系統程式設計
Systems Programming

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Contents

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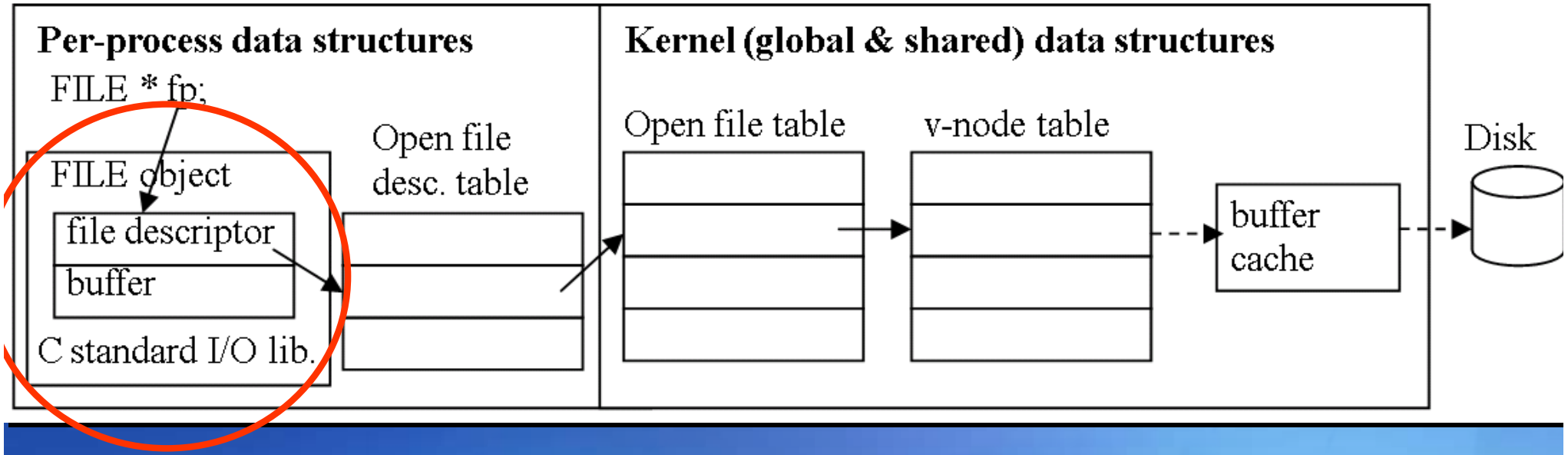
Standard I/O Library

- **Major revision by Dennis Ritchie in 1975**
- **An ANSI C standard**
  - Easy to use and portable
  - Details handled:
    - Buffer allocation, optimal-sized I/O chunks, better interface, etc.

