CHAPTER 4

GETTING THE MOST OUT OF C

Basic Names for Integer Types: *char* and *int*

- *unsigned*, *signed*, *short*, and *long* are modifiers (adjectives).
- If one or more modifiers is used, *int* is assumed and may be omitted.
- If neither *signed* or *unsigned* is used, *signed* is assumed and may be omitted.
- *int* with no modifier is a data type whose size varies among compilers.

Integer Data Types

Data Type		*Size*	*Range*
unsigned	char	8 bits	0 to 255
	short int	16 bits	0 to 65,535
	int	16 or 32 bits	*16 bits: same as unsigned short int;* *32 bits: same as unsigned long int.*
	long int	32 bits	0 to 4,294,967,295
signed	char	8 bits	-128 to +127
	short int	16 bits	-32,768 to +32,767
	int	16 or 32 bits	*16 bits: same as signed short int;* *32 bits: same as signed long int.*
	long int	32 bits	-2,147,483,648 to +2,147,483,647

Mixing Signed & Unsigned Integers

Always TRUE or always FALSE?

```
unsigned int u ;

...

if (u > -1) ...
```

The constant -1 is signed, but when combined with an unsigned, the bit pattern used to represent –1 is interpreted as unsigned with a full-scale value! Thus regardless of the value in ‘u’, the condition will always be

Minimum and Maximum Integer Values defined in LIMITS.H

Data Type	Minimum	Maximum
signed char	SCHAR_MIN	SCHAR_MAX
signed short int	SHRT_MIN	SHRT_MAX
signed long int	LONG_MIN	LONG_MAX
signed long long int	LLONG_MIN	LLONG_MAX
unsigned char	0	UCHAR_MAX
unsigned short int	0	USHRT_MAX
unsigned long int	0	ULONG_MAX
unsigned long long int	0	ULLONG_MAX

Contents of ANSI File (limits.h)

Notice anything odd?

```
#define SCHAR_MIN     -127
#define SCHAR_MAX     127

#define SHRT_MIN      -32767
#define SHRT_MAX      32767

#define INT_MIN       -2147483647
#define INT_MAX       2147483647

#define LONG_MIN      -2147483647
#define LONG_MAX      2147483647
```

1999 ISO (C99) New Data Types

#include <stdint.h>

	Signed	Unsigned
8-bits	int8_t	uint8_t
16-bits	int16_t	uint16_t
32-bits	int32_t	uint32_t
64-bits	int64_t	uint64_t

Note: If your compiler doesn’t already provide these data types, you can create your own using typedefs.

If Your Compiler Doesn’t Support C99

```
#ifndef __STDC_VERSION__

typedef signed    char          int8_t   ;
typedef signed    short int         int16_t  ;
typedef signed    long int          int32_t  ;
typedef signed    long long int     int64_t  ;

typedef unsigned  char          uint8_t  ;
typedef unsigned  short int     uint16_t ;
typedef unsigned  long int          uint32_t ;
typedef unsigned  long long int   uint64_t ;

#endif
```

Using #defines to simplify changes

```
#define ENTRIES(a)
(sizeof(a)/sizeof(a[0]))

unsigned counts[100] ;


for (i = 0; i < 100; i++) ...
```

```
for (i = 0; i < ENTRIES(counts); i+
+) ...
```

Careful: #define is text substitution!

```
#define SUM(a, b)  a + b

y = 5 * SUM(t1, t2) ;
```

Becomes...

```
y = 5 * t1 + t2 ;
```

```
#define  TIMES(a, b)  (a * b)

y = TIMES(t1-2, t2+3) ;
```

Becomes...

```
y = (t1 – 2 * t2 + 3) ;
```

C99 Boolean Data Type

#include
<stdbool.h>

```
#define bool   _Bool        // New C99 data type
#define false  ((_Bool) 0)
#define true   ((_Bool) 1)
```

Other Alternative Booleans

```
#ifndef __STDC_VERSION__
#define bool unsigned char       // using macros
#define false 0
#define true 1
#endif

#ifndef __STDC_VERSION__
typedef unsigned char bool ;          // using unsigned char's
const unsigned char false = 0 ;
const unsigned char true = 1 ;
#endif

#ifndef __STDC_VERSION__
typedef enum {false = 0, true = 1} bool ;  // using an
enumerated type
#endif
```

Boolean Values

- Most implementations of C don't provide a Boolean data type.
- Boolean operators yield results of type *int*, with true and false represented by 1 and 0.
- Any numeric data type may be used as a Boolean operand.
- Zero is interpreted as false; any non-zero value is interpreted as true.

