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Advanced Data Structures

MSc-Vorlesung
Wintersemester 2012/13
KIT

Preliminaries

- 5 ECTS
- lectures in German, slides etc. in English
- prequisites:
  - Algorithmen II
  - interest in discrete, combinatorial problems
- ~14 lectures (NOT 27.12.12/03.01.13)
- oral exam (20-25 mins)

Preliminaries

- course homepage:
  `http://algo2.iti.kit.edu/2056.php`
  - slides & script
  - additional course information
- Johannes.Fischer@kit.edu (room 207)
- office hours: Thursday 14-15

BADS'13

- write a **paper** on a data structure **not** covered in the lecture
    - list of topics on course website
    - can be strengthened by experiments
- use LaTeX ⇒ learn to write scientifically
    - vector graphics: ipe, xfig, ... (no bitmap!)
- website will provide style files, etc.

The Process

- as **author**:
  - write paper (5-10 pages)
  - submit to conference management system
- as member of **program committee**: 10%
  - blind peer reviews & ranking (~2 weeks)
- back to author role:
  - submit final version $\Rightarrow$ proceedings 20%
  - symposium: 20 min oral presentation 10%

What is a data structure?

What is a Data Structure?

A **Data Structure** specifies how to encode data from some Data Type so as to support the operators specified by a given Abstract Data Type.

Example: Permutations

- data type: **permutation** π of $[1,n]$
- ADS operations:
  - $\texttt{access}_\pi(i)$: return $\pi[i]$
  - $\texttt{inverse}_\pi(j)$: return i such that $\pi[i]=j$
- data structure: 2 arrays $A[1,n]$, $A^{-1}[1,n]$
  - $\texttt{access}_\pi(i) = A[i]$
  - $\texttt{inverse}_\pi(j) = A^{-1}[j]$
- might be OK, might be not (e.g. dynamic??)

