# Systems Architecture

## 3. Input/Output in C

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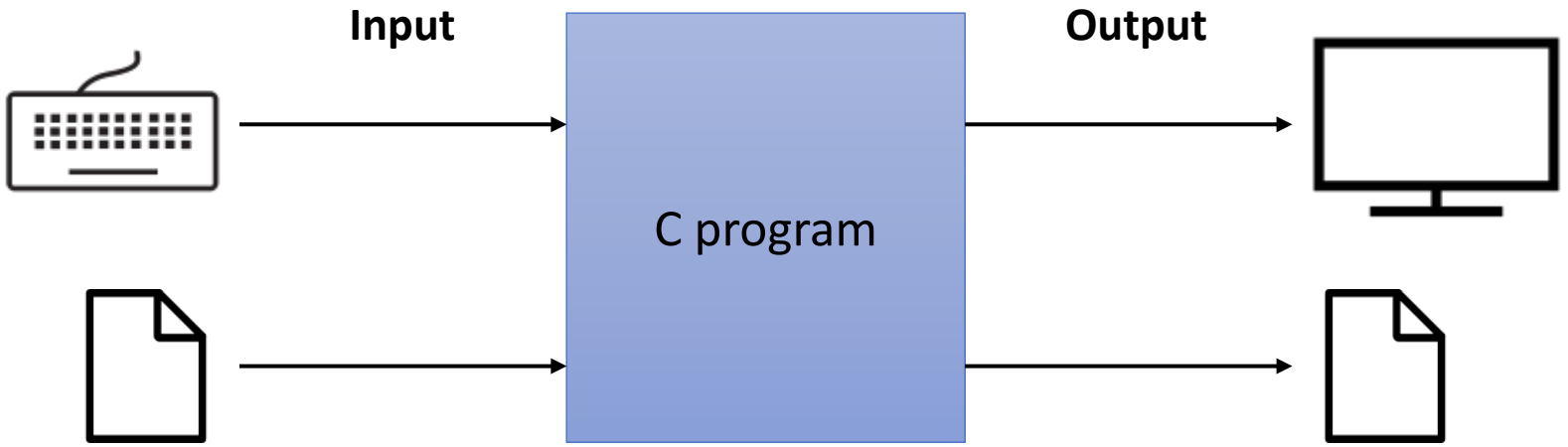
# 1. Introduction

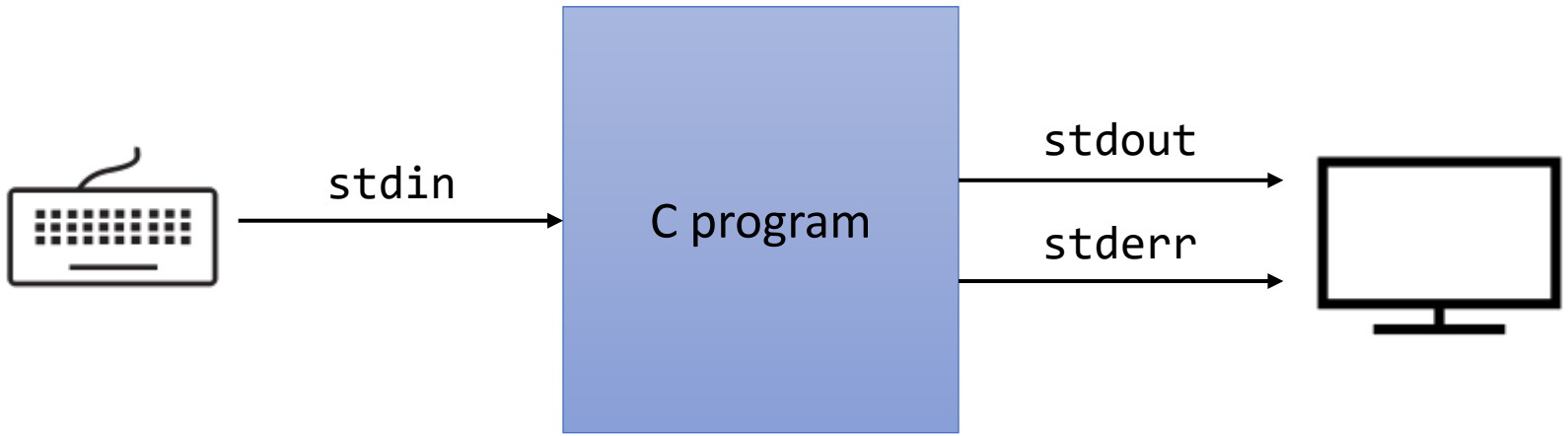
- In C programming:
  - **Input** means to get some data from a source into a program
  - **Output** means to put some data from a program to a target
  - Sources and targets can be devices (e.g., keyboard, screen, printer) or files (e.g. `/home/user/myfile`)
  - Devices are treated as files (and so, I/O in C deals always with **files**)



