Sequences and Time Series

Introduction to Sequences

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Data is central to smart services

Human-centered IT
Context-aware, location-based services
Accessible work environments
Educational networks

Smart People

Large data in the cloud
Real-time metro-area data analysis
Privacy and access control
Context-aware data warehouses

Smart Governance

Context-aware, location-based services
Navigational guidance
Ambient intelligence and RFID
Real-time sensor data analysis

Smart Living

Smart Environment

Context-aware, location-based services
Real-time sensor data analysis
Sustainability
Resilient

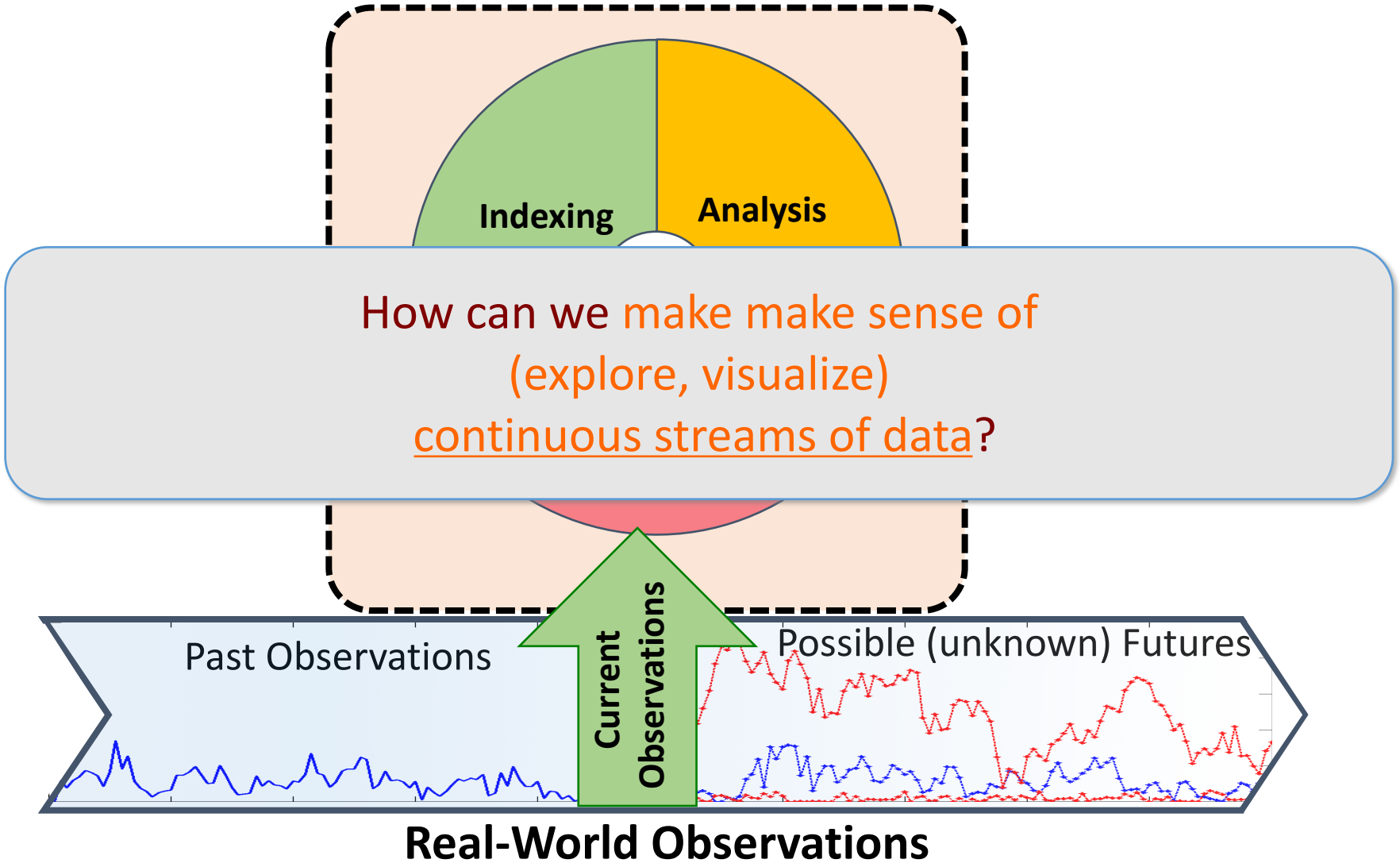
Smart Mobility

Real-time sensor data analysis
Large data in the cloud
Real-time metro-area data analysis
Social networks and evolving communities

Smart Economy

Customer Engagement
Social networks and evolving communities
Recommendation and collaborative filtering
Smart supply-chains

In many applications data is temporal



Common data representations

- Relational/ Object Oriented data
- Vector Space (spatial or high-dimensional) data
- **Strings, sequences, and time series data**
- Trees and graphs
- Fuzzy and probabilistic data

Strings, sequences, time series

- A *string* or *sequence*, $S = (c_1, c_2, ..., c_N)$, *is a finite sequence of symbols.*

abcbbbaabbaabcbbbaaabbc

- A *time series*, $T = (d_1, d_2, ..., d_N)$, *is a finite sequence of data values.*

https://trends.google.com/trends/explore?date=2008-12-19%202018-01-19&q=big%20data

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String/sequence matching and search

- Prefix search:
  - Find all strings that start with “tab”:
    - “table”; “tabular”; “tablet”; ….
- Subsequence search:
  - Find all strings that contain the subsequence “ark”:
    - “marketing”; “spark”; “quark”
  - Find all occurrences of “acd”:
    - “aabacdcdabdcababdacddcab.”
- Sequence similarity:
  - “table” vs. “cable”?
  - “table” vs. “tale”?
  - “table” vs. “tackle”?