Standard I/O Library

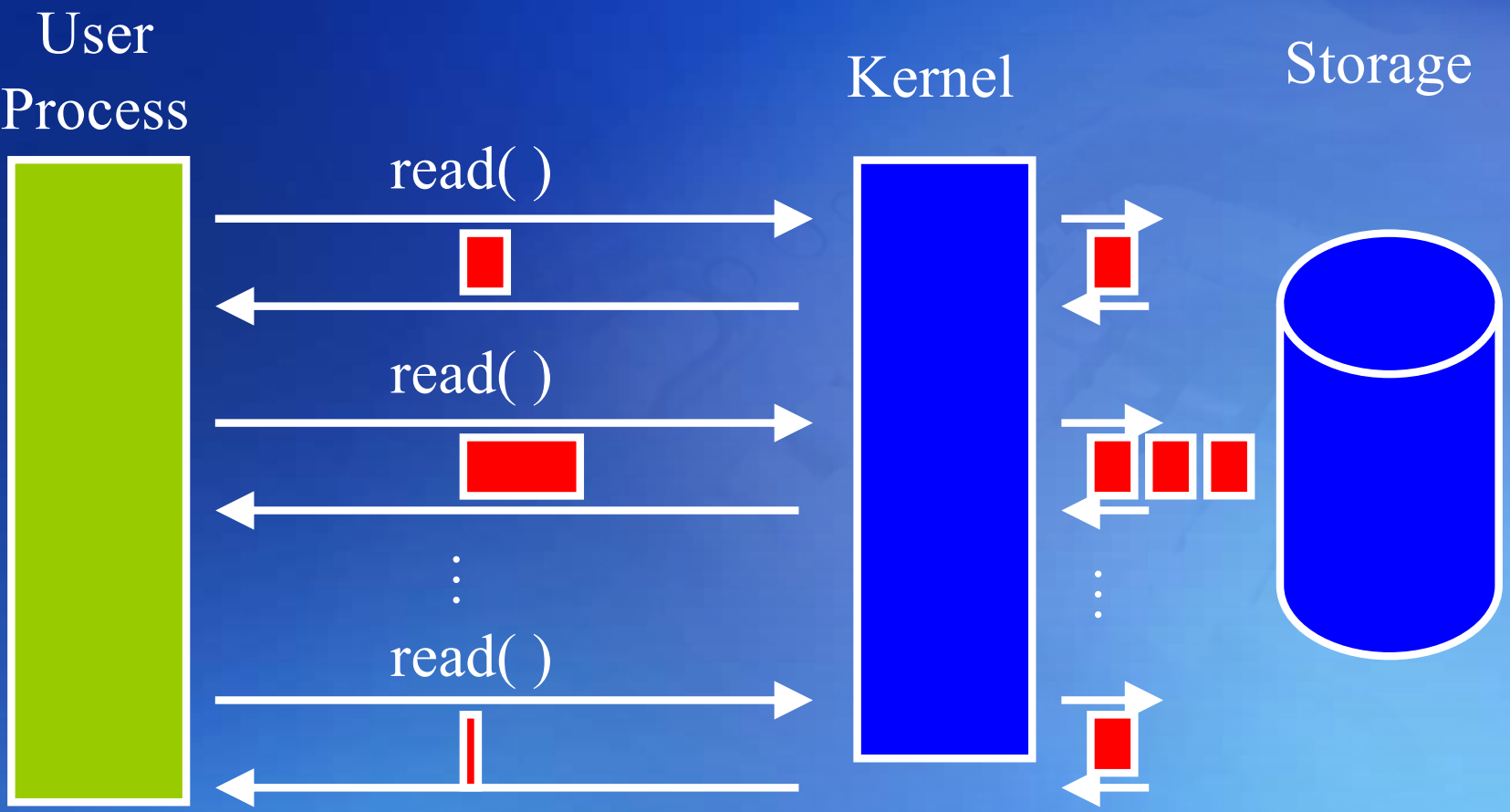
- **Difference from File I/O (unbuffered I/O)**
  - File Pointers vs File Descriptors
  - fopen vs open
    - When a file is opened/created, a *stream* is associated with the file.
    - FILE object
      - File descriptor, pointer to buffer, buffer size,
        # of remaining chars, an error flag,
        an end-of-file flag, and the like.
  - stdin, sdtout, stderr defined in <stdio.h>
    - STDIO_FILENO, STDOUT_FILENO, STDERR_FILENO

Buffering



- A wrapper of unbuffered I/O
- Linux shell command: strace

Unbuffered I/O



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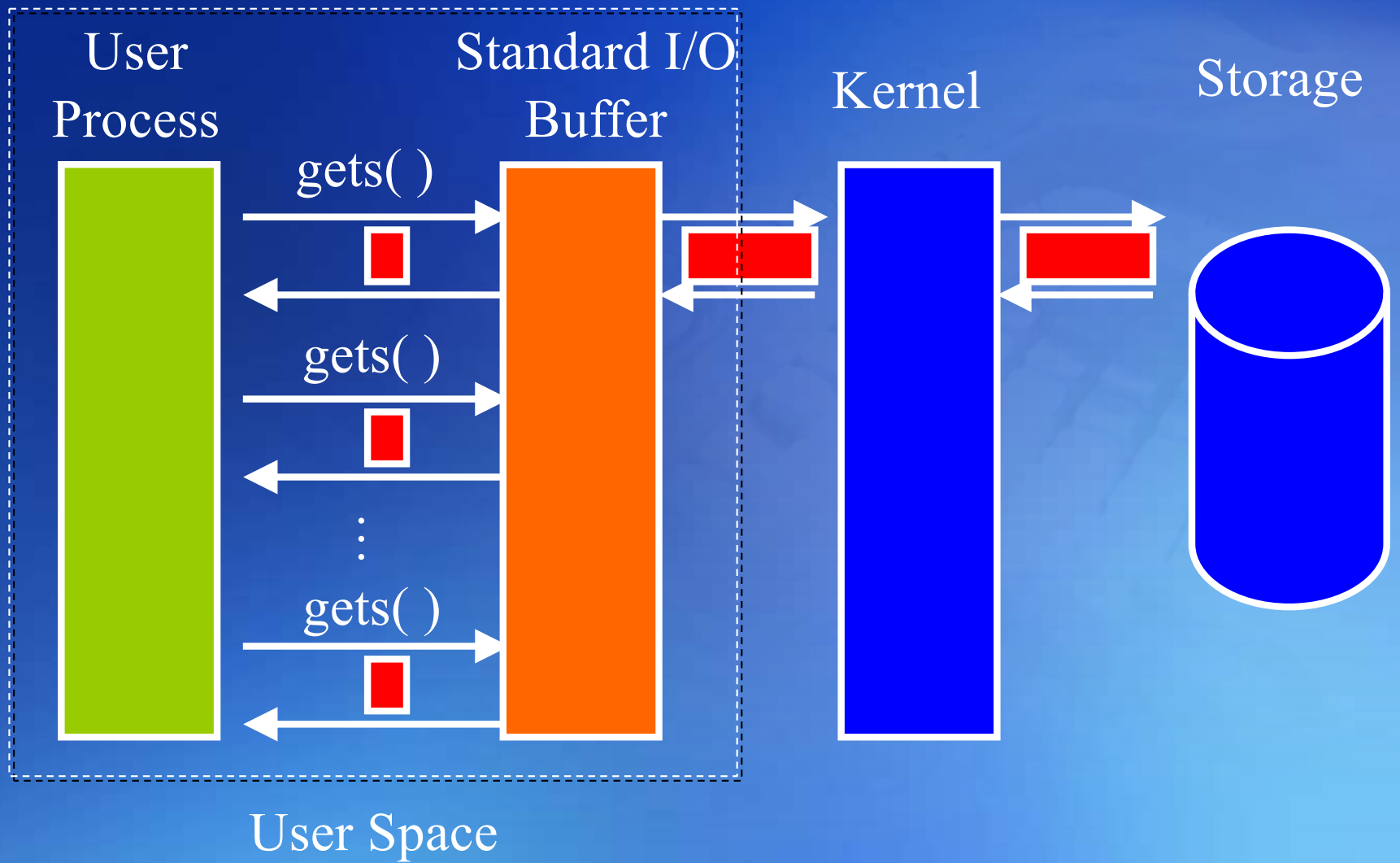
Buffered I/O



