COP 3502   2/3/26

More Recursion

1) Fast Modulor Exponentiation

2) Floodfill

3) Test

mod expo problem

give a base b, exp e, and a value m
What is the remainder when b^e is divided by m?

$b=3, e=5, m=10$ answer = 3

$3^5 = 243$ $243 \% 10 = 3$

$3^1 = 3, 3^2 = 9, 3^3 \% 10 \rightarrow 3^2 \times 3 = \underline{9 \times 3} \% 10 = 7$

$3^4 \% 10 \; ((3^3 \% 10) \times (3 \% 10)) \% 10 = (7 \times 3) \% 10 = 1$

```
int res = 1;
for (int i = 0; i < e; i++)
    res = (res * b) % m;
```

O(e)

O(1)

$b^e = b^{e-1} \times b^1$ RECURSIVE

but same run-time
WAY WORSE MEMORY!

TC

print 1st half

print 2nd half

✓

$b^e = b^{e/2} \times b^{e/2}$

good as long as e is even!

```
if (e%2 == 0) {
    int tmp = modexp(b, e/2, m);
    ~~int tmp2 = modexp(b, e/2, m);~~
    return (tmp * tmp~~2~~ )%m;
}
else return (modexp(b,e-1,m) * b )%m;
```

never happens twice in a row!

Odd 1 step ⇒ even next

$e \to ? \to e/2 \to 1$

in 2 steps exponent must be divided by 2

$$\frac{e}{2^k} = 1 \to e = 2^k \to k = \log_2 e$$

k = # of 2 steps we take

$\#\ \text{iterations} \le 2 \times \log_2 e = O(\lg e)$

100000 → 10000 → 1000 → 100 → 10 → 1

101101 → 101100 → 10110 → 1011 → 1010 → 101 → 100 → 10 → 1

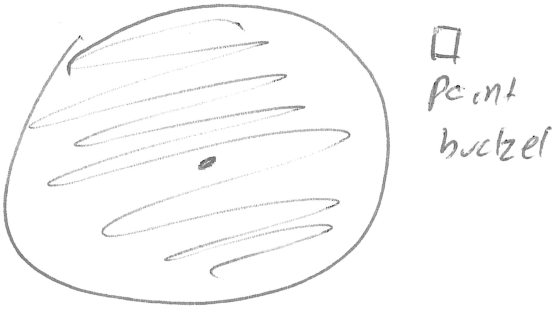
Recursive Binary Search

	0	1	2	3	4	5	6	7	8	9	10	11
arr	2	6	10	100	121	131	178	200	300	321	661	987

binsearchrec (arr, ~~lo~~ 6, ~~hi~~ 8, 178) return true 1
is 178 is in the sorted subarray
arr[6..8] or false 0 otherwise

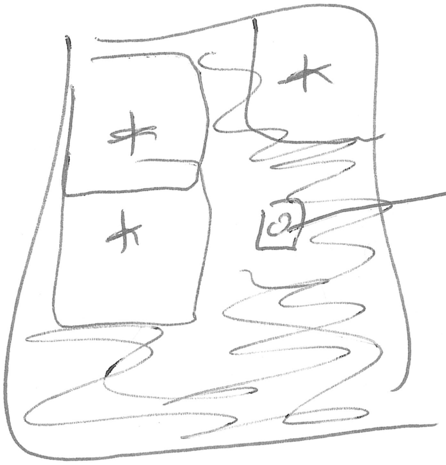
```
int  binsearchrec(int * arr, int lo, int hi, int val){
    if  (lo > hi) return 0;
    int  mid = (lo+hi)/2;
    if( val < arr[mid])
        return binsearch(arr, lo, mid-1, val);
    else if (val > arr[mid])
        return binsearch(arr, mid+1, hi, val);
    else
        return 1;
}
```

Floodfill



1. Minesweeper

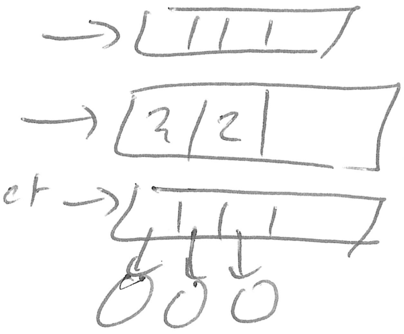
2. Counting Stars (Kattis)



is 0, then run floodfill recursive clear function

TEST

1) Dyn Memory



- array of primitive
- array of struct
- array of ptr to struct
- 2D array int
- 2D array char
  (array of strings)
- creating returning from function
- pictures

2) Alg Analysis

O(n) notation

timing problems

summations

tracing code for run time

Some anlysis problems

3) Recursion

- basic (fact, power, tipchart, ...)
- towers of hanoi, binsearch } consider 2 diff
  fastmodexpo } rec calls
- floodfill (multiple rec calls)