Engineering &
Computer Science
Syracuse University

# CIS 657 – Principles of Operating Systems

Topic: Memory

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# Acknowledgement


- Youjip Won (Hanyang University)
- OSTEP book – by Remzi and Andrea Arpaci-Dusseau (University of Wisconsin)

# Memory Virtualization

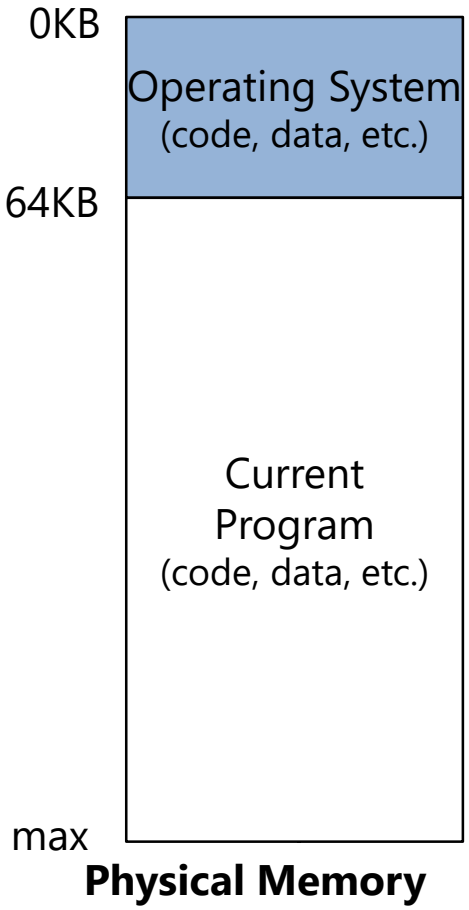
- What is **memory virtualization**?
  - OS virtualizes its physical memory.
  - OS provides an illusion memory space per each process.
  - It seems to be seen like each process uses the whole memory .

# Benefit of Memory Virtualization

- Ease of use in programming
- Memory efficiency in terms of time and space
- The guarantee of isolation for processes as well as OS
  - Protection from errant accesses of other processes

# OS in The Early System

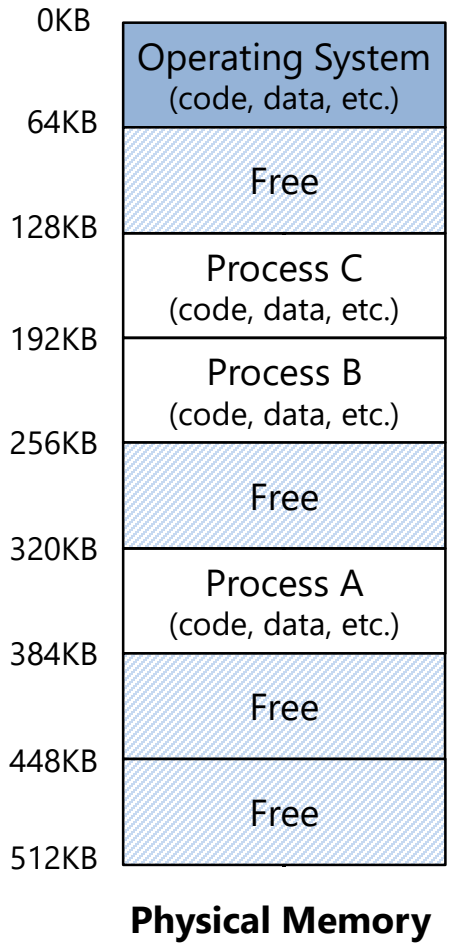
- Load only one process in memory.
  - Poor utilization and efficiency



# Multiprogramming and Time Sharing

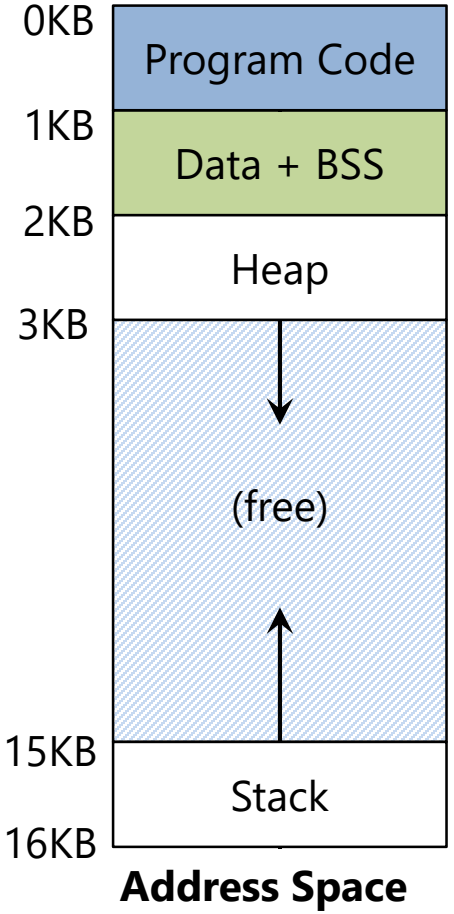
- **Load multiple processes** in memory.
  - Execute one for a short while.
  - Switch processes between them in memory.
  - Increase utilization and efficiency.

