C 语言排序算法性能测试

摘要

本实验主要探讨堆排序,冒泡排序,斐波那契堆排序的性能
通过在不同的编译优化条件下分别对10,100,1000,10000,100000个数据排序所用时间和空间的对比来判堆算法的性能
最后结果表明:

1. 堆排序最快
2. 数据量小于100时冒泡排序比斐波那契堆排序
3. 数据量大于1000时三种算法速度有**堆排序>斐波那契堆排序>冒泡排序**的关系

前言

什么样的程序才是好的程序?

对于用户来,说好的程序往往代表着人性化的交互界面,高效率,安全等等.
而效率就像货币一样,通过牺牲效率我们可以换来更安全的程序,更方便的图形界面.
一个好的算法往往可以带来更高的效率.本次实验将实现三个经典的排序算法:
冒泡排序,**堆排序**和**斐波那契堆排序**并测试这三种算法在不同数据量下的性能.

环境配置

- 下载VMware和Ubuntu22.04 LTS
  本实验在Linux虚拟机中进行所以先安装虚拟机软件.在VMware官网下载VMware并进行安装,再到ubuntu官网下载Ubuntu22.04 LTS.
- 安装Linux系统
  打开VMware创建新的虚拟机,选择自定义后按下一步至选择系统文件处.选择下载好的Ubuntu系统并按下一步安装.
  设置密码后设置虚拟机安装位置.选择合适的配置后安装虚拟机.按推荐方式安装Ubuntu后将自动进行网络配置.
- 安装gcc,vscode
  待Ubuntu安装完成后在终端中执行
  `sudo apt install gcc`
  `sudo apt install build-essential`
  安装gcc.
  通过`gcc --version`检查gcc是非安装成功.
  并于vscode官网安装vscode安装包, 下载完后双击安装.

算法实现

- 冒泡排序

```
#include "bubbleSort.h"
```

```
void bubbleSort(int* arry, int length){
    int flag = 1;
    for (int i = 0; i < length - 1; i++){
        flag = 1;
        for (int j = 0; j< length - 1 - i; j++){
            if (arry[j] > arry[j + 1]){
               int tmp = arry[j];
                arry[j] = arry[j + 1];
               arry[j + 1] = tmp;
                flag = 0;
            }
        }
        if (flag) break;
    }
}
```

- 堆排序

```
#include<stdlib.h>

int* heapSort(int* arry, int length){
    //堆化
   for (int i = length; i > 1; i--){
        int index = i;
       while (index > 1) {
            if (arry[index] < arry[index / 2]){
               int tmp = arry[index];
               arry[index] = arry[index / 2];
               arry[index / 2] = tmp;
               index /= 2;
           }else break;
       }
  }

   int length2 = length;
   int* result = (int*)(malloc((length2 + 1) * sizeof(int)));
   result[0] = 0;
  //取出堆中最小值
  for (int i = 1; i < length2 + 1; i++){
      int min = 1;
      int smallChilden = min * 2;
      result[i] = arry[1];
      arry[1] = arry[length];//将最后一个叶子节点放至根节点
      length -= 1;
      //当有子结点时进行循环，维持堆结构
      while (min * 2 < length + 1) {
          if (smallChilden < length && arry[smallChilden] > arry[smallChilden + 1]) smallChilden +=   1;//如果有右孩且右孩子比左孩子小
           if (arry[min] > arry[smallChilden]) {
               int tmp = arry[min];
               arry[min] = arry[smallChilden];
               arry[smallChilden] = tmp;
```

```
                min = smallChilden;
                smallChilden *= 2;
            }else{
                break;
            }
        }
    }

    return result;
}
```

- 斐波那契堆排序

▶ 点击展开代码

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

typedef int Type;

typedef struct FibNode {
    Type key;                       //关键字(键值)
    int degree;                     //度数
    struct FibNode* left;           //左兄弟
    struct FibNode* right;          //右兄弟
    struct FibNode* child;          //第一个孩子结点
    struct FibNode* parent;         //父结点
}FibNode;

typedef struct FibHeap {
    int   keyNum;                    //堆中结点的总数
    int   maxDegree;                 //最大度
    struct FibNode* min;             //最小结点(某个最小堆的根结点)
    struct FibNode** cons;           //最大度的内存区域
}FibHeap;