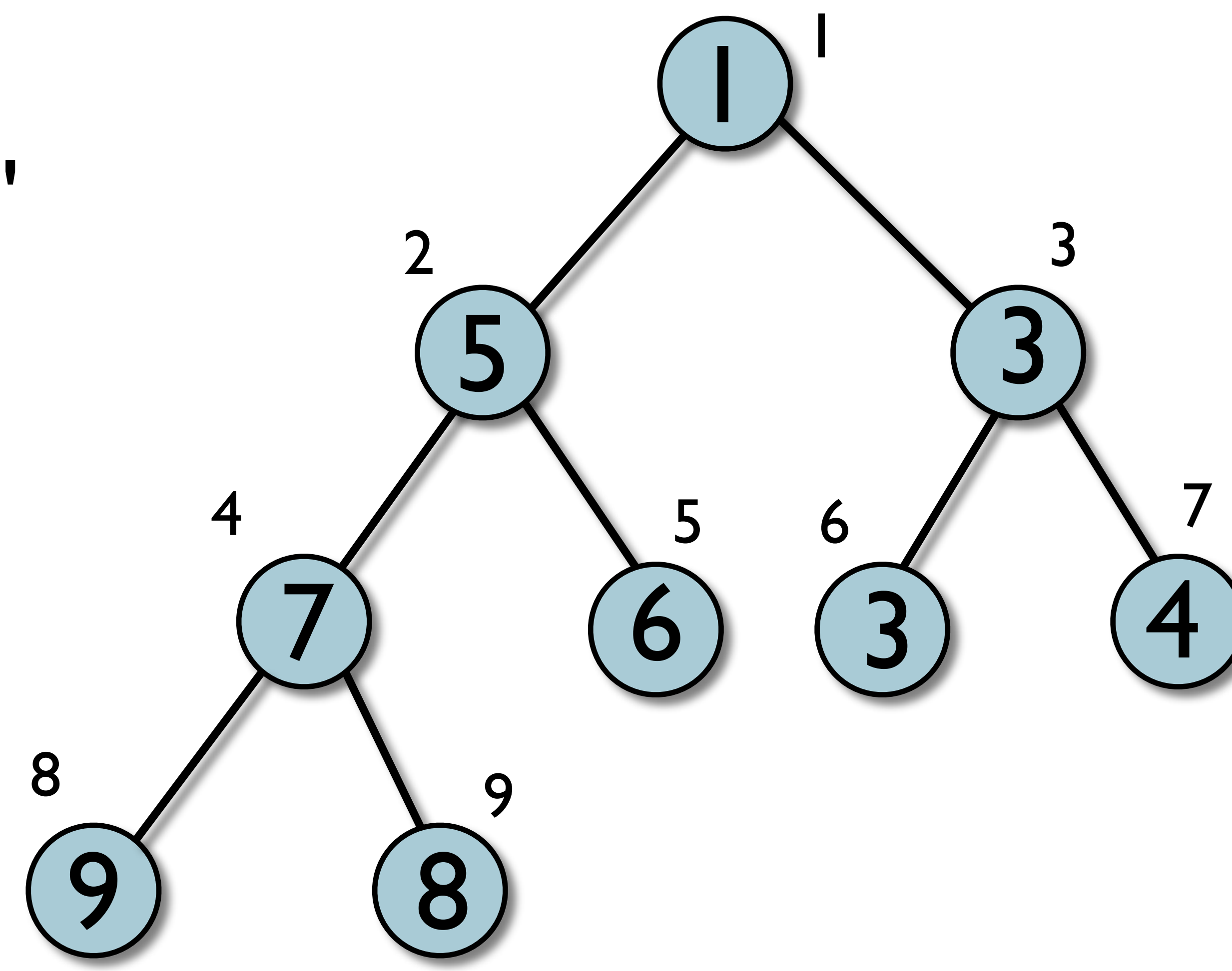
Extending Functionality

- have: DS **D** for ADT **T**
  - e.g. permutations with `access`/`inverse`
- want: DS **D'** for ADT **T'** with **T'** $\supseteq$ **T**
  - e.g. perms with `access`/`inverse` **plus** $\texttt{inversions}_{\pi}(i) = |\{j<i : \pi[j] > \pi[i]\}|$
- use **D** as black box: **D'** is called **index**
  - sublinear space possible: |**D'**| = o(|**D**|)

Implicit DS

- clever storage
  - functionality "for free"
- e.g. heap:

$$\text{parent}(x) = \left\lfloor \frac{x}{2} \right\rfloor$$



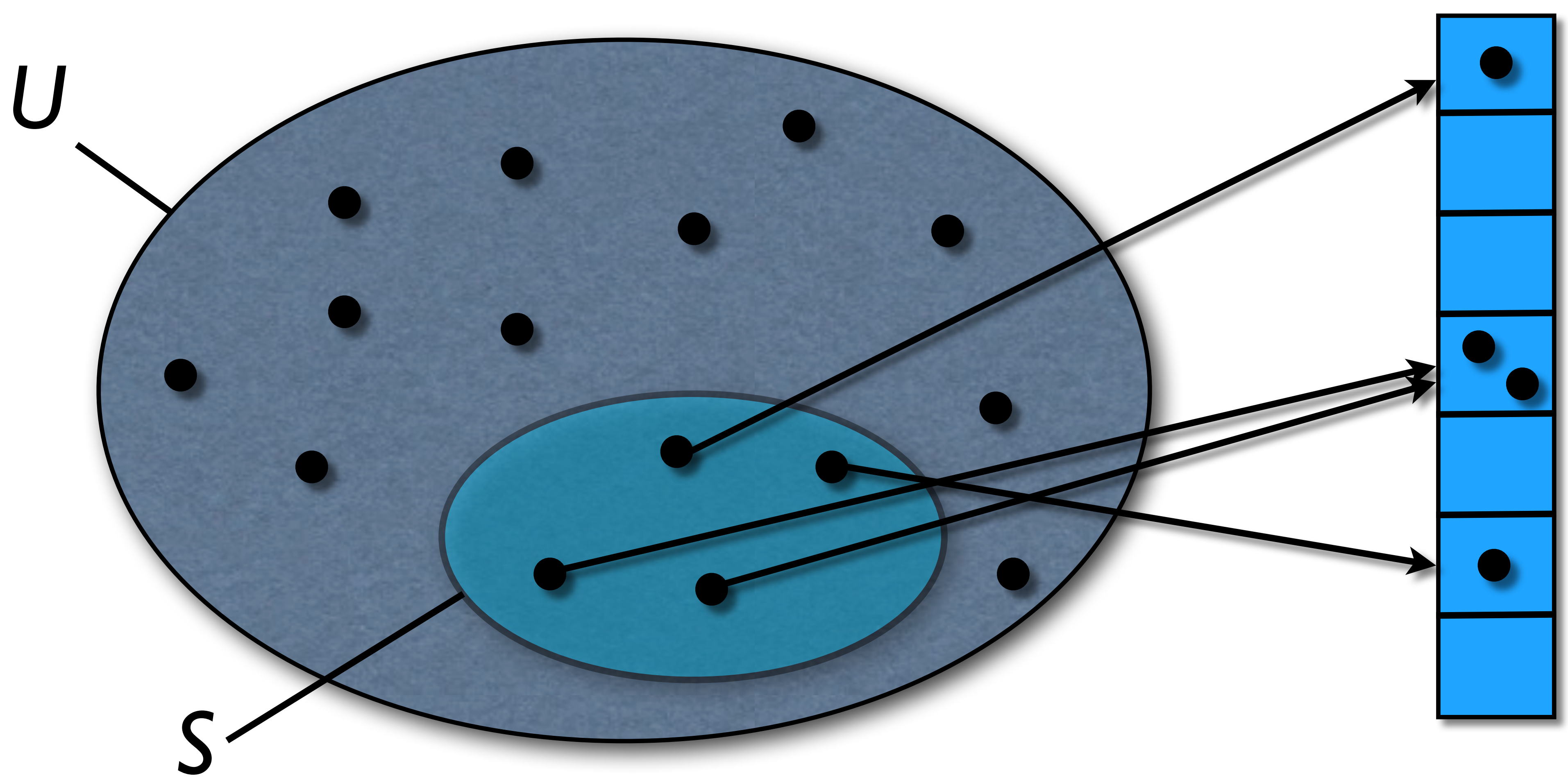
1	2	3	4	5	6	7	8	9
1	5	3	7	6	3	4	9	8

Course Contents

- hashing
- predecessor data structures
- integer sorting/searching
- distance oracles
- tree labelings
- lowest common/level ancestors
- range minimum queries
- succinct trees
- text indexing

