Lecture 4: Bitwise Operations

(CPEG323: Intro. to Computer System Engineering)

Bit Operators (I)

unsigned char a = 0x55; 0 1 0 1 0 1 0 1 remember hexadecimal?

unsigned char b = 0x0f; 0 0 0 0 1 1 1 1

Bit-wise Logical Operators (in C, C++, Java, many other languages)

unsigned char c = a | b; *(bit-wise OR)*

```
    0 1 0 1  0 1 0 1
OR  0 0 0 0  1 1 1 1
-------------------
    0 1 0 1  1 1 1 1
```

unsigned char d = a & b; *(bit-wise AND)*

```
    0 1 0 1  0 1 0 1
AND 0 0 0 0  1 1 1 1
-------------------
    0 0 0 0  0 1 0 1
```

unsigned char e = a ^ b; *(bit-wise XOR)*

```
    0 1 0 1  0 1 0 1
XOR 0 0 0 0  1 1 1 1
-------------------
    0 1 0 1  1 0 1 0
```

unsigned char n = ~a; *(bit-wise NOT)*

```
NOT 0 1 0 1  0 1 0 1
-------------------
    1 0 1 0  1 0 1 0
```

exclusive or: one or the other, but not both nor neither

Bit-wise Arithmetic 1

```
int a = 5;
int g = a | 3;
```

What is g ?

1) 0x5
2) 0x7
3) 0x8
4) 0x12

Bit-wise Arithmetic 2

```
int b = -7;
int j = b & 0xf;
```

What is j ?

