Structures

COMP2017/COMP9017

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What is a *Structure*?

- So far the only collection of data we’ve covered is the *array*
- Arrays are used to hold items of the **same type** and access them by giving an index
- Sometimes we want to hold a collection of data items of ***different*** types.
- For example: a library catalogue for a book might contain the title, author’s name, call number, date acquired, date due back etc

- For this type of collection C has a data type called a ***structure***

Structure definition example

name of the type of structure

```
struct date
{
    enum day_name     day;
    int               day_num;
    enum month_name   month;
    int               year;
};
```

fields of the structure

structure example

```
struct date {
        enum day_name    day;
        int              day_num;
        enum month_name  month;
        int              year;
} Big_day   {
        Mon, 7, Jan, 1980
};
struct date  moonlanding;
struct date  deadline = {day_undef, 1, Jan, 2000};
struct date  *completion;
struct date {
        enum day_name      day;
        int                day_num;
        enum month_name    month;
        int                year;

} Big_day
{
        Mon, 7, Jan, 1980
};

struct date     moonlanding;
struct date     deadline = {day_undef, 1, Jan, 2000};
struct date     *completion;
```

Structure definition

Structure declaration

Structure initialisation

Structures

```
struct date {
        enum day_name     day;
        int               day_num;
        enum month_name   month;
        int               year;

};
struct date  moonlanding;


struct date  deadline =  {day_undef, 1, Jan, 2000};


struct date  *completion;
```

Structures

```
struct car_desc
{
   enum car_cols   colour;
   enum car_make   make;
   int             year;
};
```

General form

```
struct [tag]
{
    member-declarations

} [identifier-list];
```

› Once tag is defined, can declare structs with:

```
struct tag identifier-list;
```

Accessing Elements of a struct

```
struct date bigday;
int             theyear;

theyear = bigday.year
```

A dot used to nominate an element of the structure.

Accessing Elements of a struct

```
struct date bigday;
struct date * mydate;
int            theyear;

mydate = &bigday;

theyear = mydate->year
```

If a pointer to the structure is used, then the -> operator indicates the element required.

typedef

```
typedef struct date{
    enum day_name          day;
    int                    day_num;
    enum month_name        month;
    int                    year;
} Date;
```

typedef

```
typedef struct date{
    enum day_name      day;
    int                day_num;
    enum month_name    month;
    int                year;
} Date;
```

```c
typedef struct date{
   enum day_name      day;
   int                day_num;
   enum month_name    month;
   int                year;
} Date;


Date Big_day = {Mon, 7, Jan, 1980};
Date moonlanding;
Date dopday = {day_undef, 1, Jan, 2000};
Date *completion;
```

Struct: function arguments, returns

```
struct  customer    customer;
struct  salesrep    rep;
struct sale transaction = transact(customer, rep);

struct sale transact(struct customer c1,
                     struct salesrep s2)
{
        struct sale  the_sale;
        ...
        return the_sale;
}
```

