ĐẠI HỌC QUỐC GIA THÀNH PHỐ HỒ CHÍ MINH TRƯỜNG ĐẠI HỌC BÁCH KHOA



GIẢI THUẬT MERGESORT BẰNG HỢP NGỮ ASSEMBLY MIPS

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Mục lục

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1 Mã giả giải thuật hiện thực trong MIPS

- 1. Tạo stack lưu giá trị
 - Địa chỉ trả về
 - Đia chỉ mảng
 - Luu right
 - Lưu mid
 - Luu left
- 2. mid = (right + left)/2
- 3. Cập nhật thanh ghi lưu giá tri right thành mid (để recursive cho left, mid)
- 4. Gọi đệ quy để MSort nửa trái (Điều kiện dừng là low >= hight)
- 5. Cập nhật giá trị mid = mid + 1 (để recursive cho mid + 1, right)
- 6. Sau đó nhảy đến hàm Merge
- 7. Tạo stack lưu giá trị
 - Địa chỉ trả về
 - Đia chỉ mảng
 - Luu right
 - Lưu mid
 - Luu left
- 8. Trong lúc merge in ra các bước
- 9. Khi 2 nửa mảng đều còn chứa phần tử
 - Kiểm tra a[i] và a[j]
 - Phần tử nào nhỏ hơn thì đẩy vào array2
- 10. Vét phần tử còn lại trong đoạn left, mid. Nếu hết thì nhảy qua while3 vét phần tử đoạn mid + 1, right
- 11. Duyệt chuyển toàn bộ phần tử array2 qua array
- 12. Kết thúc giải thuật

Hàm MSort sẽ gọi đệ quy liên tục tới khi tách mảng ra có các phần tử riêng lẻ Sau đó hàm Done sẽ trả giá trị từ stack về cho left,mid,right để gọi hàm Merge từng các giá trị lại với nhau Nhiệm vụ của Stack y như nhiệm vụ của bộ nhớ stack lúc gọi đệ quy.

2 Testcases

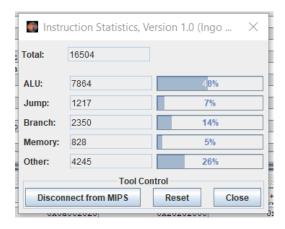
 Ưng với mỗi đầu vào là mảng có 20 phần tử, thực hiện in ra mảng sau mỗi bước MERGE 2 mảng con lại với các tham số left, mid, right. Tổng cộng có 19 lần MERGE 2 mảng con để kết thúc thuật toán sắp xếp Mergesort có 20 phần tử sắp xếp theo thứ tự không giảm.

Vì Mergesort là thuật toán ổn định, ứng với các đầu vào khác nhau, thuật toán đều tạo ra độ phức tạp trong các trường hợp Worst case, Average case và Best case là O(n*logn), với n là số lượng phần tử trong mảng cần sắp xếp. Ta có thể nhận ra điều này qua bảng thống kê Instructions Statistics được trình bày ứng với mỗi testcase bên dưới. Tổng số lệnh Total sau khi thực thi xong chương trình đều khoảng 16000 ứng với các đầu vào khác nhau.



