

## Feedback — Homework 3

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You submitted this homework on **Sun 18 Oct 2015 3:39 AM PDT**. You got a score of **100.00** out of **100.00**.

In Module 3, we will consider two methods for clustering set of points in the plane. One of these methods (hierarchical clustering) will rely on a fast divide-and-conquer method for computing the closest pair of points from a set of points.

In doing the Homework and preparing for the Project and Application, we suggest that you review the class notes on [closest pairs of points](#) and [clustering methods](#). You may also want to print out this [short summary](#) of the pseudo-code that we will use in this Module.

### Question 1

Given an array  $A[0 \dots n-1]$ , an *inversion* is a pair of indices  $(i, j)$  such that  $0 \leq i < j \leq n-1$  and  $A[i] > A[j]$ . In Questions 1-5, we will consider the problem of counting the number of inversions in an array with  $n$  elements.

To begin, how many inversions are there in the array  $A = [5, 4, 3, 6, 7]$ ? Enter your answer as a number in the box below.

You entered:

Your Answer		Score	Explanation
3	✓	5.00	Correct.
Total		5.00 / 5.00	

## Question 2

In an array with  $n$  elements, what is the maximum possible number of inversions? Enter your answer below as a math expression in terms of  $n$ .

You entered:

$n*(n-1)/2$

Preview

[Help](#)

Your Answer	Score	Explanation
$n*(n-1)/2$	✓ 5.00	
Total	5.00 / 5.00	

### Question Explanation

Consider which class of examples generated the maximal number of inversions and derive a formula for the number of inversions as an arithmetic sum.

## Question 3

What is the best case running time of a brute-force algorithm that counts the number of inversions in an array with  $n$  elements by checking every pair of elements in the array? Choose the tightest big-O bound for this best case time listed below.

Your Answer	Score	Explanation
<input type="radio"/> $O(n)$		
<input checked="" type="radio"/> $O(n^2)$	✓ 5.00	Correct. The brute force method compares every element to every other element so it has to be $O(n^2)$ .
<input type="radio"/> $O(n^3)$		
<input type="radio"/> $O(n \log n)$		

○  $O(1)$

Total 5.00 /  
5.00

## Question 4

In Questions 4 and 5, we will consider the following divide-and-conquer algorithm for counting the number of inversions in an array  $A$ .

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### Algorithm 1: CountInversions.

---

**Input:** Array  $A[0 \dots n - 1]$ .

**Output:** The number of inversions in  $A$ .

```

if  $n = 1$  then
  return 0;
else
  copy  $A[0 \dots \lfloor n/2 \rfloor - 1]$  to  $B[0 \dots \lfloor n/2 \rfloor - 1]$ ;
  copy  $A[\lfloor n/2 \rfloor \dots n - 1]$  to  $C[0 \dots \lceil n/2 \rceil - 1]$ ;
   $il \leftarrow \text{CountInversions}(B)$ ;
   $ir \leftarrow \text{CountInversions}(C)$ ;
   $im \leftarrow \text{Merge}(B, C, A)$ ;
  return  $il + ir + im$ ;

```

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### Algorithm 2: Merge.

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**Input:** Two sorted arrays  $B[0 \dots p - 1]$  and  $C[0 \dots q - 1]$ , and an array  $A[0 \dots p + q - 1]$ .

**Output:** The number of inversions involving an element from  $B$  and an element from  $C$ .

**Modifies:**  $A$ .

```

 $count \leftarrow 0$ ;
 $i \leftarrow 0$ ;  $j \leftarrow 0$ ;  $k \leftarrow 0$ ;
while  $i < p$  and  $j < q$  do
1   if ... then
     $A[k] \leftarrow B[i]$ ;  $i \leftarrow i + 1$ ;
    else
2      $A[k] \leftarrow C[j]$ ;  $j \leftarrow j + 1$ ;
     $count \leftarrow count + \dots$ ;
     $k \leftarrow k + 1$ ;
if  $i = p$  then
  copy  $C[j \dots q - 1]$  to  $A[k \dots p + q - 1]$ ;
else
  copy  $B[i \dots p - 1]$  to  $A[k \dots p + q - 1]$ ;
return  $count$ ;


```

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If you prefer, you can open this figure in a [separate tab](#).

