Searching and Sorting

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(thanks to John Park for slides)

Searching and Sorting

Topics

- Algorithms and Reusability
- Algorithmic Classes: Example 1--Search
- Algorithmic Classes: Example 2--Sorting

Reading

- Sections 6.6 - 6.8

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Common Problems/ Common Solutions

- When writing most *interesting* programs, there is often a core algorithmic challenge
- Many different problem domains actually have similar underlying solutions
  - Abstraction is the key to reuse
  - E.g.: textual search ←→identifying genetic patterns
- Reuse has important benefits
  - Saves work
  - Increases reliability
- Donald Knuth's <u>The Art of Computer Programming</u>
  - The "bible" of programming

Common Problems/ Common Solutions (cont.)

- There are some very common problems that we use computers to solve:
  - **Searching** through a lot of records for a specific record or set of records
  - Placing records in order, which we call **sorting**
- There are numerous algorithms to perform searches and sorts.
  - Knuth dedicates 800(!) pages to the subject: Vol. 3: <u>Sorting and Searching</u>
- We will briefly explore a few common ones.

Searching and Sorting

Topics

- Algorithms and Reusability
- Algorithmic Classes: Example 1--Search
  - Sequential Search on an Unordered File
  - Sequential Search on an Ordered File
  - Binary Search
- Algorithmic Classes: Example 2--Sorting

Searching

- A question you should always ask when selecting a search algorithm:
  - "How fast does the search have to be?"
  - In general, the faster the algorithm is, the more complex it is.
- Bottom line: you don't always need to use, nor should you use, the "fastest" algorithm.
- Let's explore two sample search algorithms, keeping speed in mind.
  - Sequential (linear) search
  - Binary search

Sequential Search on an Unordered File

- Basic algorithm:

  Get the search criterion (the **key**)

  Get the first record from the file

  While ((record != key) and (still more records))

      Get the next record

  End_while

- When do we know that there wasn't a record in the file that matched the key?

Sequential Search on an Ordered File

- Basic algorithm:

  Get the search criterion (the key)

  Get the first record from the file

  While ((record < key) and (still more records))

      Get the next record

  End_while

  If (record = key)

      Then success

      Else there is no match in the file

  End_else

- When do we know that there wasn't a record in the file that matched the key?

Sequential Search of Unordered vs. Ordered List

- Let's do a comparison.
- If the order was ascending alphabetical on customer's last names, how would the search for John Adams on the unordered list compare with the search on the ordered list?
  - Unordered list
    - if John Adams was in the list?
    - if John Adams was not in the list?
  - Ordered list
    - if John Adams was in the list?
    - if John Adams was not in the list?

Unordered vs Ordered (con't)

- How about George Washington?
  - Unordered
    - if George Washington was in the list?
    - If George Washington was not in the list?
  - Ordered
    - if George Washington was in the list?
    - If George Washington was not in the list?
- How about James Madison?