# 1. Introduction

- There are 3 **standard streams** in C (typically used with the shell):

| Name | File descriptor | Device | Description |
|---|---|---|---|
| Standard input | `stdin` | Keyboard | Default input stream (text from the keyboard typed by an user) |
| Standard output | `stdout` | Screen | Default output stream (text written to the screen to be read by an user) |
| Standard error | `stderr` | Screen | Default output stream for errors (text written to the screen to be read by an user) |



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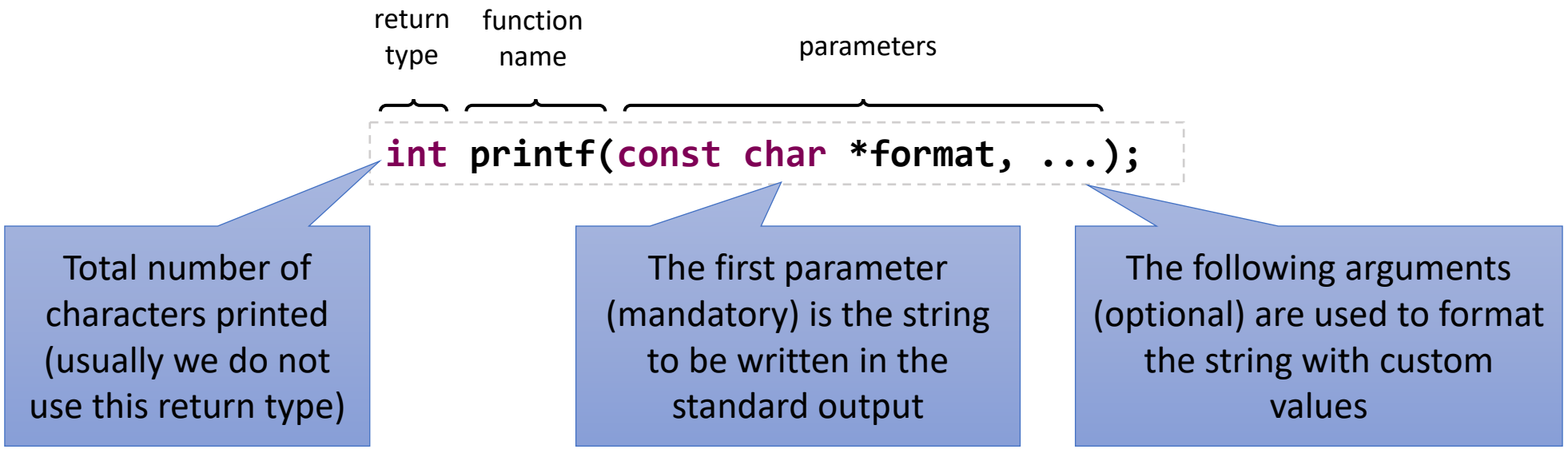
# 2. Basic I/O functions - Standard output: `printf`

