Procedure Programming

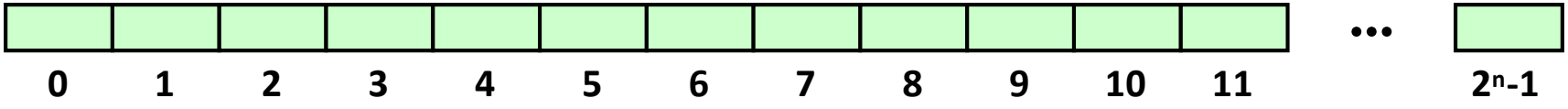
Pointers

Instructor: Jeeho Ryoo

Announcements

- Lab1 grading
    - In person grading
    - Online submissions
        - If you get 0, talk to me.
        - Everyone have to get 1 in lab1 EVENTUALLY
- Future lab grading
    - Learning hub submissions??
- Quiz1
    - Next Wednesday
    - Coding and LH submission
    - Zoom vs in person??
- Assignment 1
    - Will be released this weekend
    - A group of 3-4 students
    - Different sets fine

Digression – Memory Organization



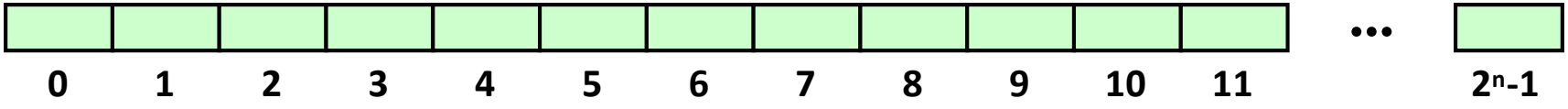
All modern processors have memories organized as sequence of *numbered bytes*

- Many (but not all) are linear sequences

Definitions:–

- *Byte:* an 8-bit memory cell capable of storing a value in range 0 … 255
- *Address:* number by which a memory cell is identified

Memory Organization (continued)



Larger data types are sequences of bytes – e.g.,

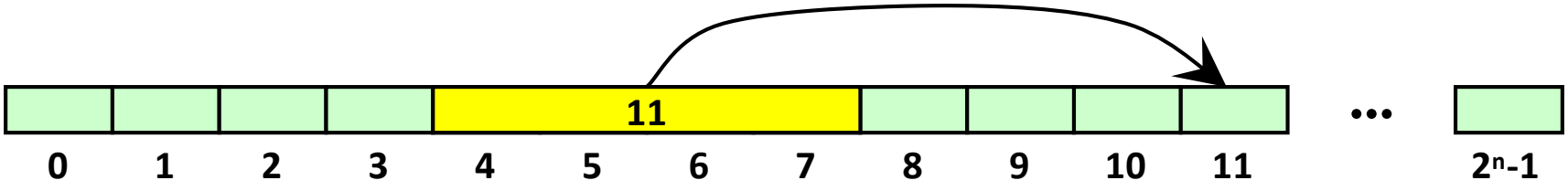
- **`short int`** – 2 bytes
- **`int`** – 2 or 4 bytes
- **`long`** – 4 or 8 bytes
- **`float`** – 4 bytes
- **`double`** – 8 bytes

(Almost) always aligned to multiple of size in bytes

Address is "first" byte of sequence (i.e., byte zero)

