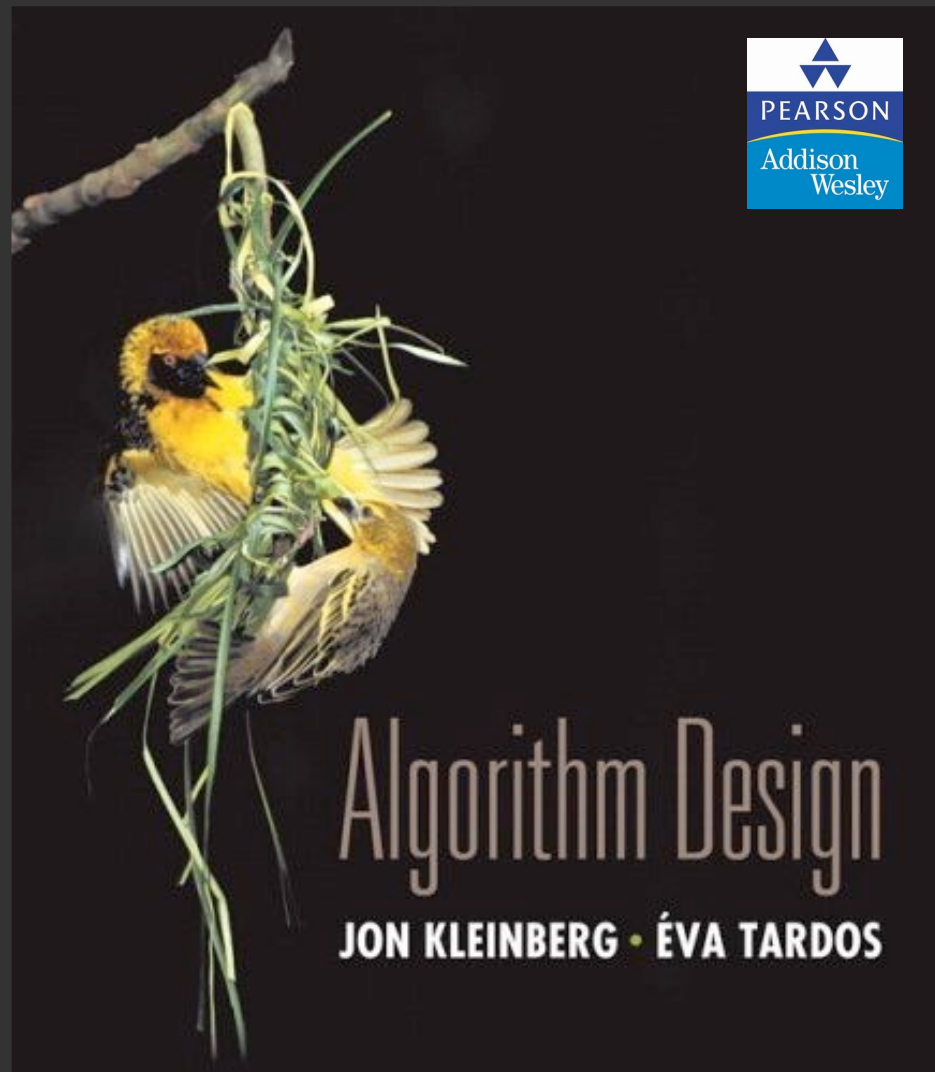


LONGEST INCREASING SUBSEQUENCE



Lecture slides by Kevin Wayne

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<http://www.cs.princeton.edu/~wayne/kleinberg-tardos>

Longest increasing subsequence

Longest increasing subsequence. Given a sequence of elements c_1, c_2, \dots, c_n from a totally-ordered universe, find the longest increasing subsequence.

Ex. 7 2 8 1 3 4 10 6 9 5 .

Maximum Unique Match finder

Application. Part of MUMmer system for aligning entire genomes.

$O(n^2)$ dynamic programming solution. LIS is a special case of edit-distance.

- $x = c_1 c_2 \dots c_n$.
- $y =$ sorted sequence of c_k , removing any duplicates.
- Mismatch penalty = ∞ ; gap penalty = 1.

