CSAPP：datalab 实验报告

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实验目标

datalab 实验要求我们使用限定的运算符 `&` `|` `<<` `>>` `!` 等，完成每一个函数的功能并满足所有限制条件。

文件包中有以下文件，注释了各自的功能。

```
Makefile     - Makes btest, fshow, and ishow
README       - This file
bits.c       - The file you will be modifying and handing in
bits.h       - Header file
btest.c      - The main btest program
  btest.h    - Used to build btest
  decl.c     - Used to build btest
  tests.c        - Used to build btest
  tests-header.c- Used to build btest
dlc*         - Rule checking compiler binary (data lab compiler)
driver.pl*   - Driver program that uses btest and dlc to autograde bits.c
Driverhdrs.pm    - Header file for optional "Beat the Prof" contest
fshow.c      - Utility for examining floating-point representations
ishow.c      - Utility for examining integer representations
```

题目及解法

bitAnd

第一题较为简单 `A & B = ~((~A) | (~B))`

```
/*
```

```
 * bitAnd - x&y using only ~ and |
 *   Example: bitAnd(6, 5) = 4
 *   Legal ops: ~ |
 *   Max ops: 8rr
 *   Rating: 1
 */
int bitAnd(int x, int y) {

  int res = ~((~x)|(~y));
  return res;

}
```

getByte

题目要求反回 `32` 位数 `x` 中的第 `n` 个字节，通过移位运算和掩码即可。

```
/*
 * getByte - Extract byte n from word x
 *   Bytes numbered from 0 (LSB) to 3 (MSB)
 *   Examples: getByte(0x12345678,1) = 0x56
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 6
 *   Rating: 2
 */
int getByte(int x, int n) {

  int shifts = n << 3;
  int res = x >> shifts;
  res &= 0xff;

  return res;

}
```

logicalShift

题目要求实现逻辑右移，我的想法是通过加法将算术右移填充的 `1` 溢出成 `0`，还可以在 `x >> 1` 之后将符号位直接清 `0`。

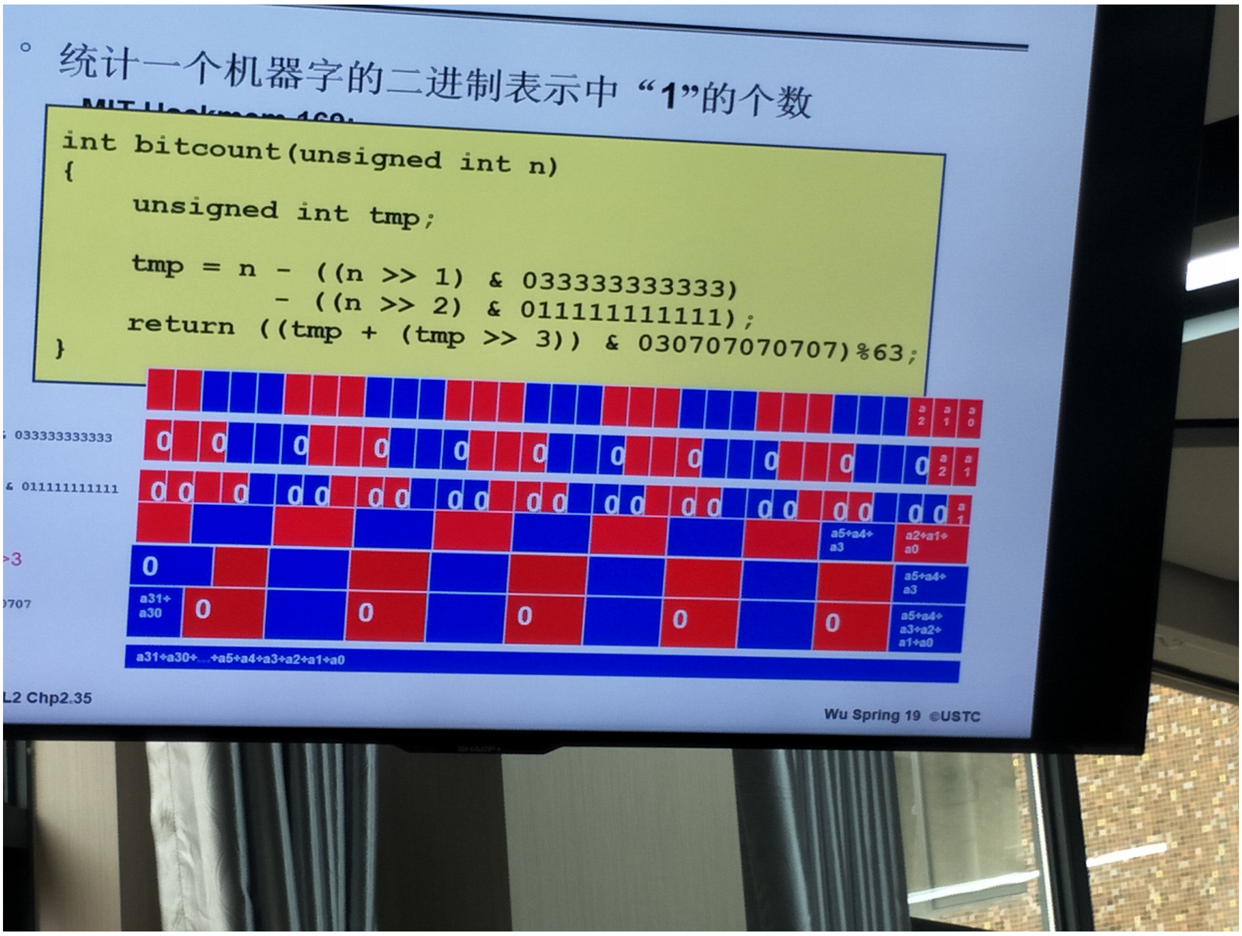
```
/*
 * logicalShift - shift x to the right by n, using a logical shift
 *   Can assume that 0 <= n <= 31
 *   Examples: logicalShift(0x87654321,4) = 0x08765432
 *   Legal ops: ! ~ & ^ | + << >>
```

```
 *   Max ops: 20
 *   Rating: 3
 */
int logicalShift(int x, int n) {

  int bias = (x >> 31) & 2;
  int res, tem;
  tem = (31 ^ n);
  bias <<= tem;
  res = bias + (x >> n);

  return res;

}
```

