Operating Systems

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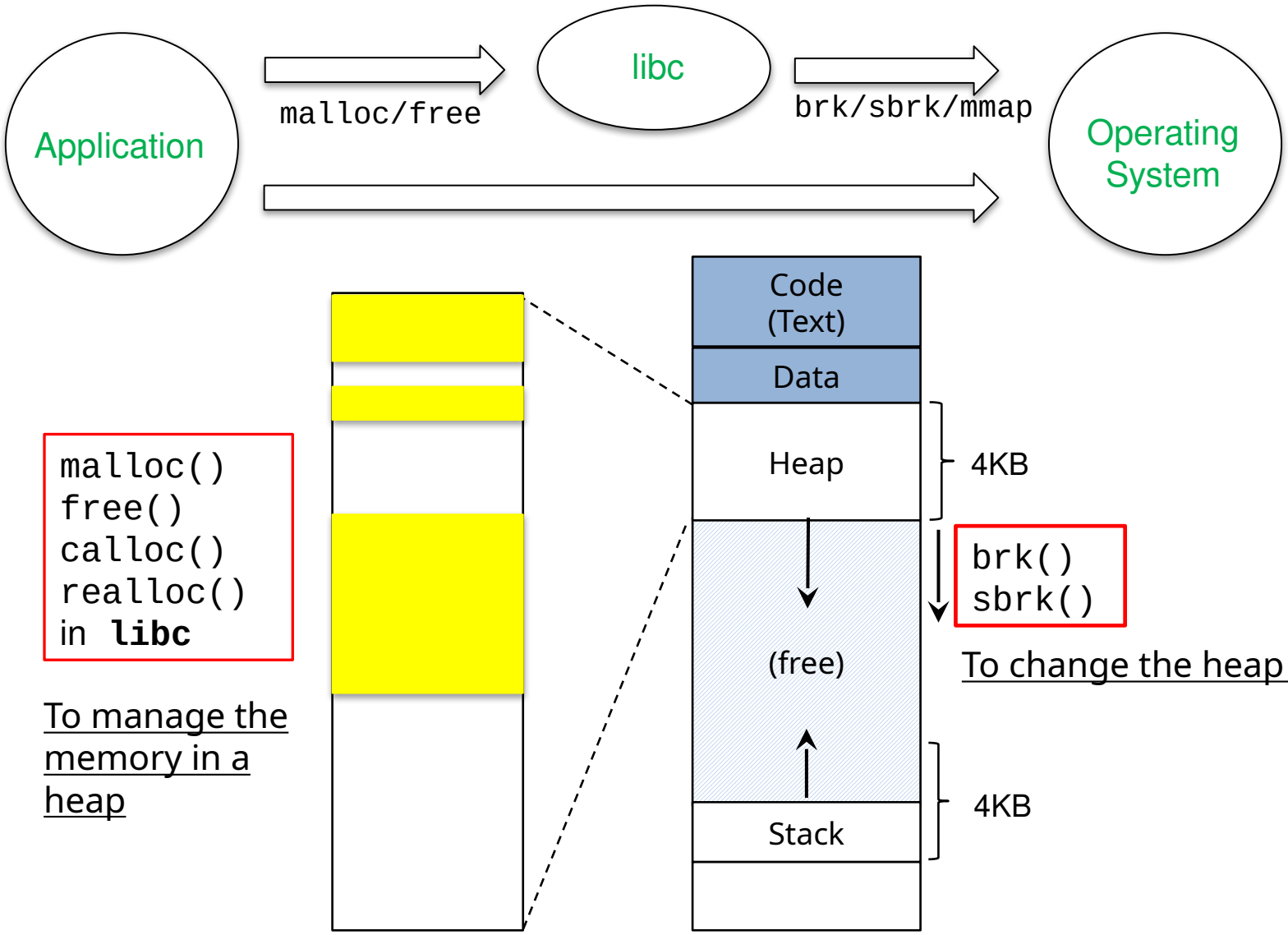
14. Memory API

Overview

- `malloc/free`
- `calloc/realloc`
- `brk/sbrk`
- `mmap/mumap`

Virtual Address Space



malloc()

```
#include <stdlib.h>

void* malloc(size_t size)
```

- Allocate a memory region on the heap.
  - Argument
    - `size_t size` : size of the memory block(in bytes)
    - `size_t` is an unsigned integer type.
  - Return
    - Success : a void type pointer to the memory block allocated by `malloc`
    - Fail : a null pointer

sizeof()

- Routines and macros are utilized for `size` in `malloc` instead typing in a number directly.
- Two types of results of `sizeof` with variables
  - The actual size of ‘x’ is known at run-time.

```
int *x = malloc(10 * sizeof(int));
printf(“%d\n”, sizeof(x));
```

```
4
```

  - The actual size of ‘x’ is known at compile-time.

```
int x[10];
printf(“%d\n”, sizeof(x));
```

```
40
```

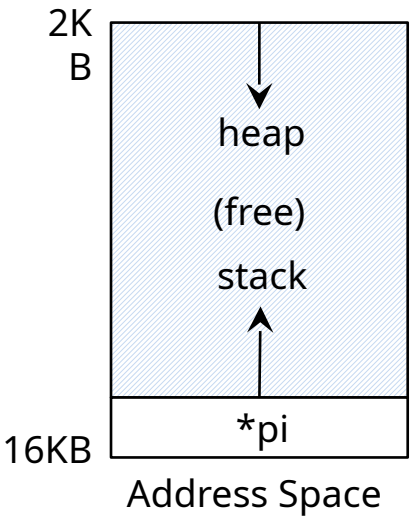
Memory API: `free()`

```
#include <stdlib.h>

void free(void* ptr)
```