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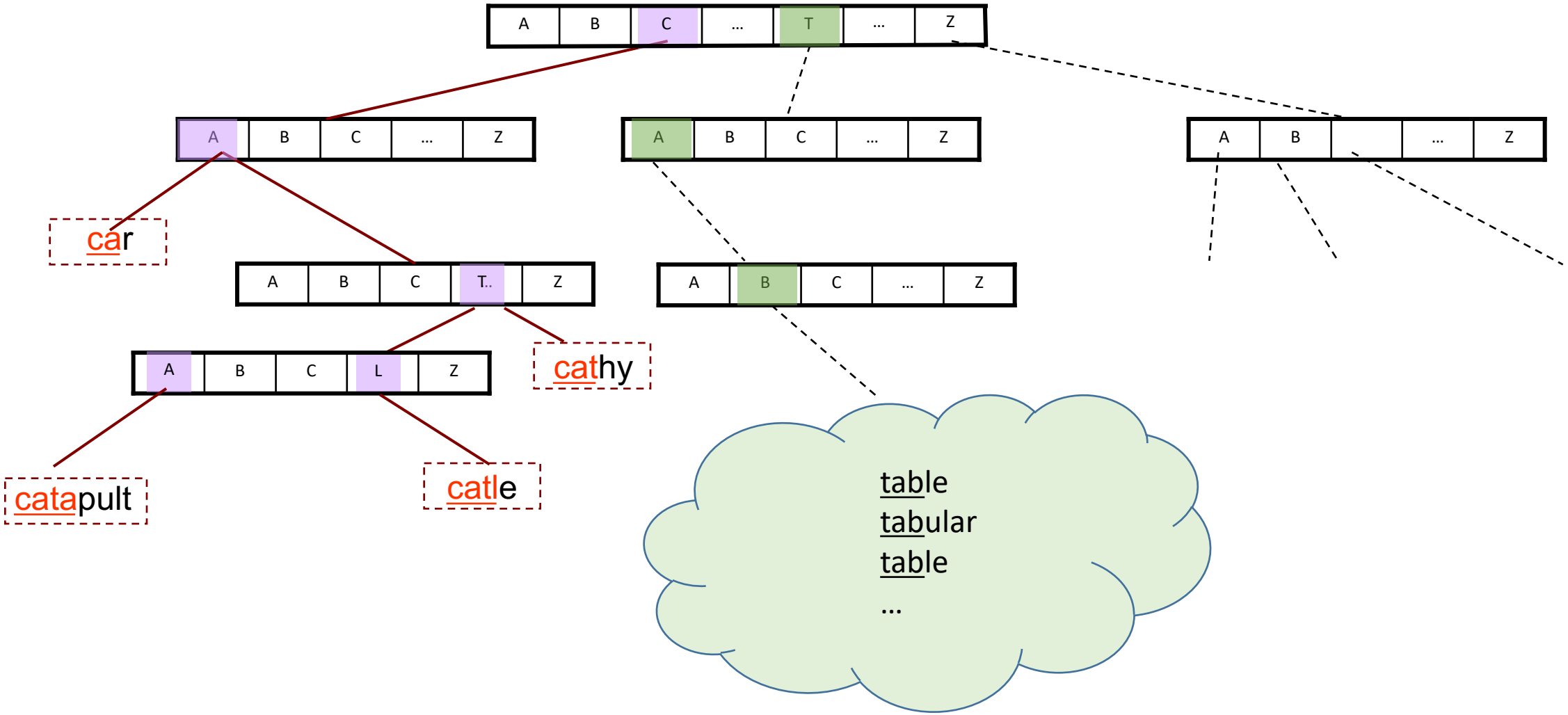
Trie data structure



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Subsequence/Pattern Search

data: abcbbbaabbaabcbbbaaabbccbbbaabbaacbbbaabbccbcbbbaabcbbbaabab

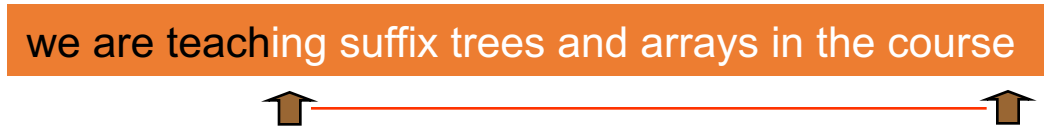
pattern: abbcc

- Brute force approach:
  - scan the sequence, while aligning the pattern for each position in the sequence
- Given a sequence of length N, and pattern of length M
  - Cost: O(NxM)
  - For the above example, cost: 60 x 5

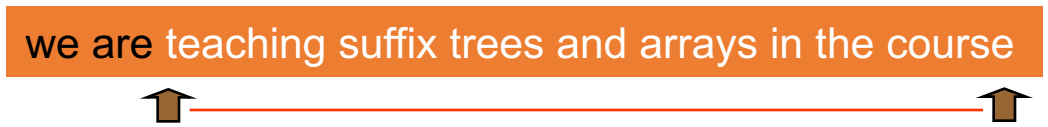
Suffix Trees and Arrays

- Tries work well if we search for a prefix

- Suffix trees and suffix arrays
  - Input text: a single long string
  - each position in the text gives a suffix

