

Lazy Segment Trees

CS 491 – Competitive Programming

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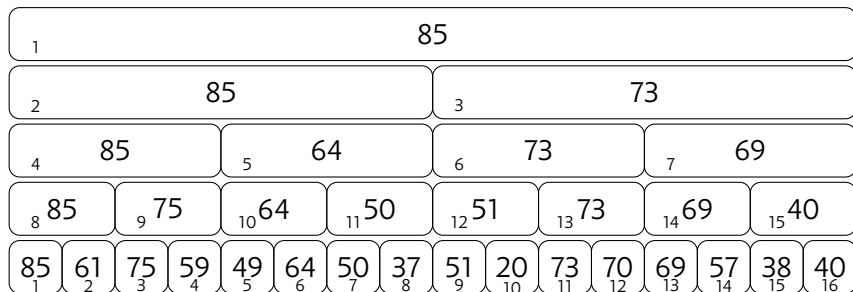
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Objectives

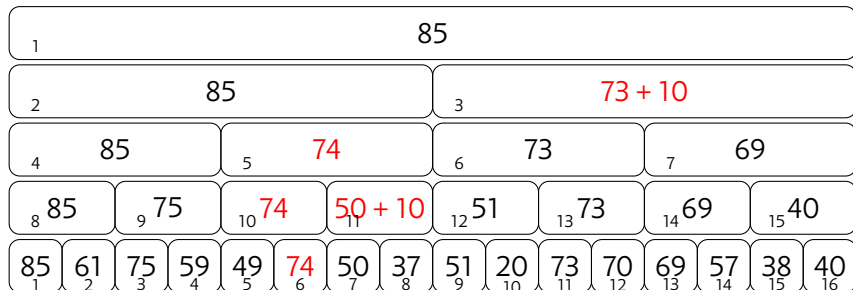
- ▶ Use lazy updating to perform updates to data in $\mathcal{O}(\log_2 n)$ time.

Segment Trees, Example from last time.



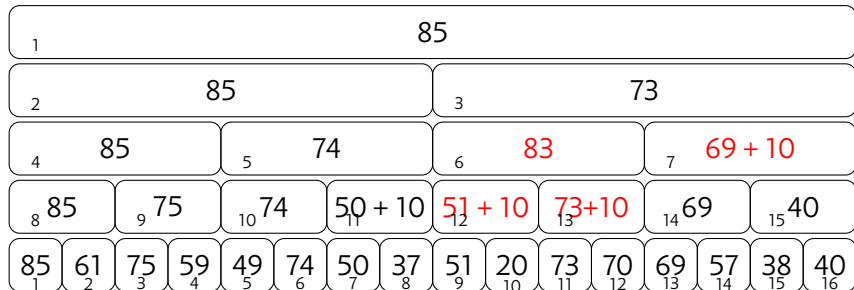
- What if we want to add 10 to elements 6 (64) to 16 (40)?

Segment Trees, Example from last time, pt 2.



- ▶ What if we want to add 10 to elements 6 (64) to 16 (40)?
- ▶ The action is similar to a query.
 - ▶ If a node is completely contained, we annotate it.
 - ▶ If a node is a leaf, we update it.
 - ▶ Propagation occurs whenever a query descends through a node.
- ▶ What if I ask about nodes 9 and 10 (51 and 20) now?

Segment Trees, Example from last time, pt 3



- ▶ What if I ask about nodes 9 and 10 (51 and 20) now?
 - ▶ Previous update instructions get propagated down the tree....
 - ▶ Answer is 61.

The Segment Tree Class

- CP 4 has a much nicer segment tree implementation

```
1  class SegmentTree {
2      private:
3          int n; // size
4          vi A, st, lazy;
5          int l(int p) { return p<<1; } // go left
6          int r(int p) { return (p<<1)+1; } // go right
7
8          int conquer(int a, int b) {
9              if (a == -1) return b; // corner case
10             if (b == -1) return a;
11             return min(a, b); // RMQ
12         }
```

Building

```
13 void build(int p, int L, int R) { //  $O(n)$ 
14     if (L == R) st[p] = A[L]; // base case
15     else {
16         int m = (L+R)/2;
17         build(l(p), L , m);
18         build(r(p), m+1, R);
19         st[p] = conquer(st[l(p)], st[r(p)]);
20     }
```

Code for Searching

- ▶ L and R give you the bounds with respect to the original array.
- ▶ i and j give you the bounds for the query

```

21 int RMQ(int p, int L, int R, int i, int j) { //  $O(\log n)$ 
22     propagate(p, L, R); // lazy propagation
23     if (i > j) return -1; // infeasible
24     if ((L >= i) && (R <= j)) return st[p]; // found the segment
25     int m = (L+R)/2;
26     return conquer(RMQ(l(p), L, m, i, min(m, j)),
27                   RMQ(r(p), m+1, R, max(i, m+1), j));
28 }
```


Range Update

```

29 void update(int p, int L, int R, int i, int j, int val) {
30     propagate(p, L, R); // lazy propagation
31     if (i > j) return;
32     if ((L >= i) && (R <= j)) { // found the segment
33         lazy[p] = val; // update this
34         propagate(p, L, R); // lazy propagation
35     } else {
36         int m = (L+R)/2;
37         update(l(p), L, m, i, min(m, j), val);
38         update(r(p), m+1, R, max(i, m+1), j, val);
39         int lsub = (lazy[l(p)] != -1) ? lazy[l(p)] : st[l(p)];
40         int rsub = (lazy[r(p)] != -1) ? lazy[r(p)] : st[r(p)];
41         st[p] = (lsub <= rsub) ? st[l(p)] : st[r(p)]; } }

```

Propagation

```
42 void propagate(int p, int L, int R) {
43     if (lazy[p] != -1) { // has a lazy flag
44         st[p] = lazy[p]; // [L..R] has same value
45         if (L != R) // not a leaf
46             lazy[l(p)] = lazy[r(p)] = lazy[p]; // propagate down
47         else // L == R, a single index
48             A[L] = lazy[p]; // time to update this
49         lazy[p] = -1; // erase lazy flag
50     }
```