COMP2521 25T2
Sorting Algorithms (I)
Introduction to Sorting Algorithms

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sorting
properties of sorting algorithms

Motivation

- Sorting enables faster searching
  - Binary search
- Sorting provides a useful intermediate for other algorithms
  - For example, duplicate detection/removal, merging two collections

Sorting

- Sorting involves arranging a collection of items in order
  - Arrays, linked lists, files
- Items are sorted based on some property (called the **key**), using an ordering relation on that property
  - Numbers are sorted numerically
  - Strings are sorted alphabetically

Sorting

We sort arrays of `Items`, which could be:

- Simple values: `int`, `char`, `double`
- Aggregate values: strings
- Structured values: `struct`

The items are sorted based on a key, which could be:

- The entire item, if the item is a single value
- One or more fields, if the item is a struct

Sorting

Example: Each student has an ID and a name

5151515 John	5012345 Jane	3456789 Bob	5050505 Alice	5555555 John	5432109 Andrew

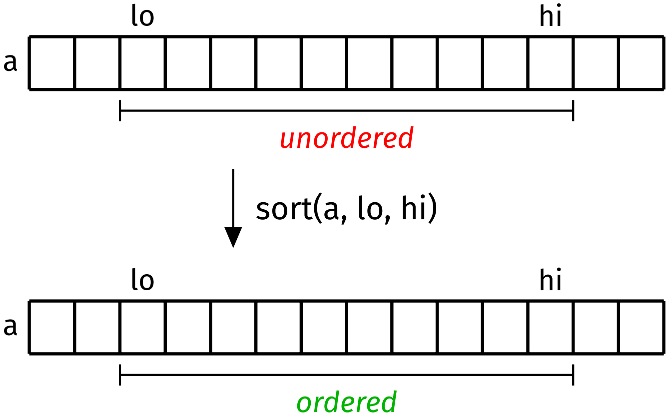
Sorting by ID (i.e., key is ID):

3456789 Bob	5012345 Jane	5050505 Alice	5151515 John	5432109 Andrew	5555555 John

Sorting by name (i.e., key is name):

5050505 Alice	5432109 Andrew	3456789 Bob	5012345 Jane	5151515 John	5555555 John

Arrange items in array slice `a[lo..hi]` into sorted order:



To sort an entire array of size `N`, `lo == 0` and `hi == N - 1`.

Examples of Sorting Algorithms

Elementary sorting algorithms:

- Selection sort
- Bubble sort
- Insertion sort
- Shell sort

Divide-and-conquer sorting algorithms:

- Merge sort
- Quick sort

Non-comparison-based sorting algorithms:

- Radix sort
- Key-indexed counting sort

Analysis of Sorting Algorithms

Three main cases to consider for input order:

- Random order
- Sorted order
- Reverse-sorted order

When analysing sorting algorithms, we consider:

- n: the number of items ($\texttt{hi} - \texttt{lo} + 1$)
- C: the number of comparisons between items
- S: the number of times items are swapped

Properties of Sorting Algorithms

Properties:

- Stability
- Adaptability
- In-place

Properties of Sorting Algorithms

Stability

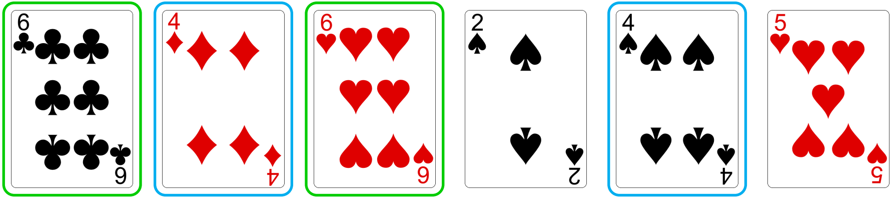
- A stable sort preserves the relative order of items with equal keys.
- **Formally:** For all pairs of items x and y where $\text{KEY}(x) \equiv \text{KEY}(y)$, if x precedes y in the original array, then x precedes y in the sorted array.

