Scalable Frequent Sequence Mining With Flexible Subsequence Constraints

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Frequent Sequence Mining (FSM)

Fundamental task in data mining

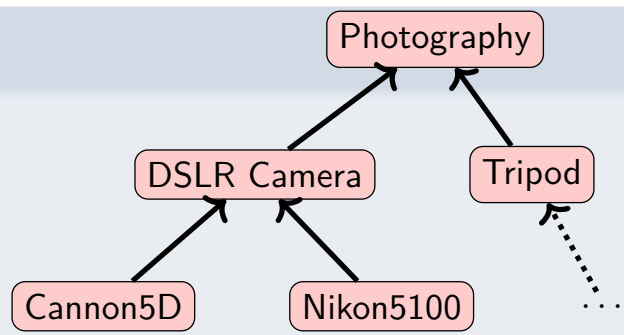
- Data modeled as sequences of items or events
- Often items are arranged in a hierarchy
- Goal is to discover frequent subsequences

Example (market-basket data)

- Sequence = purchases of customer over time
- Item = product + product hierarchy
- Example subsequence = *DSLR Camera* $\rightarrow$ *Tripod* $\rightarrow$ *Flash*

Applications

- Natural language processing
- Information extraction
- Web usage analysis
- ...



Example product hierarchy

Challenge: Flexibility

- Unconstrained FSM outputs a multitude of frequent subsequences

a bell (302392),
become president (234311),
graduated from (3962),
why so many of us (234),
of the (220125),
going to (12897),

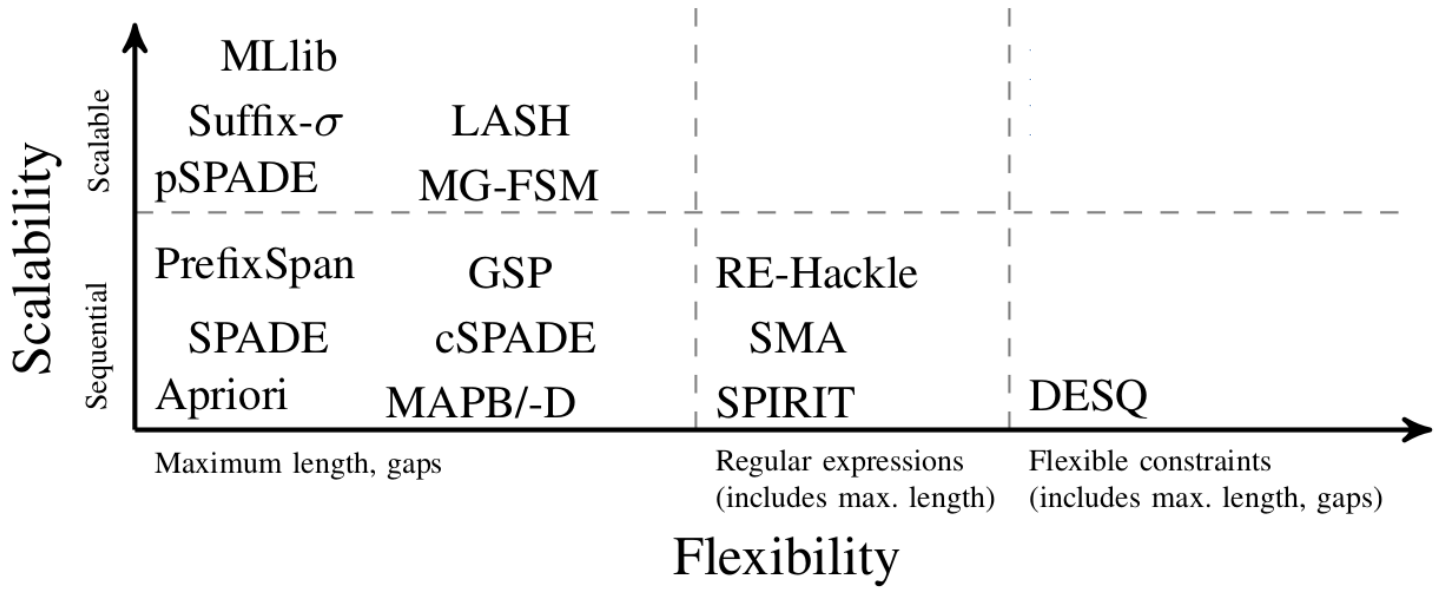
had never used (23202),
PER be professor (1582),
large enough to be (12083),
who VERB also (22 223),
lives in (4322),
great artist (2394),
...

