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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1. Frequent Sequence Mining

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

Google books Ngram Viewer

Graph these comma-separated phrases: Albert Einstein, Sherlock Holmes

between 1800 and 2000 from the corpus English with smoothing of 3.
Special case: \textit{n-gram} mining

An \textit{n-gram} is a sequence of \textit{n} consecutive words

- Extensively used in text mining and natural-language processing
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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.
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
  
  Open_Ocean  Frozen_Seas  LOTR1  Coral_Seas  LOTR2  LOTR3  Coasts

  - 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)

\[
\begin{align*}
\text{acdcba, acdb, acbc, adcb, accb} \\
\text{can reduce communication by up to 100x}
\end{align*}
\]
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](https://github.com/rgemulla/desq)


Thank you!