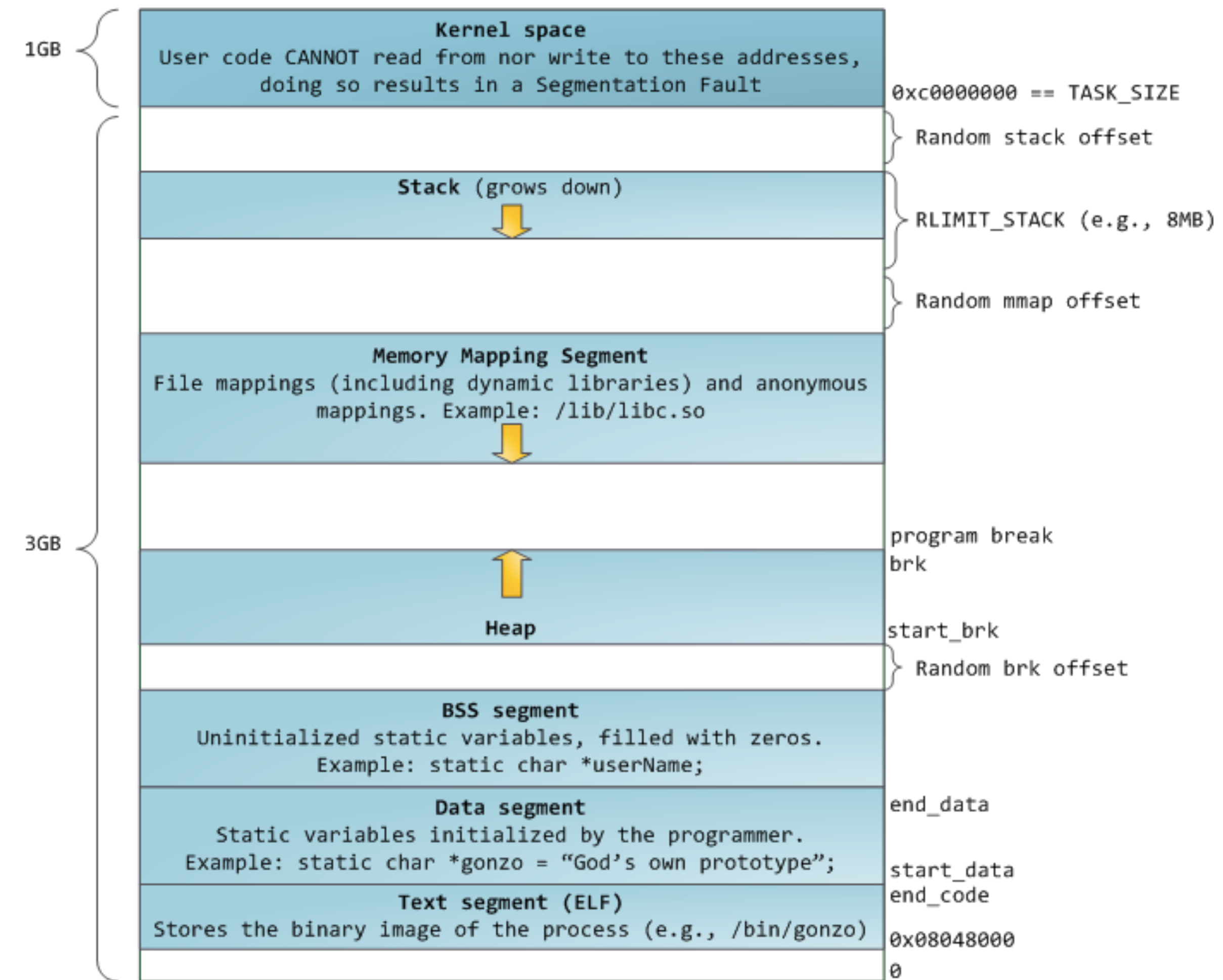


Lecture 07 – Heap control data

Stephen Checkoway
University of Illinois at Chicago

Layout of program memory

- Heap is managed by malloc
 - Many different malloc implementations
 - glibc uses a modified version of Doug Lea's Malloc (dlmalloc)
- Responsibilities
 - Requesting pages of memory from the OS
 - Managing free *chunks* of memory
 - Allocating memory for the program



Chunks

- Basic unit of memory managed by malloc
- prev_size: size of the previous chunk in memory
- size: size of this chunk
 - lsb is 1 if the previous chunk is in use (PREV_IN_USE bit)
- fd: forward pointer in free list
- bk: backward pointer in free list

```
struct malloc_chunk {  
    size_t prev_size;  
    size_t size;  
    struct malloc_chunk *fd;  
    struct malloc_chunk *bk;  
}
```

Free chunks/free lists

- A chunk can be allocated or free
- Free chunks are stored in doubly-linked lists using the fd and bk pointers
- prev_size refers to the size of the previous chunk adjacent to the current chunk, *not* the chunk pointed to by the bk pointer
- malloc maintains several different free lists for chunks of various sizes

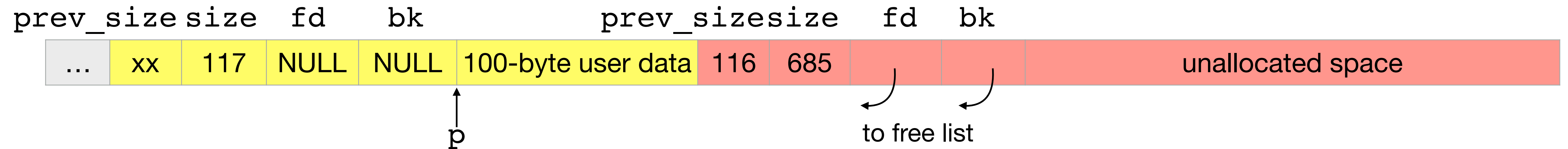
Example (lie, truth shortly)



Example (lie, truth shortly)



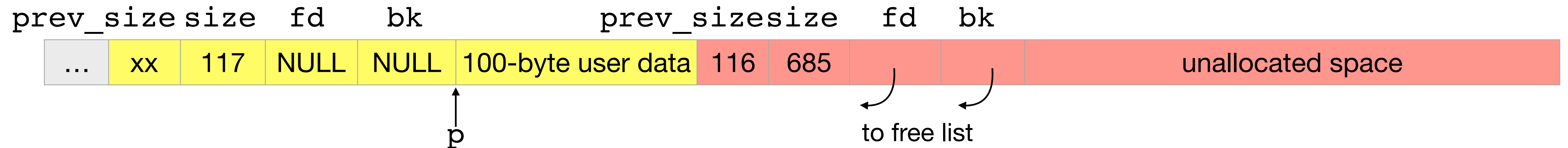
```
void *p = malloc(100);
```



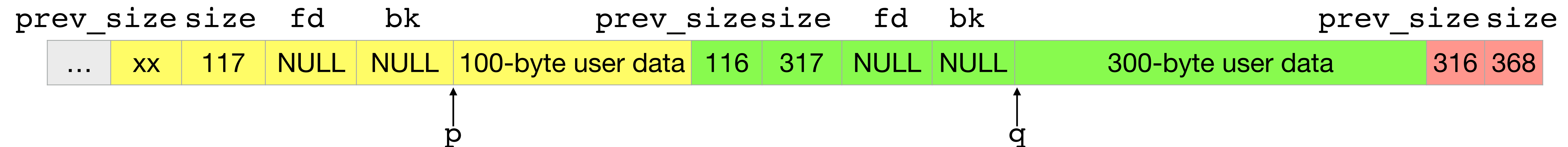
Example (lie, truth shortly)



```
void *p = malloc(100);
```



```
void *q = malloc(300);
```