- Typically, only few of them are interesting to a specific application
  - E.g., only relational phrases between entities are of interest

- Flexible methods (that can be tailored to applications) are essential

Goal: flexible and scalable FSM

- Common approach: flexible subsequence constraints
- Problem: existing FSM algorithms are **flexible or scalable**



- Our paper: **flexible and scalable**

Outline

1. Frequent Sequence Mining
2. Flexibility
3. Scalability
4. Conclusion

Flexible FSM with DESQ

- We adopt the unified FSM framework **DESQ** [ICDM '16, TODS '19]
  - Applications can describe flexible subsequences constraints in an intuitive, declarative way
  - Alleviates need for customized mining algorithms

- Provides **pattern expression language** to specify subsequence constraints
  - Syntax like regular expressions
  - Supports captures groups and hierarchies

Example pattern expressions for applications

1. **Noun modified by adjective or noun** ([ADJ|NOUN] NOUN)
   big country (110), research scientist (473)

2. **Relational phrase between entities** ENTITY (VERB$^+$ NOUN$^+$? PREP?) ENTITY
   is being advised by (15), has coached (10)

3. **Products bought after a digital camera** DigitalCamera[.{0,3}(.$^\uparrow$)]{1,4}
   Camera Lenses, Tripods & Monopods (11),
   Camera Batteries, SD & SDHC Cards (12)

4. **Amino acid sequences that match** $[S \mid T].[R \mid T]$ $([S \mid T]).^*(.).^*([R \mid T])$
   S L R(103,093), T A K(102941)

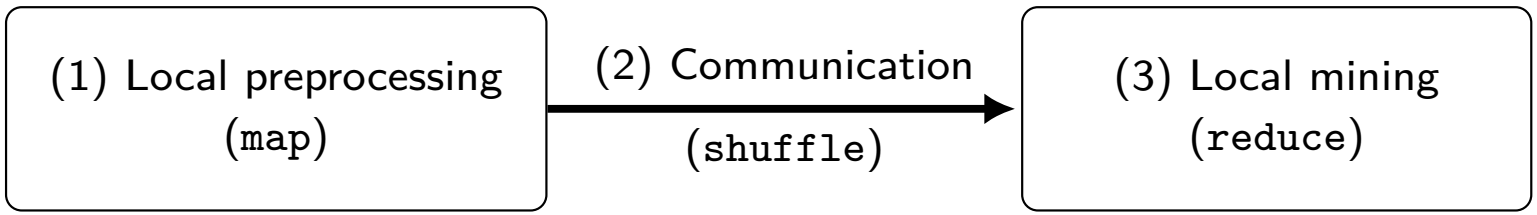
Example pattern expressions for traditional constraints

1. 3-grams $(...)$
2. 3−, 4-, and 5-grams $(.)\{3,5\}$
3. skip 3-grams with gap 1 $(.)\,.\,(.)\,.\,(.)$
4. All subsequences $[.^*(.)]^+$
5. length 3–5 subsequences $[.^*(.)]\{3,5\}$
6. bounded gap of 0–3 $(.)[.\{0,3\}(.)]+$
7. serial episodes of length 3, window 5 $(.)[.?.?(.) \mid .?(.).? \mid (.).?.?](.)$
8. generalized 5-grams $(.^{\uparrow})\{5\}$
9. subsequences matching regex $[a|b]\,c^*d$ $(a|b)[.^*(c)]^*.^*(d)$
10. ...