2.1 Testcase 1

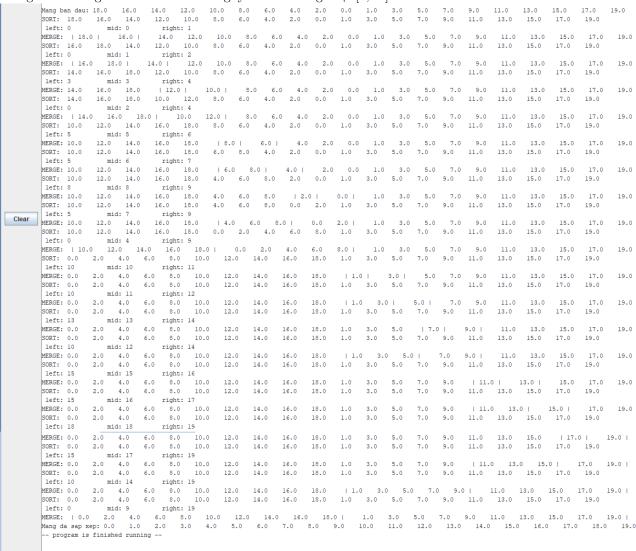
Mảng đầu vào ngẫu nhiên với các số nguyên dương nằm trong đoạn[1, 20] Mang ban dau: 3.0 5.0 SORT: 3.0 5.0 7.0 7.0 10.0 12.0 14.0 15.0 13.0 10.0 12.0 14.0 15.0 13.0 1.0 9.0 6.0 4.0 8.0 11.0 16.0 17.0 18.0 20.0 19.0 right: 1 7.0 10.0 mid: 0 | 3.0 | 5.0 | 12.0 14.0 15.0 13.0 1.0 2.0 9.0 6.0 4.0 11.0 16.0 18.0 20.0 MERGE: 19.0 12.0 right: 2 2.0 9.0 6.0 4.0 SORT: 3.0 5.0 7.0 14.0 15.0 13.0 1.0 8.0 11.0 16.0 17.0 20.0 MERGE: | 3.0 5.0 | 12.0 14.0 15.0 1.0 2.0 9.0 16.0 12.0 10.0 13.0 6.0 4.0 18.0 19.0 SORT: 3.0 5.0 10.0 14.0 15.0 13.0 1.0 2.0 9.0 6.0 4.0 8.0 11.0 16.0 17.0 18.0 20.0 19.0 mid: 3 right: 4 5.0 | 10.0 | 12.0 | 14.0 15.0 MERGE: 3.0 7.0 13.0 1.0 2.0 9.0 6.0 4.0 11.0 16.0 17.0 18.0 20.0 19.0 12 0 11.0 2.0 9.0 6.0 4.0 left: 0 mid: 2 right: 4 ™... 5.0 7.0 MERGE: | 3.0 10.0 12.0 I 14.0 15.0 13.0 1.0 2.0 9.0 6.0 4.0 11.0 16.0 18.0 20.0 19.0 2.0 4.0 SORT: 10.0 12.0 8.0 11.0 mid: 5 right: 6 left: 5 10.0 MERGE: 3.0 5.0 12.0 | 14.0 | 15.0 L 13.0 1.0 2.0 9.0 6.0 4.0 8.0 11.0 16.0 18.0 20.0 19.0 2.0 11.0 left: 5 mid: 6 right: 7 MERGE: 3.0 10.0 12 0 | 14.0 15.0 | 13.0 | 1.0 2.0 9.0 6.0 4.0 11.0 16.0 18.0 20.0 left: 8 mid: 8 right: 9 10.0 2.0 | 11.0 18.0 MERGE: 3.0 12.0 14.0 15.0 4.0 20.0 19.0 14.0 4.0 11.0 2.0 6.0 SORT: 12.0 1.0 15.0 17.0 18.0 3.0 5.0 10.0 13.0 9.0 16.0 20.0 19.0 left: mid: 7 right: 9 Clear 10.0 | 13.0 14.0 2.0 13.0 4.0 SORT: 3.0 5.0 7.0 10.0 12.0 1.0 14.0 15.0 9.0 6.0 8.0 11.0 16.0 17.0 18.0 20.0 19.0 m_. 5.0 3.0 left: 0 right: 9 10.0 14.0 15.0 | 2.0 12.0 6.0 4.0 8.0 11.0 SORT: 1.0 5.0 10.0 13.0 14.0 15.0 9.0 16.0 17.0 18.0 20.0 19.0 left: 10 mid: 10 right: 11 MERGE: 1.0 | 9.0 | 4.0 19.0 7.0 9.0 8.0 11.0 SORT: 1.0 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 6.0 4.0 16.0 17.0 18.0 20.0 19.0 left: 10 mid: 11 right: 12 3.0 1 6.0 9.0 | MERGE: 1.0 7.0 9.0 SORT: 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 4.0 6.0 8.0 11.0 16.0 17.0 18.0 20.0 19.0 right: 14 mid: 13 5.0 10.0 11.0 I | 8.0 | 16.0 18.0 MERGE: 1.0 3.0 19.0 7.0 SORT: 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 4.0 6.0 9.0 8.0 11.0 16.0 17.0 20.0 19.0 right: 14 left: 10.0 3.0 11.0 | MERGE: 1.0 7.0 13.0 14.0 15.0 1 4.0 6.0 9.0 | 8.0 16.0 18.0 19.0 SORT: 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 6.0 8.0 9.0 11.0 17.0 20.0 19.0 left: 15 mid: 15 right: 16 5.0 MERGE: 1.0 2.0 3.0 7.0 10.0 12.0 13.0 14.0 15.0 4.0 6.0 8.0 11.0 | 16.0 | 17.0 | 18.0 20.0 19.0 10.0 17.0 right: 17 left: mid: 16 MERGE: 1.0 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 11.0 | 16.0 17.0 | 20.0 19.0 17.0 SORT: mid: 18 right: 19 left: 18 MERGE: 1.0 10.0 10.0 SORT: 2.0 5.0 12.0 14.0 6.0 16.0 17.0 18.0 13.0 15.0 11.0 left: 15 mid: 17 right: 19 10.0 17.0 20.0 17.0 18.0 19.0 SORT: 1.0 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 4.0 6.0 8.0 9.0 11.0 16.0 left: 10 mid: 14 right: 19 7.0 18.0 19.0 19.0 20 16.0 4.0 8.0 9.0 11.0 17.0 18.0 20.0 SORT: 1.0 2.0 3.0 5.0 10.0 12.0 13.0 14.0 15.0 6.0 left: 0 mid: 9 right: 19 MERGE: | 1.0 2.0 3.0 5.0 Mang da sap xep: 1.0 2.0 3.0 12.0 13.0 0 15.0 | 9.0 10.0 .0 9.0 13.0 1 11.0 16.0 14.0 8.0 17.0 18.0 19.0 20.0 3.0 4.0 5.0 7.0 19.0 8.0 12.0 14.0 15.0 16.0 17.0 18.0 6.0 10.0 11.0 -- program is finished running --





2.2 Testcase 2

Mảng đầu vào ngẫu nhiên với các số nguyên nằm trong đoạn[0, 19]