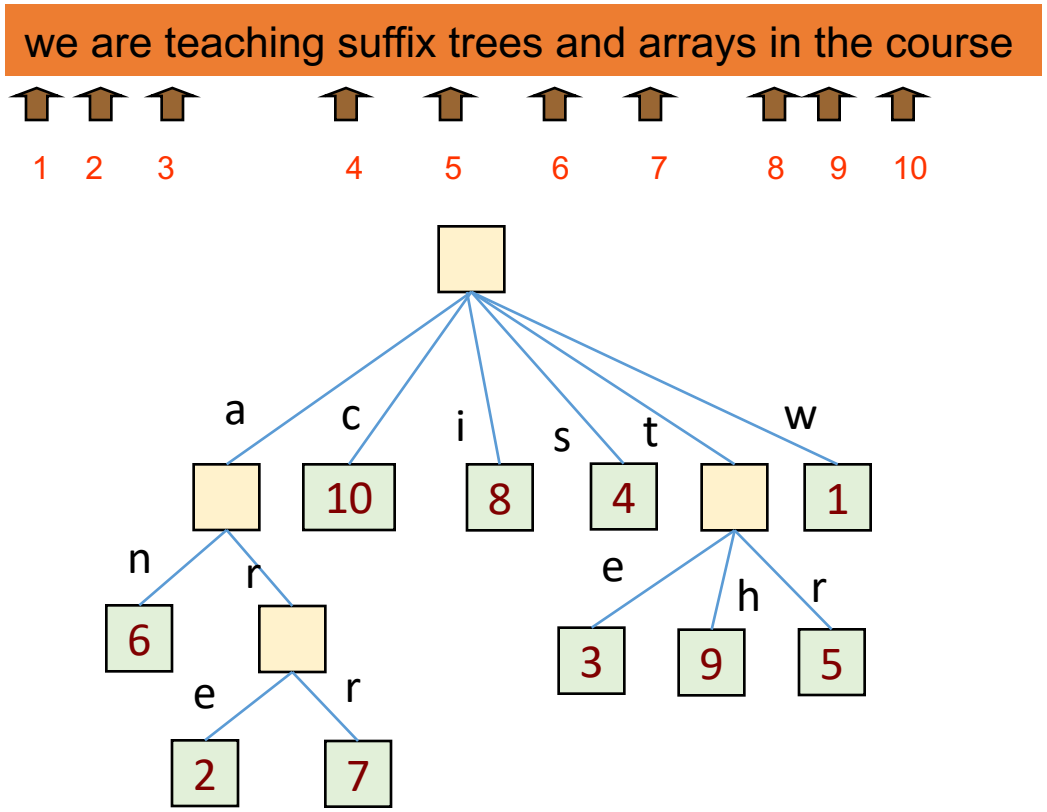


  - alternatively, start of each word in the text gives a suffix



Suffix Trees

- Suffix trees
  - Input text: a single long string
  - each word position in the text gives a suffix



Suffix Arrays

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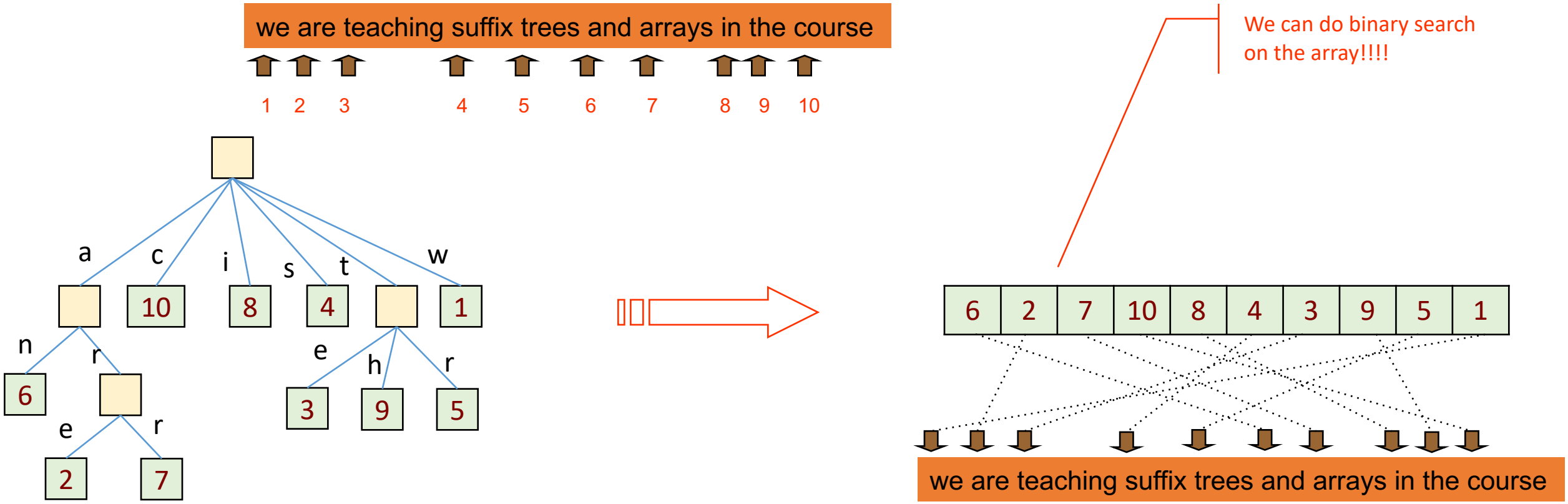