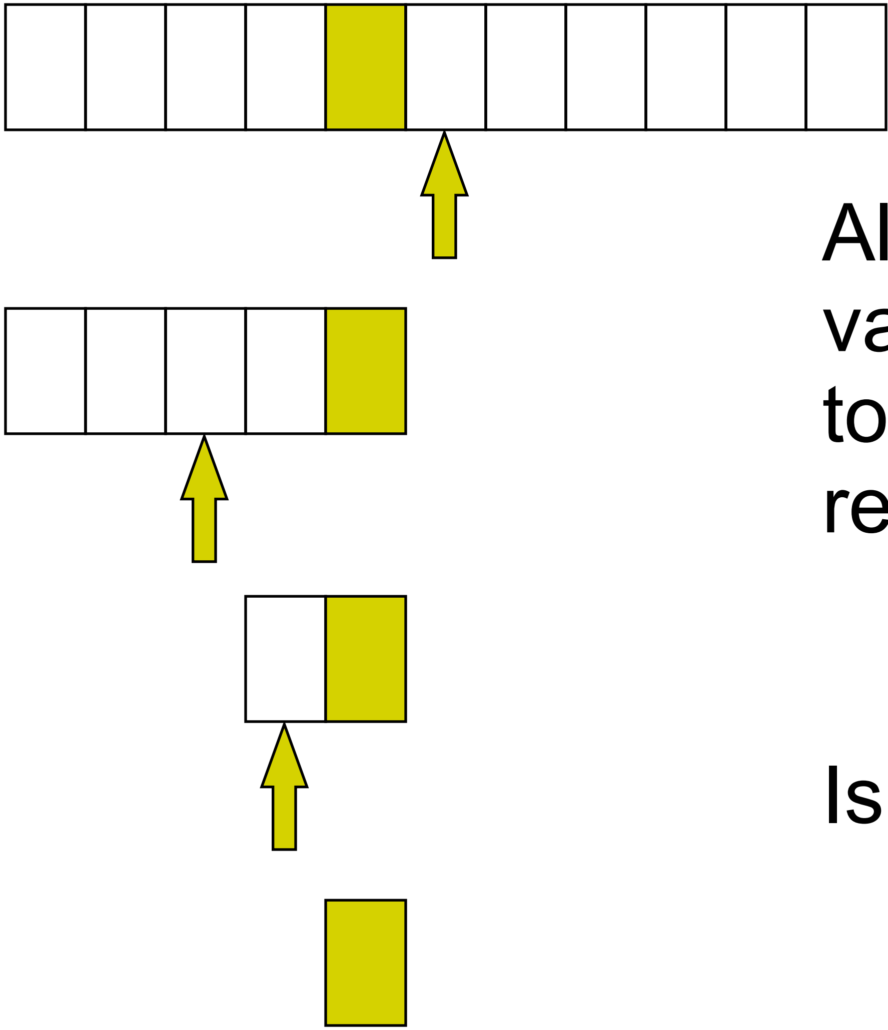
Unordered vs. Ordered (con't)

- Observation: the search is faster on an ordered list only when the item being searched for is not in the list.
  - (But didn't we find "Adams" more quickly in ordered?...)
- Also, keep in mind that the list has to first be placed in order for the ordered search.
- Conclusion: the **efficiency** of these algorithms is roughly the same.
- So, if we need a faster search, we need a completely different algorithm.
- How else could we search an ordered file?

Binary Search

- If we have an ordered list and we know how many things are in the list (i.e., number of records in a file), we can use a different strategy.
- The **binary search** gets its name because the algorithm continually divides the list into two parts.

How a Binary Search Works



Always look at the center value. Each time you get to discard half of the remaining list.

Is this fast ?

How Fast is a Binary Search?

- Worst case: 11 items in the list took 4 tries
- How about the worst case for a list with 32 items ?
  - 1st try - list has 16 items
  - 2nd try - list has 8 items
  - 3rd try - list has 4 items
  - 4th try - list has 2 items
  - 5th try - list has 1 item

How Fast is a Binary Search? (con't)

<u>List has 250 items</u>

1st try - 125 items

2nd try - 63 items

3rd try - 32 items

4th try - 16 items

5th try - 8 items

6th try - 4 items

7th try - 2 items

8th try - 1 item

<u>List has 512 items</u>

1st try - 256 items

2nd try - 128 items

3rd try - 64 items

4th try - 32 items

5th try - 16 items

6th try - 8 items

7th try - 4 items

8th try - 2 items

9th try - 1 item

What’s the Pattern?

- List of 11 took 4 tries
- List of 32 took 5 tries
- List of 250 took 8 tries
- List of 512 took 9 tries

- $32 = 2^5$ and $512 = 2^9$
- $8 < 11 < 16$ $2^3 < 11 < 2^4$
- $128 < 250 < 256$ $2^7 < 250 < 2^8$

A Very Fast Algorithm!

- How long (worst case) will it take to find an item in a list 30,000 items long?

$2^{10} = 1024$

$2^{11} = 2048$

$2^{12} = 4096$

$2^{13} = 8192$

$2^{14} = 16384$

$2^{15} = 32768$

- So, it will take only 15 tries!

Lg n Efficiency

- We say that the binary search algorithm runs in **$\log_2$ n time**. (Also written as **lg n**)
- Lg n means the log to the base 2 of some value of n.
- $8 = 2^3$ lg 8 = 3 $16 = 2^4$ lg 16 = 4
- <u>There are no algorithms that run faster than lg n time</u>.

Sorting--Motivation

- So, the binary search is a very fast search algorithm.
- But, the list has to be sorted before we can search it with binary search.
- To be really efficient, we also need a fast sort algorithm.