- Cause an important **protection issue**.
  - Errant memory accesses from other processes



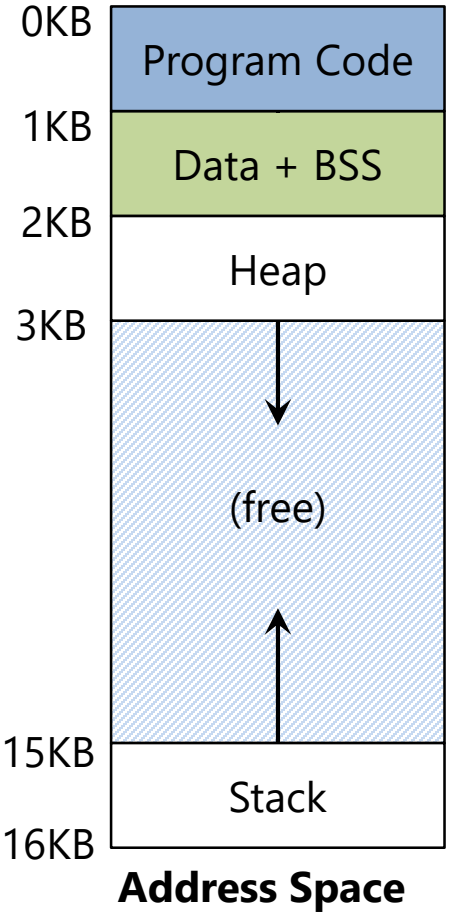
# Address Space

- OS creates an **abstraction** of physical memory.
  - The address space contains the content of a running (precisely, alive) process.
  - That is consist of program code, heap, stack and etc.



# Address Space

- Code
  - Where instructions live
- Heap
  - Dynamically allocate memory.
    - `malloc` in C language
    - `new` in object-oriented language
- Stack
  - Store return addresses or values.
  - Contain local variables arguments to routines/functions/methods.



# Virtual Address

- **Every address** in a running program is **virtual**.
  - OS translates the virtual address to physical address

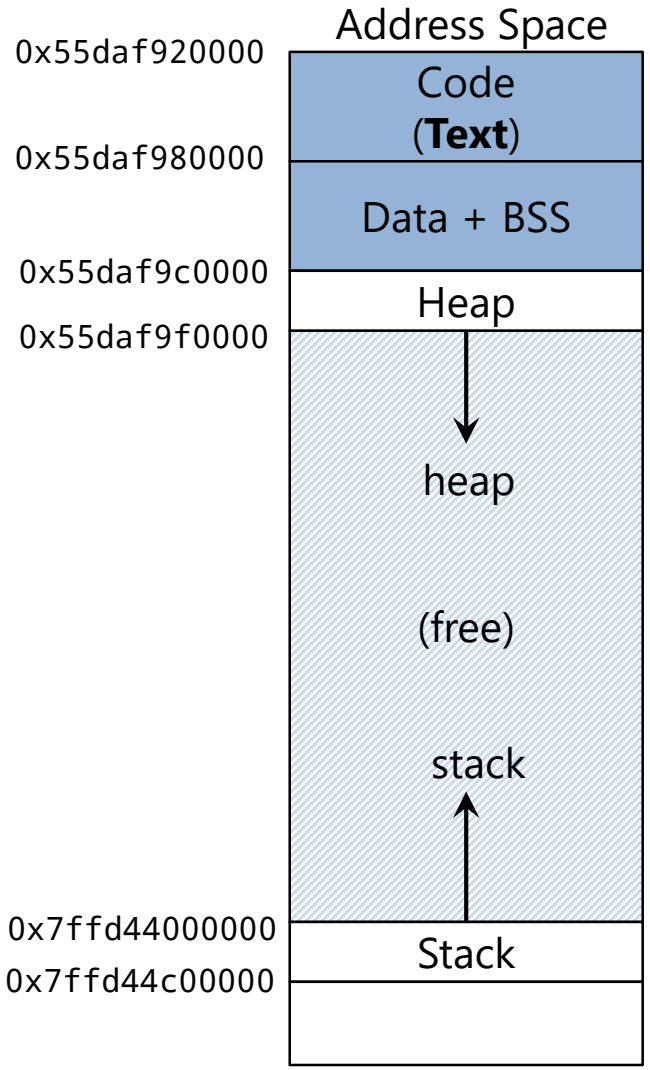
```c
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[]){

    printf("location of code  : %p\n", (void *) main);
    printf("location of heap  : %p\n", (void *) malloc(1));
    int x = 3;
    printf("location of stack : %p\n", (void *) &x);

    return x;
}
```

**A simple program that prints out addresses**

# Virtual Address

- The output in 64-bit Linux machine

```
location of code  : 0x55daf92ed6fa
location of heap  : 0x55daf9cda670
location of stack : 0x7ffd44c580b4
```



# MEMORY API

# Memory API: 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));
```

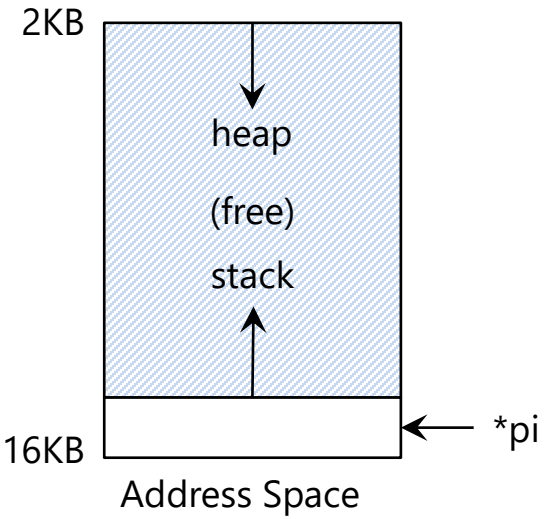
```
40
```

# Memory API: free()

```
#include <stdlib.h>

void free(void* ptr)
```

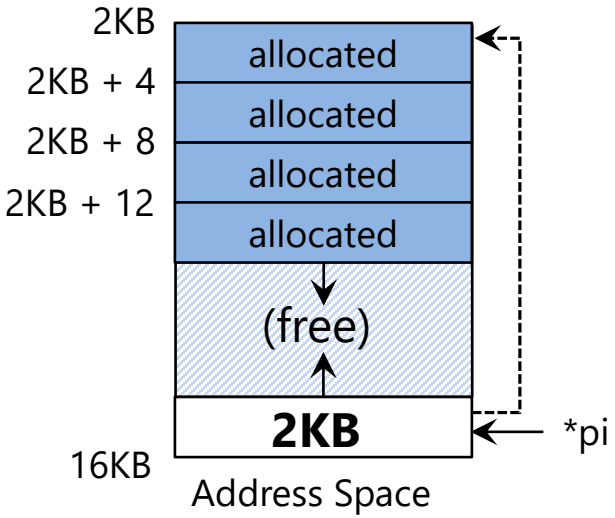
- Free a memory region allocated by a call to `malloc`.
  - Argument
    - `void *ptr` : a pointer to a memory block allocated with `malloc`
  - Return
    - none

# Memory Allocating



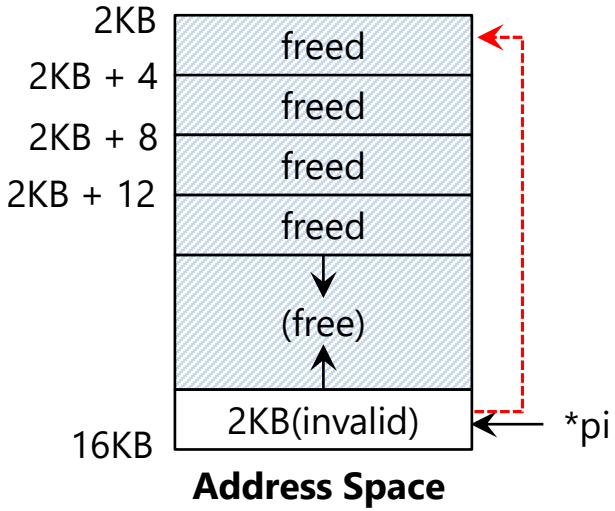

pointer

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

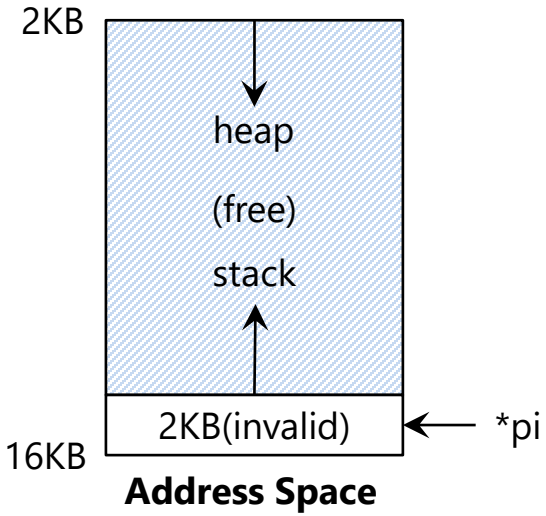



