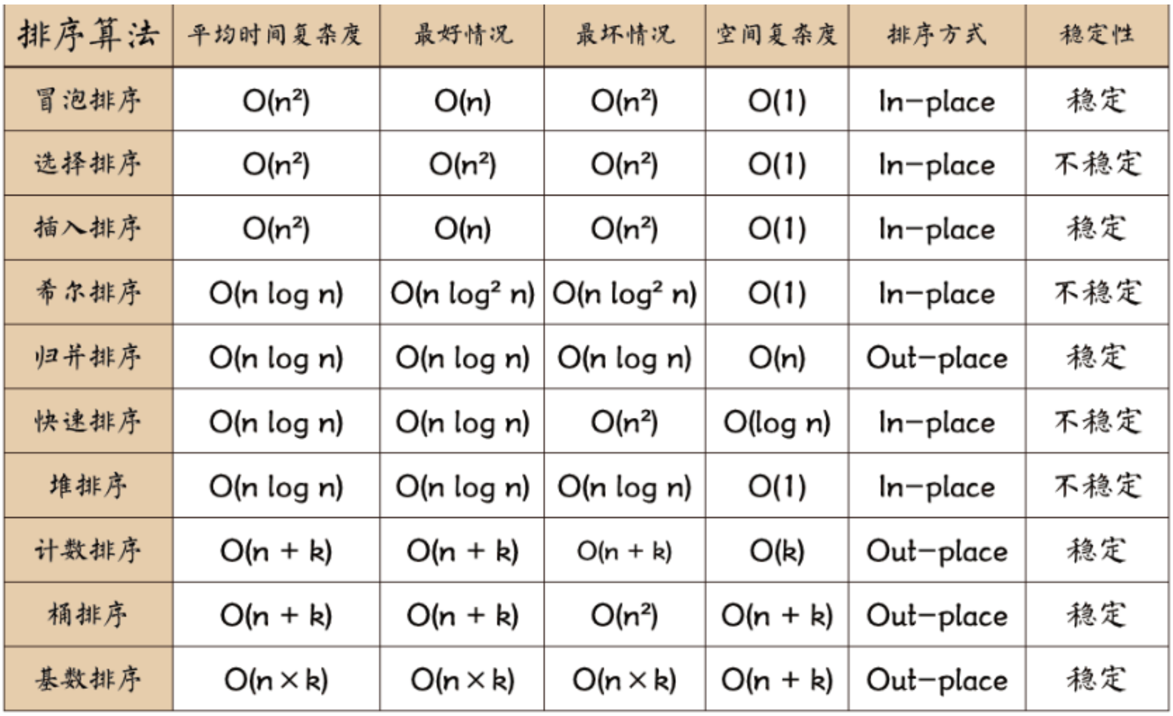
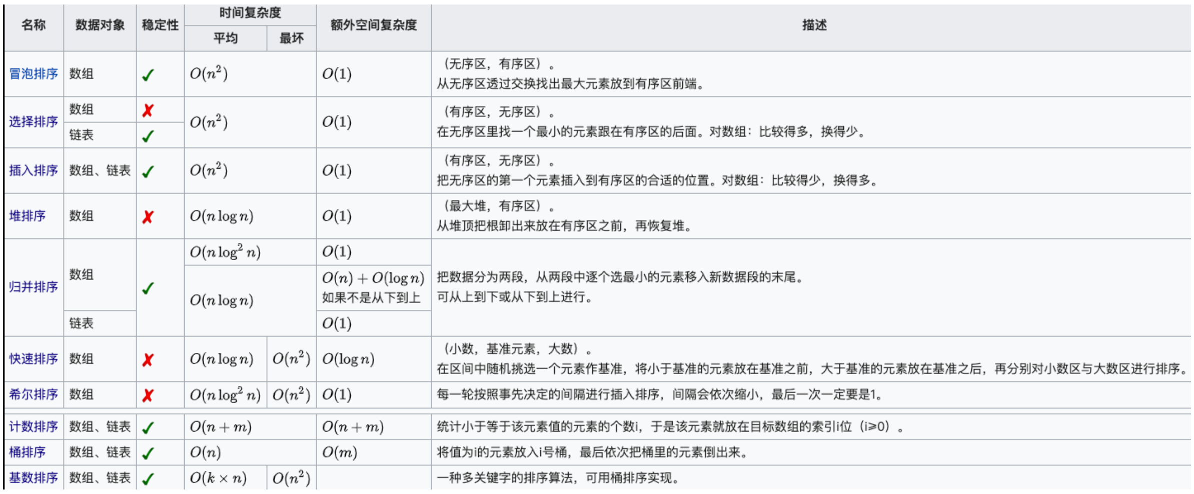
数组排序



排序算法	平均时间复杂度	最好情况	最坏情况	空间复杂度	排序方式	稳定性
冒泡排序	$O(n^2)$	$O(n)$	$O(n^2)$	$O(1)$	In-place	稳定
选择排序	$O(n^2)$	$O(n^2)$	$O(n^2)$	$O(1)$	In-place	不稳定
插入排序	$O(n^2)$	$O(n)$	$O(n^2)$	$O(1)$	In-place	稳定
希尔排序	$O(n \log n)$	$O(n \log^2 n)$	$O(n \log^2 n)$	$O(1)$	In-place	不稳定
归并排序	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(n)$	Out-place	稳定
快速排序	$O(n \log n)$	$O(n \log n)$	$O(n^2)$	$O(\log n)$	In-place	不稳定
堆排序	$O(n \log n)$	$O(n \log n)$	$O(n \log n)$	$O(1)$	In-place	不稳定
计数排序	$O(n + k)$	$O(n + k)$	$O(n + k)$	$O(k)$	Out-place	稳定
桶排序	$O(n + k)$	$O(n + k)$	$O(n^2)$	$O(n + k)$	Out-place	稳定
基数排序	$O(n \times k)$	$O(n \times k)$	$O(n \times k)$	$O(n + k)$	Out-place	稳定



名称	数据对象	稳定性	时间复杂度		额外空间复杂度	描述
			平均	最坏		
冒泡排序	数组	✓	$O(n^2)$		$O(1)$	（无序区，有序区）。 从无序区透过交换找出最大元素放到有序区前端。
选择排序	数组	✗	$O(n^2)$		$O(1)$	（有序区，无序区）。 在无序区里找一个最小的元素跟在有序区的后面。对数组：比较得多，换得少。
	链表	✓				
插入排序	数组、链表	✓	$O(n^2)$		$O(1)$	（有序区，无序区）。 把无序区的第一个元素插入到有序区的合适的位置。对数组：比较得少，换得多。
堆排序	数组	✗	$O(n\log n)$		$O(1)$	（最大堆，有序区）。 从堆顶把根卸出来放在有序区之前，再恢复堆。
归并排序	数组	✓	$O(n\log^2 n)$		$O(1)$	把数据分为两段，从两段中逐个选最小的元素移入新数据段的末尾。 可从上到下或从下到上进行。
			$O(n\log n)$		$O(n)+O(\log n)$ 如果不是从下到上	
	链表				$O(1)$	
快速排序	数组	✗	$O(n\log n)$	$O(n^2)$	$O(\log n)$	（小数，基准元素，大数）。 在区间中随机挑选一个元素作基准，将小于基准的元素放在基准之前，大于基准的元素放在基准之后，再分别对小数区与大数区进行排序。
希尔排序	数组	✗	$O(n\log^2 n)$	$O(n^2)$	$O(1)$	每一轮按照事先决定的间隔进行插入排序，间隔会依次缩小，最后一次一定要是1。
计数排序	数组、链表	✓	$O(n+m)$		$O(n+m)$	统计小于等于该元素值的元素的个数i，于是该元素就放在目标数组的索引i位（i⩾0）。
桶排序	数组、链表	✓	$O(n)$		$O(m)$	将值为i的元素放入i号桶，最后依次把桶里的元素倒出来。
基数排序	数组、链表	✓	$O(k \times n)$	$O(n^2)$		一种多关键字的排序算法，可用桶排序实现。

选择排序

时间复杂度 `O(n^2)`

空间复杂度 `O(1)`

不稳定

比较次数`1 + 2 + 3 +...+ n-1 = n(n-1)/2`

移动次数 `3*(n-1)`

```cpp
void select_sort(vector<int> &arr) {
    for (int i = 0; i < arr.size(); ++i) {
        int min = i;
        for (int j = i + 1; j < arr.size(); ++j) {
            if (arr[j] <= arr[min]) {
                min = j;
            }
        }
        swap(arr[i], arr[min]);
    }
}
```