Searching and Sorting

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- Algorithms and Reusability
- Algorithmic Classes: Example 1--Search
- Algorithmic Classes: Example 2--Sorting
  - Bubble Sort
  - Insertion Sort

Common Sort Algorithms

Bubble Sort	Heap Sort
Selection Sort	Merge Sort
Insertion Sort	Quick Sort

- There are many known sorting algorithms. Bubble sort is the slowest, running in **n^2 time**. Quick sort is the fastest, running in **n·lg n time**.
- As with searching, the faster the sorting algorithm, the more complex it tends to be.
- We will examine two sorting algorithms:
  - Bubble sort
  - Insertion sort

Bubble Sort - Let’s Do One!

C
P
G
A
T
O
B

- [Sorting Demos]

Bubble Sort Code

```
void bubbleSort (int a[ ] , int size)
{
    int i, j, temp;
    for ( i = 0; i < size; i++ )    /* controls passes through the list */
    {
            for ( j = 0; j < size - 1; j++ )   /* performs adjacent comparisons */
            {
                    if ( a[ j ] > a[ j+1 ] )   /* determines if a swap should occur */
                    {
                            temp = a[ j ];      /* swap is performed */
                            a[ j ] = a[ j + 1 ];
                            a[ j+1 ] = temp;
                    }
            }
     }
}
```

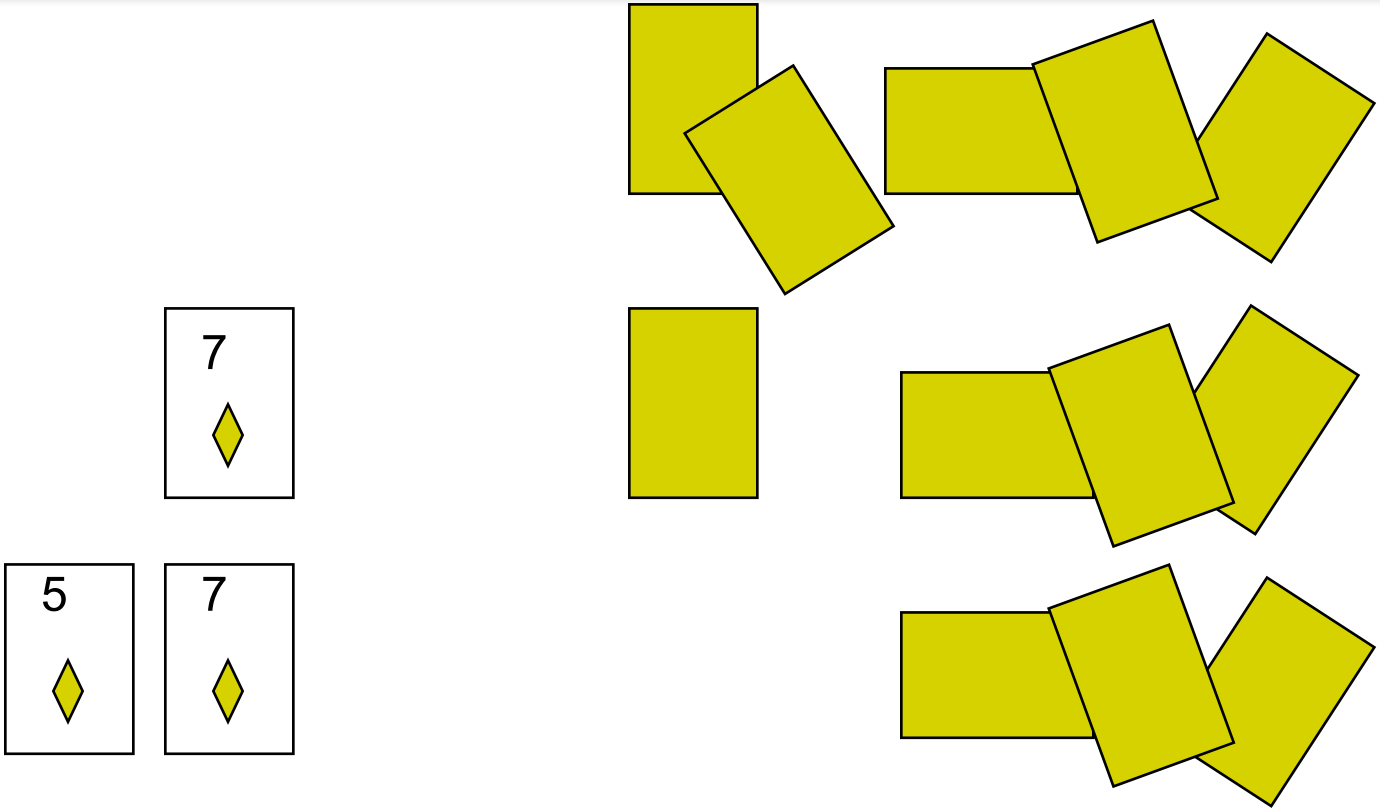
Bubble Sort--Optimizations

- Can you think of quick-and-dirty tweaks to the code to:
  - Trim the inner loop to fewer turns?
  - Stop the outer loop early in opportune cases?