Freeing chunks

- When freeing a chunk *c*, malloc looks at the chunk just before and the chunk just after *c* to see if they are free
- The adjacent free chunks are
 - removed from their free lists
 - combined with *c* to form a new, larger chunk *c'*
- *c'* (or *c* if neither neighbor were free) is added to a free list
- Malloc uses the `prev_size` and `size` fields plus some pointer arithmetic to find the preceding and following chunks
- Malloc uses the `lsb` of the `size` fields to determine if the previous chunks are in use or free

Optimization

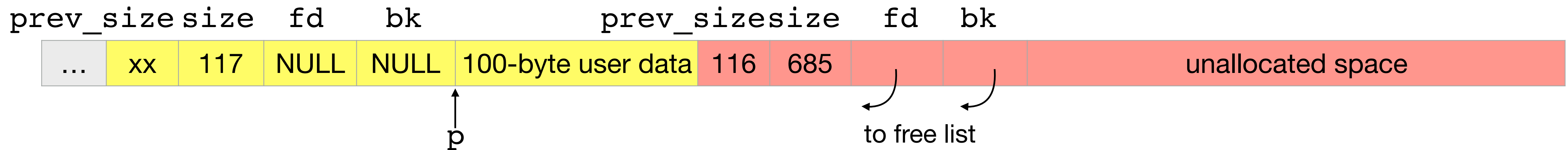
- fd and bk are only used when the chunk is free
- prev_size is only used when the previous chunk is free (to combine with the current chunk)
- Malloc saves space by overlapping these fields with user data

```
struct malloc_chunk {  
    size_t prev_size;  
    size_t size;  
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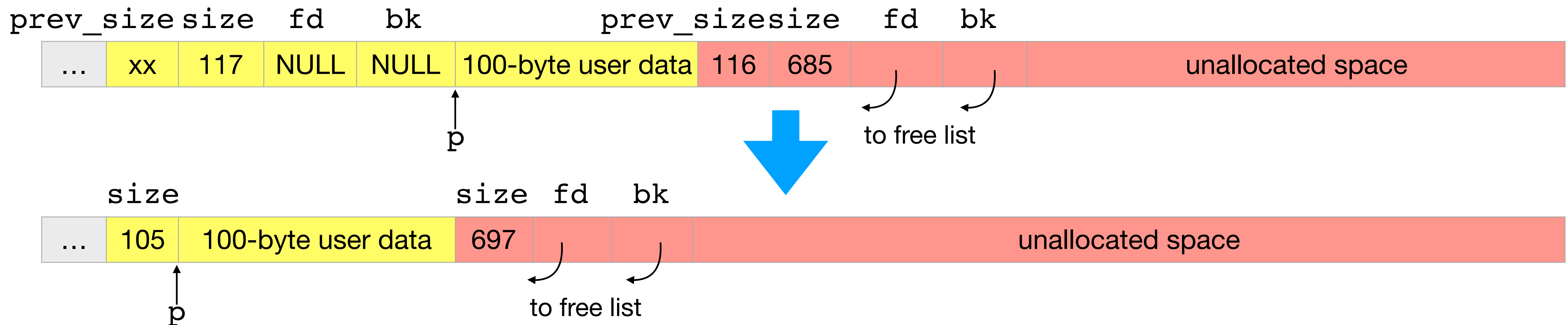
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    struct malloc_chunk *fd;  
    struct malloc_chunk *bk;  
}
```



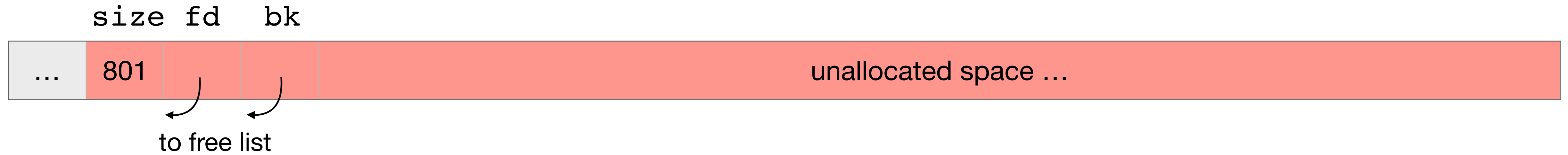
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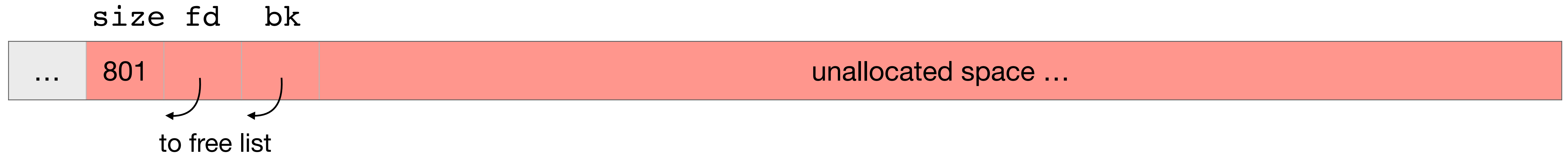
```
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    struct malloc_chunk *fd;  
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}
```



Example (truth but not to scale)

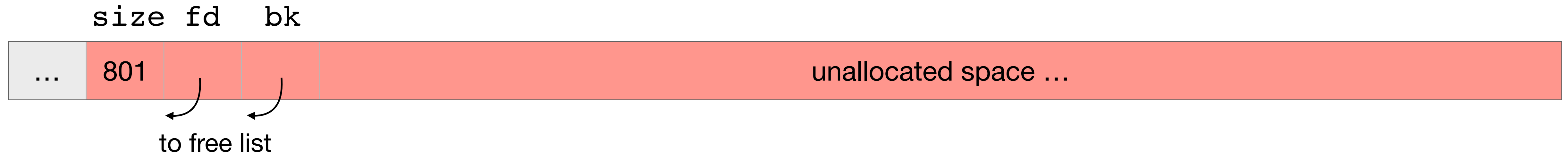


Example (truth but not to scale)

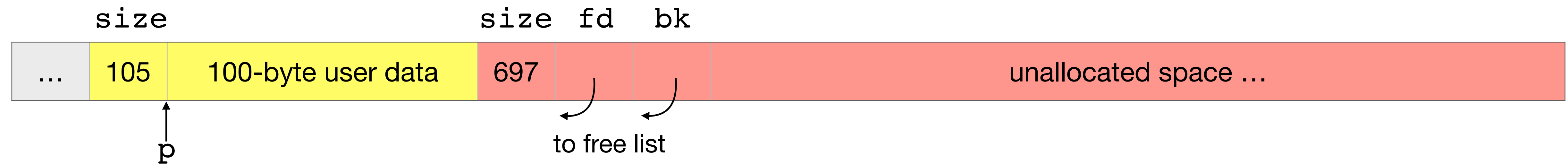


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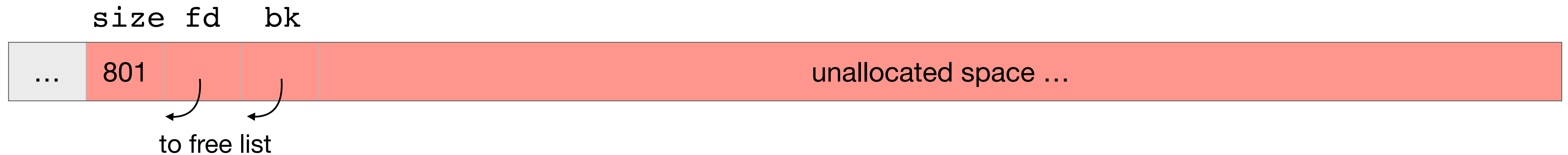
Example (truth but not to scale)



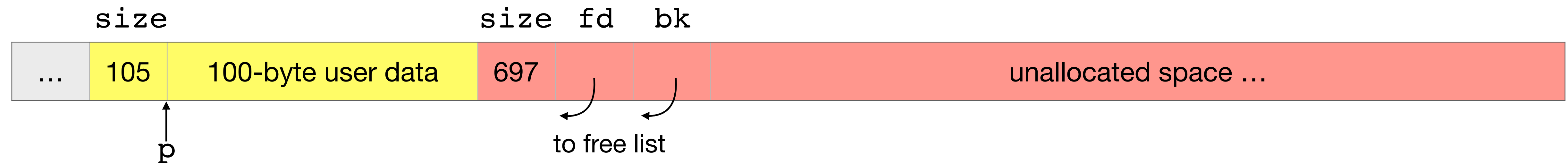
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Example (truth but not to scale)

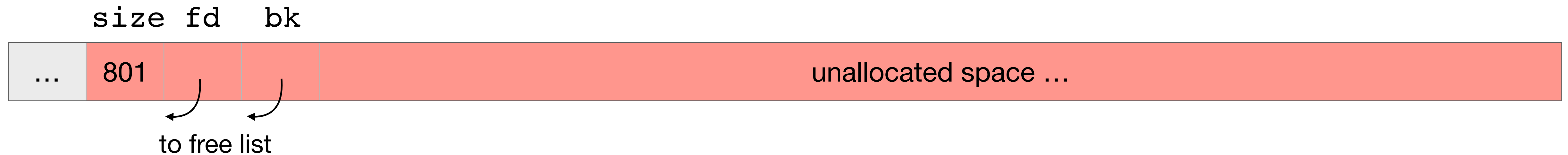


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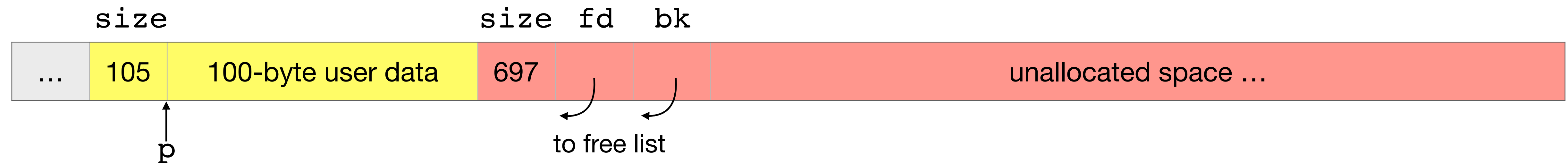


```
void *q = malloc(300);
```

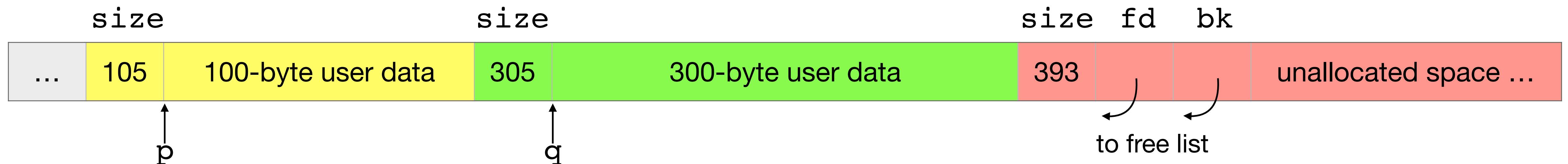
Example (truth but not to scale)



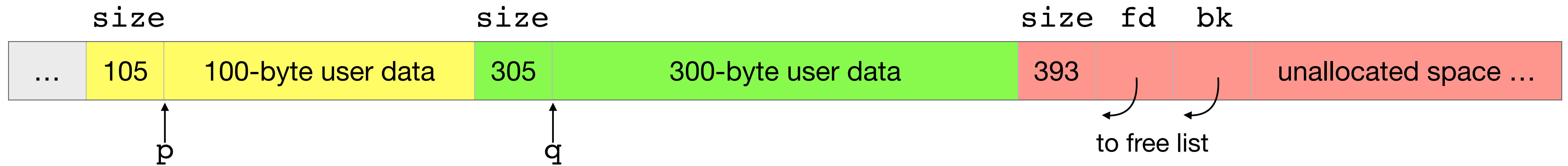
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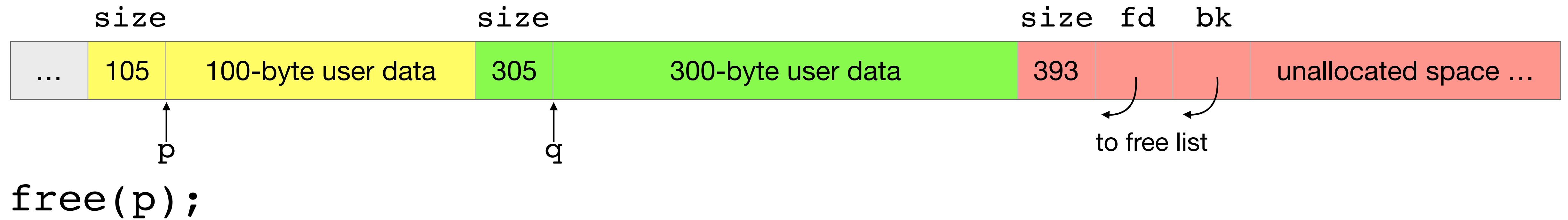
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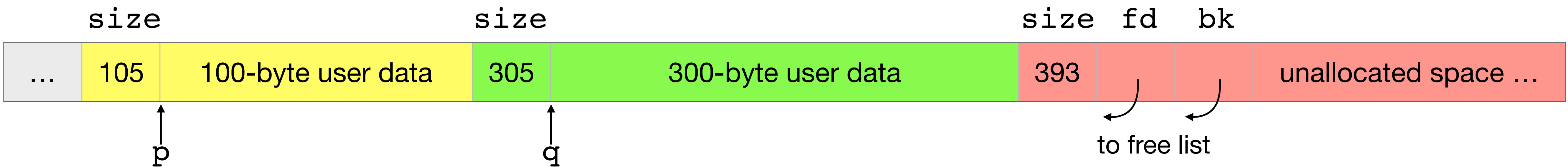
Example continued



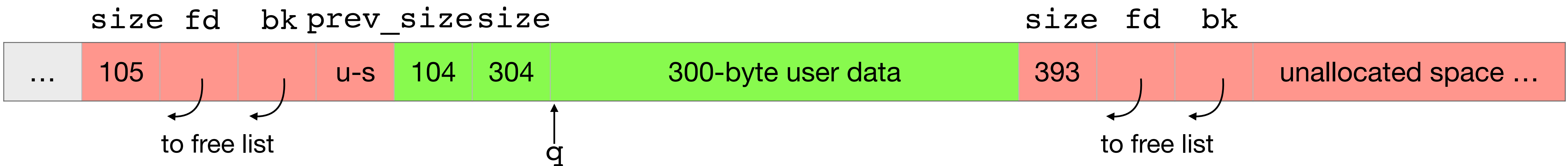
Example continued



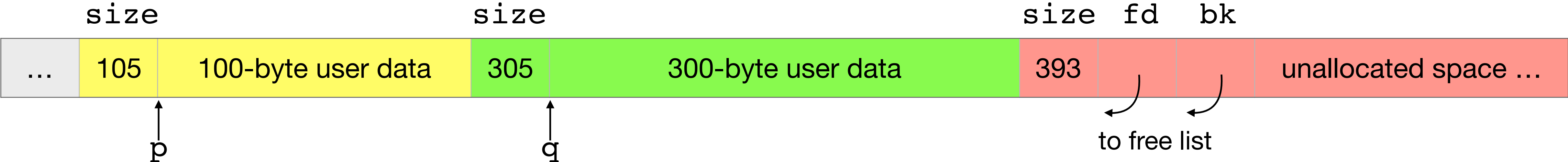
Example continued



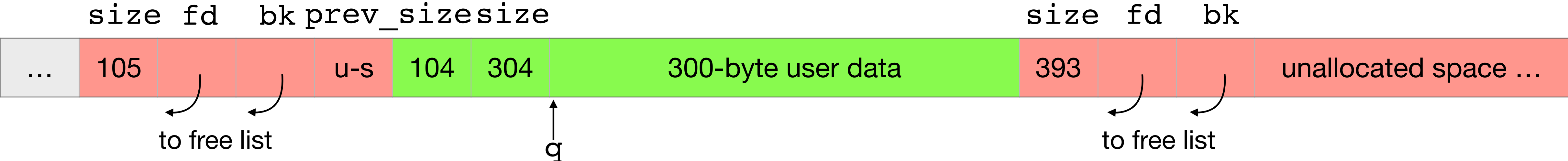
`free(p);`



Example continued

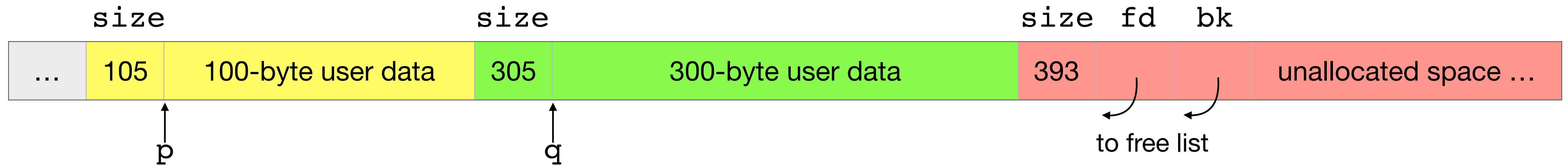


```
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```

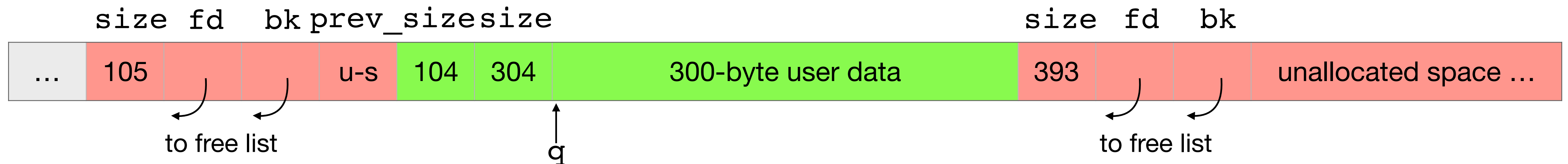


```
void *r = malloc(252);
```

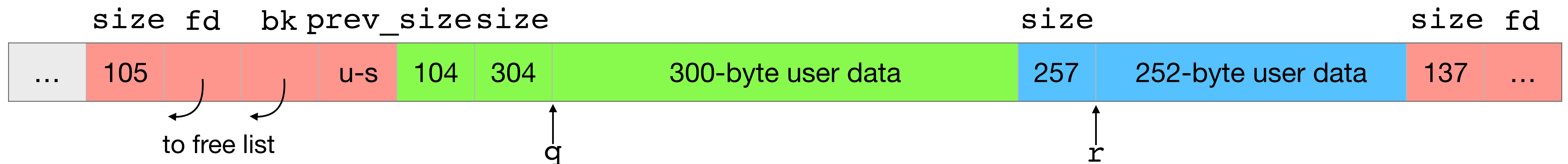
Example continued



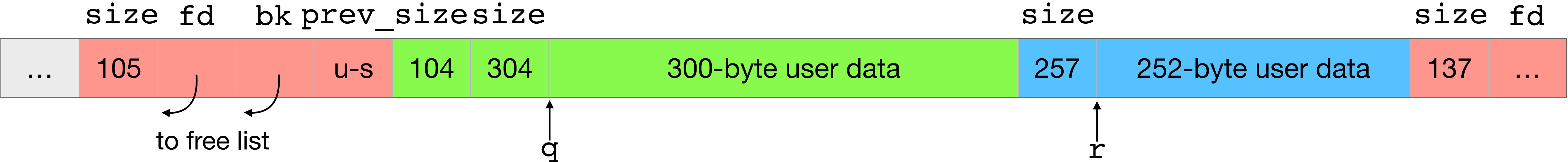
```
free(p);
```



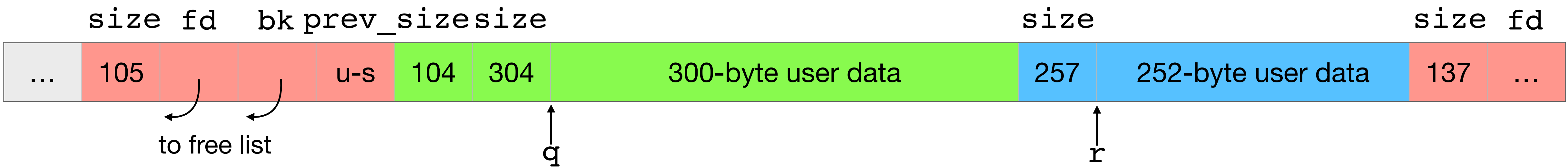
```
void *r = malloc(252);
```



Example continued

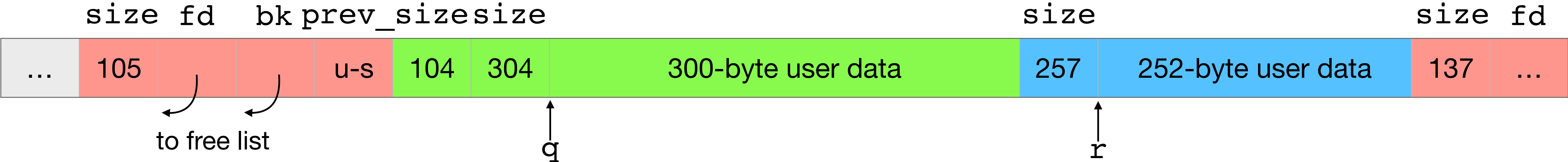


Example continued

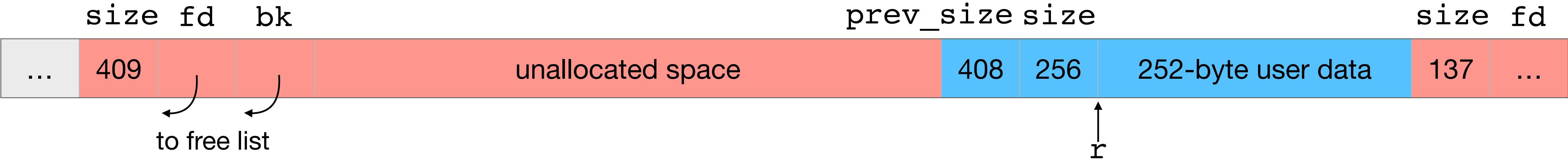