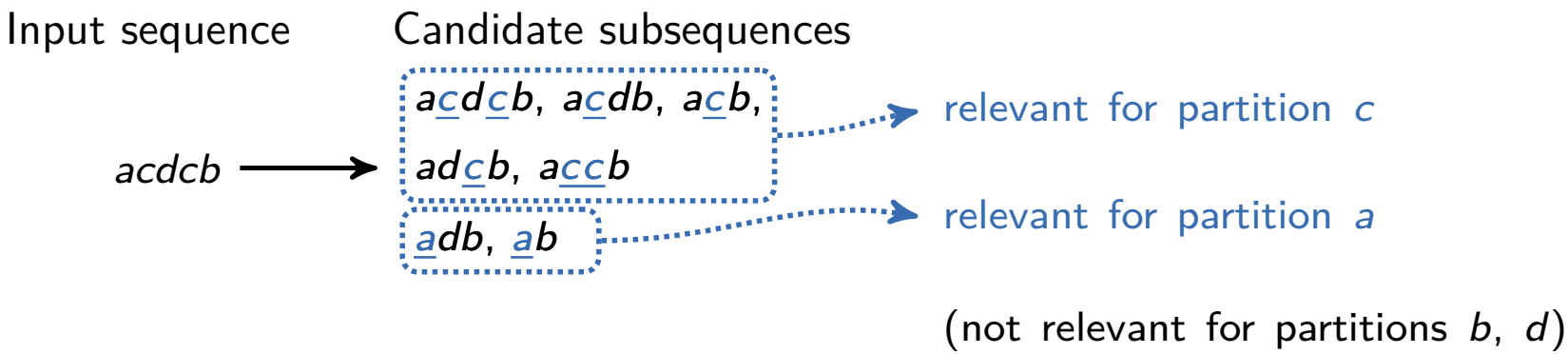
Outline

A general framework for distributed FSM

- Bulk synchronous parallel with 1 round of communication



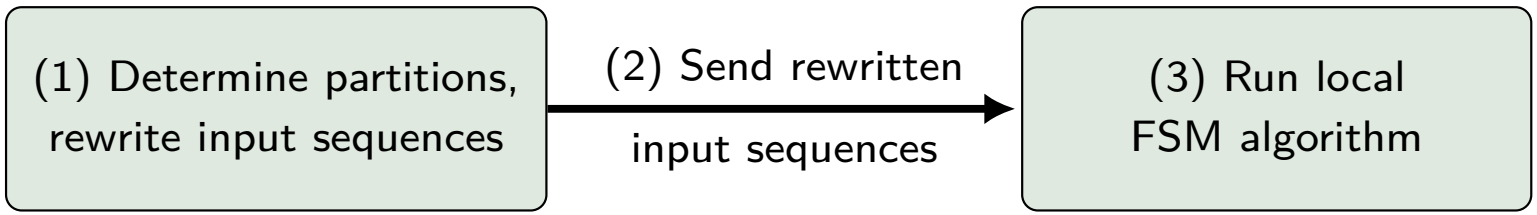
- Item-based partitioning [SIGMOD '00, PPoPP '07, SIGMOD '13]



- Key challenges
  - How to distribute computation
  - What to communicate

Communicate inputs

- Send each input sequence to all partitions to which it can contribute

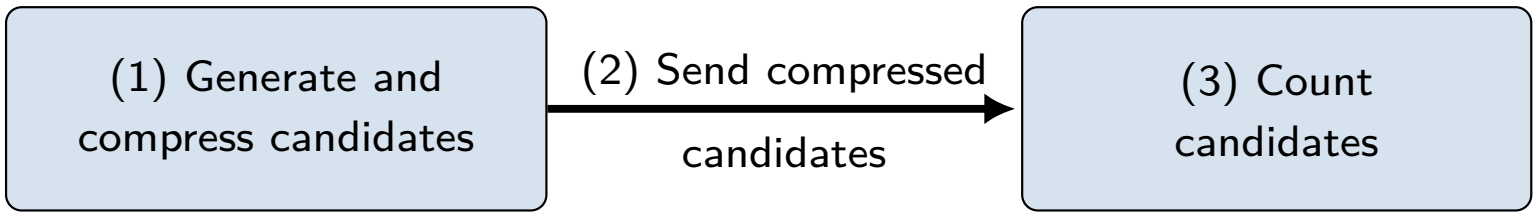


- Often sufficient to send parts of the input sequence

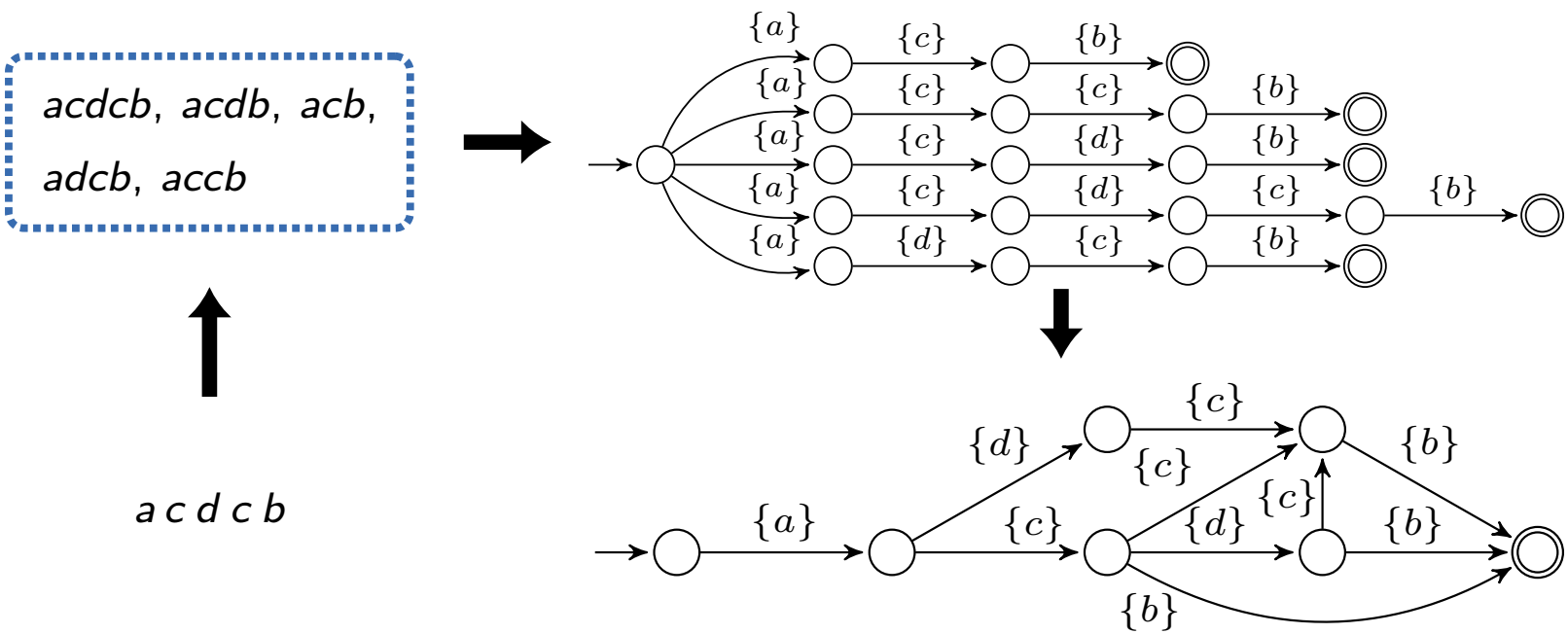
- Example: if e's not relevant for mining task, don't send them