2.3 Testcase 3

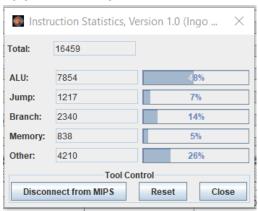
Mảng đầu vào ngẫu nhiên có cả số nguyên âm, nguyên dương -18.0 -18.0 -2.0 9.0 Mang ban dau: 19.0 17.0 -16.0 -16.0 15.0 17.0 -14.0 16.0 -13.0 13.0 -12.0 SORT: 19.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 MERGE: | 19.0 | -18.0 I -16.0 16.0 13.0 9.0 -2.0 0.0 -14.0 -13.0 -12.0 -10.0 -8.0 3.0 -1.0 17.0 SORT: -18.0 19.0 17.0 -16.0 15.0 -14.0 16.0 -13.0 13.0 -12.011.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 left: 0 right: 2 MERGE: | -18.0 -16.0 17.0 15.0 -14.0 11.0 19.0 | 16.0 -13.0 13.0 -12.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 SORT: -18.0 17 0 -16 0 15.0 -14.0 16.0 13.0 -12.0 9.0 7.0 9 0 -10.0 mid: 3 right: MERGE: -18.0 17.0 19.0 17.0 19.0 | -16.0 | 15.0 I -14.0 16.0 -13.0 13.0 -12.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 SORT: 19.0 15.0 9.0 7.0 9.0 left: 0 right: 4 mid: 2 MERGE: | -18.0 19.0 -16.0 15.0 I 17.0 -14.0 16.0 -13.013.0 -12.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 17.0 left: 5 mid: 5 right: 6 17.0 17.0 MERGE: -18.0 -16.0 15.0 19.0 | -14.0 | 16.0 I -13.0 13.0 -12.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 -16.0 15.0 19.0 16.0 9.0 mid: 6 left: 5 right: 7 17.0 17.0 MERGE: -18.0 -16.0 15.0 19.0 | -14.0 16.0 -13.0 I 13.0 -12.0 11.0 -10.0 -8.0 3.0 -2.0 0.0 SORT: -18.0 -13.0 -2.0 -16.0 15.0 -8.0 0.0 19.0 13.0 -12.0 11.0 9.0 -1.0 -10.0 left: 8 mid: 8 right: 9 17.0 17.0 -10.0 MERGE: -18.0 15.0 19 N -14 0 13.0 7.0 9.0 SORT: 19.0 -8.0 3.0 -2.0 0.0 -18.0 -16.0 15.0 -14.0 -13.016.0 -12.0 11.0 -10.0 9.0 -1.0 mid: 7 left: 5 right: 9 MERGE: -18.0 15.0 17.0 17.0 19.0 | -14.0 -13.0 16.0 | 11.0 -10.0 -2.0 7.0 -13.0 -12.0 13.0 SORT: -18.0 -16.0 15.0 19.0 -14.0 16.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 left: 0 mid: 4 right: 9 17.0 19... 0 -12.0 MERGE: | -18.0 -13.0 -12.0 13.0 -8.0 -1.0 -16.0 -13.0 7.0 -16.0 -14.0 13.0 15.0 16.0 17.0 9.0 SORT: -18.0 19.0 11.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 left: 10 mid: 10 right: 11 MERGE: -18.0 -14.0 -14.0 | 11.0 | -1.0 -16.0 -13.0 11.0 7.0 SORT: -18.0 -16.0 -13.0 -12.0 13.0 15.0 16.0 17.0 19.0 -10.0 9.0 -8.0 3.0 -2.0 -1.0 0.0 9.0 left: 10 mid: 11 right: 12 MERGE: -18.0 -14.0 -14.0 -12.0 -2.0 11.0 | 0.0 -16.0 -10.0 -8.0 -1.0 9.0 -13.0 SORT: -18.0 -16.0 -13.0 -12.0 13.0 15.0 16.0 17.0 19.0 -10.0 9.0 11.0 -8.0 3.0 -2.0 -1.0 0.0 7.0 9.0 -14.0 11.0 13.0 17.0 19.0 9.0 3.0 | -2.0 -1.0 0.0 MERGE: -18.0 -16.0 -13.0 | -8.0 | 9.0 SORT: -18.0 -16.0 -14.0 -13.0 -12.0 13.0 15.0 16.0 17.0 19.0 -10.0 9.0 11.0 -8.0 3.0 -2.0-1.0 0.0 7.0 9.0 mid: 12 right: 14 -14.0 -14.0 -12.0 MERGE: -18.0 -16.0 -13.0 13.0 15.0 16.0 17.0 19.0 | -10.0 9.0 11.0 | -8.0 3.0 | -2.0 -1.0 0.0 7.0 9.0 SORT: -13.0 -8 0 9 0 left: 15 mid: 15 right: 16 -14.0 MERGE: -18.0 -16.0 -13.0 -12.0 19.0 -10.0 -8.0 11.0 1 -2.0 1 -1.0 I 0.0 7.0 SORT: -16.0 -12.0 -1.0 9.0 left: 15 mid: 16 right: 17 -14.0 -14.0 -12.0 MERGE: -18.0 -16.0 -13.0 13.0 15.0 19.0 -10.0 1 - 2.0-1.0 I9.0 -12.0 -1.0 left: 18 MERGE: -18.0 mid: 18 -16.0 -14.0 right: 19 -13.0 9.0 [-14.0 SORT: -18.0 -16.0 -13.0 -12.0 13.0 15.0 16.0 17.0 19.0 -10.0 -8.0 3.0 9.0 11.0 -2.0 -1.0 0.0 7.0 9.0 mid: 17 right: 19 -14.0 -12.0 11.0 MERGE: -18.0 -16.0 13.0 15.0 16.0 17.0 19.0 -10.0 -8.0 3.0 | -2.0 -1.0 0.0 [-13.0 9.0 | SORT: -18.0 -16.0 -14.0 -13.0 -12.0 13.0 15.0 16.0 19.0 -10.0 -8.0 3.0 9.0 11.0 -2.0 -1.00.0 7.0 9.0 -16.0 -14.0 | -10.0 3.0 MERGE: -18.0 -13.0 -8.0 9.0 11.0 | 9.0 | SORT: -18.0 -16.0 -14.0 -13.0 -12.0 13.0 15.0 16.0 17.0 19.0 -10.0 -8.0 -2.0 -1.0 0.0 3.0 7.0 9.0 9.0 11.0 mid: 9 right: 19 MERGE: | -18.0 -16.0 -14.0 Mang da sap xep: -18.0 -16.0 -- program is finished running ---12.0 MERGE: -13.0 13.0 15.0 16.0 17.0 19.0 | -10.0 -8.0 -1.0 0.0 9.0 9.0 11.0 -14.0 -13.0 Mang da sap xep: -18.0 -12.0 0.0 3.0 7.0 11.0 13.0 15.0 16.0