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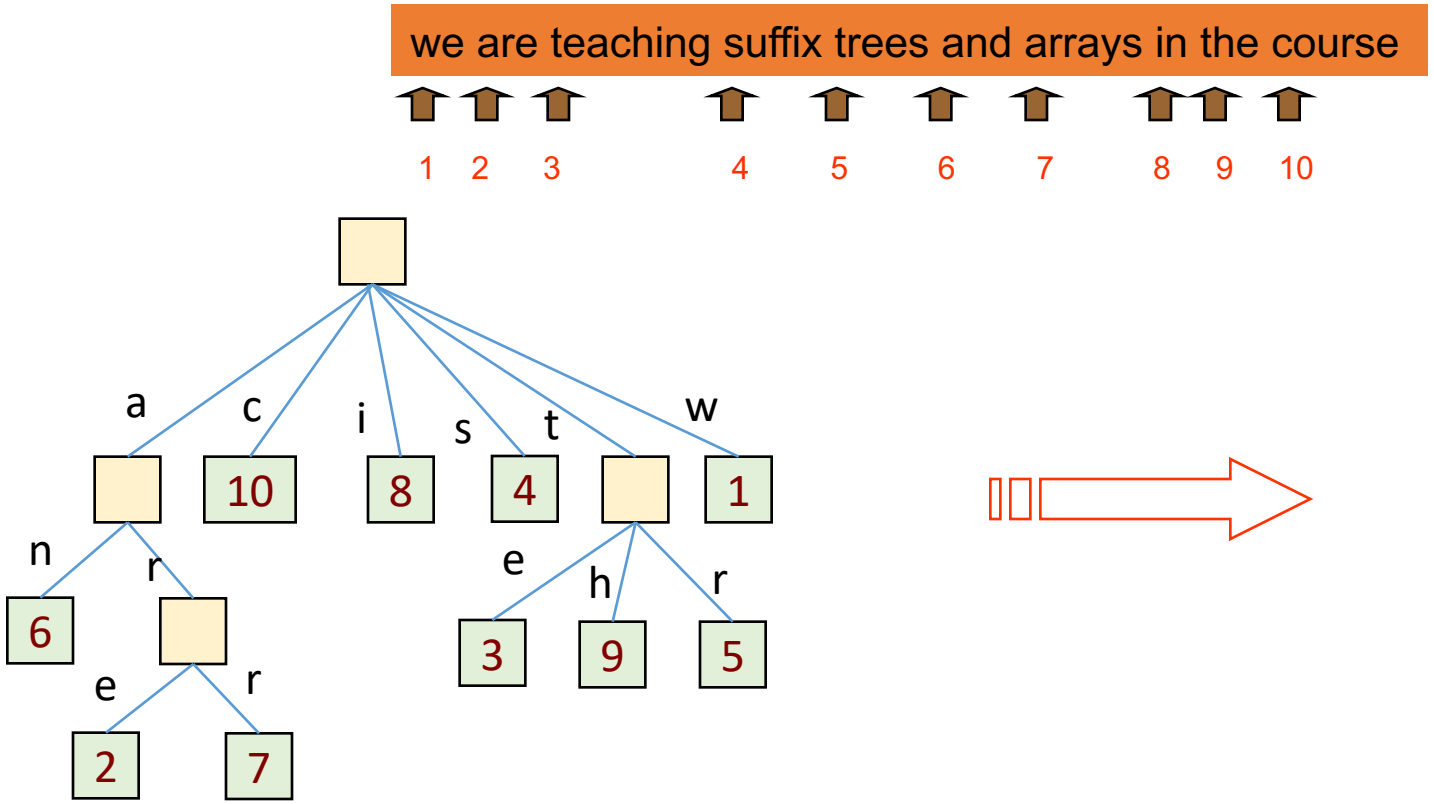
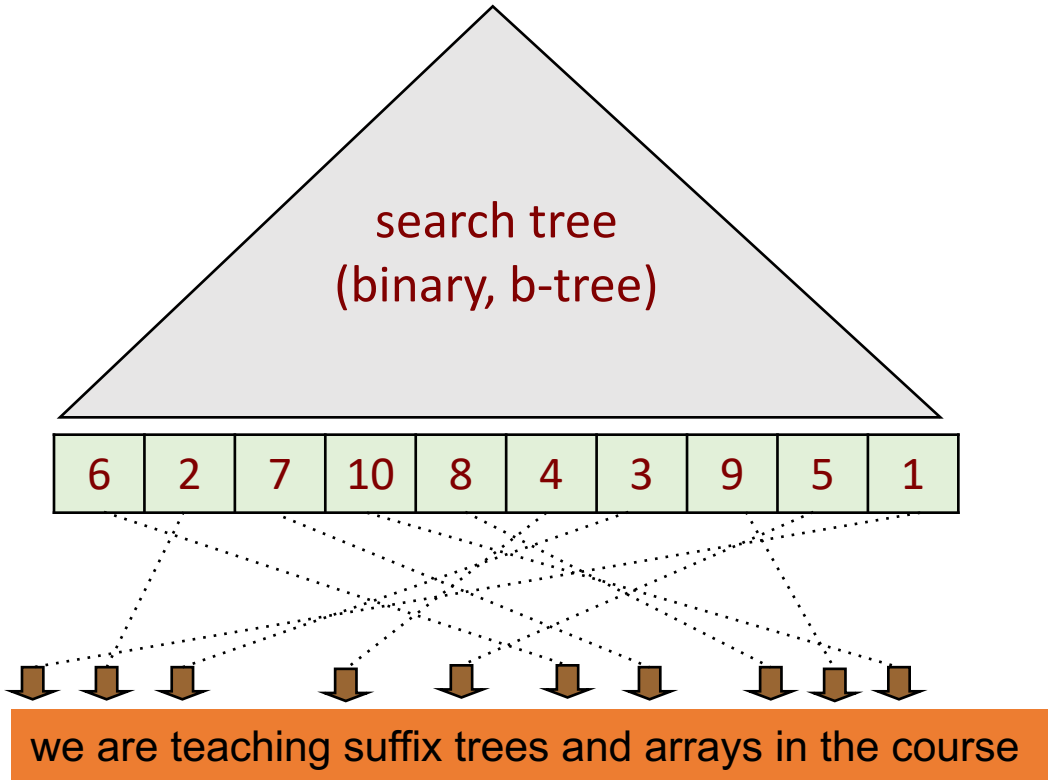