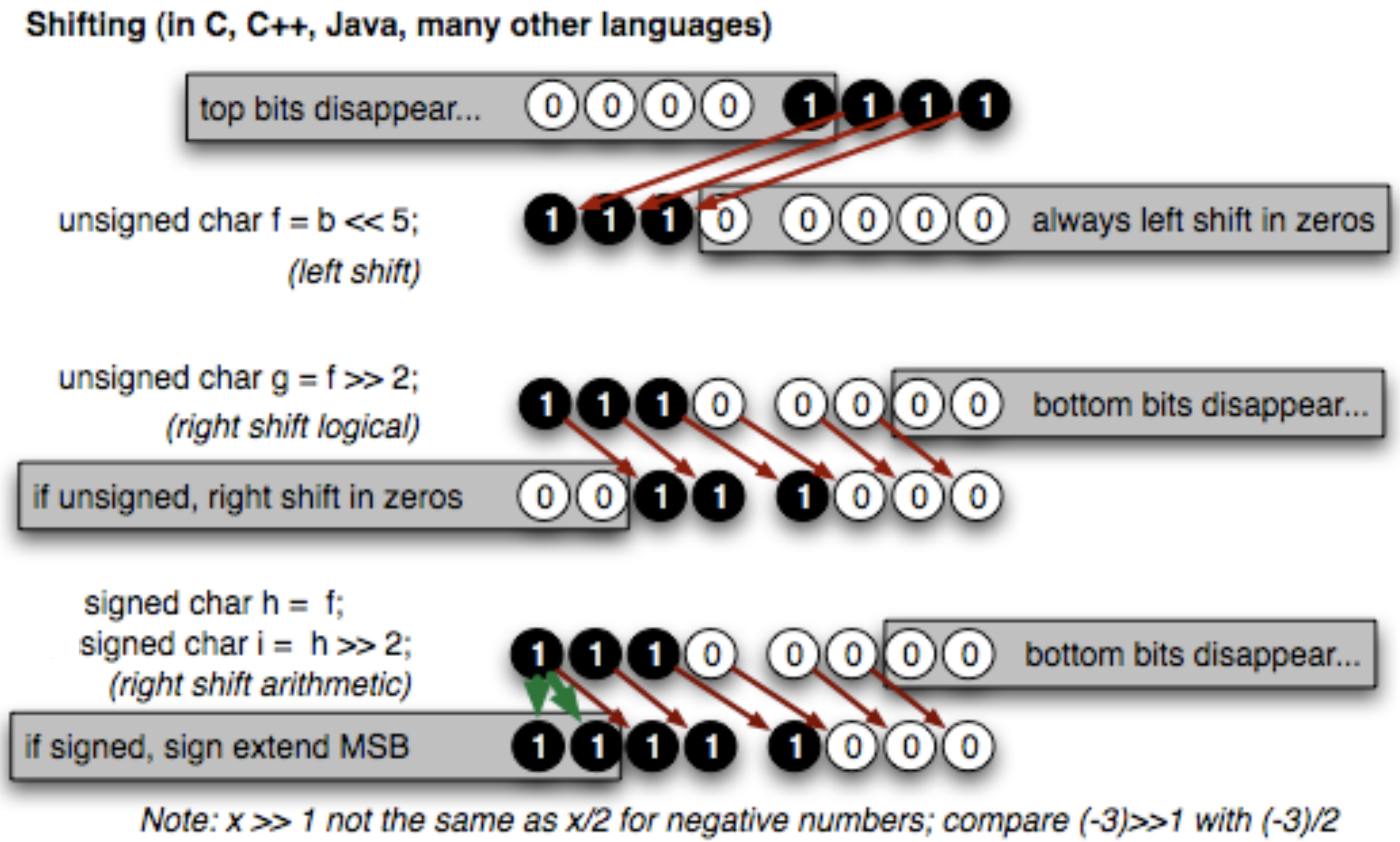
1) 0x7

2) 0x9

3) 0xa

4) 0xf

Bit Operators (II)



Bit-wise Arithmetic 3

```
int a = 5 (0000 0101);
int f = a << 2;
```

What is f?

1)0x10

2)0x12

3)0x14

4)0x07

Bit-wise Arithmetic 4

```
int b = -7 (1111 … 1001);
int h = b >> 2;
```

What is contained in h ?

1)0

2)-1

3)-2

4)-5

Bit-wise Arithmetic 5

```
int b = -7 (1111 ··· 1001);
int h = b >> 2;
int i = ((unsigned)b) >> 2;
```

Which is true ?

1)h > i

2)h == i

3)h < i

Low-level Programming in “High-level” Languages

- **Very often it is necessary to store a large number of very small data items.**

Low-level Programming in "High-level" Languages

- Very often it is necessary to store a large number of very small data items.

- Example: A Social Security Number (SSN) registry
  - Needs to keep track of which SSNs have already been allocated.
- Assume there are 10^9 possible SSN numbers, how much space is required?

Storing collections of bits as integers

- Store N SSN's in each N-bit integer, only need 10^9/N integers
  - Requires 125 megabytes : Around the size of a music album!
- Allocate array:

  int array_size = 1000000000/____________ size of an integer in bits

  unsigned int SSN_registry[array_size];

01000110011111010111010100101001
11011101011010010001010100101011
10010101111010010101100100100010
10010101010101100101010010110010
10010101000101011001010111111101
00001000010111001100100011110101
01101011101001010001000000101011

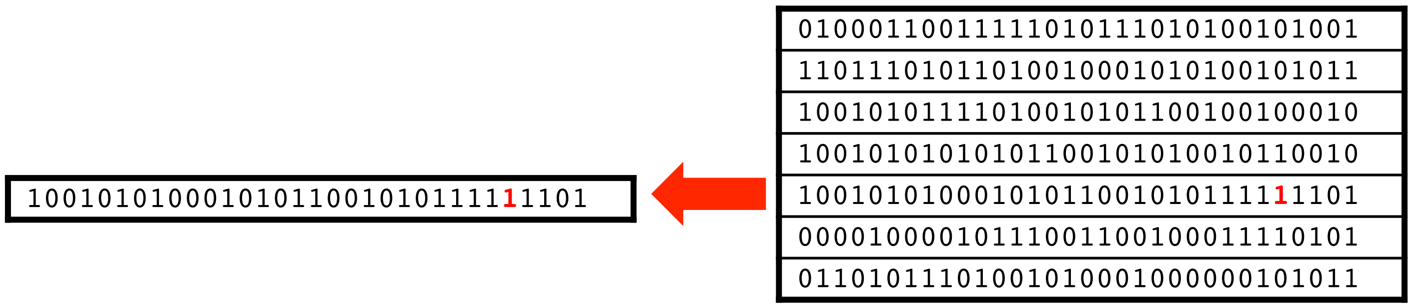
- Want two operations on this array:
  - check_SSN: returns 1 if SSN is used, 0 otherwise
  - set_SSN: marks an SSN as used.

