HashNWalk: Hash and Random Walk Based Anomaly Detection in Hyperedge Streams

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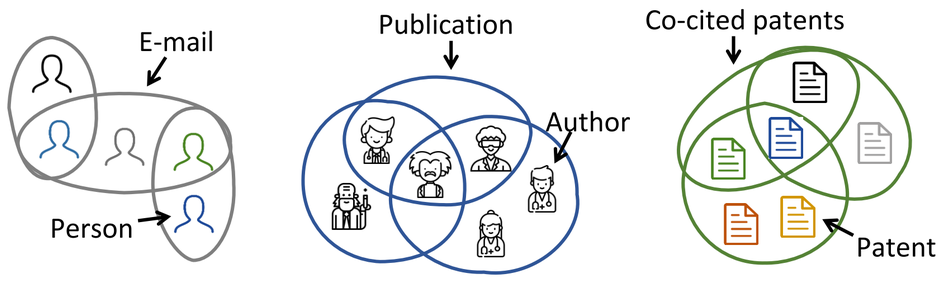
Summary

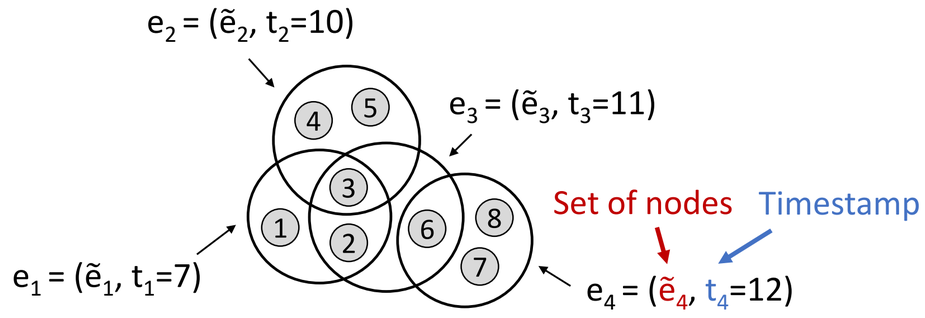
- **Goal:** to detect anomalous hyperedges in a hyperedge stream
- **Previous Work:**
  - proposed algorithms for (pairwise) *graphs*
  - focused on *only one* of the aspects of anomalousness
- **Proposed Method (HashNWalk):**
  - an online algorithm for detecting anomalous hyperedges
  - detects structurally/temporally abnormal hyperedges
- **Results:**
  - **Speed:** processes each hyperedge in near real-time
  - **Space:** requires constant space, controlled by the user
  - **Accuracy:** outperforms the competitors up to 47% ↑ AUROC

Background: Hypergraphs

- **Hypergraphs** model **group interactions**
  - each **hyperedge** is a subset of any number of nodes



- In many real-world scenarios, hypergraphs **evolve over time**
  - a **hyperedge stream** $\{(\boldsymbol{e_i}, \boldsymbol{t_i})\}_{i=1}^{\infty}$ is a sequence of hyperedges



Background: Random Walk

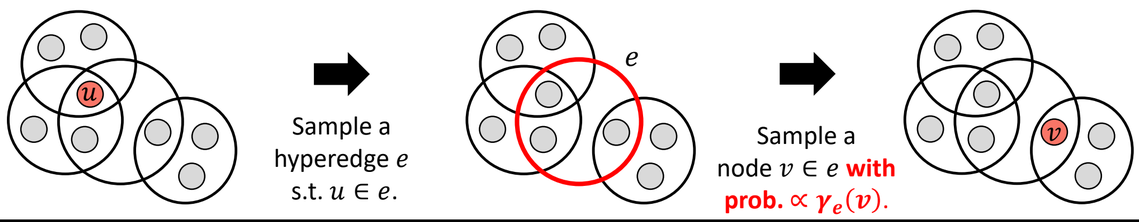
- **Random walk based on edge-dependent vertex weights for exploiting higher-order information**

  If the current node is u,

  ① Select a hyperedge e that contains node u (i.e., $u \in e$) with probability proportional to the weight $\omega(e)$.