```
free(q);
```

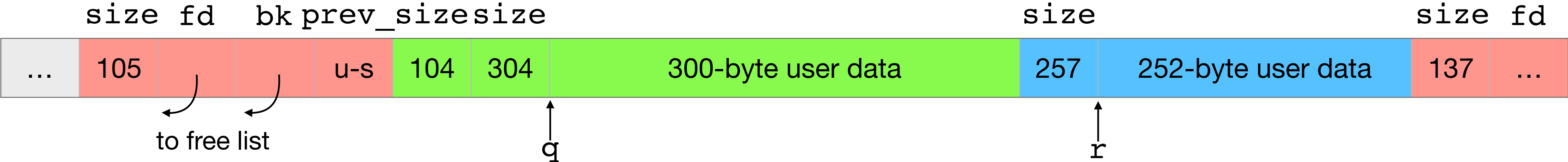
Example continued



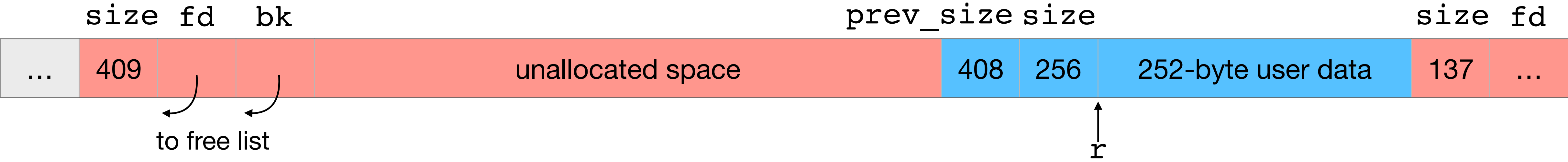
`free(q);`



Example continued

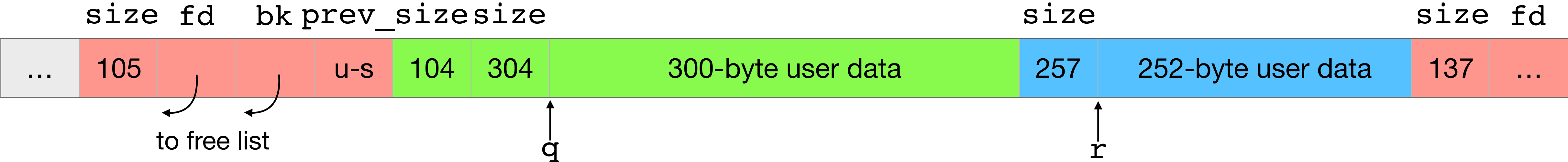


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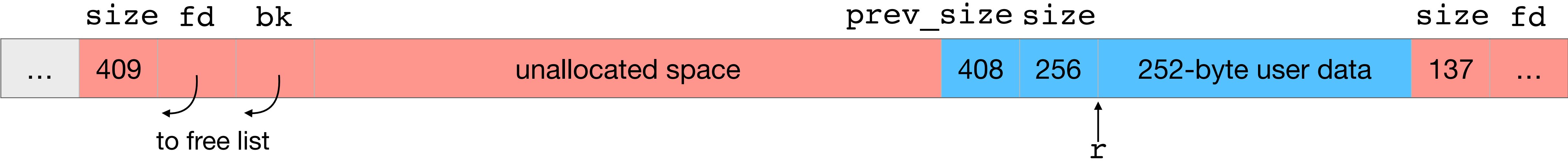


```
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```

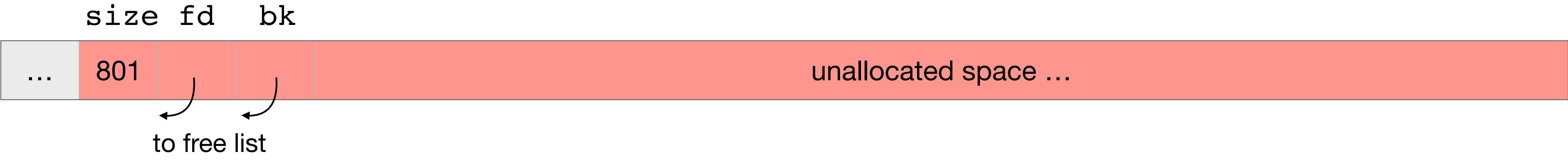
Example continued



`free(q);`



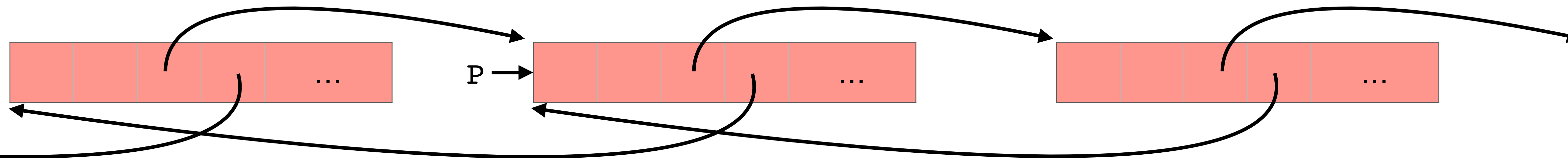
`free(r);`



Removing chunks from free lists

- Chunks are removed using the unlink macro
- P is the chunk to unlink
- BK and FD are temporaries

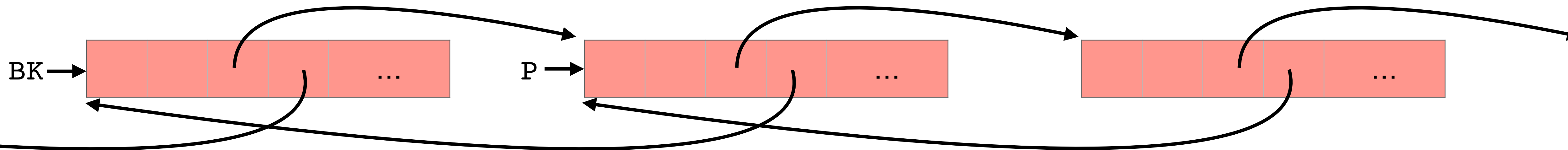
```
#define unlink(P, BK, FD) \
    BK = P->bk; \
    FD = P->fd; \
    FD->bk = BK; \
    BK->fd = FD;
```