//将node从双链表移除
void fibNodeRemove(FibNode* node) {
    node->left->right = node->right;
    node->right->left = node->left;
}

//将单个结点node加入双向链表root之前
void fibNodeAdd(FibNode* node, FibNode* root) {
    node->left = root->left;
    root->left->right = node;
    node->right = root;
    root->left = node;
}

//将双向链表b链接到双向链表a的后面
```

```
void fibNodeCat(FibNode* a, FibNode* b) {
    FibNode* tmp;
    tmp = a->right;
    a->right = b->right;
    b->right->left = a;
    b->right = tmp;
    tmp->left = b;
}

//创建斐波那契堆
FibHeap* fibHeapMake() {
    FibHeap* heap;
    heap = (FibHeap*)malloc(sizeof(FibHeap));
    if (heap == NULL) {
        printf("Error: make FibHeap failed\n");
        return NULL;
    }
    heap->keyNum = 0;
    heap->maxDegree = 0;
    heap->min = NULL;
    heap->cons = NULL;
    return heap;
}

//创建斐波那契堆的结点
FibNode* fibNodeMake(Type key) {
    FibNode* node;
    node = (FibNode*)malloc(sizeof(FibNode));
    if (node == NULL) {
        printf("Error: make Node failed\n");
        return NULL;
    }
    node->key = key;
    node->degree = 0;
    node->left = node;
    node->right = node;
    node->parent = NULL;
    node->child = NULL;
    return node;
}

//将结点node插入到斐波那契堆heap中
void fibHeapInsert_node(FibHeap* heap, FibNode* node) {
    if (heap->keyNum == 0) {
        heap->min = node;
    }
    else {
        fibNodeAdd(node, heap->min);
        if (node->key < heap->min->key) {
            heap->min = node;
        }
    }
    heap->keyNum++;
}
```

```
//新建键值为key的结点，并将其插入到斐波那契堆中
void fibHeapInsert_key(FibHeap* heap, Type key) {
    FibNode* node;
    if (heap == NULL) {
        printf("The heap does not exist\n");
        return;
    }
    node = fibNodeMake(key);
    if (node == NULL) {
        printf("Cannot make node\n");
        return;
    }
    fibHeapInsert_node(heap, node);
}

//将"堆的最小结点"从根链表中移除，即"将最小结点所属的树"从堆中移除
FibNode* fibHeapRemove_min(FibHeap* heap) {
    FibNode* min = heap->min;
    if (heap->min == min->right) {
        heap->min = NULL;
    }
    else {
        fibNodeRemove(min);
        heap->min = min->right;
    }
    min->left = min->right = min;
    return min;
}

//将node链接到root根结点
void fibHeapLink(FibHeap* heap, FibNode* node, FibNode* root) {
    //将node从双链表中移除
    fibNodeRemove(node);
    //将node设为root的孩子
    if (root->child == NULL) {
        root->child = node;
    }
    else {
        fibNodeAdd(node, root->child);
    }
    node->parent = root;
    root->degree++;
}

//创建fib_heap_consolidate所需空间
void fibHeapConsInit(FibHeap* heap) {
    int old = heap->maxDegree;
    //计算log2(x)，向上取整
    heap->maxDegree = (int)(log((double)(heap->keyNum)) / log(2.0)) +
1;
    //如果原本空间不够，则再次分配内存
    if (old >= heap->maxDegree) {
        return;
```

```
    }
    //因为度为heap->maxDegree可能被合并，所以要maxDegree+1
    heap->cons = (FibNode**)realloc(heap->cons, sizeof(FibHeap*) *
(heap->maxDegree + 1));
}