2.4 Testcase 4

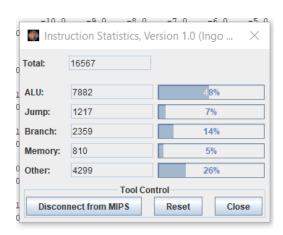
Mảng đầu vào đã được sắp xếp là các số nguyên dương từ 1 đến 20 Mang ban dau: 1.0 2.0 SORT: 1.0 2.0 3.0 3.0 4.0 5.0 4.0 5.0 6.0 6.0 7.0 9.0 10.0 10.0 11.0 11.0 12.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 _a: 0 - | 2.0 | 2.0 ° left: 0 right: 1 6.0 7.0 MERGE: | 1.0 | 3.0 5.0 5.0 right: 2 4.0 5.0 7.0 8.0 10.0 11.0 12.0 13.0 14.0 16.0 17.0 18.0 20.0 1.0 8.0 10.0 mid: 1 left: 0 2.0 | 3.0 1 20.0 MERGE: 1 1.0 6.0 7.0 8.0 11.0 12.0 13.0 15.0 17.0 18.0 5.0 6.0 7.0 8.0 9.0 10.0 SORT: 11.0 12.0 17.0 20.0 13.0 14.0 15.0 16.0 19.0 18.0 left: 3 mid: 3 right: 4 5.0 60 2.0 7.0 8.0 9.0 4.0 10.0 SORT: 1.0 3.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 m. 2.0 0 right: 4 left: 0 2.0 7.0 8.0 9.0 10.0 4.0 5.0 SORT: 1.0 6.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 left: 5 mid: 5 right: 6 7.0 | MERGE: 1.0 | 6.0 | 8.0 9.0 10.0 SORT: 1.0 2.0 3.0 4.0 5.0 6.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 left: 5 MERGE: 1.0 mid: 6 6.0 SORT: 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 mid: MERGE: 1.0 2.0 3.0 6.0 10.0 | | 9.0 | 11.0 12.0 13.0 15.0 14.0 20.0 5.0 3.0 SORT: 2.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 right: 9 7.0 MERGE: 1.0 3.0 1 6.0 10.0 | 11.0 12.0 5.0 8.0 | 13.0 15.0 16.0 18.0 19.0 20.0 SORT: 1.0 2.0 3.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 mid: 4 right: 9 MERGE: | 1.0 2.0 3.0 4.0 5.0 [6.0 7.0 8.0 9.0 10.0 | 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 3 0 5.0 SORT: 2.0 4.0 6.0 7.0 10.0 mid: 10 right: 11 left: 10 3.0 MERGE: 1.0 2.0 5.0 10.0 | 11.0 | 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 SORT: 12.0 mid: 11 right: 12 left: 10 2.0 4.0 MERGE: 1.0 3.0 6.0 1.11.0 12.0 L 13.0 L 14.0 15.0 16.0 18.0 20.0 SORT: 12.0 left: 13 mid: 13 right: 14 MERGE: 1.0 2.0 6.0 11.0 12.0 20.0 6.0 12.0 19.0 mid: 12 left: 10 right: 14 12.0 MERGE: 1.0 2.0 4.0 1 11.0 13.0 I 14.0 15.0 I 16.0 17.0 18.0 19.0 17.0 SORT: 1.0 11.0 15.0 18.0 20.0 2.0 3.0 4.0 6.0 7.0 8.0 9.0 10.0 16.0 19.0 left: 15 mid: 15 right: 16 2.0 4.0 | 16.0 | 17.0 SORT: 2.0 5.0 4.0 6.0 9.0 11.0 12.0 13.0 14.0 15.0 19.0 20.0 left: 15 mid: 16 right: 17 17.0 18.0 SORT: 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 19.0 20.0 left: 18 mid: 18 right: 19 20.0 SORT: 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 left: 15 mid: 17 right: 19 | 16.0 17.0 18.0 | 16.0 17.0 18.0 19.0 SORT: 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 20.0 right: 19 mid: 14 16.0 17.0 18.0 19.0 16.0 17.0 18.0 19.0 20. MERGE: 1.0 | 11.0 12.0 13.0 14.0 15.0 | 12.0 13.0 14.0 15.0 SORT: 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 mid: right: 19 4.0 5.0 3.0 4.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 | MERGE: | 1.0 8.0 9.0 7.0 8.0 10.0 | 2.0 3.0 Mang da sap xep: 1.0 2.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0