SSN #7

SSN #68

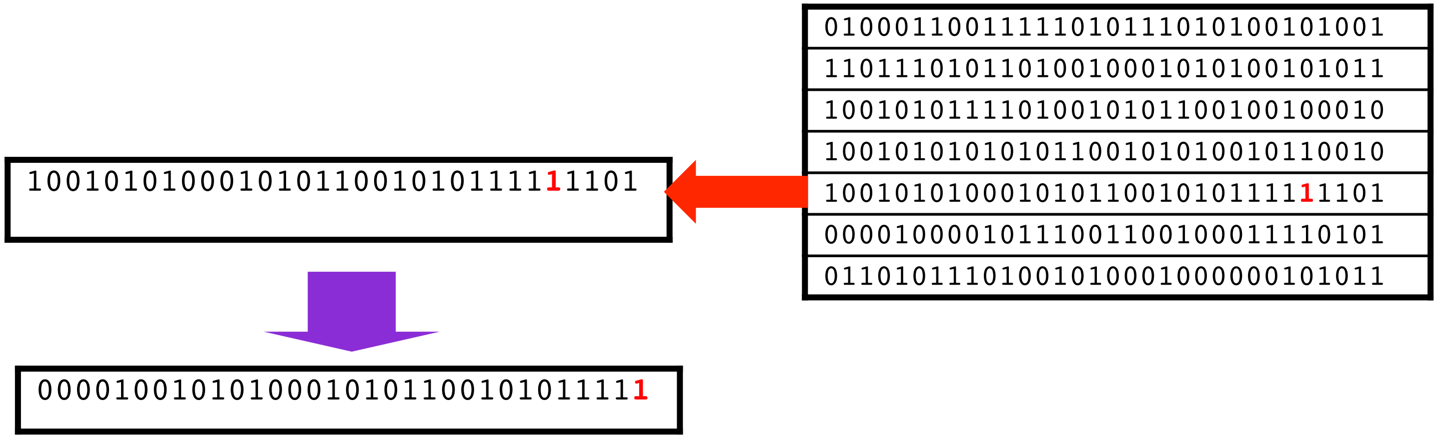
check_SSN

```
int check_SSN(unsigned int SSN_registry[], int ssn) {
    int word_index = ssn / (8*sizeof(int));
    unsigned int word = SSN_registry[word_index];
```



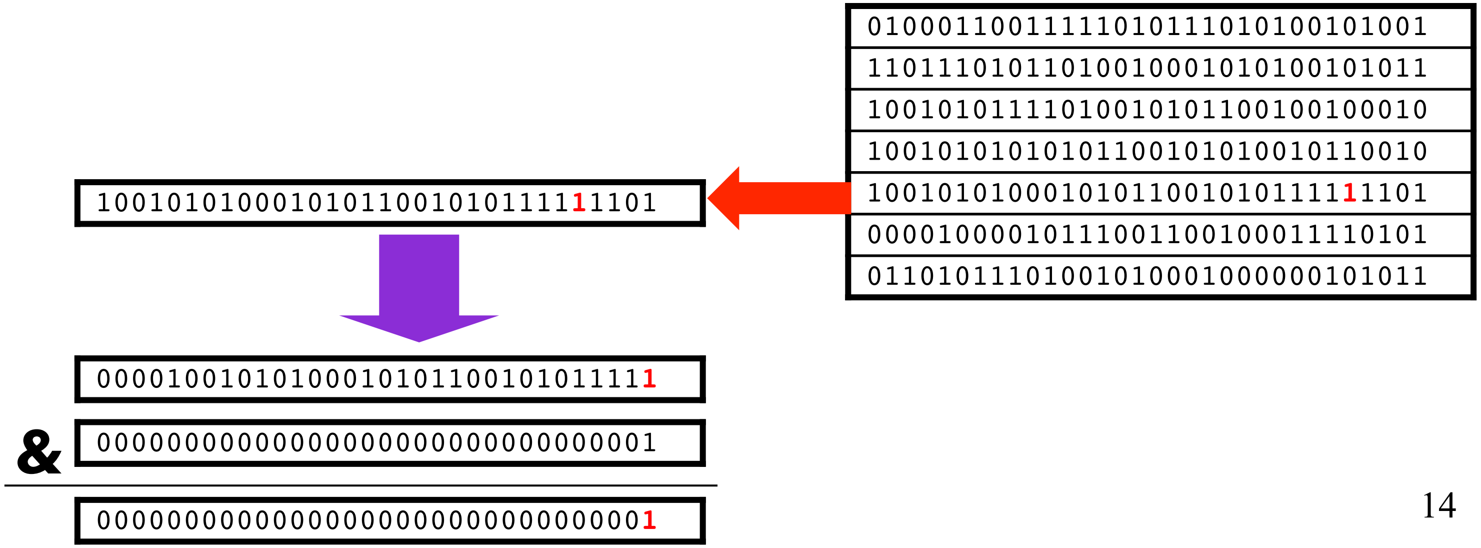
check_SSN

```
int check_SSN(unsigned int SSN_registry[], int ssn) {
    int word_index = ssn / (8*sizeof(int));
    unsigned int word = SSN_registry[word_index];
    int bit_offset = ssn % (8*sizeof(int)) // % is the remainder operation
    word = word >> bit_offset;  // >> shifts a value “right”
        (note: zeros are inserted at the left because it is an unsigned int)
```