Removing chunks from free lists

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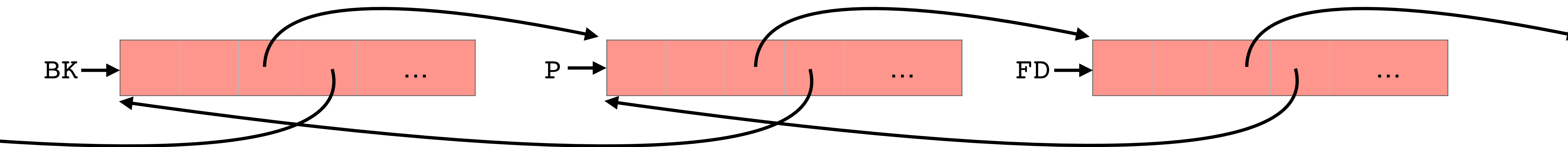
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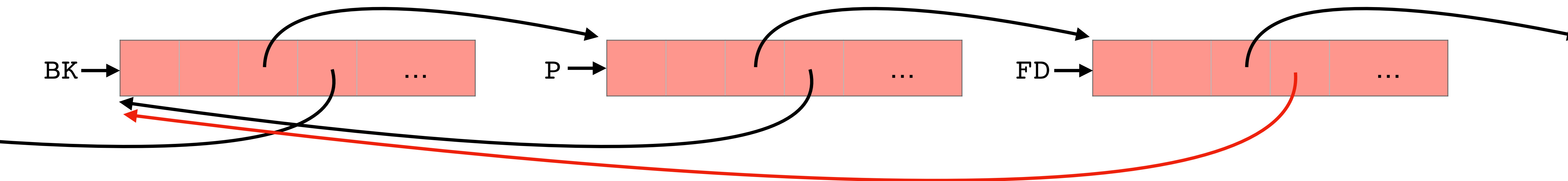
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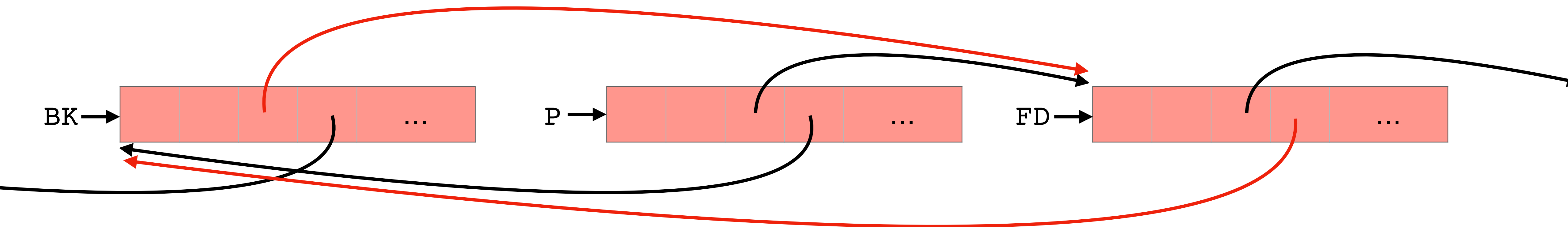
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Removing chunks from free lists

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    BK = P->bk;           \
    FD = P->fd;           \
    FD->bk = BK;          \
    BK->fd = FD;
```



Overwriting heap metadata

- The chunk metadata is inline (meaning the user data and the metadata are side-by-side)
- We can modify the metadata with a buffer overflow on the heap

- Consider