Communicate candidates

- Send each candidate subsequence to its corresponding partition

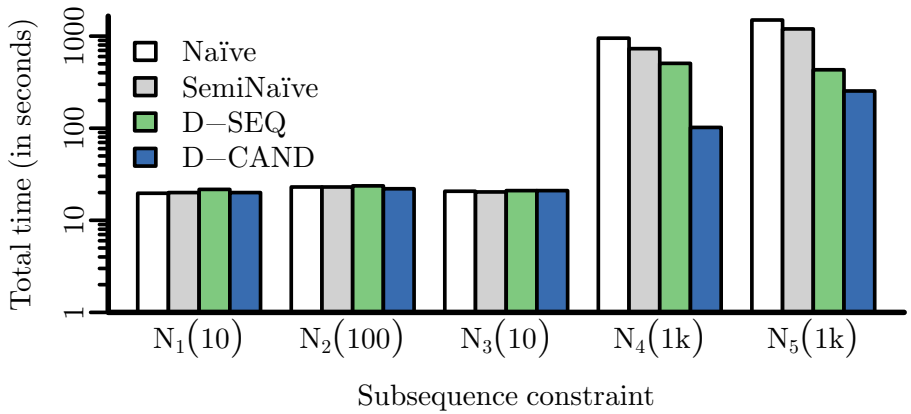


- Important optimization: compress candidates

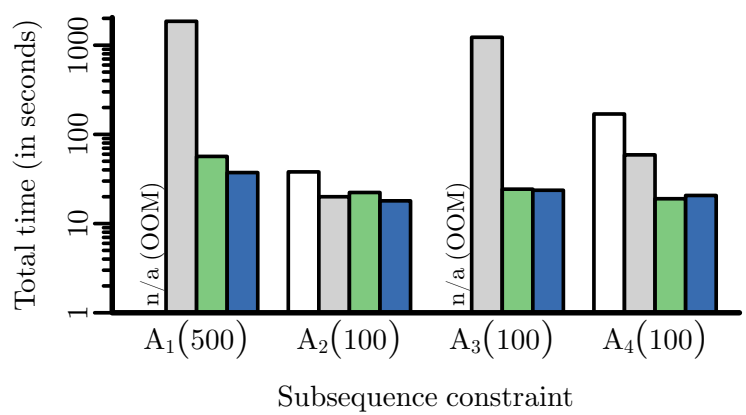


Experimental study: key results

- Up to 50x faster than naïve approaches, up to 100x less communication



(a) New York Times data



(b) Amazon Review data

- Sending candidates is up to 5x faster for selective constraints
- 1-4x generalization overhead over specialized, less general approaches
- Both approaches scale nearly linearly with number of input sequences

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Conclusion

- Existing algorithms: **flexible or scalable**. Ours: both
- Adopt DESQ: a framework to tailor FSM to applications
- Distributed mining via item-based partitioning
  1. Communicate inputs
  2. Communicate candidates
- Available as open source Apache Spark library, link at

  `https://github.com/rgemulla/desq/tree/distributed`

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