Standard structures

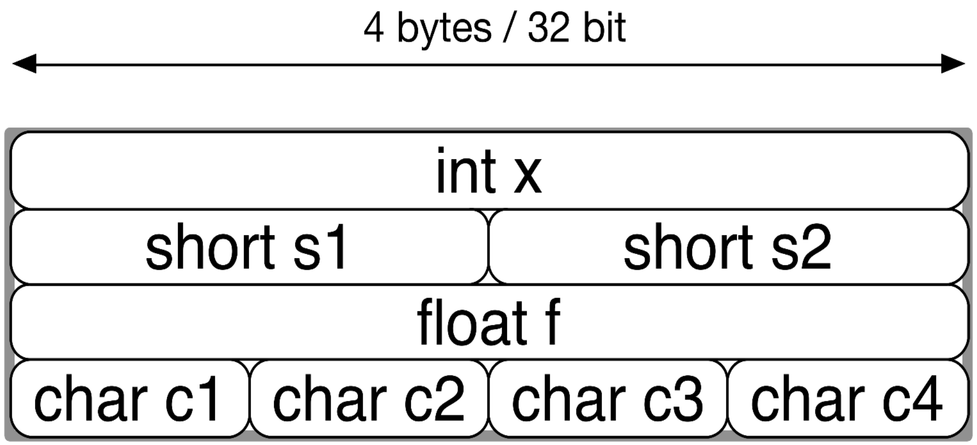
- `stdio.h`
- `time.h`
- `stat.h`
- `pwd.h`

```
struct tm
{
  int tm_sec;/* Seconds.     [0-60] */
  int tm_min;/* Minutes.     [0-59] */
  int tm_hour;/* Hours.       [0-23] */
  int tm_mday;/* Day.         [1-31] */
  int tm_mon; /* Month.       [0-11] */
  int tm_year;/* Year - 1900.  */
  int tm_wday;/* Day of week. [0-6] */
  int tm_yday;/* Days in year.[0-365] */
  int tm_isdst;/* DST indicator */
  long int tm_gmtoff; /* Seconds east of UTC.  */
  const char *tm_zone;/* Timezone abbreviation.  */
};

struct tm * localtime(long *); /* forward decl. */
struct tm * now;

now = localtime(&sometime);
        /* sometime contains time in seconds after
             Jan 1 1970 */
```

```
Hour_now = now->tm_hour;


printf ("%d/%d/%d\n", now->tm_mday, now->tm_mon,
                                    now->tm_year);
```

Memory alignment

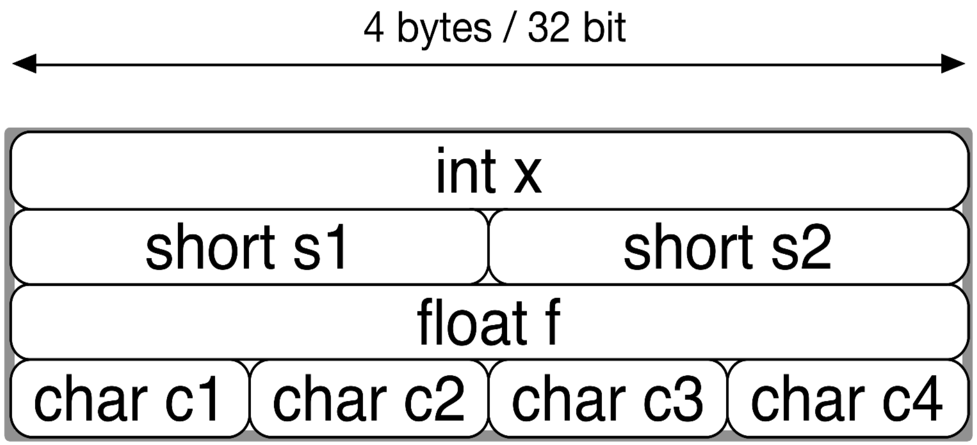
```
struct a {
   int x;
   short s1, s2;
   float y;
   char c1, c2, c3, c4;
};
```



```
sizeof (struct a) == 16
```

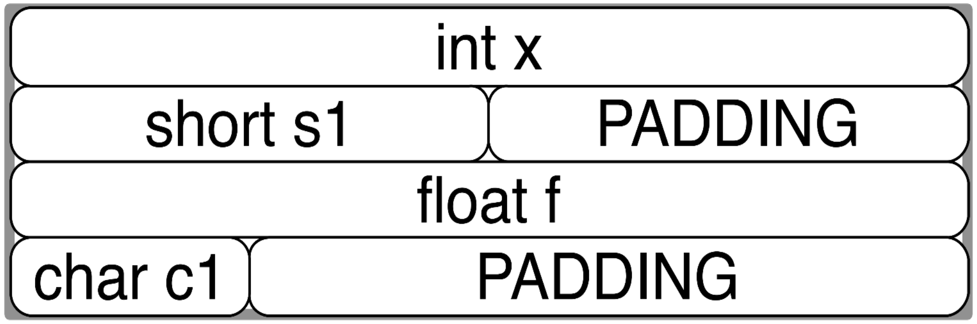
Memory alignment

```
struct a {
    int x;
    short s1, s2;
    float y;
    char c1, c2, c3, c4;
};
```



```
sizeof (struct a) == 16
```