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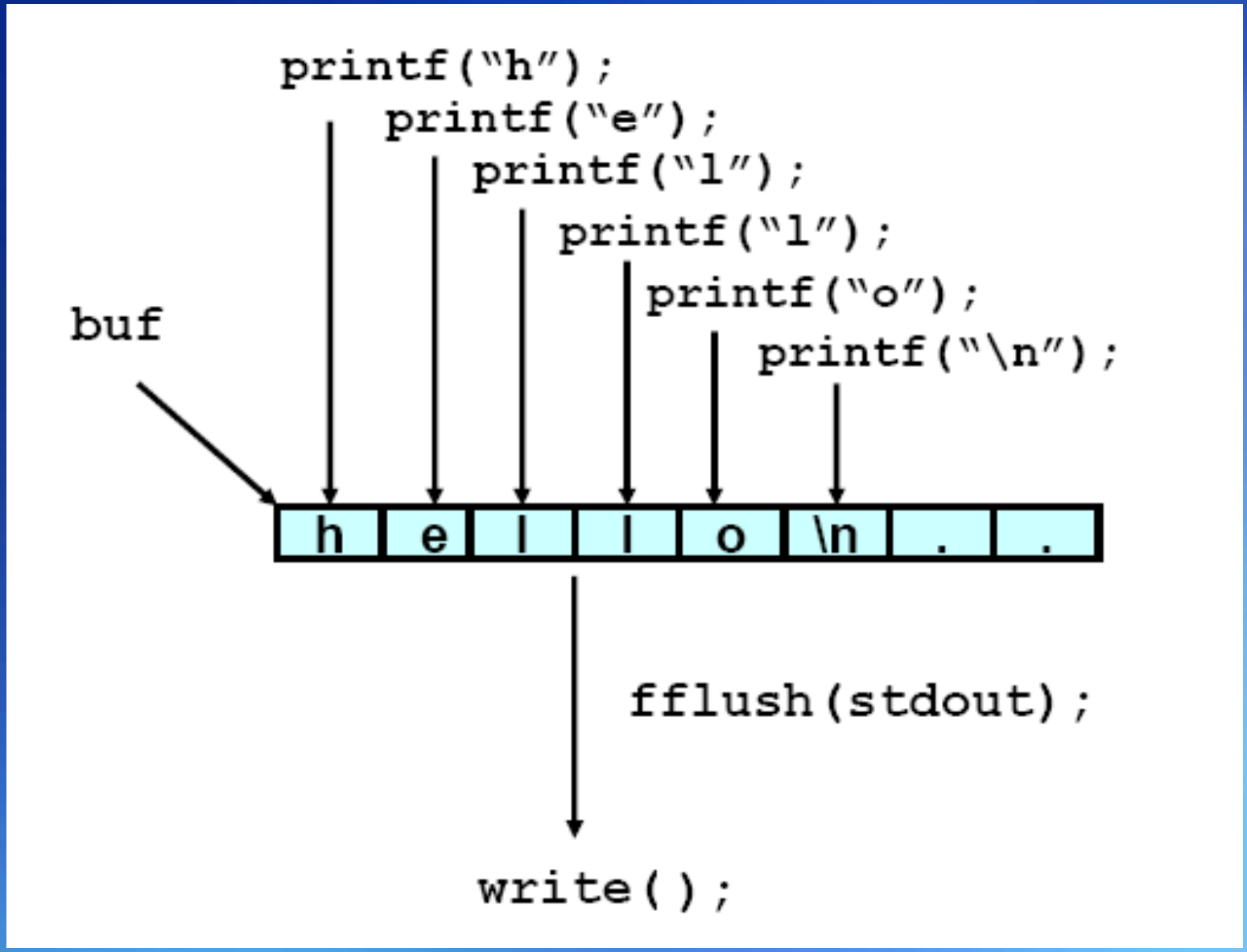
printf("h");
printf("e");
printf("l");
printf("l");
printf("o");
printf("\n");
buf
h
e
l
l
o
\n
.
.
fflush(stdout);
write();