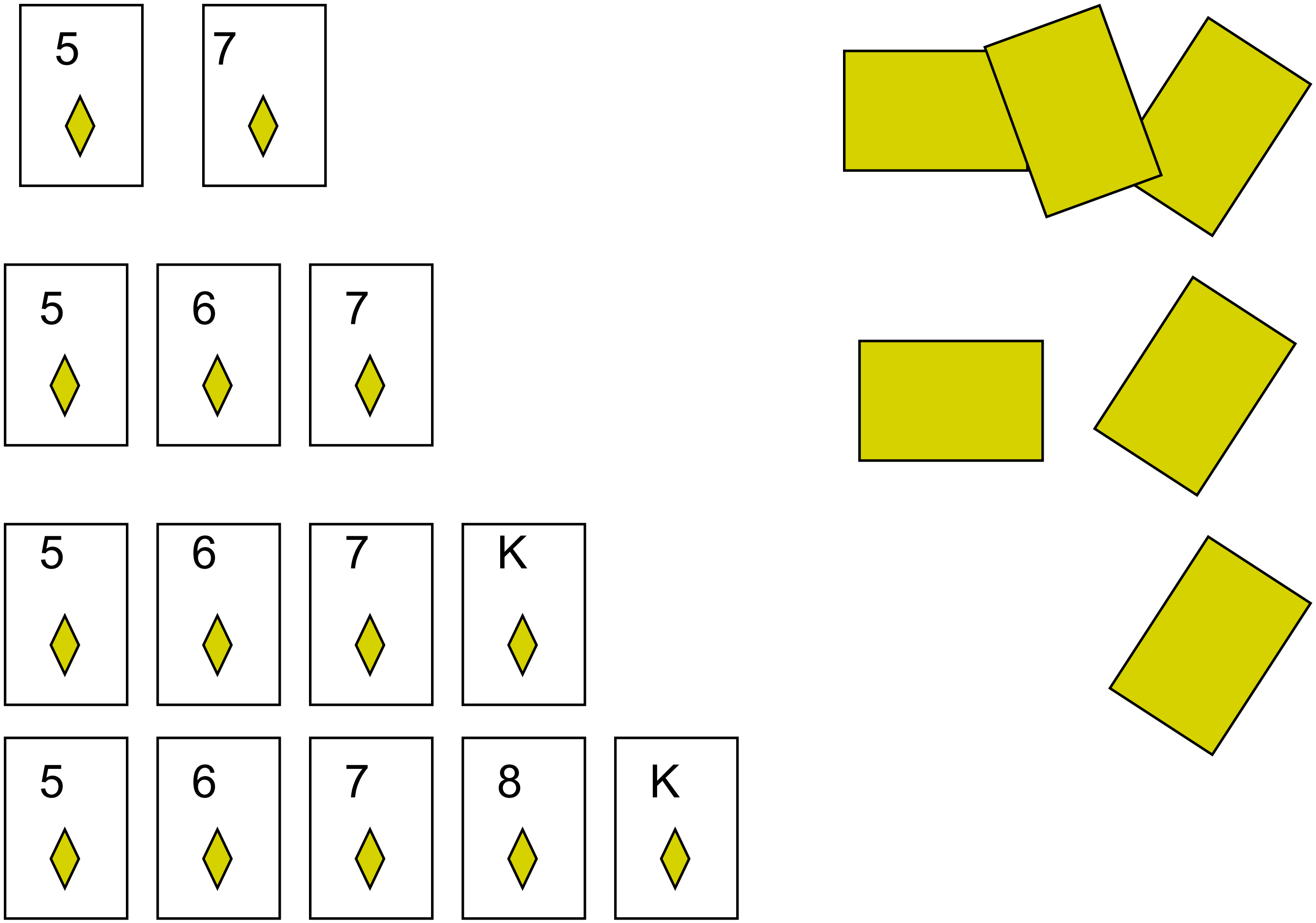
Insertion Sort

- Insertion sort is slower than quicksort, but not as slow as bubble sort, and it is easy to understand.
- Insertion sort works the same way as arranging your hand when playing cards.
  - Out of the pile of unsorted cards that were dealt to you, you pick up a card and place it in your hand in the correct position relative to the cards you're already holding.

