Online Discovery and Maintenance of Time Series Motifs

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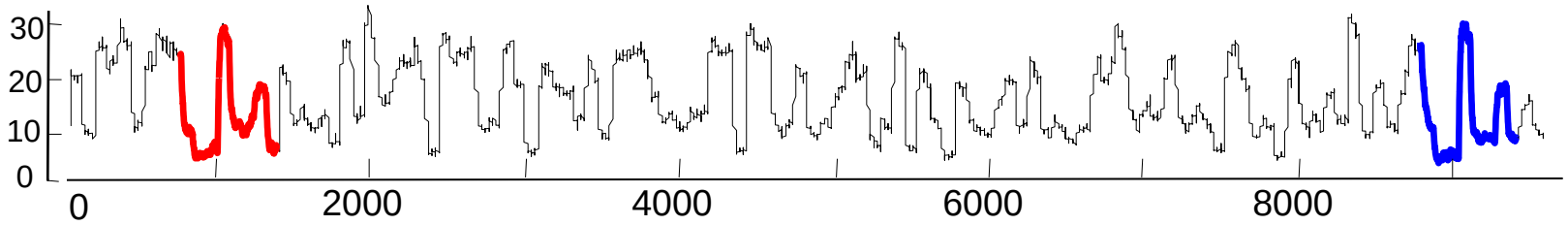
Time Series Motifs

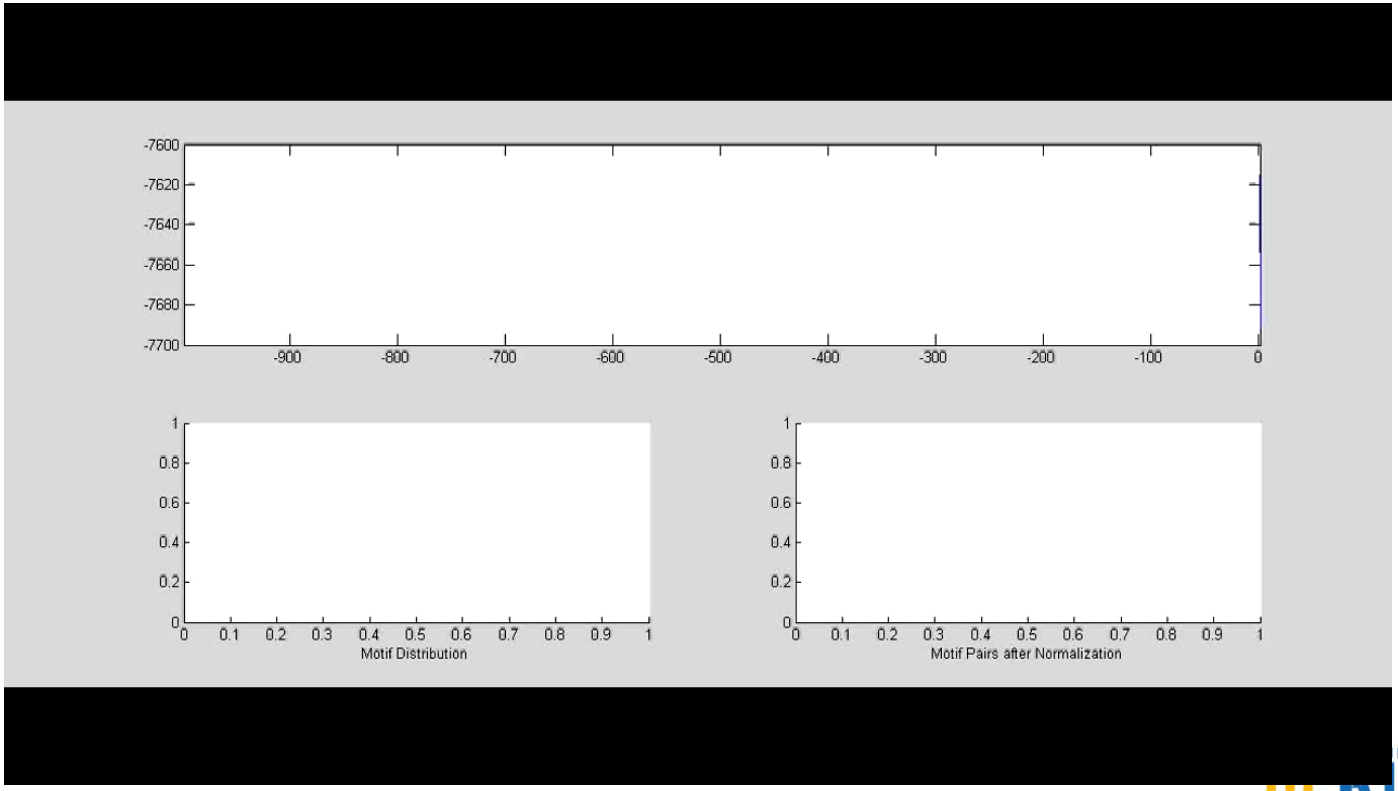
- Repeated pattern in a time series



- Utility:
  - Activity/Event discovery
  - Summarization
  - Classification
- Application
  - Data Center Chiller Management (Patnaik, et al. KDD 09)
  - Designing Smart Cane for Elders (Vahdatpour, et al. IJCAI 09)