Standard I/O Library - Open

```
#include <stdio.h>
FILE *fopen(const char *pathname, const char *type);
```

- text file vs. binary file: b (in rb, wb, ab, r+b, …) stands for binary file – no effect for Unix kernel
- Append mode supports multiple access (atomic operation)

Restriction	r	w	a	r+	w+	a+
file must already exist	•			•		
previous contents of file discarded		•			•	
stream can be read	•			•	•	•
stream can be written		•	•	•	•	•
stream can be written only at end			•			•

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Example of freopen()

FILE *freopen(const char *pathname,
const char *type, FILE *fp);

- close fp stream first and clear a stream's orientation
- typically used to open a specified file as one of the predefined streams: standard input/output/error.

The example logs all standard output to the /tmp/logfile file.

```
FILE *fp;
fp = freopen ("/tmp/logfile", "a+", stdout);
printf("Sent to stdout and redirected to /tmp/logfile");
fclose(stdout);
```

fdopen & fclose

FILE *fdopen(int fildes, const char *type);

- Associate (standard) I/O stream with an existing file descriptor – POSIX.1
  - Pipes, network channels
  - No truncating for the file for “w”

int fileno(FILE *fp);

- Get filedes for fcntl, dup, etc.

int fclose(FILE *fp);

- Flush buffered output
- Discard buffered input
- All I/O streams are closed after the process exits.
- The relocated buffers must be valid before the stream is closed.

Potential problem when using fclose

- **Never be referenced after their stack frames (see Ch.7) are released.**

```
#define DATAFILE    "datafile"

FILE *
open_data(void)
{
    FILE    *fp;
    char    databuf[BUFSIZ];   /* setvbuf makes this the stdio buffer */

    if ((fp = fopen(DATAFILE, "r")) == NULL)
        return(NULL);
    if (setvbuf(fp, databuf, _IOLBF, BUFSIZ) != 0)
        return(NULL);
    return(fp);     /* error */
}
```

Explain later

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Buffering

- **Goal**
  - Use the minimum number of read and write calls.
- **Allocation**
  - Automatically allocated when the first-time I/O (malloc) is performed on a stream.
  - Call setbuf() or setvbuf()
- **Types**
  - Fully Buffered
    - Actual I/O occurs when the buffer is filled up.
    - Disk files, pipes, and sockets are normally fully buffered.

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- Line Buffered
  - Perform I/O when a newline char is encountered! – usually for terminals (e.g., stdin, stdout).
  - Caveats
    - The filling of a fixed buffer could trigger I/O.
    - The flushing of all line-buffered outputs if input is requested (from the kernel).

    Example:

```
char buf[100];
printf("$ ");            // "prompt" in shell
scanf("%s", buf);   // trigger the output of $
```

- Unbuffered
  - Expect to output ASAP, e.g. using write()
  - E.g., stderr

- **ANSI C Requirements**
  - Fully buffered for stdin and stdout unless interactive devices are referred to.
    - SVR4/4.3+BSD – line buffered
  - Standard error is never fully buffered.
    - SVR4/4.3+BSD – unbuffered

