

Searching and Sorting

- Searching
 - Linear search
 - Binary search
- Sorting
 - Insertion sort
 - Merge sort

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Searching

- **Searching.** Given a **sorted** array A and number x, determine if x appears in the array.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50

Linear Search

- **Linear search.** Check if each entry matches x .
- **Time?**
- **Challenge.** Can we take advantage of the sorted order of the array?

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50

Binary Search

- **Binary search.** Compare x to middle entry m in A .
 - if $A[m] = x$ return true and stop.
 - if $A[m] < x$ continue **recursively** on the right half.
 - if $A[m] > x$ continue **recursively** on the left half.
- If array size ≤ 0 return false and stop.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50

Binary Search

```
BINARYSEARCH(A,i,j,x)
  if j < i return false
  m = ⌊(i+j)/2⌋
  if A[m] = x return true
  elseif A[m] < x return BINARYSEARCH(A,m+1,j,x)
  else return BINARYSEARCH(A,i,m-1,x)    // A[m] > x
```

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50

- Time?
- **Analysis 1.** Analogue of recursive peak algorithm.
 - A recursive call takes constant time.
 - Each recursive call **halves** the size of the array. We stop when the size is ≤ 0 .
 - \Rightarrow Running time is $\Theta(\log n)$

Binary Search

- **Analysis 2.** Let $T(n)$ be the running time for binary search.
 - Solve the **recurrence relation** for $T(n)$.

$$T(n) = \begin{cases} T(n/2) + c & \text{if } n > 1 \\ d & \text{otherwise} \end{cases}$$

$$\begin{aligned} T(n) &= T\left(\frac{n}{2}\right) + c \\ &= T\left(\frac{n}{4}\right) + c + c \\ &= T\left(\frac{n}{8}\right) + c + c + c \\ &\quad \vdots \\ &= T\left(\frac{n}{2^k}\right) + ck \\ &\quad \vdots \\ &= T\left(\frac{n}{2^{\log_2 n}}\right) + c \log_2 n \\ &= T(1) + c \log_2 n \\ &= d + c \log_2 n \\ &= \Theta(\log n) \end{aligned}$$

Searching

- We can search in
 - $\Theta(n)$ time with linear search.
 - $\Theta(\log n)$ time with binary search.

Searching and Sorting

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- Sorting
 - Insertion sort
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Sorting

- **Sorting.** Given array $A[0..n-1]$ return array $B[0..n-1]$ with same values as A but in sorted order.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
33	4	25	28	45	18	7	12	36	1	47	42	50	16	31

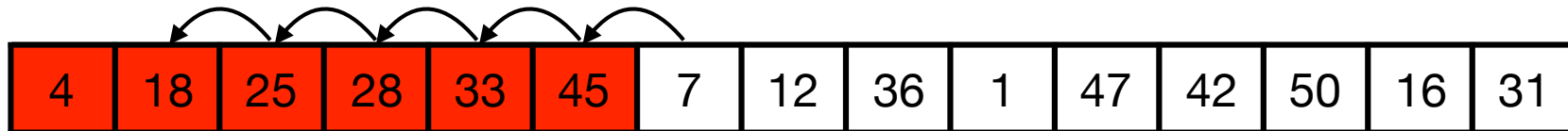
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50

Application

- **Obvious.**
 - Sort list of names, show Google PageRank results, show social media feed in chronological order.
- **Non obvious.**
 - Data compression, computer graphics, bioinformatics, recommendations systems.
- **Easy problem for sorted data.**
 - Search, find median, find duplicates, find closest pair, find outliers.

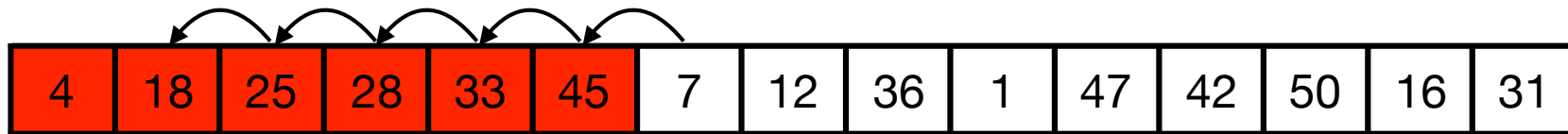
Insertion Sort

- **Insertion sort.** Start with unsorted array A.
- Proceed left-to-right in n **rounds**.
- Round i:
 - Subarray $A[0..i-1]$ is sorted.
 - Insert $A[i]$ into $A[0..i-1]$ to make $A[0..i]$ sorted.



