# Multimodal Information Recommendation in Open-world Environment

*Situational Knowledge on Demand*

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Purdue University

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Advisors: Bharat Bhargava, Michael Stonebraker

NORTHROP GRUMMAN

# Finding Child Left Alone in Cars

Social -Guy
@SocGuy
Follow

Heard a baby crying in a silver sedan on 3rd St

2:48 PM - 4 Oct 2019

TryMe
@try-me
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A baby left without any adult on a blinking car on 3rd St

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**Traffic Cam Snapshot of Silver Sedan**

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**Context:**
*Earthquake* &
*Rescue Personnel*

**Good**

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**Mission-relevant info forwarded to Rescue Coordinators!**

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**Context:**
*Normal Day* &
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**Bad**

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**Context:**
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*Regular Petrol*

**Bad**

**Mission-relevant info forwarded to Police!**

# SOTA Datasets in MMIR

- The Acadian flycatcher is a small insect-eating bird of the tyrant flycatcher family.

- Adults have olive upperparts, darker on the wings and tail, with whitish underpants; they have a white eye ring, white wing bars and a wide bill.

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- With a wingspan of six feet (2 m), the Laysan albatross is one of the smaller species and is adept at diving for squid, fish and crustaceans.

Laysan albatross

# Person Query System (Recommendation)

[Datasets]

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Datasets

User: TMGREENE WEST LAFAYETTE POLICE DEPARTMENT 04/23/2020 14:07

**Incident / Investigation - Case #: 2015-003151 : Off. Narr**

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When the three subjects arrived to my location, I had officers bring Kierre MCCOY out of the vehicle and put him up against the wall of the CVS building so that the victims and witness could see him. The male victim, Tyler HO advised that he was not sure on the subject because he was on the ground getting assaulted. The male witness, James ROACH advised that he MCCOY looked familiar when I asked him if he did. I then asked if he was sure and he stated that he was about eighty percent sure. I then had the female, Maggie LENGACHER (who was the victim of the attempted robbery) step out of the police car to look at MCCOY. When LENGACHER stepped out and looked at MCCOY she stated, "ya" and that he was the third one to exit the vehicle when the fight broke out. She also stated she observed him in the front passenger seat and that he exited after the driver and backseat passenger did to fight her friends. LENGACHER also advised that all three of them attempted to take her purse during my video recorded interview with her. When I asked her how certain she was on MCCOY being one of the suspects she advised she was eighty-five percent sure and that she really remembers one wearing a white shirt, one wearing a black shirt, and the other wearing a red shirt.

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sldmemo

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*sidmemo*

Page 1

**Suspect was a white male, wearing buttoned-up shirt and blue jeans.**

# Research Questions

- What will be the best method to **represent heterogenous knowledge for meaningful retrieval?**
- How difficult is it to **integrate representations** from different modules and identify relevance with user's information need?
- How will the data be delivered to user on-time?
- How can we **model the searcher's intent** within specific context to deliver more relevant result beyond the specific query?
- Can we identify significant events without explicit inquiry?

# Overview

**Model the User**

Techniques to model the user, specifically their information-needs, preferences, and capabilities

**Data Management**

- Resource aware management
- Content Reduction to event association
- Metadata Tagging
- Security Policies