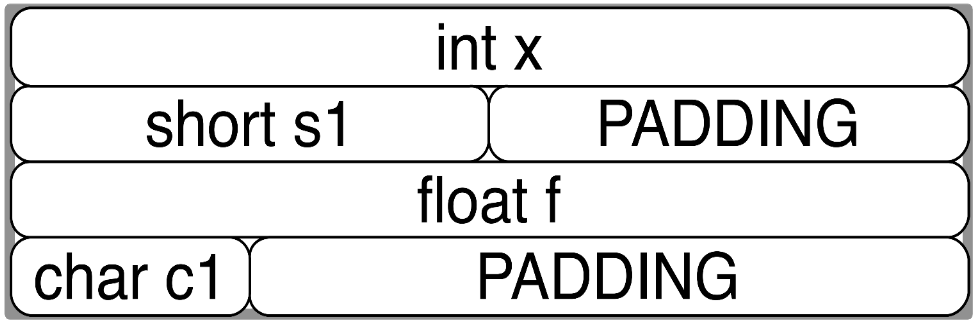
```
struct b {
    int x;
    short s1;
    float y;
    char c1;
};
```



```
sizeof (struct b) == 16
```

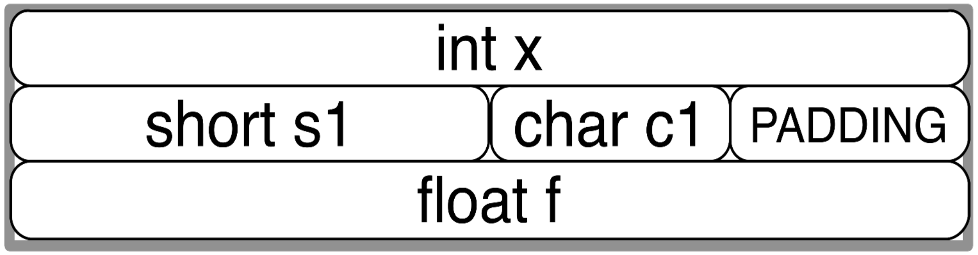
Memory alignment

```
struct b {
    int x;
    short s1;
    float y;
    char c1;
};
```



```
sizeof (struct b) == 16
```

```
struct c {
    int x;
    short s1;
    char c1;
    float y;
};
```



```
sizeof (struct c) == 12
```

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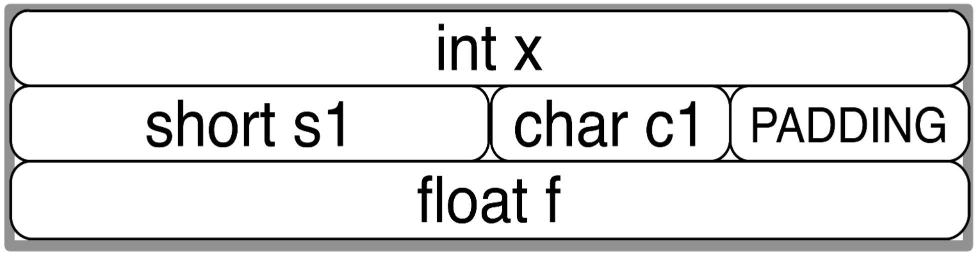
Memory alignment

- Address of a struct variable will give us direct access to bytes of the first members
  - Alignment depends on architecture
  - Special compiler extensions can be used to prevent padding
  - h/w speed/memory

```
struct c {
    int x;
    short s1;
    char c1;
    float y;
};
```



```
sizeof (struct c) == 12
```

Unions

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Unions

› Sometimes we want several field variants within a structure but don’t want to consume more memory