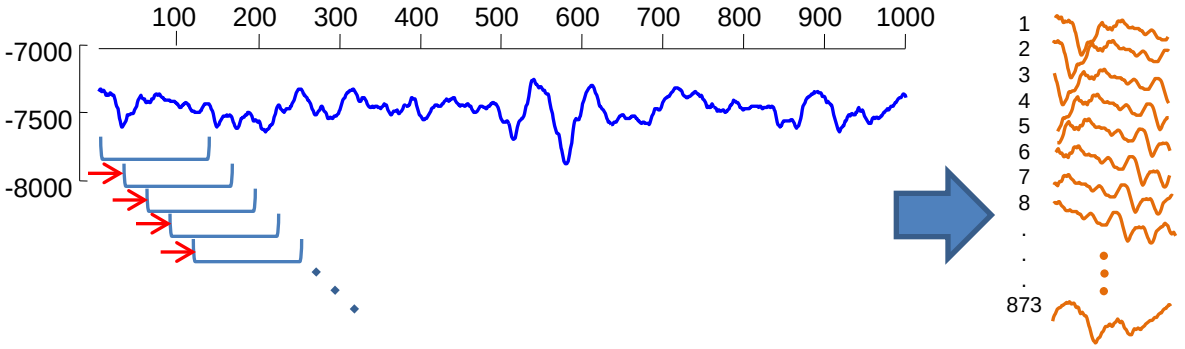
Online Time Series Motifs

- Streaming time series
- Sliding window of the recent history
  - What minute long trace repeated in the last hour?

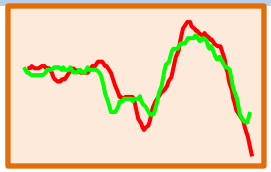


Problem Formulation

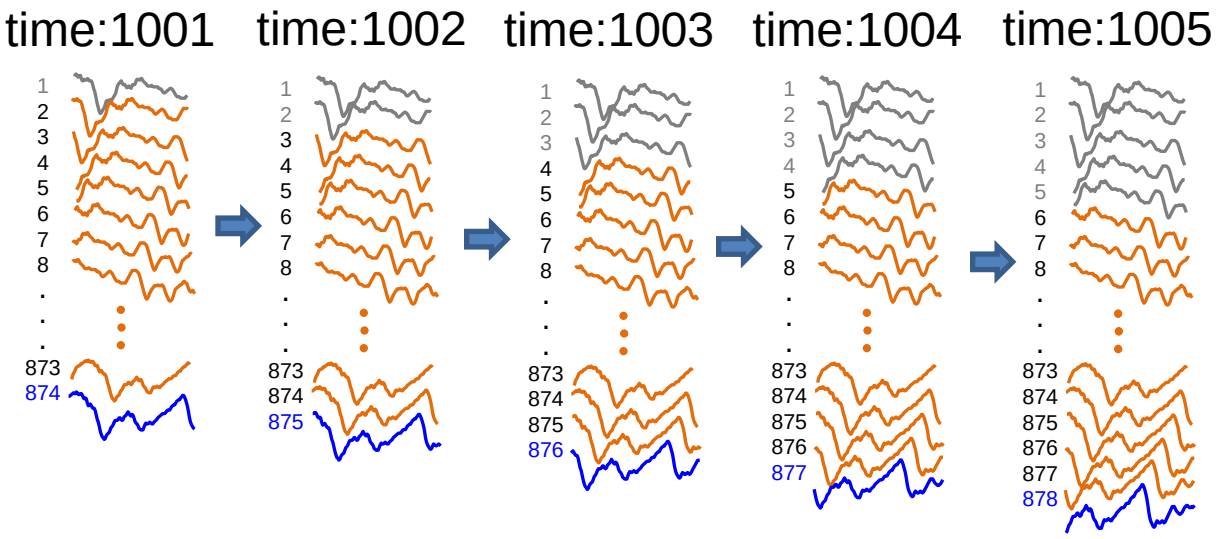
Discovery



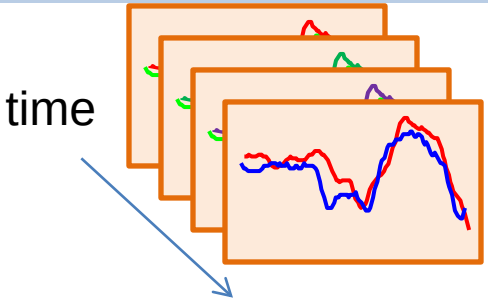
The most similar pair of non-overlapping subsequences