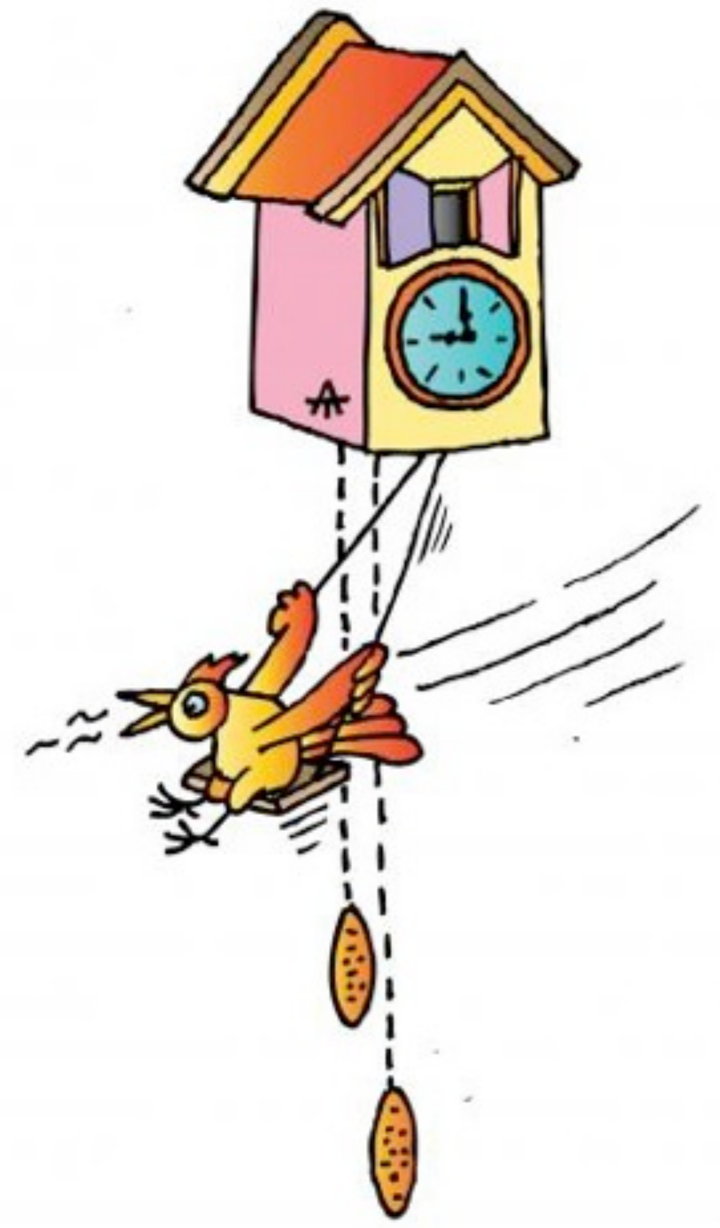
Hashing

- set S of n objects from a LARGE universe U
- query for membership (+satellite info)
- Use space $O(n)$, not $O(|U|)$



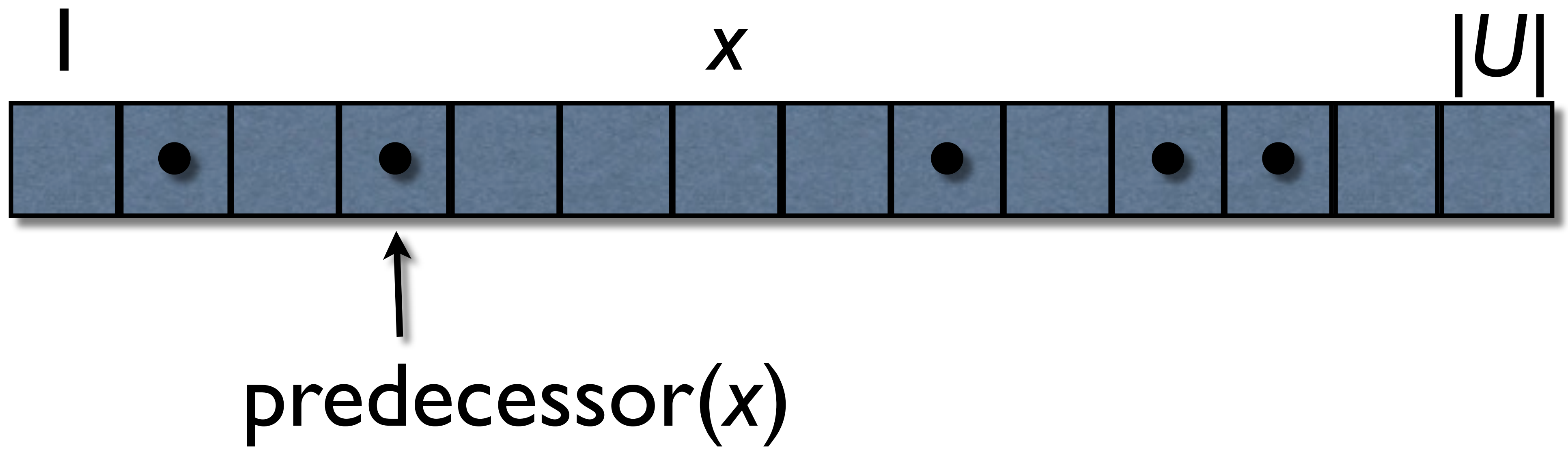
Hashing: lookup time

- chaining/linear probing:
  $O(1)$ **expected** time
- cuckoo hashing:
  $O(1)$ **worst case** time
- other operations $O(1)$
  amortized & expected