bitCount

题目要求我们统计 `32` 位数字二进制表示中数字 `1` 出现的次数，并且限定操作符在 `40` 个以内。

老师上课时讲过一种统计方法，如图。因为有 $2^n - 2^{n-1} - 2^{n-2}...-1 = 1$ 通过图中计算 `tmp` 的方式，可以每 3 位为一组，计算这一组中 `1` 的个数。`(tmp + (tmp >> 3)) & 0x030707070707` 将相邻红蓝块数值合并入蓝块中。因为 $1 \equiv 64 \pmod{63}$ 所以对 `63` 取模就得到了蓝块之和，即答案。



而我采用了类似线段树值合并的思想，有点类似上述方法，通过移位和加法，逐步将 `1` 的个数统计出来。

```
/*
 * bitCount - returns count of number of 1's in word
 *   Examples: bitCount(5) = 2, bitCount(7) = 3
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 40
 *   Rating: 4
 */
int bitCount(int x) {

  int bias1 = 0x55;
  int bias2 = 0x33;
  int bias3 = 0x0f;
  int bias4 = 0xff;
  int bias5 = 0xff;

  bias1 |= bias1 << 8;
  bias1 |= bias1 << 16;

  bias2 |= bias2 << 8;
  bias2 |= bias2 << 16;

  bias3 |= bias3 << 8;
  bias3 |= bias3 << 16;

  bias4 |= bias4 << 16;

  bias5 |= bias5 << 8;

  x = (x & bias1) + ((x >> 1) & bias1);
  x = (x & bias2) + ((x >> 2) & bias2);
  x = (x & bias3) + ((x >> 4) & bias3);
  x = (x & bias4) + ((x >> 8) & bias4);
  x = (x & bias5) + ((x >> 16) & bias5);

  return x;

}
```

bang

`当 x!= 0 时 !x = 0 , x = 0 时 !x = 1` 题目要求不使用 `!` 求出 `!x`，只需要检查 `x` 二进制表示中是否有 `1` 即可。

```
/*
```

```
 * bang - Compute !x without using !
 *   Examples: bang(3) = 0, bang(0) = 1
 *   Legal ops: ~ & ^ | + << >>
 *   Max ops: 12
 *   Rating: 4
 */
int bang(int x) {

  x |= x >> 16;
  x |= x >> 8;
  x |= x >> 4;
  x |= x >> 2;
  x |= x >> 1;

  return (x & 1) ^ 1;

}
```