check_SSN

```
int check_SSN(unsigned int SSN_registry[], int ssn) {
    int word_index = ssn / (8*sizeof(int));
    unsigned int word = SSN_registry[word_index];
    int bit_offset = ssn % (8*sizeof(int))
    word = word >> bit_offset;
    word = (word & 1);  // & is the bit-wise logical AND operator
    return word;           (each bit position is considered independently)
}
```



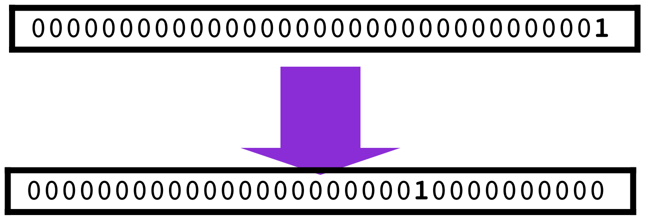
set_SSN

void set_SSN(unsigned int SSN_registry[], int ssn) {

int bit_offset = ssn % (8*sizeof(int))

int new_bit = (1 << bit_offset) // “left” shift the 1 to the desired spot

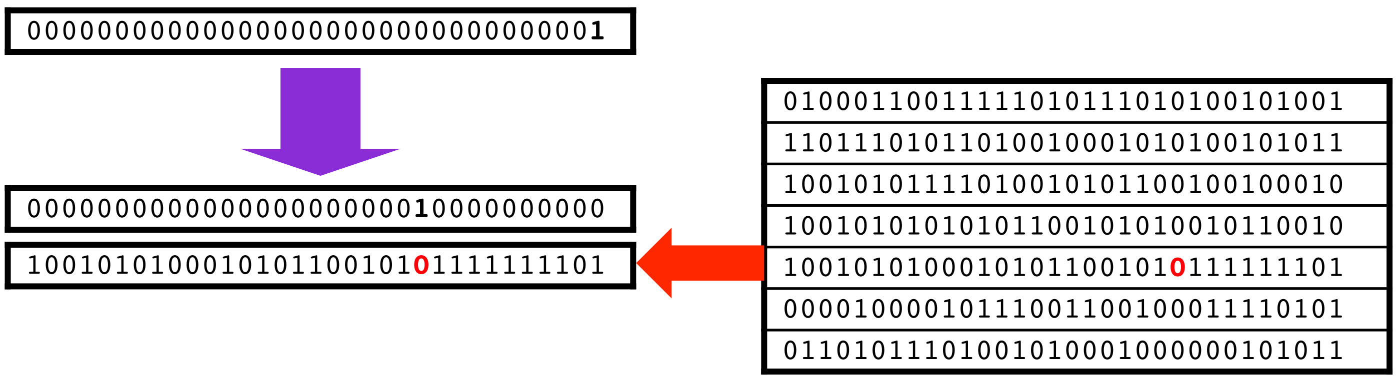
(always shifts in 0’s at the right)



01000110011111010111010100101001
11011101011010010001010100101011
10010101111010010101100100100010
10010101010101100101010010110010
1001010100010101100101**0**111111101
00001000010111001100100011110101
01101011101001010001000000101011