› the C *union* lets you declare multiple fields that occupy the **same** memory

Example

- A library catalogue that contains information about books and films
- for books we want to store:
  - author
  - ISBN
- for films we want to store:
  - director
  - producer

Solution 1

```
enum holding_type {book, film};
struct catalog
{
        char *  title;
        enum holding_type type;
        struct /* book */
        {
                char * author;
                char *  ISBN;
        } book_info;
        struct /* film */
        {
                char *  director;
                char *  producer;
        } film_info;
};
```

How many bytes total?

only one of the structures **book_info** or **film_info** is used at any one time.

this can be a major waste of memory

First Solution

- in the first solution, only one of the structures book_info or film_info is used at any one time.
- this can be a major waste of memory
- instead, we can use a *union* to indicate that each variant occupies the **same** memory area

Solution 2

```
enum holding_type {book, film};
struct catalog
{
        char *   title;
        enum holding_type type;
        union
        {
                struct /* book */
                {
                        char * author;
                        char *   ISBN;
                } book_info;

                struct /* film */
                {
                        char *   director;
                        char *   producer;
                } film_info;
        } info;
};
```

we can use a *union* to indicate that each variant occupies the **same** memory area

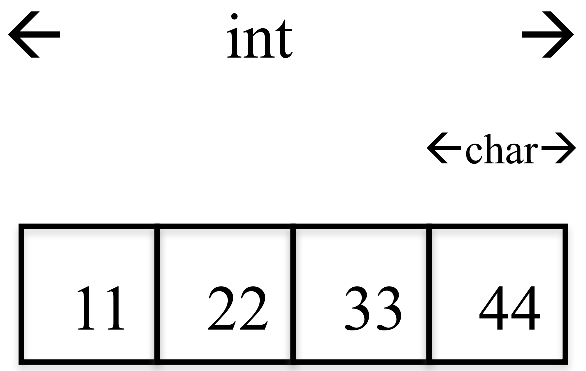
Access

› to access elements of a union we use the notation
`union_name.part_name`

› example:

```
union
{
        int     a;
        char    b;
} x;

x.a = 0x11223344;
```

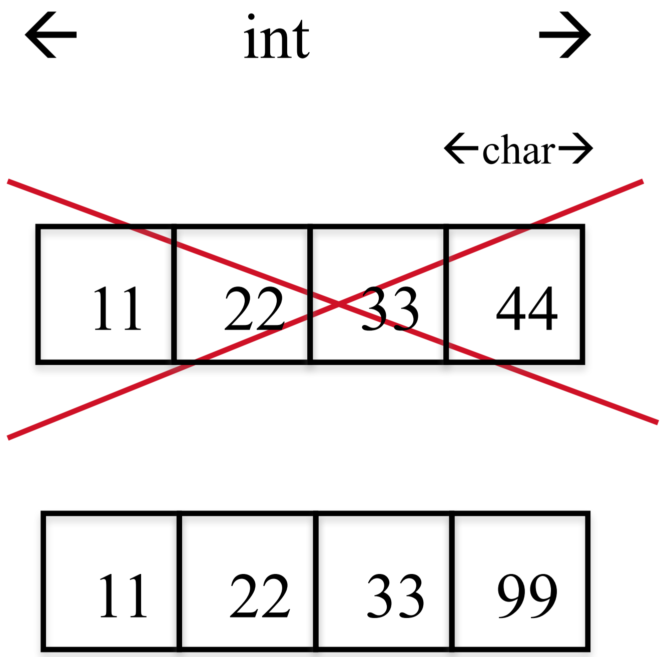


Access

- to access elements of a union we use the notation
  `union_name.part_name`
- example:

```
union
{
        int     a;
        char    b;
} x;

x.a = 0x11223344;
x.b = 'c';
```



Access

› in our example, we would access the author this way:

```
struct catalog x;

x.info.book_info.author
```

Access

- How can you tell what variant of the union is being used?

- Answer: you can’t!

