Lecture 10 – Heap control data

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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

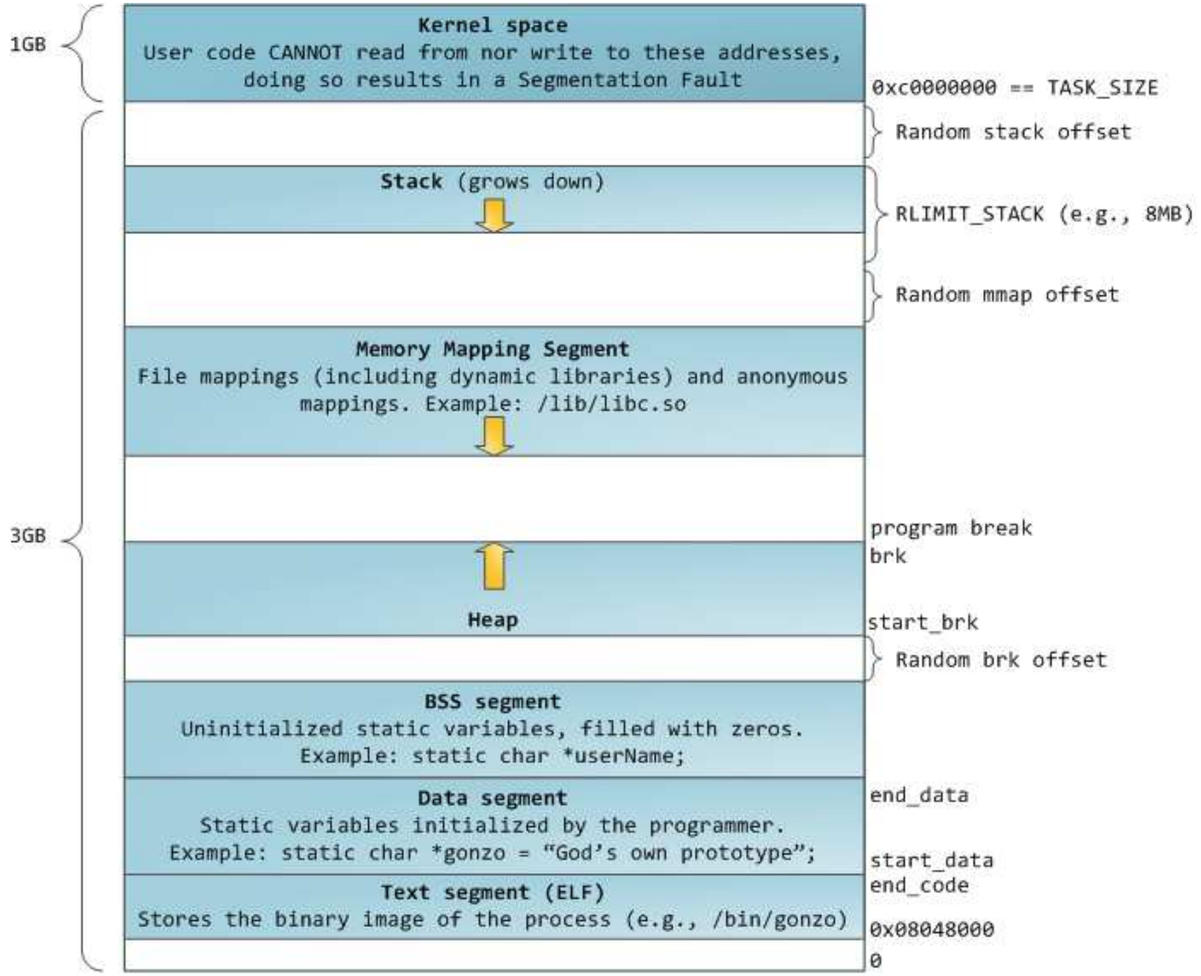

Image source: http://duartes.org/gustavo/blog/post/anatomy-of-a-program-in-memory/

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)

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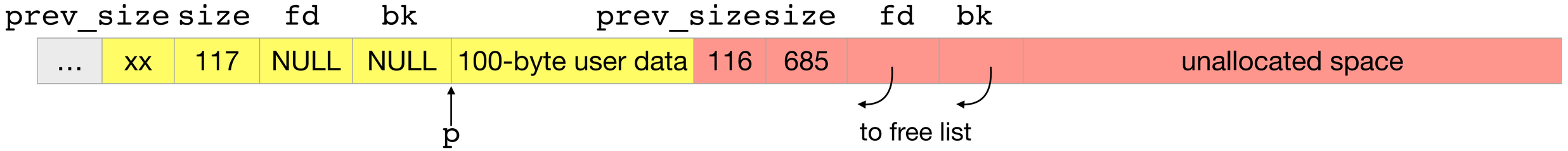
```
void *p = malloc(100);
```



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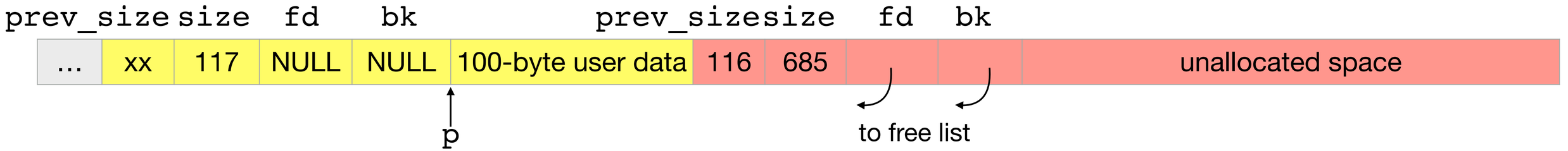
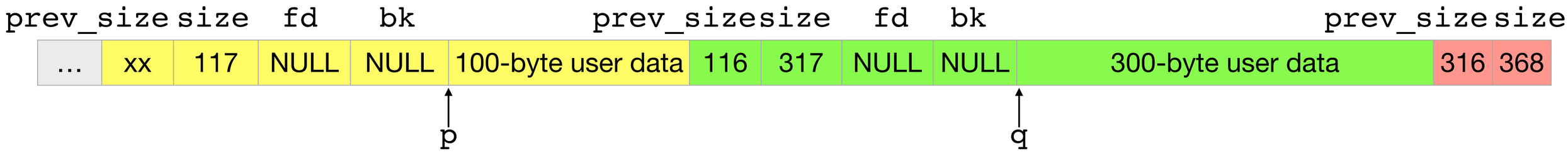



```
void *q = malloc(300);
```



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

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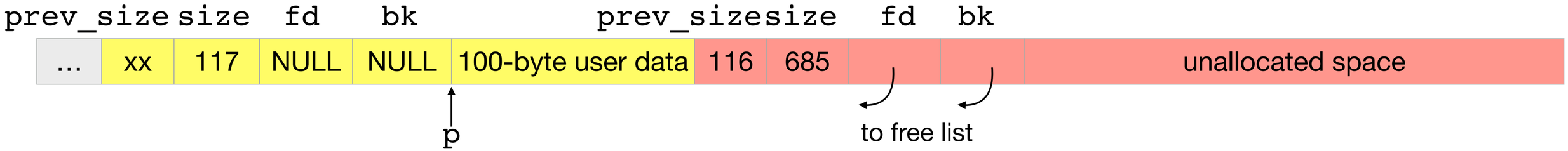