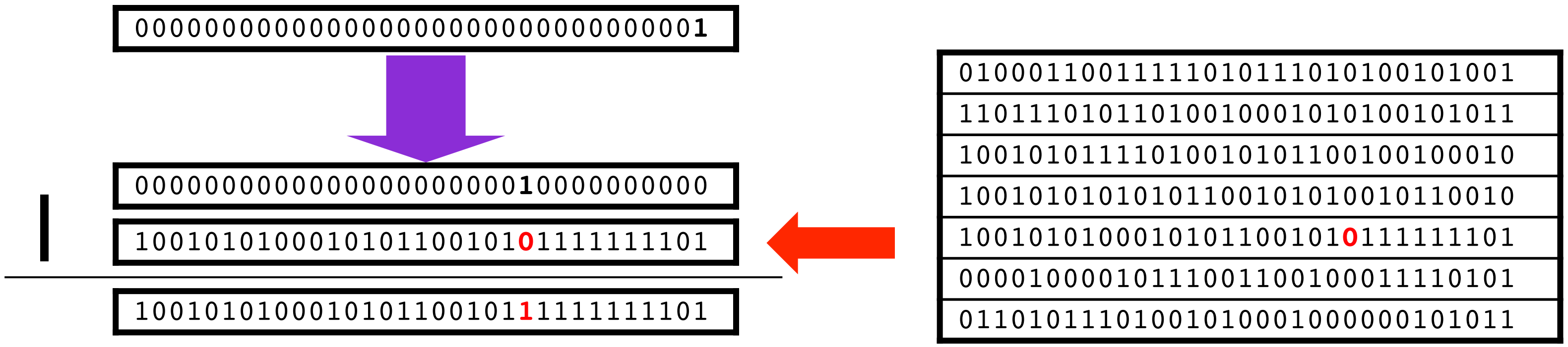
set_SSN

```
void set_SSN(unsigned int SSN_registry[], int ssn) {
    int bit_offset = ssn % (8*sizeof(int))
    int new_bit = (1 << bit_offset)
    int word_index = ssn / (8*sizeof(int));
    int word = SSN_registry[word_index];
```



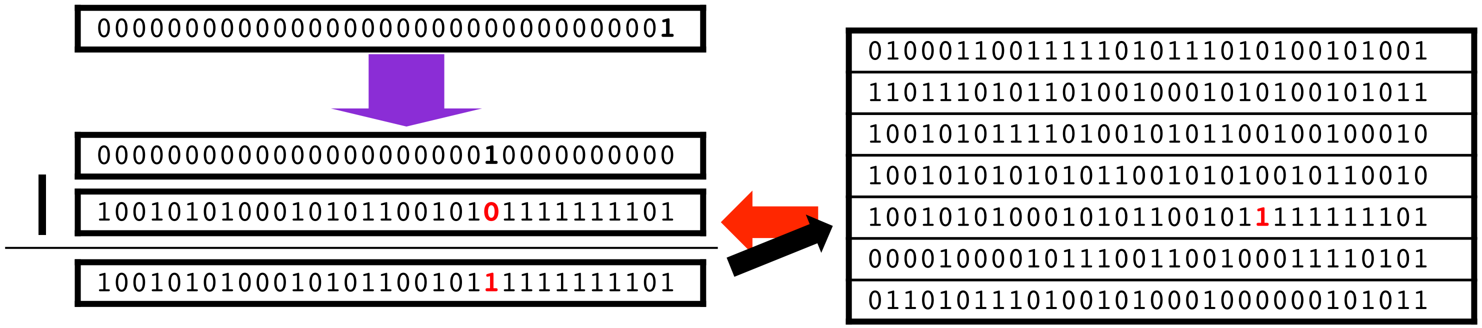
set_SSN

```
void set_SSN(unsigned int SSN_registry[], int ssn) {
    int bit_offset = ssn % (8*sizeof(int))
    int new_bit = (1 << bit_offset)
    int word_index = ssn / (8*sizeof(int));
    int word = SSN_registry[word_index];
    word = word | new_bit;  // bit-wise logical OR sets the desired bit
```



set_SSN

```
void set_SSN(unsigned int SSN_registry[], int ssn) {
    int bit_offset = ssn % (8*sizeof(int))
    int new_bit = (1 << bit_offset)
    int word_index = ssn / (8*sizeof(int));
    int word = SSN_registry[word_index];
    word = word | new_bit;
    SSN_registry[word_index] = word;  // write back the word into array
}
```



Shorthand for last 3 lines: SSN_registry[word_index] |= new_bit;