```
pi = (int *)malloc(sizeof(int)* 4);
```

# Memory Freeing



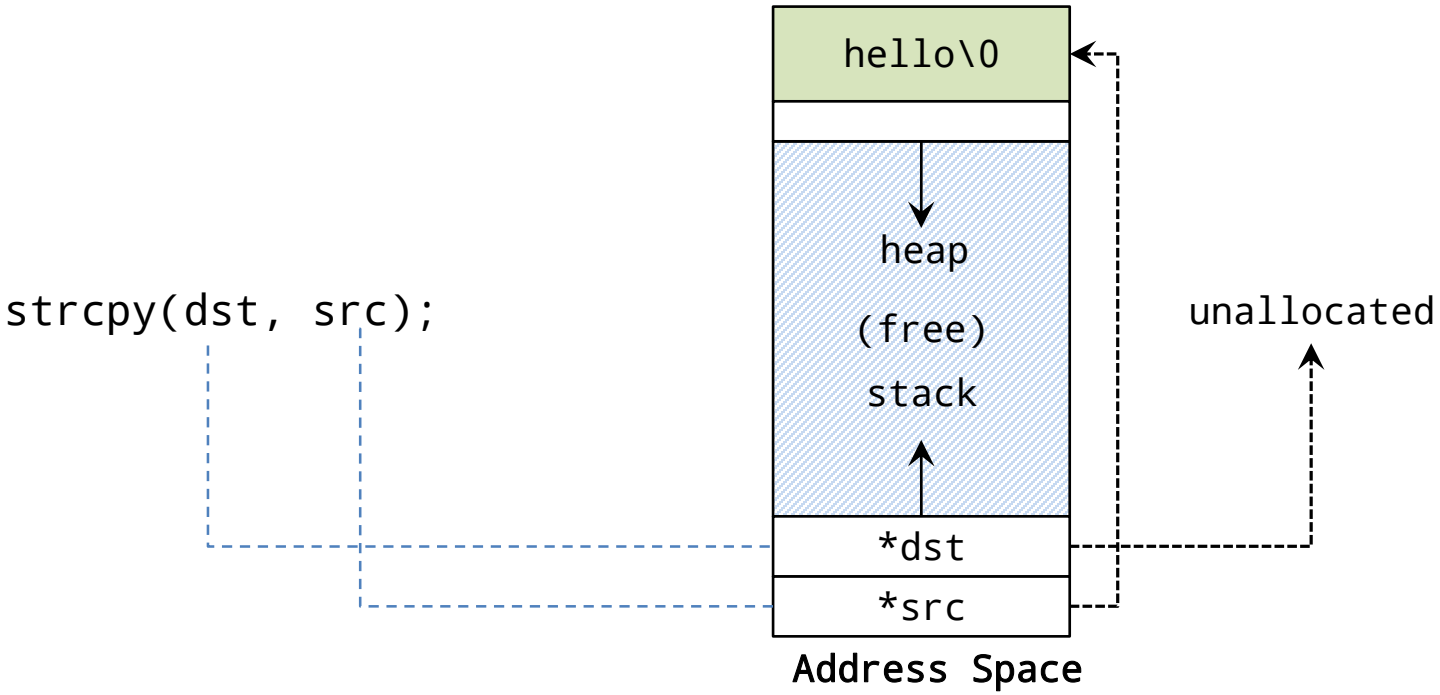