Note that lines 1 and 2 in the function **Merge** are incomplete. Which of the following options completes these two lines so that the algorithm is correct?

**Hint:** Note that **CountInversions** sorts  $A$  as a byproduct of counting the inversions.

Your Answer	Score	Explanation
<input type="radio"/> <ul style="list-style-type: none"> <li>Line 1: <math>B[i] \leq C[j]</math></li> <li>Line 2: <math>q - j</math></li> </ul>		
<input type="radio"/> <ul style="list-style-type: none"> <li>Line 1: <math>B[i] \leq A[k]</math></li> <li>Line 2: <math>p + q - i</math></li> </ul>		
<input type="radio"/> <ul style="list-style-type: none"> <li>Line 1: <math>B[i] \leq C[j]</math></li> <li>Line 2: <math>p</math></li> </ul>		
<input type="radio"/> <ul style="list-style-type: none"> <li>Line 1: <math>B[i] \geq C[j]</math></li> <li>Line 2: <math>i - p</math></li> </ul>		
<input checked="" type="radio"/> <ul style="list-style-type: none"> <li>Line 1: <math>B[i] \leq C[j]</math></li> <li>Line 2: <math>p - i</math></li> </ul>	 5.00	Correct.
Total	5.00 / 5.00	

### Question Explanation

Note that line 1 should be consistent with sorting  $A$  and that line 2 should count the number of inversions that are detected when  $C[j]$  is moved to  $A[k]$ .

## Question 5

Which of the following gives the recurrence that results in the tightest running time for Algorithm **CountInversions**?

Your Answer	Score	Explanation
<input type="radio"/> $T(n) = T(n/2) + O(n)$ .		
<input type="radio"/> $T(n) = 2T(n/2) + O(n^2)$		

☐  $T(n) = 2T(n/2) + O(1).$

☐  $T(n) = 2T(n/2) + O(\log n)$

☒  $T(n) = 2T(n/2) + O(n)$



5.00

Correct.

Total

5.00 / 5.00

## Question 6

Which of the following gives the tightest order of growth for the solution of the following recurrence?

- $T(n) = 4T(n/2) + n$
- $T(1) = 1$

The video lectures and slides cover the Master Theorem. If you want access to more material on the subject, you may wish to review the [Wikipedia page](#) on the Master Theorem.

Your Answer		Score	Explanation
<input checked="" type="radio"/> $O(n^2)$		5.00	Correct.
<input type="radio"/> $O(n)$			
<input type="radio"/> $O(n \log n)$			
<input type="radio"/> $O(\log n)$			
<input type="radio"/> $O(n^3)$			
Total		5.00 / 5.00	

### Question Explanation

Review the Master theorem if necessary.

## Question 7

Which of the following gives the tightest order of growth for the solution of the following

recurrence?

- $T(n) = 4T(n/2) + n^3$
- $T(1) = 1$

Your Answer	Score	Explanation
<input type="radio"/> $O(n \log n)$		
<input type="radio"/> $O(n^2)$		
<input type="radio"/> $O(\log n)$		
<input checked="" type="radio"/> $O(n^3)$	✓ 5.00	Correct.
<input type="radio"/> $O(n)$		
Total	5.00 / 5.00	

#### Question Explanation

Review the Master theorem if necessary.

## Question 8

In Questions 8-10, we will consider the following mystery algorithm:

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#### Algorithm 1: Mystery.

---

**Input:** Sorted array  $A[0..n-1]$  of distinct integers, and left/right boundaries  $l$  and  $r$ .

**Output:** ...

```

1 if  $l > r$  then
    | return  $-1$ ;
2  $m \leftarrow \lfloor (l+r)/2 \rfloor$ ;
3 if  $A[m] = m$  then
4     | return  $m$ ;
5 else
    | if  $A[m] < m$  then
    |     | return Mystery( $A, m+1, r$ );
    | else
    |     | return Mystery( $A, l, m-1$ );
```

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If you prefer, you can open this figure in a [separate tab](#).