- May be low-order or high-order byte
- *Big endian* or *Little endian*

Definition – *Pointer*



A *value* indicating the *number* of (the first byte of) a data object

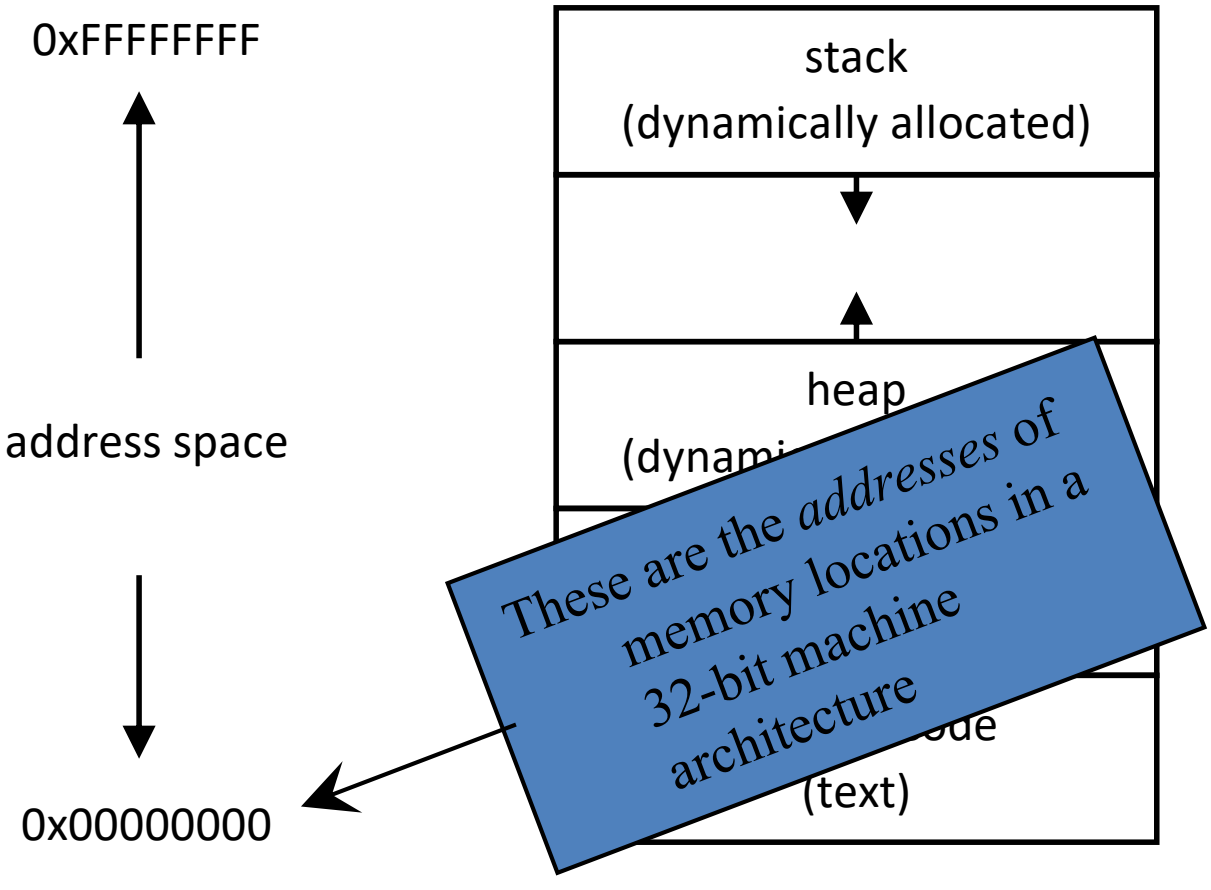
- Also called an *Address* or a *Location*

Used in machine language to identify which data to access

- E.g., *stack pointer* is address of most recent entry of *The Stack*

Usually 2, 4, or 8 bytes, depending upon machine architecture

Memory Addressing



Pointers in *C*

Used *everywhere*

- For building useful, interesting, data structures
- For returning data from functions
- For managing arrays

`'&'` unary operator generates a *pointer* to **`x`**

- E.g., **`scanf("%d", &x);`**
- E.g., **`p = &c;`**
- Operand of **`'&'`** must be an *l-value* — *i.e.,* a legal object on left of assignment operator (`'='`)

Unary `'*'` operator *dereferences* a pointer

- i.e., gets value pointed to
- E.g. **`*p`** refers to value of **`c`** (above)
- E.g., **`*p = x + y; *p = *q;`**