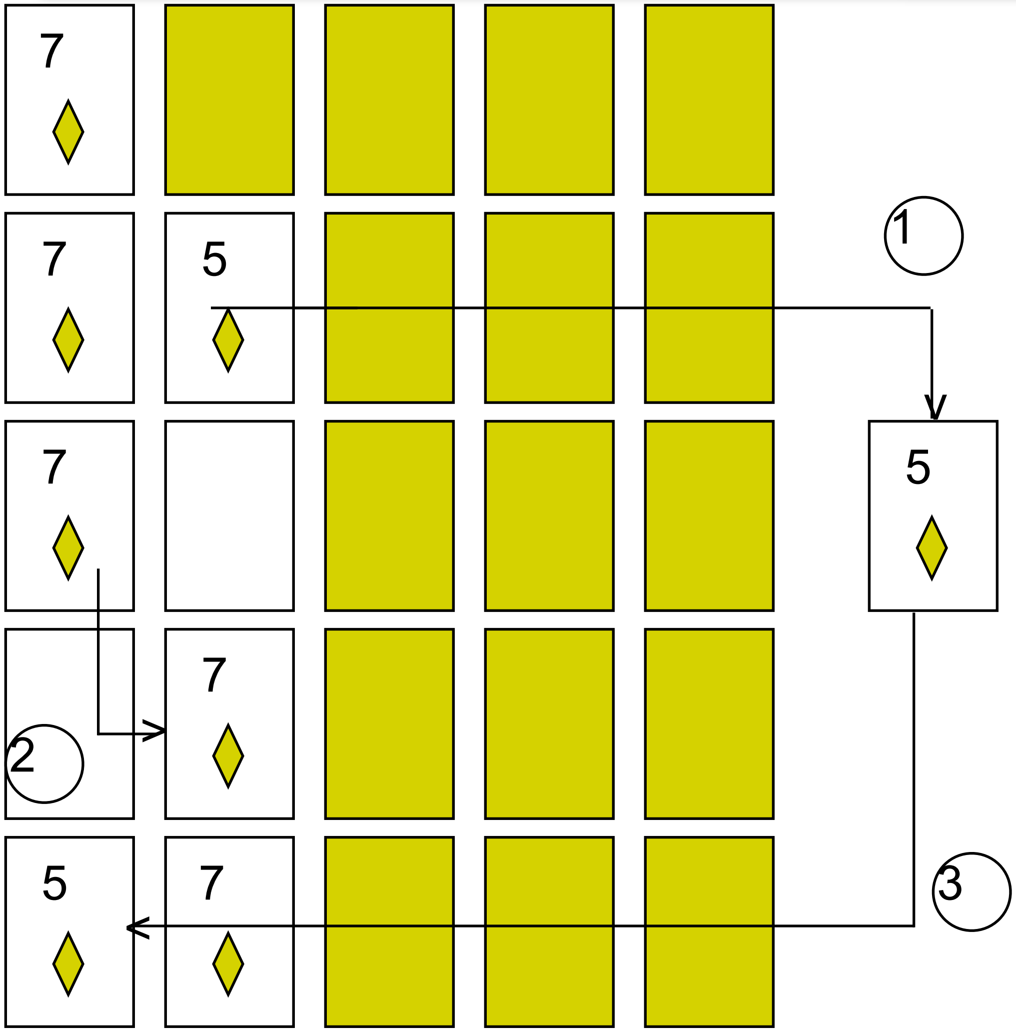
Arranging Your Hand



Arranging Your Hand



Insertion Sort



Unsorted - shaded

Look at 2nd item - 5.

Compare 5 to 7.