```
char *x = malloc(100);  
void *y = malloc(100);  
strcpy(x, attacker_controlled);  
free(y);
```



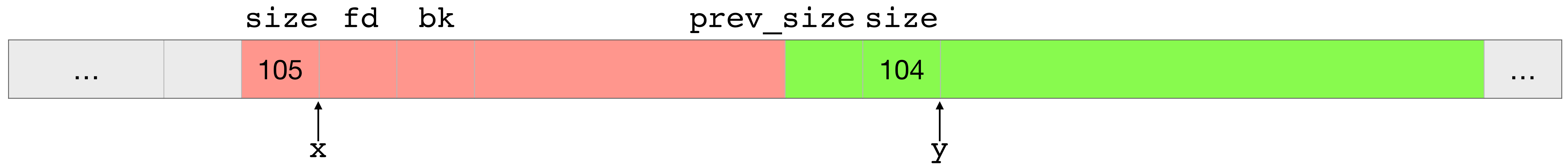
- We can overflow x and overwrite y's metadata

Attacking malloc



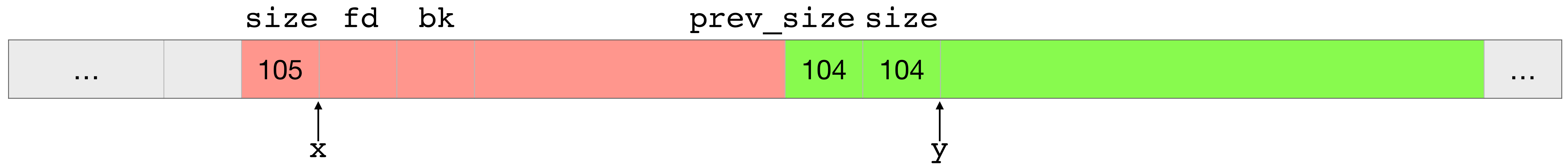
- When `free(y)` is called, it will examine `x`'s chunk to see if it is free.
- If `x`'s chunk is free, then `unlink` will be called on it to remove it from its free list
- We can carefully structure the attacker-controlled data to
 - convince `free` that `x`'s chunk is free (how do we do this?)
 - convince the `unlink` macro to overwrite a saved instruction pointer on the stack by setting `x`'s chunk's `fd` and `bk` pointers
 - inject shellcode
- When the function returns, our shellcode runs!

Attacking malloc



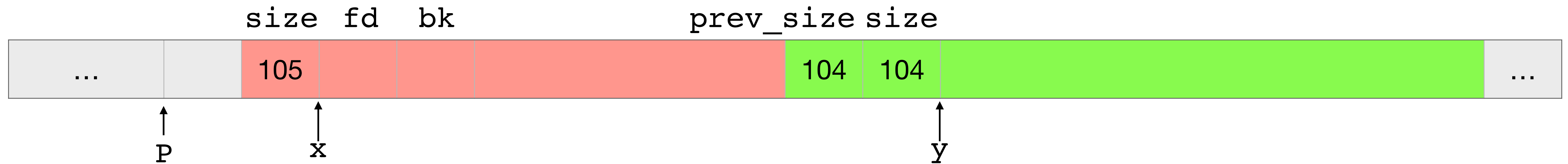
1. Change y's chunk's size from 105 to 104 (clears the PREV_IN_USE bit); y's chunk's prev_size and x's chunk's fd and bk are now used

Attacking malloc



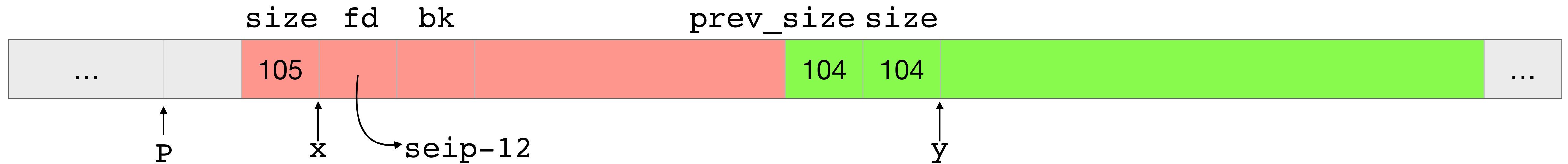
1. Change y's chunk's size from 105 to 104 (clears the PREV_IN_USE bit); y's chunk's prev_size and x's chunk's fd and bk are now used
2. Set y's chunk's prev_size to 104 so free looks back 104 bytes to find the start of the chunk to unlink

Attacking malloc