```
free(pi);
```



# Forgetting To Allocate Memory

- Incorrect code

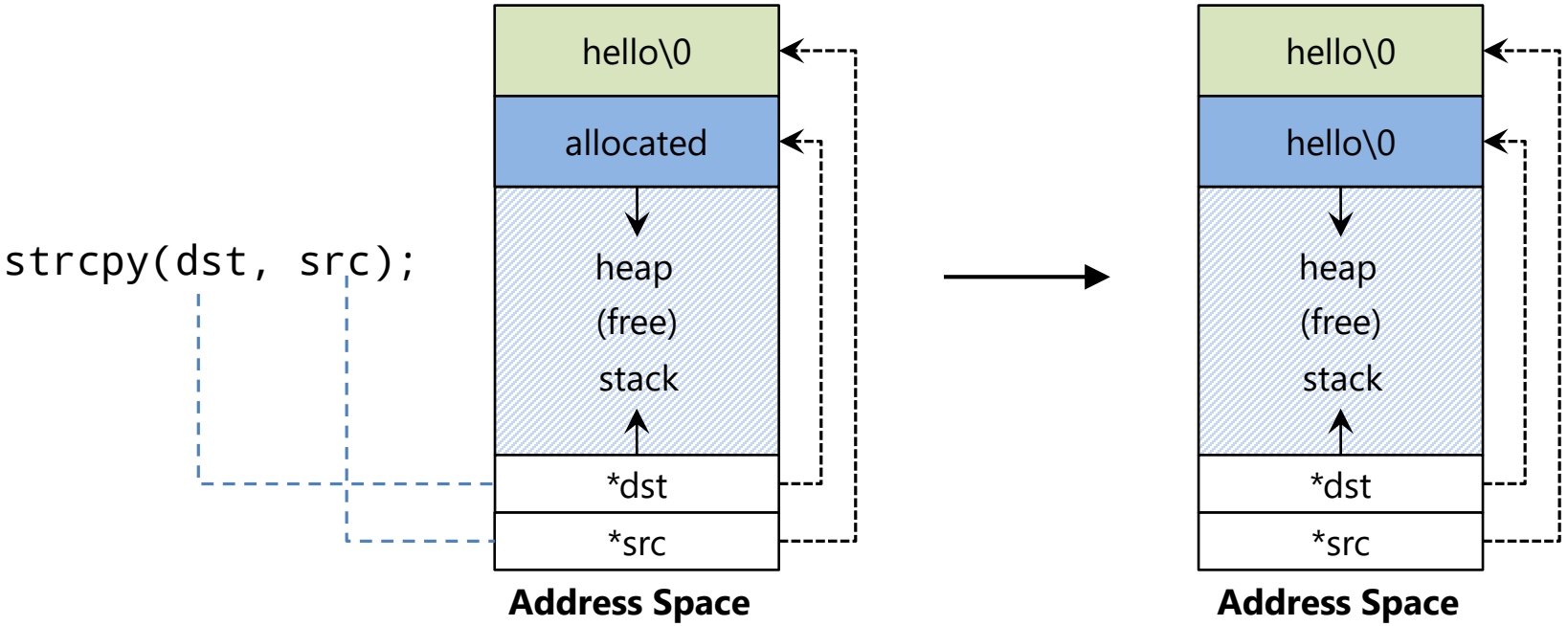
```
char *src = “hello”; //character string constant
char *dst;           //unallocated
strcpy(dst, src);    //segfault and die
```



# Forgetting To Allocate Memory

- Correct code

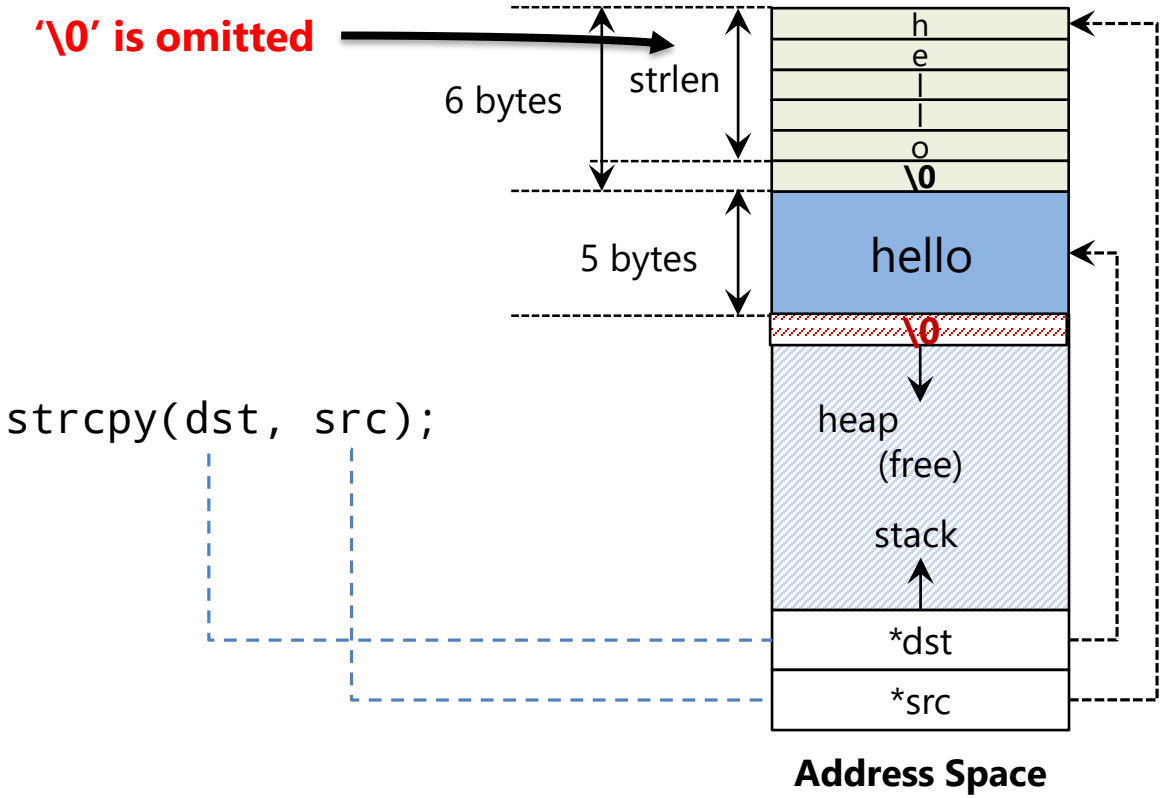
```
char *src = "hello";   //character string constant
char *dst = (char *)malloc(strlen(src) + 1 ); //allocated