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Unary `'*'` operator *dereferences* a pointer

- i.e., gets value pointed to
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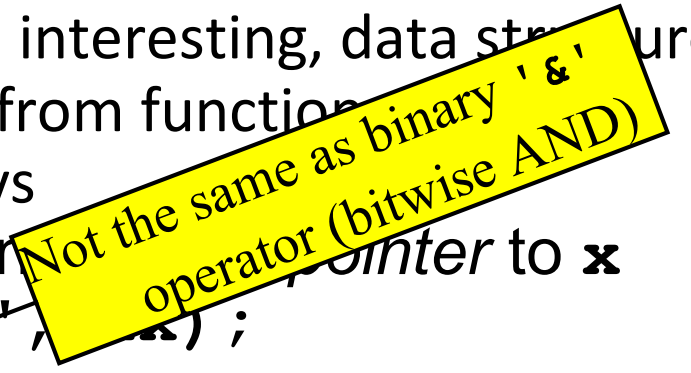


Declaring Pointers in *C*

`int *p;` — a pointer to an **`int`**

`double *q;` — a pointer to a **`double`**

`char **r;` — a pointer to a pointer to a **`char`**

type **`*s;`** — a pointer to an object of type *type*

Declaring Pointers in *C* (continued)

Pointer declarations:–read from *right* to *left*

```
const int *p;
```

- **p** is a pointer to an integer constant
- i.e., pointer can change, thing it points to cannot

```
int * const q;
```

- **q** is a constant pointer to an integer variable
- i.e., pointer cannot change, thing it points to can!

```
const int * const r;
```

- **r** is a constant pointer to an integer constant

Pointer Arithmetic

```
int *p, *q;
q = p + 1;
```

Construct a pointer to the next *integer* after ***p** and assign it to **q**

```
double *p, *r;
int n;
r = p + n;
```

Construct a pointer to a *double* that is **n** *doubles* beyond ***p**, and assign it to **r**

n may be negative

Pointer Arithmetic (continued)

```
long int *p, *q;
p++; q--;
```

Increment **p** to point to the next **long int**; decrement **q** to point to the previous **long int**

```
float *p, *q;
int n;
n = p - q;
```

n is the number of floats between ***p** and ***q**; i.e., what would be added to **q** to get **p**

Pointer Arithmetic (continued)

```
long int *p, *q;
p++; q--;
```

C never checks that the resulting pointer is valid

Increment **p** to point to the next **long int**; decrement **q** to point to the previous **long int**

```
float *p, *q;
int n;
n = p - q;
```

n is the number of floats between ***p** and ***q**; i.e., what would be added to **q** to get **p**

Why introduce pointers in the middle of a lesson ?

Arrays and pointers are *closely related* in *C*

In fact, they are essentially the same thing!

Esp. when used as parameters of functions

```
int A[10];
int *p;
```

- *Type* of **A** is **int ***
- **p = A** is legal assignment
- ***p** refers to **A[0]**
  ***(p + n)** refers to **A[n]**
- **p = &A[5];** is the same as **p = A + 5;**

Arrays and Pointers (continued)

`double A[10];` *vs.* **`double *A;`**

Only difference:–

`double A[10]` sets aside *ten* units of memory, each large enough to hold a **`double`**, and **`A`** is initialized to point to the zeroth unit.

`double *A` sets aside *one* pointer-sized unit of memory, not initialized

- You are expected to come up with the memory elsewhere!

Note:– all pointer variables are the same size in any given machine architecture

- Regardless of what types they point to

Note

C does *not* assign arrays to each other

e.g,

```
double A[10];
double B[10];

A = B;
```

- assigns the pointer value **B** to the pointer value **A**
- Original contents of array **A** are untouched (and possibly unreachable!)