Predecessor Queries

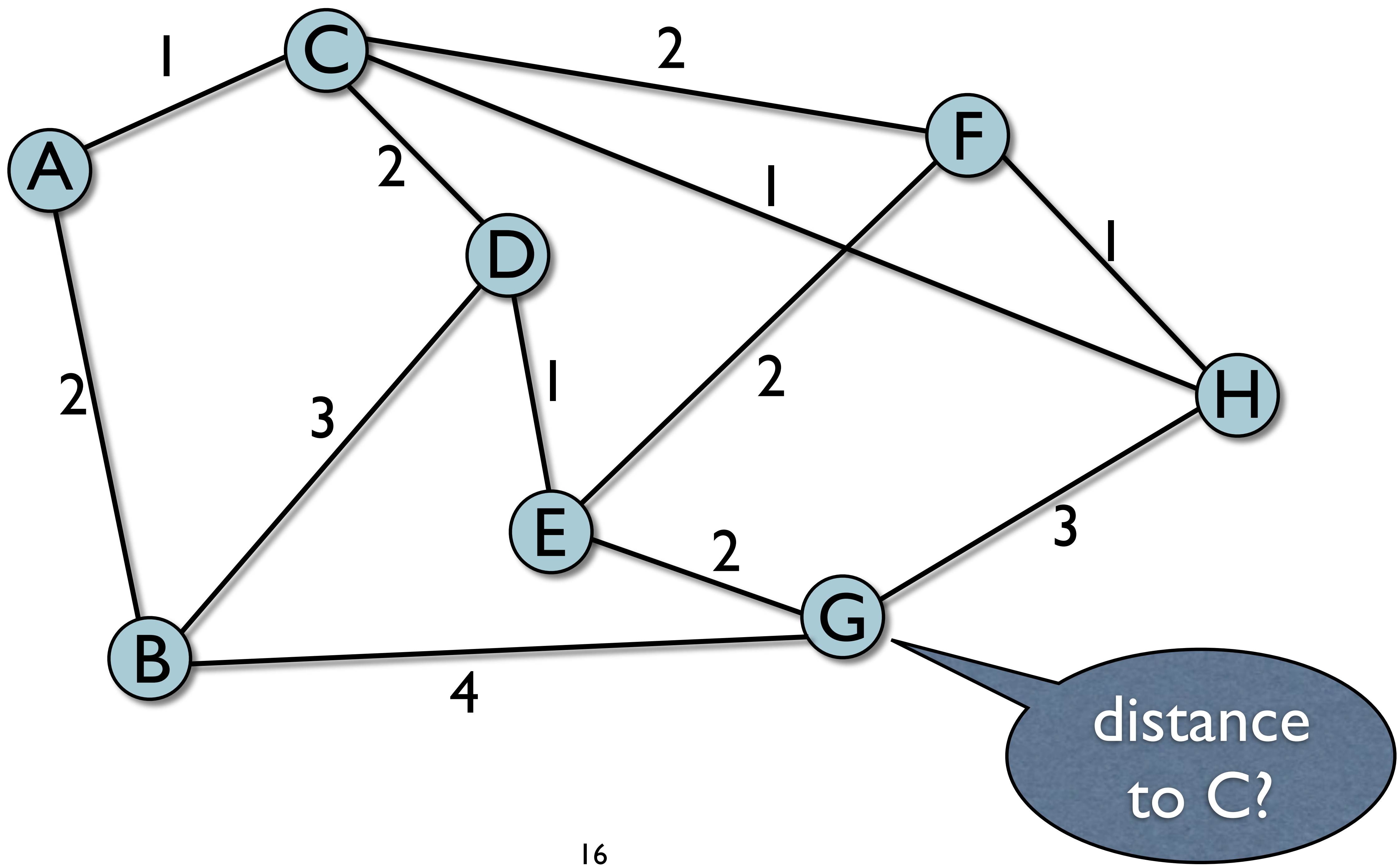
- S: n objects from a SORTED universe U
- given $x \in U$, return $\max\{y \leq x : y \in S\}$
- fast if elements are integers: $O(\lg\lg |U|)$