**Scaling**

Techniques to support 1000s of users

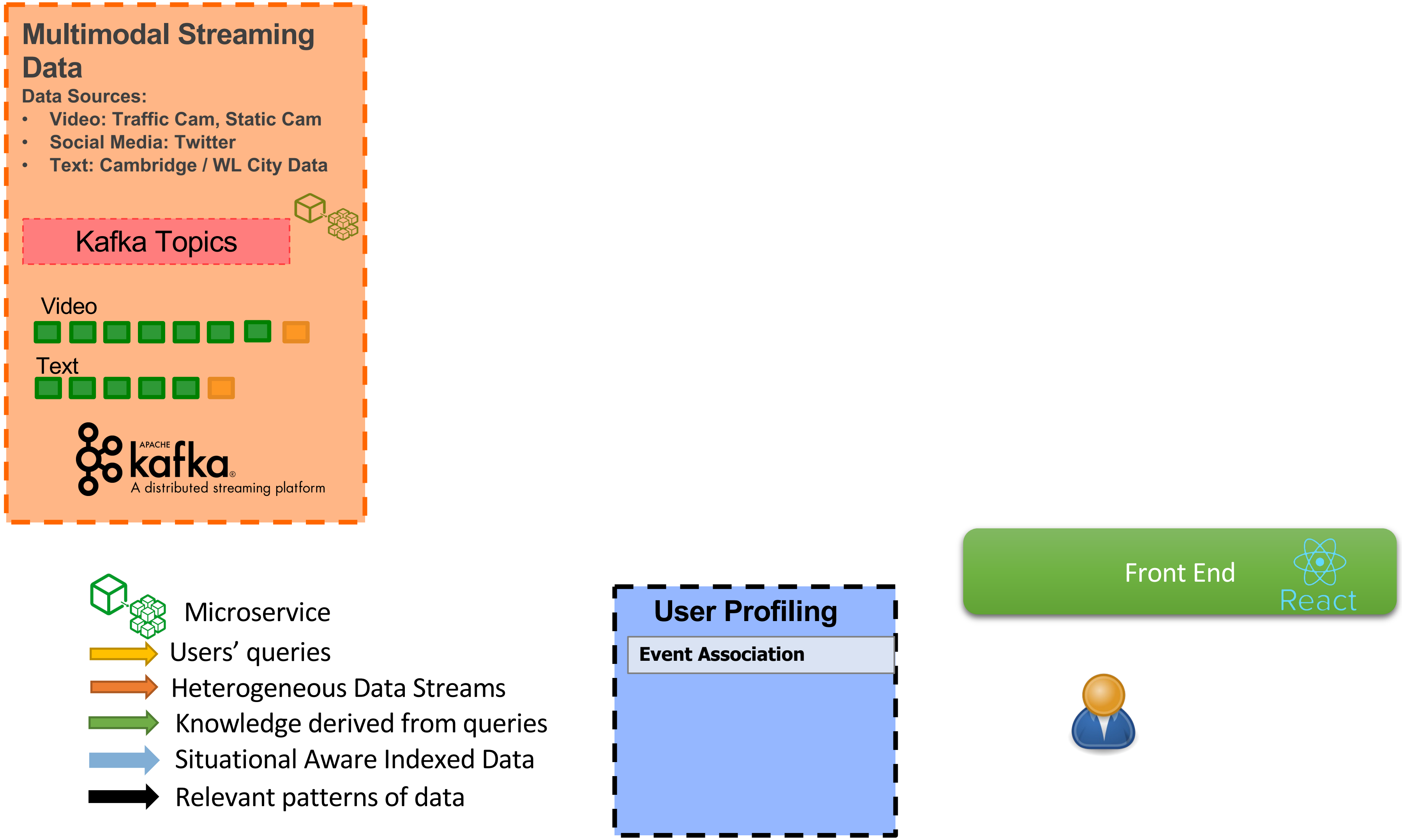
**Data Relevance**

- Identify the relevance to user's needs
- Assess patterns in data
- Connect disaggregate data sources