Arrays as Function Parameters

```
void init(float A[], int arraySize);
void init(float *A, int arraySize);
```

- Are identical function prototypes!
- Pointer is passed by value
- i.e. caller copies the *value* of a pointer to **`float`** into the parameter **`A`**
- Called function can reference *through* that pointer to reach thing pointed to

Streams

All input and output is done with streams

Input steam

A sequence of bytes flowing into a program

Output stream

A sequence of bytes flowing out of a program

Standard Input/Output Streams

stdin stands for Standard Input

Keyboard, Scanner are standard input devices

Standard input is data going into a program

stdout stands for Standard output

Screen, printer are standard output device

Standard output is data going out from a computer

printf()

Output function
printf() prints the value given to the console
Built into the input output header file stdio.h

```
#include <stdio.h>
int main()
{
    printf("Good Morning");
    return 0;
}
```

scanf()

Input function
Also built into the header file stdio.h
scanf() takes input from the user
Uses same format identifier %d as printf()

```
int x;
scanf("%d", &x);
```

Note the **&** symbol, scanf requires a memory address (called address-of operator)

Format identifiers Console I/O

%d will scan or print an integer aka int (*example: 5*)
%f will scan or print a floating point aka float (*example: 5.1*)
%c will scan or print a character aka char (*example: m*)
%s will scan or print a char array aka string (*example: george*)

scanf() and printf() Example

```
#include <stdio.h>

int main()
{
    int x;
    printf(“Enter a value...");
    scanf("%d", &x);
    printf( "\nYou entered: %d", x);
    return 0;
}
```

printf() and scanf() Strings Example

```
char  s[20];
printf("How are you doing?...");
scanf("%s", s);
printf( "\nYou entered: %s", s);
return 0;
```

A string in scanf doesn't require the **&** because it's an array (discussed earlier)

Note even with strings whitespace is a delimeter by default

getchar()

Input function
Also built into the header file stdio.h
It reads one character
Example

```
char c;
c = getchar();
```

fgets()

Input function
Reads up to and including a newline character (enter)
Takes in three arguments

- A ***string***
- Number of character to copy (***int***)
- File type (in our case it's the standard input, ***stdin***)

fgets(str, 20, stdin);