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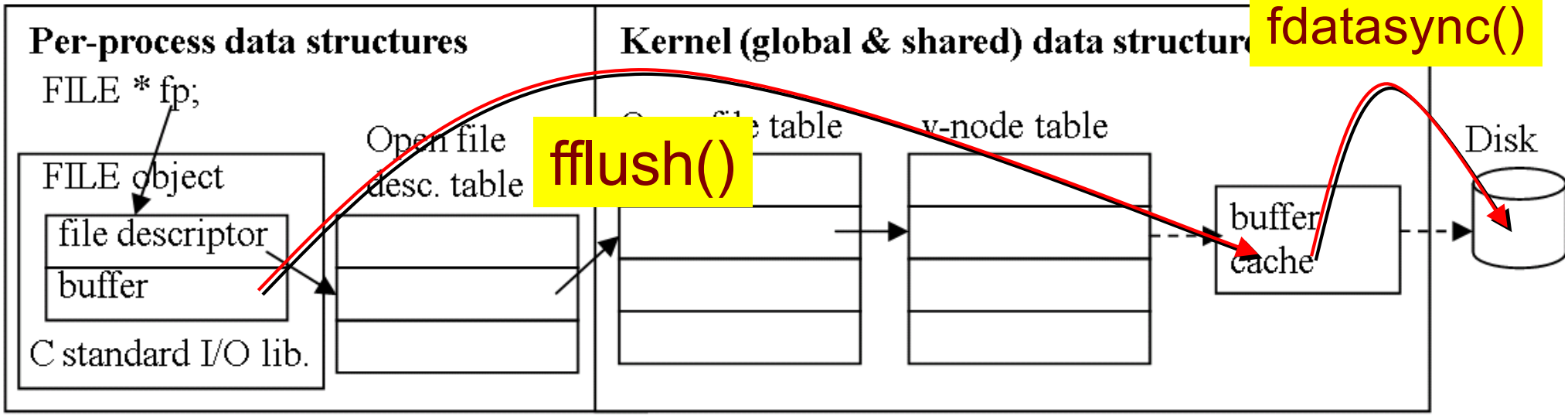
Way to Synchronize Data

int fflush(FILE *fp);

- Any unwritten data in the stream are passed to kernel
- All output streams are flushed if fp == NULL
- Call fsync() after each call to fflush() if necessary. Calling fsync() without calling fflush() might do nothing if all the data are still in the C library buffer.

sync()
fsync()
fdatasync()



Build up your own buffer

Must be called before any op is performed on streams!

void setbuf(FILE *fp, char *buf);

- Full/line buffering if buf is not NULL (BUFSIZ)
  - Ex: line buffer for terminals
- Turn buffering off if buf is NULL
- #define BUFSIZ 1024 (<stdio.h>)

int setvbuf(FILE *fp, char *buf, int mode, size_t size);

- Specify the type of buffering
- mode: _IOFBF, _IOLBF, _IONBF (<stdio.h>)
  - Optional size → st_blksize (stat())

- **Possible Memory Access Errors**
  - Note buffer's life cycle (close the stream before terminating a process/function if automatic variable is used)
- **Part of the buffer for internal bookkeeping**

	Mode	*Buf*	Buffer and Length	Type of Buffering
setbuf		Non-null	User *buf* of length BUFSIZE	Fully buffered or line buffered
		NULL	(no buffer)	Unbuffered
setvbuf	_IOFBF	Non-null	User *buf* of length *size*	Fully buffered
		NULL	System buffer of appropriate length	
	_IOLBF	Non-null	User *buf* of length *size*	Line buffered
		NULL	System buffer of appropriate length	
	_IONBF	(ignored)	(no buffer)	Unbuffered

Positioning-a-Stream

#include <stdio.h>

long ftell(FILE *fp);

- Current file offset in bytes

int fseek(FILE *fp, long offset, int whence);

void rewind(FILE *fp);

- Assumption: a file's position can be stored in a long
- Another version: fello, fseeko (off_t)

  fgetpos, fsetpos (fpos_t) (ANSI C Standard)
- whence: same as lseek
  - Binary files: No requirements for SEEK_END under ANSI C (good under Unix, possible padding for other systems).
  - Text files: SEEK_SET only – 0 or returned value by ftell

Standard I/O Library – Reading/Writing

- **Unformatted I/O**
  - Character-at-a-time I/O, e.g., getc
    - Buffering handled by standard I/O lib
  - Line-at-a-time I/O, e.g., fgets
    - Buffer limit might need to be specified.
  - Direct I/O, e.g., fread
    - Read/write a number of objects of a specified size.
    - An ANSI C term, e.g., = object-at-a-time I/O, binary I/O, record/structure-oriented I/O, etc.

Character-at-a-Time I/O

```
#include <stdio.h>
int getc(FILE *fp);
int fgetc(FILE *fp);
int getchar(void);
```

- getchar == getc(stdin)
- Differences between getc and fgetc
  - getc could be a macro
  - Argument's side effect (e.g., getc(f*++) will fail, exec time, passing of the function address.
- unsigned char converted to int in returning to return error number.
- Error value: -1 for EOF and error. (How do you know exactly what happens?)

- **The following code works correctly on some machines, but not on others. What could be the problem?**

```
int main()
{
    char    c;
    while ((c = getchar()) != EOF)
            putchar(c);
}
```

A system could choose “unsigned” or “signed” for “char” type.