strcpy(dst, src);      //work properly
```



# Not Allocating Enough Memory

- Incorrect code, but work properly

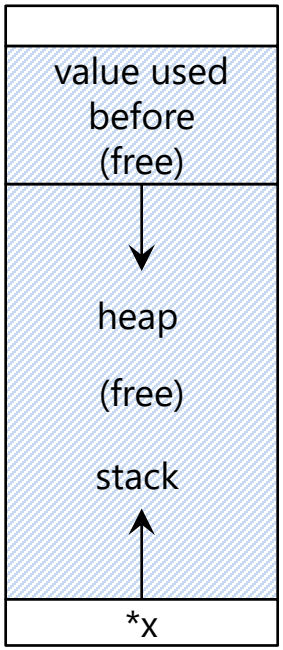
```
char *src = "hello"; //character string constant
char *dst = (char *)malloc(strlen(src)); // too small
strcpy(dst, src);    //work properly
```



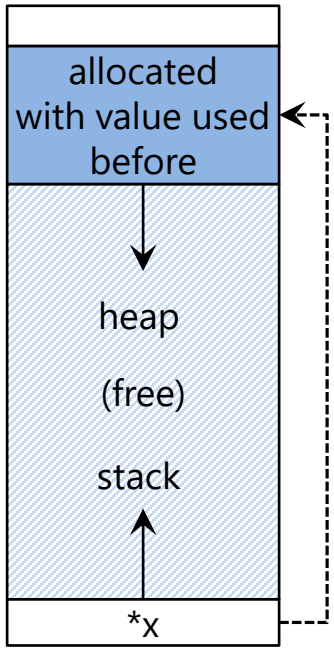
# Forgetting to Initialize

- Encounter an uninitialized read

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