Maintenance

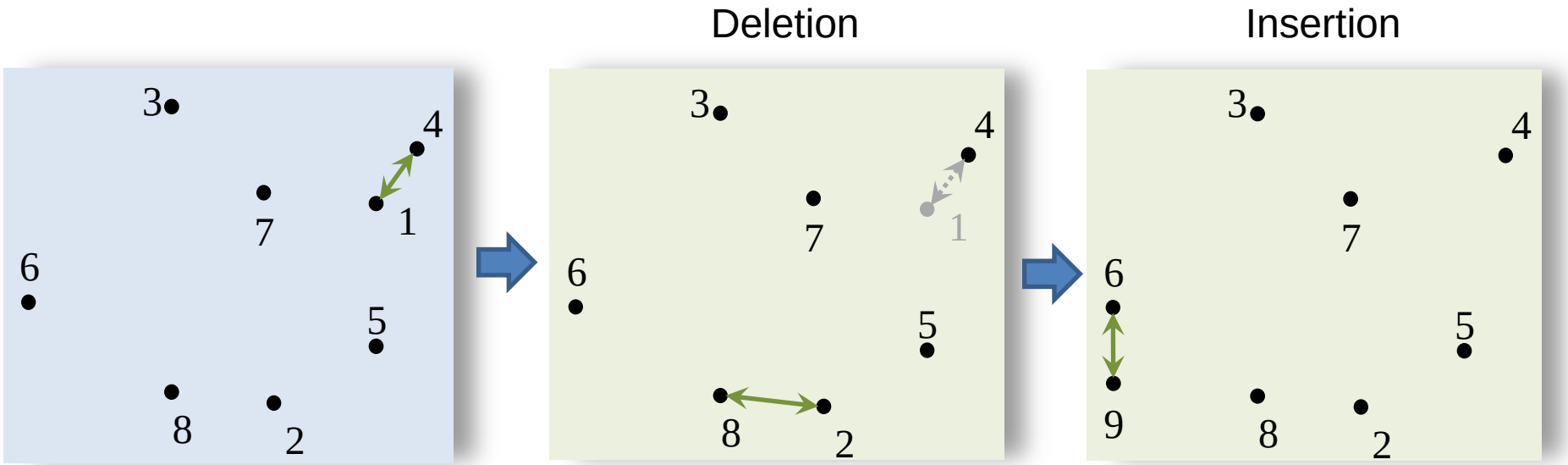


Update motif pair after every time tick



Challenge

- A subsequence is a high dimensional point
  - The dynamic closest pair of points problem
- Closest pair may change upon every update
- Naïve approach: Do quadratic comparisons.



Our Approach

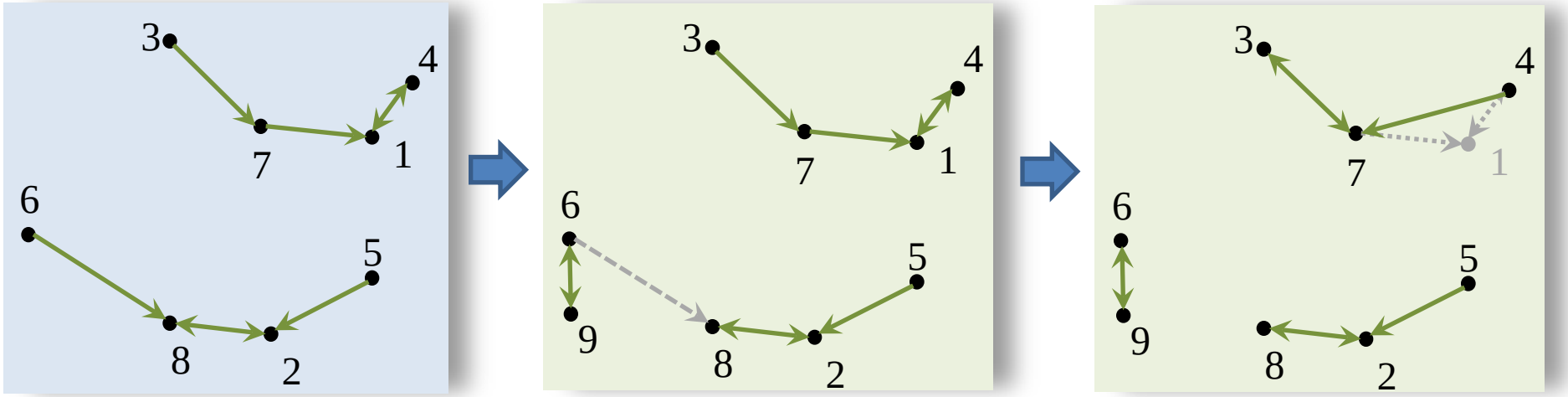
- Goal: Algorithm with Linear update time
- Previous method for dynamic closest pair (Eppstein,00)
  - A matrix of all-pair distances is maintained
    - $O(w^2)$ space required
  - Quad-tree is used to update the matrix
- Maintain a set of neighbors and reverse neighbors for all points
- We do it in $O(w\sqrt{w})$ space