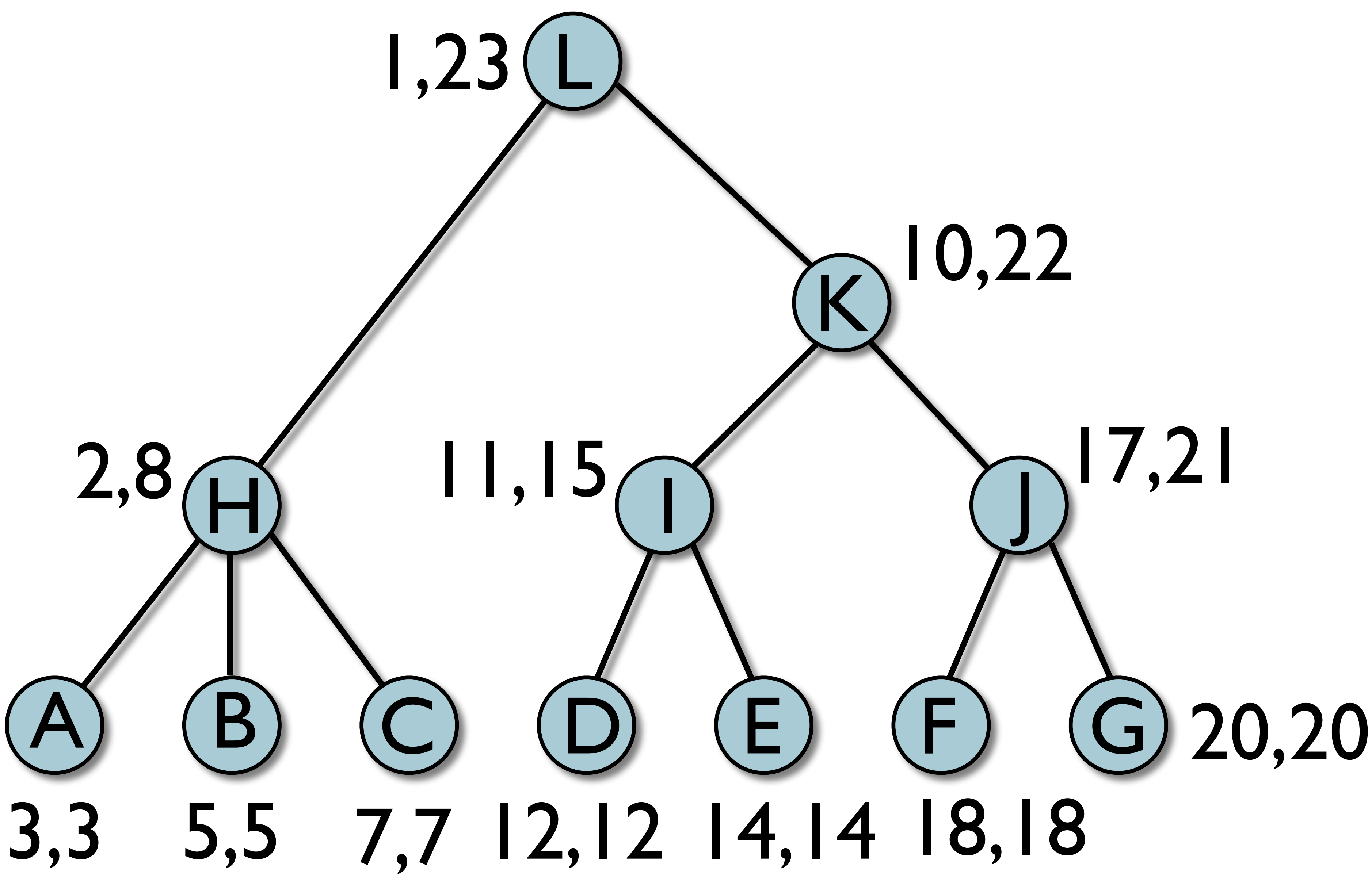
Integer Sorting

- sort n elements from a universe $[0,2^w-1]$
  - comparison based sorting: $\Theta(n \lg n)$
- counting sort: $O(n + 2^w)$
- with predecessor queries: $O(n \lg w)$
- **signature sort**:
  - $O(n)$ for w sufficiently large
  - $O(n \lg\lg n)$ for all w