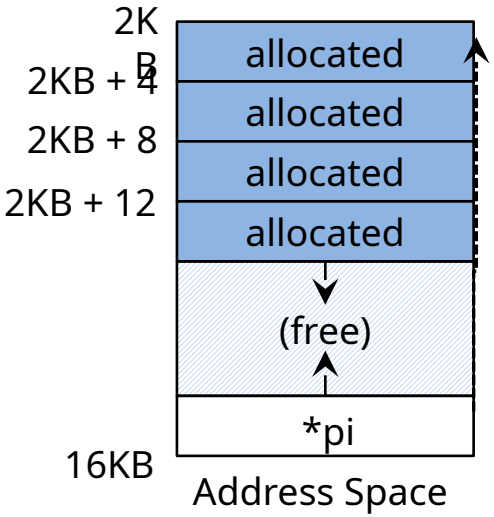
- Free a memory region allocated by a call to `malloc`.
  - Argument
    - `void *ptr` : a pointer to a memory block allocated with `malloc`
  - Return
    - none

Memory Allocating



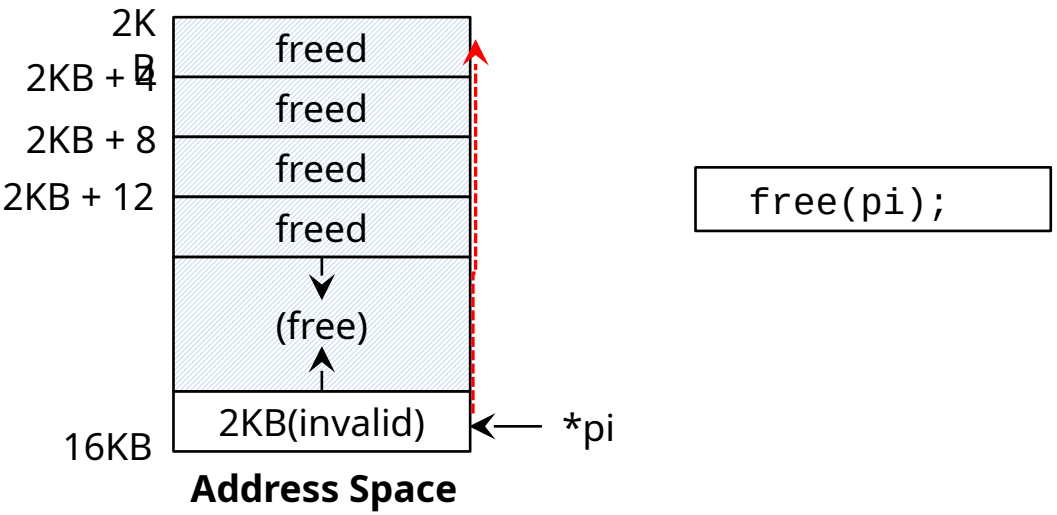
----------> pointer

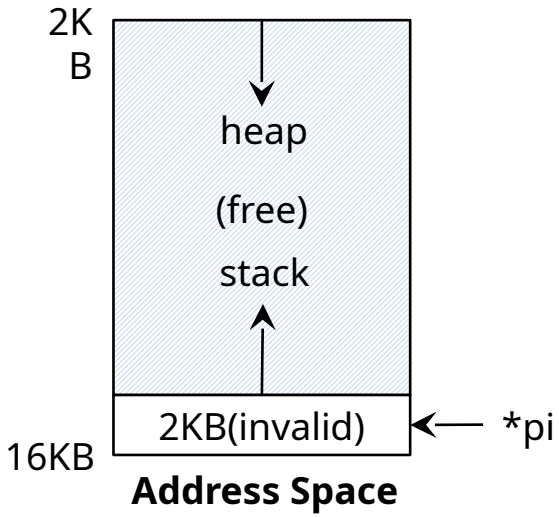
```
int *pi; // local variable
```




```
pi = (int *)malloc(sizeof(int)*
4);
```