//合并斐波那契堆的根链表中左右相同度数的树
void fibHeapConsolidate(FibHeap* heap) {
    //开辟所用空间
    fibHeapConsInit(heap);
    int i;
    int D = heap->maxDegree + 1;
    for (i = 0; i < D; i++) {
        heap->cons[i] = NULL;
    }
    //合并相同度的根结点，使每个度数的树唯一
    while (heap->min != NULL) {
        FibNode* x = fibHeapRemove_min(heap);    //取出堆中的最小树(最小结
点所在的树)
        int d = x->degree;                       //获取最小树的度数
        //heap->cons[d] != NULL，意味着有两棵树(x和y)的"度数"相同。
        while (heap->cons[d] != NULL) {
            FibNode* y = heap->cons[d];          //y是"与x的度数相同的树"
            if (x->key > y->key) {               //保证x的键值比y小
                FibNode* tmp = x;
                x = y;
                y = tmp;
            }
            fibHeapLink(heap, y, x);             //将y链接到x中
            heap->cons[d] = NULL;
            d++;
        }
        heap->cons[d] = x;
    }
    heap->min = NULL;
    //将heap->cons中的结点重新加到根表中
    for (i = 0; i < D; i++) {
        if (heap->cons[i] != NULL) {
            if (heap->min == NULL) {
                heap->min = heap->cons[i];
            }
            else {
                fibNodeAdd(heap->cons[i], heap->min);
                if ((heap->cons[i])->key < heap->min->key) {
                    heap->min = heap->cons[i];
                }
            }
        }
    }
}

//移除最小结点min
FibNode* fibHeapExtractMin_node(FibHeap* heap) {
    if (heap == NULL || heap->min == NULL) {
```

```
        return NULL;
    }
    FibNode* child = NULL;
    FibNode* min = heap->min;
    //将min每一个儿子(儿子和儿子的兄弟)都添加到"斐波那契堆的根链表"中
    while (min->child != NULL) {
        child = min->child;
        fibNodeRemove(child);
        if (child->right == child) {//感觉可以优化
            min->child = NULL;
        }
        else {
            min->child = child->right;
        }
        fibNodeAdd(child, heap->min);
        child->parent = NULL;
    }
    //将min从根链表中移除
    fibNodeRemove(min);
    if (min->right == min) { //若min是堆中唯一结点，则设置堆的最小结点为NULL；
        heap->min = NULL;
    }
    else {                   //否则，设置堆的最小结点为一个非空结点(min->right)，然后再进行调节。
        heap->min = min->right;
        fibHeapConsolidate(heap);
    }
    heap->keyNum--;
    return min;
}

int fibHeapExtractMin(FibHeap* heap) {
    FibNode* node;
    if (heap == NULL || heap->min == NULL) {
        return 0;
    }
    node = fibHeapExtractMin_node(heap);
    if (node != NULL) {
        int a = node->key;
        free(node);
        return a;
    }
}
//从node开始销毁结点
void fibNodeDestroy(FibNode* node) {
    FibNode* start = node;
    if (node == NULL) {
        return;
    }
    do {
        fibNodeDestroy(node->child);
        // 销毁node，并将node指向下一个
        node = node->right;
```

```
            free(node->left);
        } while (node != start);
    }

    //销毁斐波那契堆
    void fibHeapDestroy(FibHeap* heap) {
        fibNodeDestroy(heap->min);
        free(heap->cons);
        free(heap);
    }

    int* fibSort(FibHeap* heap) {
        int* a = (int*)malloc(sizeof(int) * heap->keyNum);
        int length = heap->keyNum;
        for (int i = 0; i < length; i++) {
            a[i] = fibHeapExtractMin(heap);
        }
        return a;
    }
```

测试数据生成

```
srand(time(NULL)); //设置随机种子
int n = 10;
FILE *f = fopen("../data/1_1.txt","w");
for (int i = 0; i < n; i++) {
    int random_num = rand() % 10000; // 生成0到9999之间的随机数
    fprintf(f, "%d ", random_num);
}
fclose(f);
/*
在main函数中使用以上代码随机生成一些数并储存在data文件夹中,每次手动改变n数量为
10,100,1000,10000,100000后运行三次分别生成    1_1.txt,1_2.txt,1_3.txt以及
2_1.txt,2_2.txt等等
*/
```

编译与性能测试

修改.vscode文件夹下task.json确保编译器正确链接文件
通过在-g下方添加-o1,-o2等进行不同程度编译优化

```
{
    "tasks": [
        {
            "type": "cppbuild",
            "label": "C/C++: gcc-13 生成活动文件",
            "command": "/usr/bin/gcc-13",
            "args": [
                "-fdiagnostics-color=always",
```