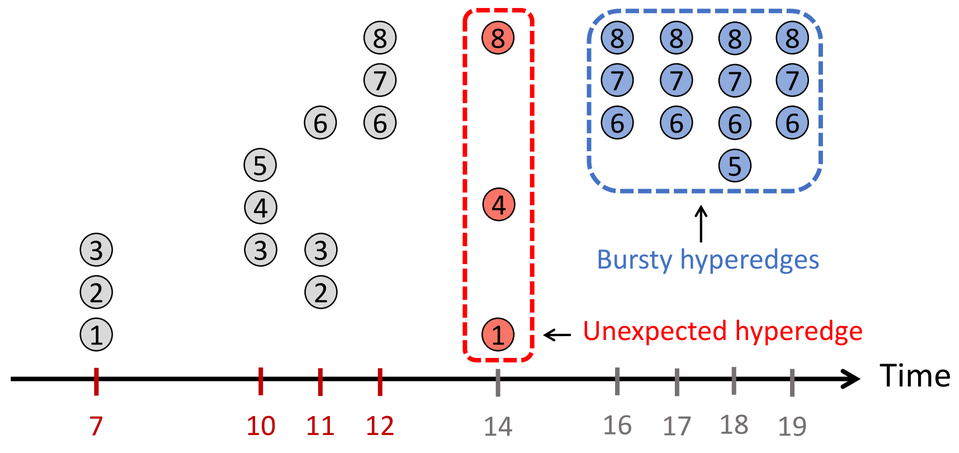
  ② Select a node $v \in e$ with probability proportional to the edge-dependent vertex weight $\gamma_e(v)$.

  ③ Walk to node v.



Problem Definition

- **Anomalies in Hypergraphs:**
  - **Unexpected hyperedges** consist of unnatural comb. of nodes
  - **Bursty hyperedges** appear in bursts in a short period of time

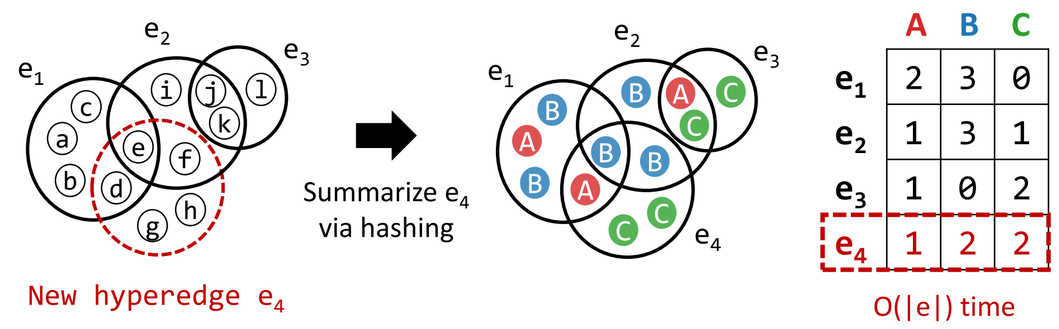


- **Formal Problem Definition:**
  - **Given:** a hyperedge stream
  - **Detect:** anomalous (i.e., unexpected/bursty) hyperedges
  - **Desired:** (a) in near real-time
    (b) using constant space

Proposed Algorithm: HashNWalk

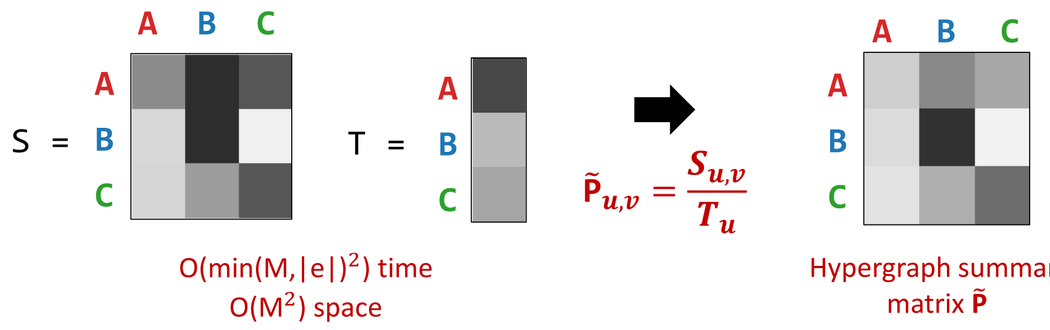
(1) Hypergraph Summarization

- a new hyperedge arrives in the input hyperedge stream
- nodes are merged into M supernodes by **hashing**
- each hyperedge is represented as an M-dimensional vector