Memory Freeing

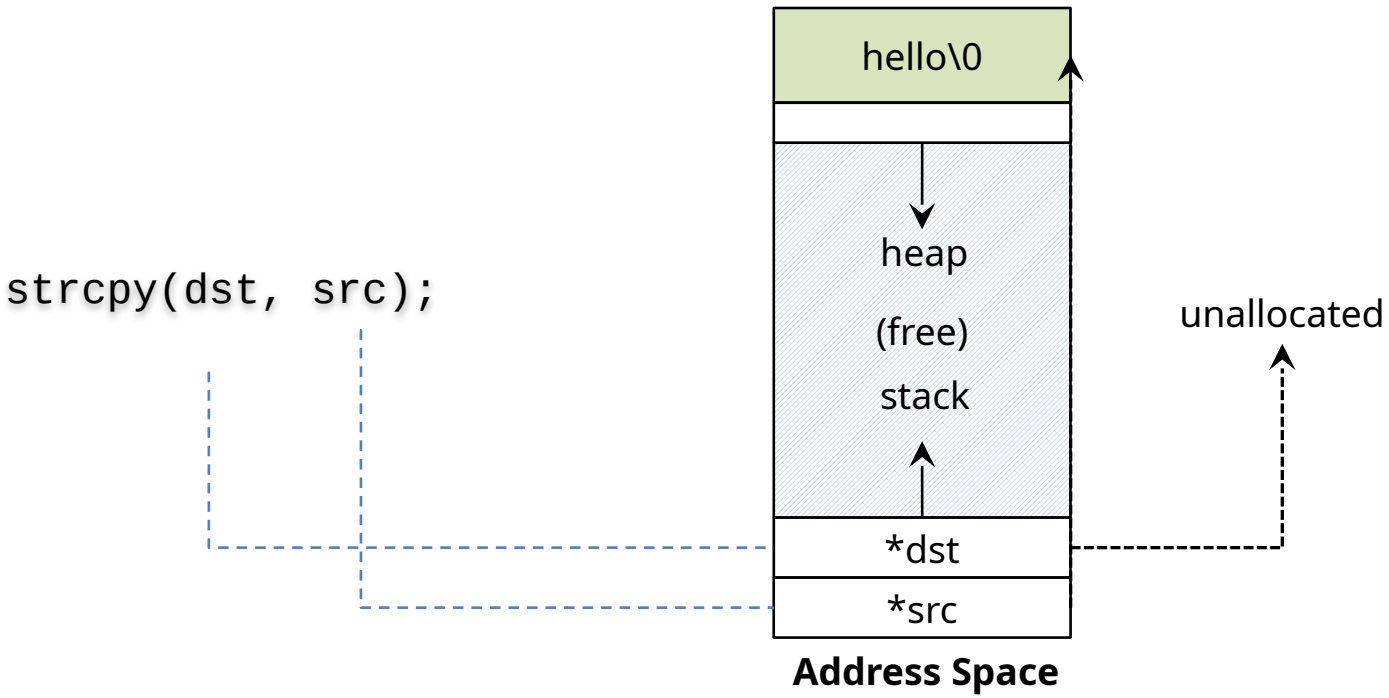




Forgetting To Allocate Memory

- Incorrect code

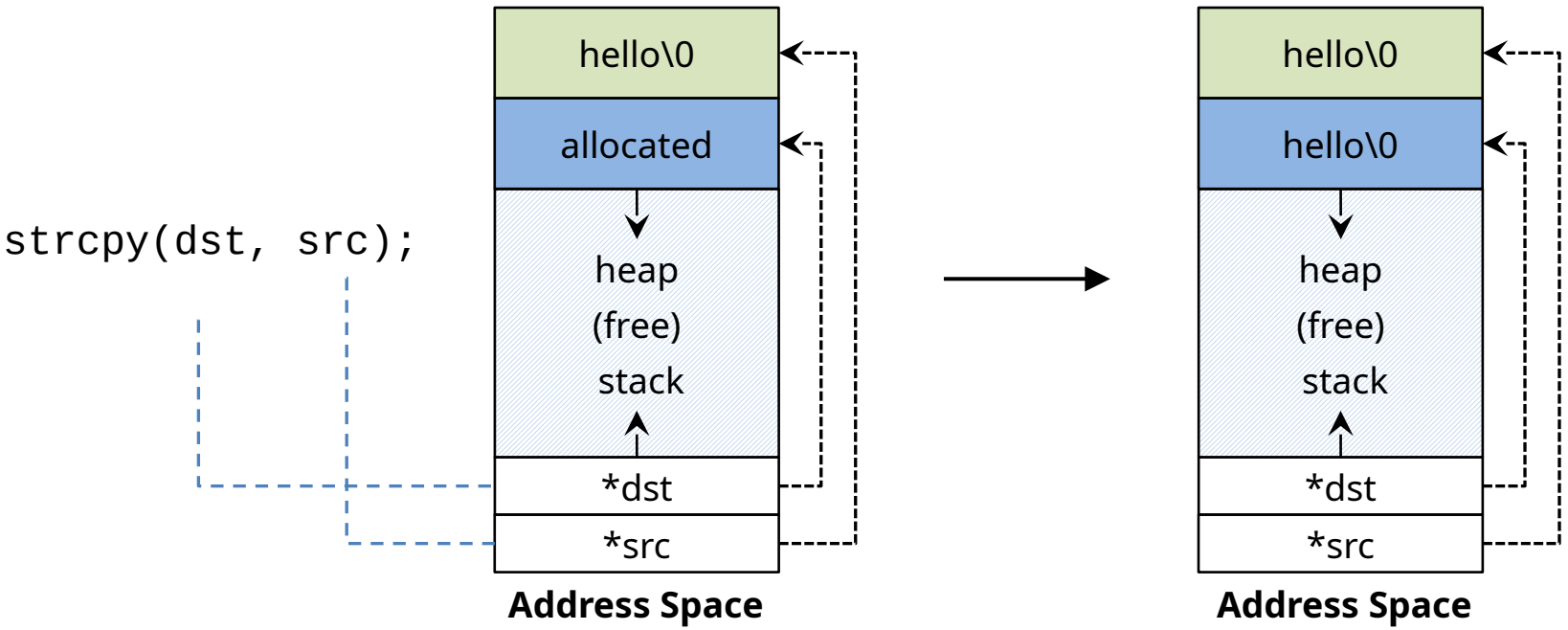
```
char *src = “hello”; //character string constant
char *dst;           //unallocated
strcpy(dst, src);    //segfault and die
```



Forgetting To Allocate Memory(Cont.)