A stable sorting algorithm *always* performs a stable sort.

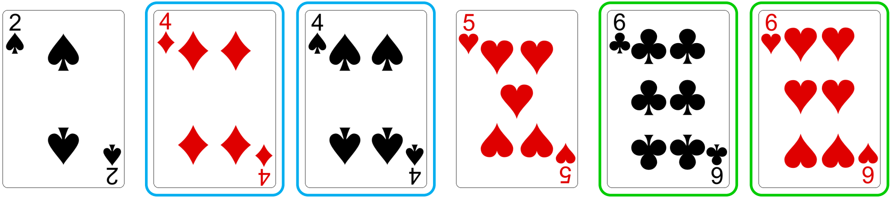
Properties of Sorting Algorithms

Stability

Example: Each card has a value and a suit



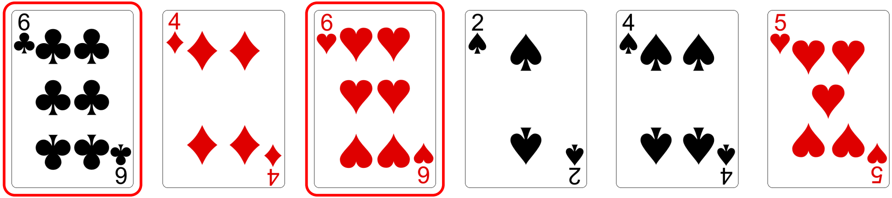
A stable sort on value:



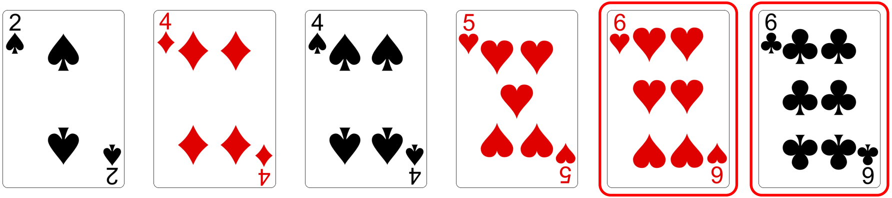
Properties of Sorting Algorithms

Stability

Example: Each card has a value and a suit



Example of an unstable sort on value:



Properties of Sorting Algorithms

Stability

When is stability important?

- When sorting the same array multiple times on different keys
    - Some sorting algorithms rely on this, for example, radix sort

Properties of Sorting Algorithms

Stability

Example: Array of first names and last names

Alice Wunder	Andrew Bennett	Jake Renzella	Alice Hatter	Andrew Taylor	John Shepherd

Sort by last name:

Andrew Bennett	Alice Hatter	Jake Renzella	John Shepherd	Andrew Taylor	Alice Wunder

Then sort by first name (using stable sort):

Alice Hatter	Alice Wunder	Andrew Bennett	Andrew Taylor	Jake Renzella	John Shepherd

Properties of Sorting Algorithms

Stability

Stability doesn't matter if...

- All items have unique keys
  - Example: Sorting students by ID
- The key is the entire item
  - Example: Sorting an array of integer values

Properties of Sorting Algorithms

Adaptability

- An adaptive sorting algorithm takes advantage of existing order in its input
  - The nature of the algorithm allows sorted or nearly-sorted inputs to be sorted *much* quicker than other inputs