2.5 Testcase 5

Mảng đầu vào ngẫu nhiên có cả số nguyên âm, nguyên dương. Mang ban dau: 20.0 -19.0 -18.0 -17.0 -16.0 SORT: 20.0 -19.0 -18.0 -17.0 -16.0 -15.0 -10 0 -5.0 -4 0 -8.0 -9.0 -3.0 left: 0 mid: 0 right: 1 -18.0 -17.0 MERGE: | 20.0 | -17.0 -15.0 -14.0 -13.0 -12.0 -11.0 -4.0 SORT: -19.0 20.0 -7.0 -16.0 -8.0 -6.0 -5.0 -3.0 -2.0 -15.0 -14.0 -13.0 -12.0 -11.0 -10.0 -9.0 -4.0 -1.0 left: 0 right: 2 -18.0 -17.0 -16.0 SORT: -19.0 -15.0 -14.0 -13.0 -12.0 -11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 left: 3 mid: 3 right: 4 MERGE: -19.0 | -17.0 | -17.0 -1 -16.0 SORT: -19.0 -18.0 20.0 -15.0 -14.0-13.0 -12.0 -11.0-10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 mid: 2 right: 4 left: 0 MERGE: | -19.0 -17.0 -16.0 | -18.0 -16.0 SORT: -19.0 -18.0 -17.0 20.0 -15.0 -14.0 -13.0 -12.0 -11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 mid: 5 -15.0 | MERGE: -19.0 -12.0 -11.0 -10.0 -9.0 -7.0 -6.0 -5.0 -4.0 -18.0 -16.0 -1.0 -14.0 -13.0 SORT: -19.0 -18.0 -17.0 -16.0 20.0 -15.0 -12.0 -11.0 -10.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -14.0 | | -15.0 -13.0 I -9.0 -7.0 -6.0 MERGE: -19.0 -18.0 -16.0 -10.0 -4.0 -3.0 SORT: -19.0 -18.0 -17.0 -16.0 20.0 -15.0 -14.0 -13.0 -12.0 -11.0 -10.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 left: 8 mid: 8 right: 9 -17.0 MERGE: -19.0 -15.0 -14.0 -13.0 -18.0 -16.0 | -12.0 | -11.0 | -10.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -1.0 -2.0 SORT. -19.0 -18.0 -17.0 -16.0 20.0 -15.0 -13.0 -12.0 -11.0 left: right: 9 mid: 1 -15.0 -14.0 -17.0 MERGE: -19.0 -18.0 -16.0 -13.0 | -12.0 -11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 SORT: -15.0 -14.0 -13.0 -12.0 -11.0 left: 0 mid: 4 right: 9 -18.0 -17.0 -15.0 MERGE: | -19.0 -16.0 20.0 I -14.0 -13.0 -12.0 -11.0 I -10.0 -9.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 -16.0 -17.0 right: 11 left: 10 mid: 10 | -10.0 | -16.0 MERGE: -19.0 -18.0 -17.0 -14.0 -13.0 -12.0 -11.0 20.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -19.0 -18.0 -9.0 left: 10 mid: 11 right: 12 1 -10.0 -18.0 -18.0 -17.0 -17.0 MERGE: -13 0 -12 0 -15.0 -19.0 -8.0 SORT: 20.0 -5.0 -2.0 -14.0 -12.0 -4.0 -3.0 -13.0 -11.0 -1.0 left: 13 mid: 13 right: 14 -17.0 MERGE: -19.0 -10.0 -18.0 -15.0 -14.0 -13.0 -12.0 -6.0 SORT: -19.0 -18.0 -17.0 -16.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -9.0 -8.0 -7.0 -5.0 -4.0 -3.0 -2.0 -1.0 left: 10 mid: 12 right: 14 -17.0 -16.0 -16.0 -9.0 SORT: -19.0 -18.0 -17.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 right: 16 -16.0 left: 15 mid: 15 -17.0 MERGE: -19.0 | -5.0 | -4.0 SORT: -19.0 -18.0 -17.0-16.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -3.0 -2.0 -1.0 left: 15 mid: 16 right: 17 -4.0 | MERGE: -19.0 -18.0 -16.0 | -5.0 -4.0 SORT: -19.0 -18.0 -17.0-16.0 -15.0 -14.0 -13.0 -12.0-11.0 20.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -3.0 -2.0 -1.0mid: 18 -18.0 -17.0 -1.0 SORT: -19.0 -18.0 -17.0 -16.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 right: 19 left: 15 mid: 17 -17.0 -16.0 -16.0 | -5.0 -4.0 -3.0 | -4.0 -3.0 -2.0 SORT: -19.0 -18.0 -17.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -1.0 right: 19 -16.0 left: 10 mid: 14 ..0 -4.0 -4.0 _.0 -2.0 -2.0 MERGE: -19.0 -18.0 | -10.0 -9.0 -8.0 -7.0 -6.0 | -5.0 -3.0 -1.0 | -17.0 -3.0 SORT: -19.0 -18.0 -17.0 | left: 0 mid: 9 right: 19 | MERGE: | -19.0 -18.0 -17.0 -16.0 -15.0 | MERGE sap xep: -19.0 -18.0 -17.0 -16.0 | -5.0 SORT: -19.0 -18.0 -16.0 -15.0 -14.0 -13.0 -12.0 -11.0 20.0 -10.0 -9.0 -8.0 -7.0 -6.0 -1.0 -14.0 -13.0 -10.0 -9.0 -8.0 -7.0 9.0 -8.0 -7.0 -6 -12.0 -11.0 -5.0 -4.0 -3.0 -2.0 20.0 | -6.0 -6.0 -5.0 -15.0-14.0 -13.0-12.0 -11.0 -10.0 -9.0 -4.0 -3.0 -2.0 -1.0- program is finished running --





2.6 Testcase 6

Mảng đầu vào ngẫu nhiên là các số thực.