- Correct code

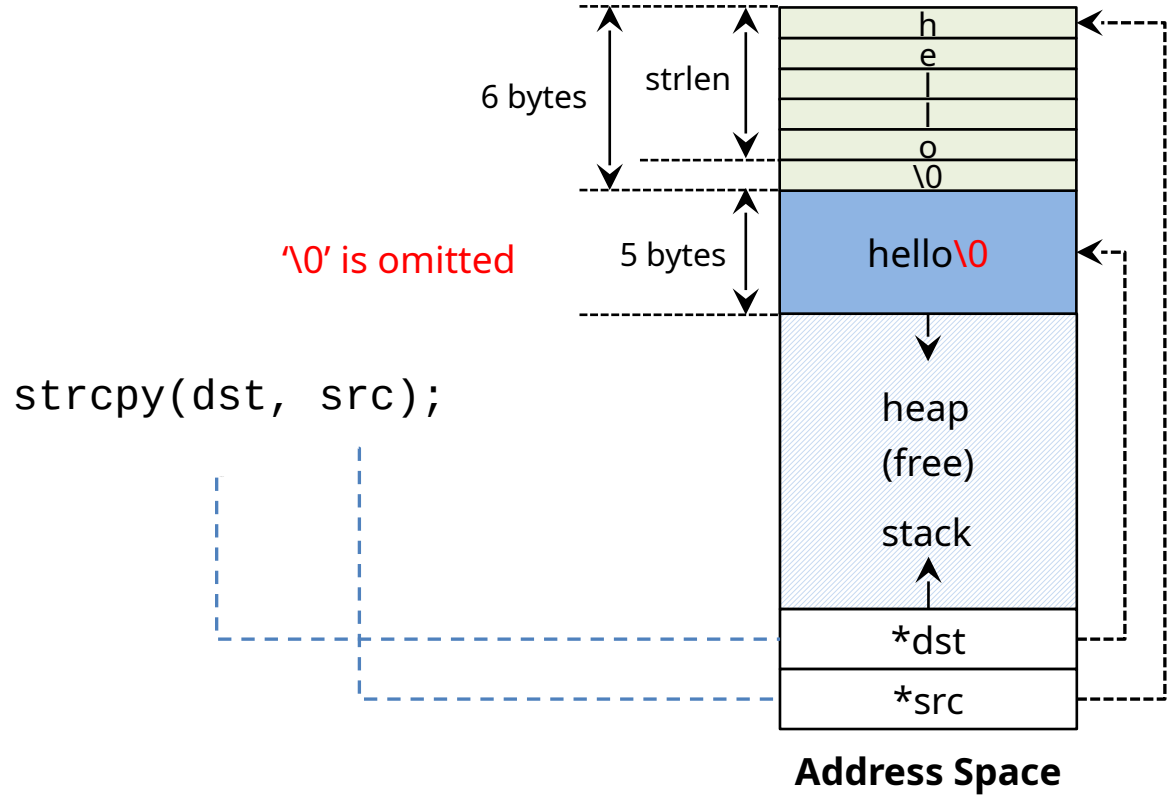
```
char *src = “hello”;   //character string constant
char *dst (char *)malloc(strlen(src) + 1 ); // allocated
strcpy(dst, src);      //work properly
```



Not Allocating Enough Memory

- Incorrect code, but work properly

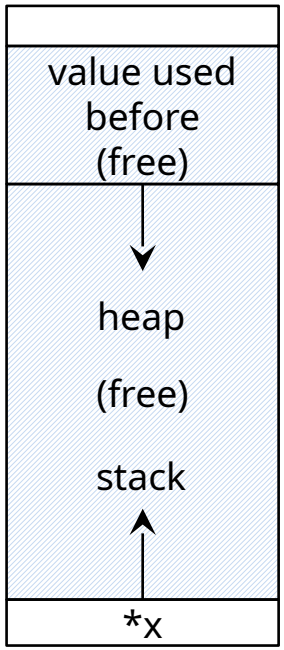
```
char *src = “hello”; //character string constant
char *dst (char *)malloc(strlen(src)); // too small
strcpy(dst, src);    //work properly
```



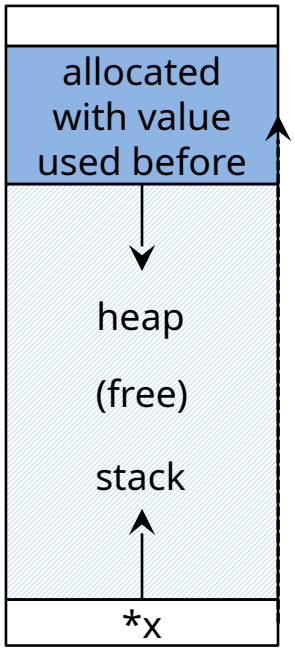
Forgetting to Initialize

- Encounter an uninitialized read

```
int *x = (int *)malloc(sizeof(int)); // allocated
printf("*x = %d\n", *x); // uninitialized memory access
```