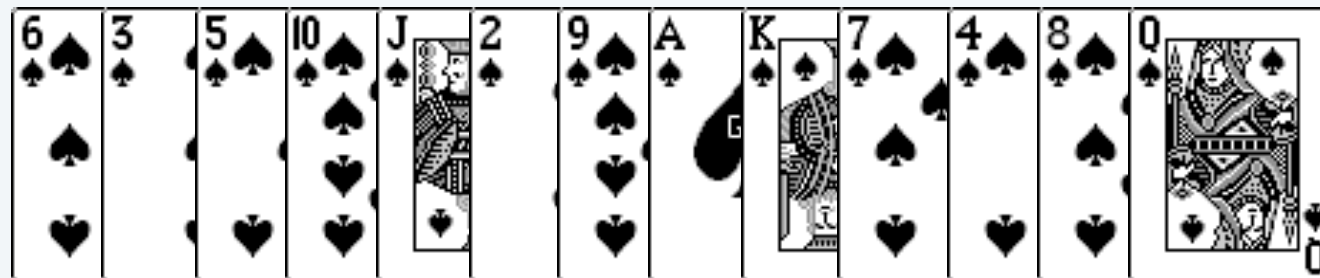
Patience solitaire

Patience. Deal cards c_1, c_2, \dots, c_n into piles according to two rules:

- Can't place a higher-valued card onto a lowered-valued card.
- Can form a new pile and put a card onto it.

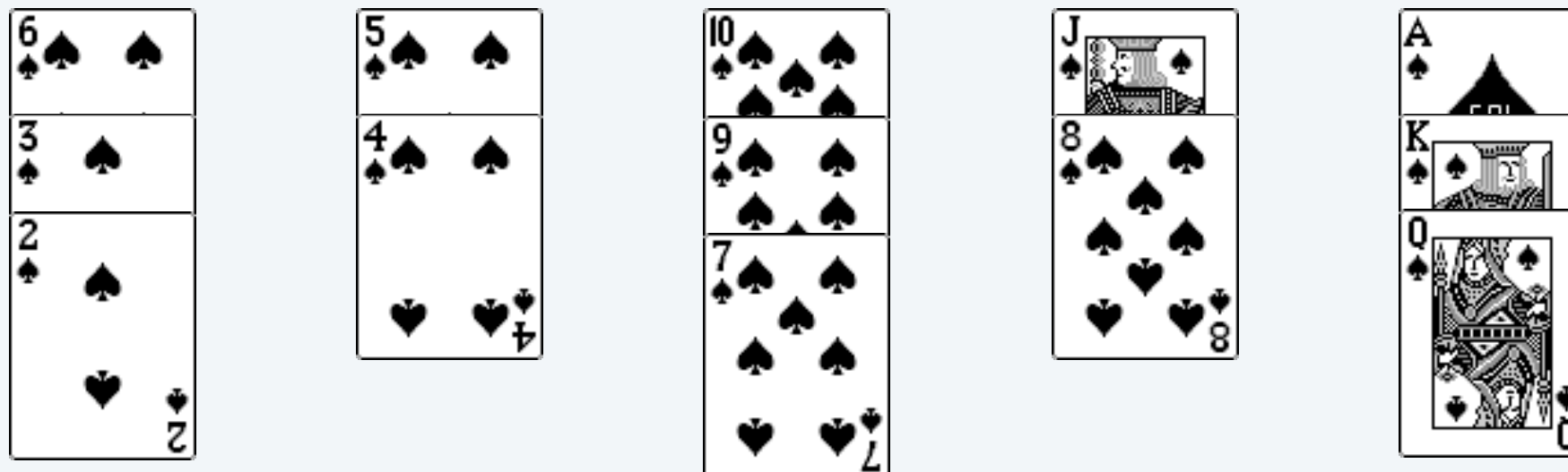
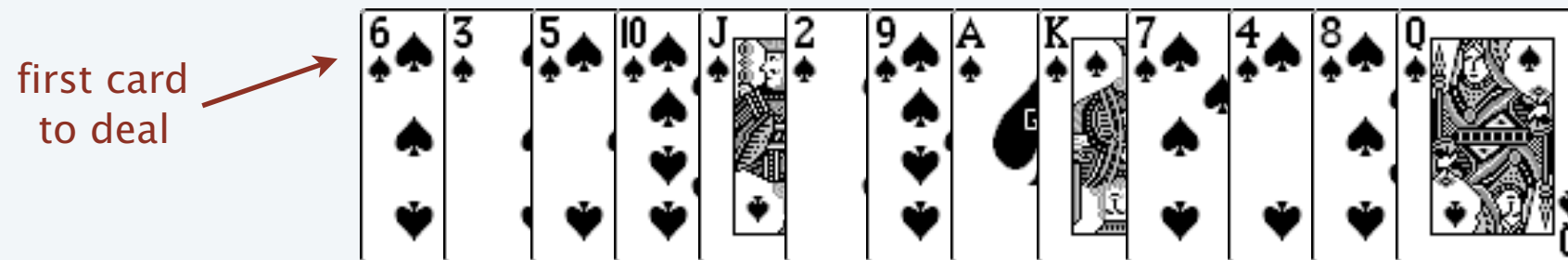
Goal. Form as few piles as possible.