**Novelties**

- Detect, and Adapt to Novelties
- Model Robustness

# Situational Knowledge on Demand



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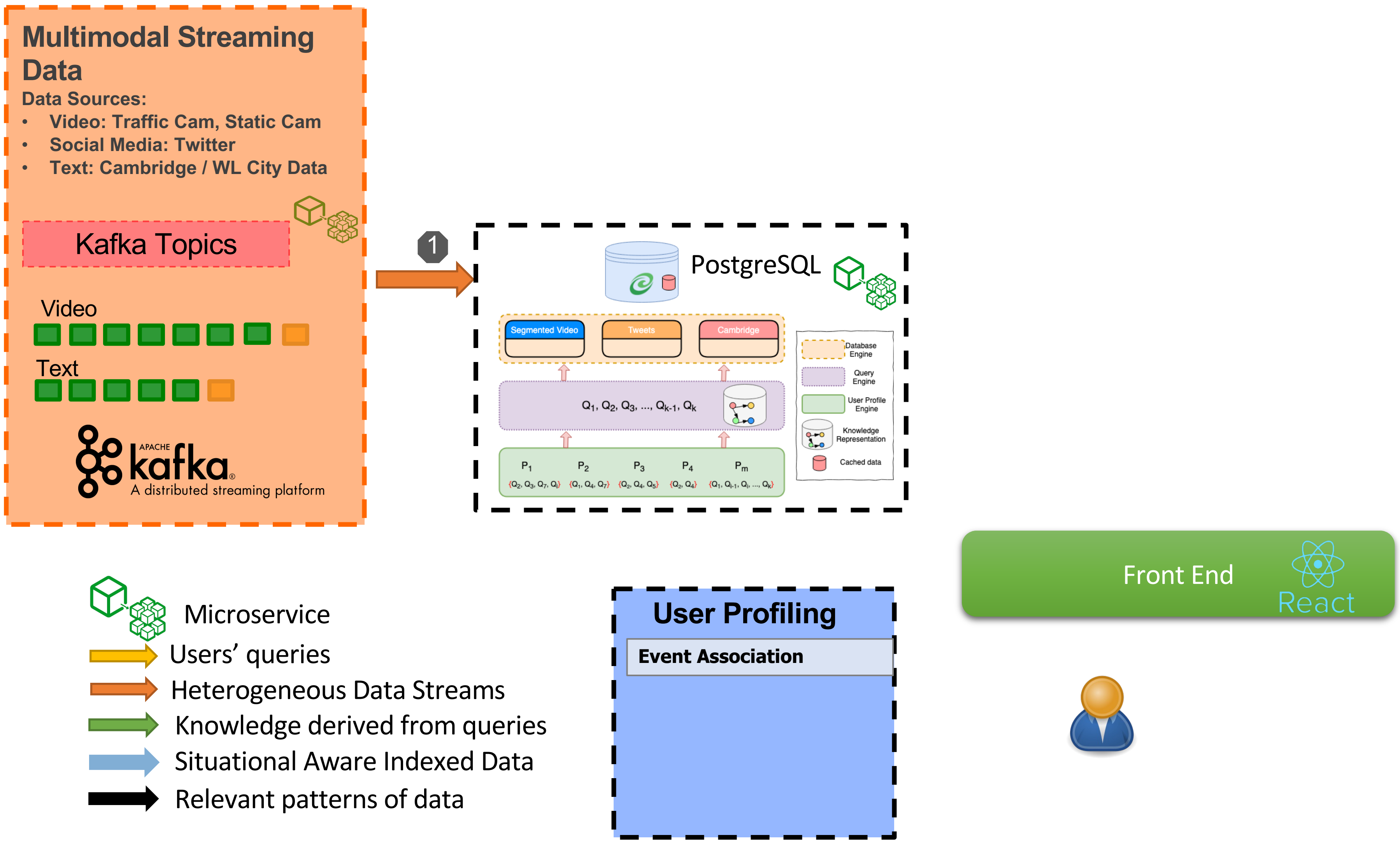