Address Space



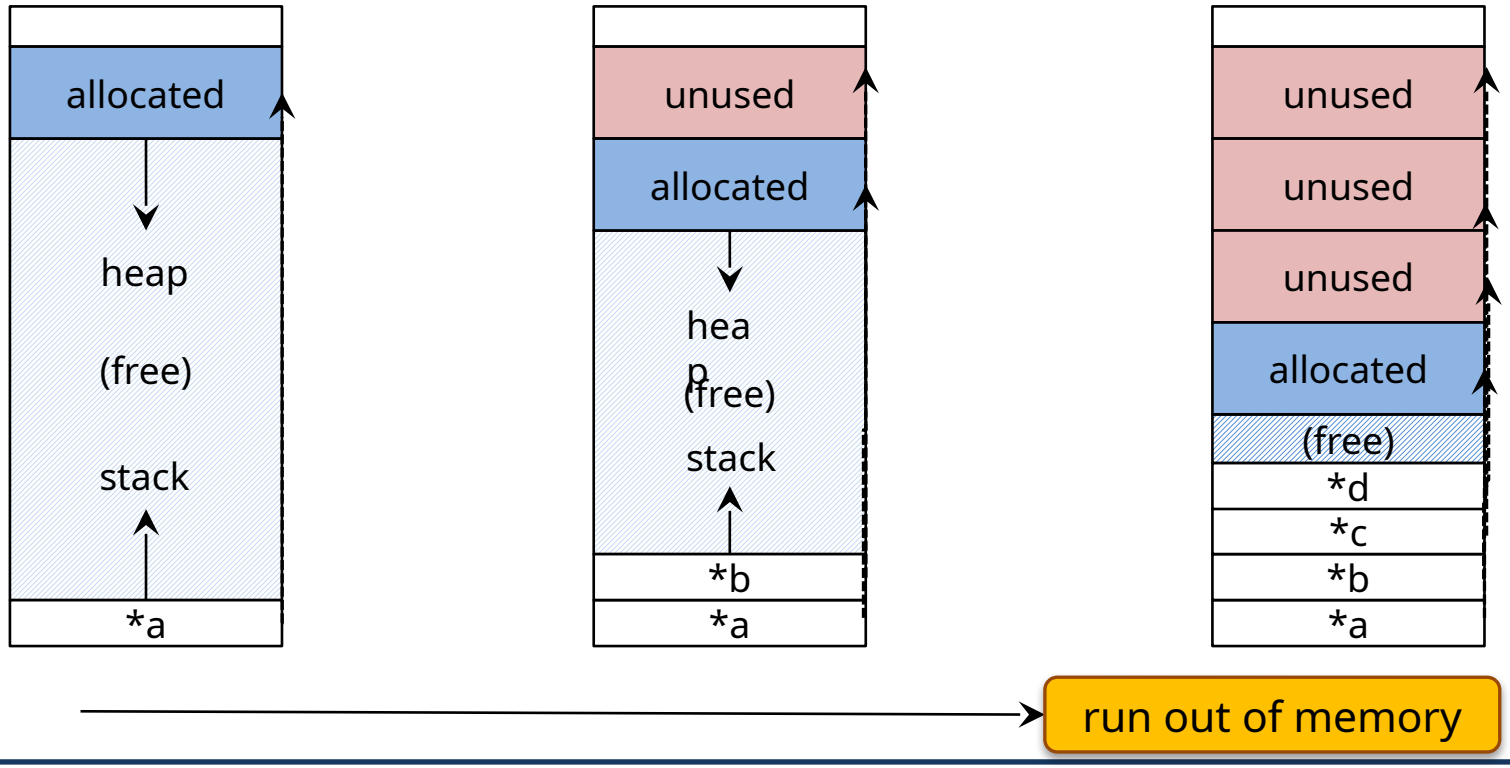
Address Space

Memory Leak

- A program keeps allocating memory without freeing it.
- A program runs out of memory and eventually is killed by OS.