冒泡排序

时间复杂度 `O(n^2)`

空间复杂度 `O(1)`

稳定

最好情况

- `123456`
- 比较次数 `n-1`
- 移动次数`0`
- 时间复杂度 `O(n)`

最坏情况

- `654321`
- 比较次数`1 + 2 + 3 +...+ n-1 = n(n-1)/2`
- 移动次数 `3*n(n-1)/2`
- 时间复杂度 `O(n^2)`

```cpp

void swap_xor(vector<int>::value_type &value1, vector<int>::value_type &value2) {
    value1 = value1 ^ value2;
    value2 = value1 ^ value2;
    value1 = value1 ^ value2;
};

void bubble_sort(vector<int> &arr) {
    if (arr.empty() || arr.size() < 2) return;
    bool flag = false;
    for (int e = arr.size() - 1; e >= 0; --e) {
        for (int i = 0; i < e; ++i) {
            if (arr[i] > arr[i + 1]) {
                swap(arr[i], arr[i + 1]);
                flag = true;
            }
        }
        if (!flag) break;
    }
}
```

插入排序

时间复杂度 `O(n^2)`

空间复杂度 `O(1)`

稳定

最好情况

- `123456`
- 比较次数 `n-1`
- 移动次数`0`
- 时间复杂度 `O(n)`

最坏情况

- `654321`
- 比较次数`1 + 2 + 3 +...+ n-1 = n(n-1)/2`
- 移动次数 `2+3+4+...+n=(n+2)(n-1)/2`
- 时间复杂度 `O(n^2)`

```

    void insertSort(vector<int> &arr) {
        for (int i = 1; i < arr.size(); ++i) {
            for (int j = i-1; j >=0 && arr[j] > arr[j+1] ; j--) {
                swap(arr[j],arr[j+1]);
            }

        }
    }
```

希尔排序 `( while )`

```
void shell_sort1(vector<int> &arr) {
    int len = arr.size();
    int interval = len >> 1; // 获取初始长度
    while (interval >= 1) {
        for (int i = interval; i < len; ++i) {

            vector<int>::value_type tmp = arr[i];
            int j = i;
            while ((j - interval >= 0) && (arr[j - interval] > tmp)) {

                arr[j] = arr[j - interval];
                j -= interval;

            }
            arr[j] = tmp;
        }
        interval /= 2;
    }
}
```

希尔排序 `(for)`

时间复杂度 `O(n^1.3~n^2)`

空间复杂度 `O(1)`

不稳定

```cpp
// 4. 希尔排序 3 for
void shell_sort2(vector<int> &nums) {
    int len = nums.size();
    for (int gap = len / 2; gap > 0; gap /= 2) {
        for (int i = gap; i < len; i++) {
            for (int j = i - gap; j >= 0; j -= gap) {
                if (nums[j] > nums[j + gap]) {
                    swap(nums[j + gap], nums[j]);
                } else break;
            }
        }
    }
}
```

归并排序 (递归)

时间复杂度 `O(nlogn)`

空间复杂度 `O(n)`

稳定

```cpp

    vector<int> tmp;

    void  merge_sort(vector<int> &arr){
        tmp.resize(arr.size());
        merge_sort(arr,0,arr.size()-1);
    }

    void merge(vector<int> & arr, int lo, int mid ,int hig) {
        for (int i = lo; i <=hig; ++i) {
            tmp[i]=arr[i];
        }
        int i=lo,j=mid+1;
        for (int k = lo; k <=hig; ++k) {
            if(i==mid+1){
                arr[k]=tmp[j++];
            }else if(j==hig+1){
                arr[k]=tmp[i++];
            }else if(tmp[i]<tmp[j]){
                arr[k]=tmp[i++];
            }else{
                arr[k]=tmp[j++];
            }

        }
    }

    void merge_sort(vector<int> &arr, int lo, int hig) {
        if (lo >= hig) return;
        int mid = lo + (hig - lo) / 2;
        merge_sort(arr, lo, mid);
        merge_sort(arr, mid + 1, hig);
        merge(arr, lo, mid,hig);
    }
```

归并排序 (迭代)