• unsigned char → the character's value no longer equals -1, so the loop never terminates
• signed char → the character’s value equals -1 when reading char 255, so the loop terminates before EOF

Standard I/O Library – Reading/Writing

```
#include <stdio.h>
int ferror(FILE *fp);
int feof(FILE *fp);
void clearerr(FILE *fp);
```

- Clear both of error and EOF flags

```
int ungetc(int c, FILE *fp);
```

- No pushing back of EOF (i.e., -1)
- No need to be the same char read!
- Clear EOF flag
- The character is stored in IO buffer, instead of file.

Using ungetc to remove white space at the start of a line.

```
While (ftell(my_stream) != EOF){
do
  in_char = getc (my_stream);
while (isspace (in_char));

/* Back up to first non-whitespace character */
ungetc (in_char, my_stream);

getline (&my_string, &nchars, my_stream);
}
```

Character-at-a-Time I/O

```
#include <stdio.h>
int putc(int c, FILE *fp);
int fputc(int c, FILE *fp);
int putchar(int c);
```

- putchar(c) == putc(c, stdout)
- Differences between putc and fputc
  - putc() can be a macro.

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Line-at-a-Time I/O

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

```
char *fgets(char *buf, int n, FILE *fp);
```

- Include '\n' and be terminated by *null*
- Could return a partial line with (n-1) bytes if the line is too long.

```
char *gets(char *buf);
```

- Read from stdin.
- No buffer size is specified → overflow (unsafe)
- *buf does not include '\n' and is terminated by *null.*

Example of Unsafe gets()

```
#include <stdio.h>

typedef struct MyStruct
{
  char buf[5];
  int  i;
} MyStruct_t;

int main(void)
{
  MyStruct_t my;

  my.i = 10;

  printf ("my.i is %d\n", my.i);
  printf ("Enter a 10 digit number:");  /
* Too big on purpose  */
```

(cont.)

```
  gets(my.buf);

  printf ("my.buf is >%s<\n",
my.buf);
  printf ("my.i is %d\n", my.i);

  return(0);
}
```

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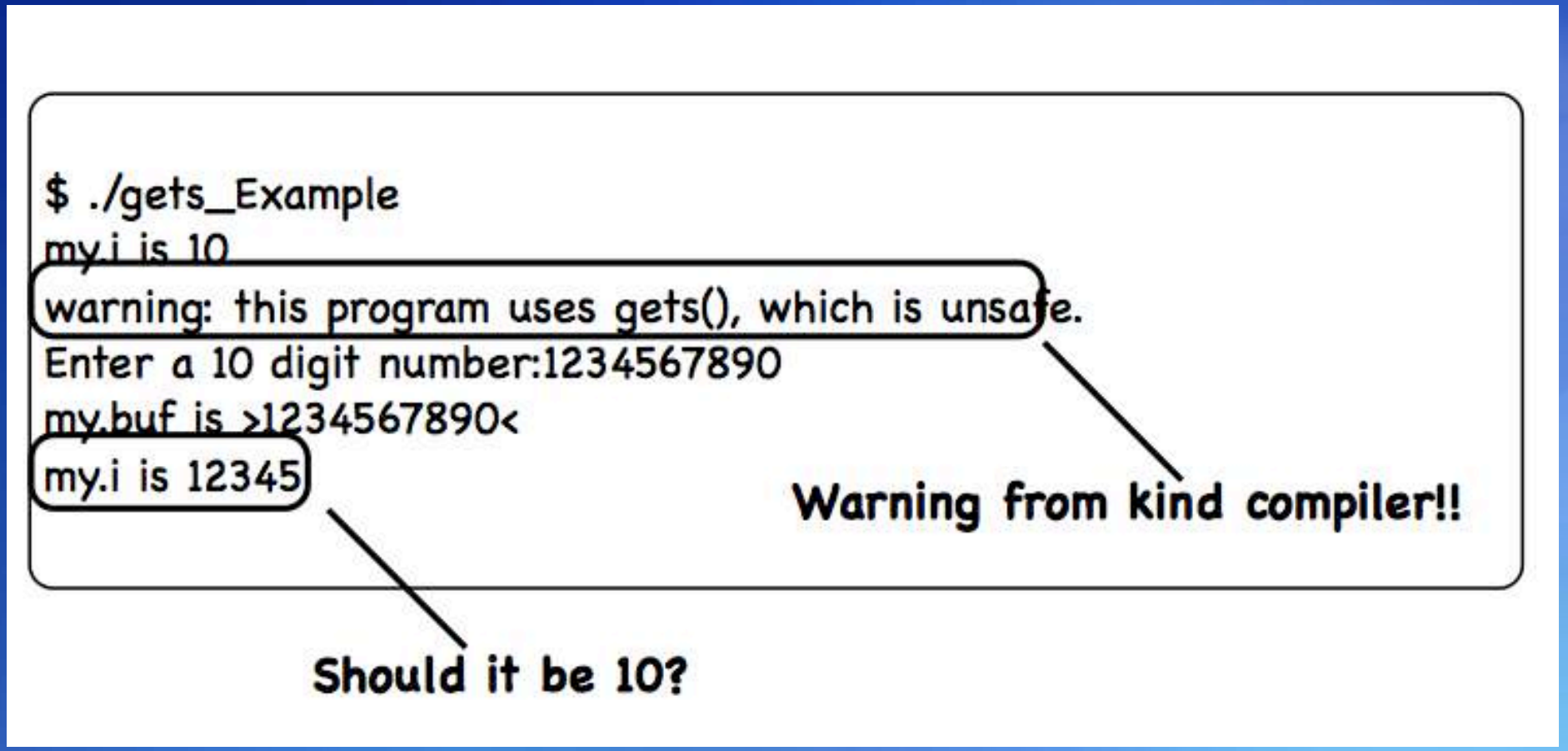
$ ./gets_Example
my.i is 10
warning: this program uses gets(), which is unsafe.
Enter a 10 digit number:1234567890
my.buf is >1234567890<
my.i is 12345
Warning from kind compiler!!
Should it be 10?