-

Access Example

an enum that indicates the variant

```
struct catalog x;

switch (x.holding_type)
{
    case book:
            printf("author: %s\n", x.info.book_info.author);
            break;
    case film:
            printf("producer: %s\n", x.info.film_info.producer);
            break;
}
```

Bitfields

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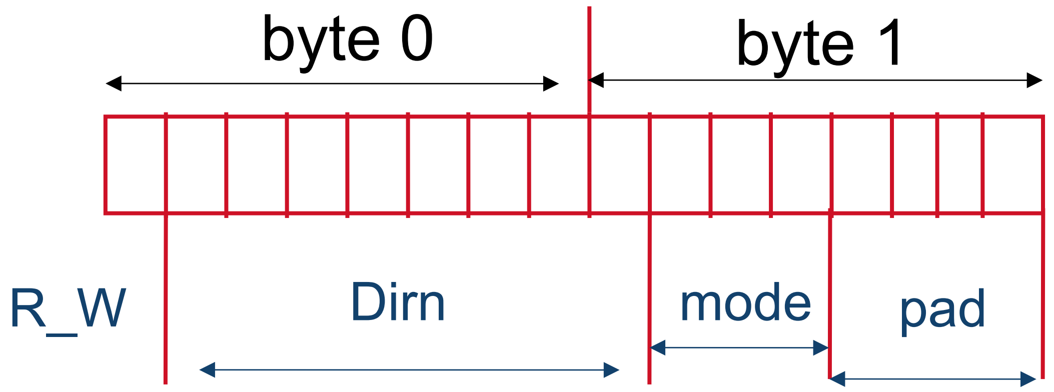
Bit fields

- for some specialised applications you need data fields that are smaller than a byte or are packed into several bytes



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Bit Fields

› can specify a size, in bits, for elements of a structure

› the size is placed after the field name, with a colon between:

```
struct IOdev
{
        unsigned R_W: 1;
        unsigned Dirn: 8;
        unsigned mode: 3;
};
```

this variable occupies only 3 bits

```
struct IOdev
{
        unsigned R_W: 1;
        unsigned Dirn: 8;
        unsigned mode: 3;
        unsigned pad: 4;
};

struct IOdev    dev = {1, 0, 7};

void main()
{
        printf("mode = %d\n", dev.mode);
}
```