时间复杂度 `O(nlogn)`

空间复杂度 `O(n)`

稳定

```
// 5. 归并排序 （迭代）
void merge_sort2(vector<int> & arr) {
    int len = arr.size();
    vector<int> tmp(len,0);

    for (int seg = 1; seg < len; seg += seg) {
        for (int start = 0; start < len; start += seg + seg) {
            int low = start, mid = min(start + seg, len);
            int high = min(start + seg + seg, len);
            int k = low;
            int start1 = low, end1 = mid;
            int start2 = mid, end2 = high;

            while (start1 < end1 && start2 < end2) {
                tmp[k++] = arr[start1] < arr[start2] ? arr[start1++] : arr[start2++];
            }
            while (start1 < end1) {
                tmp[k++] = arr[start1++];
            }
            while (start2 < end2) {
                tmp[k++] = arr[start2++];
            }
        }
        copy(tmp.begin(), tmp.end(), arr.begin());
    }
}
```

快速排序

时间复杂度 `O(nlogn)`

空间复杂度 `O(1)`

不稳定

最好情况

- 每次选择的分界点都是最好的分界点
- 时间复杂度 `O(nlogn)`

最坏情况

- `654321` `123456`
- 时间复杂度 `O(n^2)`

```
int quick_sort_parition(vector<int> &arr, int  low, int  hig) {
    swap(arr[low], arr[low+rand()%(hig-low+1)]);
    vector<int>::value_type pivot =arr[low];

    while (low < hig) {
        while (low < hig && arr[hig] >= pivot   ) {
            hig--;
        }
        arr[low]=arr[hig];
        while (low<hig && arr[low] <= pivot ) {
            low++;
        }
        arr[hig]=arr[low];
    }
    arr[low] = pivot;
    return low;
}
void quick_sort(vector<int> &arr,int low, int hig){
    if(low<hig){
        int pivot = quick_sort_parition(arr, low, hig);
        quick_sort(arr, low, pivot - 1);
        quick_sort(arr, pivot + 1, hig);
    }
}
```

```
 void quickSort(int nums[], int left, int right) {
        if (left >= right) {
            return;
        }
        int  i = left - 1, j = right + 1;
        swap(nums[left],nums[left+rand()%(right-left)]);
        int x = nums[left];
        while (i < j) {
             while (nums[++i] < x); // 找到第一个大于等于x的元素
             while (nums[--j] > x); //  找到第一个小于等于x的元素
             if (i < j) swap(nums[i], nums[j]);
        }
        quickSort(nums,left,j);
        quickSort(nums,j+1,right);
    }
```

快排 三向切分

```

void threeWayPartition(vector<int> &nums) {
        threeWayPartition(nums, 0, nums.size() - 1);
```

```
    }
    void threeWayPartition(vector<int> &nums, int start, int end) {
        if (start >= end) {
            return;
        }
        int lt = start;
        int eq = start;
        int gt = end;
        int base = nums[eq];
        while (eq <= gt) {
            if (nums[eq] > base) swap(nums[eq], nums[gt--]);
            else if (nums[eq] < base) swap(nums[lt++], nums[eq++]);
            else eq++;
        }
        threeWayPartition(nums, start, lt - 1);
        threeWayPartition(nums, gt + 1, end);
    }
```

记数排序

```

void count_sort(vector<int> &arr) {

    int len = arr.size();
    vector<int>::value_type maxx = *max_element(arr.begin(), arr.end());
    vector<int>::value_type minx = *min_element(arr.begin(), arr.end());
    vector<int> tmp(maxx - minx + 1, 0);
    vector<int> ans;
    for (int i = 0; i < len; ++i) {
        tmp[arr[i] - minx]++;
    }
    for (int j = 0; j < maxx - minx + 1; ++j) {
        while (tmp[j] != 0) {

            ans.push_back(j + minx);
            tmp[j]--;
        }

    }
    copy(ans.begin(), ans.end(), arr.begin());
}
```

桶排序

```
void insert_list_sort(vector<int> &arr) {
    int len = arr.size();
    for (int i = 1; i < len; ++i) {
        for (int j = i-1; j >=0 ; j--) {
            if(arr[j]>arr[j+1]){
                swap(arr[j],arr[j+1]);
            }
        }
    }
}

void bucket_sort(vector<int> & arr) {

    vector<int>::value_type maxx = *max_element(arr.begin(), arr.end());
    vector<int>::value_type minx = *min_element(arr.begin(), arr.end());
    const int bucket_size=maxx / 10 - minx / 10 + 1;;

    vector<vector<int>> bucket(bucket_size);  // 10个桶   或者使用 unordered_map 创建桶
    // 初始化空桶
    for (int i = 0; i < bucket_size; ++i) {
        vector<int> x{0};
        bucket.push_back(x);
    }
    for (int i = 0; i < arr.size(); ++i) {
        bucket[arr[i] / 10].push_back(arr[i]);
    }
    int index = 0;
    for (int i = 0; i < bucket_size; ++i) {
        // sort of bucket
        insert_list_sort(bucket[i]);

        for (auto it = bucket[i].begin(); it != bucket[i].end(); ++it) {
            arr[index++] = *it;

        }
    }
}
```

