Lab Report

CMPT 225

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2020/4/5

Part one:

Purpose:

I choose six different size of data (10000,20000,30000,40000,50000,60000) as our x variable. We test two different data type (integer and char) each one we divided into two different orders of data (we call it data family) (random and reverse). We try to use three different sorting methods (C++ sort, Quick sort, Insert sort) to test their time efficiency. What's more, when we using Quick sort we also need two different pivot point positions (random and mid). Our main goal is figure out how different pivot point positions will influence the Quick sort running time.

Code of two different pivot point positions:

```
void QuickSort(int A[], int lo, int hi ){
   // Sorts A[lo] to A[hi].
   int temp ; // auxilliary variable used for performing swaps.
   if( lo < hi ){
      // Choose a pivot.
      // This is an easy, but poor, choice.
       int pivotIndex =rand()%(hi-lo+1)+lo ;
                      =(lo+hi)/2 ;
```

Code of two different ways of choosing data order:

```
 for( int t = 0 ; t < TIMES ; t++ ){

    for(int i = 0 ; i < SIZE ; i++ ){
       int x = SIZE - i ; // reverse-ordered
       int x = rand() % SIZE*10; //random
       A1[i] = x ;
       A2[i] = x ;
       A3[i] = x ;
    }
```

Sort methods	Different size of ***random integer*** data type array ***Mid pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.4708	1.0077	1.6385	2.1596	2.7638	3.3995	1.90665
Quick sort	0.974	2.2027	3.3895	4.5398	5.9044	7.2741	4.04741
Insert sort	58.6448	244.755	552.843	988.029	1531.92	2225.7	933.6486

Sort methods	Different size of ***random integer*** data type array ***Random pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.476	1.0097	1.5785	2.2429	2.7588	3.3833	1.9082
Quick sort	1.028	2.2389	3.4924	4.6691	6.0347	7.3232	4.13105
Insert sort	62.6012	249.702	561.882	996.392	1558.92	2242.97	951.451

Sort methods	Different size of ***reverse integer*** data type array ***Mid pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.0322	0.0706	0.0866	0.1164	0.1464	0.1707	0.10381
Quick sort	0.4465	0.9927	1.3863	1.9198	2.4323	2.9054	1.6805
Insert sort	117.968	474.497	1054.43	1914.34	3036.17	4168.87	1794.37

Sort methods	Different size of ***reverse integer*** data type array ***Random pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.0327	0.0643	0.0925	0.1202	0.1499	0.2055	0.11085
Quick sort	0.6729	1.4143	2.1988	3.0474	3.9808	4.6256	2.65663
Insert sort	124.259	498.879	1118.46	1990.28	3106.33	4485.04	1887.20

Sort methods	Different size of ***random*** ***char*** data type array ***Mid pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.3043	0.5706	0.861	1.1413	1.3957	1.6775	0.99173
Quick sort	1.3381	4.1645	8.1795	13.6428	20.7467	29.4812	12.9254
Insert sort	58.817	236.061	523.221	920.036	1441.95	2079.55	876.605

Sort methods	Different size of ***random*** ***char*** data type array ***Random pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.291	0.5826	0.7641	1.1881	1.416	1.6787	0.98675
Quick sort	1.0601	4.4773	8.6816	14.3953	21.9042	30.259	13.4629
Insert sort	61.5937	246.213	548.267	983.879	1516.09	2182.45	923.082

Sort methods	Different size of ***reverse*** ***char*** data type array ***Mid pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.1665	0.3125	0.4533	0.6013	0.7329	0.8748	0.52355
Quick sort	0.8307	2.7192	4.653	8.2488	12.172	16.2737	7.4829
Insert sort	61.1482	244.83	543.92	972.051	1510.72	2071.02	900.614

Sort methods	Different size of ***reverse*** ***char*** data type array ***Random pivot***						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.1636	0.3192	0.4536	0.6521	0.764	0.8943	0.54113
Quick sort	0.878	2.4514	5.0807	8.0254	11.8067	16.5059	7.45801
Insert sort	64.4763	257.298	574.065	1020.43	1591.41	2293.54	966.869