Outline

- Methods
- Evaluation
- Extensions
- Case Studies
- Conclusion

Maintaining Motif

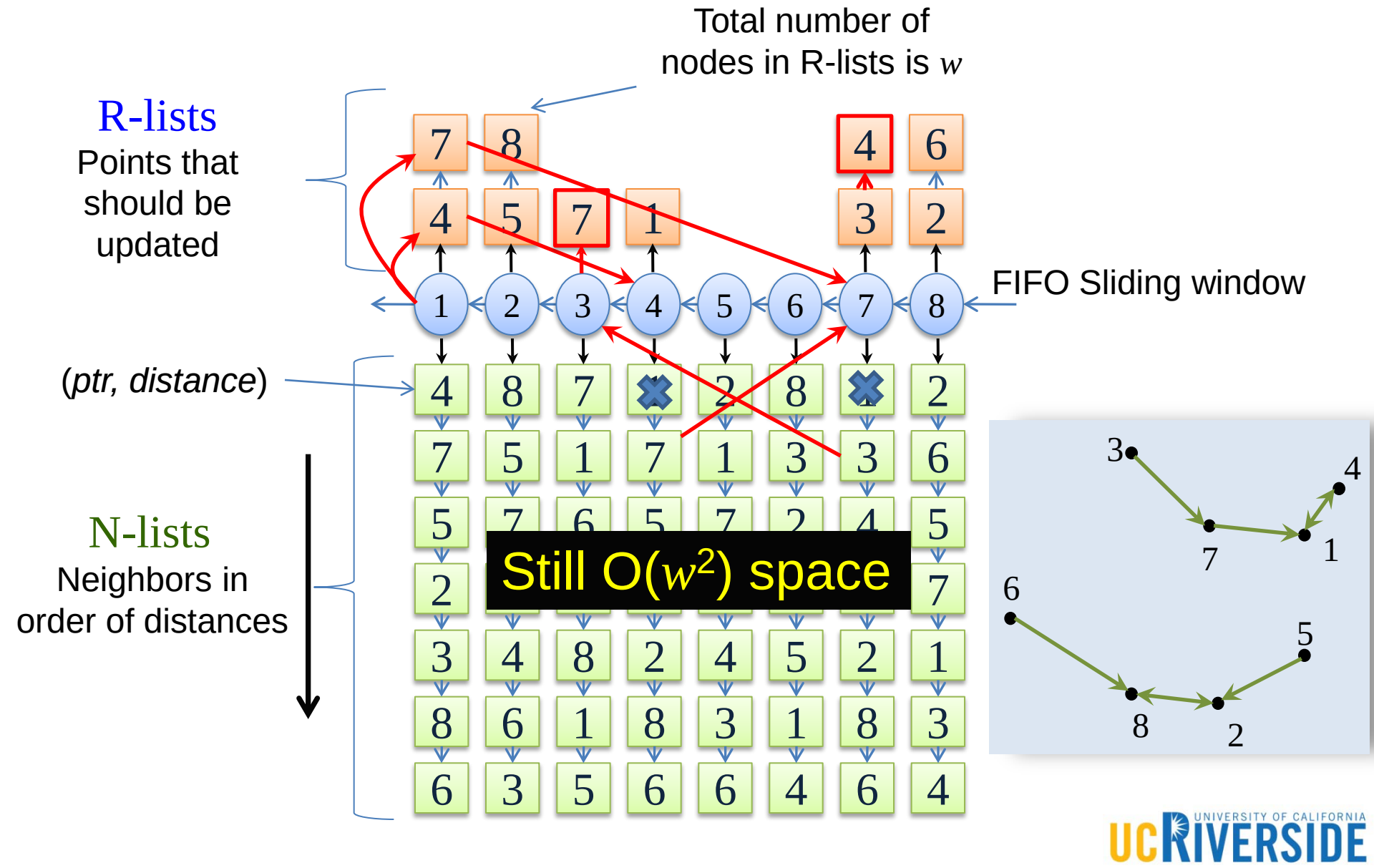
- Smallest nearest neighbor → Closest pair
- Upon insertion
  - Find the nearest neighbor; Needs O(w) comparisons.
- Upon deletion
  - Find the next NN of all the reverse NN



