

# Homework 30

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In the CREW algorithm, the concurrent read step is  $D[i, j] \leftarrow \min(D[i, j], D[i, m] + D[m, j])$ , since processor  $i = 5$  is reading  $D[i = 5, m = 4]$  at the same time processor  $j = 4$  is reading  $D[m = 5, j = 4]$  (These represent the same memory location). To make the algorithm EREW, make  $n$  copies of  $D$  into a 3D array  $D'$  so that each of the  $n^3$  processors  $p_{i,j,k}$  is reading from a different cell in  $D'$ .

$n^3$  processors can make  $n$  copies of  $D$  (which is size  $n^2$ ) into a 3D array  $D'$  in  $\log^2 n$  time.

With  $n^3$  processors, the concurrent read step of the CREW algorithm becomes an exclusive read step:  $D[i, j, k] \leftarrow \min(D[i, j, k], D[i, m, k] + D[m, j, k])$ .

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**Algorithm 1** EREW  $O(\log^2(n))$  algorithm for APSP

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**Require:**

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while  $c \leq 1$  do
  if  $k < c$  then
     $D'[i, j, k + c] = D'[i, j, k]$ 
  end if
   $b = \lfloor \frac{c}{2} \rfloor$ 
  while  $x < b$  do
     $D'[i, j, i] = \min(D'[i, j, i], D[i + b, k + b, i] + D'[k + b, j, i])$ 
  end while
  if  $i == 0$  and  $j == 0$  and  $k == 0$  then
    return  $D'[0, 0, 0]$ 
  end if
end while
```

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The algorithm can be modified as follows to return the actual paths. First, when setting up the 2D array  $D$  that contains information for all pairs  $(v_i, v_j) \in G$ , instead of storing the distance between  $v_i$  and  $v_j$  store a pair: the first element is a list of vertices representing a path from  $v_i$  to  $v_j$ , and the second element is the distance between  $v_i$  and  $v_j$ .

When setting up  $D$  initially,  $D[i, j]$  is initialized as follows: if  $i = j$ , then  $D[i, j] \leftarrow ([v_i], 0)$ . Else if there is an edge between  $v_i$  and  $v_j$ , then  $D[i, j] \leftarrow ([v_i, v_j], \text{edge\_weight}(v_i, v_j))$ . Otherwise,  $D[i, j] \leftarrow ([], \infty)$ .

When  $D[i, j]$  is updated to be  $D[i, m] + D[m, j]$ , then  $D[i, j] \leftarrow (fst(D[i, m]) + fst(D[m, j]), snd(D[i, m]) + snd(D[m, j]))$ , where  $fst$  returns the first element of a tuple,  $snd$  returns the second element of a tuple, and  $a + b$  represents list  $a$  concatenated with list  $b$ .

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**Algorithm 2** EREW  $O(\log^2(n))$  algorithm for APSP that returns the paths

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**Require:**

**while**  $c \leq 1$  **do**

**if**  $k < c$  **then**

$D'[i, j, k + c] = D'[i, j, k]$

**end if**

$b = \lfloor \frac{c}{2} \rfloor$

**while**  $x < b$  **do**

$D'[i, j, i] = \min(D'[i, j, i], ((fstD[i + b, k + b, i]) + (fstD'[k + b, j, i]), (sndD'[i + b, k + b, i]) + snd(D'[k + b, j, i])))$

**end while**

**if**  $i == 0$  and  $j == 0$  and  $k == 0$  **then**

    return  $D'[0, 0, 0]$

**end if**

**end while**

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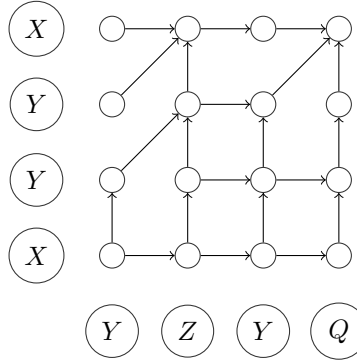
The main idea of this algorithm is to convert the input of longest common subsequence (referred to as LCS) to the input for all-pairs shortest path (APSP). Because we showed in class a CREW algorithm for APSP that runs in time  $\log^2 n$  with a polynomial number of processors, if we can do the input conversion in  $\log^2 n$  time, we can pass the converted input into our APSP algorithm to get our output in  $\log^2 n$  time.

Because the CREW algorithm for APSP has already been extensively defined, this algorithm will focus on the input conversion. The constructed graph will have  $N * M = n^2$  nodes, where  $N$  and  $M$  are the lengths of the input strings to LCS, where node  $n_{ij}$  corresponds to the  $i$ 'th letter in  $A$  and the  $j$ 'th letter in  $B$  (if the input strings to LCS are  $A$  and  $B$ ). Edges are created according to the following rules:

- If  $A[i] = B[j]$ , then add an edge from  $n_{ij}$  to  $n_{i+1j+1}$  with weight -1
- If  $A[i] \neq B[j]$  then add edges from  $n_{ij}$  to  $n_{i+1j}$  and  $n_{ij+1}$  with weights 1

Thus the minimum weight path from node  $n_{00}$  to  $n_{NM}$  will have taken the maximum number of 'diagonal' edges (that is, from  $n_{ij}$  to  $n_{i+1j+1}$ ) as these edges have negative weight and will contribute to the min distance.

A simple example of this conversion is provided, where the input strings to LCS are  $A = XYXX$  and  $B = YZYQ$ :



In this picture, the edges with weight -1 are the diagonals, while all horizontal/vertical edges have weight 1. It is important to note that this constructs a graph with no cycles of negative aggregate weight. This is because in any cycle, there will be more positive weighted edges than negatives. With  $n^2$  processors, where each processor is assigned an  $i, j$ , an algorithm is given:

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**Algorithm 3** CRCW  $O(1)$  algorithm for converting input from LCS to input for APSP

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**Require:** 2 Strings A and B of size  $N$  and  $M$ , a processor  $p_{ij}$  and an adjacency matrix Adj of size  $NM \times NM$ 

```
if A[i] == B[j] then
    Adj[i + 1][j + 1]  $\leftarrow$  -1           $\triangleright$  Negative edge weight, because we found a candidate character for the LCS
else
    Adj[i + 1][j]  $\leftarrow$  1                 $\triangleright$  Positive edge weight, not part of the LCS
    Adj[i][j + 1]  $\leftarrow$  1
end if
```

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This construction takes constant time, as each processor simply compares 2 characters and makes either 1 or 2 writes. Also note that because  $i, j$  are unique for each processor, this algorithm is exclusive write. Once we have the adjacency matrix constructed, we can simply pass it into the defined algorithm for APSP. Since the input transformation takes constant time, and time for APSP with  $p = O(n)$  is  $\log^2 n$ , our algorithm also runs in time  $\log^2 n$  with  $p = O(n)$  processors.