- The **`printf`** function writes a formatted string to the **standard output**
  - The `printf` function (and the rest of I/O functions we see) is defined in the **`stdio.h`** library
  - `printf` is a variadic function, and its prototype is as follows:



# 2. Basic I/O functions - Standard output: `printf`

- The string to be written in the standard output with **`printf`** can be formatter using *format specifiers* (the symbol **%** followed a character) to convert different types:

```c
#include <stdio.h>

int main() {
    char string[] = "Hello world";

    printf("%s\n", string);

    return 0;
}
```

```
Hello world
```

# 2. Basic I/O functions - Standard input: `scanf`

- The **`scanf`** function reads data from the standard input according to the format provided
  - The format specifiers used with **`printf`** are also used with **`scanf`** to specify different types (integers, strings, characters, etc.) to be read
  - The prototype of **`scanf`** is:

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

On success, the function returns the number of items of the argument list successfully read. If a reading error happens, then **EOF** is returned. EOF stands for "*End of File*" an it is a keyword in C reserved to determine the end of a file

The *varargs* parameters in **`scanf`** need to be pointers, because the changes made inside the function **`scanf`** are reflected in caller parameters

# 2. Basic I/O functions - Standard input: `scanf`

- Basic example using `scanf`:

```c
#include <stdio.h>

int main() {
    char str[40];

    printf("Enter a string: ");
    scanf("%s", str);

    printf("You entered: %s\n", str);

    return 0;
}
```

```
Enter a string: hello
You entered: hello
```

```
Enter a string: hello world
You entered: hello
```

In order to read a complete line, other functions (such as `fgets` or `readline`) are preferred

# 2. Basic I/O functions - Standard input: `scanf`

- Another example using `scanf`:

```c
#include <stdio.h>

int main() {
    char str[40];
    int i;

    printf("Enter a string and an integer: ");
    scanf("%s %d", str, &i);

    printf("You entered: %s %d\n", str, i);

    return 0;
}
```

```
Enter a string and an integer: hello 100
You entered: hello 100
```

# 2. Basic I/O functions - Standard input: `scanf`

- The **`scanf`** function work using arguments passed by reference:

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

The *varargs* parameters in **`scanf`** need to be pointers, because the changes made inside the function **`scanf`** are reflected in caller parameters

- For this reason, when we invoke **`scanf`** for basic types (e.g. **`char`**, **`int`**, etc.), we need to use the reference operator (&)

```
int i;
char str[40];

scanf("%d", &i);
scanf("%s", str);
```

# 2. Basic I/O functions - Standard input: `scanf`

- Another example using `scanf`:

```c
#include <stdio.h>

int main() {
    int i, res;

    printf("Enter an integer: ");
    res = scanf("%d", &i);

    if (res == EOF) {
        printf("You sent EOF\n");
    } else {
        printf("You entered: %d\n", i);
    }

    return 0;
}
```

```
Enter an integer: ^D
You sent EOF
```

EOF can be typed by a user in the shell using Ctrl+D in Unix-like systems

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# 3. Other I/O functions - Handling characters: `getchar` and `putchar`

- The functions to read and write **characters** in C:

| Prototype | Description |
|---|---|
| `int getchar(void);` | Read a character (only one) from the standard input and returns it as an integer |
| `int putchar(int c);` | Write a character (only one) to the standard output (and returns the same character) |

```c
#include <stdio.h>

int main() {
    printf("Enter a character: ");
    char ch = getchar();

    printf("You entered: ");
    putchar(ch);

    return 0;
}
```

```
Enter a character: c
You entered: c
```

```
Enter a character: hello
You entered: h
```