Boolean Expressions

```
(5 || !3) && 6
```

= (true OR (NOT true)) AND true

= (true OR false) AND true

= (true) AND true

= true

= 1

Boolean and Binary Operators

Operation	Boolean Operator	Bitwise Operator
AND	&&	&
OR	||	|
XOR	*unsupported*	^
NOT	!	~

- Boolean operators are primarily used to form conditional expressions (as in an *if* statement)
- Bitwise operators are used to manipulate bits.

Bitwise Operators

- Bitwise operators operate on individual bit positions within the operands
- The result in any one bit position is entirely independent of all the other bit positions.

Bitwise Expressions

(5 | ~3) & 6

= (00..0101 OR ~00..0011) AND 00..0110

= (00..0101 OR 11..1100) AND 00..0110

= (11..1101) AND 00..0110

= 00..0100

= 4

Packed Operands

MS/DOS packed representation of time.

7	6	5	4	3	2	1	0
Carrier Detect	Ring Indicator	Data Set Ready	Clear To Send	Δ Carrier Detect	Ring Indicator	Δ Data Set Rdy	Δ Clear To Send

UART modem status port

7	6	5	4	3	2	1	0
Reserved	Reserved	Reserved	Enable IRQ	Select Printer	Initialize Printer	Auto LineFeed	Data Strobe

IBM-PC printer control port

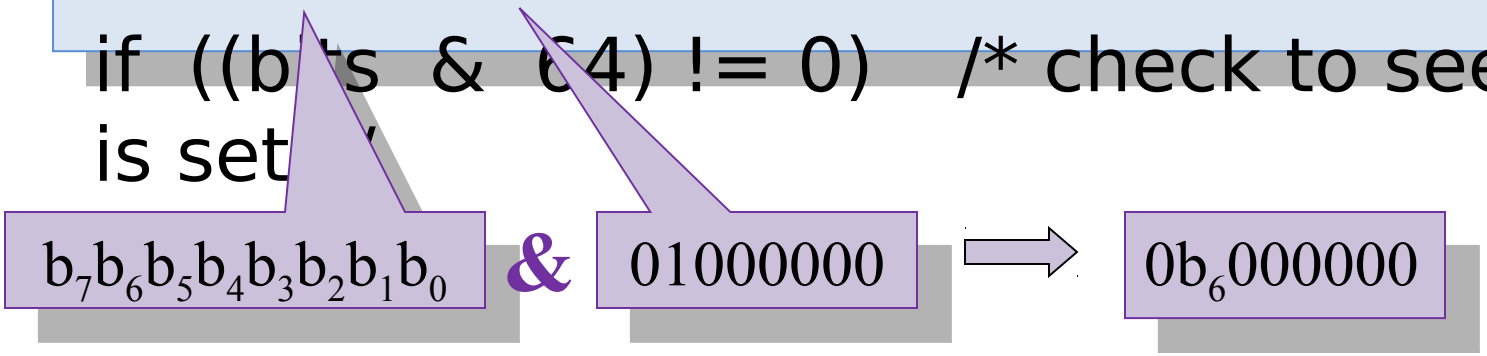
Interpreting the Bitwise-AND

m	p	m AND p		Interpretation
0	0	0	0	If bit *m* of the mask is 0, bit *p* is **cleared to 0** in the result.
	1	0		
1	0	0	p	If bit *m* of the mask is 1, bit *p* is passed through to the result **unchanged**.
	1	1		

Testing Bits

- A 1 in the bit position of interest is AND'ed with the operand. The result is non-zero if and only if the bit of interest was 1:

```
if ((bits & 64) != 0)   /* check to see if bit 6 is set */
```



Testing Bits

- Since any non-zero value is interpreted as *true*, the redundant comparison to zero may be omitted, as in:

```
if  (bits & 64)  /* check to see if bit 6 is
   set */
```

Testing Bits

- The mask (64) is often written in hex (0x0040), but a constant-valued shift expression provides a clearer indication of the bit position being tested:

```
if  (bits & (1 << 6)) /* check to see if bit 6 is set
    */
```

- Almost all compilers will replace such constant-valued expressions by a single constant, so using this form almost never generates any additional code.