基数排序

`d` 为操作的趟数

`n` 为分配的次数 也是元素的个数

`r` 为队列的个数 也是划分元素的子集个数 例如 `{0,1,2,3,4,5,6,7,8,9}`

时间复杂度 `O(d(n+r))`

空间复杂度 `O(r)`

稳定

```
void radix_sort(vector<int> &arr) {
    // get numberOfDigits  : numberOfDigits为位数
    vector<int>::value_type max = *max_element(arr.begin(), arr.end());
    int numberOfDigits = 0;
    while (max > 0) {
        max /= 10;
        numberOfDigits++;
    }
    const int BUCKETS = 10;
    vector<vector<int>> buckets(BUCKETS);
    for (int poss = 0; poss <= numberOfDigits - 1; ++poss) {
        int denominator = static_cast<int> (pow(10, poss));
        for (int &tmp: arr) {
            buckets[(tmp / denominator) % 10].push_back(tmp);

        }
        int index = 0;
        for (auto &thebuckett: buckets) {
            for (int &k: thebuckett) {
                arr[index++] = k;
                thebuckett.clear();
            }
        }
    }
}
```

堆排序

排序时间复杂度 `O(nlgn)` 调用 `n` 次 `Heapify O(lgn)`

建堆时间复杂度 `T(4*n)` `O(n)`

空间复杂度 `O(1)`

不稳定

```
class Solution {
public:

    void maxHeapify(vector<int> &arr, int i, int heapSize) {
        while (2*i+1<=heapSize){
            int leftChild=(2*i)+1,rightChild=(2*i)+2,target=leftChild;
            if(rightChild <=heapSize && arr[rightChild]> arr[leftChild]){
                target=rightChild;
            }
            if(arr[target] > arr[i]){
                swap(arr[target],arr[i]);
            }else{
                break;
            }
            i=target;
        }
    }

    void maxHeapify2(vector<int>& a, int i, int heapSize) {
        int l = i * 2 + 1, r = i * 2 + 2, largest = i;
        if (l <= heapSize && a[l] > a[largest]) {
            largest = l;
        }
        if (r <= heapSize && a[r] > a[largest]) {
            largest = r;
        }
        if (largest != i) {
            swap(a[i], a[largest]);
            maxHeapify2(a, largest, heapSize);
        }
    }

    void  maxSwim(vector<int> & arr, int i){
        while (i>=0 && arr[i/2]< arr[i]){
            swap(arr[i/2],arr[i]);
            i=i/2;
        }
    }

    void build_heap(vector<int> &arr, int size) {
        for (int i =  size/2; i >= 0; i--) {
            maxHeapify(arr, i, size);
        }
    }

    void heap_sort(vector<int> & arr) {
        int len=arr.size()-1;
        build_heap(arr, len);
        for (int i = len ; i >=1; i--) {
            swap(arr[i], arr[0]);
            len--;
            maxHeapify(arr, 0, len);
        }
    }

};


class Solution2 {
public:
    void minHeapify(vector<int> &arr, int i, int heapSize) {
        while (2*i+1<=heapSize){
            int leftChild=(2*i)+1,rightChild=(2*i)+2,target=leftChild;
            if(rightChild <=heapSize && arr[rightChild]> arr[leftChild]){
                target=rightChild;
            }
            if(arr[target] > arr[i]){
                swap(arr[target],arr[i]);
            }else{
                break;
            }
            i=target;
        }
    }

    void  mixSwim(vector<int> & arr, int i){
        while (i>=0 && arr[i/2]> arr[i]){
            swap(arr[i/2],arr[i]);
            i=i/2;
        }
    }

    void build_heap(vector<int> &arr, int size) {
        for (int i =  size/2; i >= 0; i--) {
            minHeapify(arr, i, size);
        }
    }
    void heap_sort(vector<int> & arr) {
        int len=arr.size()-1;
        build_heap(arr, len);
        for (int i = len ; i >=1; i--) {
            swap(arr[i], arr[0]);
            len--;
            minHeapify(arr, 0, len);
        }
    }
};
```