What does **Mystery**( $[-2,0,1,3,7,12,15],0,6$ ) compute? Enter your answer as a number in the box below.

You entered:

3

Your Answer	Score	Explanation
3	✓ 5.00	
Total	5.00 / 5.00	

**Question Explanation**

You may wish to implement the mystery function in Python.


## Question 9

What does Algorithm **Mystery** compute when run on input  $(A[0..n-1], 0, n-1)$ ?

Your Answer	Score	Explanation
<input type="radio"/> Returns $i$ if there exists an $i$ such that $A[i] > A[\lfloor (n-1)/2 \rfloor]$ , and $-1$ otherwise.		
<input checked="" type="radio"/> Returns $i$ if there exists an $i$ such that $A[i] = i$ , and $-1$ otherwise.	✓ 5.00	Correct.
<input type="radio"/> Returns $i$ if there exists an $i$ such that $A[i] < A[\lfloor (n-1)/2 \rfloor]$ , and $-1$ otherwise.		
<input type="radio"/> Returns $-1$ , regardless of the content of $A$ .		
Total	5.00 / 5.00	

## Question 10


What are the best case and worst case running times of Algorithm **Mystery** as a function of the input size  $n$  (and assume  $l \leq r$  in the input)?

Your Answer	Score	Explanation
<input checked="" type="radio"/> Best case: $O(1)$ Worst case: $O(\log n)$	 5.00	Correct.
<input type="radio"/> Best case: $O(n)$ Worst case: $O(n \log n)$		
<input type="radio"/> Best case: $O(n)$ Worst case: $O(n^2)$		
<input type="radio"/> Best case: $O(1)$ Worst case: $O(n)$		
<input type="radio"/> Best case: $O(n)$ Worst case: $O(\log n)$		
Total	5.00 / 5.00	

## Question 11

In Questions 11-14, we consider [clusterings of points](#) in preparation for the Project and Application.

Let  $S(n, k)$  denote the number of ways that a set of  $n$  points can be clustered into  $k$  non-empty clusters. Which of the following is a correct recurrence for  $S(n, k)$ , for  $n \geq 1$ ? Assume, for the base cases, that  $S(n, n) = S(n, 1) = 1$ .

Your Answer	Score	Explanation
<input checked="" type="radio"/> $S(n, k) = k S(n - 1, k) + S(n - 1, k - 1)$	 5.00	Correct.
<input type="radio"/> $S(n, k) = k S(n, k - 1)$		
<input type="radio"/> $S(n, k) = k S(n - 1, k)$		
<input type="radio"/> $S(n, k) = k S(n - 1, k - 1)$		
<input type="radio"/> $S(n, k) = n S(n, k - 1)$		
Total	5.00 / 5.00	



**Question Explanation**

When deriving the recurrence, consider the case when the  $n$ th point goes into an existing non-empty cluster or when it creates a new cluster.

**Question 12**

Which of the following formulas gives the number of ways of clustering a set of  $n$  points into 2 non-empty clusters; that is, a solution to the recurrence from the previous question for  $k = 2$ ?

Your Answer	Score	Explanation
<input type="radio"/> $n + 1$		
<input checked="" type="radio"/> $2^{n-1} - 1$	✓ 5.00	Correct.
<input type="radio"/> $n - 1$		
<input type="radio"/> $2^{n-1} - 2$		
<input type="radio"/> $2^n - 2$		
Total	5.00 / 5.00	

**Question Explanation**

Remember that there are  $2^n$  subsets of the  $n$  points. Try to think of one cluster as a subset of the  $n$  points and the other cluster as the complement of that subset.

Alternatively, consider implementing the recurrence in Python, computing the value of the recurrence for small values of  $n$ , and deriving a pattern.

**Question 13**

Consider the following pseudo-code of the hierarchical clustering algorithm:

**Algorithm 1: HierarchicalClustering.**

**Input:** A set  $P$  of points whose  $i$ th point,  $p_i$ , is a pair  $(x_i, y_i)$ ;  $k$ , the desired number of clusters.

**Output:** A set  $C$  of  $k$  clusters that provides a clustering of the points in  $P$ .

```

1  $n \leftarrow |P|$ ;
2 Initialize  $n$  clusters  $C = \{C_1, \dots, C_n\}$  such that  $C_i = \{p_i\}$ ;
3 while  $|C| > k$  do
4    $(C_i, C_j) \leftarrow \operatorname{argmin}_{C_i, C_j \in C, i \neq j} d_{C_i, C_j}$ ;
5    $C \leftarrow C \cup \{C_i \cup C_j\}$ ;
6    $C \leftarrow C \setminus \{C_i, C_j\}$ ;
7 return  $C$ ;
```

If you prefer, you can open this figure in a [separate tab](#).

Assuming that Line 4 takes  $h(n)$  time in each iteration, for some function  $h$ , which of the following gives the tightest worst-case running time of the algorithm as a function of the number of points,  $n$ , when  $k$  is one? Assume that the union and difference of two sets  $A$  and  $B$  takes  $O(|A| + |B|)$  time to compute.

Your Answer	Score	Explanation
<input checked="" type="radio"/> $O(n^2 + h(n) n)$	5.00	Correct.
<input type="radio"/> $O(n + h(n))$		
<input type="radio"/> $O(n^3 + h(n) n^2)$		
<input type="radio"/> $O(n \log n)$		
Total	5.00 / 5.00	

## Question 14

Consider the following pseudo-code of the  $k$ -means clustering algorithm:

Algorithm 2: KMeansClustering.

**Input:** A set  $P$  of points whose  $i$ th point,  $p_i$ , is a pair  $(x_i, y_i)$ ;  $k$ , the desired number of clusters;  $q$ , a number of iterations.  
**Output:** A set  $C$  of  $k$  clusters that provides a clustering of the points in  $P$ .

```
1  $n \leftarrow |P|$ ;  
2 Initialize  $k$  centers  $\mu_1, \dots, \mu_k$  to initial values (each  $\mu$  is a point in the 2D space);  
3 for  $i \leftarrow 1$  to  $q$  do  
4   Initialize  $k$  empty sets  $C_1, \dots, C_k$ ;  
5   for  $j = 0$  to  $n - 1$  do  
6      $\ell \leftarrow \operatorname{argmin}_{1 \leq f \leq k} d_{p_j, \mu_f}$ ;  
7      $C_\ell \leftarrow C_\ell \cup \{p_j\}$ ;  
8   for  $f = 1$  to  $k$  do  
9      $\mu_f = \operatorname{center}(C_f)$   
10 return  $\{C_1, C_2, \dots, C_k\}$ ;
```

If you prefer, you can open this figure in a [separate tab](#).

Which of the following gives the tightest worst-case running time of the algorithm as a function of the number of points,  $n$ , and the number of clusters  $k$ , and the number of iterations  $q$ ? Assume that adding  $\{p_j\}$  to  $C_l$  in line 7 takes  $O(1)$  time.

Your Answer	Score	Explanation
<input checked="" type="radio"/> $O(q k n)$	✓ 5.00	Correct.
<input type="radio"/> $O(q k n^2)$		
<input type="radio"/> $O(q k n \log n)$		
<input type="radio"/> $O(k n)$		
Total	5.00 / 5.00	

Question 15


Consider a list of  $n$  numbers sorted in ascending order. Which of the following gives the worst-case running time of the most efficient algorithm for finding a closest pair of numbers in this list?

Your Answer	Score	Explanation
<input type="radio"/> $O(n \log^2 n)$		
<input type="radio"/>		

$O(\log^2 n)$

☐  $O(\log n)$

☐  $O(n^2)$

☒  $O(n)$      5.00    Correct. Scan through the list and compute the minimum difference between consecutive numbers.