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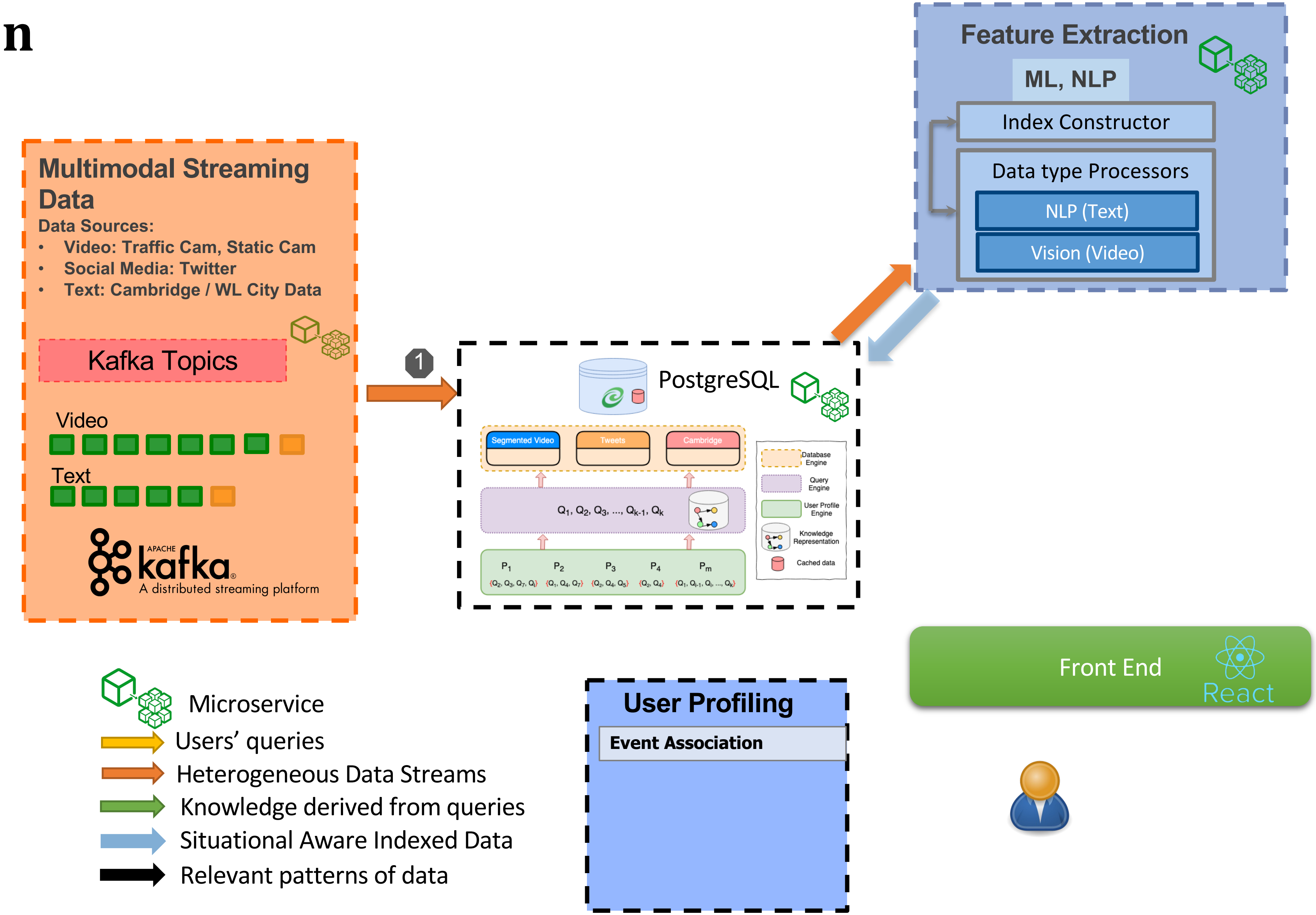

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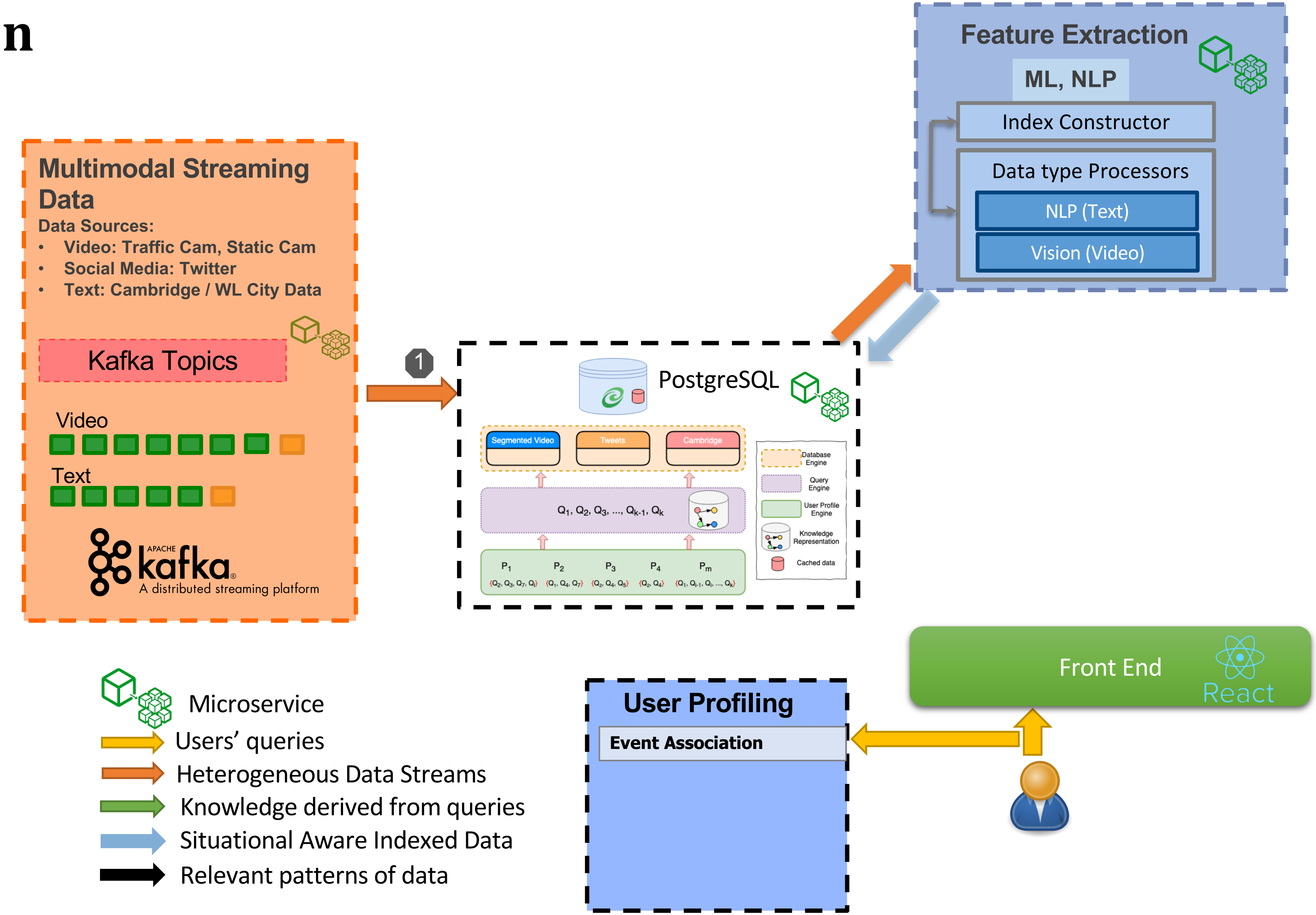