Bit Fields

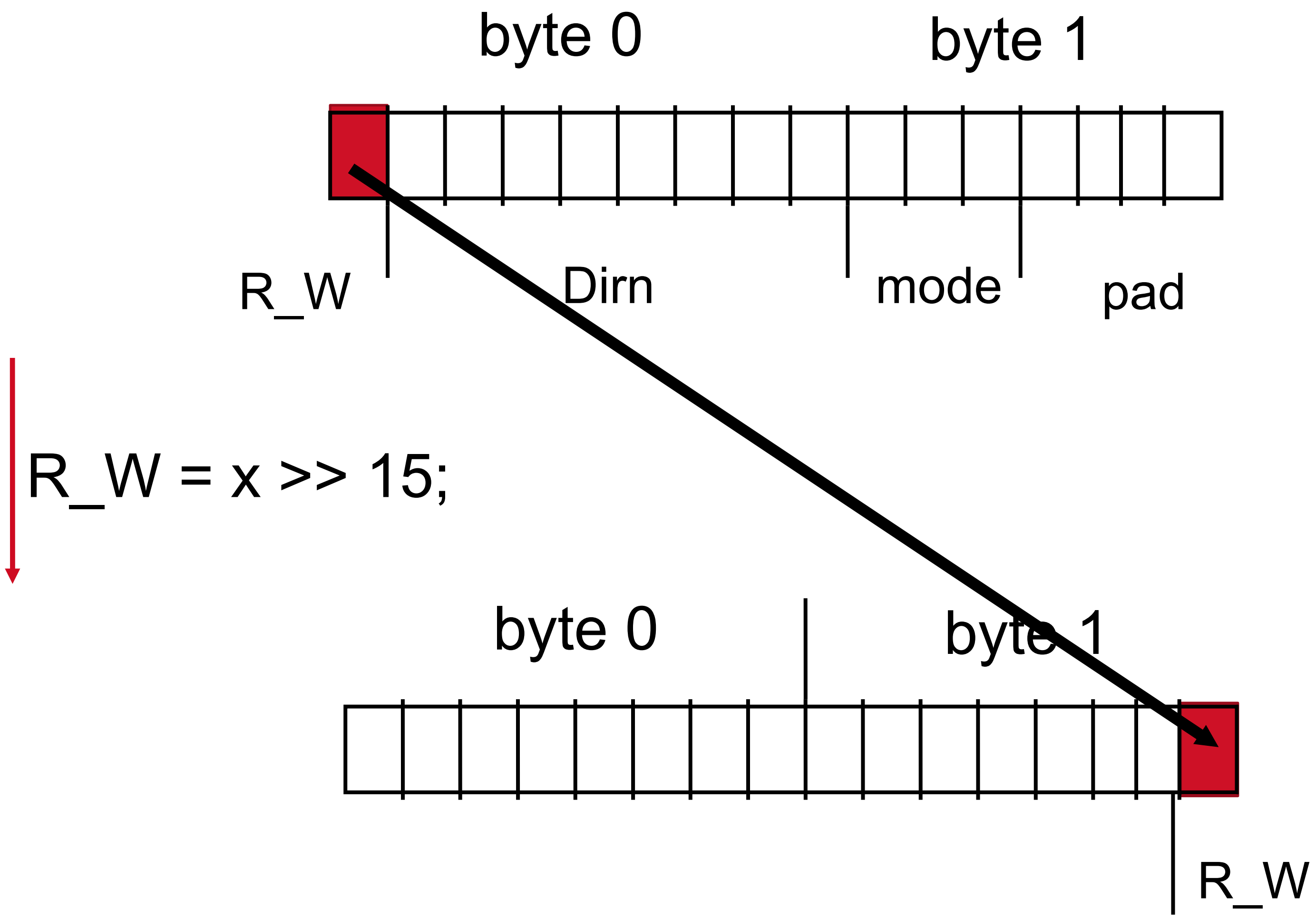
- › bitfields are good for low level programming of device registers (drivers, embedded systems etc)
- › bitfields are good for “unpacking” data structures
- › however bitfields may not be portable
  - padding
  - left-right vs right-left
- › only for experts!