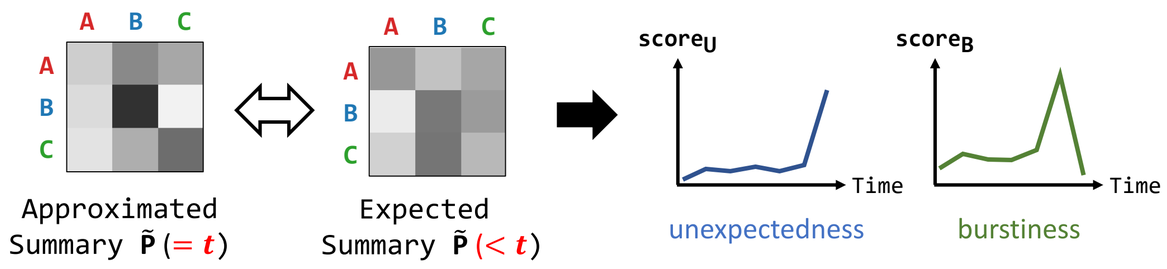
(2) Incremental Update

- $\widetilde{\boldsymbol{P}}_{\boldsymbol{u},\boldsymbol{v}}$ is the **transition probability** of supernode $\boldsymbol{u} \to \boldsymbol{v}$
- $\widetilde{\boldsymbol{P}}$ is computed from $\boldsymbol{S}$ and $\boldsymbol{T}$
- They are **incrementally updated** in response to new hyperedges



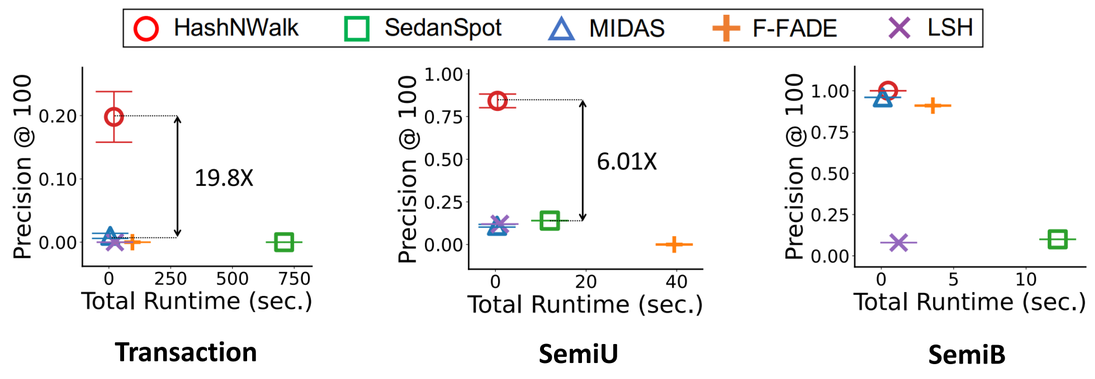
(3) Anomaly Detection

- the hypergraph summary $\widetilde{\boldsymbol{P}}$ is compared with its expectation
- functions $\mathbf{score_U}$ and $\mathbf{score_B}$ measure anomalousness



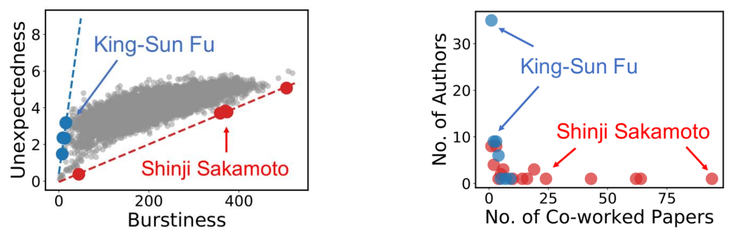
Experimental Results

Q1. Performance: HashNWalk is **accurate** and **fast** in a real dataset (credit card transactions) and two semi-real datasets

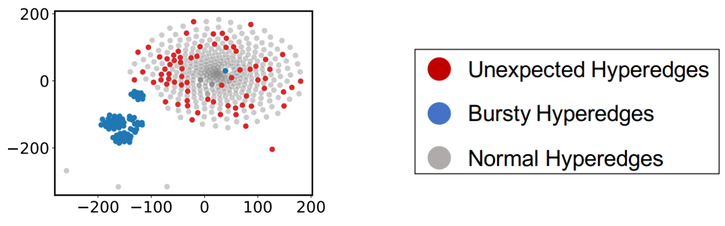


Q2. Discoveries: HashNWalk detects **meaningful events**.

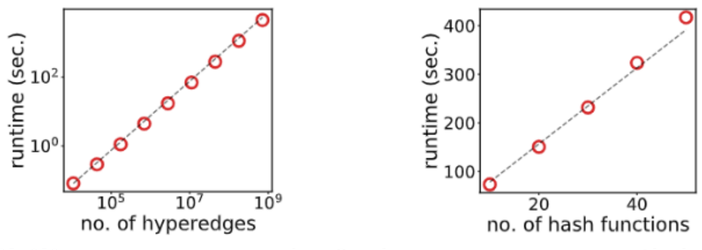
(1) Case study in **DBLP hypergraph**



(2) Case study in **cite-patent hypergraph**



Q3. Scalability: HashNWalk **scales linearly** with the hypergraph size



- **Reproducibility:** source code & datasets are available at:
  https://github.com/geonlee0325/HashNWalk