```
                "-g",
                "${fileDirname}/main.c",
                "${fileDirname}/bubbleSort.c",
                "${fileDirname}/heapSort.c",
                "${fileDirname}/fibSort.c",
                "-o",
                "${fileDirname}/${fileBasenameNoExtension}",
                "-lm"
            ],
            "options": {
                "cwd": "${fileDirname}"
            },
            "problemMatcher": [
                "$gcc"
            ],
            "group": {
                "kind": "build",
                "isDefault": true
            },
            "detail": "调试器生成的任务。"
        }
    ],
    "version": "2.0.0"
}
```

- 冒泡排序数据测试

```
#include"bubbleSort.h"
#include<stdio.h>
#include <sys/resource.h>
#include<time.h>


void main(){
    struct rusage usage;
    getrusage(RUSAGE_SELF, &usage);
    const int length = 10;
    int a[length];
    int index = 0;
    FILE* f = fopen("../data/1_1.txt","r");
    while(fscanf(f,"%d",&a[index]) == 1){
        index++;
    }
    fclose(f);

    clock_t start = clock();
    bubbleSort(a, length);
    clock_t end = clock();
    double timeUsed = ((double)(end - start)) / CLOCKS_PER_SEC;

    FILE* file = fopen("../data/00/bubbleSort_1_1.txt","w");
    fprintf(file, "用时:%fs\n占用内存%ldKB\n排序结果为:\n", timeUsed,
```

```
usage.ru_maxrss);
    for(int i = 0; i < length; i++){
        fprintf(file, "%d ",a[i]);
    }
}
```

- 堆排序数据测试

```
#include"heapSort.h"
#include<stdio.h>
#include <sys/resource.h>
#include<time.h>
#include <stdlib.h>


void main(){

    struct rusage usage;
    getrusage(RUSAGE_SELF, &usage);
    const int length = 10;
    int a[length];
    int index = 0;
    FILE* f = fopen("../data/1_1.txt","r");
    while(fscanf(f,"%d",&a[index]) == 1){
        index++;
    }
    fclose(f);

    clock_t start = clock();
    int* b = (int*)malloc(sizeof(int) * length);
    b = heapSort(a, length);
    clock_t end = clock();
    double timeUsed = ((double)(end - start)) / CLOCKS_PER_SEC;
    FILE* file = fopen("../data/Ofast/heapSort_1_1.txt","w");
    fprintf(file, "用时:%fs\n占用内存%ldKB\n排序结果为:\n", timeUsed,
usage.ru_maxrss);
    for(int i = 0; i < length; i++){
        fprintf(file, "%d ",b[i]);
    }
    fclose(file);

}
```

- 斐波那契堆排序数据测试

```
#include"fibSort.h"
#include<stdio.h>
#include <sys/resource.h>
#include<time.h>
```

```c
#include <stdlib.h>


void main(){
    struct rusage usage;
    getrusage(RUSAGE_SELF, &usage);
    const int length = 10;
    int a[length];
    int index = 0;
    FibHeap* heap = fibHeapMake();
    FILE* f = fopen("../data/1_1.txt","r");
    while(fscanf(f,"%d",&a[index]) == 1){
        fibHeapInsert_key(heap,a[index]);
        index++;
    }
    fclose(f);
    int* b = (int*)malloc(sizeof(int) * length);
    clock_t start = clock();
    b = fibSort(heap);
    clock_t end = clock();
    double timeUsed = ((double)(end - start)) / CLOCKS_PER_SEC;
    FILE* file = fopen("../data/O0/fibSort_1_1.txt","w");
    fprintf(file, "用时:%fs\n占用内存%ldKB\n排序结果为:\n", timeUsed,
usage.ru_maxrss);
    for(int i = 0; i < length; i++){
        fprintf(file, "%d ",b[i]);
    }
    fclose(file);