Clearing Bits

- Clearing a bit to 0 is accomplished with the bitwise-AND operator:

```
bits &= ~(1 << 7) ;   /* clears bit 7
   */
```

```
(1 << 7)     ⇒ 10000000

~(1 << 7)    ⇒ 01111111
```

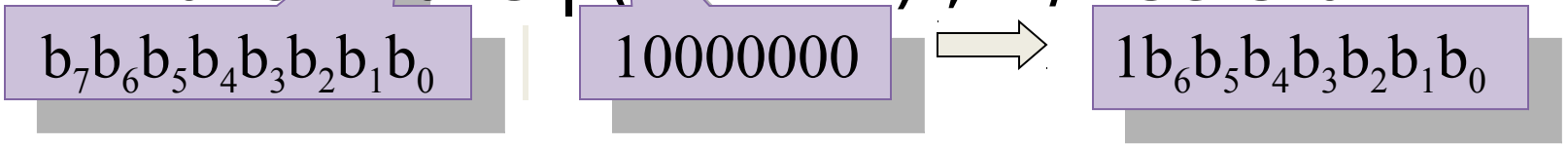
Interpreting the Bitwise-OR

m	p	m OR p		Interpretation
0	0	0	p	If bit *m* of the mask is 0, bit *p* is passed through to the result **unchanged**.
	1	1		
1	0	1	1	If bit *m* of the mask is 1, bit *p* is **set to 1** in the result.
	1	1		

Setting Bits

- Setting a bit to 1 is easily accomplished with the bitwise-OR operator:

```
bits = bits | ( 1 << 7 ) ;   /* sets bit 7
```



- This would usually be written more succinctly as:

```
bits |= (1 << 7);          /* sets bit
```

Interpreting the Bitwise-XOR

m	p	m XOR p		Interpretation
0	0	0	p	If bit *m* of the mask is 0, bit *p* is passed through to the result **unchanged**.
	1	1		
1	0	1	~p	If bit *m* of the mask is 1, bit *p* is passed through to the result **inverted**.
	1	0		

Inverting Bits

- Inverting a bit (also known as toggling) is accomplished with the bitwise-XOR operator as in:

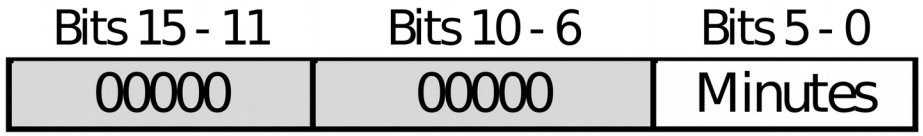
```
bits  ^=  (1 << 6) ;    /* flips bit 6 */
```

Extracting Bits

time

time >>5

(time >>5) & 0x3F

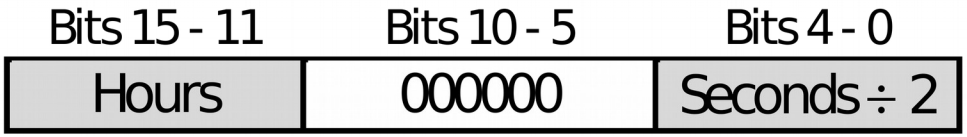


minutes =(time >>5) & 0x3F

Inserting Bits

oldtime

newtime = oldtime & ~(0x3F << 5)



newtime |= (newmins & 0x3F) << 5

Automatic Insertion and Extraction Using Structure Bit Fields

```
struct {
   uint16_t   seconds   :5 ,   /* secs divided
   by 2 */     minutes   :6 ,
              hours     :5 ;
} time ;

time.hours = 13 ;
time.minutes = 34 ;
time.seconds = 18 / 2 ;
```

Leave the insertion (or extraction) problems to the compiler!

Packed Structures

```
#pragma pack(1)// turn off structure padding
typedef struct // This structure occupies 6 bytes
   {
   uint8_t   a ; // 1 byte (would otherwise pad to 4 bytes)
   uint32_t b ; // 4 bytes
   uint8_t   c ; // 1 byte (would otherwise pad to 4 bytes)
   } ;
#pragma pack()   // turn on structure padding
```

Pros/Cons of Structure Bit-Fields

Pros:

- Cleaner syntax
- Fewer lines of C code
- Easier to read
- Compiles into bitwise operations

Cons:

- No standard regarding left-to-right vs. right-to-left Bit-Field assignment

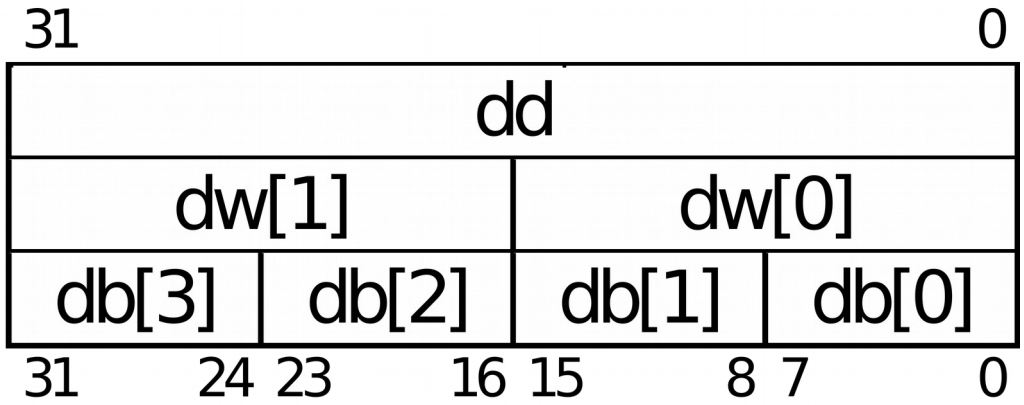
Variant Access with Pointers, Casts, & Subscripting

- Given an address, we can cast it as a pointer to data of the desired type, then dereference the pointer by subscripting.
- Without knowing the data type used in its declaration, we can read or write various parts of an object named *operand* using:

```
((uint8_t *) &operand)[k]
```

Variant Access with Unions

```
union {
   uint32_t    dd;
   uint16_t    dw[2];
   uint8_t     db[4];
};
```



Variant Access vs. Unions

Both:

- Bit-fields must lie on byte boundaries

Variant Access:

- Syntax is somewhat complex.
- No union declaration required.

Unions:

- Cleaner syntax
- Easier to read
- Compiles into variant access code

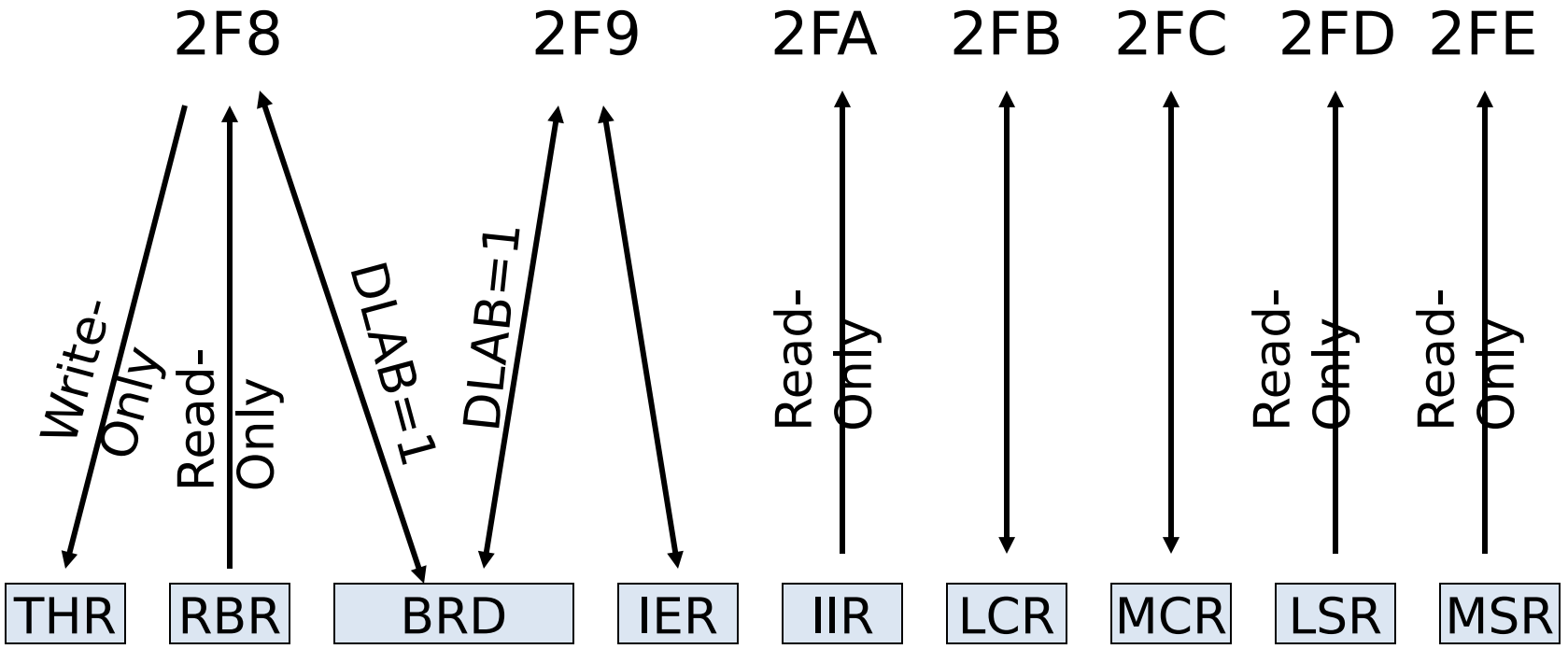
Manipulating Bits in I/O Ports

- I/O ports must be accessed using functions.
- It is often common for I/O ports to be either read-only or write-only.
- It is often common for several I/O ports to be assigned to a single I/O address.

I/O Addresses Used by One of the IBM/PC Serial Ports.

Addr.	DLAB	Restriction	Description
02F8	0	Write-Only	Transmitter holding register (holds character to be sent)
	0	Read-Only	Receiver buffer register (contains the received character)
	1		Least significant byte of baud rate divisor latch
02F9	1		Most significant byte of baud rate divisor latch
	0		Interrupt enable register
02FA	n/a	Read-Only	Interrupt ID register
02FB	n/a		Line control register *(Bit 7 is the DLAB bit)*
02FC	n/a		Modem control register
02FD	n/a	Read-Only	Line status register
02FE	n/a	Read-Only	Modem status register
02FF	n/a		Reserved

I/O Addresses Used by One of the PC Serial Ports.



Modifying Bits in Write-Only I/O Ports

- The read-modify-write techniques presented earlier for manipulating bits can’t be used.
- Solution: Keep in memory a copy of the last bit-pattern written to the port. Apply the read-modify-write techniques to the memory copy, and then write that value to the port.

Sequential Access to I/O Ports

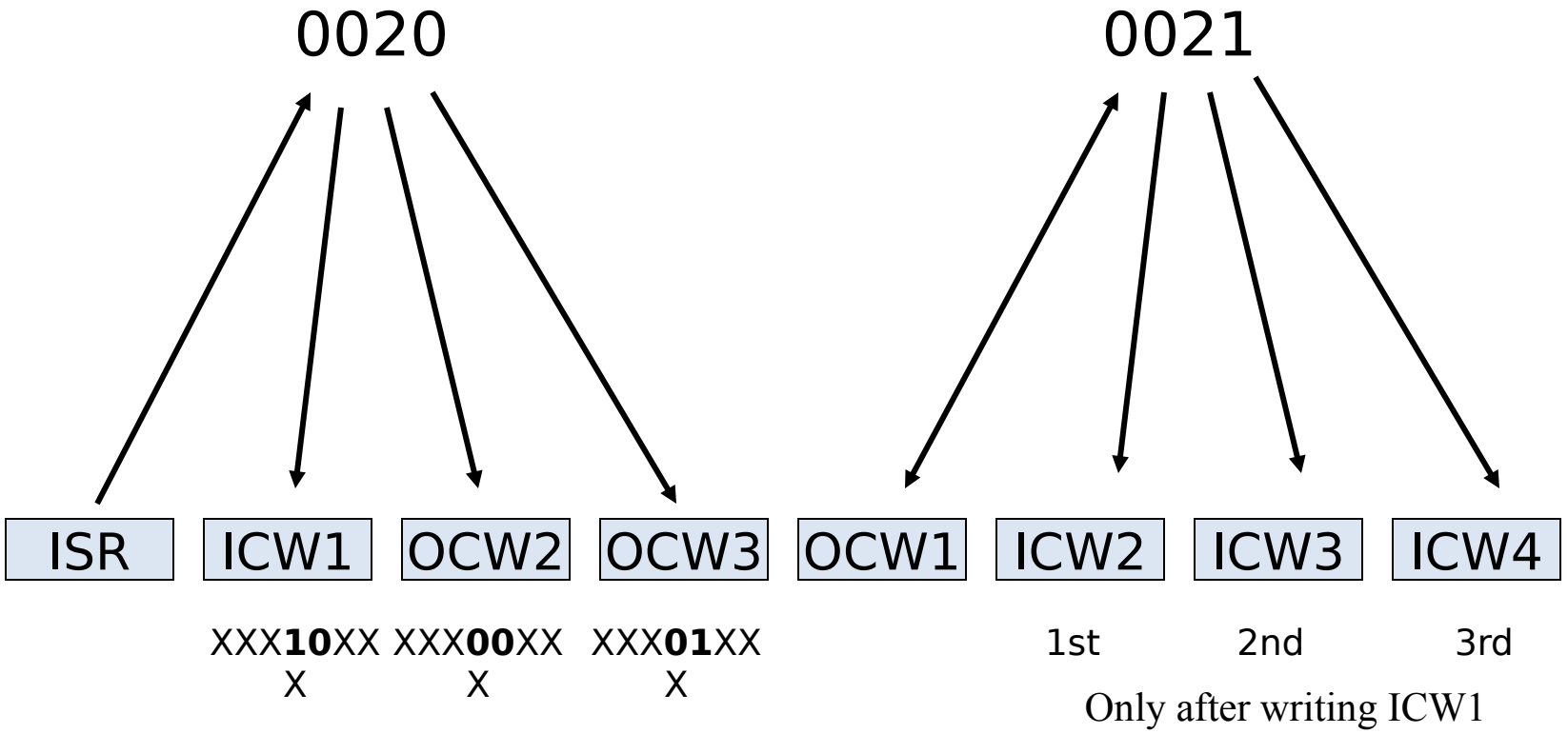
- Sometimes multiple read-only ports assigned to one address are distinguished by the *order* in which the data is read.