ort methods	Different size of *random integer* data type array — *Mid pivot*						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.4708	1.0077	1.6385	2.1596	2.7638	3.3995	1.90665
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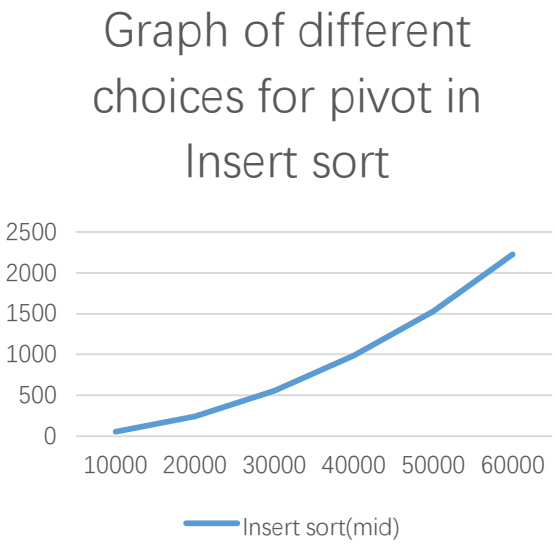

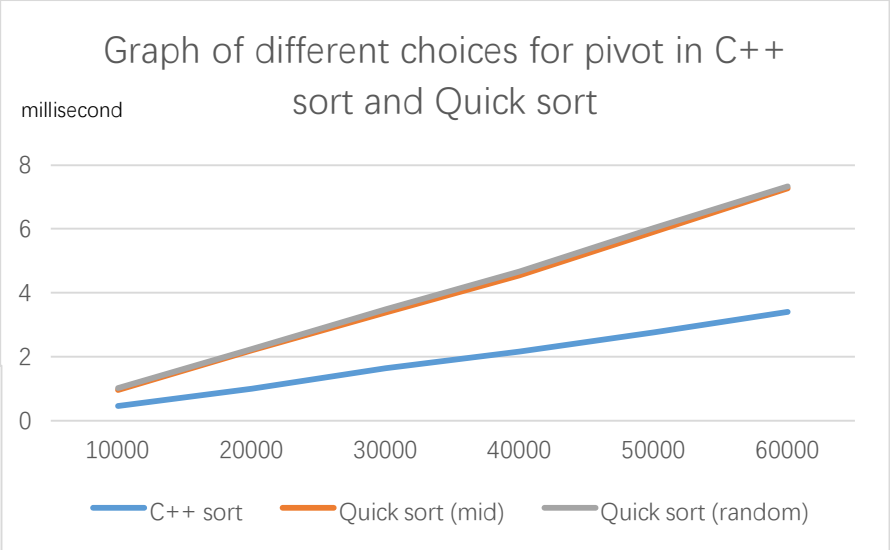

Due to the large result in insert sort for both different case, we move it to independent plot. As we can observe in these two graph, for the quick sort method that we used, the result for both mid pivot choosing and random pivot choosing is almost same (we talking about the integer case). For handling with a large size of data, the C++ sort is the most efficient way, and then Quick sort finally the insert sort.

For the rest of all data and comparisons, when data type, the way of choose data family are same, the time efficiency is almost same for them. So we do not show all plot for the same result. However, when talking about integer and we use reverse order of data, results are quite different.