Only a character is actually read

# 3. Other I/O functions - Handling lines: `gets` and `puts`

- Other functions to read and write **strings** are:

| Prototype | Description |
|---|---|
| `char *gets(char *str);` | Read a string from the standard input until a terminating newline |
| `int puts(const char *str);` | Writes a string plus a newline to the standard output |

```c
#include <stdio.h>
#define MAX 80

int main() {
    char str[MAX];
    printf("Enter a string: ");
    gets(str);

    printf("You entered: ");
    puts(str);

    return 0;
}
```

```
gets_and_puts.c: In function ‘main’:
gets_and_puts.c:7:5: warning: implicit
declaration of function ‘gets’; did you mean
‘fgets’? [-Wimplicit-function-declaration]
    7 |     gets(str);
      |     ^~~~
      |     fgets
/usr/bin/ld: /tmp/ccKHJUYZ.o: in function
`main':
gets_and_puts.c:(.text+0x39): warning: the
`gets' function is dangerous and should not be
used.
```

We get a warning when compiling this program since the `gets` function is deprecated in favor to `fgets` (since it protects from buffer overflow problems)

```
Enter a string: hello
You entered: hello
```

```
Enter a string: hello and bye
You entered: hello and bye
```

# 3. Other I/O functions - Handling lines: `fgets`

- The function **`fgets`** reads a line from the specified file and stores it into the string pointed to by a pointer
  - Prototype: `char *fgets(char *str, int n, FILE *fd);`
  - It stops when either (n-1) characters are read, the newline character is read, or the end of file is reached, whichever comes first
  - It returns `str` on success, and NULL on error or when end of file

This examples reads a string from the standard input (**`stdin`**), and then, this string is written on the standard output

```c
#include <stdio.h>
#define MAX 80

int main() {
    char str[MAX];
    printf("Enter a string: ");
    fgets(str, MAX, stdin);

    printf("You entered: ");
    puts(str);

    return 0;
}
```

```
Enter line: Hello world!
You entered: Hello world!
```

# 3. Other I/O functions - Handling lines: `getline`

- Another function to read strings from a file (e.g. the input stream) is **`getline`**:

| Prototype | Description |
|---|---|
| `int *getline(char **lineptr, size_t *n, FILE *stream);` | Reads an entire line from stream, storing the text (including the newline and a terminating null character) in a buffer |

```c
#include <stdio.h>
#define MAX 80

int main() {
    char str[MAX];
    size_t bufsize = MAX;
    char *buffer = str;

    printf("Enter a string: ");
    getline(&buffer, &bufsize, stdin);

    printf("You entered: ");
    puts(str);

    return 0;
}
```

```
Enter a line: hello
6 characters were read
You entered: hello
```

`getline` is that is not available in some gcc compilers (e.g., in Windows)

# 3. Other I/O functions - Handling lines: `getline`

- **`getline`** uses a double pointer as a first argument since it dynamically allocates memory for the buffer

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

int main() {
    char *line = NULL; // Pointer to store the buffer
    size_t len = 0;    // Initial size of the buffer
    int read;          // Number of characters read

    printf("Enter a string: ");
    read = getline(&line, &len, stdin);
    printf("You entered %d characters (%ld bytes): %s\n", read, len, line);

    free(line);  // Free buffer (dynamic memory)

    return 0;
}
```

We will study dynamic memory in unit 6

# 3. Other I/O functions - Handling lines: `scanf`

- We can also use to read string lines from the user
- For that, we need a special format specifier with a regular expression (*regex*)
  - A regular expression is a sequence of characters that is used to search pattern

```c
#include <stdio.h>
#define MAX 80

int main() {
    char buffer[MAX];

    printf("Enter line: ");
    scanf("%[^\n]", buffer);

    printf("You entered: %s\n", buffer);

    return 0;
}
```

```
Enter line: hi there
You entered: hi there
```

# 3. Other I/O functions - Writing strings: `sprintf`

- The C library function **`sprintf`** sends formatted output to a string (pointed by **`str`**)