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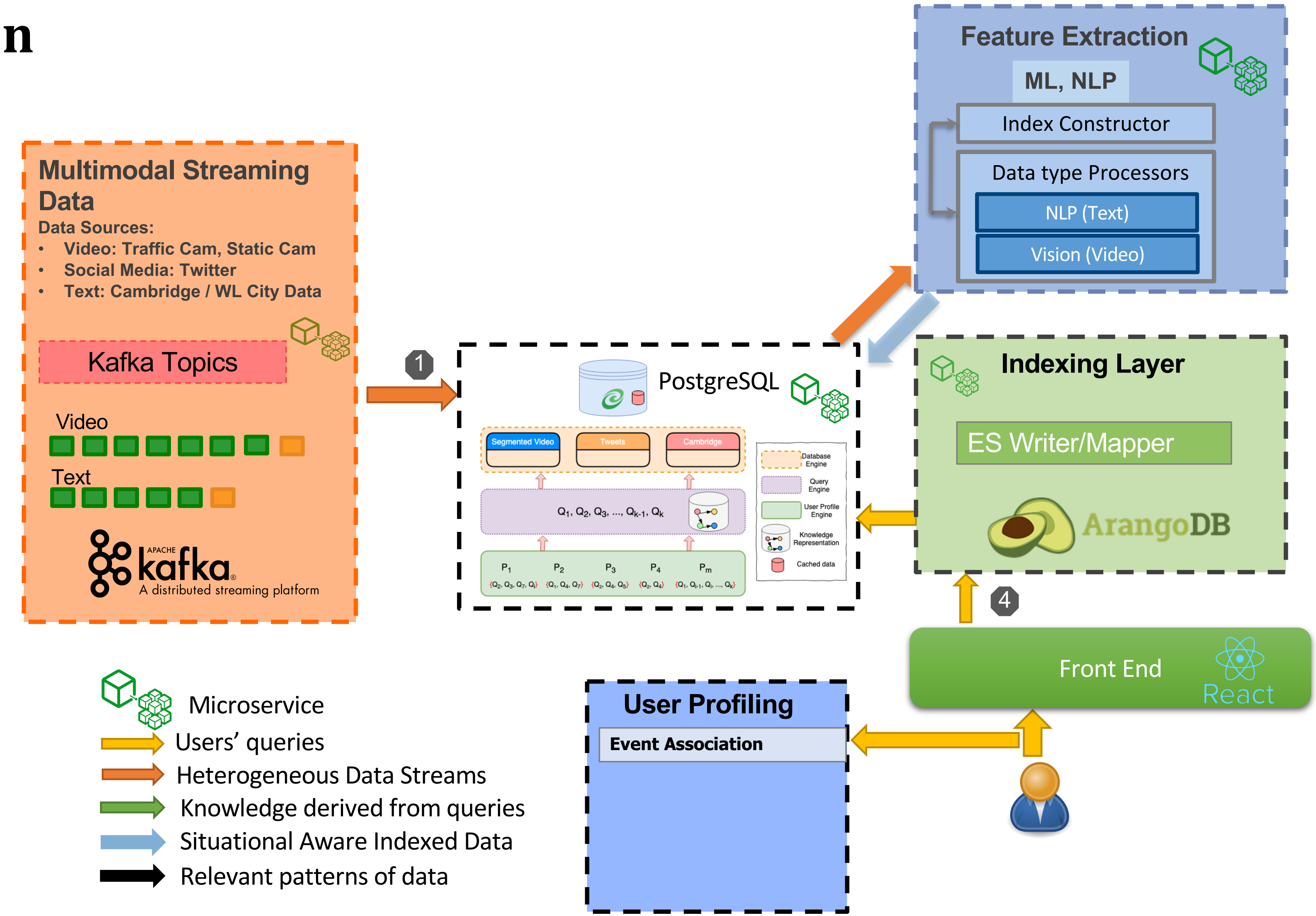