Line-at-a-Time I/O

```
#include <stdio.h>
char *fputs(const char *str, FILE *fp);
```

- Include '\n' and be terminated by *null*.
- Newline is not required for line-at-a-time output.

```
char *puts(const char *str);
```

- *str does not include '\n' and is terminated by *null*.
- puts() then writes '\n' to stdout.

Binary I/O

- **Objectives**
  - Read/write a structure at a time, which could contains null or '\n'.

```
#include <stdio.h>
size_t fread(void *ptr, size_t size, size_t nobj, FILE *fp);
size_t fwrite(const void *ptr, size_t size, size_t nobj, FILE *fp);
```

  - Reads less than the specified number of objects → error or EOF → ferror, feof
  - Write error if less than the specified number of objects are written.

Binary I/O

- **Example 1**

```
float data[10];
if (fwrite(&data[2], sizeof(float), 4, fp) != 4)
    err_sys("fwrite error");
```

- **Example 2**

```
struct {
    short count;
    long total;
    char name[NAMESIZE];
} item;
if (fwrite(&item, sizeof(item), 1, fp) != 1)
    err_sys("fwrite error");
```

Binary I/O

- **NOT PORTABLE for programs using fread and fwrite**
  1. The offset of a member in a structure can differ between compilers and systems (due to alignment).
  2. The binary formats for various data types, such as integers, could be different over different machines.

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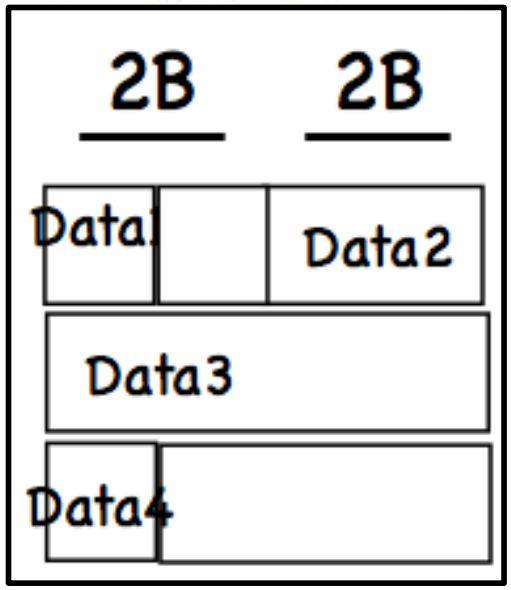
Memory Alignment

8B

```
struct MixedData
{
    char Data1;
    short Data2;
    int Data3;
    char Data4;
};
```

```
struct MixedData
{
    char Data1;          /* 1 byte */
    char Padding1[1];    /* 1 byte */
    short Data2;         /* 2 bytes */
    int Data3;           /* 4 bytes */
    char Data4;          /* 1 byte */
    char Padding2[3];    /* 3 bytes */
};
```



Memory Alignment

- Beneficial to allocate memory aligned to cache lines
- The type of each member of the structure usually has a default alignment, meaning that it will be aligned on a pre- determined boundary unless otherwise requested by the programmer.

A char (one byte) will be 1-byte aligned.

A short (two bytes) will be 2-byte aligned.

An int (four bytes) will be 4-byte aligned.

A float (four bytes) will be 4-byte aligned.

A double (eight bytes) will be 8-byte aligned on Windows and 4-byte aligned on Linux (8-byte with -malign-double compile time option).

A long double (twelve bytes) will be 4-byte aligned on Linux.