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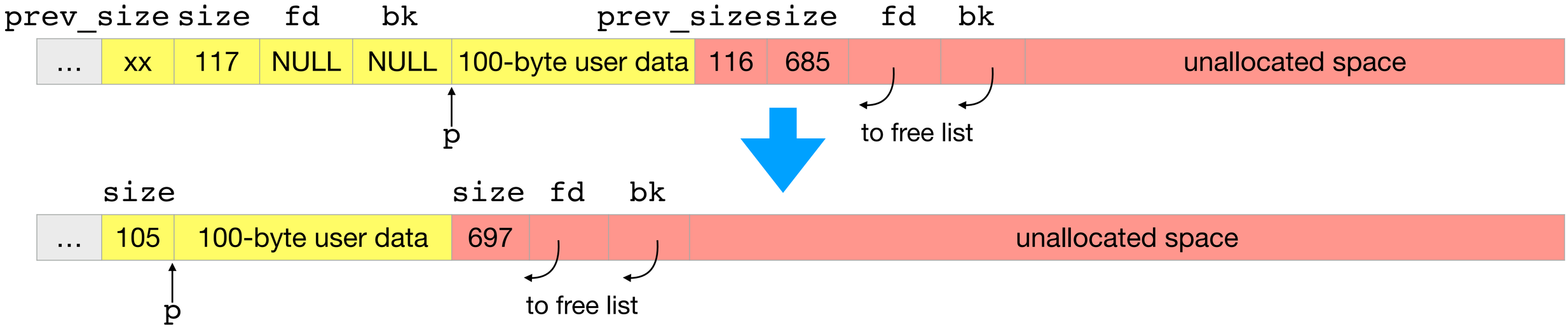
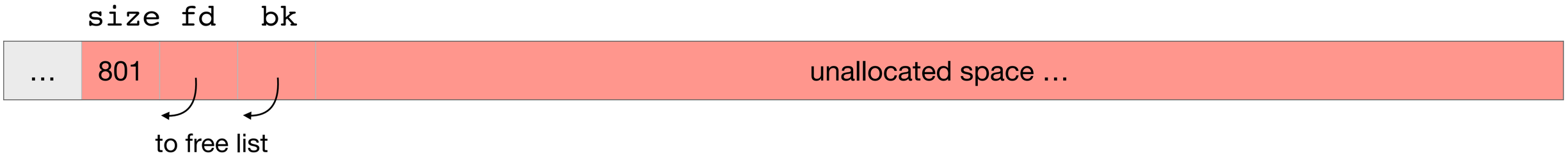


Example (truth but not to scale)



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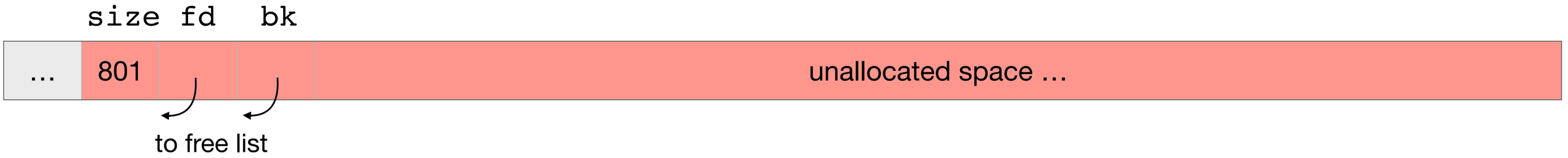


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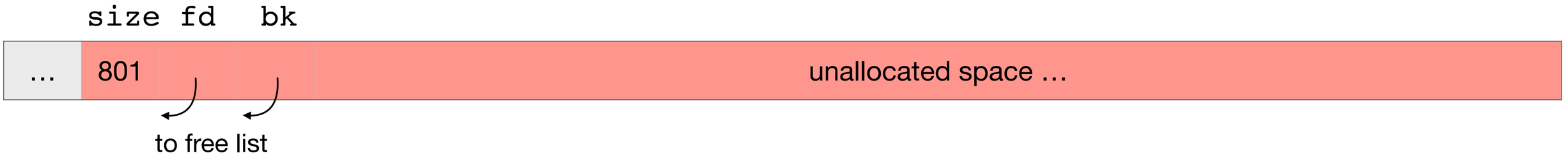


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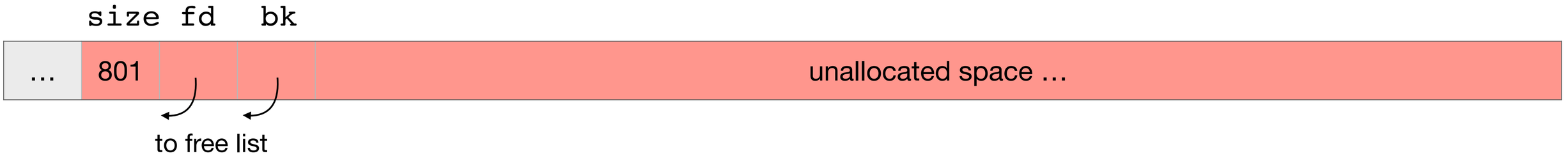


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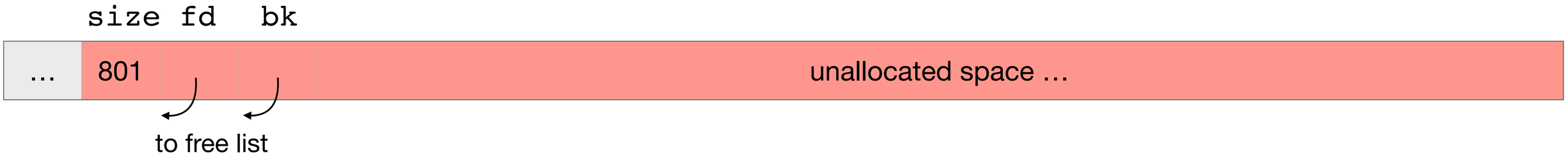


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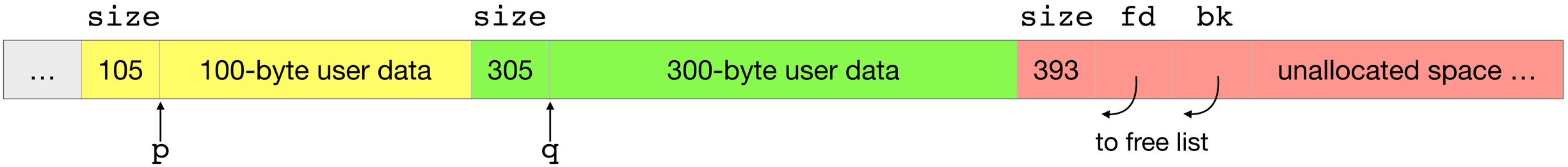
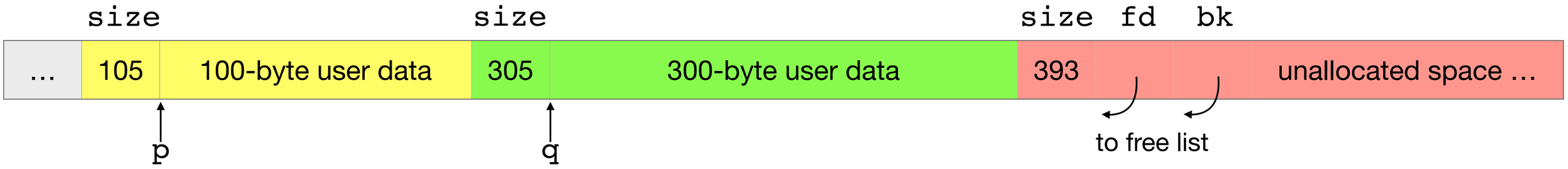
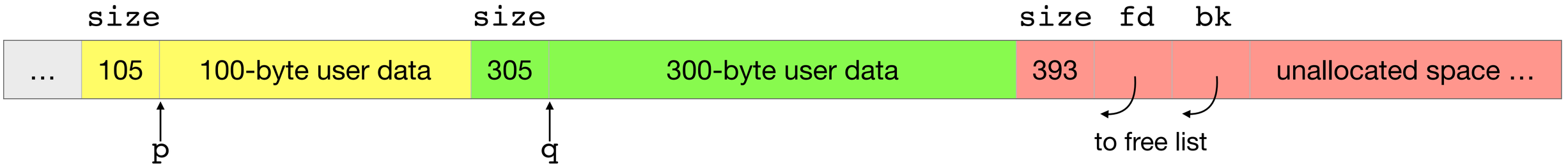