链表排序

插入排序

```
class Solution {
public:
    ListNode *insertionSortList(ListNode *head) {

        if (head == nullptr) {
            return head;
        }
        ListNode *dummyHead = new ListNode(-1);
        dummyHead->next = head;
        ListNode *lastSorted = head;
        ListNode *cur = head->next;
        while (cur != nullptr) {

            if (lastSorted->val <= cur->val) {
                lastSorted = lastSorted->next;
            } else {
                ListNode *prev = dummyHead;
                while (prev->next->val <= cur->val) {
                    prev = prev->next;
                }
                lastSorted->next = cur->next;
                // 将cur插入到 prev 后
                cur->next = prev->next;
                prev->next = cur;
            }
            cur = lastSorted->next;
        }
        return dummyHead->next;
    }
};
```

归并排序 递归

```
class Solution {
    public ListNode sortList(ListNode head) {
        if (head == null || head.next == null)
            return head;
        ListNode fast = head.next, slow = head;
        while (fast != null && fast.next != null) {
            slow = slow.next;
            fast = fast.next.next;
        }
        ListNode tmp = slow.next;
        slow.next = null;
        ListNode left = sortList(head);
        ListNode right = sortList(tmp);
        ListNode h = new ListNode(0);
        ListNode res = h;
        while (left != null && right != null) {
            if (left.val < right.val) {
                h.next = left;
                left = left.next;
            } else {
                h.next = right;
                right = right.next;
            }
            h = h.next;
        }
        h.next = left != null ? left : right;
        return res.next;
    }
}
```

```
class Solution {
public:
    ListNode* sortList(ListNode* head) {
        if (head == nullptr || head->next == nullptr) return head;

        ListNode* head1 = head;
        ListNode* head2 = split(head);

        head1 = sortList(head1);        //一条链表分成两段分别递归排序
        head2 = sortList(head2);

        return merge(head1, head2);     //返回合并后结果
    }

    //双指针找单链表中点模板
    ListNode* split(ListNode* head)
    {
        ListNode *slow = head, *fast = head->next;

        while (fast != nullptr && fast->next != nullptr)
        {
            slow = slow->next;
            fast = fast->next->next;
        }

        ListNode* mid = slow->next;
        slow->next = nullptr;           //断尾

        return mid;
    }

    //合并两个排序链表模板
    ListNode* merge(ListNode* head1, ListNode* head2)
    {
        ListNode *dummy = new ListNode(0), *p = dummy;

        while (head1 != nullptr && head2 != nullptr)
        {
            if (head1->val < head2->val)
            {
                p = p->next = head1;
                head1 = head1->next;
            }
            else
            {
                p = p->next = head2;
                head2 = head2->next;
            }
        }

        if (head1 != nullptr) p->next = head1;
        if (head2 != nullptr) p->next = head2;

        return dummy->next;
    }
};
```

归并排序 迭代

```
class Solution {
public:
    ListNode* sortList(ListNode* head) {
        if (head == nullptr) {
            return head;
        }
        int length = 0;
        ListNode* node = head;
        while (node != nullptr) {
            length++;
            node = node->next;
        }
        ListNode* dummyHead = new ListNode(0, head);
        for (int subLength = 1; subLength < length; subLength <<= 1) {
            ListNode* prev = dummyHead, *curr = dummyHead->next;
            while (curr != nullptr) {
                ListNode* head1 = curr;
                for (int i = 1; i < subLength && curr->next != nullptr; i++) {
                    curr = curr->next;
                }
                ListNode* head2 = curr->next;
                curr->next = nullptr;
                curr = head2;
                for (int i = 1; i < subLength && curr != nullptr && curr->next != nullptr; i++) {
                    curr = curr->next;
                }
                ListNode* next = nullptr;
                if (curr != nullptr) {
                    next = curr->next;
                    curr->next = nullptr;
                }
                ListNode* merged = merge(head1, head2);
                prev->next = merged;
                while (prev->next != nullptr) {
                    prev = prev->next;
                }
                curr = next;
            }
        }
        return dummyHead->next;
    }

    ListNode* merge(ListNode* head1, ListNode* head2) {
        ListNode* dummyHead = new ListNode(0);
        ListNode* temp = dummyHead, *temp1 = head1, *temp2 = head2;
        while (temp1 != nullptr && temp2 != nullptr) {
            if (temp1->val <= temp2->val) {
                temp->next = temp1;
                temp1 = temp1->next;
            } else {
                temp->next = temp2;
                temp2 = temp2->next;
            }
            temp = temp->next;
        }
        if (temp1 != nullptr) {
            temp->next = temp1;
        } else if (temp2 != nullptr) {
            temp->next = temp2;
        }
        return dummyHead->next;
    }
};
```