**Address Space**

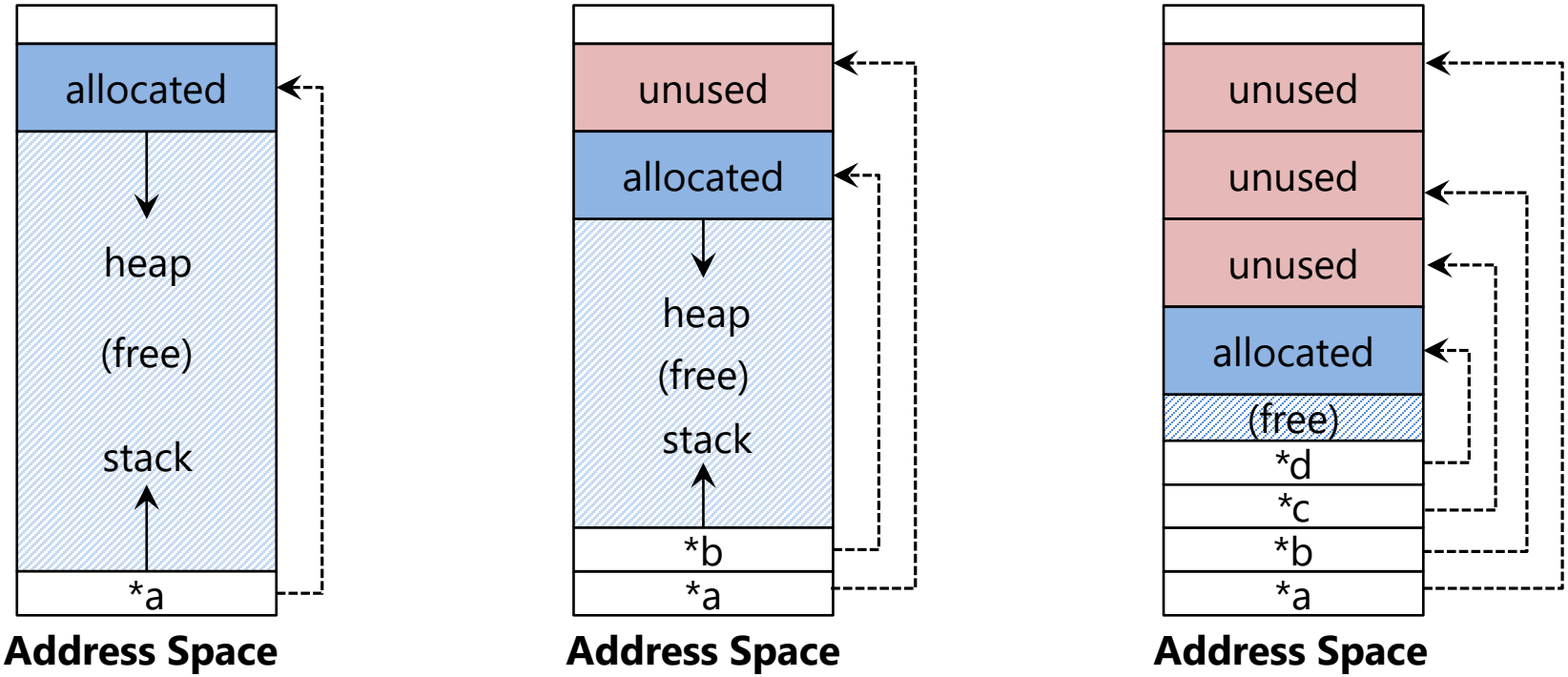



**Address Space**

# Memory Leak

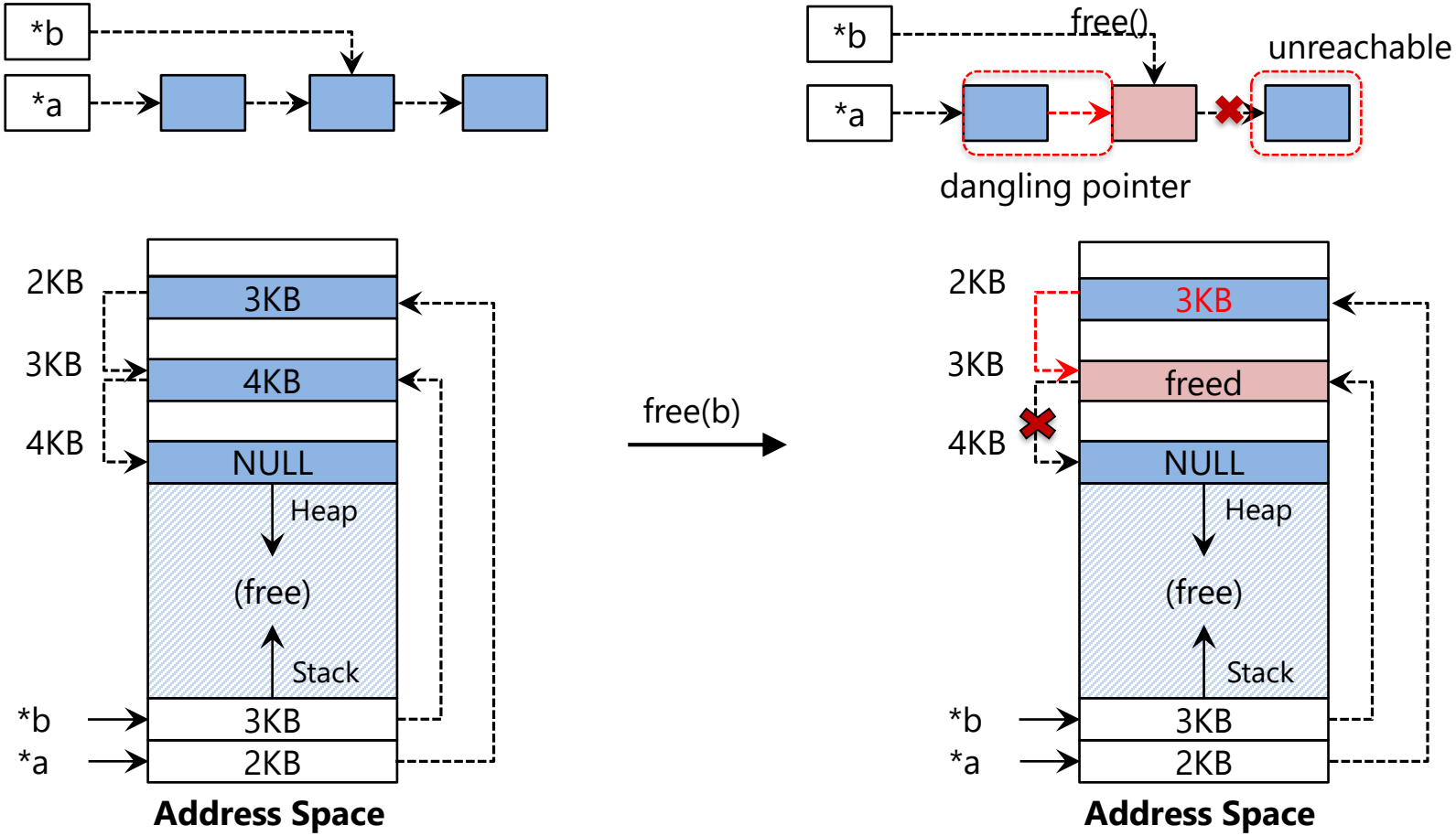
- A program runs out of memory and eventually dies.

unused : unused, but not freed



# Dangling Pointer

- Freeing memory before it is finished using
  - A program accesses to memory with an invalid pointer



# Other Memory APIs: calloc()

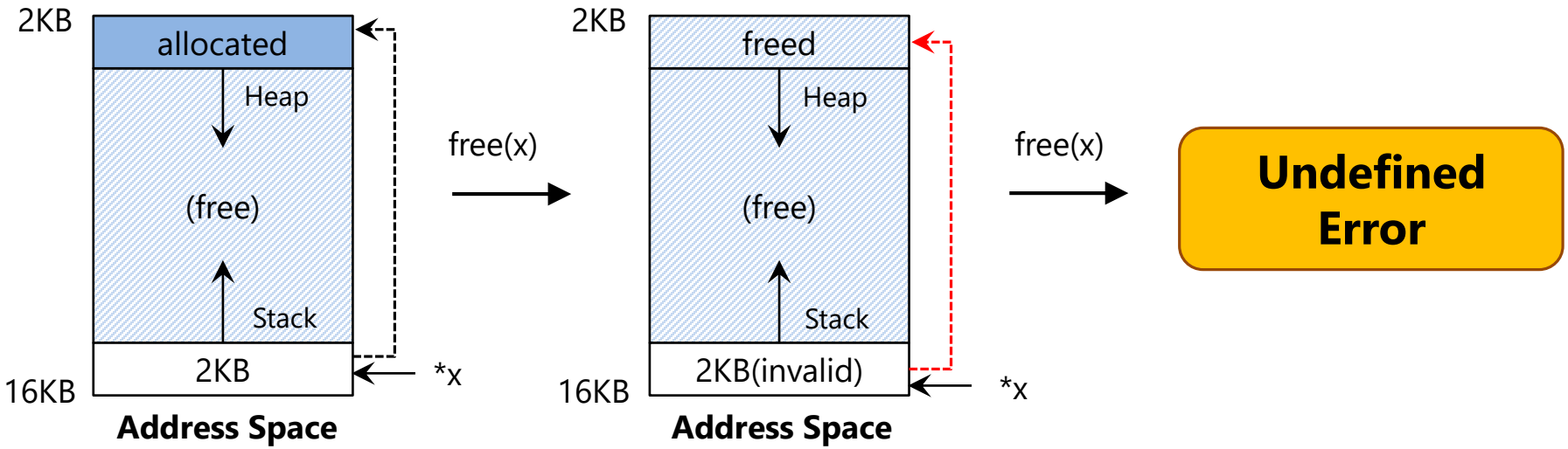
```
#include <stdlib.h>