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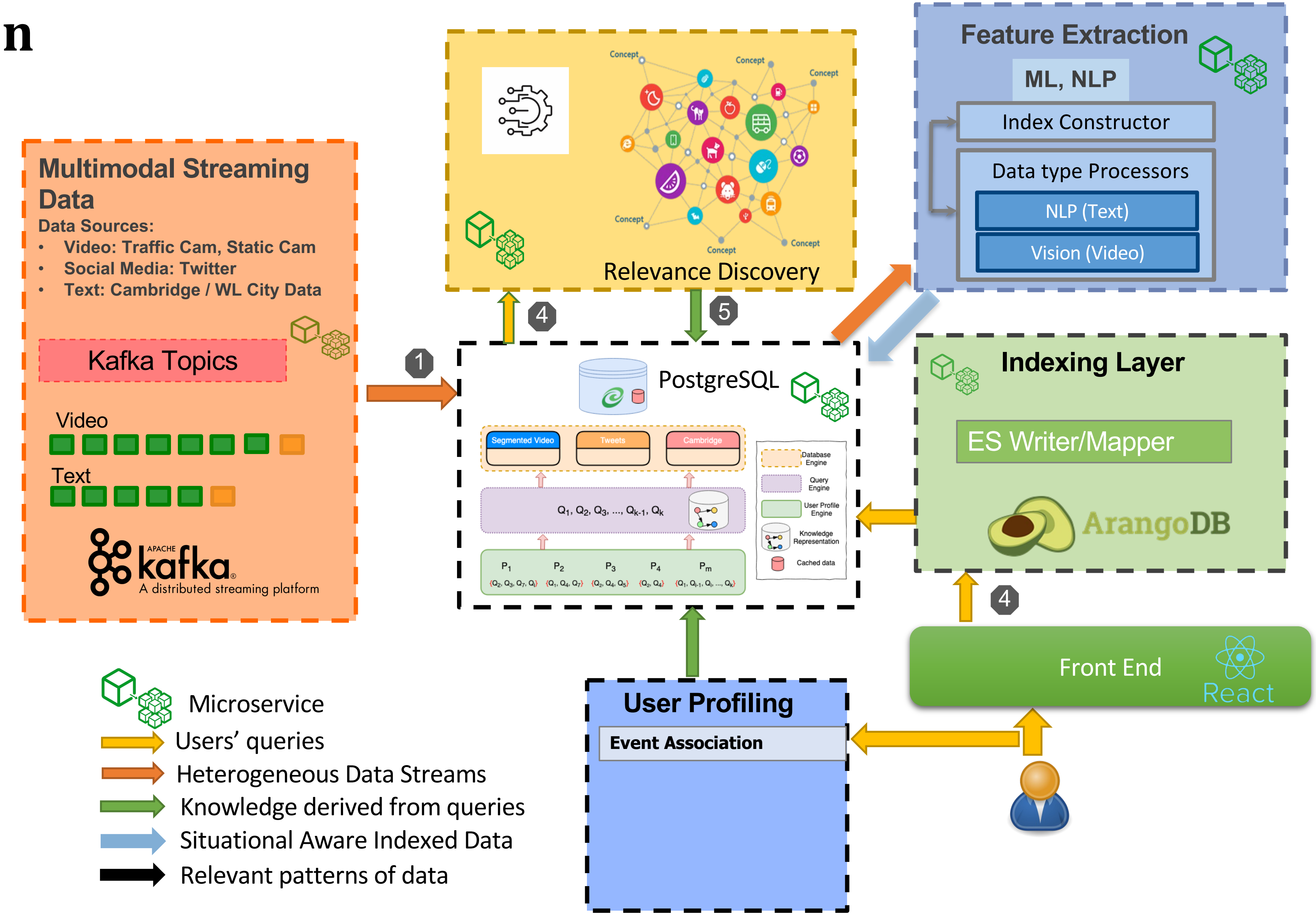