6.6 7.7 Mang ban dau: 1.1 2.2 3.3 4.4 11.11 12.12 13.13 3.3 mid: 0 mid: 0 mid: 0 sorn: 1.1 2.2 | SORT: 1.1 2.2 3.9 left: 0 MERGE: 8.8 11.11 12.12 13.13 14.14 4.4 5.5 6.6 9.9 10.1 15.15 16.16 17.0 18.0 19.0 20.0 right: 1 3.3 4.4 5.5 6.6 8.8 7.7 5.5 6.6 8.8 4.4 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 right: 2 2.2 | 5.5 6.6 8.8 11.11 20.0 4.4 5.5 SORT: 1.1 2.2 4.4 6.6 8.8 9.9 10.1 11.11 12,12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 2.2 MERGE: 1.1 3.3 | 4.4 | 5.5 | 7.7 11.11 12.12 17.0 6.6 8.8 10.1 13.13 14.14 15.15 16.16 18.0 19.0 20.0 5.5 SORT: 1.1 2.2 4.4 6.6 7.7 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 right: 4 n... 2.2 3.3 4.4 5.5 | 5.5 MERGE: | 1.1 3.3 | 4.4 6.6 8.8 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 20.0 SORT: 1.1 2.2 4.4 8.8 9.9 10.1 11.11 left: 5 mid: 5 right: 6 MERGE: 1.1 2.2 1 6.6 1 3.3 5.5 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 20.0 10.1 SORT: 6.6 7.7 9.9 right: 7 left: mid: 6 MERGE: 1.1 2.2 3.3 4.4 5.5 | 6.6 10.1 12.12 13.13 14.14 15.15 16.16 17.0 18.0 20.0 SORT: 7.7 mid: 8 right: 9 left: 8 2.2 MERGE: 1.1 3.3 4.4 5.5 6.6 1 9.9 1 10.1 I 11.11 12.12 13.13 14.14 15.15 16.16 20.0 6.6 left: mid: 7 right: 9 MERGE: 1.1 2.2 4.4 10.1 | 12.12 13.13 14.14 15.15 16.16 18.0 20.0 7.7 SORT: 6.6 8.8 9.9 10.1 1.1 2.2 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 m. 2.2 3.3 right: 9 left: 0 MERGE: | 1.1 10.1 | 11.11 12 12 13 13 14.14 SORT: 1.1 2.2 7.7 8.8 11.11 6.6 9.9 10.1 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 left: 10 mid: 10 right: 11 | 11.11 | 7.7 12.12 | 12.12 11.11 5.5 SORT: 1.1 2.2 3.3 4.4 6.6 9.9 10.1 14.14 15.15 16.16 18.0 19.0 20.0 left: 10 mid: 11 right: 12 | 11.11 MERGE: 12.12 | 12.12 13.13 SORT: 1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8 9.9 10.1 11.11 14.14 15.15 16.16 17.0 18.0 19.0 20.0 left: 13 mid: 13 right: 14 SORT: 1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 mid: 12 | 11.11 12.12 13.13 | 14.14 15.15 | 16.16 MERGE: 1.1 20.0 5.5 SORT: 1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 20.0 mid: 15 right: 16 2.2 | 16.16 | 4.4 6.6 7.7 11.11 12.12 13.13 14.14 15.15 18.0 MERGE: 1.1 3.3 5.5 8.8 9.9 10.1 20.0 11.11 17.0 SORT: 2.2 4.4 5.5 6.6 12.12 13.13 14.14 15.15 16.16 18.0 19.0 3.3 | 16.16 17.0 | MERGE: 1.1 2.2 4.4 5.5 6.6 10.1 11.11 12.12 13.13 14.14 15.15 20.0 SORT: 2.2 4.4 12,12 13.13 14.14 15.15 17.0 18.0 right: 19 5.5 6.6 mid: 18 2.2 3.3 left: 18 MERGE: 1.1 4.4 7.7 12.12 13.13 14.14 SORT: 20.0 1.1 2.2 3.3 4.4 5.5 6.6 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 left: 15 mid: 17 right: 19 | 16.16 17.0 18.0 | 16.16 17.0 18.0 19.0 SORT: 1.1 2.2 3.3 4.4 5.5 6.6 7.7 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 20.0 right: 19 5.5 19.0 19.0 left: 10 mid: 14 1 12.12 13.13 14.14 15.15 | 16.16 17.0 18.0 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 2.2 | 11.11 MERGE: 1.1 SORT: 1.1 2.2 3.3 4.4 5.5 6.6 8.8 9.9 10.1 11.11 mid: right: 19 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0 19.0 MERGE: | 1.1 10.1 | 2.2 3.3 4.4 Mang da sap xep: 1.1 2.2 3.3 6.6 7.7 8.8 9.9 10.1 11.11 12.12 13.13 14.14 15.15 16.16 17.0 18.0