}
```

结果与分析

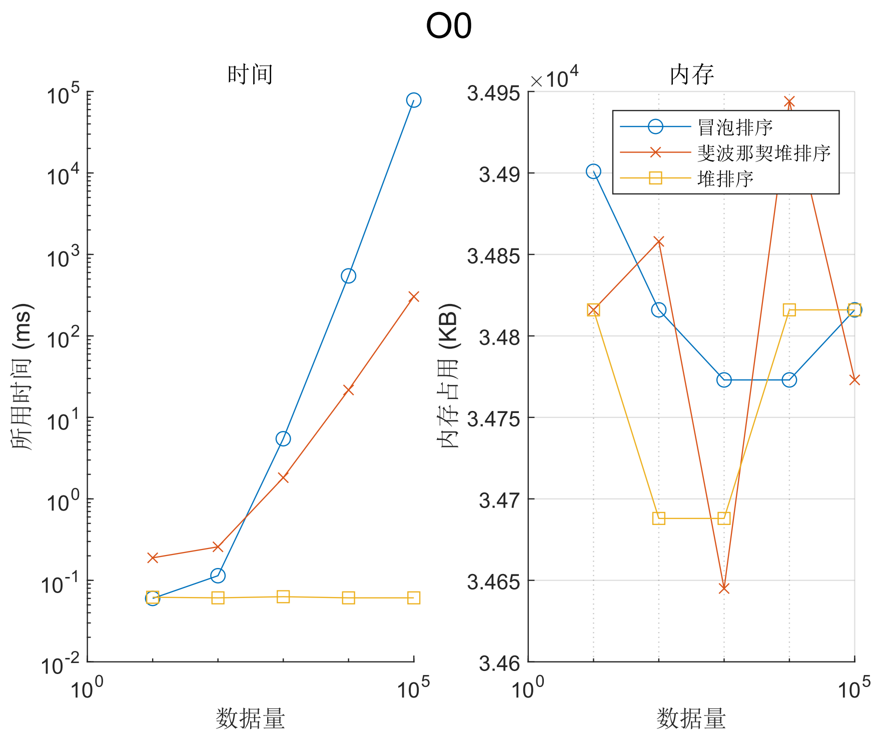
对实验结果求平均值并存在data/result文件夹下
使用matlab绘制图像并保存在data/result文件夹下

```matlab
types = ["bubbleSort", "fibSort", "heapSort"];
options = ["O0","O1","O2","O3","Ofast"];
times = [];
memory = [];

% 读取文件内容并提取数据
for i = 1:75
    % 计算类型索引，并生成路径
    index = ceil(i / 15);
    index2 = i - (index - 1) * 15;
    route = sprintf('../data/result/%s/%s%d.txt', options(index),
types(ceil(index2 / 5)), mod(i - 1, 5) + 1);

    % 打开文件并检查是否成功
```

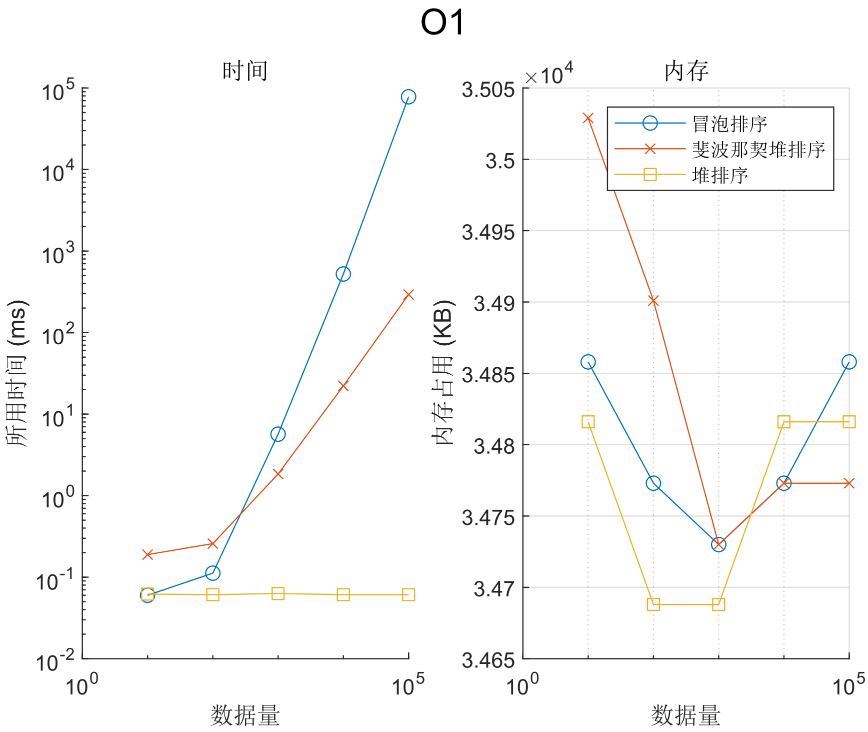
```
    fileID = fopen(route, 'r');
    if fileID == -1
        warning('无法打开文件: %s', route);
        continue;
    end