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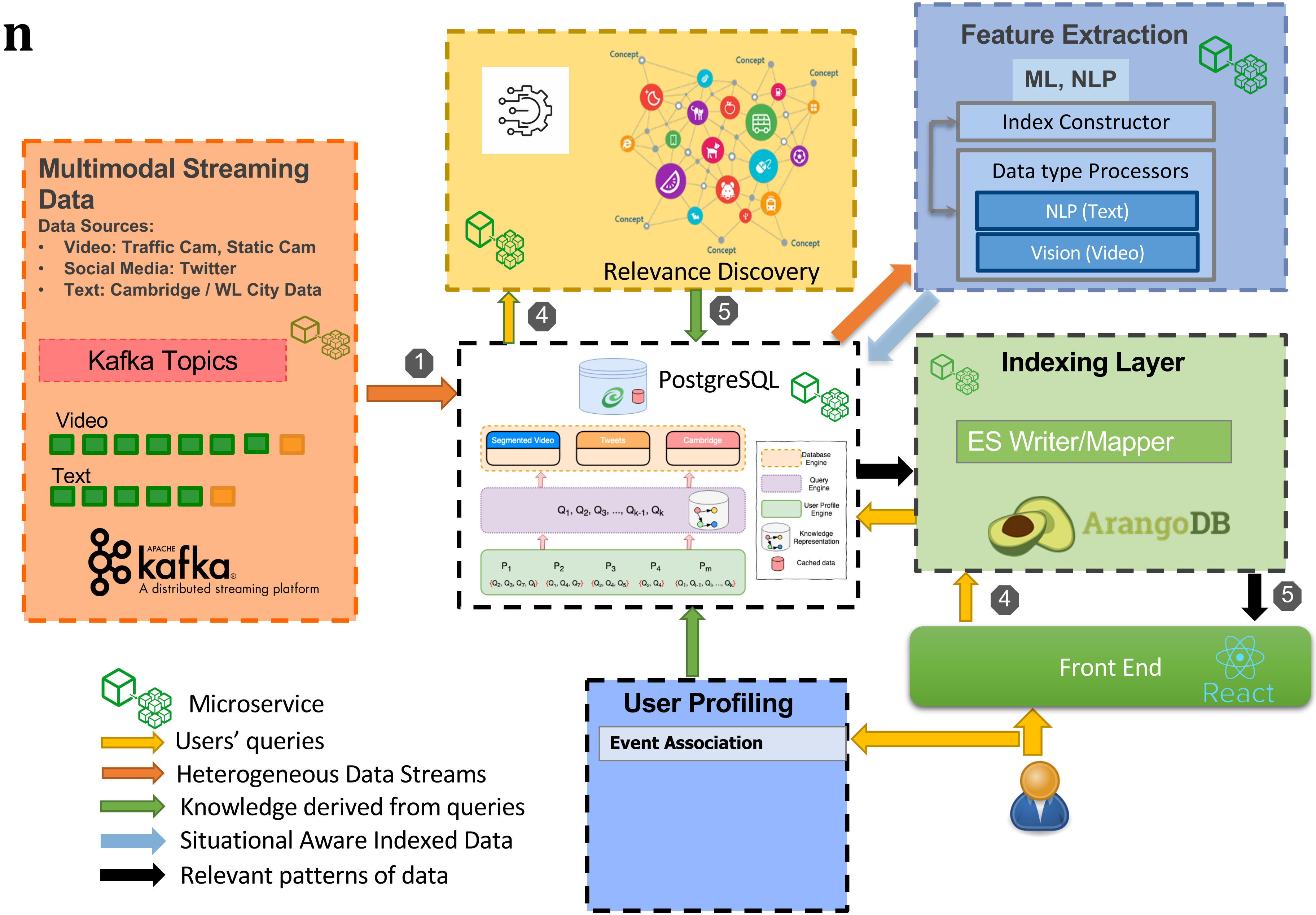