Insertion

Deletion

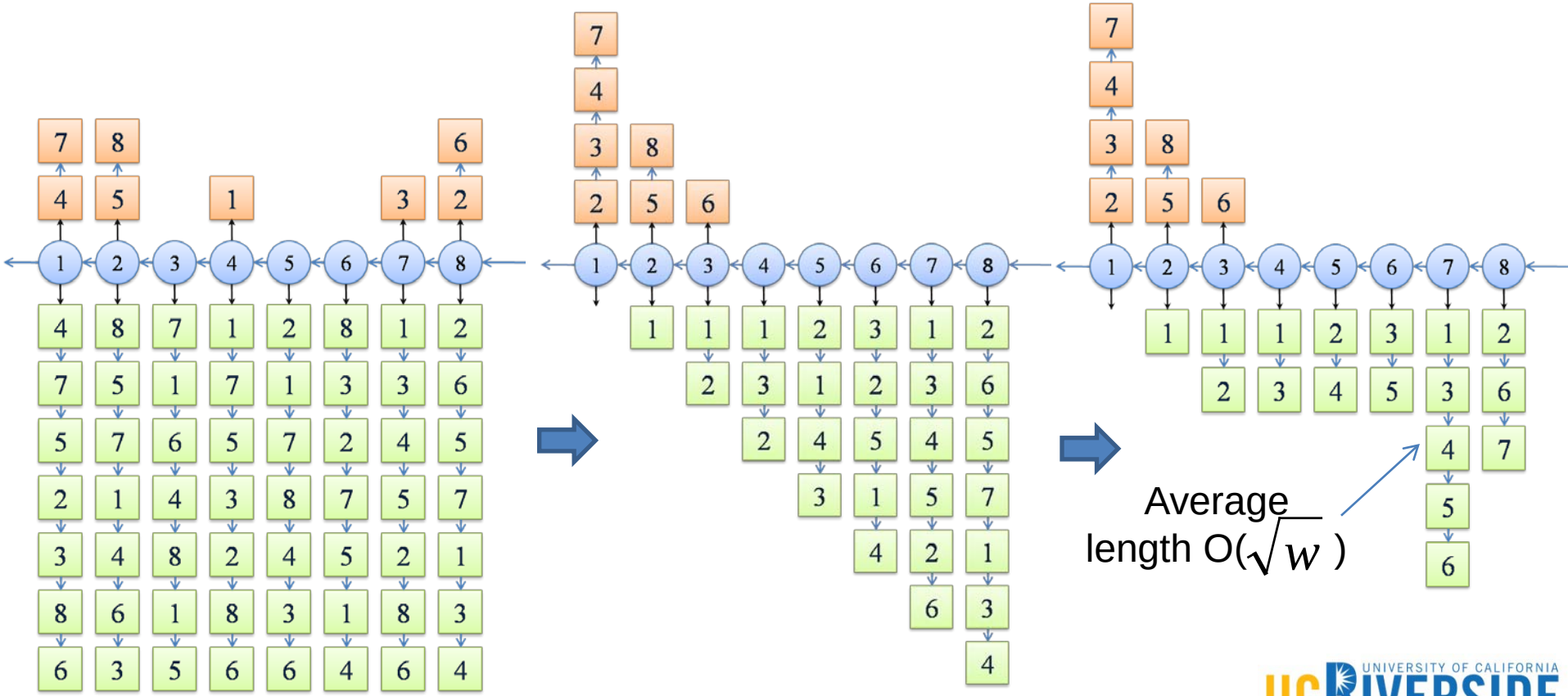
Data Structure



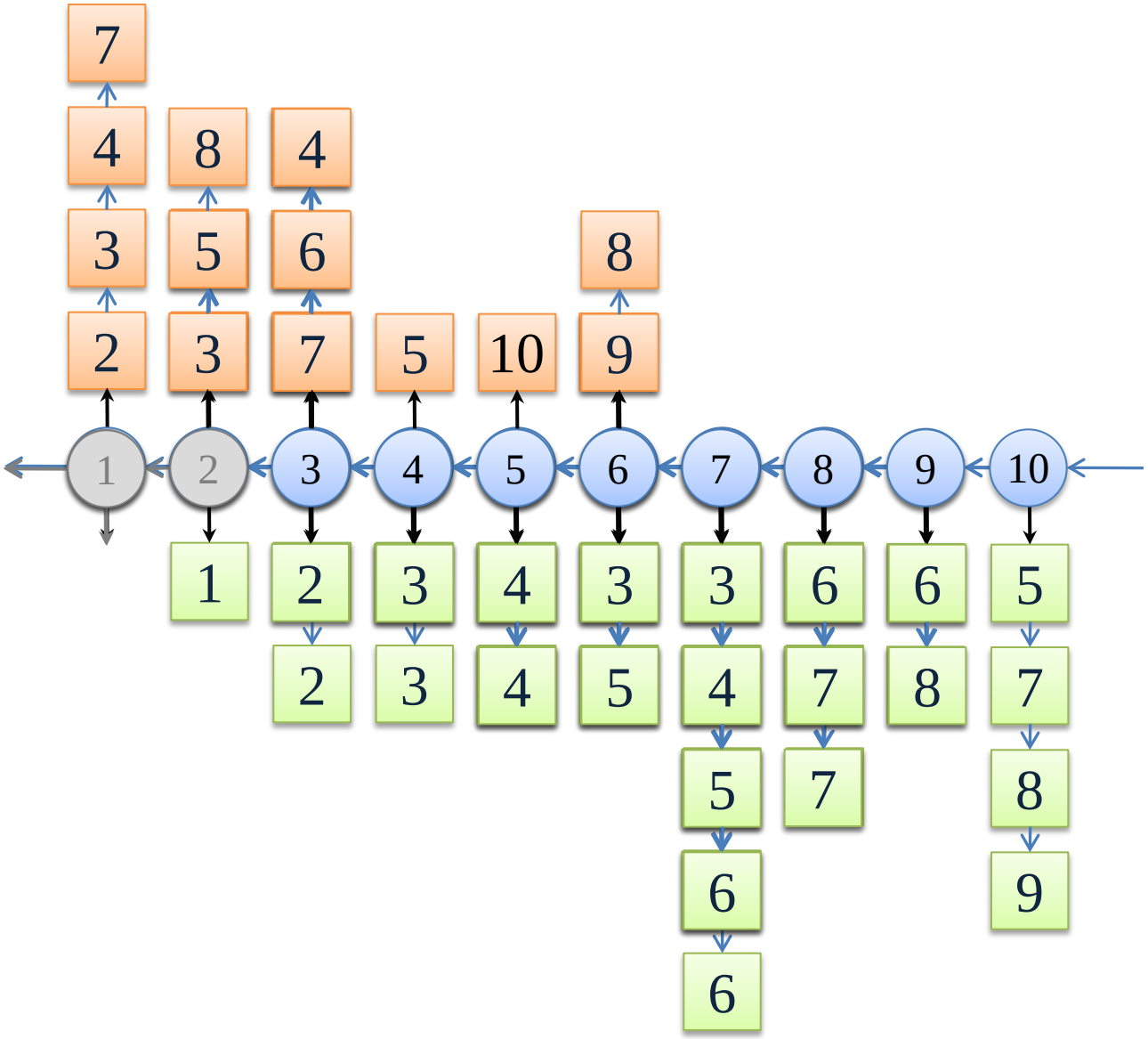
Observations

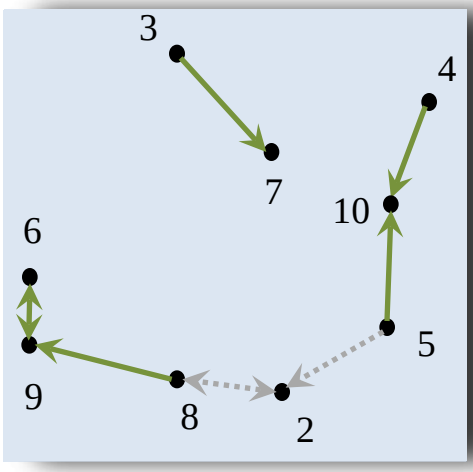
While inserting

- Updating NN of old points is not necessary
- A point can be removed from the neighbor list if it violates the temporal order