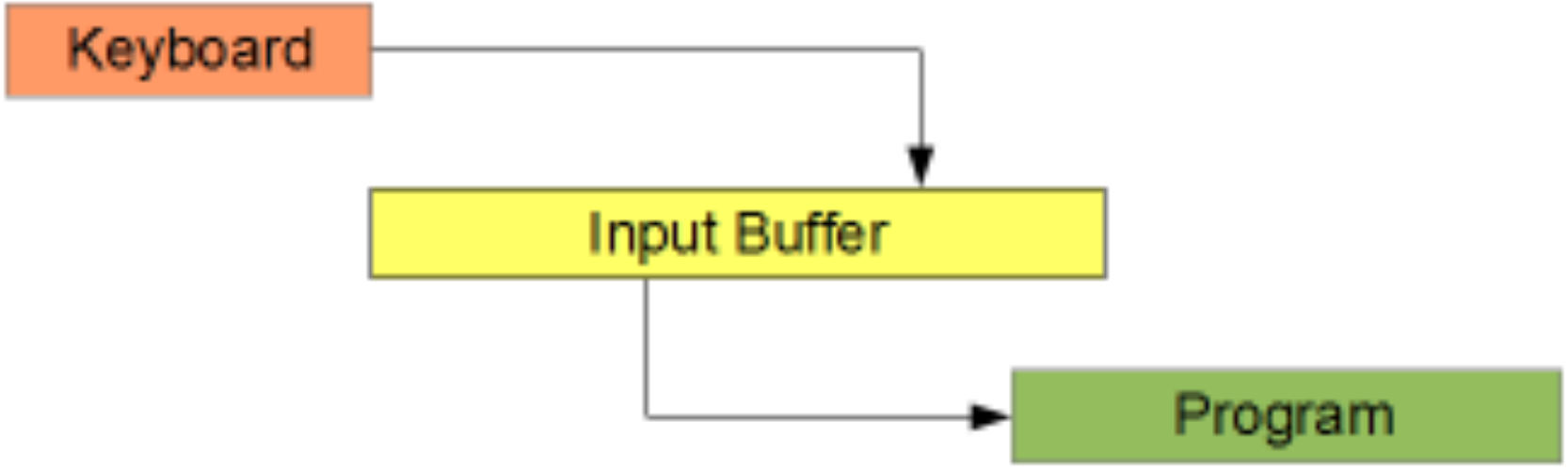
fgets() Example

Write a program that prints a sentence to the console using fgets()

```
#include <stdio.h>
int main()
{
    char str[100];
    fgets(str, 100, stdin);
    printf( "\nYou entered: %s", str);
    return 0;
}
```

Input buffer

Holds the input data temporarily between the device and program
Once enter (newline) is pressed it signals the program to start executing data from the buffer
The program only retrieves the data that it needs , and leaves rest in buffer



fputs()

Output function
Simple string output
Takes two arguments

A **string**

File type (in our case it's the standard output, ***stdout***)

fputs(str, stdout); is equivalent to *printf("%s", str)*

fputs() Example

Write a program using fputs()

```
#include <stdio.h>
int main()
{
    char str[100];
    fputs("Input something\n“, stdout);
    fgets(str, 100, stdin);
    fputs(str, stdout);
    return 0;
}
```

Characters in *C*

`char` is a one-byte data type capable of holding a character

- Treated as an arithmetic integer type
- (Usually) **`unsigned`**

May be used in arithmetic expressions

- add, subtract, multiply, divide, etc.

Character constants

- **`'a'`**, **`'b'`**, **`'c'`**, …**`'z'`**, **`'0'`**, **`'1'`**, … **`'9'`**, **`'+'`**, **`'-'`**, **`'='`**, **`'!'`**, **`'~'`**, etc, **`'\n'`**, **`'\t'`**, **`'\0'`**, etc.
- A-Z, a-z, 0-9 are *in order*, so that arithmetic can be done

Strings in *C*

Definition:– A *string* is a character array ending in `'\0'` — i.e.,

```
char s[256];
char t[] = "This is an initialized
string!";
char *u = "This is another string!";
```

String constants are in double quotes

- May contain any characters
- Including `\"` and `\'`

String constants *may not* span lines

- However, they may be concatenated — e.g., `"Hello, " "World!\n"` is the same as `"Hello, World!\n"`

Strings in *C* (continued)

Let

```
char *u = "This
is another
string!";
```

Then

```
u[0] == 'T'
u[1] == 'h'
u[2] == 'i'
…
u[21] == 'g'
u[22] == '!'
u[23] == '\0'
```

Support for Strings in *C*

Most string manipulation is done through functions in **`<string.h>`**

String functions *depend* upon final **`'\0'`**

So you don't have to count the characters!

Examples:–

`int strlen(char *s)` – returns length of string

Excluding final **`'\0'`**

`char* strcpy(char *s, char *ct)` – Copies string **`ct`** to string **`s`**, return **`s`**

`s` must be big enough to hold contents of **`ct`**

`ct` may be smaller than **`s`**

Support for Strings in *C* (continued)

Examples (continued):–

`int strcmp(char *s, char *t)`

- lexically compares **`s`** and **`t`**, returns **`<0`** if **`s < t`**, **`>0`** if **`s > t`**, zero if **`s`** and **`t`** are identical

`char* strcat(char *s, char *ct)`

- Concatenates string **`ct`** to onto end of string **`s`**, returns **`s`**
- **`s`** must be big enough to hold contents of both strings!