    % 逐行读取文件内容
    while ~feof(fileID)
        line = fgetl(fileID);
        if contains(line, '平均用时')
            time_value = sscanf(line, '平均用时:%fs');
            times = [times; time_value * 1000];  % 追加时间数据
        elseif contains(line, '占用')
            memory_value = sscanf(line, '占用%dKB内存');
            memory = [memory; memory_value];  % 追加内存数据
        end
    end

    % 关闭文件
    fclose(fileID);
end

data_sizes = [10,100,1000,10000,100000];

for i = 1:5
    bubbleSort_times = times(1 + 15 * (i - 1):5 + 15 * (i - 1));
    heapSort_times = times(6 + 15 * (i - 1):10 + 15 * (i - 1));
    fibheapSort_times = times(11 + 15 * (i - 1):15 + 15 * (i - 1));
    bubbleSort_mem = memory(1 + 15 * (i - 1):5 + 15 * (i - 1));
    heapSort_mem = memory(6 + 15 * (i - 1):10 + 15 * (i - 1));
    fiboheapSort_mem = memory(11 + 15 * (i - 1):15 + 15 * (i - 1));
    figure;
    subplot(1, 2, 1); % 左侧绘制时间曲线
    hold on;
    plot(data_sizes, bubbleSort_times, '-o', 'DisplayName', '冒泡排序');
    plot(data_sizes, heapSort_times, '-x', 'DisplayName', '斐波那契堆排序');
    plot(data_sizes, fibHeapSort_times, '-s', 'DisplayName', '堆排序');
    set(gca, 'XScale', 'log'); % 将X轴设为对数刻度
    set(gca, 'YScale', 'log'); % 将Y轴设为对数刻度
    xlabel('数据量');
    ylabel('所用时间 (ms)');
    title('时间');

    subplot(1, 2, 2); % 右侧绘制内存曲线
    hold on;
    plot(data_sizes, bubbleSort_mem, '-o', 'DisplayName', '冒泡排序');
    plot(data_sizes, heapSort_mem, '-x', 'DisplayName', '斐波那契堆排序');
    plot(data_sizes, fibHeapSort_mem, '-s', 'DisplayName', '堆排序');
    hold off;
    set(gca, 'XScale', 'log'); % 将X轴设为对数刻度

    xlabel('数据量');
    ylabel('内存占用 (KB)');
    title('内存');
```

```
    legend('show');
    grid on;