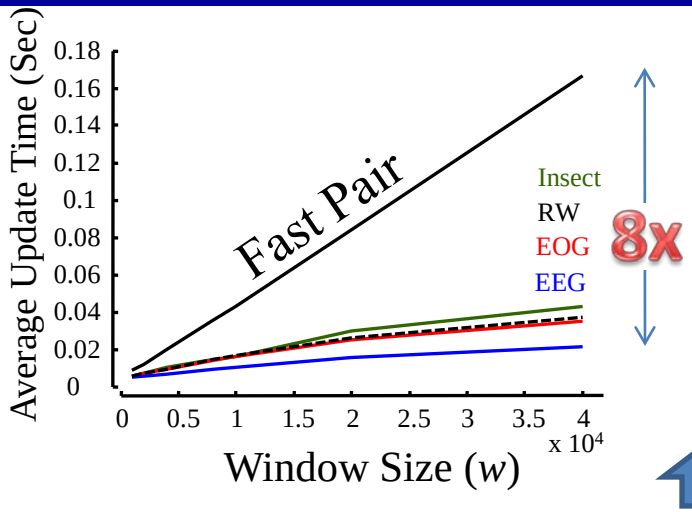


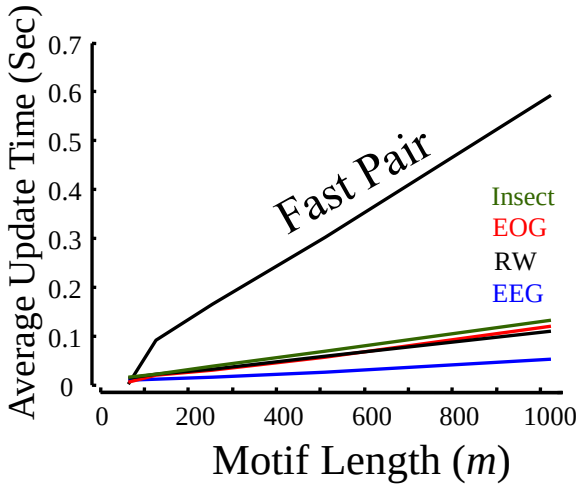
Example



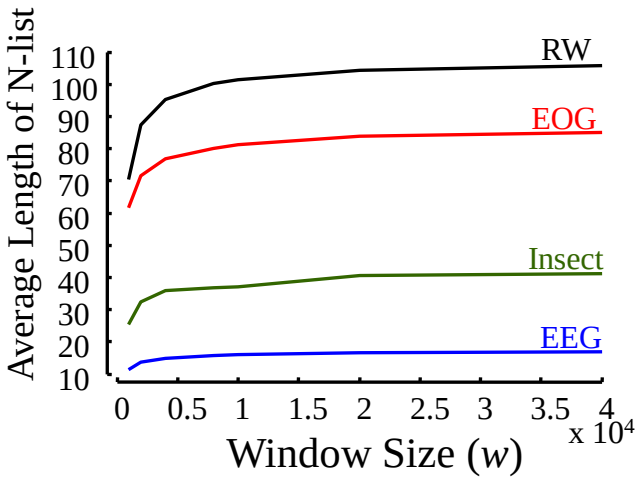


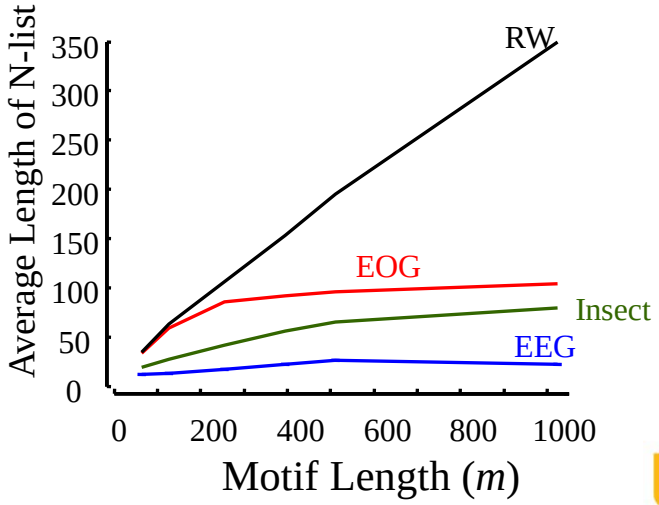
Evaluation





- Up to **8x speedup** from general dynamic closest pair
- **Stable space cost** per point with increasing window size





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Outline

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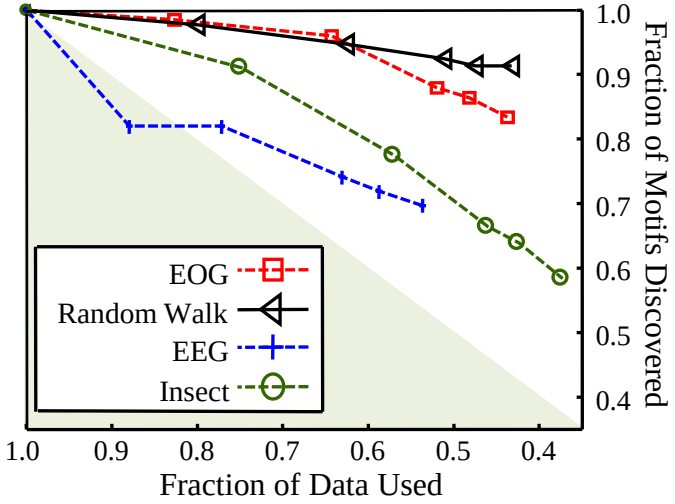
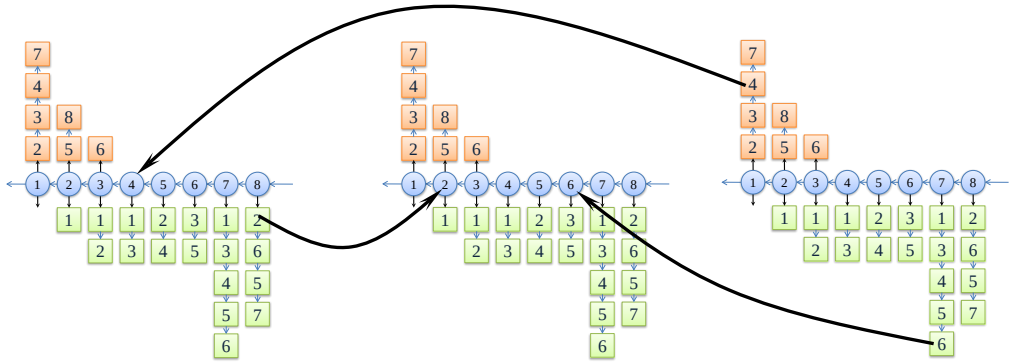
Extension