Total                      5.00 /  
5.00

## Question 16

In Question 16-20, we will consider methods for computing a [closest pair of 2D points](#) in the plane from a set of  $n$  points.

To begin, consider the pseudo-code of the brute-force algorithm for solving the closest pair problem:

---

### Algorithm 3: SlowClosestPair.

---

**Input:** A set  $P$  of ( $\geq 2$ ) points whose  $i$ th point,  $p_i$ , is a pair  $(x_i, y_i)$ .

**Output:** A tuple  $(d, i, j)$  where  $d$  is the smallest pairwise distance of points in  $P$ , and  $i, j$  are the indices of two points whose distance is  $d$ .

```

1  $(d, i, j) \leftarrow (\infty, -1, -1);$ 
2 foreach  $p_u \in P$  do
3   foreach  $p_v \in P$  ( $u \neq v$ ) do
4      $(d, i, j) \leftarrow \min\{(d, i, j), (d_{p_u, p_v}, u, v)\};$  // min compares the first element of each tuple
5 return  $(d, i, j);$ 
```

---

If you prefer, you can open this figure in a [separate tab](#).

Which of the following gives the tightest worst-case running time of the algorithm in terms of the number of points  $n$ ?

**Your Answer**

**Score**

**Explanation**

☐  $O(n \log n)$

☒  $O(n^2)$



5.00

Correct.

☐  $O(n)$

☐  $O(n^3)$

Total

5.00 / 5.00

## Question 17

Consider the following pseudo-code of a divide-and-conquer algorithm for solving the closest pair problem:

---

### Algorithm 4: FastClosestPair.

---

**Input:** A set  $P$  of ( $\geq 2$ ) points whose  $i$ th point,  $p_i$ , is a pair  $(x_i, y_i)$ , **sorted** in nondecreasing order of their horizontal ( $x$ ) coordinates.

**Output:** A tuple  $(d, i, j)$  where  $d$  is the smallest pairwise distance of the points in  $P$ , and  $i, j$  are the indices of two points whose distance is  $d$ .

```

1   $n \leftarrow |P|$ ;
2  if  $n \leq 3$  then
3     $(d, i, j) \leftarrow \text{SlowClosestPair}(P)$ ;
4  else
5     $m \leftarrow \lfloor n/2 \rfloor$ ;
6     $P_\ell \leftarrow \{p_i : 0 \leq i \leq m-1\}$ ;  $P_r \leftarrow \{p_i : m \leq i \leq n-1\}$ ;           //  $P_\ell$  and  $P_r$  are also sorted
7     $(d_\ell, i_\ell, j_\ell) \leftarrow \text{FastClosestPair}(P_\ell)$ ;
8     $(d_r, i_r, j_r) \leftarrow \text{FastClosestPair}(P_r)$ ;
9     $(d, i, j) \leftarrow \min\{(d_\ell, i_\ell, j_\ell), (d_r, i_r + m, j_r + m)\}$ ;
10    $mid \leftarrow \frac{1}{2}(x_{m-1} + x_m)$ ;                                           // center line of strip
11    $(d, i, j) \leftarrow \min\{(d, i, j), \text{ClosestPairStrip}(P, mid, d)\}$ ;
12 return  $(d, i, j)$ ;
```

---

If you prefer, you can open this figure in a [separate tab](#).

If the helper function **ClosestPairStrip** used in the conquer step in line 11 has a worst case running time that is  $O(f(n))$ , which of the following recurrences models the running time of **FastClosestPair**? You may assume that **ClosestPairStrip** examines all of its input and, therefore,  $f(n)$  grows at least as fast as  $n$ . (Here,  $d$  is a constant.)