Other string functions

`strchr()`, **`strrchr()`**, **`strspn()`**, **`strcspn()`**
`strpbrk()`, **`strstr()`**, **`strtok()`**, **…**

String Conversion Functions in *C*

See `<stdlib.h>`

```
double atof(const char *s)
int atoi(const char *s)
long atol(const char *s)

double strtod(const char *s, char **endp)
long strtol(const char *s, char **endp, int
base)
unsigned long strtoul(const char *s, char
**endp, int base)
```

Dilemma

Question:–

If strings are arrays of characters, …
and if arrays cannot be returned from functions, …
how can we manipulate variable length strings and pass them around our programs?

Answer:–

Use storage allocated in *The Heap!*

Definition — *The Heap*

A region of memory provided by most operating systems for allocating storage *not* in *Last in, First out* discipline

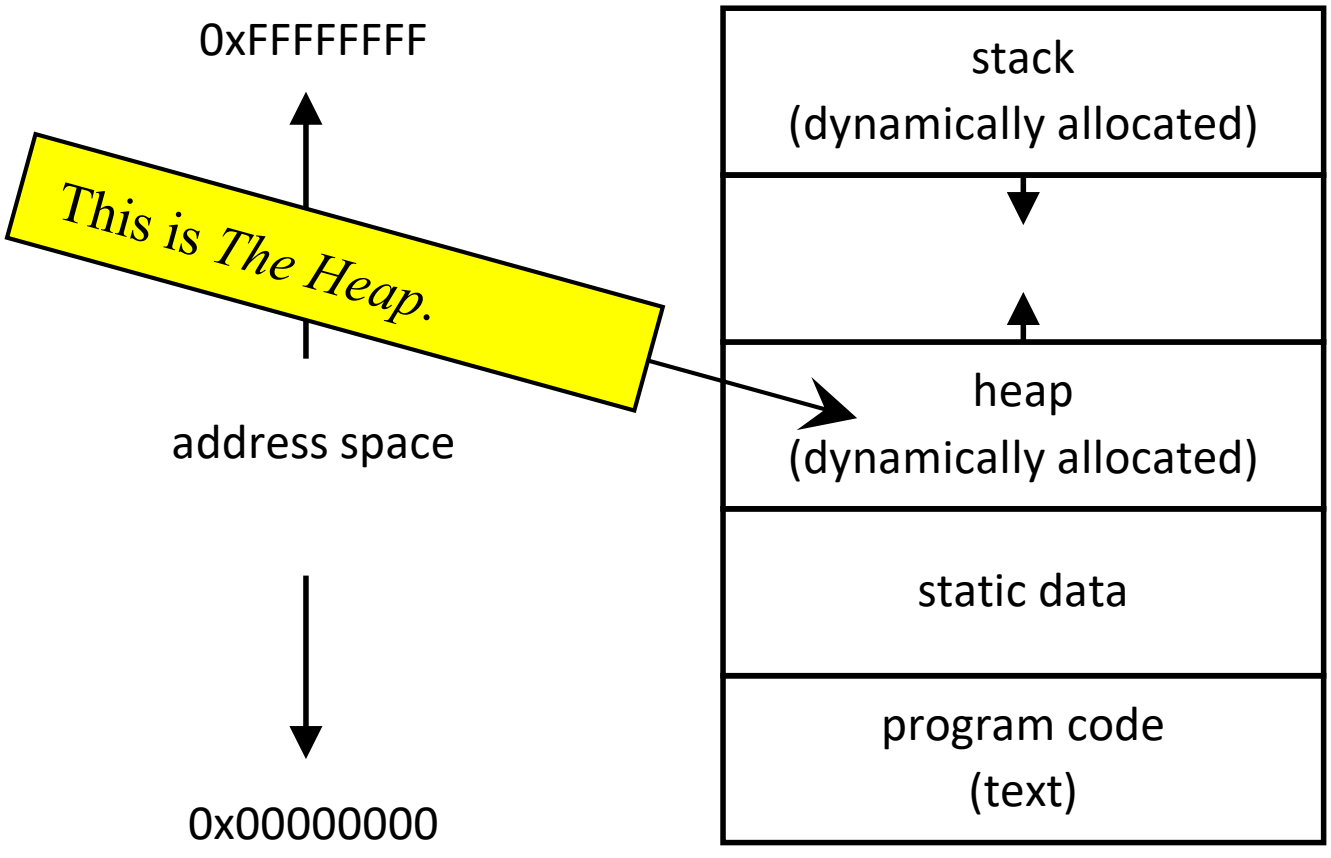
i.e., not a stack

Must be explicitly allocated *and* released
May be accessed *only* with pointers

Remember, an array is equivalent to a pointer

Many hazards to the *C* programmer

Static Data Allocation



Allocating Memory in The Heap

See **<stdlib.h>**

```
void *malloc(size_t size);
void free(void *ptr);
void *calloc(size_t nmemb, size_t size);
void *realloc(void *ptr, size_t size);