ort methods	Different size of *reverse integer* data type array — *Mid pivot*						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.0322	0.0706	0.0866	0.1164	0.1464	0.1707	0.10381
Quick sort	0.4465	0.9927	1.3863	1.9198	2.4323	2.9054	1.6805
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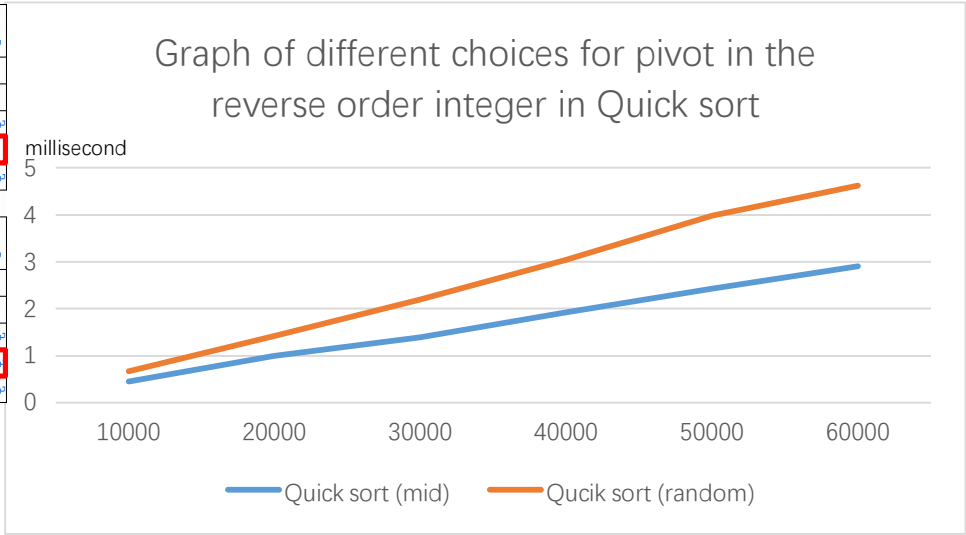
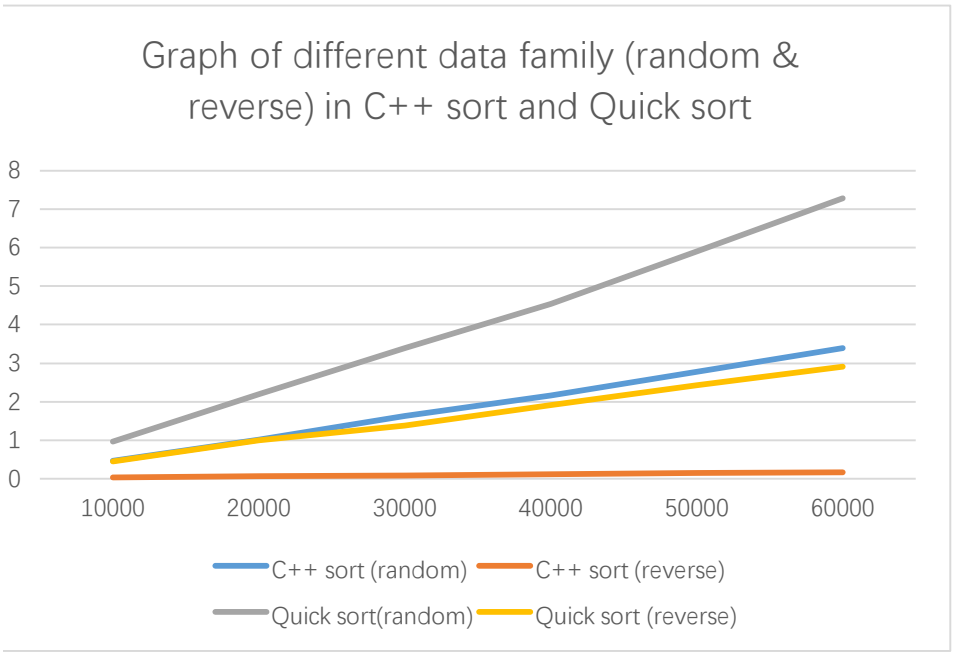


For the reverse integer, as the size of data become bigger and bigger, the random choice pivot should need more time than mid pivot. Especially, after 30000 size of data, the gap of each method become larger and larger.

Next, let's see if we can observe some difference between same choice for pivot but different data family.



Due to the large data, we also move insert sort to other plot. We can find reverse order data of C++ sort is most efficient way to sort data. Random order data of C++ sort and Reverse order data of Quick sort are almost same before around 22000. After that, random data of C++ sort will be better. Unfortunately, random order of Quick sort will take pretty long time to sort them.

ort nethods	Different size of *random integer* data type array *Mid pivot*						Average value
	10000	20000	30000	40000	50000	60000	
	Running time for each sort method (millisecond)						
C++ sort	0.4708	1.0077	1.6385	2.1596	2.7638	3.3995	1.90665
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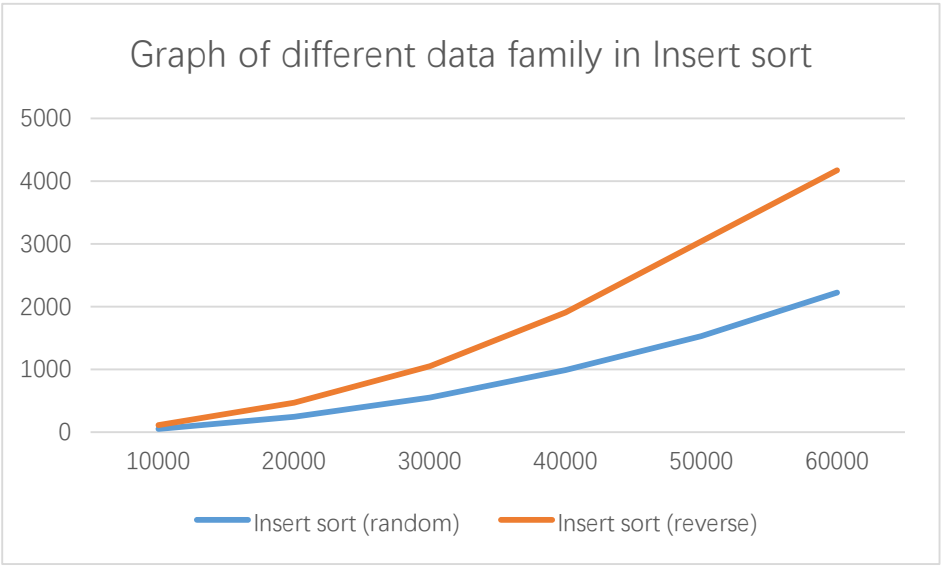
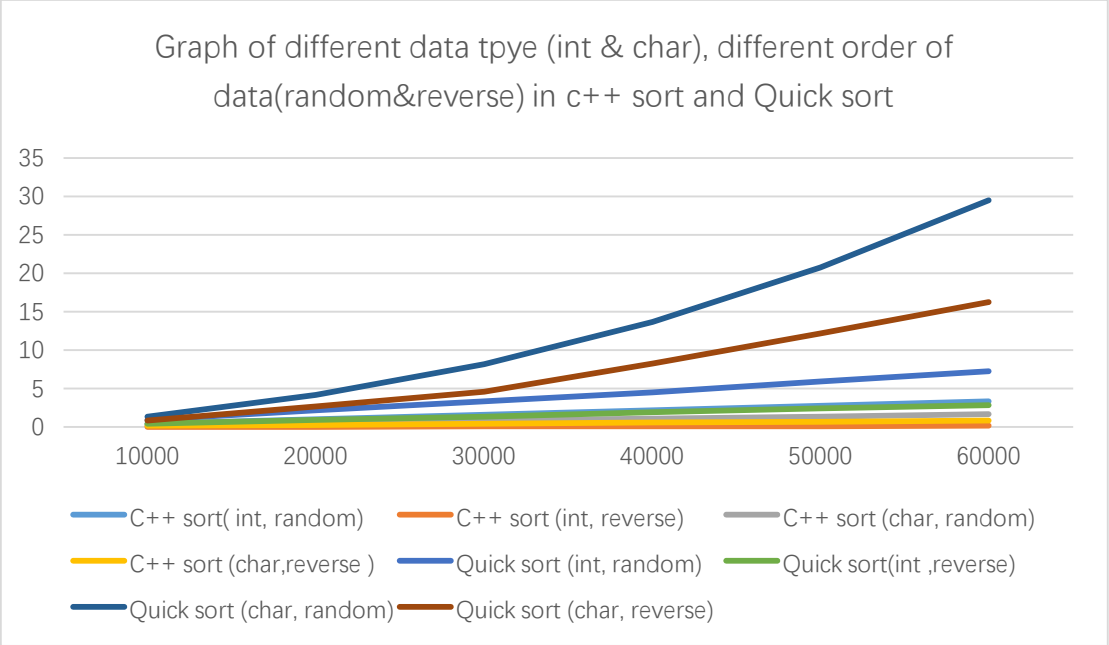
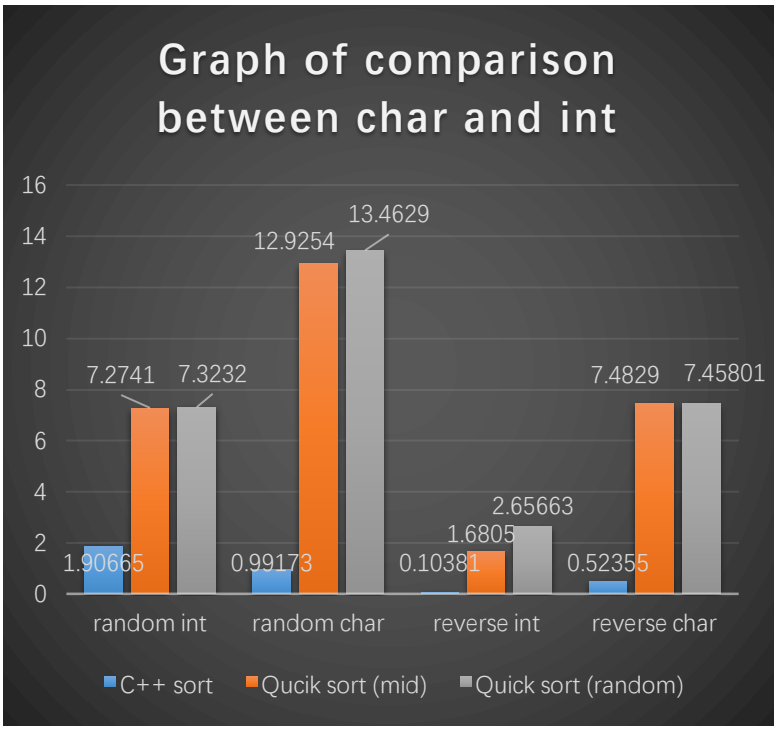