Example continued

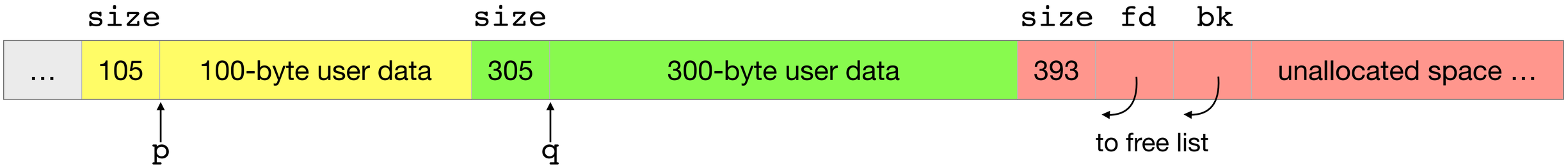


Example continued




```
free(p);
```

Example continued

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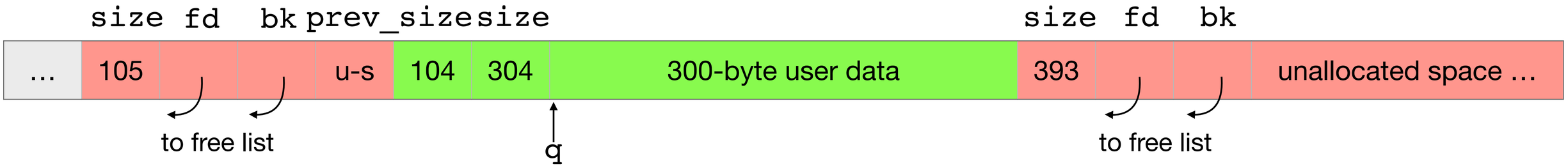
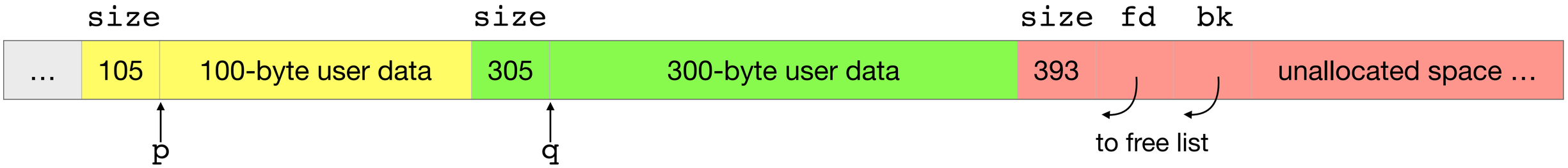


Example continued

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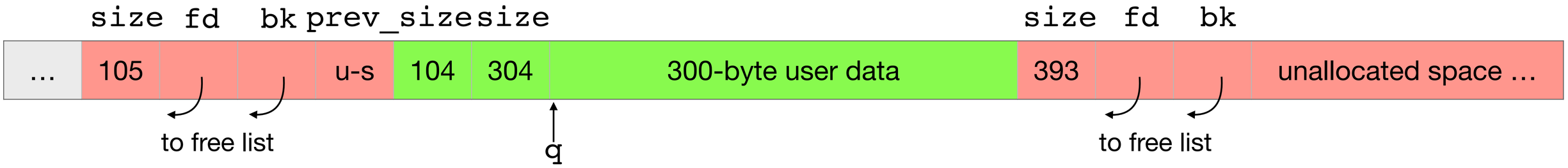
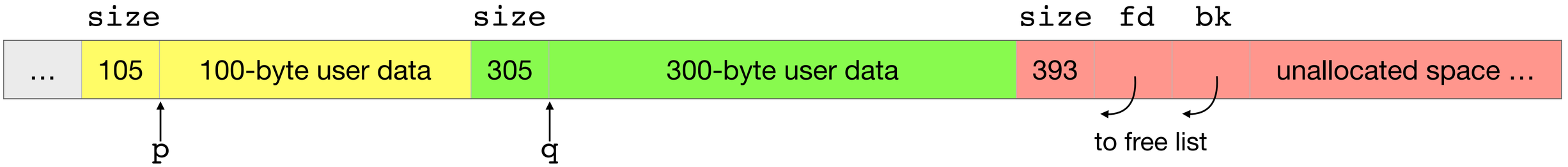



```
void *r = malloc(252);
```

Example continued

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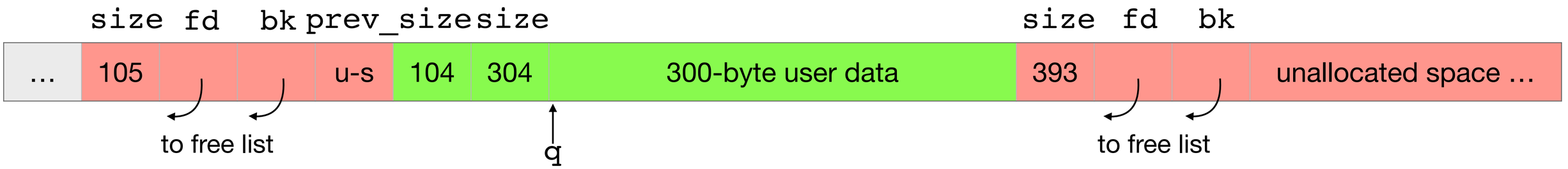


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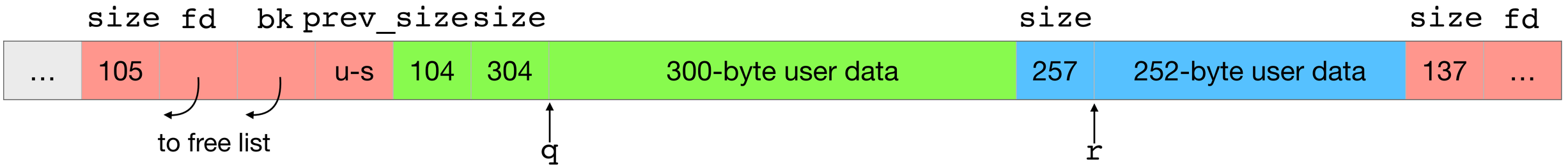