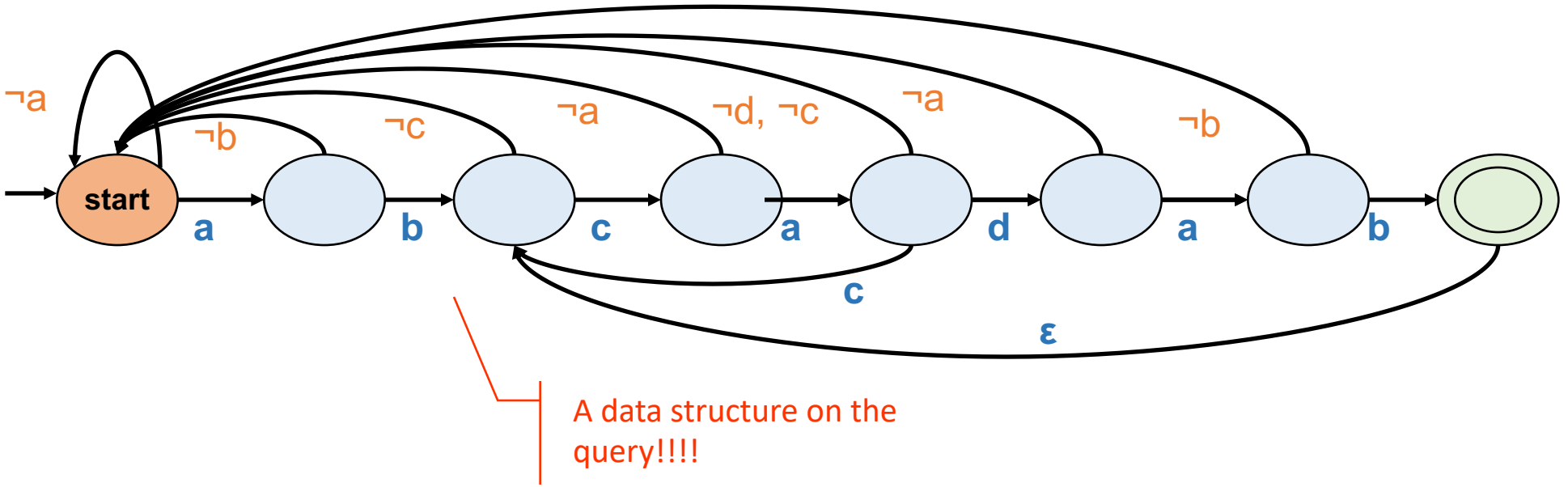


Subsequence/Pattern Search

- What if we are not given the sequence in advance; can we do search without a data structure on the sequence?
  - Yes, scan the sequence…
  - ..but, we have seen that this is expensive
    - Given a sequence of length N, and pattern of length M
    - Cost: O(NxM)
- If we are given the pattern in advance, can we create a data structure on the pattern, instead?