When we dealing with the insert sort with a large size of data, the reverse order data need more time than random order data. Especially when bigger than 30000, the reverse type growing faster than before.

All in all, when we use the C++ sort and Quick sort, the reverse order data will greater than random. Among them, the C++ is an excellent choice. However, when we using the insert sort, the random order data one will be better than random one. So the best case for integer is reverse order data by using C++ sort. The worst case is reverse order data by using insert sort.



In this section, we add one more data type (char type) into our research. In general, we observe that the regularity of char type almost as same as the int type. So we do not repeat every details in the class of char. We collect them together and make a larger plot. As we can see in the above plot, firstly whatever the data type is, the C++ sort is most efficient way to sort data; the quick sort in random integer need more time than other situations. Random data family always need more time than reverse data family from the plot. Most importantly, whatever the data type is, random pivot position always need more time than mid pivot position in the Quick sort.



As we can see in the left plot, general when we dealing with the char data type, it should use more time than the integer data type. So the extremely case of best time efficiency is reverse order of integer by using C++ sort method to sort. Interesting thing is the worst case is reverse order of integer by using Insert sort.

Part two:

Before we testing all the sort, we need to find a sorting way that actually faster than on small inputs. We test (insert sort, selection sort, and heap sort) these sort first to see which one is best sort we can form our “simple sort”.

This is the code of Heap sort:

```
//Heap sort
template <class T>
//adjust elements from i to n.
void MaxHeapify(T a[], int i, int n)
{
    int leftIndex, node;

    node = a[i];
    leftIndex = 2 * i + 1;
    while (leftIndex < n)
    {

        //find a max element in left and right child
        if (leftIndex + 1 < n && a[leftIndex + 1] > a[leftIndex])
            leftIndex++;
        //find a max element in left and right child
        if (a[leftIndex] <= node)
            break;

        a[i] = a[leftIndex];
        i = leftIndex;
        leftIndex = 2 * i + 1;
    }
    a[i] = node;
}

template <class T>
void BuildMaxHeap(T a[], int n){
    for(int i = n/2 - 1; i >= 0; i--){
        MaxHeapify(a, i ,n);
    }
}

template <class T>
void HeapSort(T a[], int n){
    for(int i = n - 1; i >= 1;i--){
        T temp=a[0];
        a[0]=a[i];
        a[i]=temp;
        MaxHeapify(a, 0, i); // rebuild max heap
    }
}
```

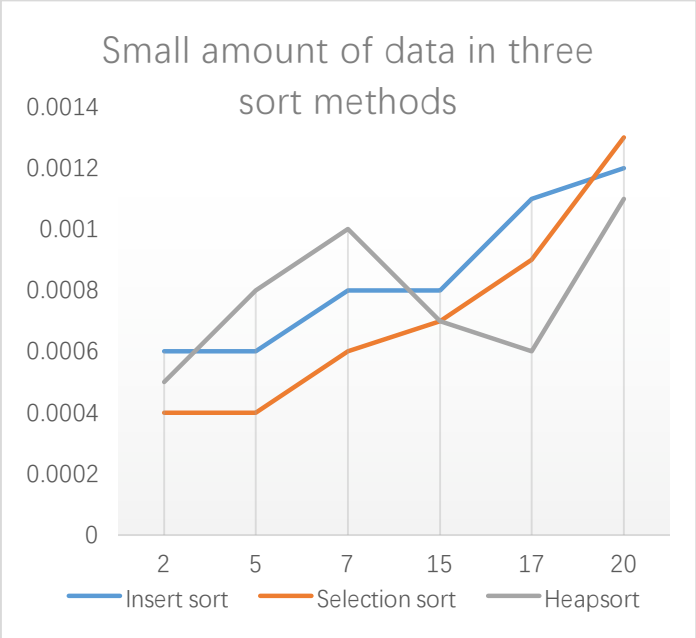
It has three parts one is main function called HeapSort. In HeapSort, it has BuildMaxHeap and MaxHeapity these two helper functions to complete the functioning.