5 is smaller, so move 5 to temp, leaving

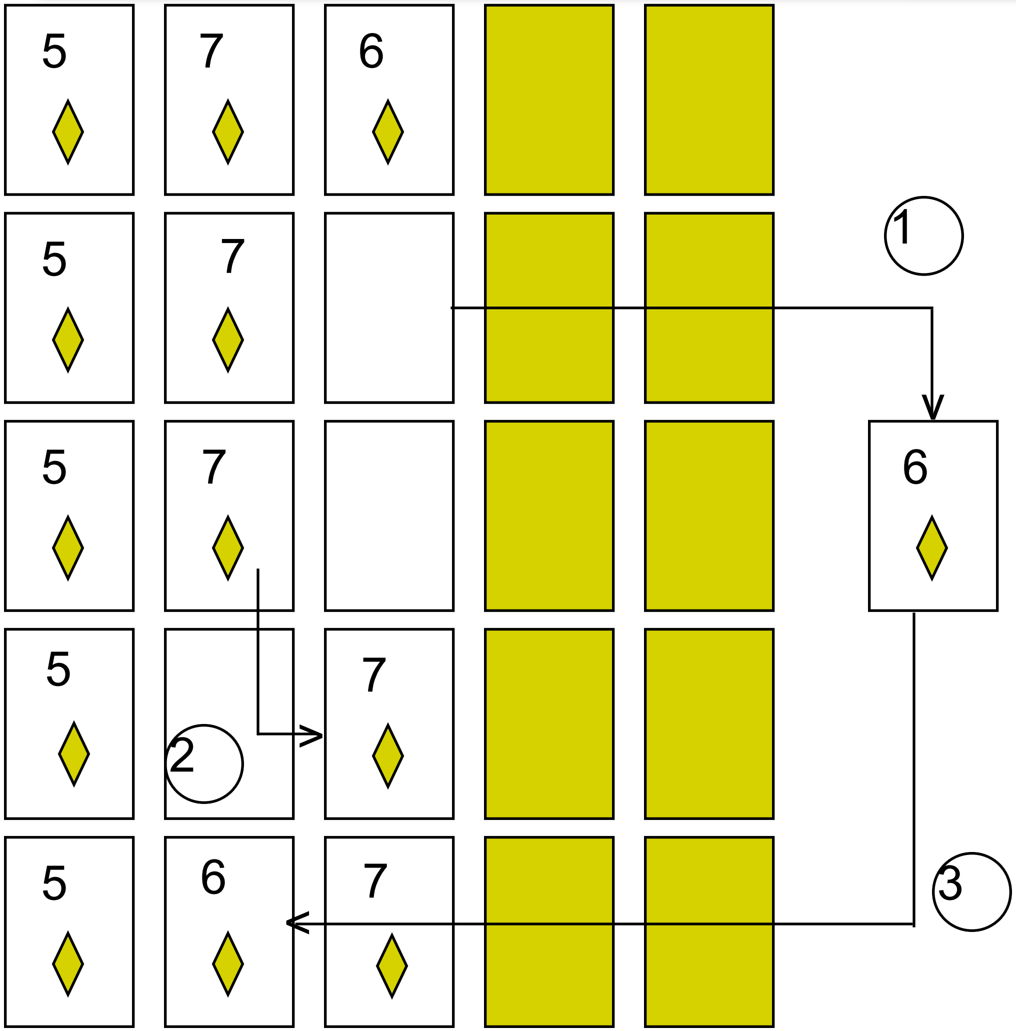
an empty slot in

position 2.

Move 7 into the empty slot, leaving position 1 open.

Move 5 into the open position.

Insertion Sort (con't)



Look at next item - 6.

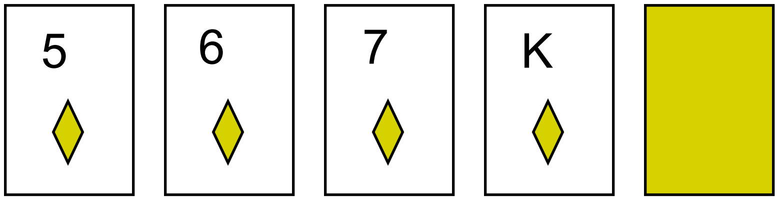
Compare to 1st - 5.

6 is larger, so leave 5.
Compare to next - 7.
6 is smaller, so move 6 to temp, leaving an empty slot.

Move 7 into the empty slot, leaving position 2 open.

Move 6 to the open 2nd position.