Bit Fields

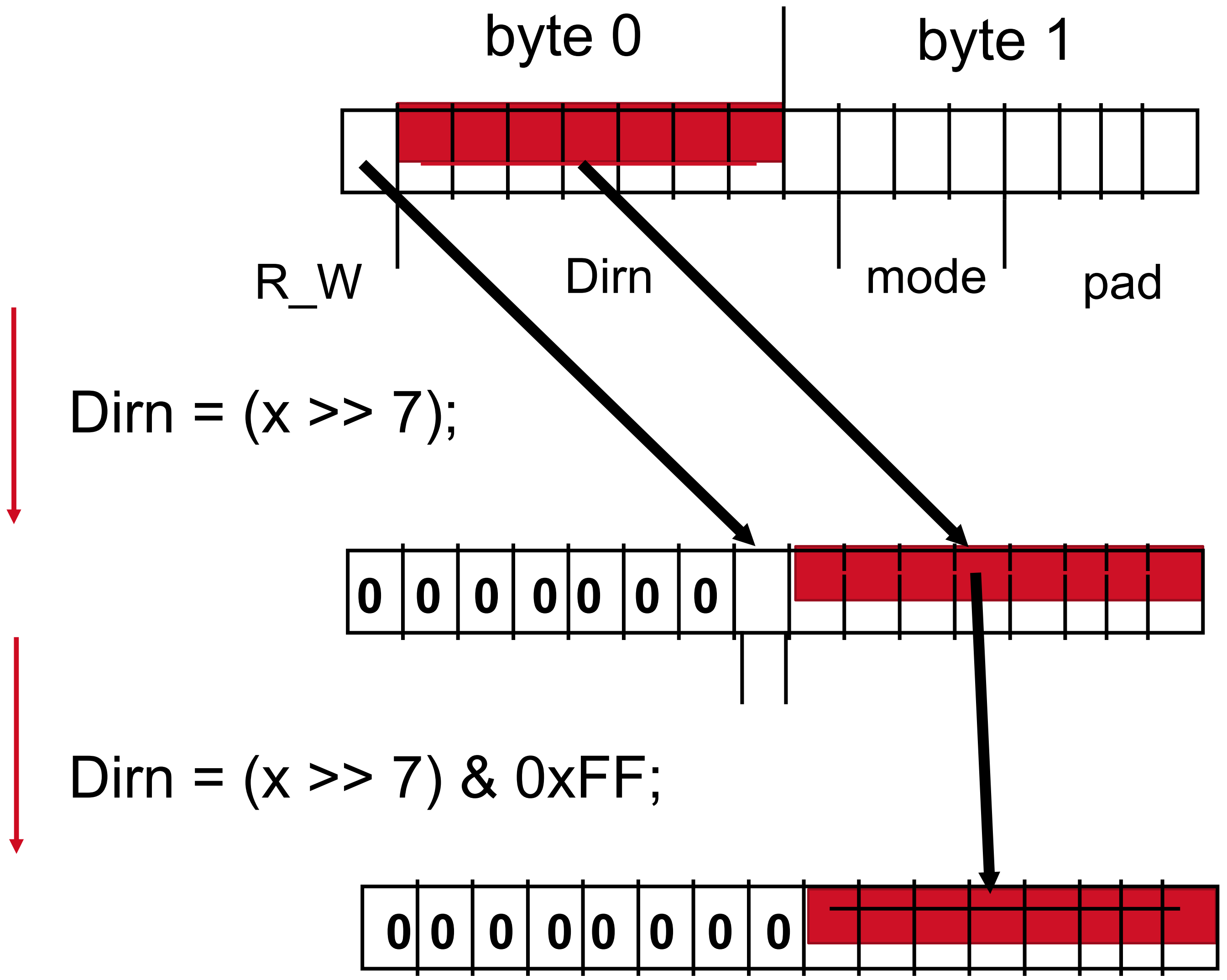
- without using the C bitfield syntax you can still unpack bit fields from data
- use shift and logical operations
- eg assuming previous packing of R_W etc:

```
unsigned short x; /* R_W:1, Dirn:8, mode:3, pad:4 */

R_W = x >> 15;
Dirn = (x >>7) & 0xFF;
mode = (x >> 4) & 0x7;
```



R_W = x >> 15;



```
Dirn = (x >> 7);
```

```
Dirn = (x >> 7) & 0xFF;
```

Bit Operations

- shift right: >>
- shift left: <<
- bitwise AND: &
- bitwise OR: |
- bitwise XOR: ^
- bitwise NOT: ~
  - Not to be confused with logical NOT !

Summary

- bitfields: easy packing/unpacking of short bit fields

- bit operations: shifting and logical

Files in C

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What are files?

› Disk storage peripherals provide persistent storage with a low-level interface
  - Fixed-size blocks
  - Numeric addresses

› Operating system arranges this into an abstraction as files
  - Files can be variable length
  - Files have names, meta-data (owner, last modified date, etc)
  - Files are arranged into eg a tree, by folder/directory structure

› Read or write a file is done through System Calls (APIs)

Files

› Devices are often represented as files
  - software reads/write file to access the device
  - E.g. Send a command to the printer by writing to a particular file name

› If a file can be a physical device, then it is not fixed in size or behaviour.

› A *stream* is associated with a file
  - May support a file position indicator [0, file length] *
  - Can be binary or not (e.g. ASCII, multibyte)
  - Can be open/closed/flushed!
  - Can be *unbuffered, fully buffered* or *line buffered*

Files

- For each file opened, there needs to be a file descriptor

- The descriptor describes the state of the file
  - Opened, closed, position etc.