first card
to deal



Patience: greedy algorithm

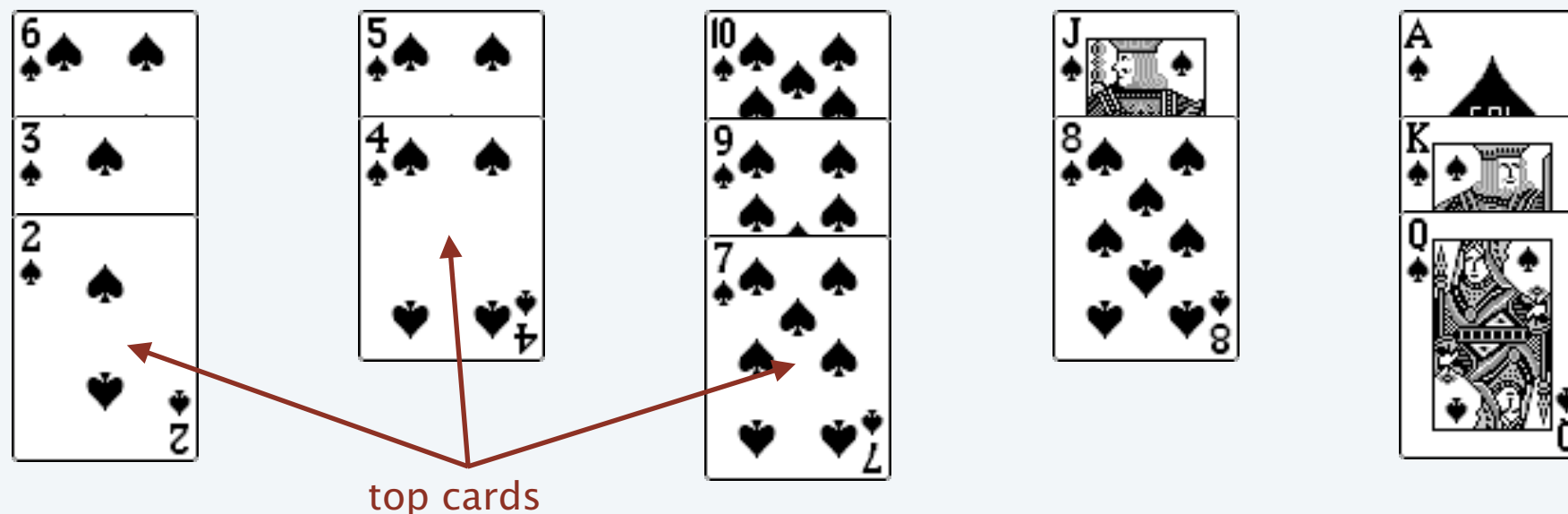
Greedy algorithm. Place each card on leftmost pile that fits.



Patience: greedy algorithm

Greedy algorithm. Place each card on leftmost pile that fits.

Observation. At any stage during greedy algorithm, top cards of piles increase from left to right.

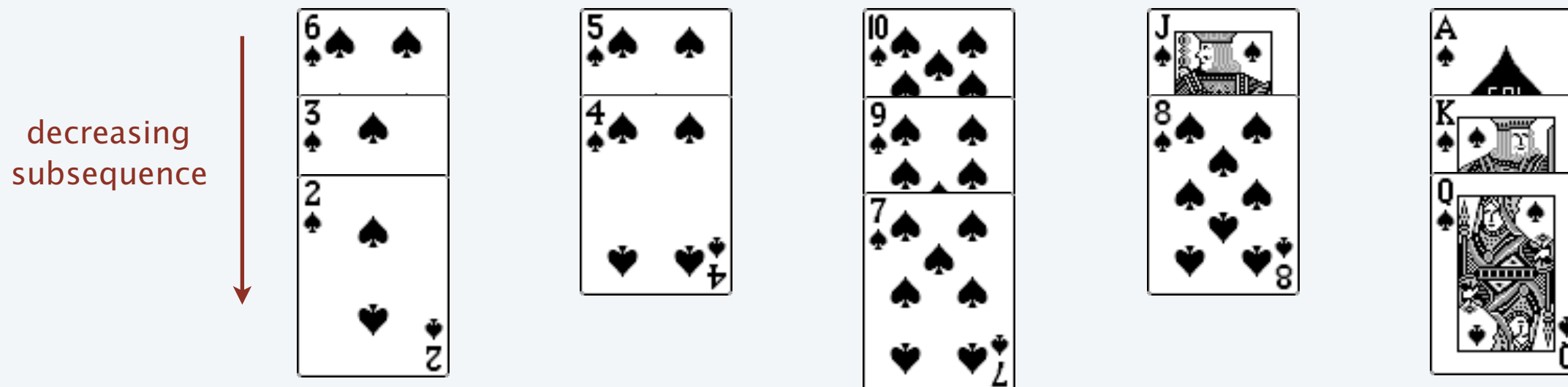
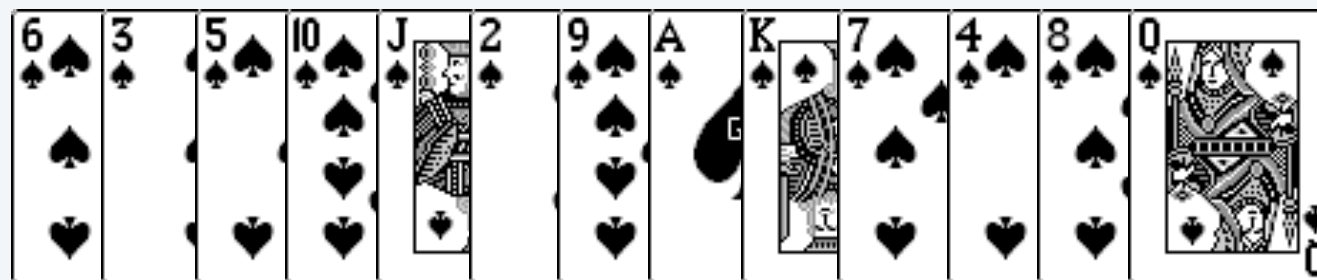


Patience-LIS: weak duality

Weak duality. In any legal game of patience, the number of piles \geq length of any increasing subsequence.

Pf.

- Cards within a pile form a **decreasing subsequence**.
- Any increasing sequence can use at most one card from each pile. ■