tmin

要求输出最小的有符号整数(int)，`tmin = 1 << 31`

```
/*
 * tmin - return minimum two's complement integer
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 4
 *   Rating: 1
 */
int tmin(void) {

  int res = 1 << 31;
  return res;

}
```

fitsBits

题目问 `x` 能否表示为 `n` 位二进制数。我一开始的做法十分复杂，其实只要将 `x` 截断为 `n` 位再还原回去，比较与原来的数是否相等就行。因为 `n` 位二进制数也是有符号的，所以如果有操作引起数值符号的改变导致与原本不相等的情况，正是压缩为 `n` 位之后最高位翻译成符号位的表现。

```
/*
 * fitsBits - return 1 if x can be represented as an
 *  n-bit, two's complement integer.
 *   1 <= n <= 32
```

```
 *   Examples: fitsBits(5,3) = 0, fitsBits(-4,3) = 1
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 15
 *   Rating: 2
 */
int fitsBits(int x, int n) {

  int m = 33 + ~n;
  int t = x << m >> m;

  return !(t ^ x);

}
```

divpwr2

就是对 `x` 进行向 `0` 舍入的移位，当 `x < 0` 时加一个偏置即可。

```
/*
 * divpwr2 - Compute x/(2^n), for 0 <= n <= 30
 *  Round toward zero
 *   Examples: divpwr2(15,1) = 7, divpwr2(-33,4) = -2
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 15
 *   Rating: 2
 */
int divpwr2(int x, int n) {

  int s = (x >> 31) & 1;
  int res = x + ((s << n) + ~0 + !s) >> n;

  return res;

}
```

negate

有关系式 `-x = ~x + 1`

```
/*
 * negate - return -x
 *   Example: negate(1) = -1.
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 5
 *   Rating: 2
```

```
 */
int negate(int x) {

  return ~x + 1;

}
```

isPositive

判断 `x` 是否大于 `0`，注意特判 `0` 的情况。

```
/*
 * isPositive - return 1 if x > 0, return 0 otherwise
 *   Example: isPositive(-1) = 0.
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 8
 *   Rating: 3
 */
int isPositive(int x) {

  int res = (x >> 31) & 1;
  res |= !x;
  return !res;

}
```

isLessOrEqual

询问是否 `x <= y` ,则可以通过先比较符号位，不等时可以直接出答案，当符号位相等时则使用减法判断大小而不会产生溢出的问题。

```
/*
 * isLessOrEqual - if x <= y  then return 1, else return 0
 *   Example: isLessOrEqual(4,5) = 1.
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 24
 *   Rating: 3
 */
int isLessOrEqual(int x, int y) {

  int s1 = (x >> 31) & 1;
  int s2 = (y >> 31) & 1;
  int res = (!s2) & s1;
  res |= (!(s1 ^ s2)) & (!(y + ~x + 1 >> 31));
```

```
    return res;

  }
```

ilog2

题目问 `x` 的最高位 `1` 在第几位上，但给出了比较严格的限制。这题的思路有点类似二分法，运用了整数能被唯一地表示为一个二进制数的知识。（通过 `!!` 符号可以将非零整数映射为 `1` ）

```
/*
 * ilog2 - return floor(log base 2 of x), where x > 0
 *   Example: ilog2(16) = 4
 *   Legal ops: ! ~ & ^ | + << >>
 *   Max ops: 90
 *   Rating: 4
 */
int ilog2(int x) {

  int res = 0;
  int t = !!(x >> 16);
  res |= t << 4;
  t = !!(x >> res + 8);
  res |= t << 3;
  t = !!(x >> res + 4);
  res |= t << 2;
  t = !!(x >> res + 2);
  res |= t << 1;
  t = !!(x >> res + 1);
  res |= t;

  return res;
}
```

float_neg

输出 `-f` ，但特别注意 `NaN` 的情况。

```
/*
 * float_neg - Return bit-level equivalent of expression -f for
 *   floating point argument f.
 *   Both the argument and result are passed as unsigned int's, but
 *   they are to be interpreted as the bit-level representations of
 *   single-precision floating point values.
 *   When argument is NaN, return argument.
 *   Legal ops: Any integer/unsigned operations incl. ||, &&. also if, while
```

```
 *   Max ops: 10
 *   Rating: 2
 */
unsigned float_neg(unsigned uf) {

  if ((uf & 0x7F800000) != 0x7F800000 || !(uf & 0x007FFFFF))
    uf ^= 1 << 31;

  return uf;

}
```