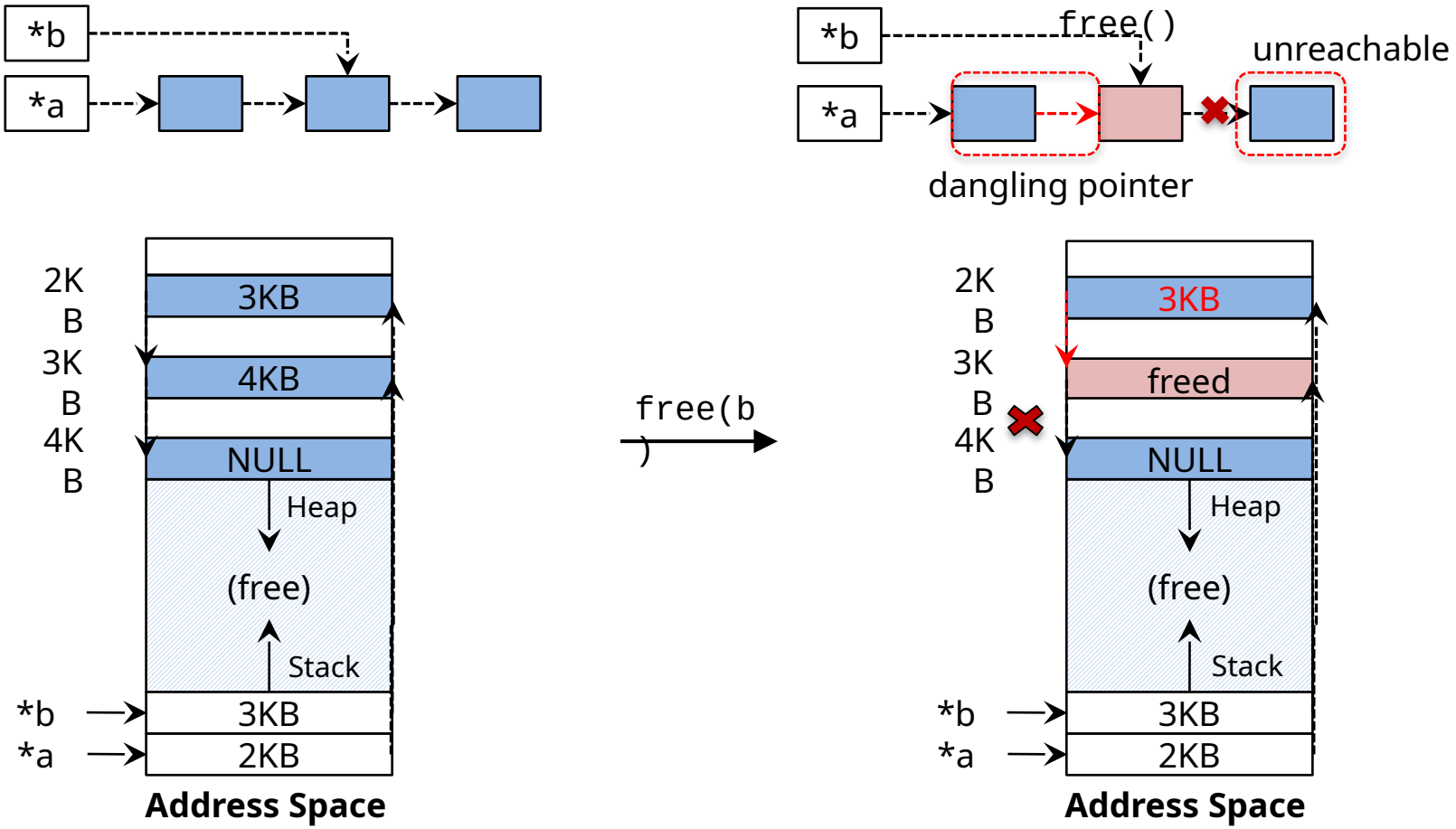
```
while(1)
    malloc(4) ;
```

unused : allocated, but not freed



Dangling Pointer

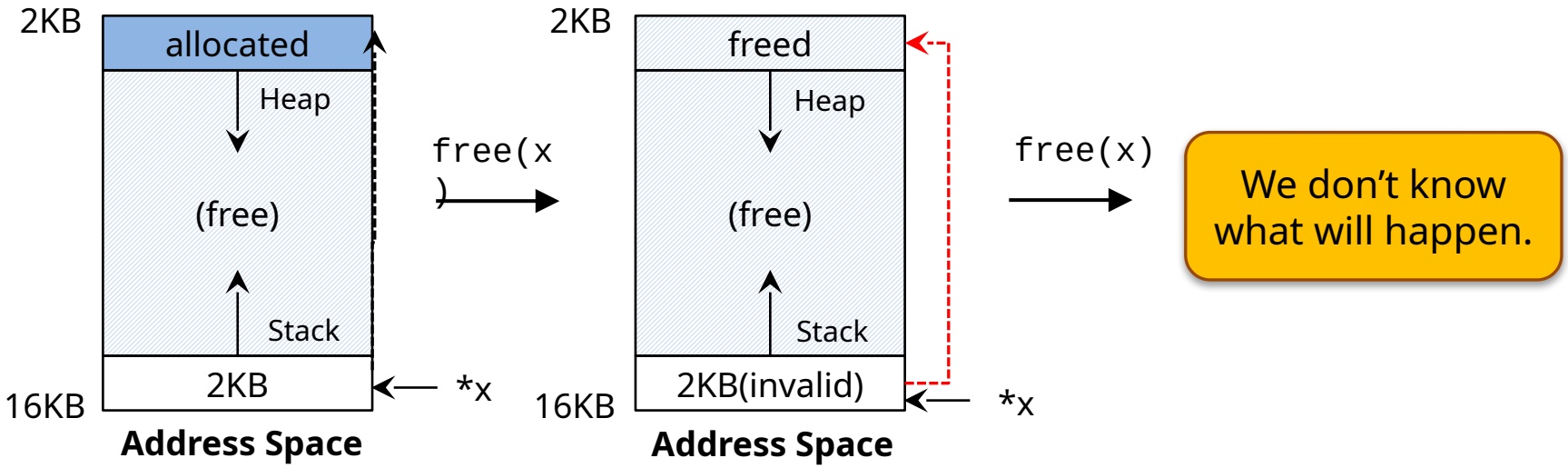
- Freeing memory while it is being used.
  - A program accesses to memory with an invalid pointer



Incorrect `free()`

- Free the memory that was freed already.

```
int *x = (int *)malloc(sizeof(int)); // allocated
free(x); // free memory
free(x); // free repeatedly
```



- Free the memory that was not allocated via `malloc()`.

```
int *x = (int *)malloc(sizeof(int)); // allocated
free(x+12); // free memory
```

Other Memory APIs: `calloc()` and `realloc()`

```
#include <stdlib.h>

void *calloc(size_t num, size_t size)
```

- Allocate memory and zeroes it before returning.
  - `size_t num` : the number of objects to allocate
  - `size_t size` : size of an ojbect (in bytes)

```
#include <stdlib.h>

void *realloc(void *ptr, size_t size)
```

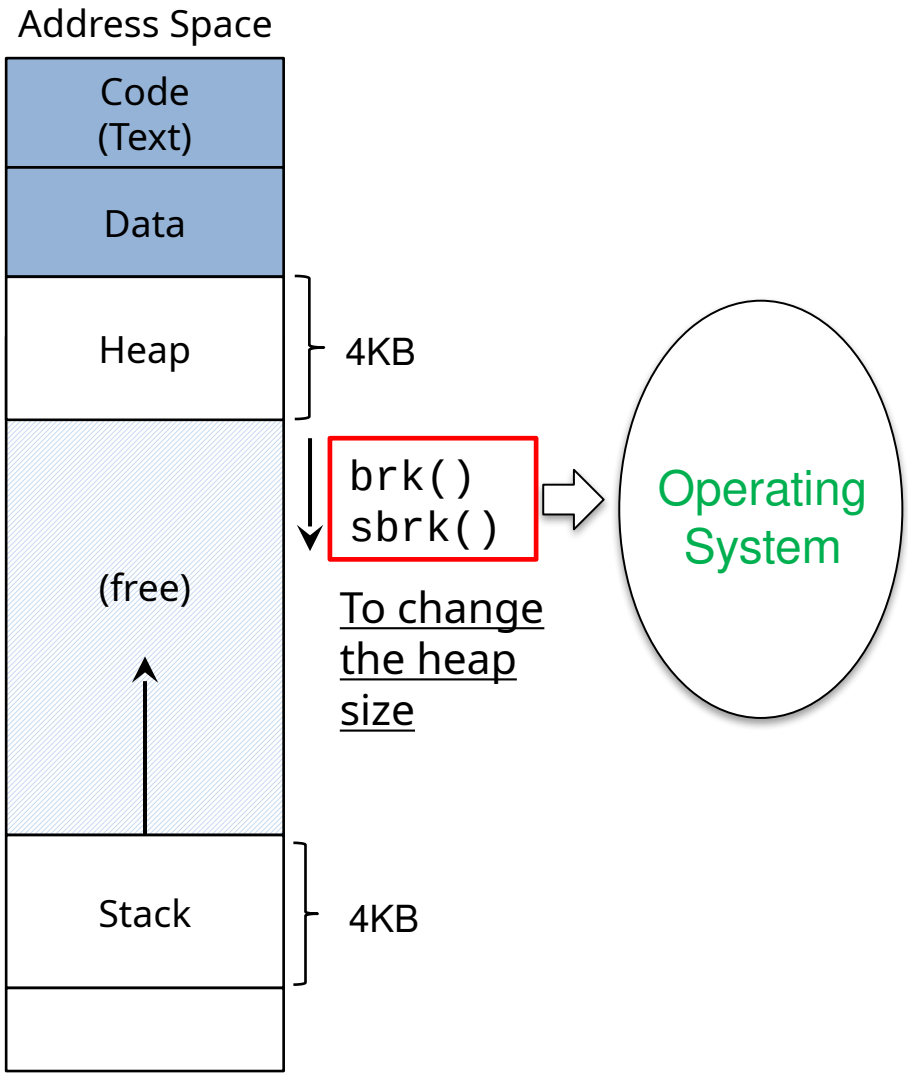
- Change the size of memory block.
  - `void *ptr`: Pointer to memory block allocated with `malloc`, `calloc` or `realloc`
  - `size_t size`: New size for the memory block(in bytes)

System Calls

```
#include <unistd.h>

int brk(void *addr)
void *sbrk(intptr_t increment);
```

- There lacks of heap space. ✉ Ask OS to expand heap.
- `break`: The location of **the end of the heap** in address space
- `malloc` uses `brk` system call.
  - `brk` is called to expand the program's *break*.
  - `sbrk` is similar to `brk`.
  - Programmers **should never directly call** either `brk` or `sbrk`.