链表快排

```
class Solution2 {
  ListNode* sortList(ListNode* head) {
        return quickSort(head , nullptr);
    }

  ListNode *quickSort(ListNode* head ,ListNode* end){
        if(head ==end || head->next ==end) return head;
        ListNode *lhead = head ,*utail = head ,*p = head->next;
        while (p != end){
            ListNode* nextNode = p->next;
            if(p->val < head->val){
                //头插
                p->next = lhead;
                lhead = p;
            }
            else {
                //尾插
                utail->next = p;
                utail = p;
            }
            p = nextNode;
        }
        utail->next = end;
        ListNode* node = quickSort(lhead, head);
        head->next =  quickSort(head->next, end);
        return node;
    }
}
```

链表选择排序

```
//
// Created by yjs on 23-7-29.
//
#include <bits/stdc++.h>
#include <iostream>

using namespace std;
struct ListNode {
    int val;
    ListNode *next;
    ListNode(int x) : val(x), next(NULL) {}
};


class Solution{
public:
    ListNode *  deleteListNode (ListNode* head){
        ListNode* cur= head->next;
        ListNode* pre=head; // pre指向头结点
        ListNode* min=cur; // 假设第一个结点为最小值的结点
        while (cur->next!= nullptr){
            if(cur->next->val < min->val){
                pre=cur;
                min=cur->next;
            }
            cur=cur->next;
        }
        pre->next=min->next; // 从链表上删除最小值结点
//        free (min);
        return head;
    }



public:

    ListNode * selectSort(ListNode* head){

        ListNode * dummyHead= new ListNode(-1);
        ListNode * dummyCurser=dummyHead;
        while (head->next!= nullptr){
            ListNode* cur= head->next;
            ListNode* pre=head; // pre指向头结点
            ListNode* min=cur; // 假设第一个结点为最小值的结点
            while (cur->next!= nullptr){
                if(cur->next->val < min->val){
                    pre=cur;
                    min=cur->next;
                }
                cur=cur->next;
            }
            pre->next=min->next; // 从链表上删除最小值结点
            dummyCurser->next=min;
            dummyCurser=dummyCurser->next;

        }
        dummyCurser->next= nullptr;
        return dummyHead->next;
    }
};

string ppint(ListNode * head){
    ListNode * cur=head;
    string res="";
    int count=0;
    while (cur!= nullptr){
        count++;
        res= res+to_string(cur->val)+" ";
        cur=cur->next;
    }
    return " ["+to_string(count)+"] "+ res+"\n";


}
```

```
int main() {

    vector<int> nums{ 12,25, 36, 17, 25, 56,1};
    ListNode* head=new ListNode(-1);
    ListNode * cur=head;

    for (int i = 0; i < nums.size(); ++i) {
        cur->next=new ListNode(nums[i]);
        cur=cur->next;
    }
    cout << ppint(head->next)<<endl;
    Solution solution;
//    for (int i = 0; i < 7; ++i) {
//        head=solution.deleteListNode(head);
//        cout << ppint(head->next)<<endl;
//    }
    ListNode * res=solution.selectSort(head);
    cout << ppint(res)<<endl;
}
```