- **`#include <stdio.h>`**
  - contains many standard I/O functions and definitions for using files

Files

› `FILE` is a struct that is defined in stdio.h and this is the descriptor

› To open a file, we use the `fopen` function

FILE *fopen(const char *path, const char *mode);

filename

```
FILE * myfile = fopen(“turtles.txt”, “w”);
```

variable

mode

path can be relative, or absolute /home/ssta7171/turtles.txt

Files

- `FILE *fopen(...)`
  - modes

r	open text file for reading
w	truncate to zero length or create text file for writing
a	append; open or create text file for writing at end-of-file
rb	open binary file for reading
wb	truncate to zero length or create binary file for writing
ab	append; open or create binary file for writing at end-of-file
r+	open text file for update (reading and writing)
w+	truncate to zero length or create text file for update
a+	append; open or create text file for update, writing at end-of-file

- File versions of your lovable input/output
  - `fscanf`
  - `fprintf`

Binary data use
- `fread`
- `fwrite`

- Finish off with `fclose`

Files

› When your program begin, special files are opened for you:
  - **`stdin, stdout, stderr`**

› You can use these files

`fscanf(stdin, …)` same as **`scanf(…)`**

`fprintf(stdout, …)` same as **`printf(…)`**

› When a stream supports file position, the position is zero
  - Every print/scan operation adjusts the position in the stream
  - Query position **`ftell`**, change position **`fseek`**

* Impl. dependent on append

Files

- For reading input files, e.g. **`stdin`**, the end of file is important
  - **`feof()`** tests the end of file indicator
  - EOF does not happen until trying to read beyond end of stream

```
while ( ! feof(stdin) ) {
    int num;
    fscanf(stdin, "%d", &num);
    fprintf(stdout, "num: %d\n", num);
}

$ ./printnum < twonum.txt
```

Files

- For reading input files, e.g. **`stdin`**, the end of file is important
  - **`feof()`** tests the end of file indicator
  - EOF does not happen until trying to read beyond end of stream

```
while ( ! feof(stdin) ) {
    int num;
    fscanf(stdin, "%d", &num);
    fprintf(stderr, "num: %d\n", num);
}
```

```
while ( ! feof(stdin) ) {
    int num;
    int nread = fscanf(stdin, "%d", &num);
    if (nread <= 0)
        break;
    fprintf(stdout, "num: %d\n", num);
}
```

Files

- unbuffered – input/output is passed on as soon as possible
- fully buffered – input/output is accumulated into a block then passed
- line buffered – the block size is based on the newline character
- Which do you get? Depends.
  - Device driver writers should consider **`setvbuf`** for optimal block size
- **`fflush`**
  - Output stream: force write all data,
  - Input stream: discard any unprocessed buffered data.

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Files fgets

- Many problems with **`fscanf`** with rules about whitespace, newlines or complex format string
- **`fgets`** reads one line of input and returning a string (with the newline character)
  - Use string processing functions to deal with the returned data
- Use **`fgets`** correctly, together with **`feof`** to distinguish read errors vs end of file.
  - it will make life easier
- **`ferror`** when you get that feeling…

fgets example

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

#define BUFLEN (64)

int main(int argc, char **argv) {
  int len;
  char buf[BUFLEN];
  while (fgets(buf, BUFLEN, stdin) != NULL) {
    len = strlen(buf);
    printf("%d\n", len);
  }
  return 0;
}
```

Summary

- struct has similar properties as a statically allocated array, but variable types within

- struct has internal alignment that dictates sizeof()

- struct supports fields that are measured in bits

- union is used to share the same memory area among two or more types

Summary

- Regular files are a special case of a stream
  - abstraction of a stream of contiguous data of fixed length
  - Internal memory and buffering are managed f*() functions
  - End of file is a test dependent on the internal data structure of FILE
  - Buffer + parsing reads fgets() preferred over direct stream processing fscanf()