2.7 Testcase 7

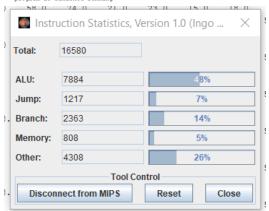
Mảng đầu vào ngẫu nhiên với các số nguyên nằm trong khoảng (0, 100) 3.0 58.0 58.0 13.0 15.0 47.0 68 0 20.0 36.0 56.0 58.0 54.0 20.0 left: 0 mid: 0 rig.. 3.0 50. 13.0 right: 1 , 100.0 | 10.0 | 10.0 100.0 3.0 MERGE: 58.0 13.0 15.0 47.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 SORT: 58.0 15.0 59.0 47.0 13.0 15.0 18.0 25.0 27.0 56.0 58.0 54.0 24.0 68.0 20.0 36.0 mid: 1 100.0 left: 0 3.0 | 50. 1 10.0 SORT: 3.0 10.0 100.0 15.0 47.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 left: 3 mid: 3 right: 4 58.0 | 58.0 SORT: 3.0 10.0 100.0 13.0 15.0 47.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 left: 0 mid: 2 right: 4 10.0 13.0 MERGE: | 3.0 13.0 58.0 SORT: 3.0 10.0 100.0 15.0 47.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 mid: 5
10.0 13.0
10.0 13.0 right: 6 MERGE: 3.0 58.0 100.0 58.0 100.0 59.0 13.0 | 15.0 | 18.0 68.0 24.0 47.0 SORT: 3.0 15.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 58.0 100.0 58.0 100.0 10.0 13.0 10.0 13.0 | 15.0 47.0 | 18.0 27.0 MERGE: 3.0 59.0 | 13.0 25.0 68.0 36.0 56.0 58.0 54.0 24.0 SORT: 3.0 47.0 59.0 13.0 15.0 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 mid: 8 right: 9 left: 10.0 13.0 10.0 13.0 58.0 MERGE: 3.0 58.0 100.0 58.0 100.0 59.0 | 13.0 | 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 SORT-15.0 47.0 59.0 15.0 left: right: 9 10.0 13.0 10.0 13.0 58.0 100.0 58.0 100.0 1 15.0 MERGE: 3.0 47.0 59.0 I 13.0 15.0 I 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 SORT: 15.0 15.0 47.0 mid: 4 rig.. 58.0 . 15.0 left: 0 13.0 10.0 MERGE: | 3.0 100.0 I 13.0 15.0 15.0 47.0 59.0 I 18.0 25.0 27.0 68.0 20.0 36.0 56.0 58.0 54.0 24.0 left: 10 mid: 10 right: 11 13.0 15.0 13.0 15.0 MERGE: 3.0 10.0 13.0 47.0 58.0 59.0 100.0 | 18.0 | 27.0 68.0 20.0 36.0 56.0 58.0 54.0 25.0 56.0 left: 10 mid: 11 right: 12 13.0 13.0 15.0 15.0 25.0 | 36.0 MERGE: 3.0 58.0 | 18.0 10.0 SORT: 13.0 47.0 68.0 20.0 36.0 56.0 24.0 15.0 58.0 59.0 100.0 58.0 54.0 left: 13 mid: 13 right: 14 13.0 15.0 13.0 15.0 68.0 SORT: 3.0 10.0 13.0 15.0 15.0 47.0 58.0 59.0 100.0 18.0 25.0 27.0 20.0 36.0 56.0 58.0 54.0 24.0 left: 10 mid: 12 right: 14 58.0 36.0 SORT: 3.0 10.0 13.0 13.0 15.0 15.0 47.0 58.0 59.0 100.0 18.0 20.0 25.0 27.0 68.0 36.0 56.0 58.0 54.0 24.0 left: 15 mid: 15 right: 16 13.0 15.0 13.0 15.0 | 36.0 | MERGE: 3.0 56.0 SORT: 3.0 10.0 13.0 47.0 58.0 59.0 100.0 18.0 20.0 25.0 27.0 68.0 36.0 58.0 54.0 24.0 mid: 16 left: 15 13.0 15.0 13.0 15.0 56.0 | 10.0 13.0 10.0 13.0 | 36.0 MERGE: 3.0 SORT: 3.0 15.0 47.0 58.0 59.0 100.0 18.0 20.0 25.0 27.0 68.0 36.0 56.0 58.0 54.0 24.0 mid: 18 right: 19 10.0 13.0 10.0 13.0 13.0 15.0 13.0 15.0 MERGE: 3.0 100.0 20.0 25.0 36.0 56.0 58.0 58.0 100.0 18.0 68.0 left: 15 mid: 17 right: 19 20.0 13.0 13.0 15.0 15.0 100.0 | 36.0 56.0 58.0 | 58.0 36.0 54.0 56.0 SORT: 27.0 24.0 10.0 13.0 15.0 47.0 58.0 59.0 100.0 18.0 20.0 25.0 68.0 left: 10 mid: 14 right: 19 20.0 24.0 25.0 27.0 36.0 54.0 58.0 56.0 68.0 SORT: 3.0 10.0 13.0 13.0 15.0 15.0 47.0 58.0 59.0 100.0 18.0 mia. 10.0 13.0 3.0 20.0 24.0 27.0 36 ° left: 0 right: 19 7.0 36.0 54.0 56.0 58.0 56.0 58.0 58.0 59.0 68. 1.0 25.0 47.0 54. 13.0 13.0 15.0 13.0 13.0 47.0 18.0 5.0 27.0 54.0 56.0 25.0 68.0 Mang da sap xep: 3.0 15.0 15.0 18.0 20.0 24.0 program is finished running --