    % 调整布局
    sgtitle(options(i));
    route2 = sprintf('../data/result/%s.svg', options(i));
    print(route2, '-dsvg');
end
```

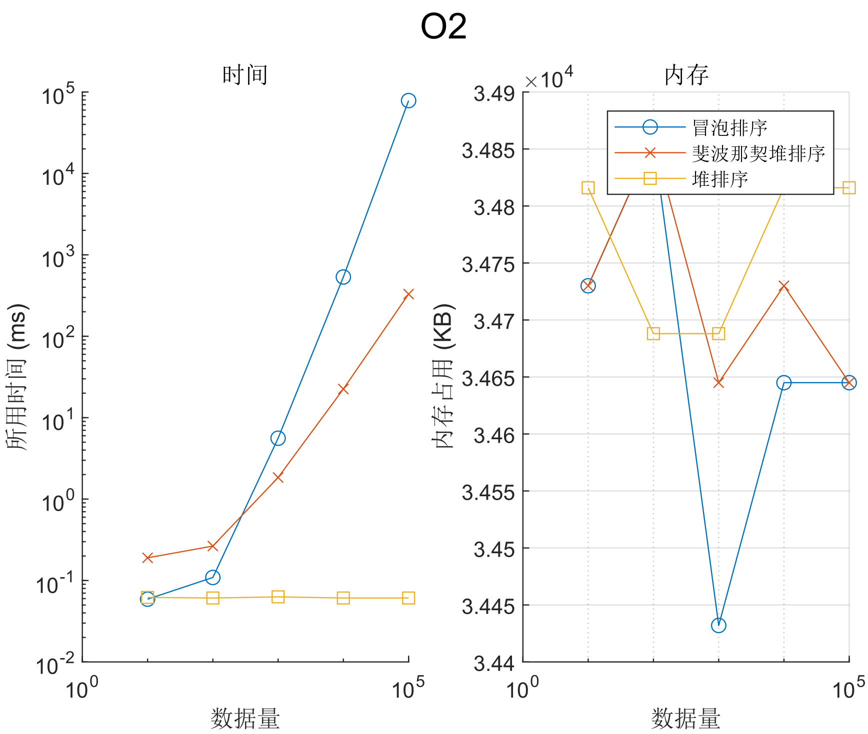
O0



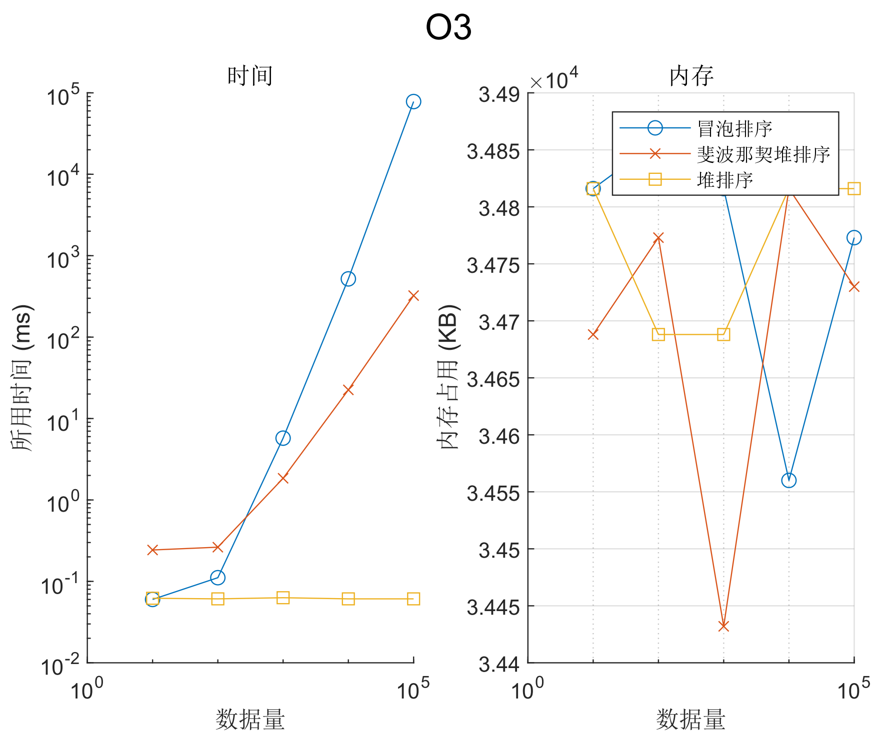
O1


O1
时间
所用时间 (ms)
数据量
内存
内存占用 (KB)
冒泡排序
斐波那契堆排序
堆排序

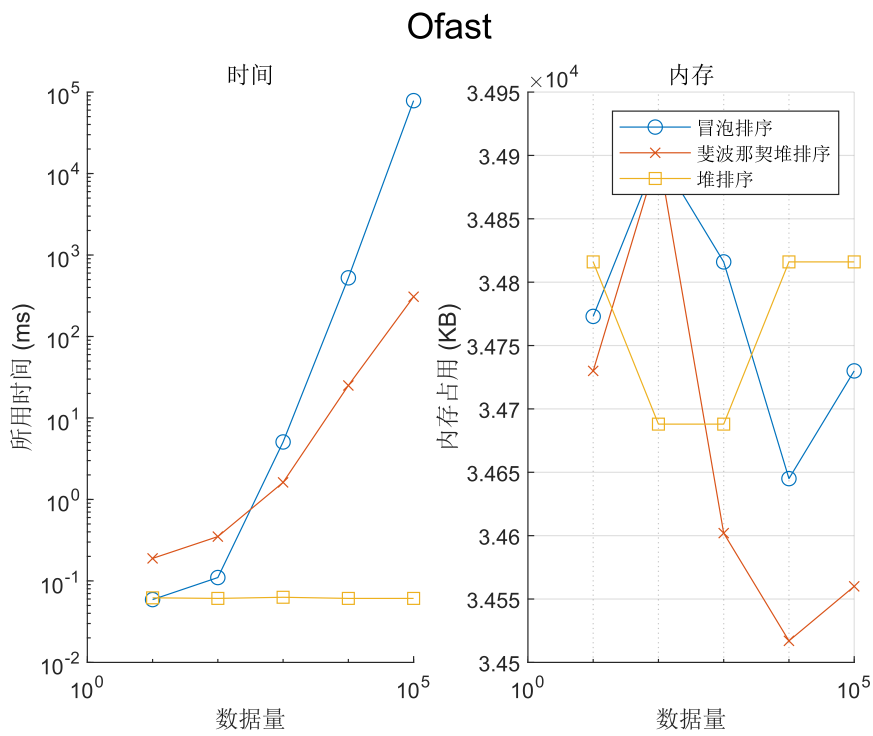
O2


O2
时间
所用时间 (ms)
数据量
内存
内存占用 (KB)
冒泡排序
斐波那契堆排序
堆排序

O3



Ofast



分析

三个算法在不同优化条件下运行时间基本相同,占用内存大小略有波动都在34000到35000KB之间.
因程序运行时间不同,**占用内存大小的波动可视为误差**
且在不同优化条件下**各算法运行速度无明显改变**
其中**冒泡排序**在数据量低于100时运行速度比**斐波那契堆排序**快
在此之后三种排序算法速度呈现**堆排序>斐波那契堆排序>冒泡排序**的趋势
而**堆排序**一直有着较快的排序速度
结果与各个排序算法的时间复杂度略有出路

冒泡排序:O(n^2)
斐波那契堆排序:O(nlogn)
堆排序:O(nlogn)
推测可能是因为斐波那契堆排序过程中**代码优化差**
或因为斐波那契堆生成过程中**其他代码消耗了过多时间**导致最后排序速度慢.

结论

在数据量小于100000的情况下**gcc的优化等级并无多大影响**