Once we build our “simple sort”, we need to locate the amount of S. We need to think about when we need to use the simple sort.

Choosing a sort method: get a roughly “S”

Because of we talking about the small amount of data size, we will choose (2,5,7,15,17,20).

Sort methods	Different size of small size data in Insert sort, selection sort and heapsort						Average value
	2	5	7	15	17	20	
	Running time for each sort method (millisecond)						
Insert sort	0.0006	0.0006	0.0008	0.0008	0.0011	0.001	0.00083
Selection sort	0.0004	0.0004	0.0006	0.0007	0.0009	0.0013	0.00065
Heapsort	0.0005	0.0008	0.001	0.0007	0.0006	0.0011	0.00091



After the experiment, we can see there is an intersection point when data size is fifteen. Before fifteen, selection is our best choice when we dealing with the small size data. After that, the heapsort is our excellent choice of sorting data. Also, we know the point of fifteen is a critical point. Our simple sort is selection sort.

This is just a roughly S !!!

```
template <class T>

void QuickSort_modify(T A[], int lo, int hi ){
   // Sorts A[lo] to A[hi].
   T temp ; // auxilliary variable used for performing swaps.
   if( lo < hi ){

       if (lo+15<hi)
           selection(A, hi-lo);
       else
       {
           int pivotIndex =(lo+hi)/2 ;
           temp = A[pivotIndex]; A[pivotIndex] = A[hi]; A[hi] = temp ;

       // Partition based on the pivot.
           T pivot = A[hi];
           int i = lo ; // i indexes the next place to put a newly found small value.
           for( int j = lo; j < hi; j++ ){
         // j indexes the next element to inspect.
               if( A[j] < pivot ){
          // swap A[i] and A[j], and increment i.
                   temp = A[i]; A[i] = A[j]; A[j] = temp;
                   i++;
               }
           }
       // swap A[hi] and A[i], to put the pivot in place.
           temp = A[hi]; A[hi] = A[i]; A[i] = temp;

       // Recursively sort the two parts.
           QuickSort_modify(A, lo, i-1 );
           QuickSort_modify(A, i+1, hi );
       }
   }
}
```

So we add simple sort into our Quick sort modify and we will use C++ sort, Quick sort-standard, Quick sort-modify, Insertion sort, simple sort to finish our final test. For the testing purpose, we will not change the pivot point position for both quick sort.

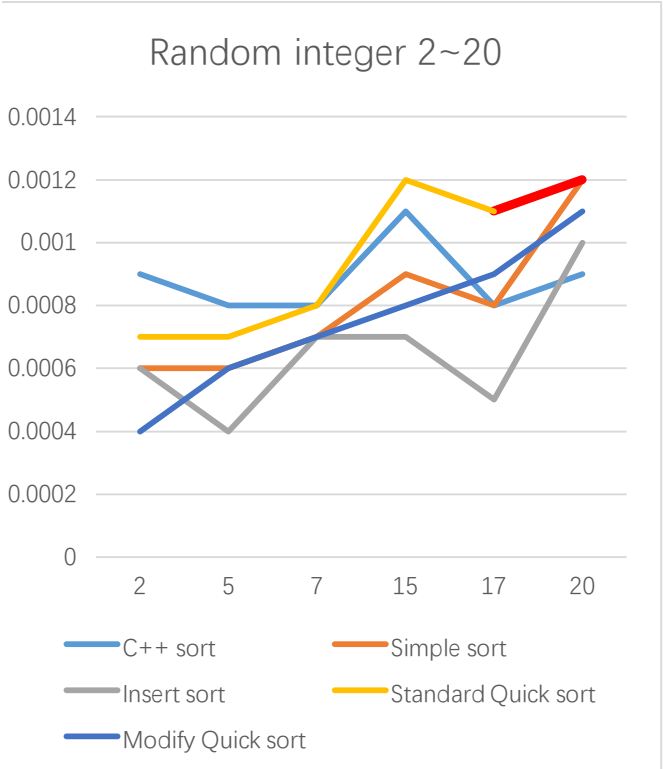
Also, due to the better observation we want to use different range of size.