- Multiple write-only ports assigned to one address can also be distinguished by order, or by the *value* of specific bits in part of the data that is written.

I/O Ports of the 8259 Programmable Interrupt Controller.

Addr.	Data	Restriction	Description
0020		Read-Only	Interrupt request or in-service register
	xxx**1**xxxx	Write-Only	Initialization command word 1 (**ICW1**)
	xxx**00**xxx	Write-Only	Operation Control Word 2
	xxx**01**xxx	Write-Only	Operation Control Word 3
0021			Operation Control Word 1 (Interrupt mask register)
		Write-Only	**ICW2, ICW3, ICW4 (in order, only just after writing ICW1)**
0022-003F			Reserved

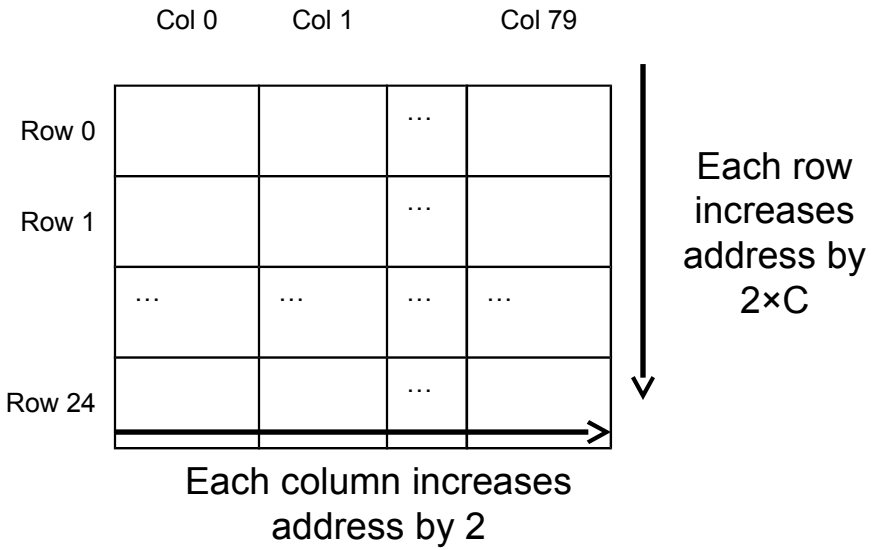
I/O Ports of the 8259 Interrupt Controller in the IBM/PC.



Accessing a Display Buffer

Display buffer memory starts at address $B8000_{16}$.

Each cell contains 2 bytes: ASCII code and an attribute byte




```
uint8_t *p = (uint8_t *) 0xB8000
       + 2 * (80 * row + col) ;

*(p + 0) = ascii_code ;
*(p + 1) = attribute_bits ;

        -- or --

p[0] = ascii_code ;
p[1] = attribute_bits ;

        -- or --

typedef uint_8  CELL[2] ;
typedef CELL ROW[80] ;
ROW *buffer = (ROW *) 0xB8000 ;

buffer[row][col][0] = ascii_code ;
buffer[row][col][1] = attribute_bits ;
```