```
int sprintf(char *str, const char *format, ...);
```

```c
#include <stdio.h>
#define MAX 22

int main() {
    int n;
    printf("Enter your age: ");
    scanf("%d", &n);

    char str[MAX];
    sprintf(str, "You are %d years old", n);
    puts(str);

    return 0;
}
```

```
Enter your age: 20
You are 20 years old
```

To prevent overflow we can use `snprintf` (see example in the repository)

# 3. Other I/O functions - Examples

- The following program asks for some character to the user:

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

int main() {
    char ch;

    for (;;) { // Infinite loop
        printf("Insert character (q to exit): ");
        scanf("%c", &ch); // equivalent to: ch = getchar();

        if (tolower(ch) == 'q') {
            puts("Goodbye!");
            break;
        }

        printf("\tYou entered: %c\n", ch);
    }

    return 0;
}
```

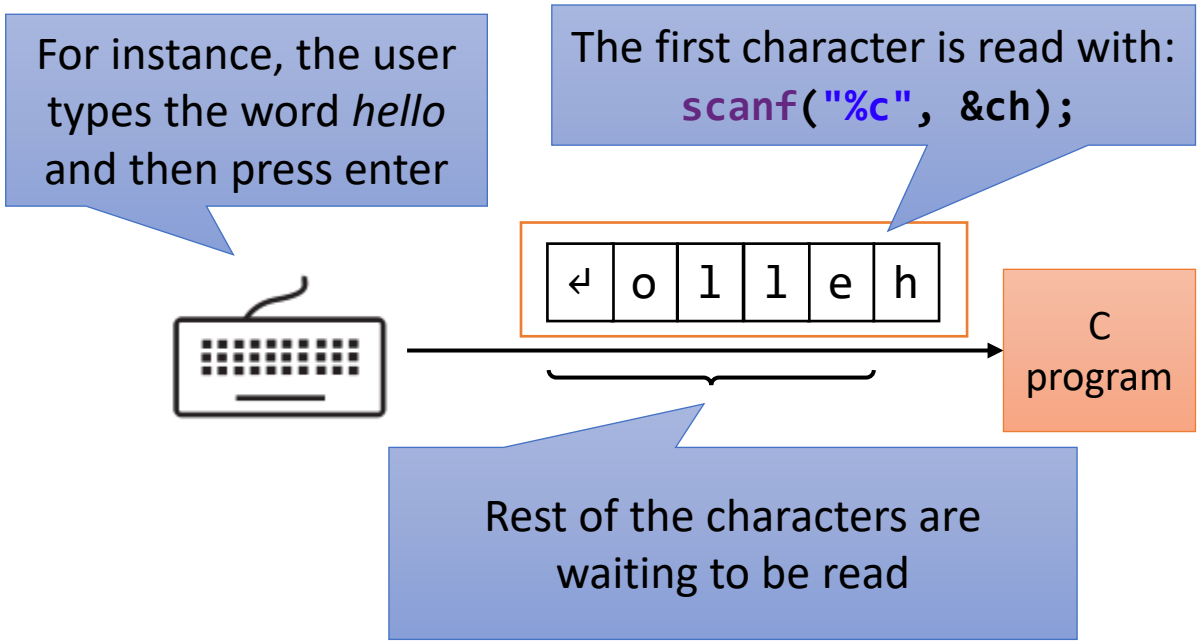
The function **tolower** converts a character to lowercase

```
Insert character (q to exit): q
Goodbye!
```

```
Insert character (q to exit): hello
        You entered: h
Insert character (q to exit):   You entered: e
Insert character (q to exit):   You entered: l
Insert character (q to exit):   You entered: l
Insert character (q to exit):   You entered: o
Insert character (q to exit):   You entered:
```

# 3. Other I/O functions - Examples

- When reading consecutive characters from the standard input, we need to consider that perhaps there are more characters waiting to be read in the *input buffer*:



# 3. Other I/O functions - Examples



- A convenient solution to this problem is to read a complete line and then get the first character:

```c
#include <stdio.h>
#include <ctype.h>
#include <string.h>

#define MAX_STR 80

int main() {
    char ch;
    char input[MAX_STR];

    for (;;) { // Infinite loop
        printf("Insert character (q to exit): ");

        fgets(input, MAX_STR, stdin); // Read a complete line from the user
        input[strlen(input) - 1] = '\0'; // Remove trailing carriage return

        printf("\tYou entered: %s (%ld characters)\n", input, strlen(input));

        ch = input[0]; // Get only the first character of the input
        if (tolower(ch) == 'q' && strlen(input) == 1) {
            puts("Goodbye!");
            break;
        }

    }

    return 0;
}
```

# 3. Other I/O functions - Examples

- The following program asks for some number to the user:

```c
#include <stdio.h>

int main() {
    int i;

    for (;;) { // Infinite loop
        printf("Enter an option from 1 to 7 (8 for exit): ");
        scanf("%i", &i);

        if (i > 0 && i < 8) {
            printf("You entered %d\n", i);
        } else if (i == 8) {
            puts("Goodbye!");
            break;
        } else {
            puts("Wrong option");
        }
    }

    return 0;
}
```

```
Enter an option from 1 to 7 (8 for exit): 1
You entered 1
Enter an option from 1 to 7 (8 for exit): 8
Goodbye!
```

This input doesn't match the format string and `scanf` leaves the invalid input in the buffer

```
Enter an option from 1 to 7 (8 for exit): hello
Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
Enter an option from 1 to 7 (8 for exit): Wrong option
...
```

# 3. Other I/O functions - Examples



- A convenient solution to this problem is to read a line and convert it to integer using the function `atoi`

`atoi` converts a string (1st argument) to an integer (type **`int`**)

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

int main() {
    int i;
    int bufsize = 80;
    char buffer[bufsize];

    for (;;) { // Infinite loop
        printf("Enter an option from 1 to 7 (8 for exit): ");
        fgets(buffer, bufsize, stdin);
        i = atoi(buffer);

        if (i > 0 && i < 8) {
            printf("You entered %d\n", i);
        } else if (i == 8) {
            puts("Goodbye!");
            break;
        } else {
            puts("Wrong option");
        }
    }

    return 0;
}
```

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# 4. File access

- The typical procedure to read/write text files in C is:
  1. Declare a `FILE` pointer which represents the file in C. Internally, `FILE` is an struct that contains information about the file stream:

```
FILE *fd;
```

  2. Open the file using `fopen` (this function will return the file descriptor)

```
FILE *fopen(const char *filename, const char *mode);
```

  3. Perform read or write operations
  4. Close the file using `fclose`:

```
int fclose(FILE *fd);
```

These steps can be done in the same line

# 4. File access - Access modes

- The following table summarizes the access modes for **text** files:

| Mode | Description | Behavior |
|---|---|---|
| `r` | Open for **reading** | If the file does not exist, `fopen()` returns `NULL` |
| `w` | Open for **writing** | If the file exists, its contents are overwritten.<br>If the file does not exist, it is created |
| `a` | Open for **append** (new data is added to the end of the file) | If the file does not exist, it is created |
| `r+` | Open for both **reading** and **writing** | If the file does not exist, `fopen()` returns `NULL` |
| `w+` | Open for both **reading** and **writing** | If the file exists, its contents are overwritten.<br>If the file does not exist, it is created |
| `a+` | Open for both **reading** and **appending** | If the file does not exist, it is created |

For **binary** files, we obtain the same behavior using the modes: `rb`, `wb`, `ab`, `rb+`, `wb+`, `ab+`

# 4. File access - Functions

- The following functions are used to **read** and **write** text from/to files:

| Prototype | Description | |
|---|---|---|
| `int fgetc(FILE *fd);` | Reads and returns a single character at a time from a file. It returns EOF (end of file) when there are no more characters | read |
| `char *fgets(char *buf, int max, FILE *fd);` | Reads a line from the file. It stops when either (n-1) characters are read, the newline character is read, or EOF is reached | |
| `int fscanf(FILE *fd, const char *format,...);` | Reads formatted input from a file (same as `scanf` but from a file) | |
| `int fputc(int ch, FILE *fd);` | Writes a single character into a file | write |
| `int fputs(const char *str, FILE *fd);` | Writes a text line into a file | |
| `int fprintf(FILE *fd, const char *format, ...);` | Write formatted text from a file (same as `printf` but from a file) | |

# 4. File access - Write text file

- Basic example for writing a text file:

The function `exit` terminates the program returning a given exit code (1 this example)

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

int main() {
    FILE *fd = fopen("file.txt", "w");
    if (fd == NULL) {
        fputs("Error opening file", stderr);
        exit(1);
    }

    // Write a line to the file
    fputs("I am writing into the file", fd);

    int i;
    printf("Enter integer: ");
    scanf("%d", &i);

    // Write another line to the file
    fprintf(fd, "You entered: %d\n", i);

    fclose(fd);

    return 0;
}
```

