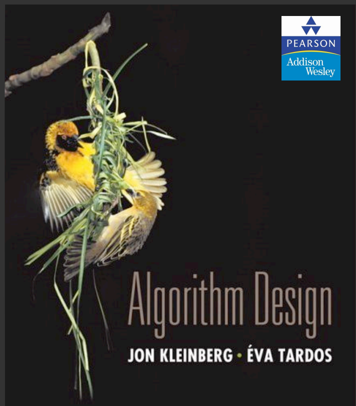

Longest Increasing Subsequence

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

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Longest increasing subsequence

Longest increasing subsequence. Given a sequence of elements $c_1, c_2, \ldots, c_n$ 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.

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

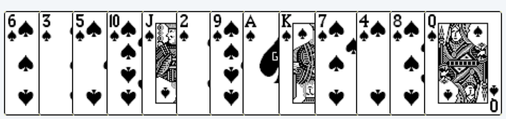
Patience solitaire

Patience. Deal cards $c_1, c_2, \ldots, c_n$ 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.

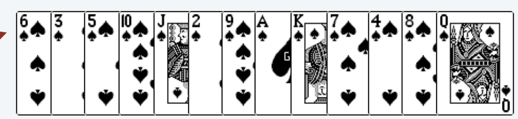
first card to deal

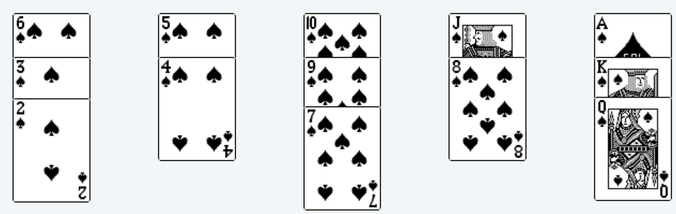


Patience: greedy algorithm

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

first card to deal

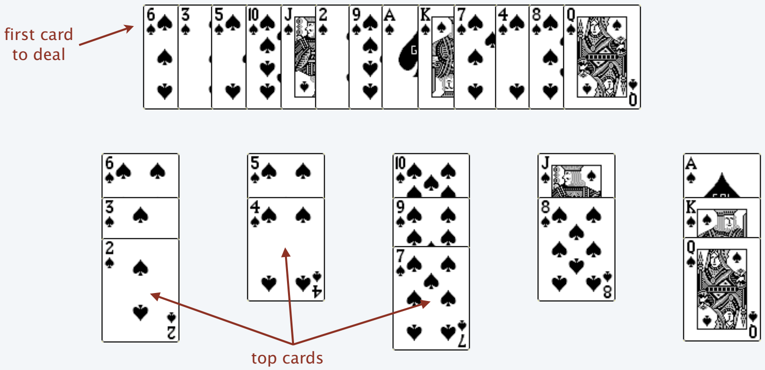




Patience: greedy algorithm

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.

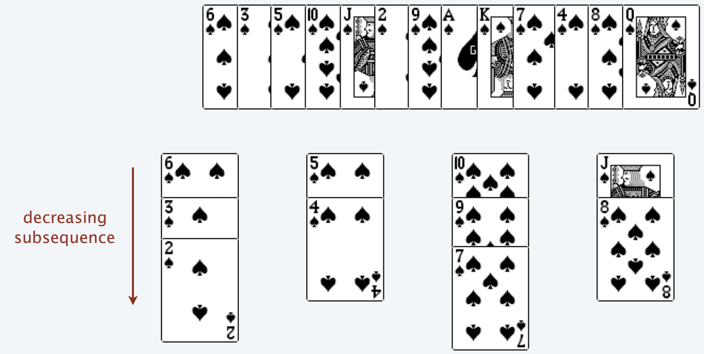


Patience-LIS: weak duality

Weak duality. In any legal game of patience, the number of piles ≥ 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. ▪



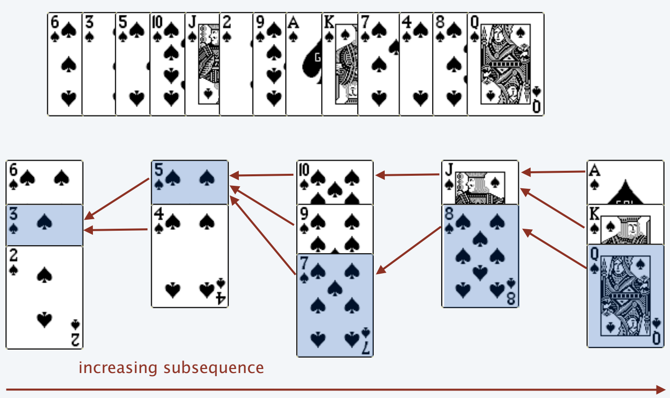
Patience-LIS: strong duality

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

at time of insertion

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, …, c_n)

INITIALIZE an array of n empty stacks S_1, S_2, …, 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 $2\,n^{1/2}$ 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. [Erdös-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]