```

malloc() — allocates **size** bytes of memory from the heap and returns a pointer to it.

NULL pointer if allocation fails for any reason

free() — returns the chunk of memory pointed to by **ptr**

Must have been allocated by **malloc** or **calloc**

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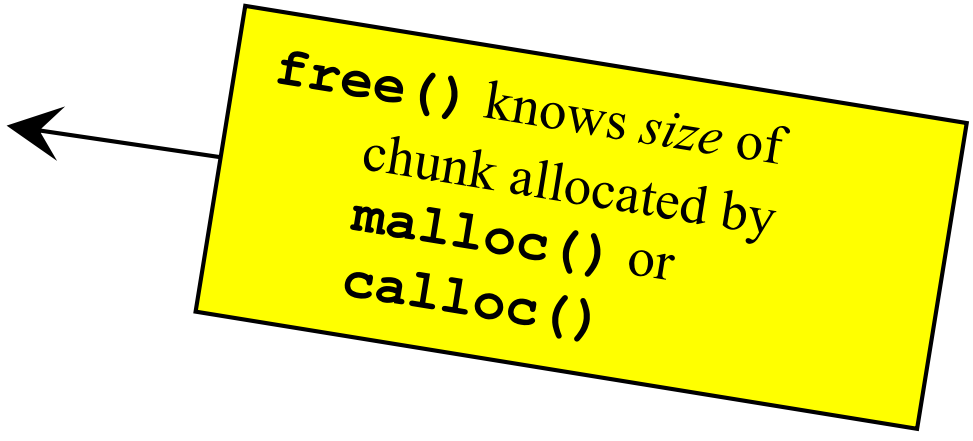

Notes

`calloc()` is just a variant of **`malloc()`**

`malloc()` is analogous to **`new`** in *C++* and Java

- **`new`** in *C++* actually calls **`malloc()`**

`free()` is analogous to **`delete`** in *C++*

- **`delete`** in *C++* actually calls **`free()`**
- Java does not have **`delete`** — uses *garbage collection* to recover memory no longer in use

Typical usage of `malloc()` and `free()`

```
char *getTextFromSomewhere(…);

int main(){
      char * txt;
      …;
      txt = getTextFromSomewhere(…);
      …;
      printf("The text is %s.", txt);
      free(txt);
}
```

Typical usage of `malloc()` and `free()`

```
char * getTextFromSomewhe
    char *t;
    ...
    t = malloc(stringLength);
    ...
    return t;
}

int main(){
    char * txt;
    …;
    txt = getTextFromSomewhere(…);
    …;
    printf("The text is %s.", txt);
    free(txt);
}
```