Your Answer	Score	Explanation
<input type="radio"/> <ul style="list-style-type: none"> <li><math>T(n) = 4 T(n/2) + f(n)</math></li> <li><math>T(2) = d</math></li> </ul>		
<input checked="" type="radio"/> <ul style="list-style-type: none"> <li><math>T(n) = 2 T(n/2) + f(n)</math></li> <li><math>T(2) = d</math></li> </ul>	<div>✓</div> 5.00	Correct.
<input type="radio"/> <ul style="list-style-type: none"> <li><math>T(n) = 2 T(n/2) + n</math></li> <li><math>T(2) = d</math></li> </ul>		



- $T(n) = T(n/2) + f(n)$
- $T(2) = d$

Total

5.00 / 5.00

## Question 18

Consider the following pseudo-code for **ClosestPairStrip**:

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### Algorithm 5: ClosestPairStrip.

---

**Input:** A set  $P$  of points whose  $i$ th point,  $p_i$ , is a pair  $(x_i, y_i)$ ;  $mid$  and  $w$ , both of which are real numbers.

**Output:** A tuple  $(d, i, j)$  where  $d$  is the smallest pairwise distance of points in  $P$  whose horizontal ( $x$ ) coordinates are within  $w$  from  $mid$ .

```

1 Let  $S$  be a list of the set  $\{i : |x_i - mid| < w\}$ ;
2 Sort the indices in  $S$  in nondecreasing order of the vertical ( $y$ ) coordinates of their associated points;
3  $k \leftarrow |S|$ ;
4  $(d, i, j) \leftarrow (\infty, -1, -1)$ ;
5 for  $u \leftarrow 0$  to  $k - 2$  do
6   for  $v \leftarrow u + 1$  to  $\min\{u + 3, k - 1\}$  do
7      $(d, i, j) \leftarrow \min\{(d, i, j), (d_{p_{S[u]}, p_{S[v]}}, S[u], S[v])\}$ ;
8 return  $(d, i, j)$ ;
```

---

If you prefer, you can open this figure in a [separate tab](#).

If  $n$  is the size of the input  $P$ , what is the **worst case** running time of **ClosestPairStrip**?

Your Answer	Score	Explanation
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 $O(n \log n)$ 

5.00

Correct.  $S$  may include all of the points in  $P$  so the sort in line 2 costs  $O(n \log n)$  time in the worst case. Note that lines 5-7 require only  $O(n)$  time.

 $O(n)$  $O(n^2)$  $O(n^2 \log n)$ 

Total

5.00 /  
5.00

**Question Explanation**

Review what the worst case running time of sorting is.

## Question 19

Based on your answers to Questions 17 and 18, what is the worst case running time of **FastClosestPair**?

To answer this question, you will need to review the full version of the Master Theorem that is available [here](#).

Your Answer		Score	Explanation
<input checked="" type="radio"/> $O(n \log^2 n)$	✓	5.00	Correct.
<input type="radio"/> $O(n \log n)$			
<input type="radio"/> $O(n^2 \log n)$			
<input type="radio"/> $O(n^2 \log^2 n)$			
Total		5.00 / 5.00	

**Question Explanation**

If your answer was incorrect, consult [this part](#) of the Master Theorem.

## Question 20

If the algorithm for **ClosestPairStrip** could be modified such that its running time  $f(n)$  is  $O(n)$ , what would be the worst case running time of **FastClosestPair**? Again, use your answer from Question 17 and consult the Master Theorem.

Your Answer		Score	Explanation
<input checked="" type="radio"/> $O(n \log n)$	✓	5.00	Correct.
<input type="radio"/> $O(n \log^2 n)$			

☐  $O(n^2 \log n)$

☐  $O(n^2 \log^2 n)$

Total

5.00 / 5.00

## Question 21

### Challenge problem

Think about how to modify **FastClosestPair** and **ClosestPairStrip** such that **ClosestPairStrip** runs in  $O(n)$  time in the worst case. The key will be to pass two copies of the list of input points, one sorted in horizontal order and one sorted in vertical order, to each call of **FastClosestPair** and **ClosestPairStrip**.

Note that this question is ungraded (counts for zero points) and does not require the input of any type of answer. We suggest that you attempt this challenge only after you have finished the entire Module since this modification is tricky.

**Your Answer**

**Score**

**Explanation**

Total

0.00 / 0.00