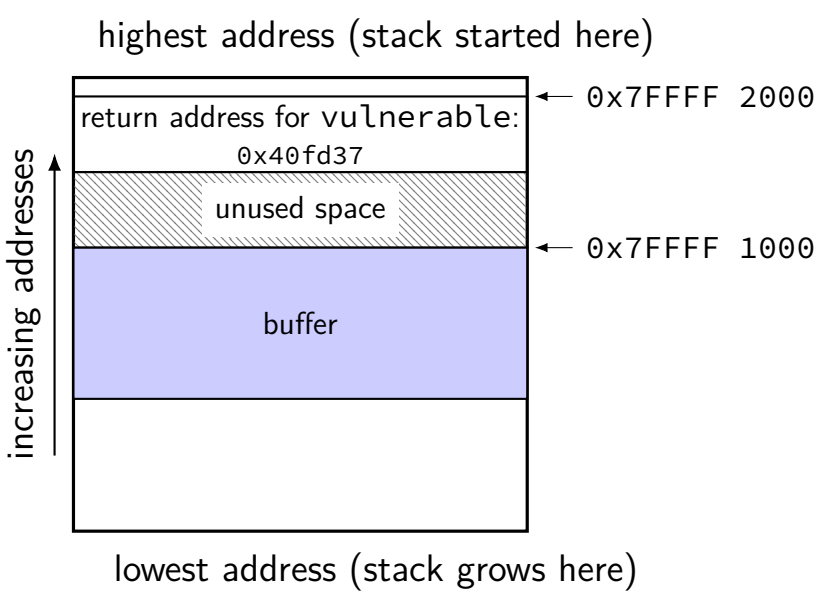


address	read	write
0x7FFFF2000-0x7FFFF2FFF	yes	yes
0x7FFFF1000-0x7FFFF1FFF	no	no
0x7FFFF0000-0x7FFFF0FFF	yes	yes

stack canary alternative 2



stack canary alternative 2



address	read	write
0x7FFFF2000–0x7FFFF2FFF	yes	yes
0x7FFFF1000–0x7FFFF1FFF	yes	no
0x7FFFF0000–0x7FFFF0FFF	yes	yes

exercise: guard page overhead

suppose heap allocations are:

- $100\,000$ objects of 100 bytes
- $1\,000$ objects of 1000 bytes
- 100 objects of approx. 10000 bytes

total allocation of approx 12 000 KB

assuming 4KB pages, estimate space overhead of using guard pages:

- for objects larger than 4096 bytes (1 page)
- for objects larger than 200 bytes
- for all objects