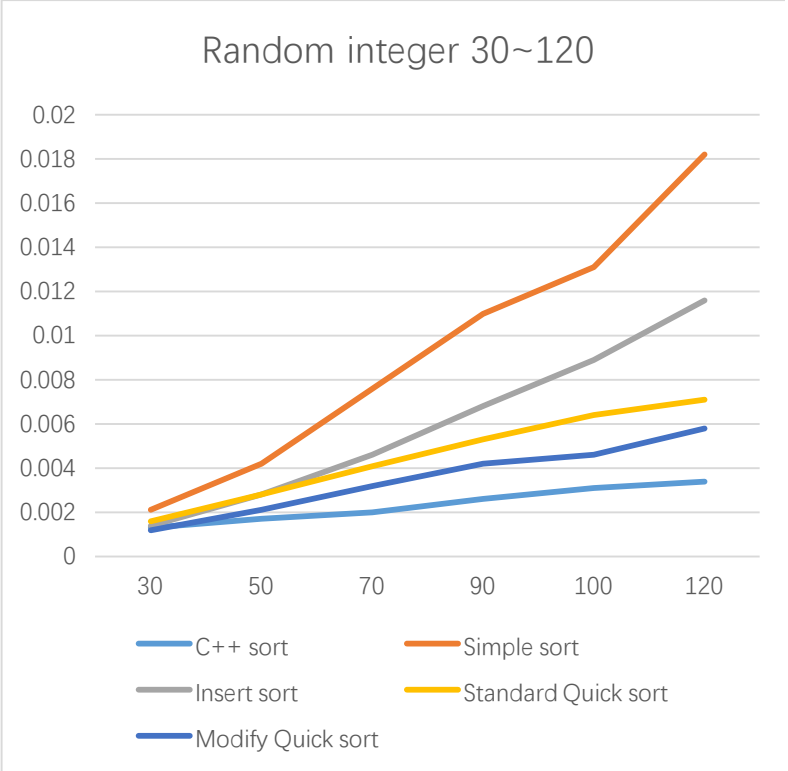
First at all, we talk about range of size (2 , 5 , 7 , 15 , 17 , 20) in the random order :

Sort methods	***Random*** order integer with five different sort methods					
	2	5	7	15	17	20
	Running time for each sort method (millisecond)					
C++ sort	0.0009	0.0008	0.0008	0.0011	0.0008	0.0009
Simple sort	0.0006	0.0006	0.0007	0.0009	0.0008	0.0012
Insert sort	0.0006	0.0004	0.0007	0.0007	0.0005	0.001
Standard Quick	0.0007	0.0007	0.0008	0.0012	0.0011	0.0012
Modify Quick	0.0004	0.0006	0.0007	0.0008	0.0009	0.0011

We talk about range of size (30 , 50 , 70 , 90 , 100 , 120) :

Sort methods	***Random*** order integer with five different sort methods					
	30	50	70	90	100	120
	Running time for each sort method (millisecond)					
C++ sort	0.0013	0.0017	0.002	0.0026	0.0031	0.0034
Simple sort	0.0021	0.0042	0.0076	0.011	0.0131	0.0182
Insert sort	0.0014	0.0028	0.0046	0.0068	0.0089	0.0116
Standard Quick	0.0016	0.0028	0.0041	0.0053	0.0064	0.0071
Modify Quick	0.0012	0.0021	0.0032	0.0042	0.0046	0.0058





As we can see in the above two plots, at the beginning (2~20) the simple sort is always better than Standard Quicksort. We also can know the insert sort show great performance. However, during the (20~120) the simple sort become slower than Standard Quicksort. So we started to focus on taking all the data in this interval.

Sort methods	***Random*** order integer with five different sort methods					
	20	22	24	26	28	30
	Running time for each sort method (millisecond)					
C++ sort	0.0009	0.0013	0.001	0.0014	0.0013	0.0015
Simple sort	0.0012	0.0015	0.0016	0.0018	0.0019	0.0021
Insert sort	0.001	0.0014	0.0012	0.0014	0.0014	0.0014
Standard Quick	0.0013	0.0015	0.0015	0.0017	0.0017	0.0016
Modify Quick	0.0011	0.0014	0.0012	0.0014	0.0015	0.0015

We only focus on the simple sort and Standard Quick sort at this time. We notice the relationship change between size of 22 and 24. So we conclusion that the S for random order integer around 23. (S_{random}=23)