Any pointer (four bytes) will be 4-byte aligned on Linux. (e.g.: char*, int*)

Formatted I/O

Input Functions:

```
int scanf(const char *format, …);
int fscanf(FILE *fp, const char *format, …);
int sscanf(char *buf, const char *format, …);
```

Output Functions:

```
int printf(const char *format, …);
int fprintf(FILE *fp, const char *format, …);
int sprintf(char *buf, const char *format, …);
```

- Overflow is possible for sprintf() – '\0' appended at the end of the string. A better substitute: snprintf()

```
int vprintf(const char *format, va_list arg);
int vfprintf(FILE *fp, const char *format, va_list arg);
int vsprintf(char *buf, const char *format, va_list arg);
```

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Problem: No Range Checking

- **strcpy does not check input size**
  - strcpy(buf, str) simply copies memory contents into buf starting from *str until “\0” is encountered, ignoring the size of area allocated to buf
- **Many C library functions are unsafe**
  - strcpy(char *dest, const char *src)
  - strcat(char *dest, const char *src)
  - gets(char *s)
  - sprintf(char *buf, const char *format, …);

Interleaved R&W restrictions

- **Output [fflush | fseek | fsetpos | rewind] Input**
  Intput [fseek | fsetpos | rewind | EOF] Output

- Note that standard IO functions are implemented by UNIX IO system calls.
  - fread() calls read() to fill local buffer when needs.
  - fwrite() calls write() to flush local buffer when needs.
- When there is no need to trigger system calls, standard IO read/write data from buffer, directed by R and W pointers, respectively.
- The inconsistent on R/W pointers leads to errors

Errors may occur in some systems

```
// In this example, we try to check the buffering
// mechanism for Standard IO library.
// One character is read and another character
// is written to the same file.
// No file position functions such as fseek is called in between.

int main( void )
{
    FILE* fp = fopen( "./test.txt", "r+" );
    // test.txt: 12345


    char c;
    fread( &c, 1, 1, fp );
    // fseek(fp,0,SEEK_CUR);

    fwrite( &c, 1, 1, fp );

    fclose( fp );
    return 0;
}
```

The Results

In Linux:
Without fseek, 11345

In Linux:

With fseek, 11345

In OSX:
Without fseek, 12345

In OSX:

With fseek, 11345

In Windows:
Without fseek, 12345 \n 1

In Windows:

With fseek, 11345

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Workaround on the Restrictions

Flush stream after every write!!

Or,

Open two streams on the same descriptor, one for reading and one for writing:

```
FILE *fpin, *fpout;

fpin = fdopen(fd, "r");
fpout = fdopen(fd, "w");
```

However, you need to position the pointers separately and close two file streams at the end.

```
fclose(fpin);
fclose(fpout);
```

Standard I/O Efficiency

98.5 MB files with 3 million lines

System times are comparable

Function	User CPU (seconds)	System CPU (seconds)	Clock Time (seconds)	Bytes of program text
Best time using read/write	0.01	0.18	6.67	
fgets, fputs	2.59	0.19	7.15	139
getc, putc	10.84	0.27	12.07	120
fgetc, fputc	10.44	0.27	11.42	120
Single byte using read/write	124.89	161.65	288.64	

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Copy stdin to stdout using getc and putc

```
#include "apue.h"

int
main(void)
{
        int     c;

        while ((c = getc(stdin)) != EOF)
            if (putc(c, stdout) == EOF)
                err_sys("output error");

        if (ferror(stdin))
            err_sys("input error");

        exit(0);
}
```

Copy stdin to stdout using fgets and fputs

```
#include "apue.h"

int
main(void)
{
    char    buf[MAXLINE];

    while (fgets(buf, MAXLINE, stdin) != NULL)
        if (fputs(buf, stdout) == EOF)
            err_sys("output error");

    if (ferror(stdin))
        err_sys("input error");

    exit(0);
}
```

Multibyte Files

```
#include <wchar.h>
int fwide(FILE *fp, int mode)
```

- Standard I/O file streams can be used with single byte and multiple byte character sets.
- By default, there is no orientation
- After the stream becomes byte-oriented or wide-oriented, the orientation of a stream will be fixed and can not be changed until the stream is closed.
- Mode:
  - Negative: set byte-oriented
  - Positive: set wide-oriented
  - 0: No change on orientation.
- Return values:
  - Positive: wide oriented
  - Negative: byte oriented
  - 0: no orientation.
- Related functions: fwprintf, fwscanf, fgetwc, fputwc, wmemcpy

What You Should Know

- **What is buffered I/O**
  - Goal and types (fully/lined buffered & unbuffered)
- **Kernel data structure for buffered I/O**
- **Flushing data**
  - fflush() vs. fsync()
- **I/O efficiency**
- **Unformatted I/O vs. Formatted I/O**