`getTextFromSomewhere(` `)` creates a new string using **`malloc()`**

Typical usage of **`malloc()`** and **`free()`**

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char * getTextFromSomewhere(...){
     char *t;
     ...
     t = malloc(stringLength);
     ...
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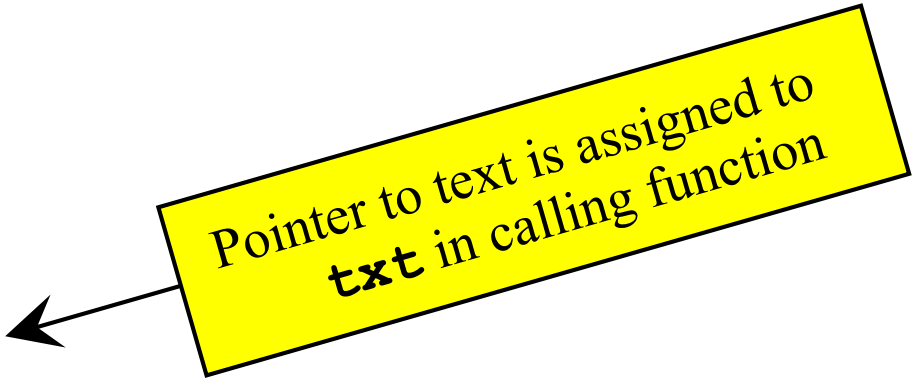
```



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     …;
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}
```

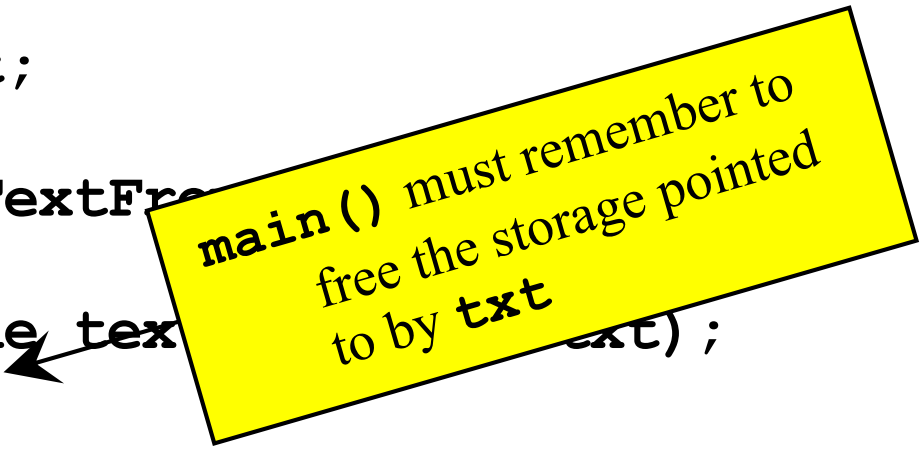

Definition – *Memory Leak*

The steady loss of available memory due to forgetting to **`free()`** everything that was **`malloc`**'ed.

- Bug-a-boo of most large *C*

If you "forget" the value of a pointer to a piece of **`malloc`**'ed memory, there is no way to find it again!

- Killing the program frees *all* memory!

String Manipulation in *C*

Almost all *C* programs that manipulate text do so with **`malloc`**'ed and **`free`**'d memory

No limit on size of string in *C*

Need to be aware of sizes of character arrays!

Need to remember to free storage when it is no longer needed

- *Before* forgetting pointer to that storage!

Input-Output Functions

`printf(const char *format, ...)`

- Format string may contain **`%s`** – inserts a string argument (i.e., **`char *`**) up to trailing **`'\0'`**

`scanf(const char *format, ...)`

- Format string may contain **`%s`** – scans a string into argument (i.e., **`char *`**) up to next "white space"
- Adds **`'\0'`**

Related functions

- **`fprintf()`**, **`fscanf()`** – to/from a file
- **`sprintf()`**, **`sscanf()`** – to/from a string

Example Hazard

```
char word[20];
…;
scanf("%s", word);
```

scanf will continue to scan characters from input until a space, tab, new-line, or **EOF** is detected

- An unbounded amount of input
- May overflow allocated character array
- Probable corruption of data!
- **scanf** adds trailing **'\0'**

Solution:

```
scanf("%19s", word);
```