float_i2f

题目要求将 `int` 类型转化为 `float` 类型。先判断 `x` 的符号，但由于 `-tmin = tmin` 所以先将其特判掉。接着按照类型转换的逻辑写下去即可，但要注意规格化问题，由于 `float` 与 `int` 精度差别，会导致舍入问题，还应考虑舍入导致的进位问题。

```
/*
 * float_i2f - Return bit-level equivalent of expression (float) x
 *   Result is returned as unsigned int, but
 *   it is to be interpreted as the bit-level representation of a
 *   single-precision floating point values.
 *   Legal ops: Any integer/unsigned operations incl. ||, &&. also if, while
 *   Max ops: 30
 *   Rating: 4
 */
unsigned float_i2f(int x) {

  unsigned res = 0;
  unsigned cnt = 0;
  unsigned y;
  int i, j;
  int zero;

  if (!x) return 0;
  if (x == 0x80000000) return 0xcf000000;

  if (x < 0) {
    x = -x;
    res = 1 << 31;
  }
  for (i = 31; i > 0; --i) {
    if (x & (1 << i)) break;
  }
  cnt = i;
  res |= cnt + 127 << 23;
  y = x << 32 - cnt;
```

```
    i = y & 0x100;
    j = y & 0x0ff;
    y >>= 9;
    res |= y;
    if (i == 0x100){
      if (j != 0 || (y & 1)) ++res;
    }

    return res;

  }
```

float_twice

题目要求计算 `2*u2f(f)` 。非规格化数只需整体左移再维护符号位不变就能达到乘二的目的，因为若在指数部分产生溢出正好将数字转为规格化(隐藏最高位 `1`)，对于规格化数指数加一就能达到要求，而对于 `NaN` 及 `无穷` 特判返回即可。

```
  /*
   * float_twice - Return bit-level equivalent of expression 2*f for
   *   floating point argument f.
   *   Both the argument and result are passed as unsigned int's, but
   *   they are to be interpreted as the bit-level representation of
   *   single-precision floating point values.
   *   When argument is NaN, return argument
   *   Legal ops: Any integer/unsigned operations incl. ||, &&. also if, while
   *   Max ops: 30
   *   Rating: 4
   */
  unsigned float_twice(unsigned uf) {

    unsigned s = uf & (1 << 31);
    unsigned e = uf & 0x7f800000;
    unsigned f = uf & 0x007fffff;
    if (e == 0x7f800000) return uf;
    if (e == 0) {
      uf <<= 1;
      uf = (uf & 0x7fffffff) | s;
      return uf;
    }

    e = (e >> 23) + 1 << 23;
    return s | e | f;

  }
```

实验结果

```
afool@ubuntu: ~/Documents/CS:APP_LAB/datalab/datalab-handout
文件(F) 编辑(E) 查看(V) 搜索(S) 终端(T) 帮助(H)
make: 对“all”无需做任何事。
afool@ubuntu:~/Documents/CS:APP_LAB/datalab/datalab-handout$ ./dlc bits.c
bits.c:382: Warning: unused variable `zero'

Compilation Successful (1 warning)
afool@ubuntu:~/Documents/CS:APP_LAB/datalab/datalab-handout$ ./btest bits.c
Score   Rating  Errors  Function
 1      1       0       bitAnd
 2      2       0       getByte
 3      3       0       logicalShift
 4      4       0       bitCount
 4      4       0       bang
 1      1       0       tmin
 2      2       0       fitsBits
 2      2       0       divpwr2
 2      2       0       negate
 3      3       0       isPositive
 3      3       0       isLessOrEqual
 4      4       0       ilog2
 2      2       0       float_neg
 4      4       0       float_i2f
 4      4       0       float_twice
Total points: 41/41
afool@ubuntu:~/Documents/CS:APP_LAB/datalab/datalab-handout$
```

实验心得

这个实验让我对类型转换有了更深入的认识，也学会了仅通过对位操作完成更加复杂的功能，以及对浮点数的表示方法、浮点数规格化与非规格化有了更深层的理解。

本实验所有资源在 https://github.com/Afool1999/CSAPP-Labs/tree/master/datalab