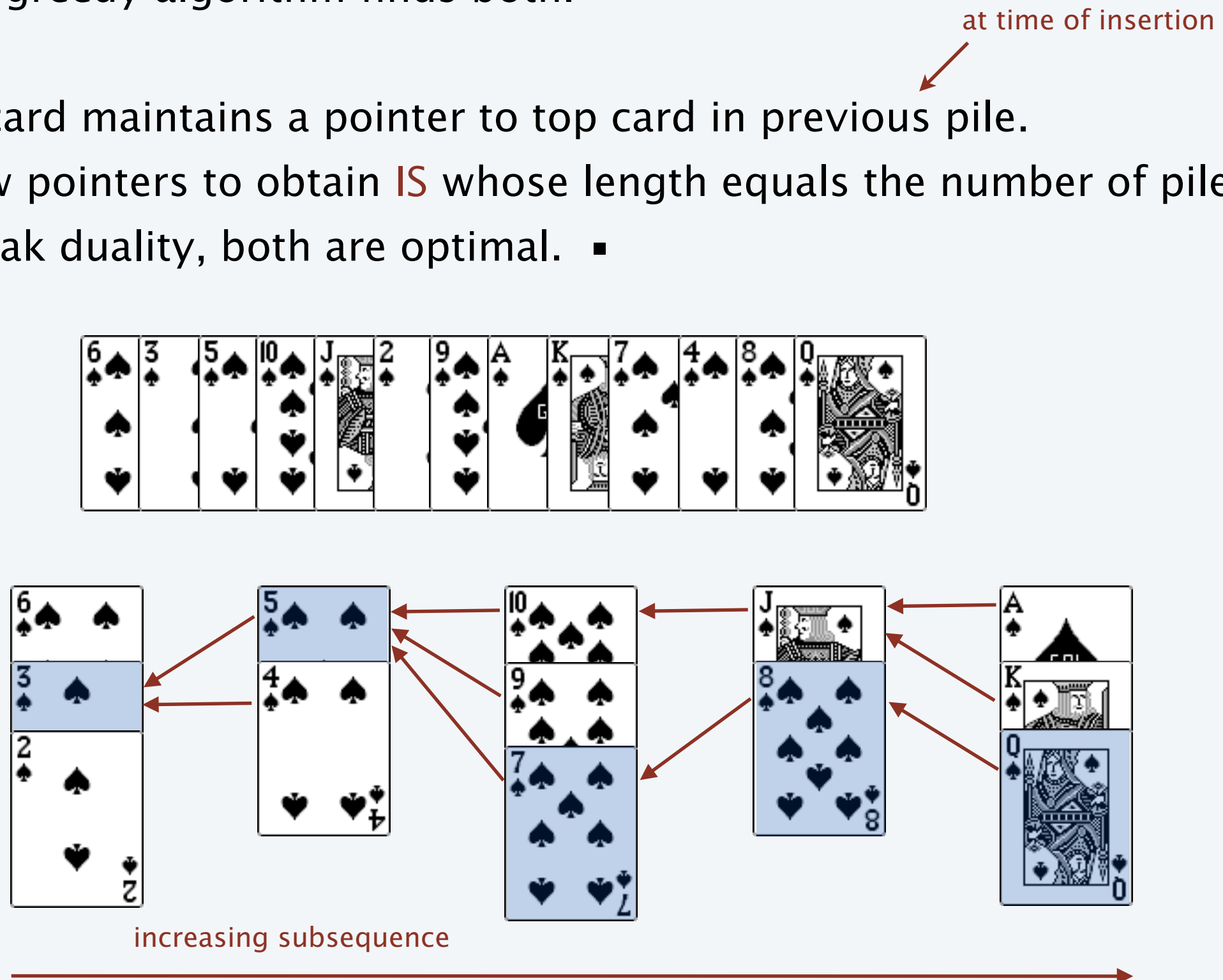


Patience-LIS: strong duality

Theorem. [Hammersley 1972] Min number of piles = max length of an IS; moreover greedy algorithm finds both.

Pf. Each card maintains a pointer to top card in previous pile.

- Follow pointers to obtain **IS** whose length equals the number of piles.
- By weak duality, both are optimal. ■



Greedy algorithm: implementation

Theorem. The greedy algorithm can be implemented in $O(n \log n)$ time.

- Use n stacks to represent n piles.
- Use binary search to find leftmost legal pile.

PATIENCE (n, c_1, c_2, \dots, c_n)

INITIALIZE an array of n empty stacks S_1, S_2, \dots, S_n .

FOR $i = 1$ **TO** n

$S_j \leftarrow$ binary search to find leftmost stack that fits c_i .

PUSH (S_j, c_i).

$pred[c_i] \leftarrow$ **PEEK** (S_{j-1}).  null if $j = 1$

RETURN sequence formed by following pointers from top card of rightmost nonempty stack.

Patience sorting

Patience sorting. Deal all cards using greedy algorithm; repeatedly remove smallest card.

Theorem. For uniformly random deck, the expected number of piles is approximately $2n^{1/2}$ and the standard deviation is approximately $n^{1/6}$.

Remark. An almost-trivial $O(n^{3/2})$ sorting algorithm.

Speculation. [Persi Diaconis] Patience sorting is the fastest way to sort a pile of cards by hand.

Bonus theorem

Theorem. [Erdős-Szekeres 1935] Any sequence of $n^2 + 1$ distinct real numbers either has an increasing or decreasing subsequence of size $n + 1$.

Pf. [by pigeonhole principle]