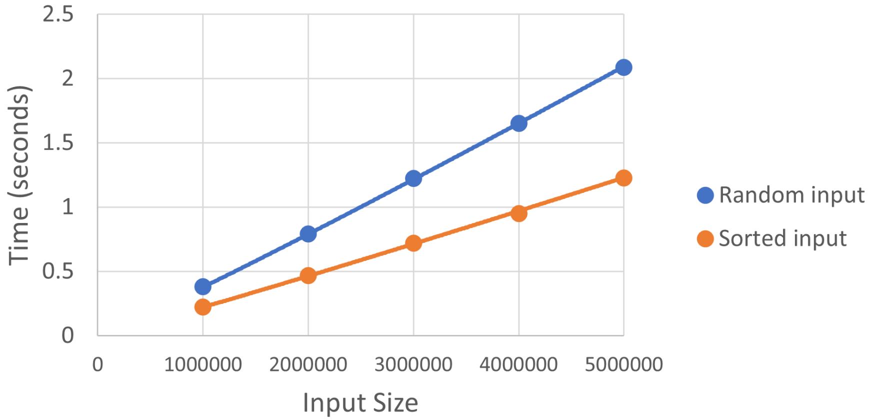
Warning!

Just because a sorting algorithm
sorts sorted input faster than it sorts random/reverse-sorted input,
does not mean that it is adaptive.

Properties of Sorting Algorithms

Adaptability

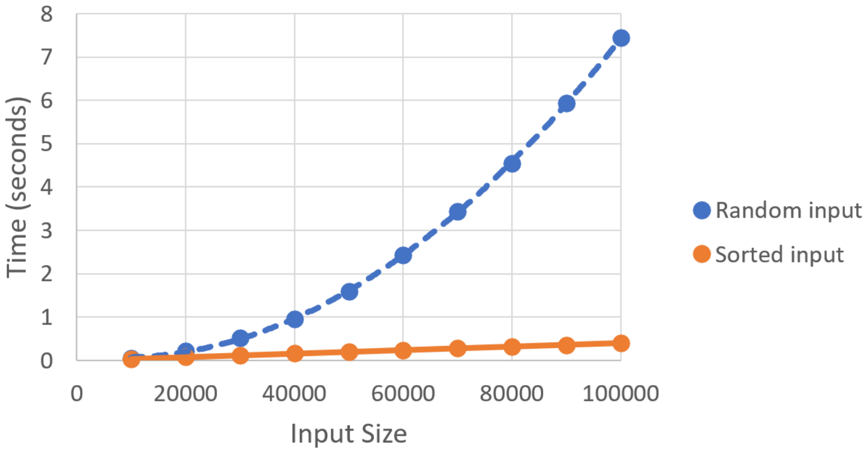
Example of data for non-adaptive sorting algorithm:



Properties of Sorting Algorithms

Adaptability

Example of data for adaptive sorting algorithm:



Properties of Sorting Algorithms

In-place

- An in-place sorting algorithm sorts the data within the original structure, without using temporary arrays

Implementing Sorting Algorithms

Generic sort function:

```
void sort(Item a[], int lo, int hi);
```

Helper function to swap elements at indices `i` and `j`:

```
void swap(Item a[], int i, int j);
```

Implementing Sorting Algorithms

`Item` is a `typedef`,
which is a way to give a new name to a type.

For example, if we want to sort integers:

```
typedef int Item;
```

For example, if we want to sort strings:

```
typedef char *Item;
```

Implementing Sorting Algorithms

We also define macros which indicate
(1) how to extract keys from an item, and
(2) how items should be compared.

For example, when sorting integers:

```
typedef int Item;

#define key(A) (A)
#define lt(A, B) (key(A) <  key(B)) // less than
#define le(A, B) (key(A) <= key(B)) // less than or equal to
#define ge(A, B) (key(A) >= key(B)) // greater than or equal to
#define gt(A, B) (key(A) >  key(B)) // greater than
```

Implementing Sorting Algorithms

When sorting structs:

```c
typedef struct {
    char *name;
    char *course;
} Item;

#define key(A) (A.name)
#define lt(A, B) (strcmp(key(A), key(B)) <  0)
#define le(A, B) (strcmp(key(A), key(B)) <= 0)
#define ge(A, B) (strcmp(key(A), key(B)) >= 0)
#define gt(A, B) (strcmp(key(A), key(B)) >  0)
```