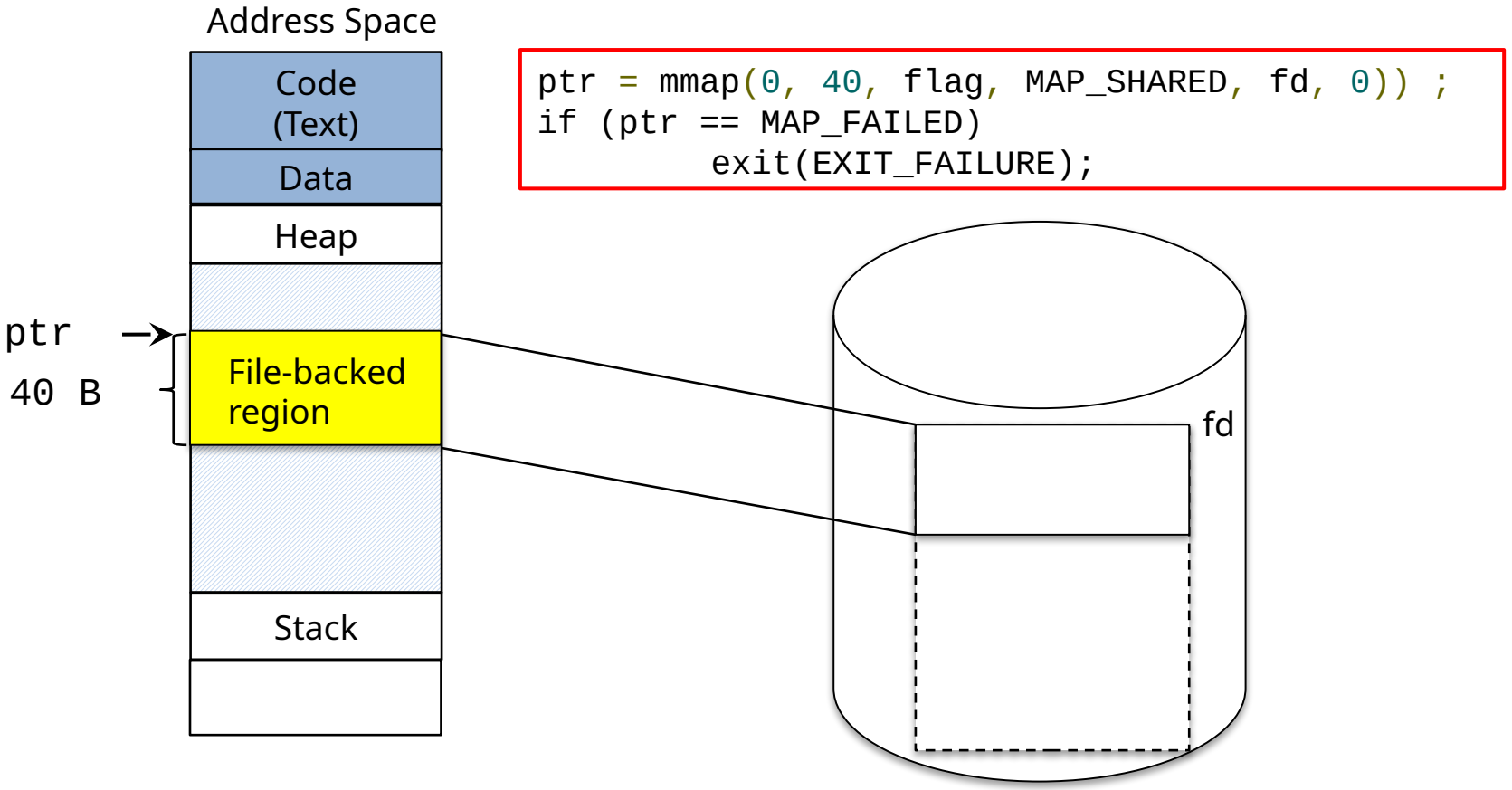
System Calls: mmap

```
#include <sys/mman.h>

void *mmap(void *ptr, size_t length, int prot, int flags,
                int fd, off_t offset)
```

- Allocate a memory region of `length` at `ptr`.
- If `fd` is not negative, associate the region to `fd` starting at `offset`.

mmap: creating file-backed region

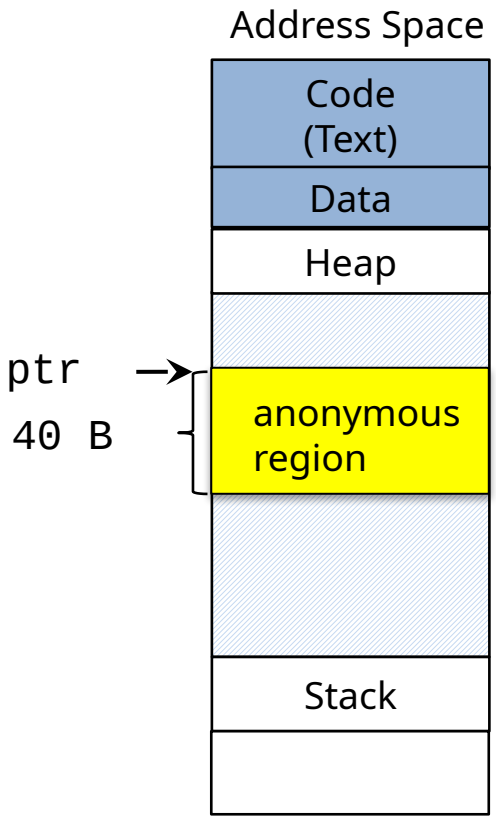



```
ptr = mmap(0, 40, flag, MAP_SHARED, fd, 0)) ;
if (ptr == MAP_FAILED)
        exit(EXIT_FAILURE);
```

mmap: creating anonymous region

```
#include <sys/mman.h>

void *mmap(void *ptr, size_t length, int
prot, int flags, int fd, off_t offset)
```




```
ptr= mmap(NULL, 40, PROT_READ |
                    PROT_WRITE, MAP_SHARED |
                    MAP_ANONYMOUS, -1, 0);
if (ptr == MAP_FAILED)
          exit(EXIT_FAILURE);
```

Summary

- `malloc/free`
- `calloc/realloc`
- `mmap/munmap`