在算法速度方面**堆排序最快,当数据量小于100时冒泡排序比斐波那契堆排序快**
之后算法速度呈现**堆排序>斐波那契堆排序>冒泡排序**的规律

讨论

- 启示
  从代码实现难易程度来看冒泡排序无疑是最简单的,斐波那契堆排序是最复杂的.
  而当数据量小于100000时冒泡排序所用的时间并非不可接受,所以根据数据量来选择算法或许是个好主意.
  斐波那契堆排序就并不适用于较小数据量的排序.
- 改进方向
  1. 数据的处理,生成和测试应选用for循环自动处理,手动处理过于枯燥和浪费时间
  2. 斐波那契堆的实现还有优化空间
  3. 未测试Os优化下算法运行情况数据可能不全面
  4. 本次测试数据范围略小,得出的结论可能并不全面

参考文献

- https://blog.csdn.net/baidu_40395808/article/details/138541629 斐波那契堆的C语言实现
- https://www.cnblogs.com/luanxm/p/10848032.html clash verge安装
- https://chatgpt.com 代码书写帮助

附录

本实验所有代码都在github上托管
[代码地址]

实验过程所遇问题

- gcc无法自动链接源文件
  解决方法:修改位于.vscode文件下的task.json文件
- 手搓斐波那契堆失败
  解决方法:CV CSDN上fufufunny的代码
- git push总是无法连接到github
  解决方法:因为手动在github上修改README.md导致需要pull.因过于麻烦故重新clone.
- 在终端push时需要passwad但远程认证服务已停止
  解决方法:在github申请token用于登录.