- Multidimensional Motif
  - Maintain motif in Multiple Synchronous time series
  - Points in one series can have neighbors in others
- Arbitrary Data Rate
  - Load shedding: Skip points if can't handle

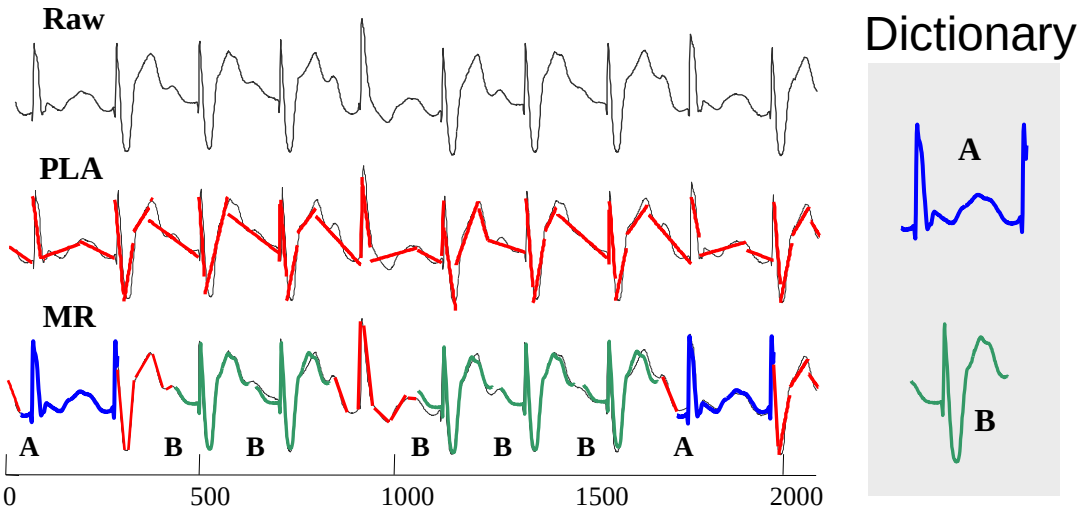




FIFO for each streams

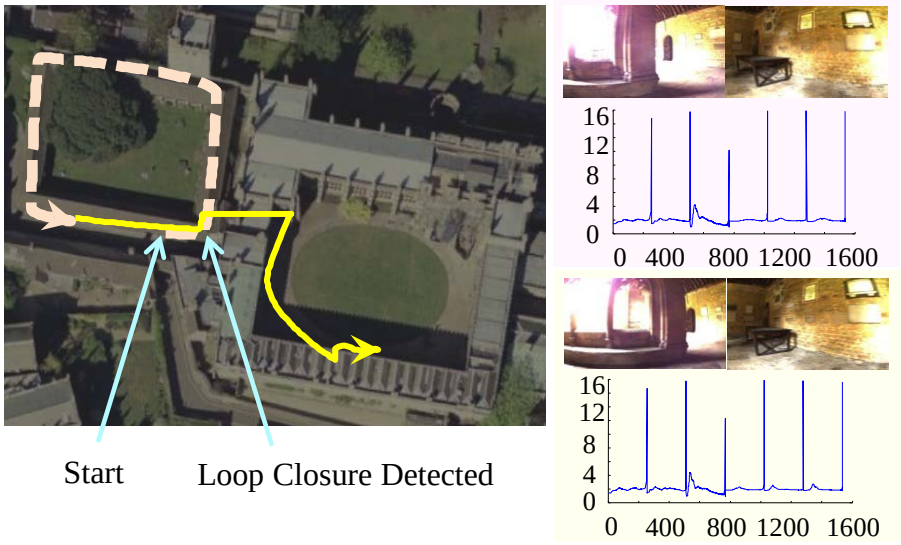
Case Study 1: Online Compression

- Replace all the occurrences of a motif by a pointer to that motif.
- For signals with regular repetitions
  - Higher compression rate with less error.



Case Study 2: Closing The Loop

- Check if a robot closed a loop
- Convert the stream of video frames to stream of color histograms.
- Most similar color histograms are good candidates for loop detection.



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Conclusion

- First attempt to maintain time series motif online
  - Maintains minutes long repetition in hours long sliding window
- Linear update time with less space cost than quad-tree based method
  - $O(w\sqrt{w})$ Vs $O(w^2)$
- Faster than general dynamic closest pair solution

Thank You

Code and Data:
http://www.cs.ucr.edu/~mueen/OnlineMotif

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