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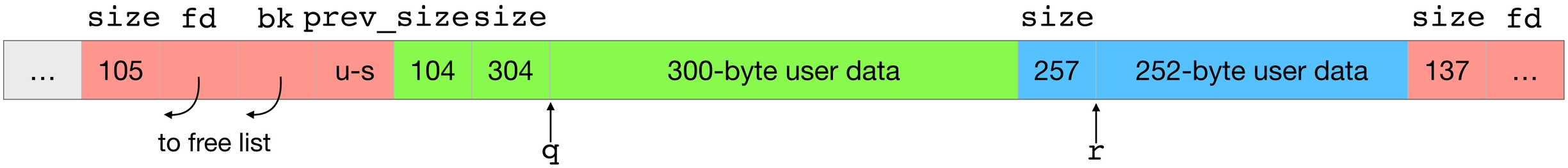

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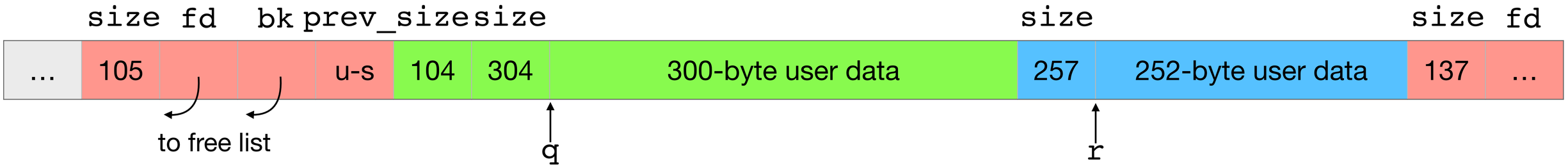


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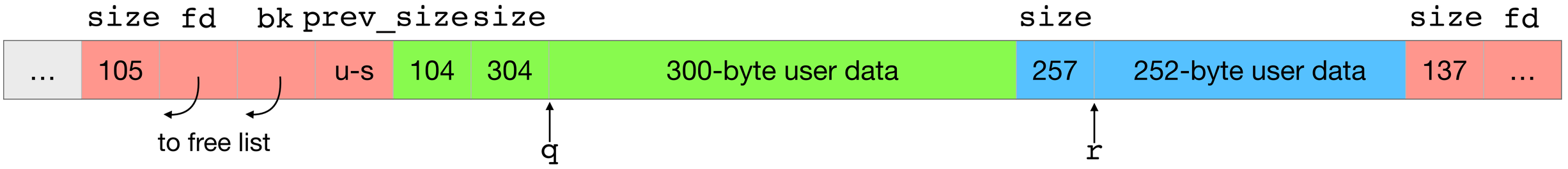
Example continued

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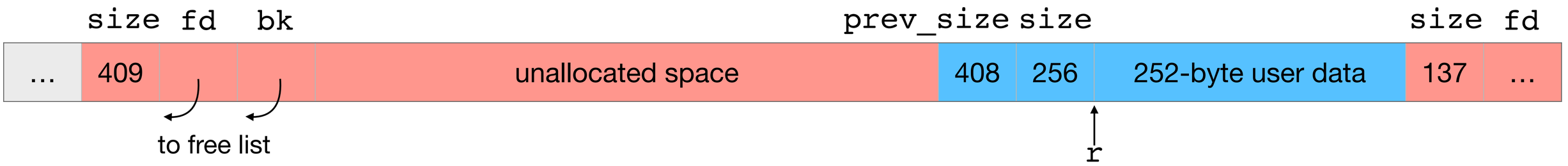

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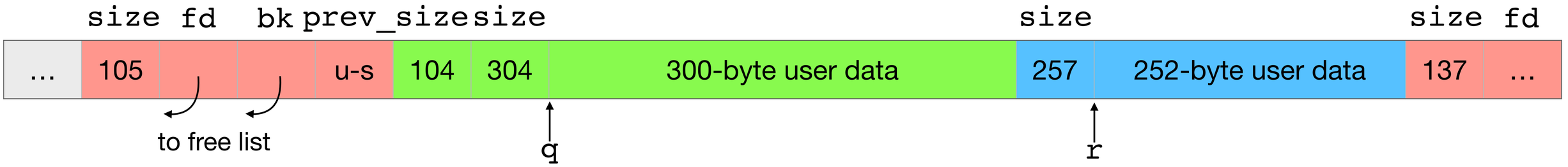


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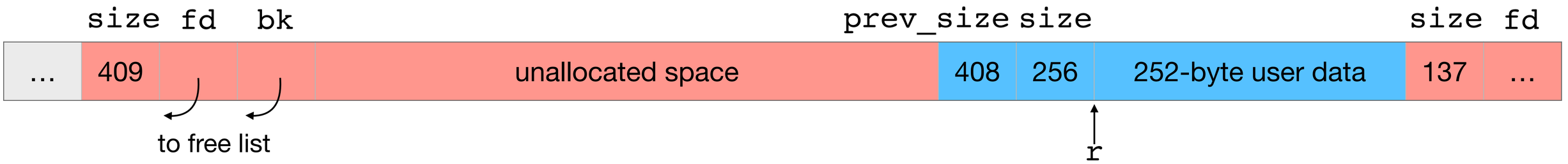


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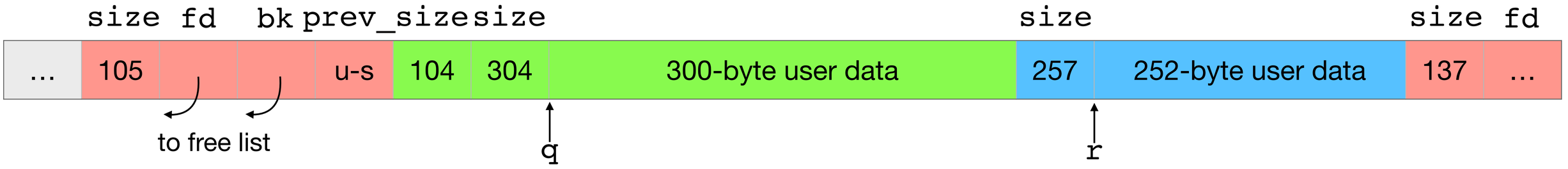


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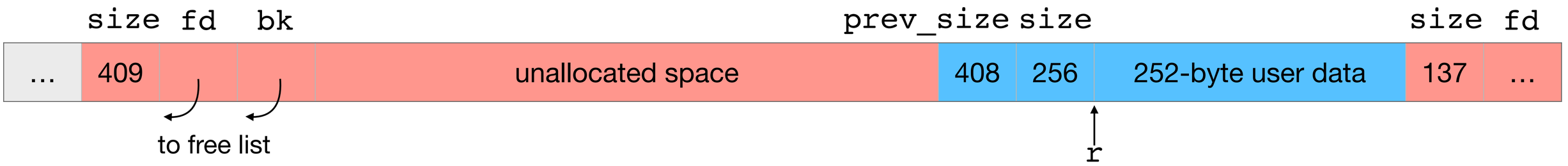


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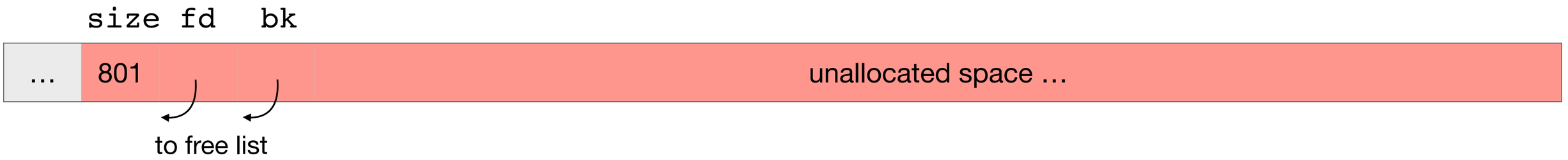