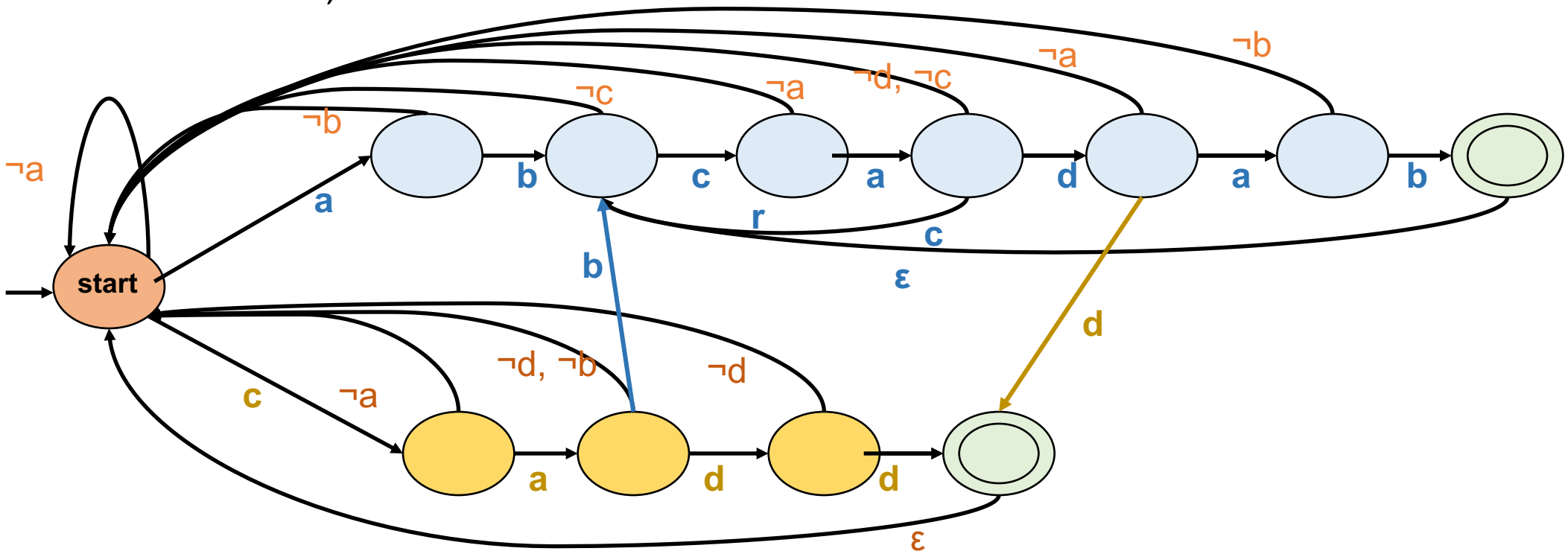
Knuth-Morris-Pratt (KMP)

- Given a sequence of length N, and pattern of length M
- Knuth-Morris-Pratt: O(N)
- Example
  - Pattern: abcadab



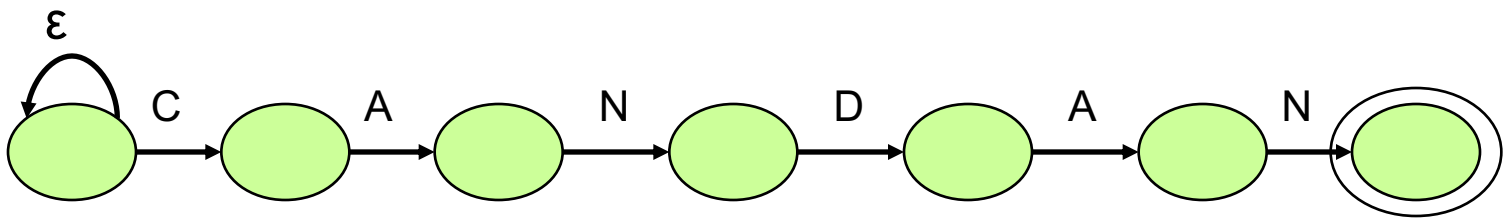
Aho-Corasick Trie

- What is we are given multiple patterns to search simultaneously
- Given a sequence of length N, and patterns of length M_1 and M_2
- Aho-Corasick Trie: O(N)
- Example
  - Patterns: abcadab; cadd

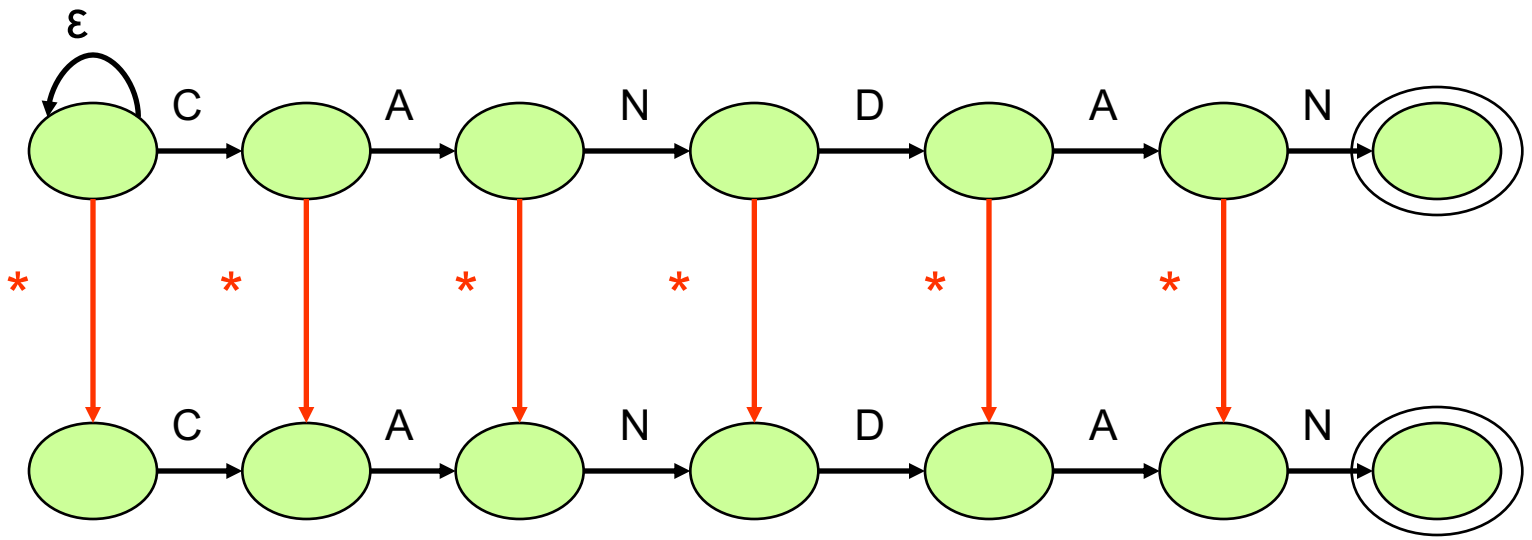


What about approximate matches?