Insertion Sort (con't)



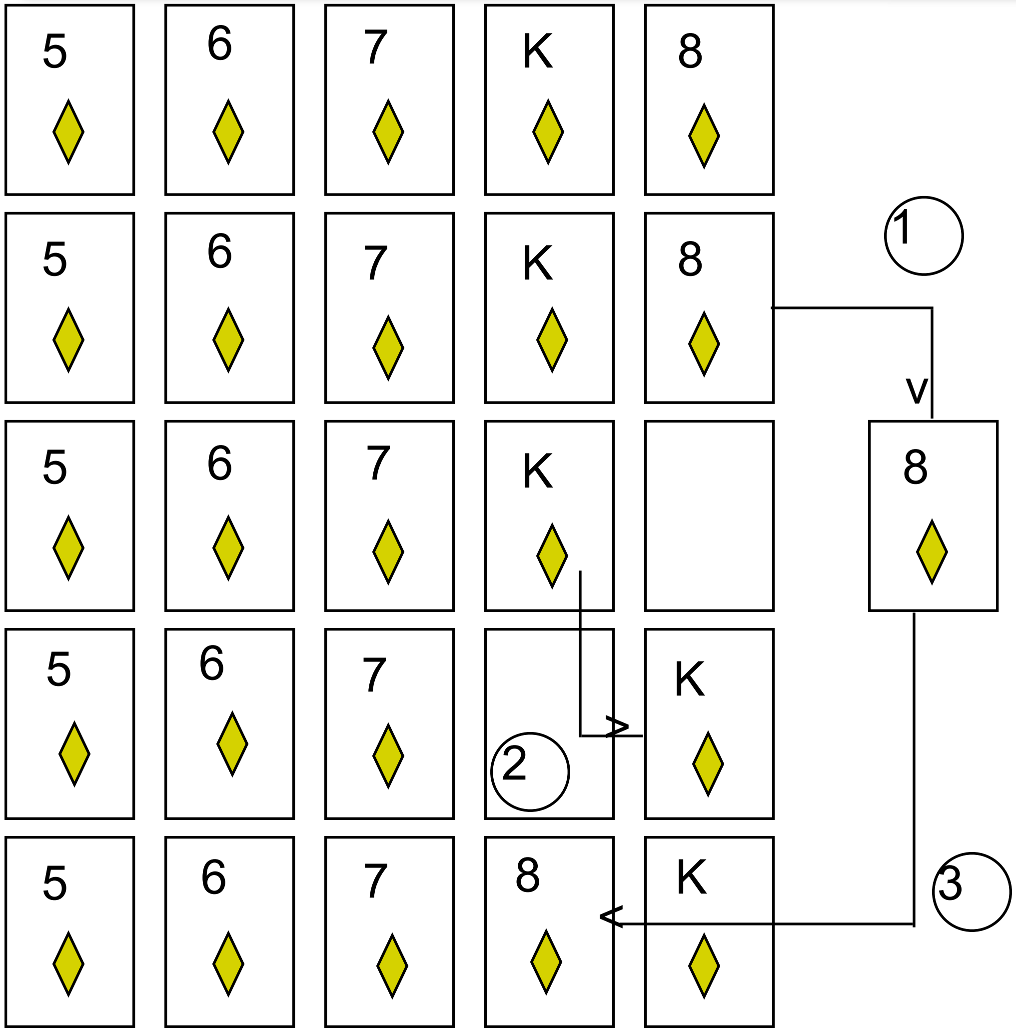
Look at next item - King.

Compare to 1st - 5.
King is larger, so
leave 5 where it is.

Compare to next - 6.
King is larger, so
leave 6 where it is.

Compare to next - 7.
King is larger, so
leave 7 where it is.

Insertion Sort (con’t)



Merge Sort

- Concept is “divide and conquer”
- We first merge and order adjacent pairs of entries
- We then merge and order our ordered-pairs of doubles
- We then merge and order our ordered-quads
- Continue until we have only one pile
- How I sort exams by alphabetical order

Quicksort

- Fastest general sort known (so far)
- Basic premise:
  - Pick random item (usually middle slot)
  - Rearrange list to move lower items to top, higher items to bottom
  - Recurse (fancy CS term) on the upper and lower subsets

How to Pick an Algorithm?

- Order of complexity is an important consideration
- Average-case and “worst-case performance
- There is rarely a “best” algorithm – just often “better ones”
- Will frequently start from some standard algorithm and (hopefully) improve
- Understanding the details of an algorithm’s behavior is critical to success