Removing chunks from free lists

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

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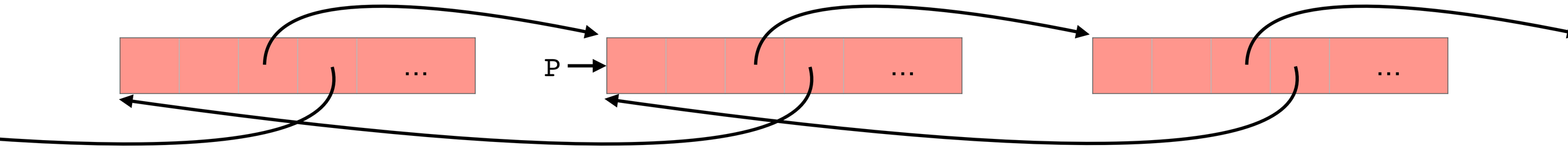

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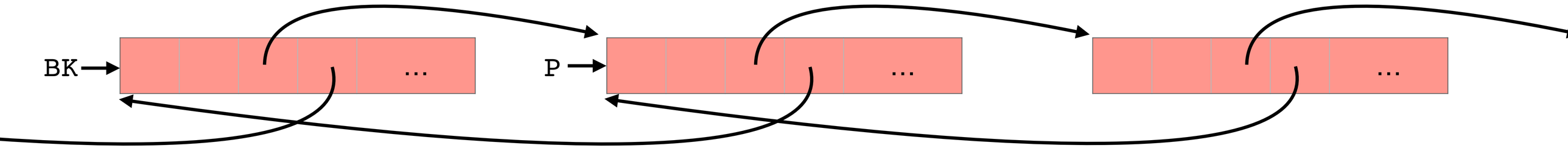

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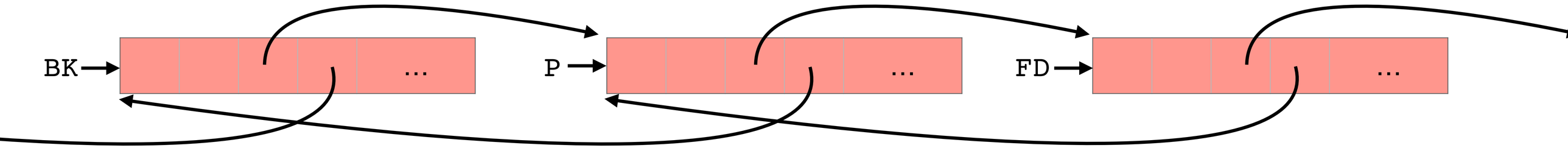

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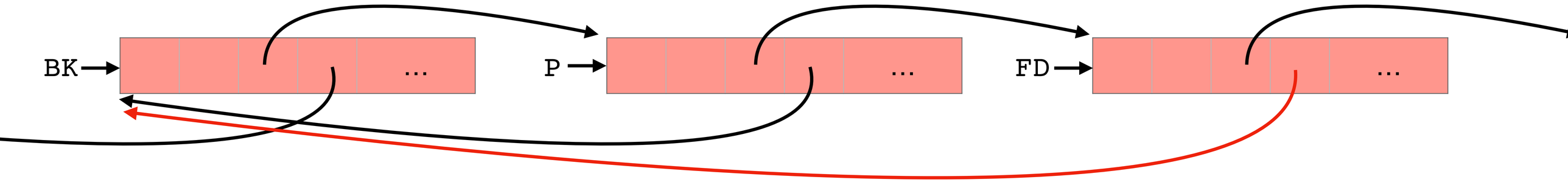

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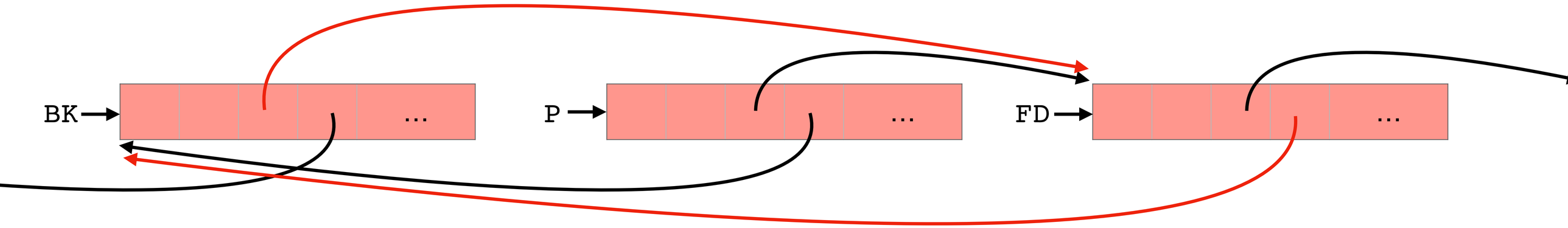
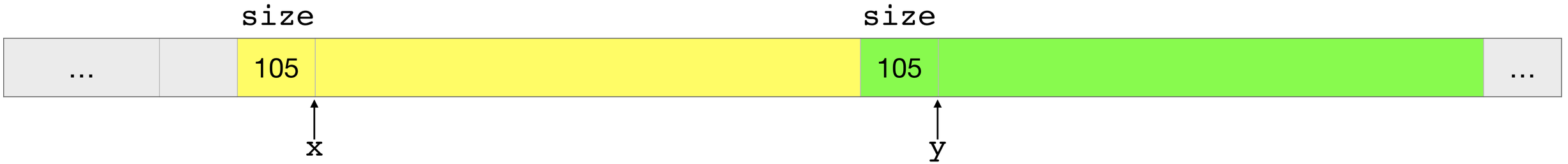


Overwriting heap metadata

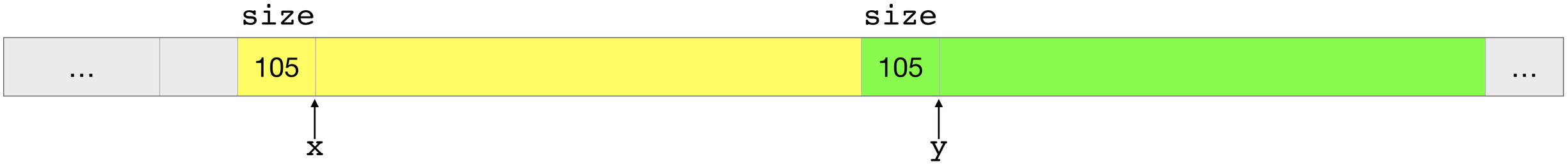
- The chunk metadata is inline (meaning the user data and the metadata are side-by-side)
- We can modify the metadata with a buffer overflow on the heap
- Consider

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



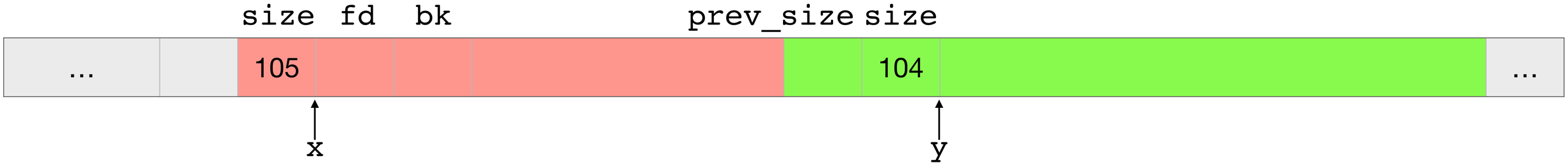
- We can overflow x and overwrite y's metadata