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

- Allocate memory on the heap and zeroes it before returning.
  - Argument
    - `size_t num` : number of blocks to allocate
    - `size_t size` : size of each block(in bytes)
  - Return
    - Success : a void type pointer to the memory block allocated by `calloc`
    - Fail : a null pointer

# Double Free

- Free memory that was freed already.

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



# Other Memory APIs: realloc()

```
#include <stdlib.h>

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

- Change the size of memory block.
  - A pointer returned by `realloc` may be either the same as `ptr` or a new.
  - Argument
    - `void *ptr`: Pointer to memory block allocated with `malloc`, `calloc` or `realloc`
    - `size_t size`: New size for the memory block(in bytes)
  - Return
    - Success: Void type pointer to the memory block
    - Fail : Null pointer

# System Calls

```
#include <unistd.h>

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

- `malloc` library call use `brk` system call.
  - `brk` is called to expand the program's *break*.
    - *break*: The location of **the end of the heap** in address space
  - `sbrk` is an additional call similar with `brk`.
  - Programmers **should never directly call** either `brk` or `sbrk`.

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# Reading Material

- **Chapter 13-14** of OSTEP book – by Remzi and Andrea Arpaci-Dusseau (University of Wisconsin)
  http://pages.cs.wisc.edu/~remzi/OSTEP/vm-intro.pdf
  http://pages.cs.wisc.edu/~remzi/OSTEP/vm-api.pdf

# Questions?