链表冒泡排序

```
class Solution {
public:
    void ListNodeSwap(ListNode *prevNode, ListNode *node1, ListNode *node2) {
        node1->next = node2->next;
        prevNode->next = node2;
        node2->next = node1;
    }
    static string ppint(ListNode *head) {
        ListNode *cur = head;
        string res = "";
        int count = 0;
        while (cur != nullptr) {
            count++;
            res = res + to_string(cur->val) + " ";
            cur = cur->next;
        }
        return " [" + to_string(count) + "] " + res + "\n";


    }



public:

    ListNode *BubbleSort(ListNode *head) {
        if (head == nullptr || head->next == nullptr) return head;

        ListNode *dummyHead = new ListNode(-1);
        ListNode *dummyCurser = dummyHead;
        while (head->next != nullptr) {
            ListNode *cur = head->next;
            ListNode *pre = head; // pre指向头结点
            while (cur->next != nullptr) {
                if (cur->val < cur->next->val) {
                    ListNodeSwap(pre, cur, cur->next);
                } else {
                    cur = cur->next;

                }
                pre = pre->next;
            }
            cout << "cur is " << cur->val << endl;
            dummyCurser->next = cur;
            dummyCurser = dummyCurser->next;
            pre->next = nullptr;

        }
        return dummyHead->next;
    }
};


int main() {

    vector<int> nums{12, 25, 36, 17, 78, 65, 25, 56, 1};
    ListNode *head = new ListNode(-1);
    ListNode *cur = head;

    for (int i = 0; i < nums.size(); ++i) {
        cur->next = new ListNode(nums[i]);
        cur = cur->next;
    }
    cout << Solution::ppint(head->next) << endl;
    Solution solution;
    ListNode *res = solution.BubbleSort(head);
    cout << Solution::ppint(res) << endl;


}
```

拓扑排序

```
#include <vector>
#include <queue>

using namespace std;



const int MAX_VERTEX_NUM = 20;   //图中顶点的最大数量

struct Node {
    int data;
    char *info;
};

struct MGraph {
    vector<vector<int>> edges;
    Node node[MAX_VERTEX_NUM];        //存储图中顶点数据
    int edgesCount, nodesCount;
};


struct ArcNode {
    int adjvex;                //存储边或弧，即另一端顶点在数组中的下标
    struct ArcNode *nextarc;//指向下一个结点
    int info;             //记录边或弧的其它信息
};
struct VNode {
    int data;          //顶点的数据域
    ArcNode *firstarc;//指向下一个结点
};//存储各链表首元结点的数组

struct ALGraph {
    VNode vertices[MAX_VERTEX_NUM];  //存储图的邻接表
    int nodesCount, edgesCount;               //记录图中顶点数以及边或弧数
};


ALGraph *MGraphToALGraph(MGraph graph) {


    //初始化邻接表
    ALGraph *alGraph = new ALGraph;
    alGraph->nodesCount = graph.nodesCount;
    alGraph->edgesCount = graph.edgesCount;
    for (int i = 0; i < graph.nodesCount; ++i) {
        alGraph->vertices[i].firstarc = nullptr;
    }

    for (int i = 0; i < graph.nodesCount; ++i) {
        for (int j = 0; j < graph.nodesCount; ++j) {
            if (graph.edges[i][j] != 0) {

                ArcNode *arcNode = new ArcNode;
                arcNode->adjvex = j;
                arcNode->info=graph.edges[i][j];
                // head insert
                arcNode->nextarc = alGraph->vertices[i].firstarc;
                alGraph->vertices[i].firstarc = arcNode;



            }



        }

    }
    return alGraph;


}



class Solution {
private:
    // 存储有向图
    vector<vector<int>> edges;
    // 存储每个节点的入度
    vector<int> indegrees;
    // 存储拓扑排序序列
    vector<int> result;

public:
    // prerequisites = [[1,0],[2,0],[3,1],[3,2]]  有向图
    vector<int> findOrder(int numCourses, vector<vector<int>>& prerequisites) {
        edges.resize(numCourses);
        indegrees.resize(numCourses);
        for (const auto& info: prerequisites) {
            edges[info[0]].push_back(info[1]);
            ++indegrees[info[1]];
        }

        queue<int> q;
        // 将所有入度为 0 的节点放入队列中
        for (int i = 0; i < numCourses; ++i) {
            if (indegrees[i] == 0) {
                q.push(i);
            }
        }

        while (!q.empty()) {
            // 从队首取出一个节点
            int u = q.front();
            q.pop();
            // 放入答案中
            result.push_back(u);
            for (int v: edges[u]) {
                --indegrees[v];
                // 如果相邻节点 v 的入度为 0，就可以选 v 对应的课程了
                if (indegrees[v] == 0) {
                    q.push(v);
                }
            }
        }

        if (result.size() != numCourses) {
            // 没有一个拓扑排序
            return {};
        }
        // 返回拓扑排序
        return result;
    }
};
```