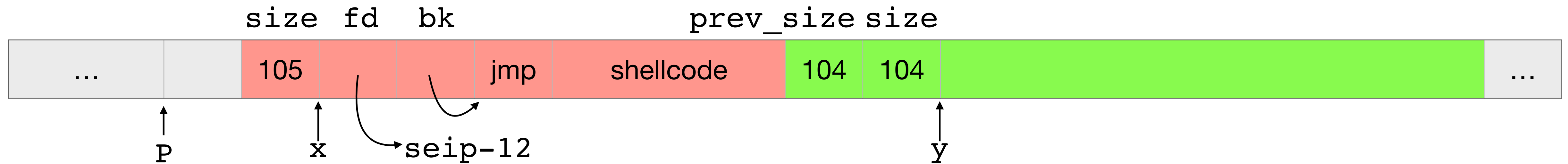
1. Change y's chunk's size from 105 to 104 (clears the PREV_IN_USE bit); y's chunk's prev_size and x's chunk's fd and bk are now used
2. Set y's chunk's prev_size to 104 so free looks back 104 bytes to find the start of the chunk to unlink
3. P in the unlink macro is x's chunk, so its fd and bk pointers need to be valid

Attacking malloc



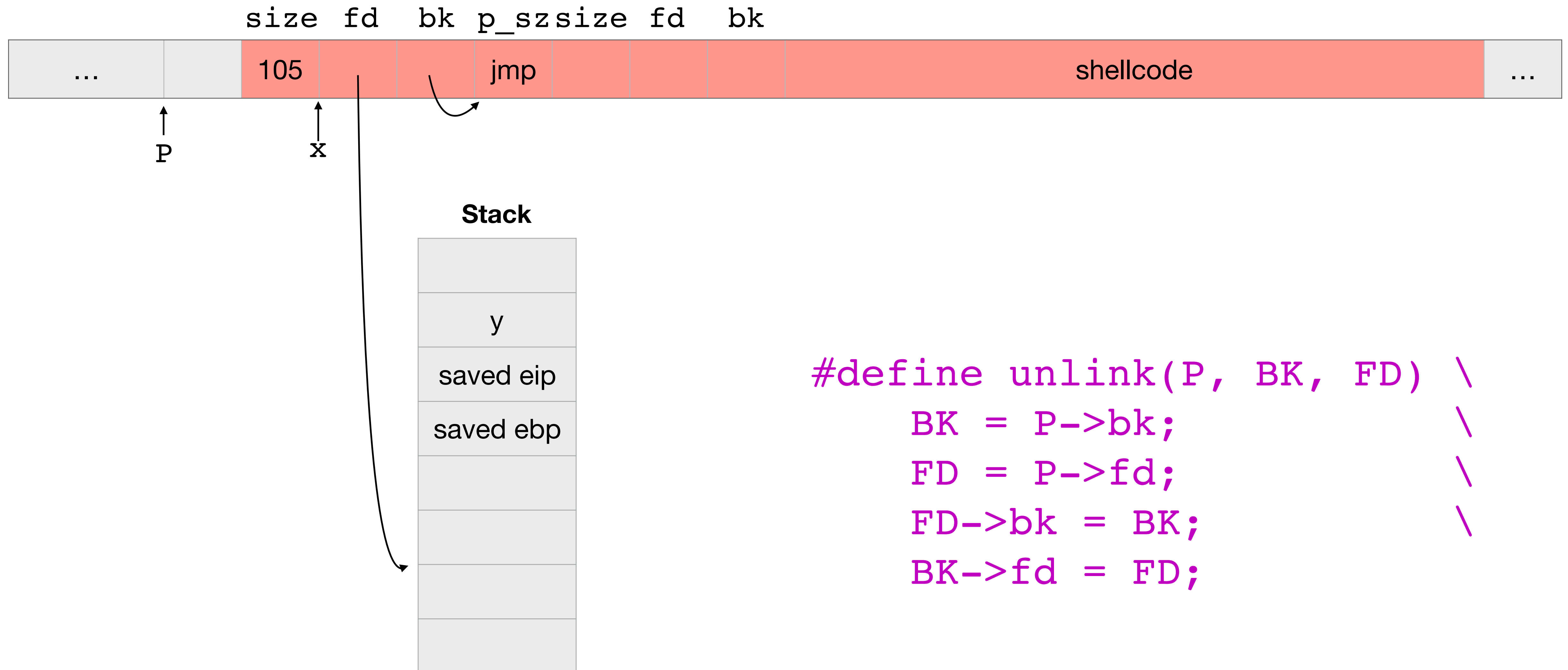
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3. P in the unlink macro is x's chunk, so its fd and bk pointers need to be valid
4. Point P->fd to saved eip (seip) - 12

Attacking malloc

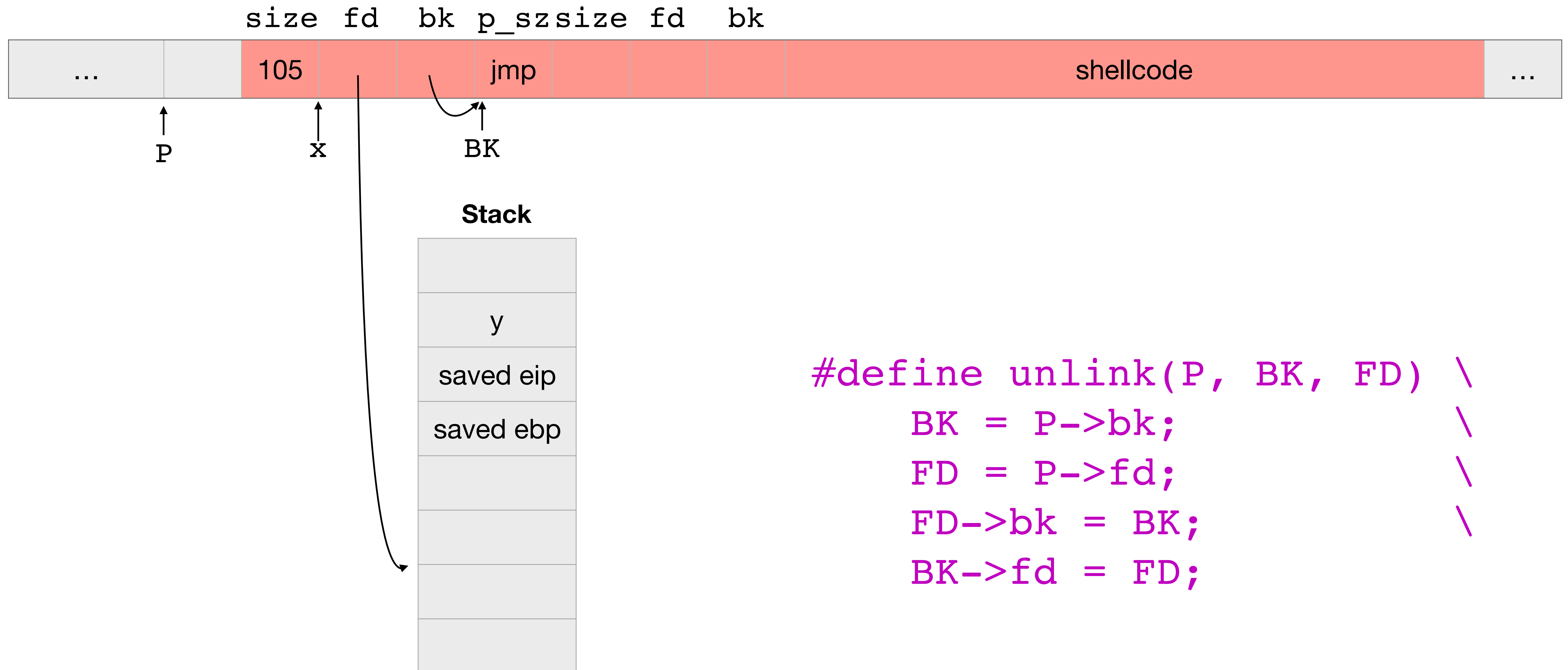


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2. Set y's chunk's prev_size to 104 so free looks back 104 bytes to find the start of the chunk to unlink
3. P in the unlink macro is x's chunk, so its fd and bk pointers need to be valid
4. Point P->fd to saved eip (seip) - 12
5. Point P->bk to a short jump to shellcode

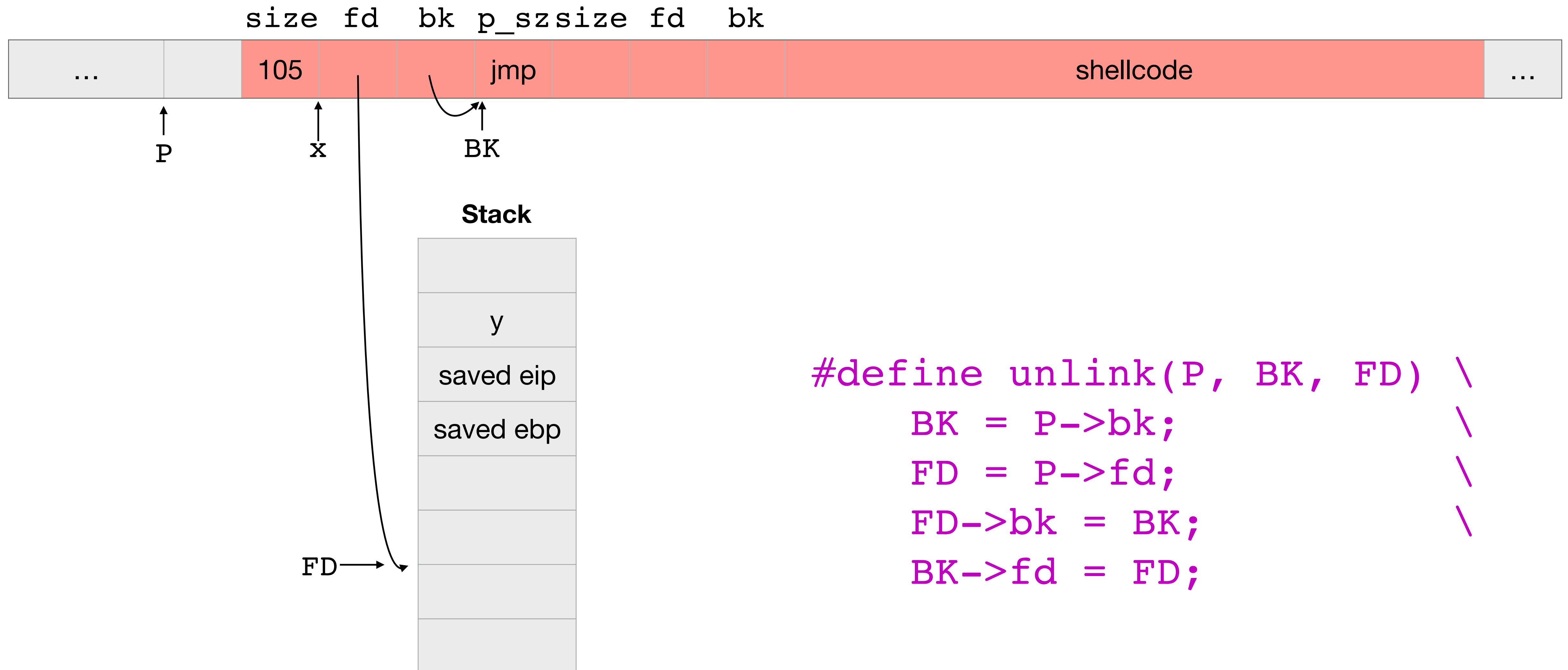
Unlinking P (zooming in on P)



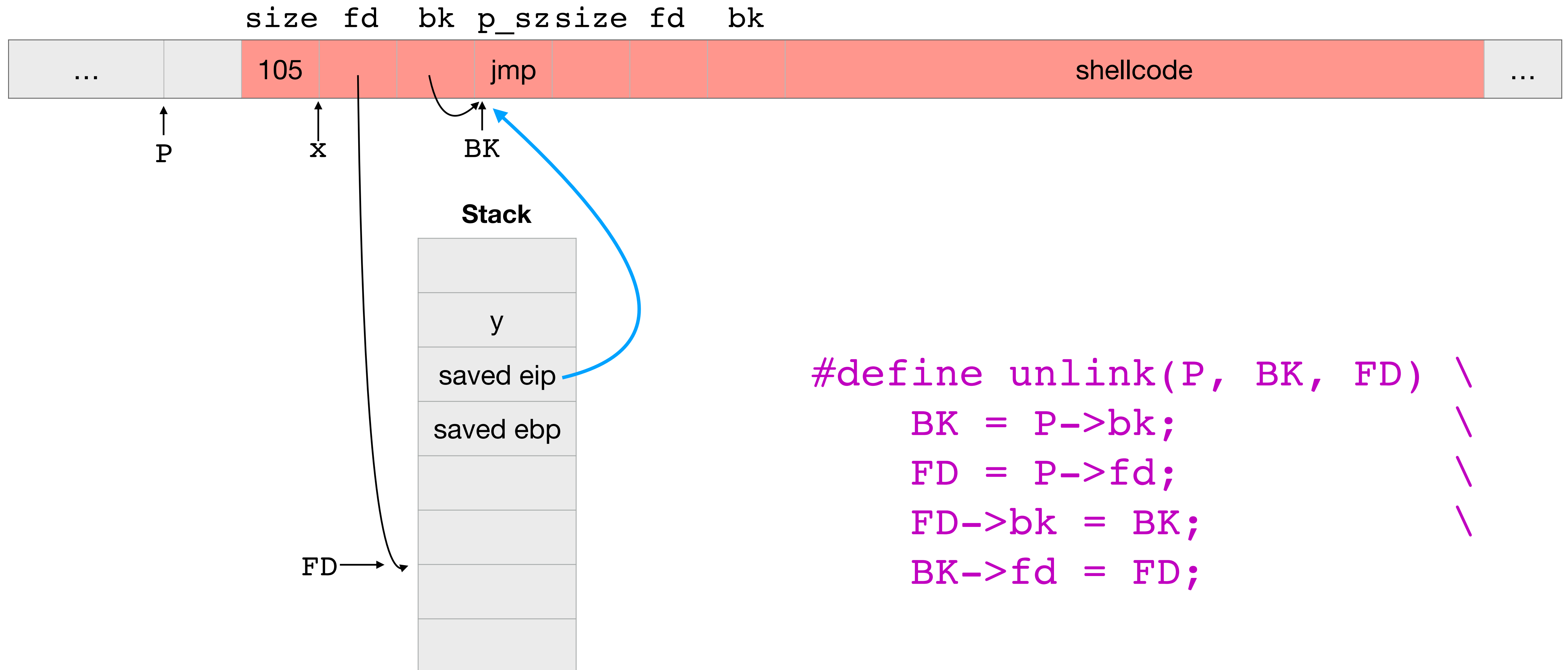
Unlinking P (zooming in on P)



Unlinking P (zooming in on P)



Unlinking P (zooming in on P)



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