Insertion Sort

```
INSERTIONSORT(A, n)
  for i = 1 to n-1
    j = i
    while j > 0 and A[j-1] > A[j]
      swap A[j] og A[j-1]
      j = j - 1
```



- Time?
 - To insert $A[i]$ we use $c \cdot i$ time for constant c .
 - \implies total time $T(n)$:

$$T(n) = \sum_{i=1}^{n-1} ci = c \sum_{i=1}^{n-1} i = \frac{cn(n-1)}{2} = \Theta(n^2)$$

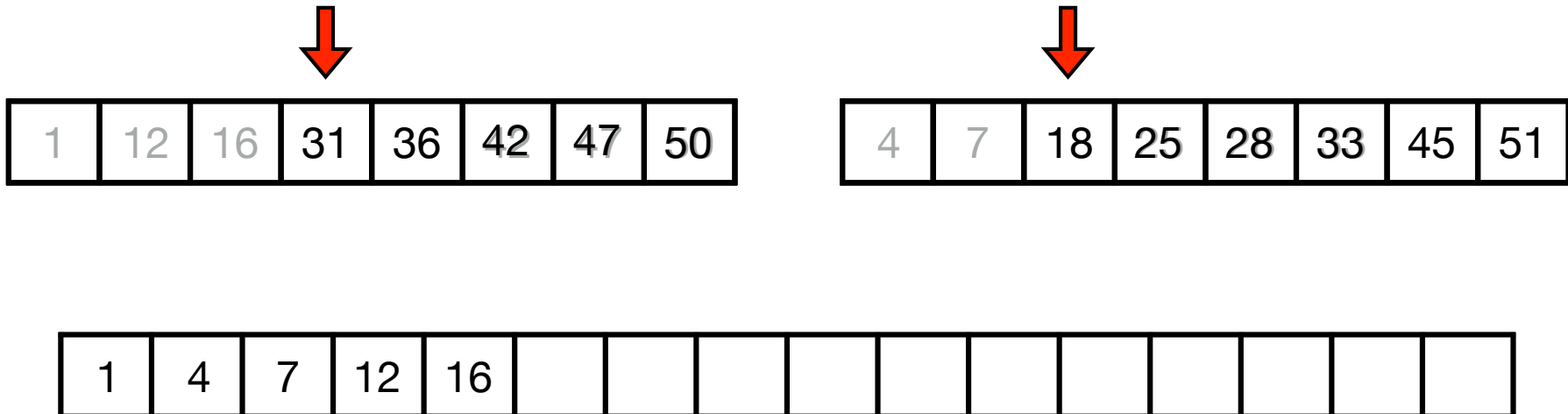
- Challenge. Can we sort faster?

Merge sort

- Merge sort.
 - Idea. Recursive sorting via merging sorted subarray.

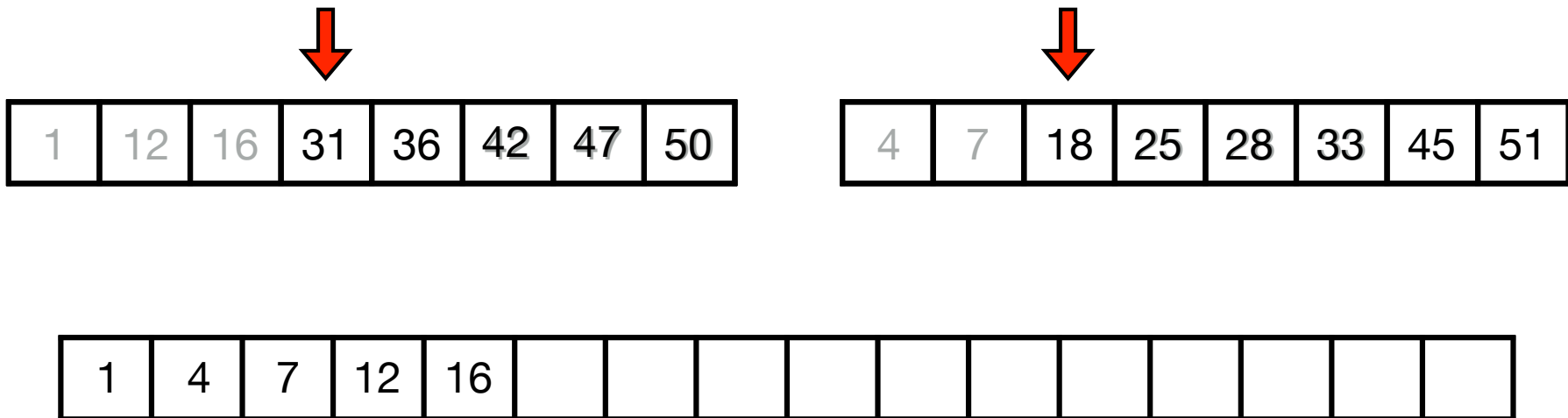
Merge

- **Goal.** Combine two sorted array into a single sorted array.
- **Idea.**
 - Scan both arrays left-to-right. In each step:
 - Insert smallest of the two entries in new array.
 - Move forward in array with smallest entry.
 - Repeat until input array exhausted.



Merge

- **Time.** Merging two arrays A_1 og A_2 ?
 - Each step take $\Theta(1)$ time.
 - Each step we move forward in one array.
 - $\Rightarrow \Theta(|A_1| + |A_2|)$ time.



Merge sort

- Merge sort.
- If $|A| \leq 1$, return A.
- Otherwise:
 - Split A into halves.
 - Sort each half recursively.
 - Merge the two halves.

16	31	1	36	47	50	42	12	7	4	51	28	45	25	18	33
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50	51

16	31	1	36	47	50	42	12
1	12	16	31	36	42	47	50

7	4	51	28	45	25	18	33
4	7	18	25	28	33	45	51

16	31	1	36	47	50	42	12	7	4	51	28	45	25	18	33
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50	51

16	31	1	36	47	50	42	12
1	12	16	31	36	42	47	50

7	4	51	28	45	25	18	33
4	7	18	25	28	33	45	51

16	31	1	36
1	16	31	36

47	50	42	12
12	42	47	50

7	4	51	28
4	7	28	51

45	25	18	33
18	25	33	45

16	31	1	36	47	50	42	12
16	31	1	36	47	50	12	42

7	4	51	28	45	25	18	33
4	7	28	51	25	45	18	33

16	31	1	36	47	50	42	12
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7	4	51	28	45	25	18	33
---	---	----	----	----	----	----	----

Merge Sort

```

MERGESORT(A, i, j)
  if i < j
    m = ⌊(i+j)/2⌋
    MERGESORT(A, i, m)
    MERGESORT(A, m+1, j)
    MERGE(A, i, m, j)
  
```

16	31	1	36	47	50	42	12	7	4	51	28	45	25	18	33
1	4	7	12	16	18	25	28	31	33	36	42	45	47	50	51

16	31	1	36	47	50	42	12
1	12	16	31	36	42	47	50

7	4	51	28	45	25	18	33
4	7	18	25	28	33	45	51

16	31	1	36	47	50	42	12
1	16	31	36	12	42	47	50

7	4	51	28	45	25	18	33
4	7	28	51	18	25	33	45

16	31	1	36	47	50	42	12
16	31	1	36	47	50	12	42

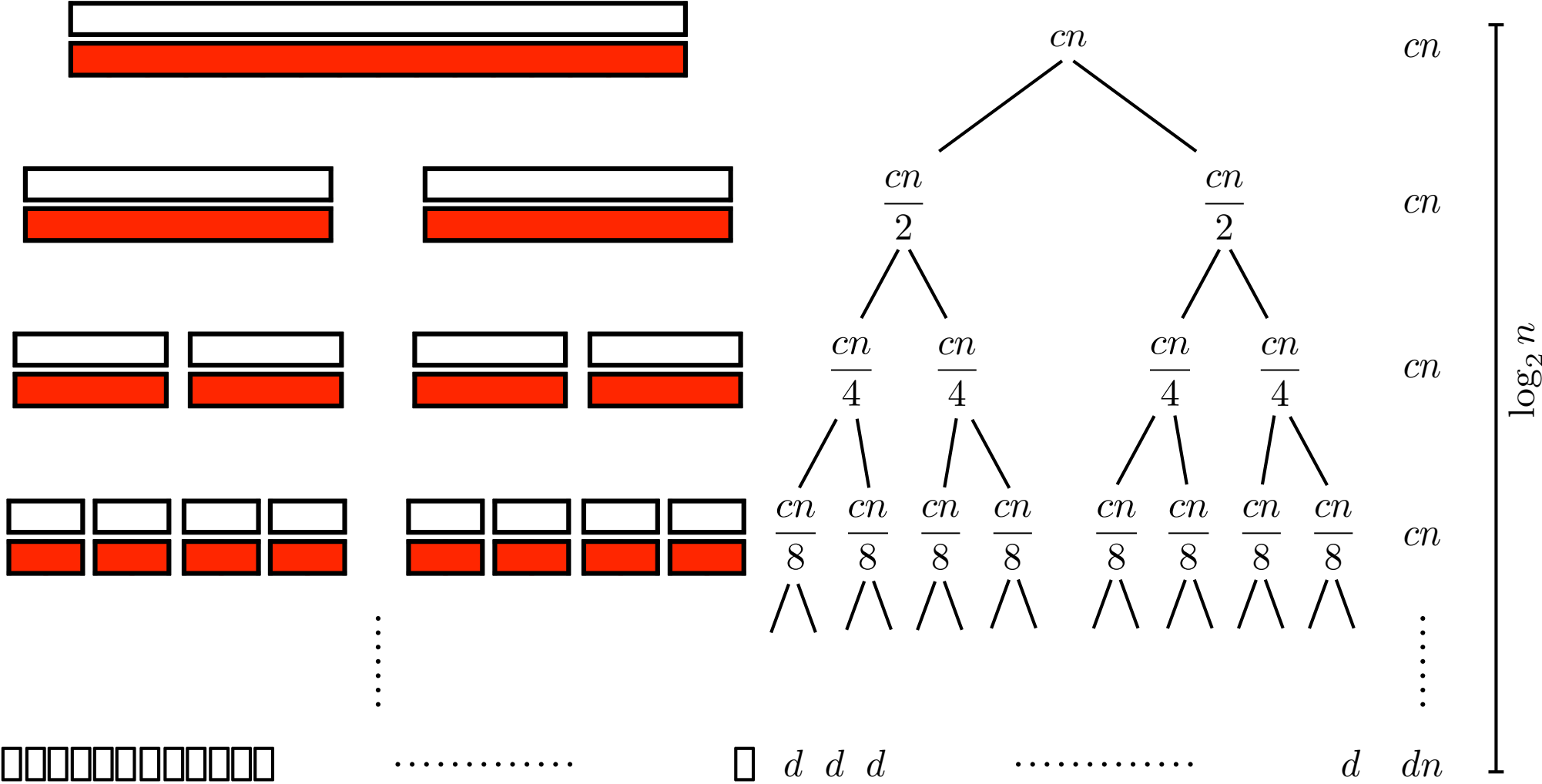
7	4	51	28	45	25	18	33
4	7	28	51	25	45	18	33

16	31	1	36	47	50	42	12
----	----	---	----	----	----	----	----

7	4	51	28	45	25	18	33
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- Time?
- Construct recursion tree.

Merge Sort



$$T(n) = cn \log_2 n + dn = \Theta(n \log_2 n)$$

Sorting

- We can sort in
 - $\Theta(n^2)$ time with insertion sort.
 - $\Theta(n \log n)$ time with merge sort.

Divide and Conquer

- Merge sort is example of a **divide and conquer** algorithm.
- Algorithmic **design paradigm**.
 - **Divide**. Split problem into subproblems.
 - **Conquer**. Solve subproblems recursively.
 - **Combine**. Combine solution for subproblem to a solution for problem.
- **Merge sort**.
 - **Divide**. Split array into halves.
 - **Conquer**. Sort each half.
 - **Combine**. Merge halves.

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