Sorting

Hsuan-Tien Lin

Dept. of CSIE, NTU

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Selection Sort: Review and Refinements

idea: linearly select the minimum one from "unsorted" part;
put the minimum one to the end of the "sorted" part

Implementations

- common implementation: swap minimum with $a[i]$ for putting in i-th iteration
- rotate implementation: rotate minimum down to $a[i]$ in i-th iteration
- linked-list implementation: insert minimum to the i-th element

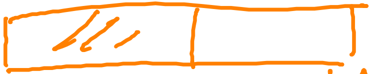
sorted unsorted

"insertion"

- space $O(1)$: in-place
- time $O(n^2)$ and $\Theta(n^2)$
- rotate/linked-list: stable by selecting minimum with smallest index —same-valued elements keep their index orders
- common implementation: unstable

idea: selection sort with a max-heap in original array
rather than unordered pile

- space $O(1)$
- time $O(n \log n)$ $\ll O(n^2)$ selection
- not stable
- usually preferred over selection (faster) ≈ sort



Bubble Sort: Review and Refinements

idea: swap disordered neighbors repeatedly

- space $O(1)$ ✓
- time $O(n^2)$
- stable
- adaptive: can early stop
- a deprecated choice except in very specific applications with a few disordered neighbors or if swapping neighbors is cheap (old tape days)

Insertion Sort: Review and Refinements

idea: insert a card from the unsorted pile to its place in the sorted pile

Implementations

- naive implementation: sequential search sorted pile from the front
  $O(n)$ time per search, $O(n)$ per insert
- backwise implementation: sequential search sorted pile from the
  Stable? back $O(n)$ time per search, $O(n)$ per insert
- binary-search implementation: binary search the sorted pile
  $O(\log n)$ time per search, $O(n)$ per insert
- linked-list implementation: same as naive but on linked lists
  $O(n)$ time per search, $O(1)$ per insert
- skip-list implementation: doable but a bit overkill (more space)
- rotation implementation: neighbor swap rather than insert
  (gnome sort)

Insertion Sort: Review and Refinements (II)

- space $O(1)$
- time $O(n^2)$
- stable
- backwise implementation adaptive
- usually preferred over bubble (faster) and over selection (adaptive)

Shell Sort: Introduction

0 10 20 30 40
1 11 21 31 41
2 12 22 32 42

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idea: adaptive insertion sort on every k_1 elements;
adaptive insertion sort on every k_2 elements; $\cdots$
adaptive insertion sort on every $k_m = 1$ element

5

2

- insertion sort with "long jumps"
- space $O(1)$, like insertion sort
- time: difficult to analyze, often faster than $O(n^2)$
- unstable, adaptive
- usually good practical performance and somewhat easy to implement

Merge Sort: Introduction

idea: combine sorted parts repeatedly to get everything sorted

Implementations

n

- bottom-up implementation:

2^i

6	5	4	7	8	3	1	2	(size-1 sorted)
5	6	4	7	3	8	1	2	(size-2 sorted)
4	5	6	7	1	2	3	8	(size-4 sorted)
1	2	3	4	5	6	7	8	(size-8 sorted)

log n

  - $O(\log n)$ loops, the i-th loop combines size-2^i arrays $O(n/2^i)$ times

merge

  - combine size-ℓ array can take $O(\ell)$ time but need $O(\ell)$ space! (how about lists?)
  - thus, bottom-up Merge Sort takes $O(n \log n)$ time

- top-down implementation:

MergeSort(arr, left, right)

= combine(MergeSort(arr, left, mid), MergeSort(arr, mid+1, right));

  - divide and conquer, $O(\log n)$ level recursive calls

Merge Sort: Review and Refinements

idea: combine sorted parts repeatedly to get everything sorted

- time $O(n \log n)$ in both implementations
- usually stable (if carefully implemented), parallellize well
- popular in external sort

Tree Sort: Review and Refinements

loosely structured

strictly

idea: replace heap with a BST;
an in-order traveral outputs the sorted result

- space $O(n)$
- time: worst $O(n^2)$ (unbalanced tree), average $O(n \log n)$, careful BST $O(n \log n)$
- unstable
- suitable for stream data and incremental sorting

Quick Sort: Introduction

idea: simulate tree sort without building the tree

a[0]

random

Tree Sort Revisited

make $a[0]$ the root of a BST
for $i \leftarrow 1, \cdots, n-1$ **do**
  if $a[i] < a[0]$
    insert $a[i]$ to the left-subtree of BST
  else
    insert $a[i]$ to the right-subtree of BST
  end if
end for
in-order traversal of left-subtree, then root, then right-subtree

Quick Sort

name $a[0]$ the pivot
for $i \leftarrow 1, \cdots, n-1$ **do**
  if $a[i] < a[0]$
    put $a[i]$ to the *left* pile of the pivot
  else
    put $a[i]$ to the *right* pile of the pivot
  end if
end for
output quick-sorted *left*; output $a[0]$; output quick-sorted *right*

Quick Sort Simulation

1 2 3 4 5 6 7 8 9 10

6, 1, 4, 9, 7, 8, 3, 10, 2, 5

1 4 3 2 5 6 9 7 8 10

ϕ 4 3 2 5

$\log n$

n

randomly choose "root" (pivot)

$O(n \log n)$

Quick Sort: Introduction (II)

Implementations

- naive implementation: pick first element in the pile as pivot
- random implementation: pick a random element in the pile as pivot
- median-of-3 implementation: pick median(front, middle, back) as pivot

- space: worst $O(n)$, average $O(\log n)$ on stack calls
- time: worst $O(n^2)$, average $O(n \log n)$
- not stable
- usually best choice for large data (if not requiring stability), can be mixed with other sorts for small data

Best Use of Different Sorting Algorithms

Implementations

- small:
- stable small:
- stable large:
- worst case time guarantee:
- least space with good time:
- adaptive:
- general:
- external:
- educational: