The DESQ Framework for Declarative and Scalable Frequent Sequence Mining

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Outline

1. Frequent Sequence Mining
2. Declarativity
3. Scalability
4. Summary

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Before and after

Anni wants to watch a movie. Anni loves LOTR1. But she does not want to see it. She had seen LOTR2 last week!

Movie streaming site

Let's look at some data

- Data from Netflix' online movie-streaming platform
  - 500k users, 18k movies, 100M ratings with timestamps
- 125k users rated both LOTR1 and LOTR2
- In which order?

105k users 20k users

- Order matters!
  - How to discover patterns in sequential data?

Frequent Sequence Mining

- Frequent sequence mining is a fundamental task in data mining
  - Data modeled as collection of **sequences of items or events**
  - Often items are arranged in a **hierarchy**
  - We seek frequent **sequential patterns**
- E.g., market-basket data
  - Sequence = purchases of a customer over time
  - Item = product (or set of products) + product hierarchy
  - Example pattern: *DSLR Camera* $\rightarrow$ *Tripod* $\rightarrow$ *Flash*
- E.g., natural-language text
  - Sequence = sentence or document
  - Item = word + syntactic/semantic hierarchy
  - Example pattern: *person* was born in *location*
- E.g., amino acid sequences
  - Sequence = protein
  - Item = amino acid
  - Example pattern: S L R

What constitutes a good pattern?

- Extensively studied
  - Interesting patterns should be new, surprising, understandable, actionable
  - No random patterns, common knowledge, redundancy
  - Details application-specific
- Many different variants, many algorithms
  - Constraints: length, positional/temporal, hierarchy, regex, ...
  - Scoring: **frequency**, utility, information gain, significance, ...
  - Pattern sets: all, top-k, maximality, closedness, MDL, ...
- Our research focuses on **unifying frequent sequence mining**
  - Study general properties instead of special cases
  - Avoid need for customized mining algorithms

DESQ

- DESQ = framework for declarative and scalable frequent sequence mining [TODS19, ICDM16, ICDE19]
  - Open source

- Key design goals are
  1. **Usefulness**
     - Can be tailored to application
     - Flexible constraints
  2. **Usability**
     - Describe pattern mining task in an intuitive, declarative way
     - Hide technical and implementation details
  3. **Efficiency**
     - Fast
     - Scalable
     - Competitive to specialized miners

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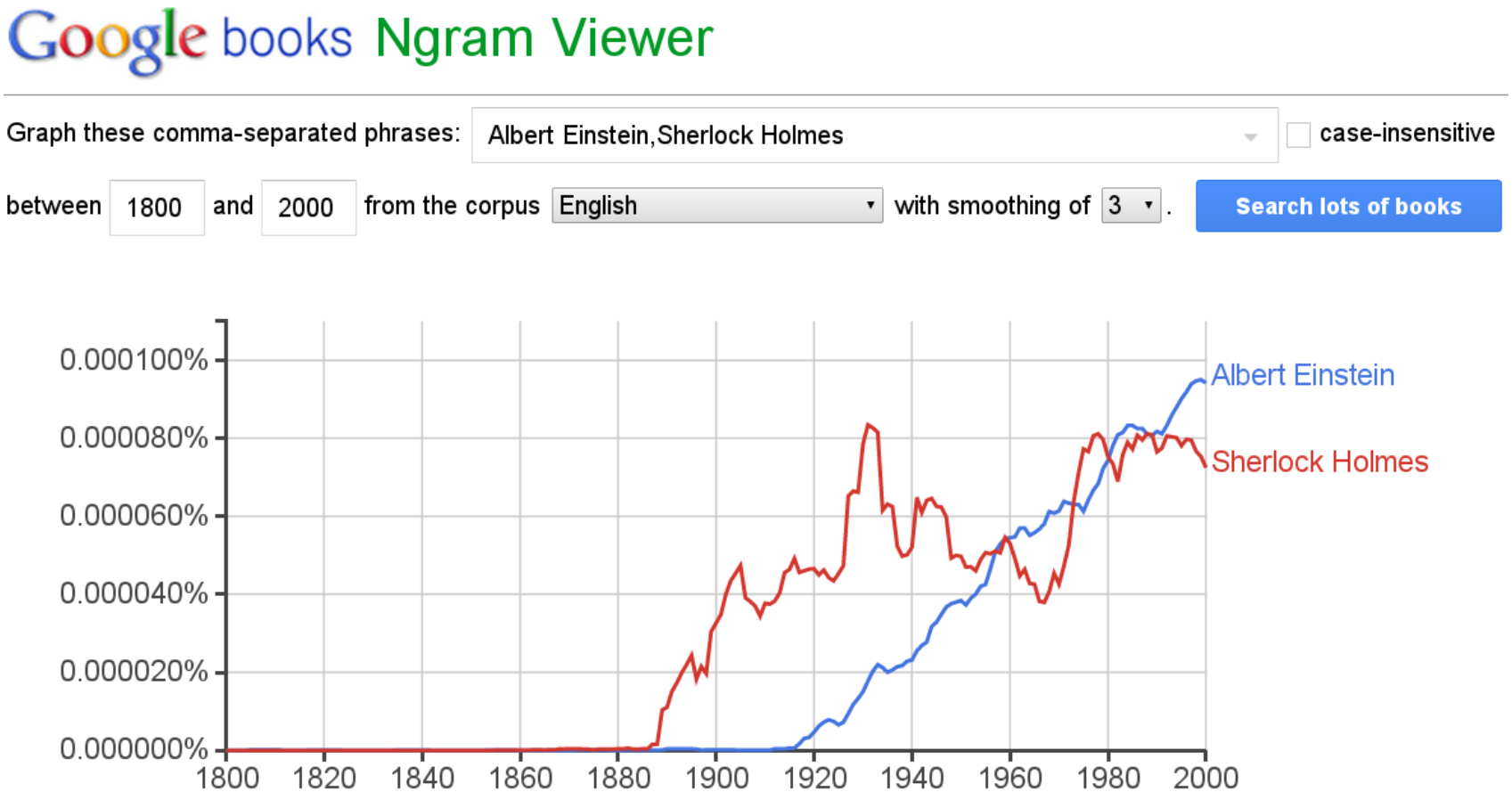
Special case: *n*-gram mining

An ***n*-gram** is a sequence of n consecutive words

- Extensively used in text mining and natural-language processing
- Web-scale *n*-gram models published by Google and Microsoft



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Going declarative

- If we simply mined all frequent n-grams, we may
  1. Produce many uninteresting patterns (low frequency threshold)
  2. Miss out on interesting patterns (high frequency threshold)
- DESQ allows data analysts to focus on what they consider relevant
  - Supports all traditional constraints (length, gap, hierarchy, ...)
  - Supports customized constraints that go beyond traditional constraints
- Based on a declarative **pattern expression language**
  - Describe relevant patterns, let DESQ take care of mining them
  - Syntax like regular expression
  - Adds capture groups and hierarchies

Some examples for text mining

1. **Noun modified by adjective or noun**
   Ex: *big country (110), green tea (337), research scientist (473)*
   PE: `([ADJ|NOUN] NOUN)`

2. **Relational phrase between entities**
   Ex: *lives in (847), is being advised by (15), has coached (10)*
   PE: `ENTITY (VERB+ NOUN+? PREP?) ENTITY`

3. **Typed relational phrases**
   Ex: *ORG headed by ENTITY (275), PERS born in LOC (481)*
   PE: `(ENTITY↑ VERB+ NOUN+? PREP? ENTITY↑)`

4. **Google *n*-gram viewer data**
   Ex: *a good day, a ADJ day, DET ADJ NOUN, have a good day*
   PE: `(.↑) (.↑)? (.↑)? | (.....?)`

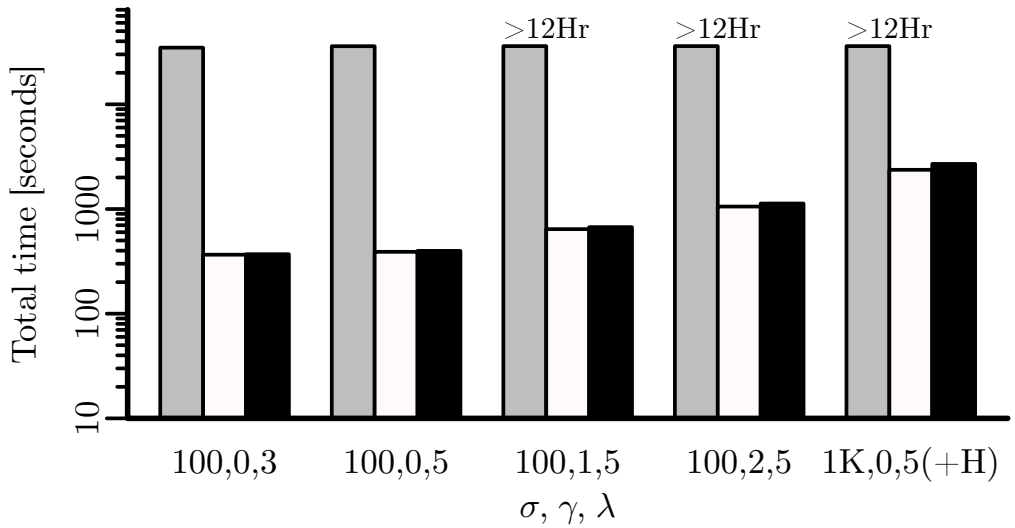
Pattern mining

- Under the hood, DESQ translates pattern expressions to finite state transducers (FST)
  - FST outputs all patterns that occur in a given input sequence

- Multiple sequential mining algorithms
  - Naive approach ("WordCount")
  - DesqCount ("WordCount" with frequency pruning)
  - DesqDfs (depth-first search)

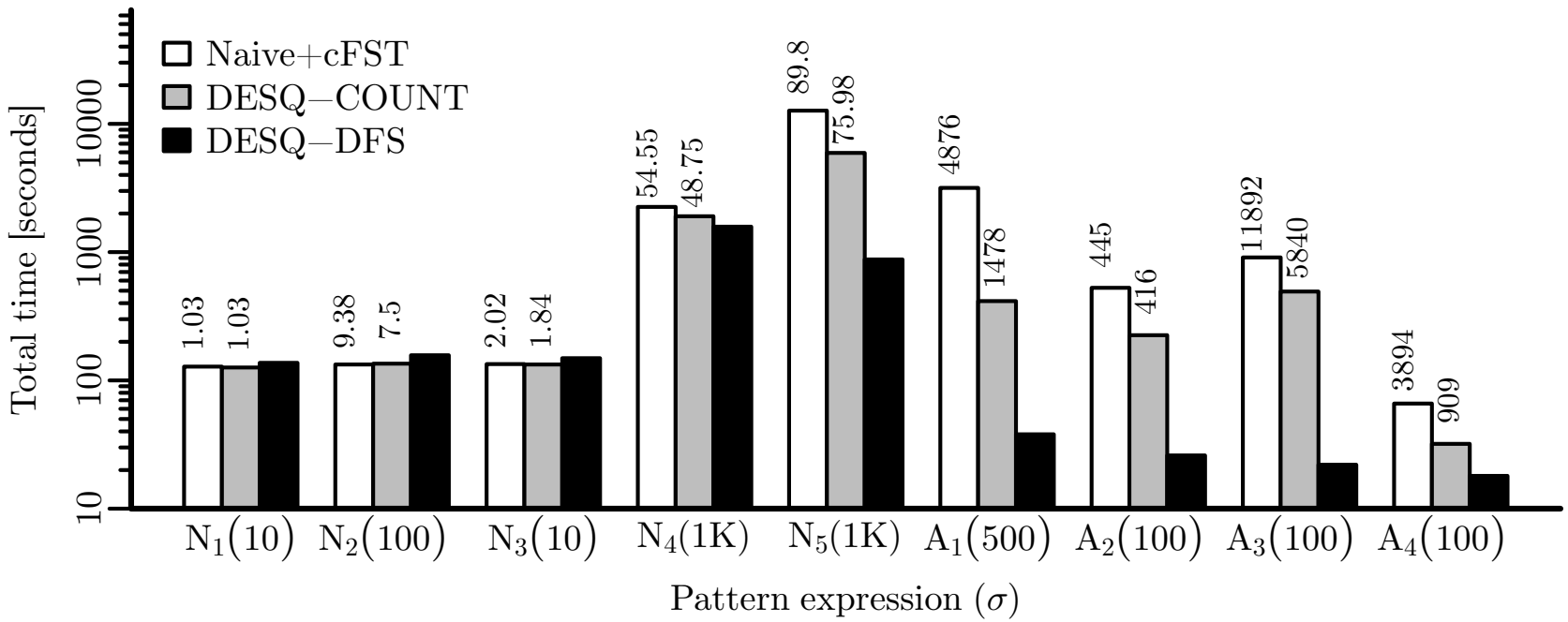
Performance comparison (traditional constraints)

Left: cSPADE, center: prefix-growth, right: DesqDfs



DESQ is competitive to state-of-the-art miners for traditional constraints.

Performance comparison (new constraints)



DesqDfs is method of choice and can be orders of magnitude faster than Naive or DesqCount.

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Distributed mining

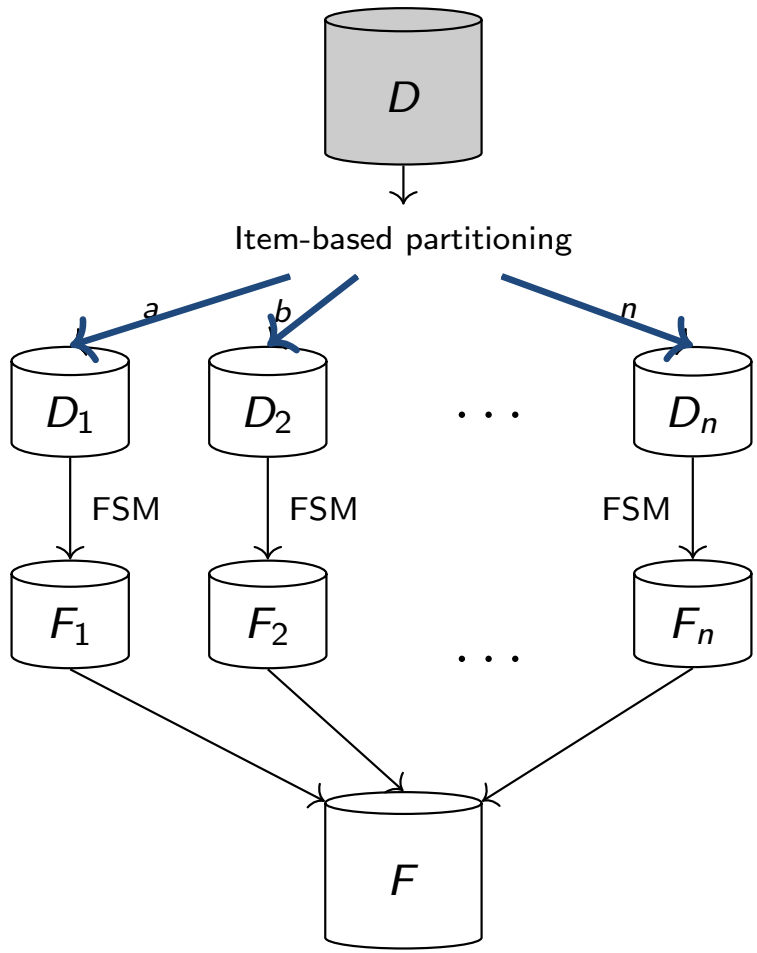
- Based on bulk synchronous parallel model

Key idea

- Partition data into smaller overlapping partitions using **item-based partitioning**
  - One partition for each frequent item
- Mine each partition locally
- Combine results

Key question

- What to communicate to partitions?
  - Inputs
  - Candidates



Communicate inputs

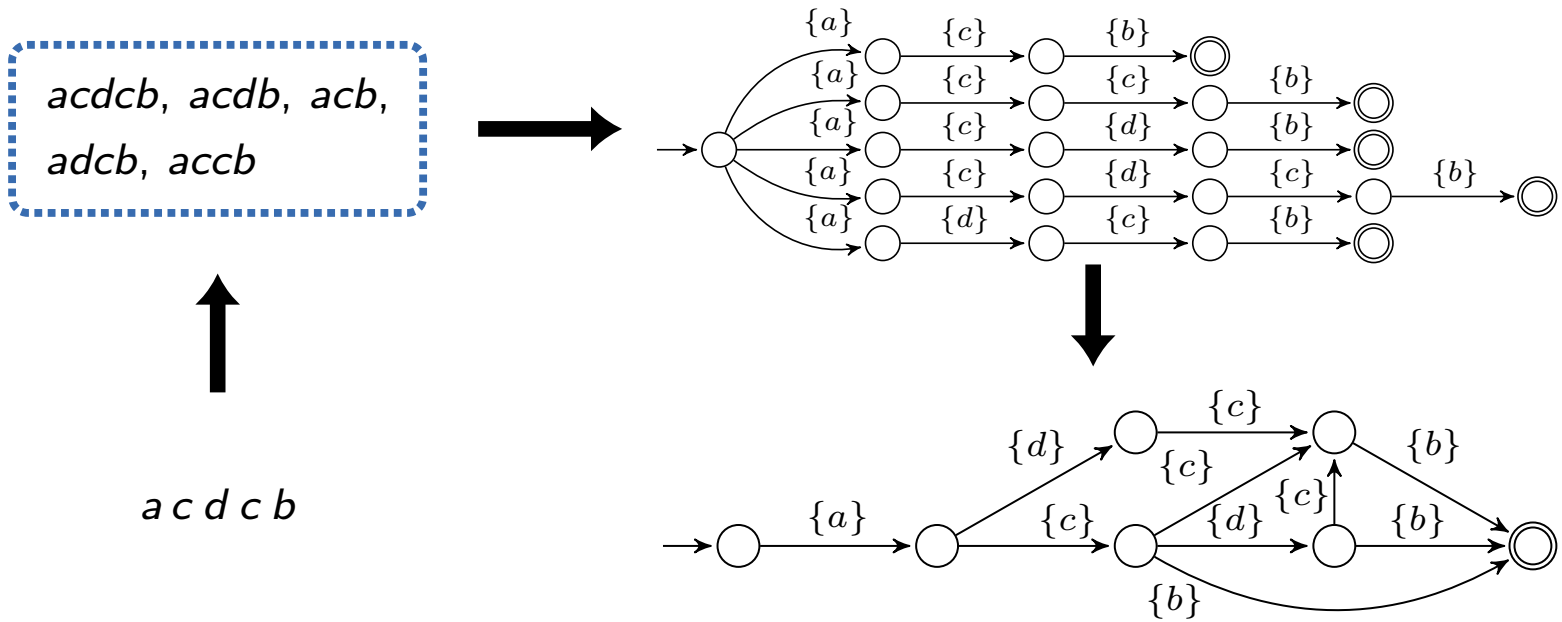
- Naïve approach: send each input sequence to all partitions for which it is "relevant"

- More efficient: send only relevant parts of input sequence
  - Example: only fantasy movies relevant for mining task

  - Can reduce communication up to 100x

Communicate candidates

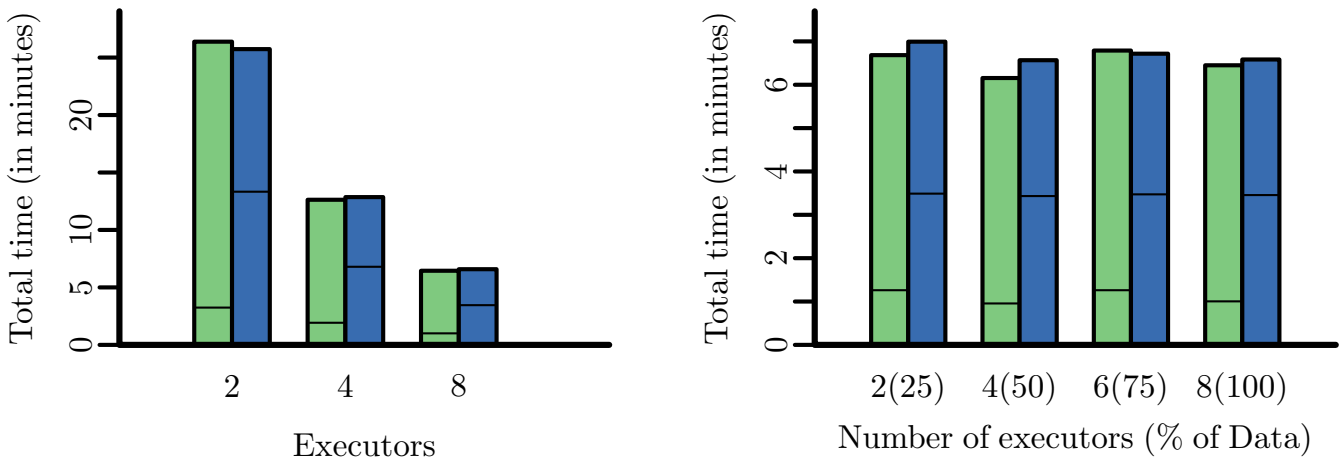
- Naïve approach: send each candidate subsequence to its corresponding partition
- More efficient: compress candidates
  - Shared structure
  - Non-deterministic finite automata (NFA)



  - Can reduce communication by up to 100x

Performance comparison

- Both approaches scale nearly linearly with number of input sequences. green: send inputs, blue: send candidates



(a) Strong scalability (b) Weak scalability

- Up to 50x faster than naïve approaches
- Sending candidates is up to 5x faster for selective constraints
- 1-4x generalization overhead over specialized approaches

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Summary

DESQ: framework for declarative and scalable frequent sequence mining

- Find patterns in sequential data
- Declarative language to specify interest
- Item-based partitioning to scale to large datasets
- Open source: https://github.com/rgemulla/desq

[ICDM16] Beedkar, K.; Gemulla, R.: DESQ: Frequent Sequence Mining with Subsequence Constraints. In: ICDM, 2016.

[TODS19] Beedkar, K.; Gemulla, R.; Martens, W.: A Unied Framework for Frequent Sequence Mining with Subsequence Constraints. ACM Trans. Database Syst., 2019.

[ICDE19] Renz-Wieland, A.; Bertsch, M.; Gemulla, R.: Scalable Frequent Sequence Mining With Flexible Subsequence Constraints. In: ICDE, 2019.

Thank you!