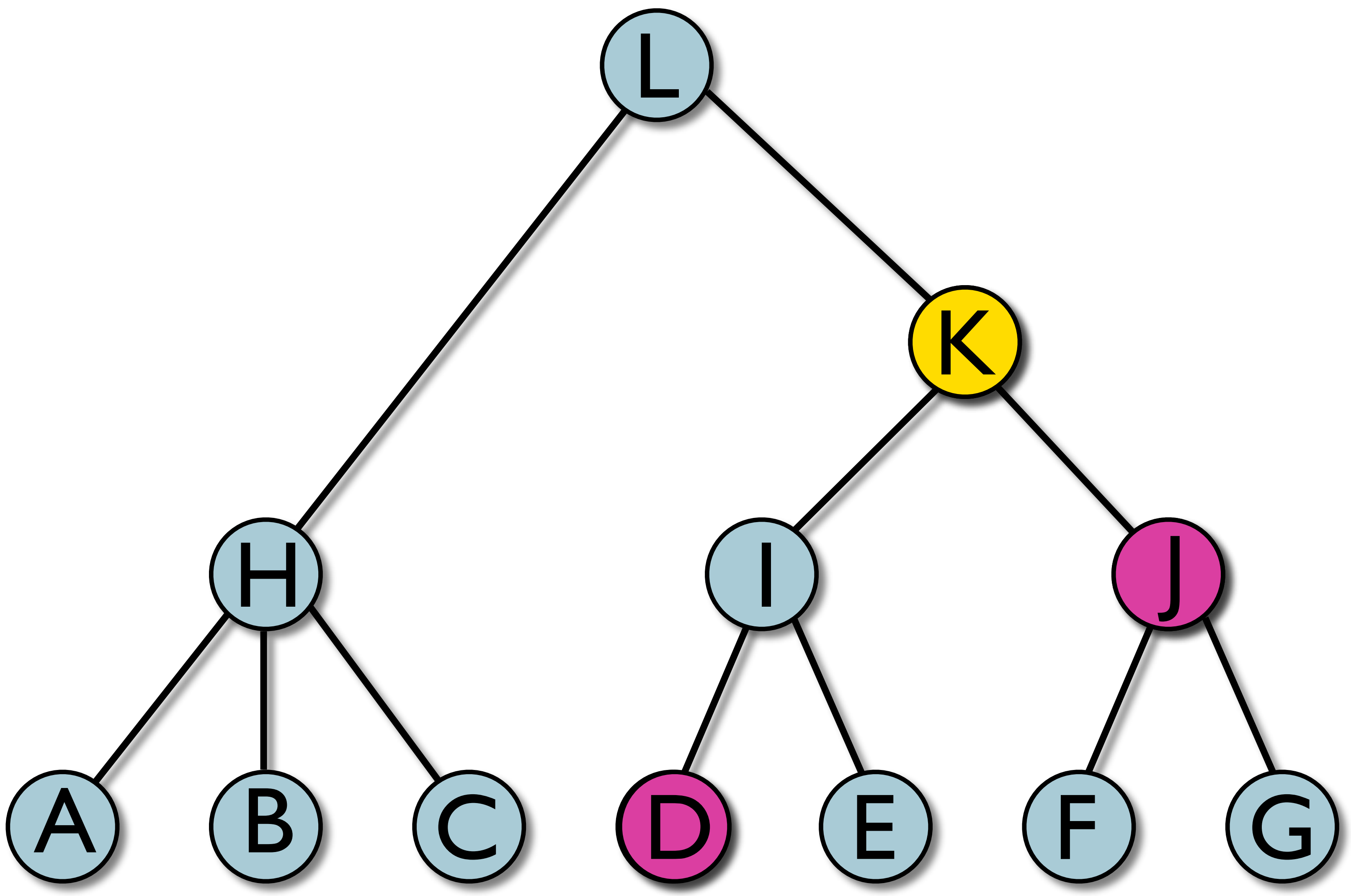
Distance Oracles



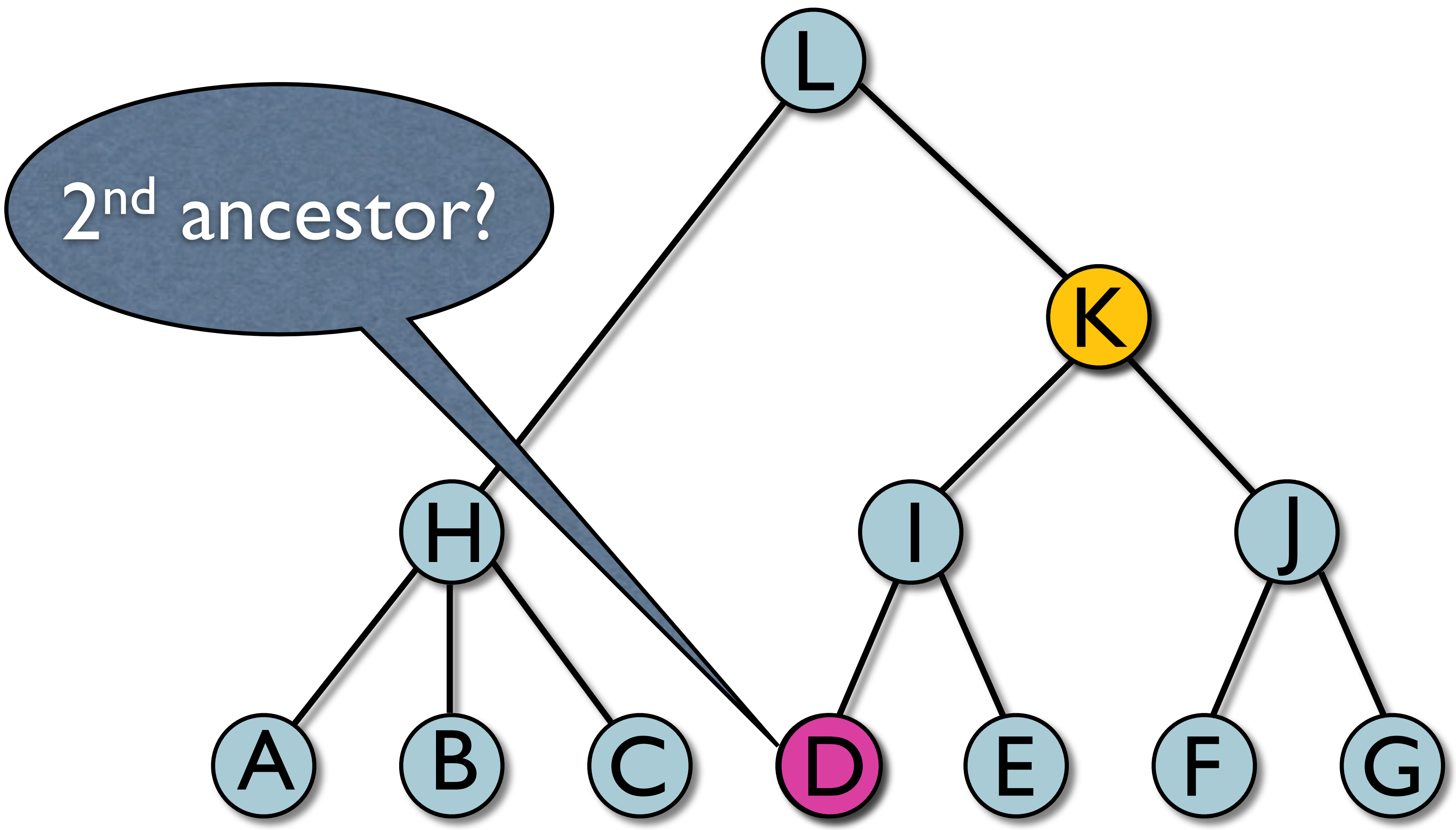
Tree Labelings: Ancestors



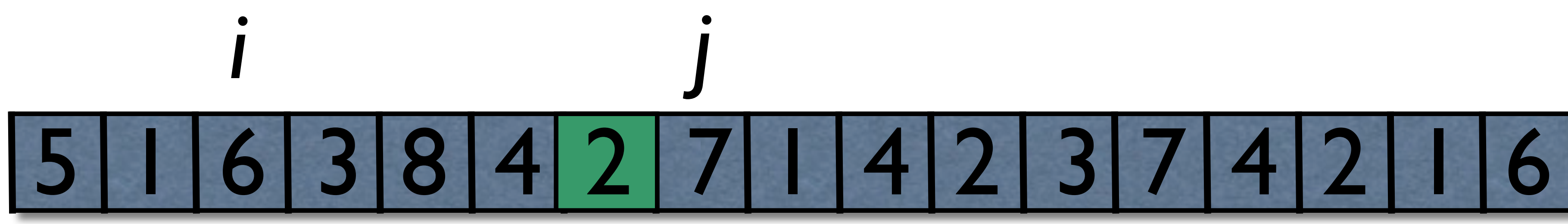
Lowest Common Ancestors



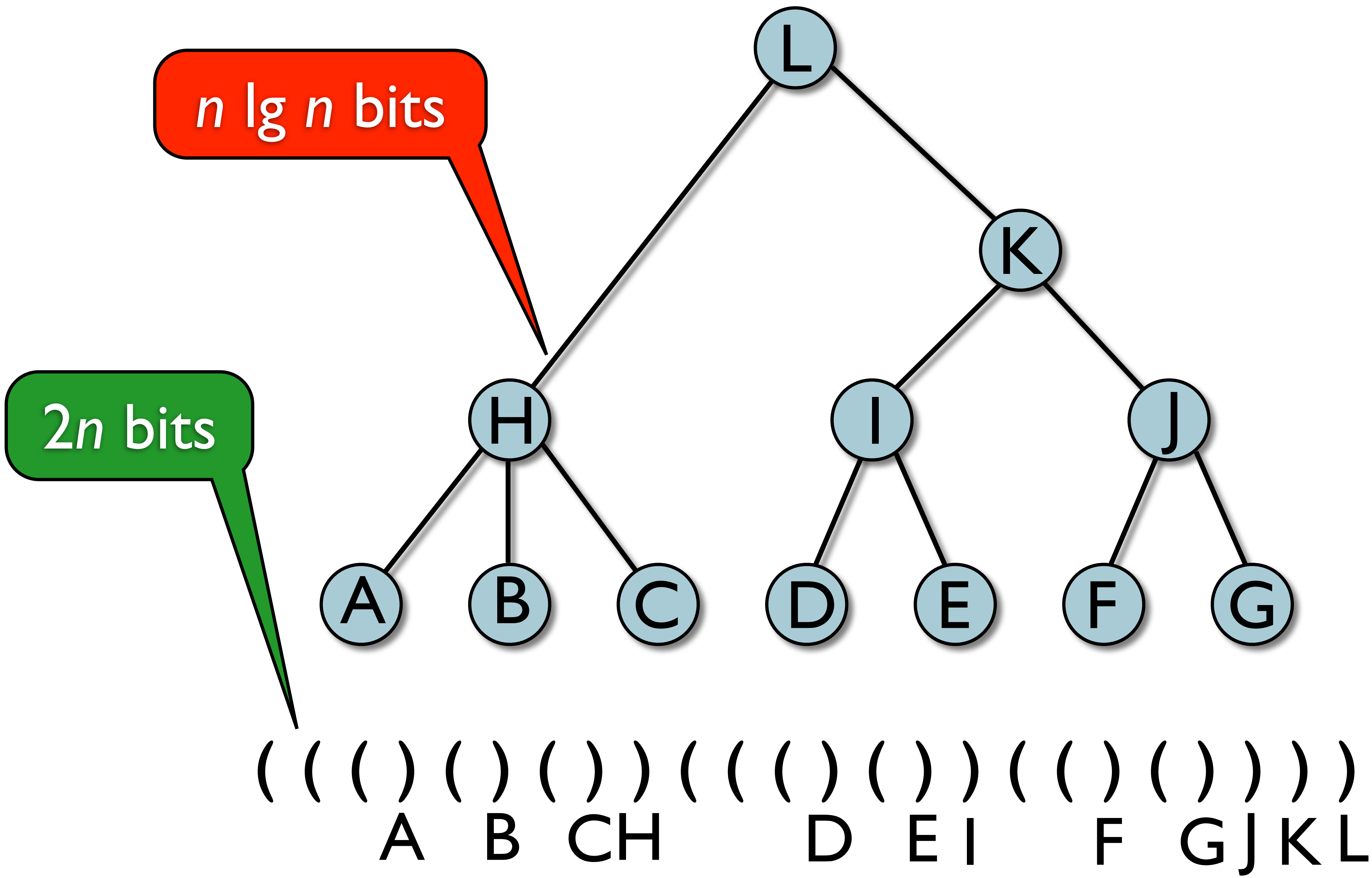
Level Ancestors



Range Minimum Queries

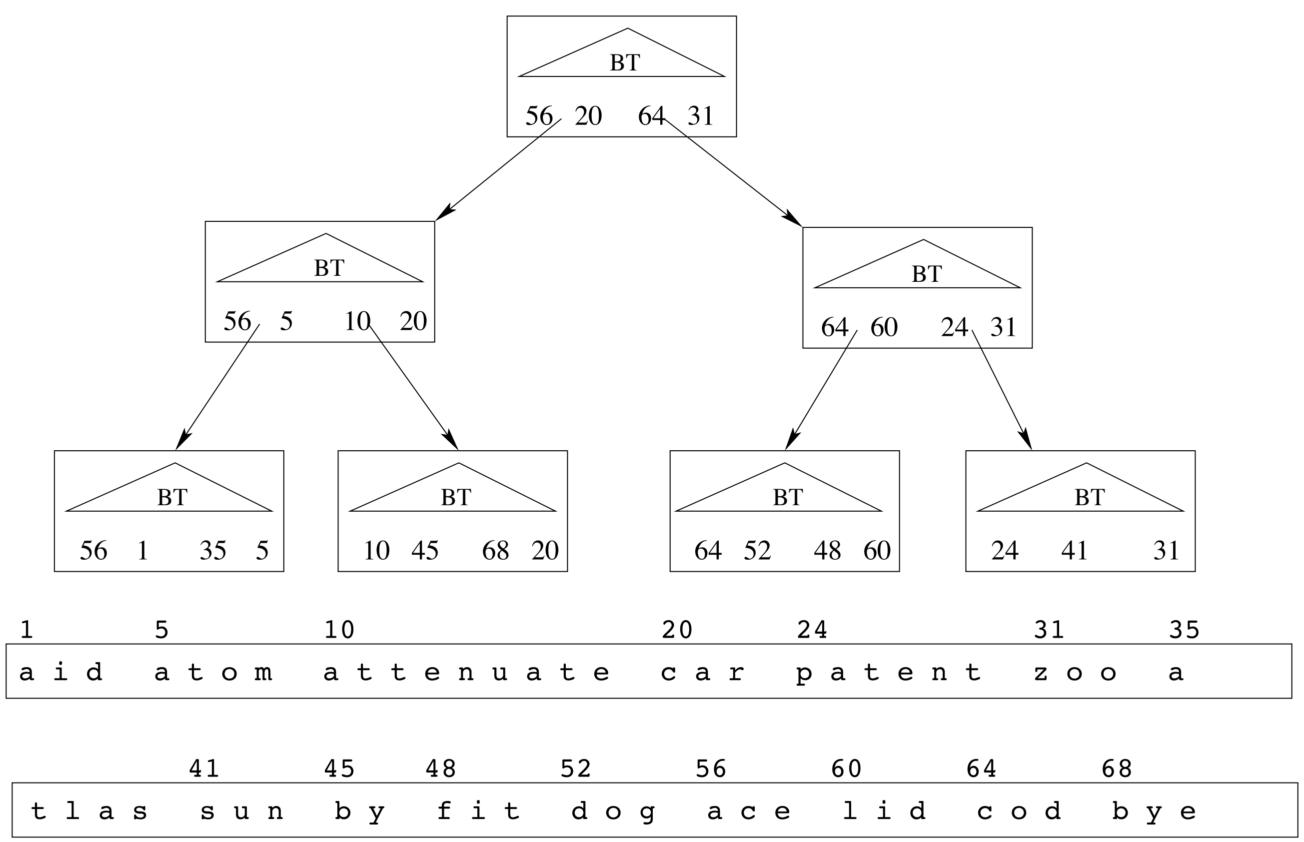


Succinct Trees



String B-Trees

- text indexing in **external** memory
- substring queries (cf suffix tree/array)
- new challanges (minimize IOs)



Theory vs. Practice

- focus on **theoretical** (=mathematical) analysis of data structures
- BUT: most methods highly **practical** (perhaps with some engineering effort)
  - VL "Algorithm Engineering"
- every method better than naive approach (complex analysis $\not\Rightarrow$ slow running time)

Classification of DSs

object	type of DS
numbers	„normal“
point sets	integer
graphs	randomized
trees	distributed
arrays	succinct
strings	external
...	parallel
	cache aware etc.

Time vs Space

e.g. tree + LCA