Attacking malloc



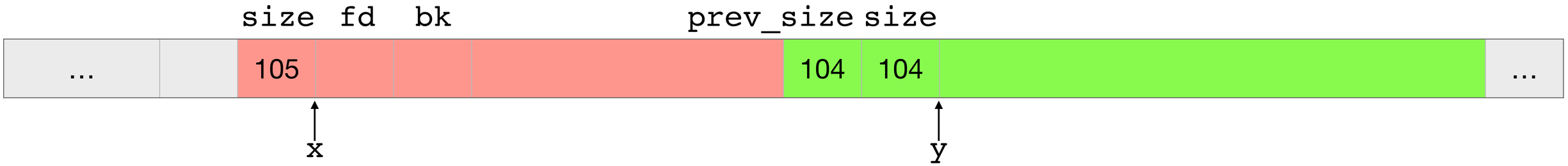
- When free(y) is called, it will examine x's chunk to see if it is free.
- If x's chunk is free, then unlink will be called on it to remove it from its free list
- We can carefully structure the attacker-controlled data to
  - convince free that x's chunk is free (how do we do this?)
  - convince the 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



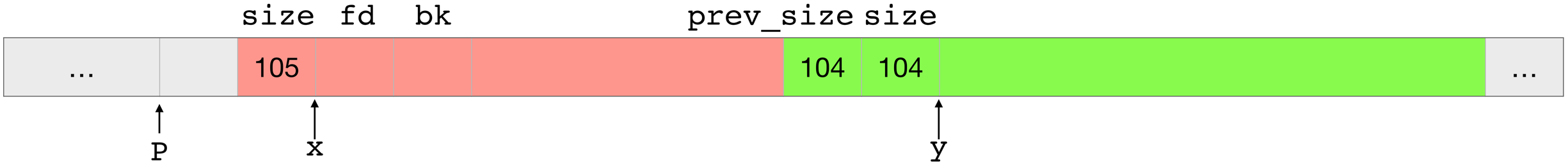
1. Change y's chunk's size from 105 to 104 (clears the PREV_IN_USE bit); y's chunk's prev_size and x's chunk's fd and bk are now used

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



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3. P in the unlink macro is x's chunk, so its fd and bk pointers need to be valid

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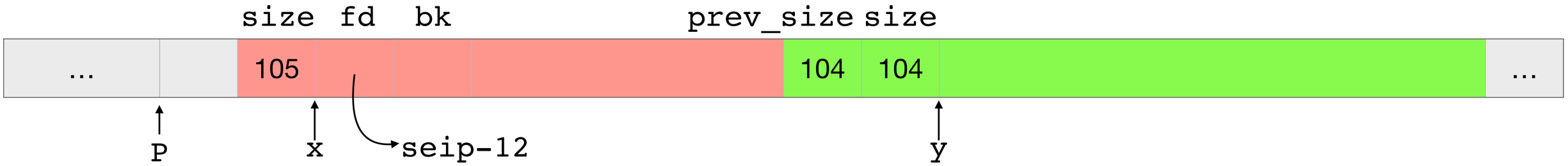

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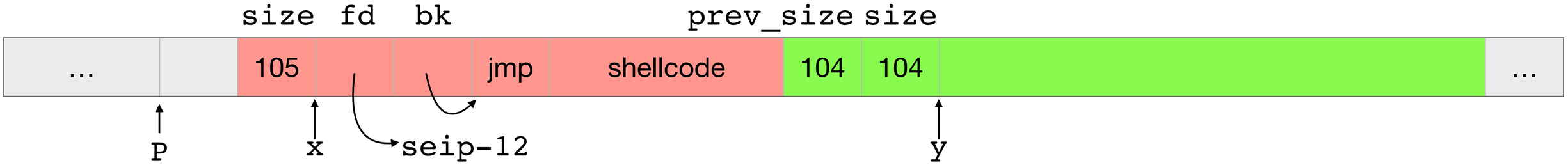

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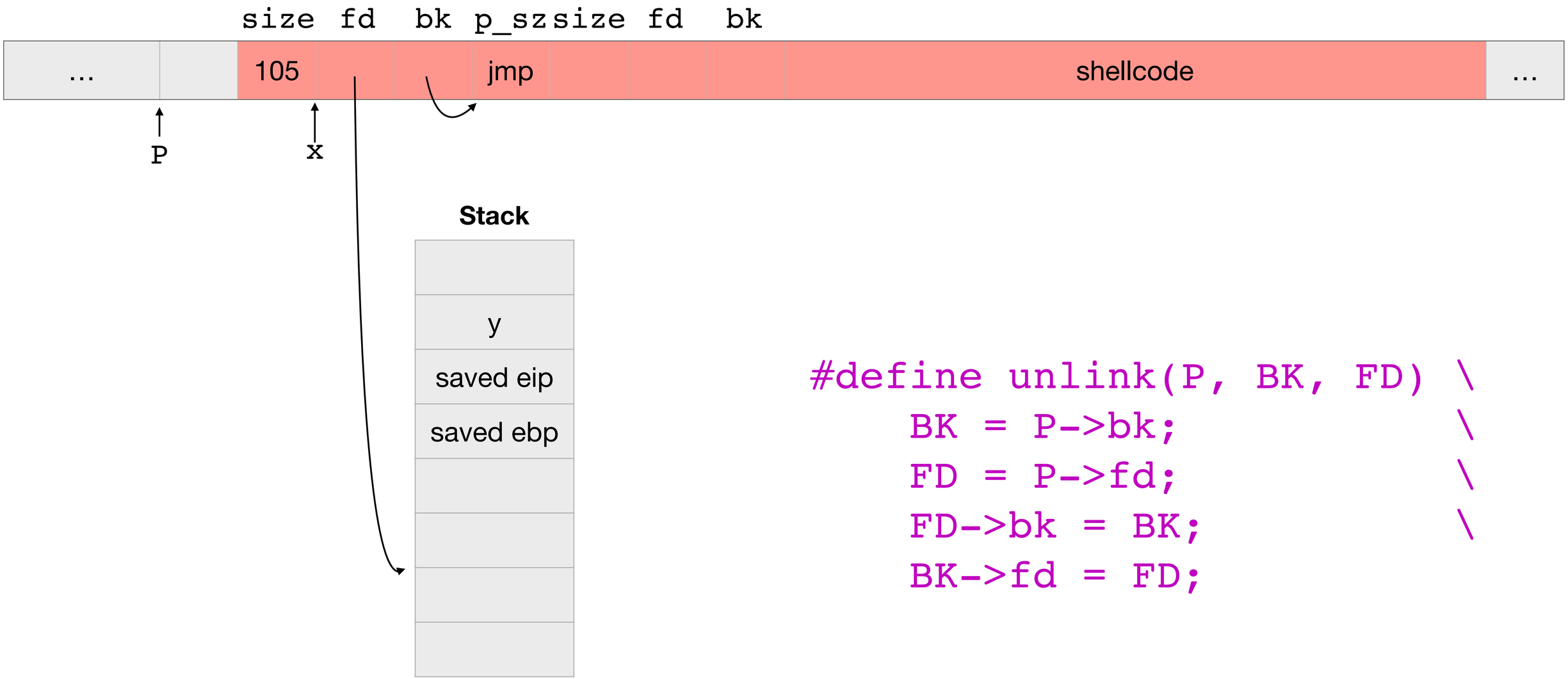
3. P in the unlink macro is x's chunk, so its fd and bk pointers need to be valid
4. Point P->fd to saved eip (seip) - 12
5. Point P->bk to a short jump to shellcode