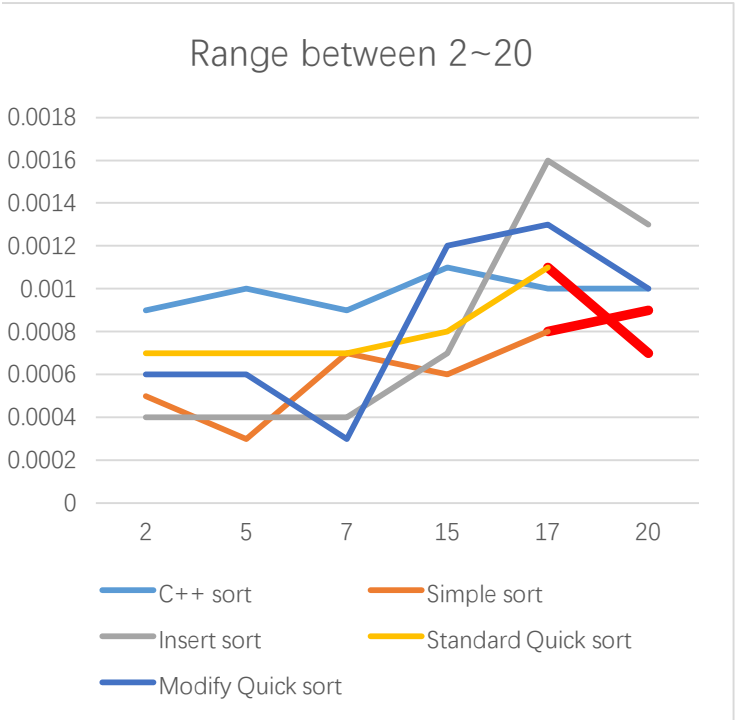
Mentioned one more detail is we tested selection sort has best functional running when small amount of data. However, when we look at the graph of range 2~20, insert sort looks like a best case. This is because unstable performance of the computer will affect the data and the data may be subject to fluctuations due to the small accuracy of the data.

Let's turn to the reverse order integer to see if the S will be the same.

Sort methods	***Reverse*** order integer with five different sort methods					
	2	5	7	15	17	20
	Running time for each sort method (millisecond)					
C++ sort	0.0009	0.001	0.0009	0.0011	0.001	0.001
Simple sort	0.0005	0.0003	0.0007	0.0006	0.0008	0.0009
Insert sort	0.0004	0.0004	0.0004	0.0007	0.0016	0.0013
Standard Quick	0.0007	0.0007	0.0007	0.0008	0.0011	0.0007
Modify Quick	0.0006	0.0006	0.0003	0.0012	0.0013	0.001

This time we found during the 17~20 the relationship changed. So we zoom that gap and also we put two more bigger data to confirm we are in the right place.

Sort methods	***Reverse*** order integer with five different sort methods					
	17	18	19	20	25	30
	Running time for each sort method (millisecond)					
C++ sort	0.0008	0.0016	0.0017	0.0009	0.001	0.0012
Simple sort	0.0006	0.0009	0.0011	0.001	0.0012	0.0015
Insert sort	0.001	0.0011	0.0011	0.001	0.0014	0.0022
Standard Quick	0.0007	0.0007	0.001	0.0009	0.0008	0.0013
Modify Quick	0.0007	0.0007	0.0008	0.0006	0.0008	0.0012



As we can see the red part, there is a intersection point. Due to the above table, we can see the S fir reverse integer is around 18 ($S_{reverse}$=18)

As the data size become larger and larger, the C++ sort shows its great performance of sorting.

Conclusion:

For the part one, we compare different data size, data family, data type and different pivot point position for Quick sort.

- We conclude whatever the data type and data family is, the random pivot point position is always need more time than reverse pivot point position
- The char data type need more time than integer data type.
- Random of data family is always need more time than reverse data family
- As the size become larger, the C++ sort method is always best choice of sorting.

In part two, we try to locate the size of S in two different data family and see if S are same or not.

- We conclude $S_{random}=23$ and $S_{reverse}=18$ for the integer.
- As the size become larger, the C++ sort method is always best choice of sorting.
- Generally, after modifying Quick sort (or we can call it Intro sort) is much better than standard Quick sort.
- From the internet, I know for the Intro sort when size over max limitation of depth usually we will use the heapsort. (We define the maximum depth limit as 2*log(N)). And when size in the middle, we can choose to use Quick sort.