# 4. File access - Read text file

- Basic example for reading a text file line by line:

This example uses the macros **EXIT_FAILURE** (value 1) and **EXIT_SUCCESS** (value 0) defined in the standard library **stdlib.h** for the exit code

```c
#include <stdio.h>
#include <stdlib.h>
#define MAX 255

int main() {
    FILE *fd = fopen("file.txt", "r");
    if (fd == NULL) {
        fputs("Error opening file", stderr);
        exit(EXIT_FAILURE);
    }

    char buffer[MAX];
    while (fgets(buffer, MAX, fd) != NULL) {
        printf("%s", buffer);
    }

    fclose(fd);

    return EXIT_SUCCESS;
}
```

# 4. File access - Read formatted text file

- Basic example for reading a formatted text file:

fscanf.c

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

int main() {
    FILE *fd = fopen("data.txt", "r");
    if (fd == NULL) {
        fputs("Error opening file", stderr);
        exit(1);
    }

    char name[80];
    int age;

    while (fscanf(fd, "%s is %d years old\n", name, &age) != EOF) {
        printf("Name: %s -- Age: %d\n", name, age);
    }

    fclose(fd);

    return 0;
}
```

data.txt

```
Alice is 24 years old
Bob is 31 years old
Charles is 12 years old
```

# 4. File access - End of file: `feof`

- The function `feof` tests the EOF for the given stream
- Its prototype is as follows:

```
int feof(FILE *fd);
```

It returns a non-zero value (i.e., *true*) when EOF is reached, else zero (i.e., *false*) is returned

# 4. File access - End of file: `feof`



- Basic example using `feof`:

```c
#include <stdio.h>
#include <stdlib.h>
#define MAX 255

int main() {
    FILE *fd = fopen("data.txt", "r");
    if (fd == NULL) {
        fputs("Error opening file", stderr);
        exit(1);
    }

    char buffer[MAX];
    while (!feof(fd)) {
        fgets(buffer, sizeof(buffer), fd);
        printf("%s", buffer);
    }

    fclose(fd);

    return 0;
}
```

The problem is the **feof** function only returns true after an attempt to read past the end of the file

```
Alice is 24 years old
Bob is 31 years old
Charles is 12 years old
Charles is 12 years old
```

Possible solutions:

1. Avoid **feof** (use other conditions to check EOF)
2. Double check the output of **feof** (see example)

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# 5. Takeaways

- In C programming, there are 3 **standard streams** (typically used in conjunction with the **shell**):
  1. Standard input (**`stdin`**): Messages typed from the **keyboard**
  2. Standard output (**`stdout`**): Messages displayed on the **screen**
  3. Standard error (**`stderr`**): Error messages displayed on the **screen**
- Input/Output (I/O) functions (defined in `stdio.h`) are used to:
  - To **read** data from files (or devices, also treated as files) using **input** functions (such as **`scanf`**, to read text from the standard input)
  - To **write** data to files (or devices) using **output** functions (such as **`printf`**, to write text to the standard output)