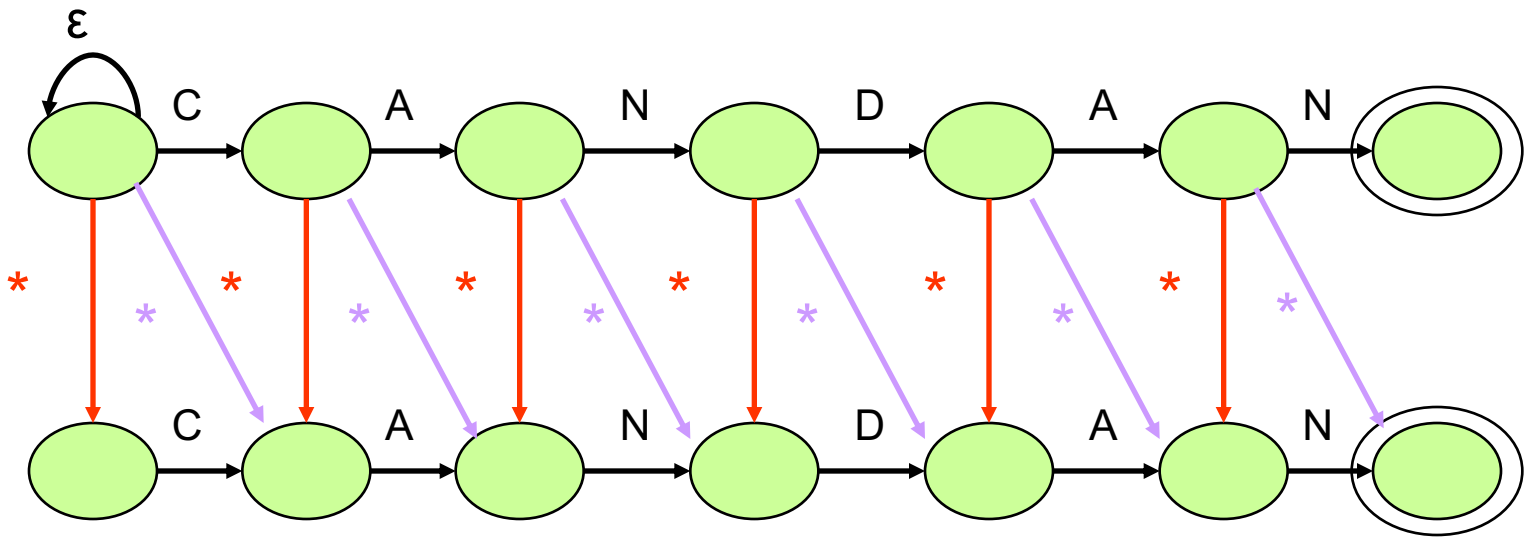
- Example
  - Pattern: CANDAN



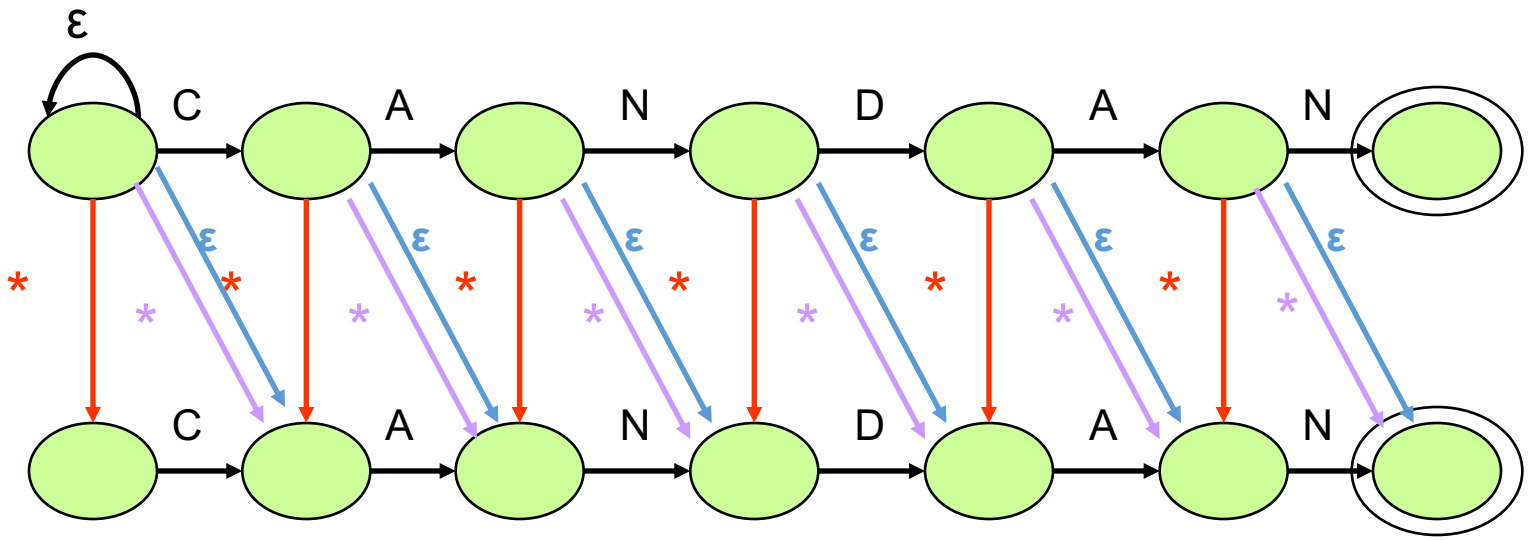
NFA…upto 1 insertion



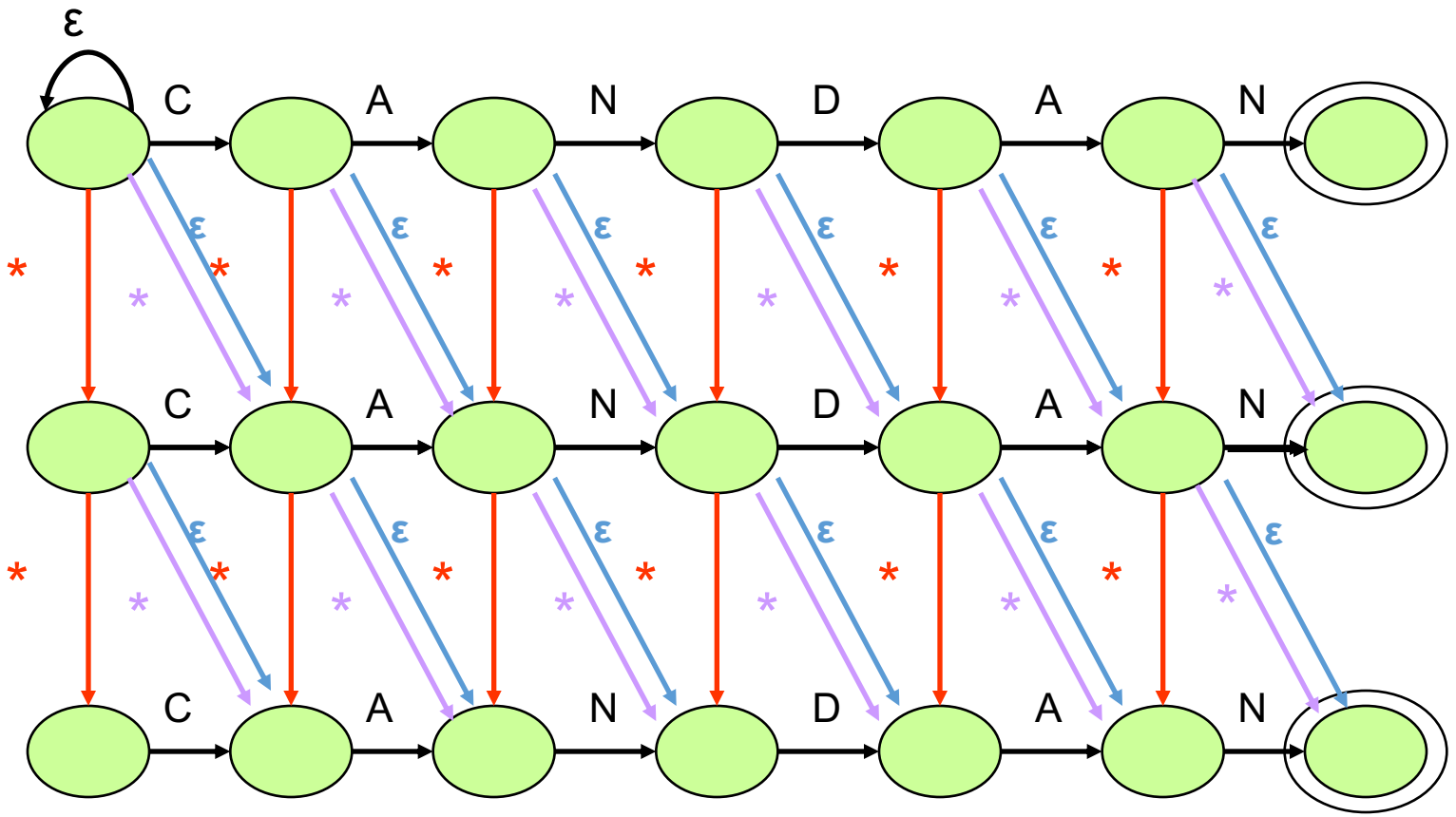
NFA…upto 1 insertion\replacement



NFA…upto 1 ins.\rep.\deletion



NFA…upto 2 ins.\rep.\deletion



Summary

- Prefix based sequence exploration:
  - Trie data structure helps prune the candidate set
- Subsequence search and exploration
  - Suffix trees and suffix arrays helps focus on the part of a long sequence
- Pattern matching
  - Non-deterministic finite automata can be used to support exact and approximate pattern matching