2.8 Testcase 8

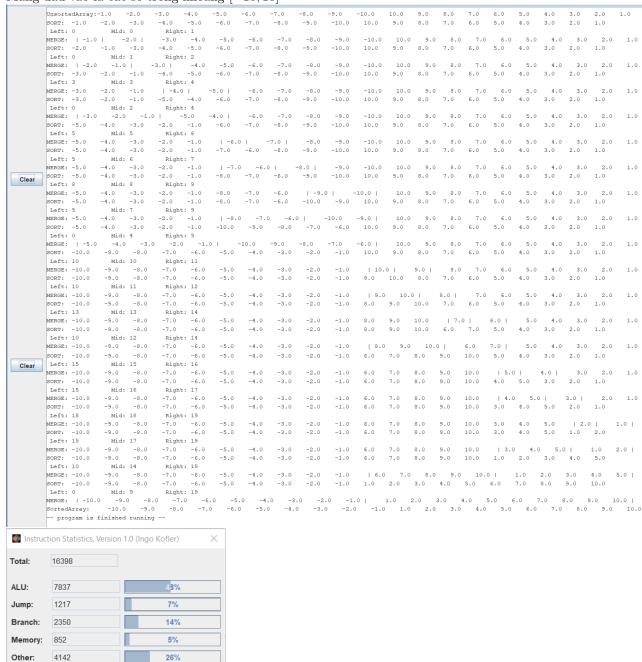
Mảng đầu vào ngẫu nhiên với các số nguyên nằm trong khoảng (0, 100) Mang ban dau: 15.0 58.0 36.0 47.0 SORT: 15.0 58.0 36.0 47.0 20.0 SORT: 10 left: 0 25.0 29.0 58.0 84.0 91.0 26.0 34.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 mid: 0 right: 1 36.0 47.0 36.0 4.. 20.0 SORT: 15.0 | 58.0 | Son left: 0 47.0 25.0 29.0 84.0 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 mid: 1 right: 2 36.0 | 47.0 47.0 20.0 MERGE: | 15.0 84.0 58.0 58.0 | 50.0 SORT: 15.0 36.0 58.0 25.0 29.0 84.0 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 mid: 3 36.0 36.0 58.0 MERGE: 15.0 25.0 29.0 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 | 47.0 | 84.0 54.0 50.0 47.0 SORT: 15.0 58.0 20.0 25.0 29.0 84.0 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 left: right: 4 MERGE: | 15.0 58.0 | 47.0 | 74.0 36.0 20.0 25.0 29.0 84.0 91.0 26.0 34.0 58.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 SORT: 20.0 36.0 47.0 58.0 29.0 21.0 mid: 5 right: 6 left: 5 20.0 36.0 20.0 36.0 MERGE: 15.0 47.0 58.0 1 25.0 1 29.0 I 84.0 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 58.0 SORT: 15.0 29.0 left: mid: 6 right: 7 20.0 47.0 47.0 MERGE: 15.0 36.0 58.0 1 25.0 29.0 | 91.0 26.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 SORT: 29.0 84.0 mid: 8 left: 8 right: 9 36.0 I 91.0 | MERGE: 15.0 20.0 58.0 29.0 84.0 34.0 58.0 21.0 15.0 18.0 54.0 50.0 15.0 20.0 36.0 58.0 25.0 29.0 58.0 74.0 23.0 18.0 19.0 54.0 50.0 left: 5 mid: 7 right: 9 20.0 47.0 47.0 58.0 18.0 MERGE: 15.0 36.0 58.0 25.0 29.0 84.0 | 26.0 34.0 21.0 15.0 54.0 84.0 SORT: 26.0 29.0 15.0 20.0 36.0 58.0 25.0 91.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 left: 0 mid: 4 right: 9 right 47.0 0 29.0 | 15.0 36.0 58.0 | 84.0 34.0 58.0 21.0 54.0 20.0 26.0 36.0 25.0 47.0 58.0 SORT: 15.0 84.0 91.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 left: 10 mid: 10 right: 11 MERGE: 15.0 | 34.0 | 58.0 SORT: 15.0 20.0 25.0 26.0 29.0 36.0 47.0 58.0 84.0 91.0 34.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 left: 10 mid: 11 right: 12 34.0 58.0 | MERGE: 15.0 SORT: 15.0 20.0 25.0 26.0 29.0 36.0 47.0 58.0 84.0 91.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 mid: 13 MERGE: 15.0 29.0 | 21.0 | 50.0 SORT: 15.0 20.0 25.0 26.0 29.0 36.0 47.0 58.0 84.0 91.0 34.0 58.0 74.0 21.0 23.0 15.0 18.0 19.0 54.0 50.0 74.0 23.0 I 20.0 25.0 26.0 29.0 26.0 29.0 58.0 34.0 58.0 21.0 15.0 18.0 54.0 MERGE: 15.0 84.0 91.0 50.0 SORT: 15.0 20.0 25.0 36.0 47.0 58.0 84.0 91.0 21.0 23.0 34.0 58.0 74.0 15.0 18.0 19.0 54.0 left: 15 mid: 15 right: 16 20.0 MERGE: 15.0 25.0 26.0 29.0 36.0 58.0 84.0 91.0 21.0 23.0 34.0 58.0 74.0 | 15.0 | 18.0 | 19.0 54.0 50.0 25.0 SORT-15.0 20.0 26.0 29 0 34.0 18.0 left: right: 17 26.0 29.0 26.0 29.0 MERGE: 15.0 20.0 25.0 36.0 58.0 84.0 91.0 21.0 23.0 34.0 1 15.0 18.0 I 19.0 I 54.0 50.0 SORT: 20.0 18.0 19.0 mid: 18 20.0 25.0 right: 19 26.0 29.0 left: MERGE: 15.0 | 54.0 | 50.0 I SORT: 15.0 20.0 25.0 26.0 29.0 36.0 47.0 58.0 84.0 91.0 21.0 23.0 34.0 58.0 74.0 15.0 18.0 19.0 50.0 54.0 mid: 26.0 29.0 26.0 29.0 74.0 | 15.0 19.0 | 50.0 84.0 91.0 21.0 18.0 MERGE: 15.0 54.0 | SORT: 15.0 20.0 25.0 36.0 47.0 58.0 84.0 91.0 21.0 23.0 34.0 58.0 74.0 15.0 18.0 19.0 50.0 54.0 mid: 14 right: 19 20.0 25.0 20.0 25.0 74.0 | 18.0 MERGE: 15.0 26.0 26.0 29.0 26.0 29.0 36.0 47.0 58.0 84.0 91.0 | 21.0 23.0 34.0 58.0 15.0 19.0 50.0 54.0 | 58.0 SORT: 15.0 36.0 58.0 84.0 15.0 18.0 19.0 21.0 23.0 34.0 50.0 54.0 right: 19 rigne. 26.0 25. 20.0 25.0 15.0 15.0 34.0 50.0 54.0 58.0 74.0 | MERGE: | 15.0 36.0 47.0 58.0 15.0 19.0 21.0 23.0 29.0 84.0 91.0 | 18.0 21.0 29.0 34.0 36.0 47.0 50.0 54.0 58.0 58.0 74.0 84.0 - program is finished running -





2.9 Testcase 9

Mảng đầu vào là các số trong khoảng [-10, 10]



Tool Control

Reset

Close

Disconnect from MIPS



2.10 Testcase 10

Mảng đầu vào là các số ngẫu nhiên trong khoảng $\left[-99,99\right]$