Unlinking P (zooming in on P)

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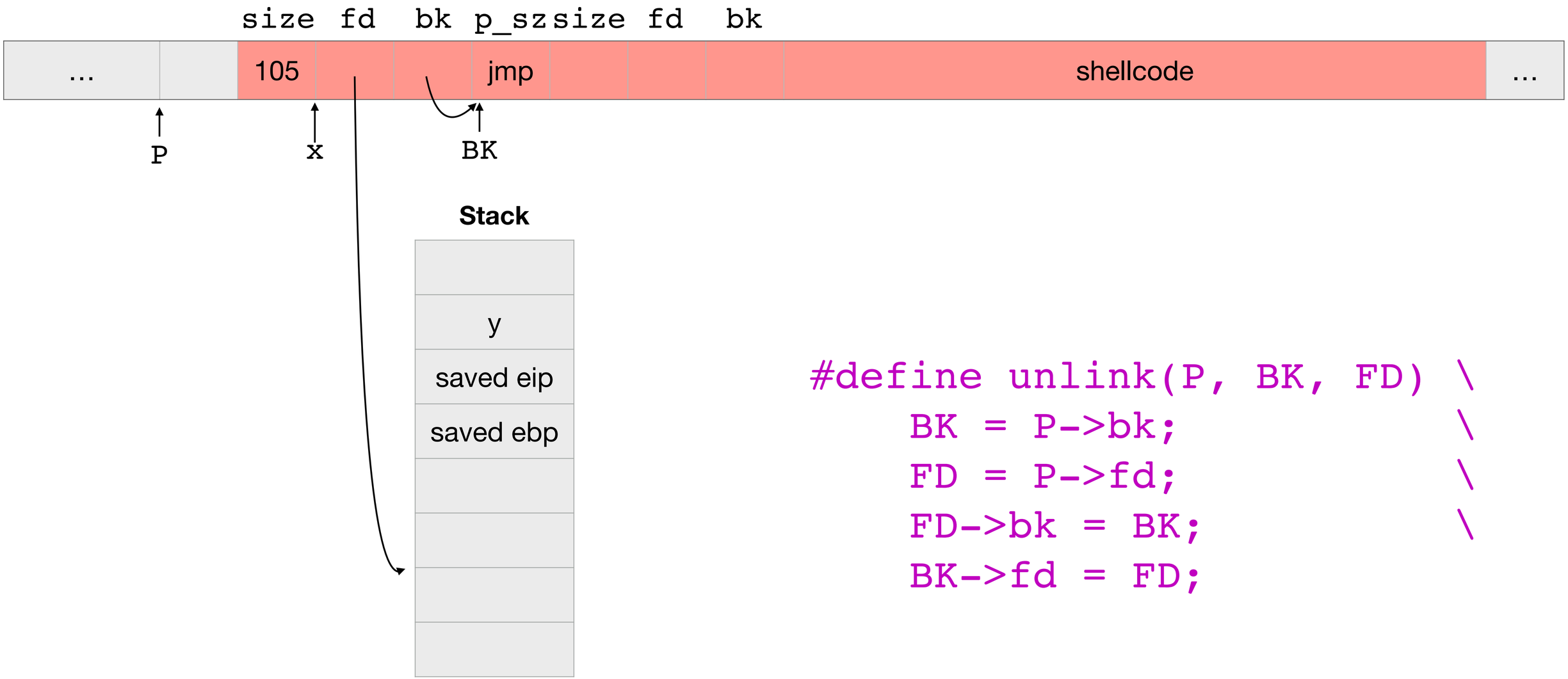
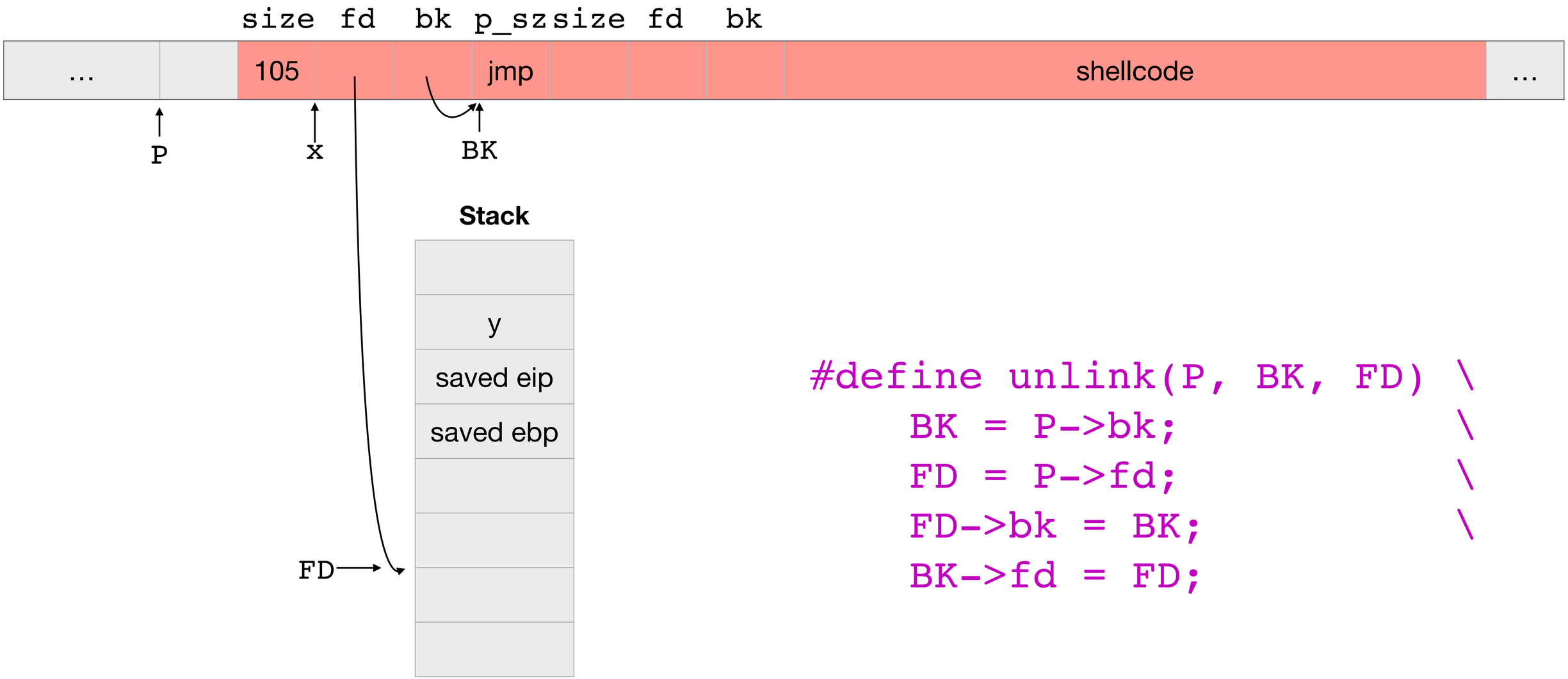
```

Unlinking P (zooming in on P)




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

Unlinking P (zooming in on P)




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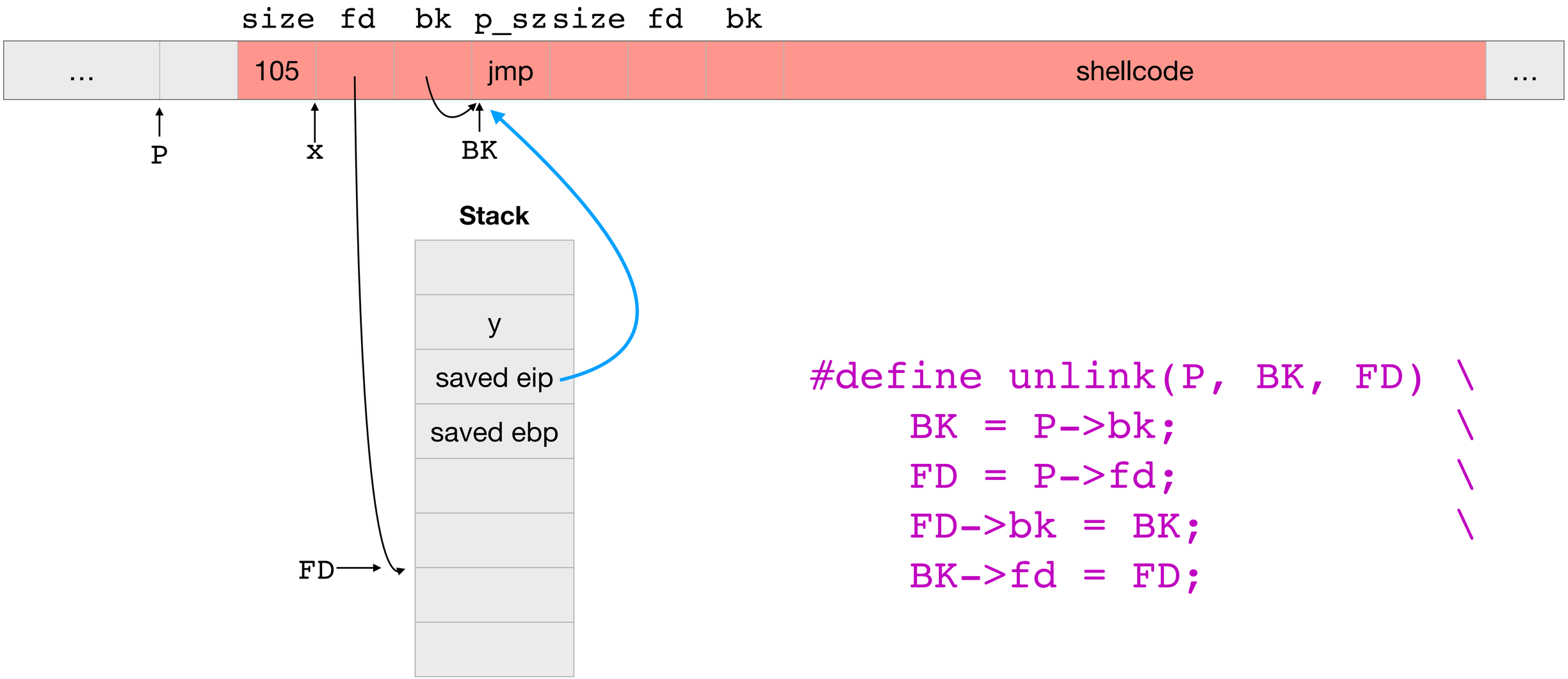
    BK = P->bk;           \
    FD = P->fd;           \
    FD->bk = BK;          \
    BK->fd = FD;
```

Unlinking P (zooming in on P)

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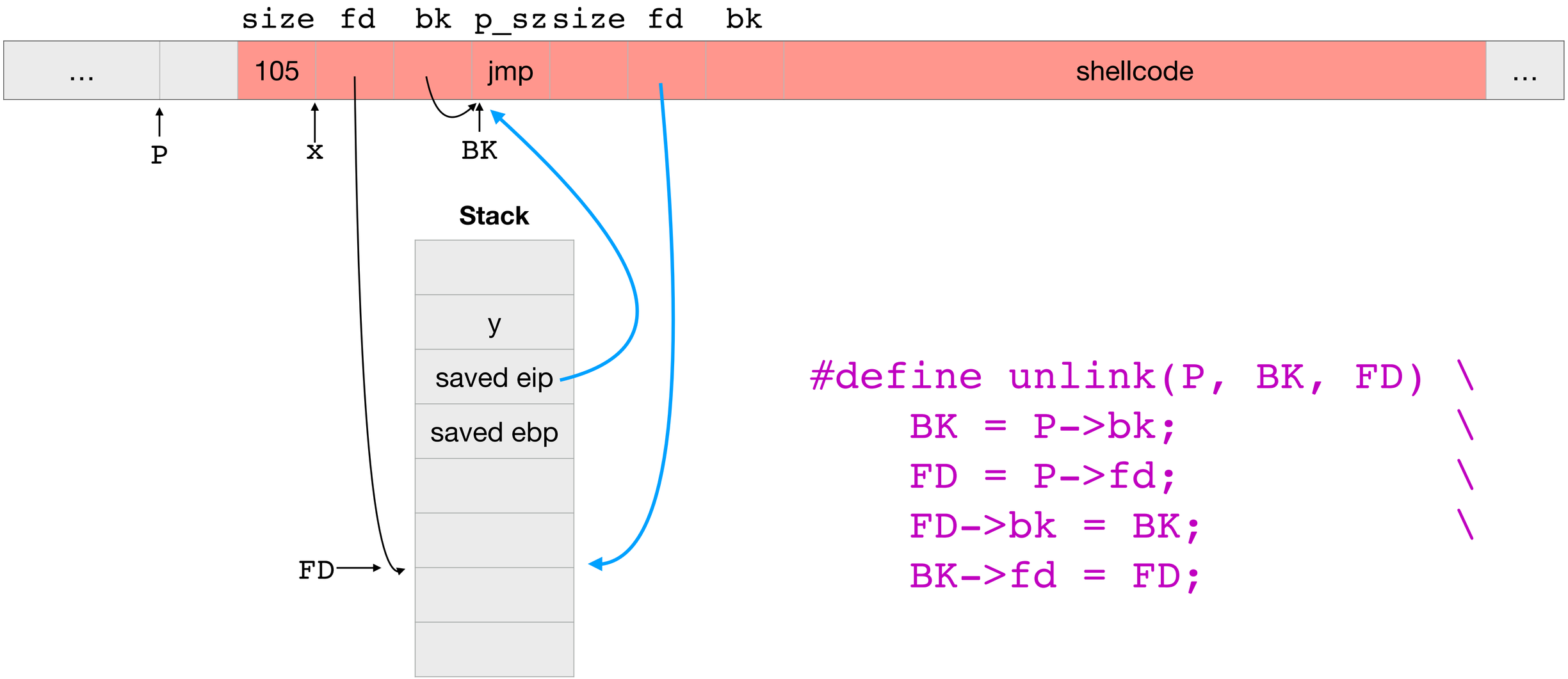

Unlinking P (zooming in on P)




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