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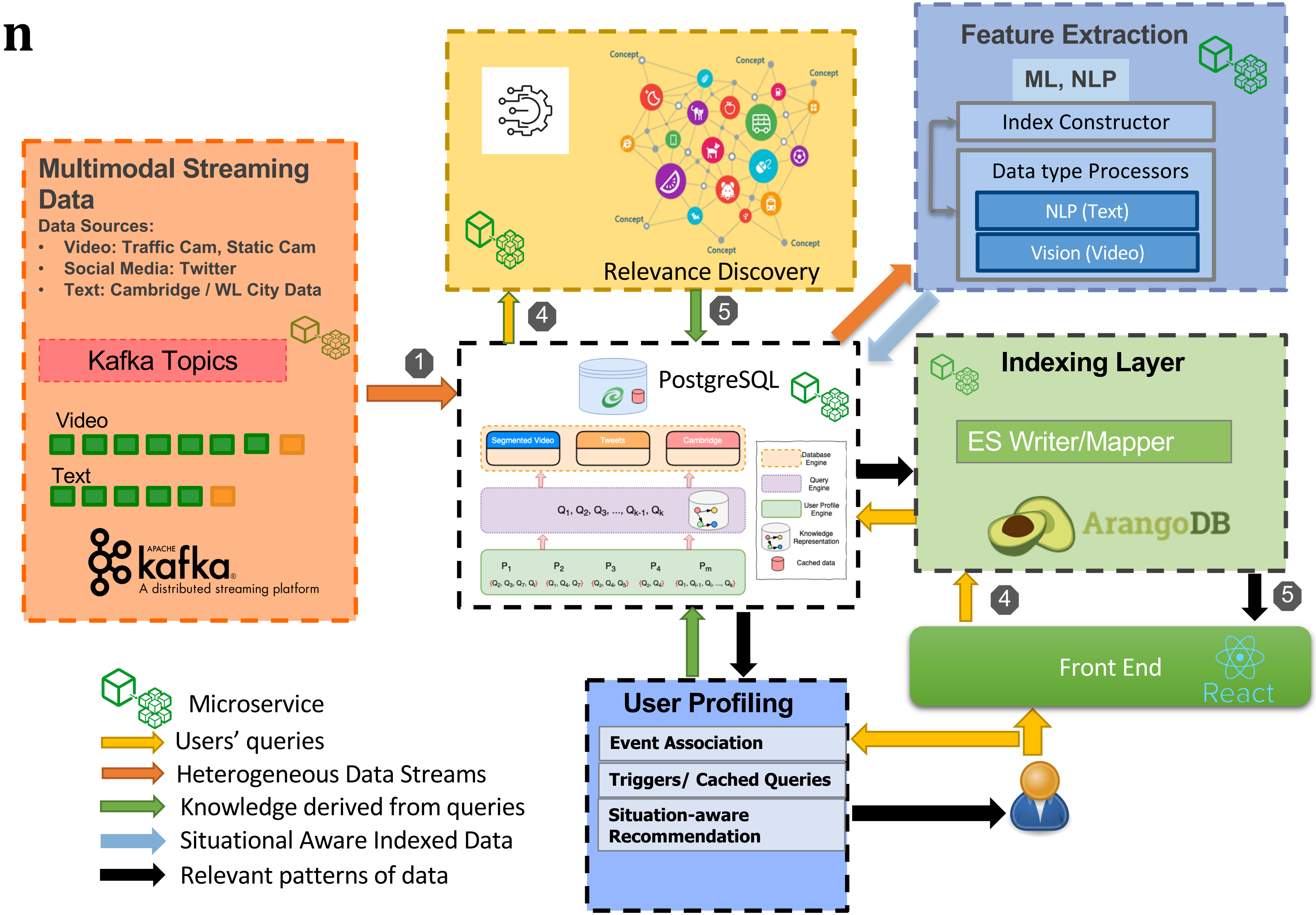

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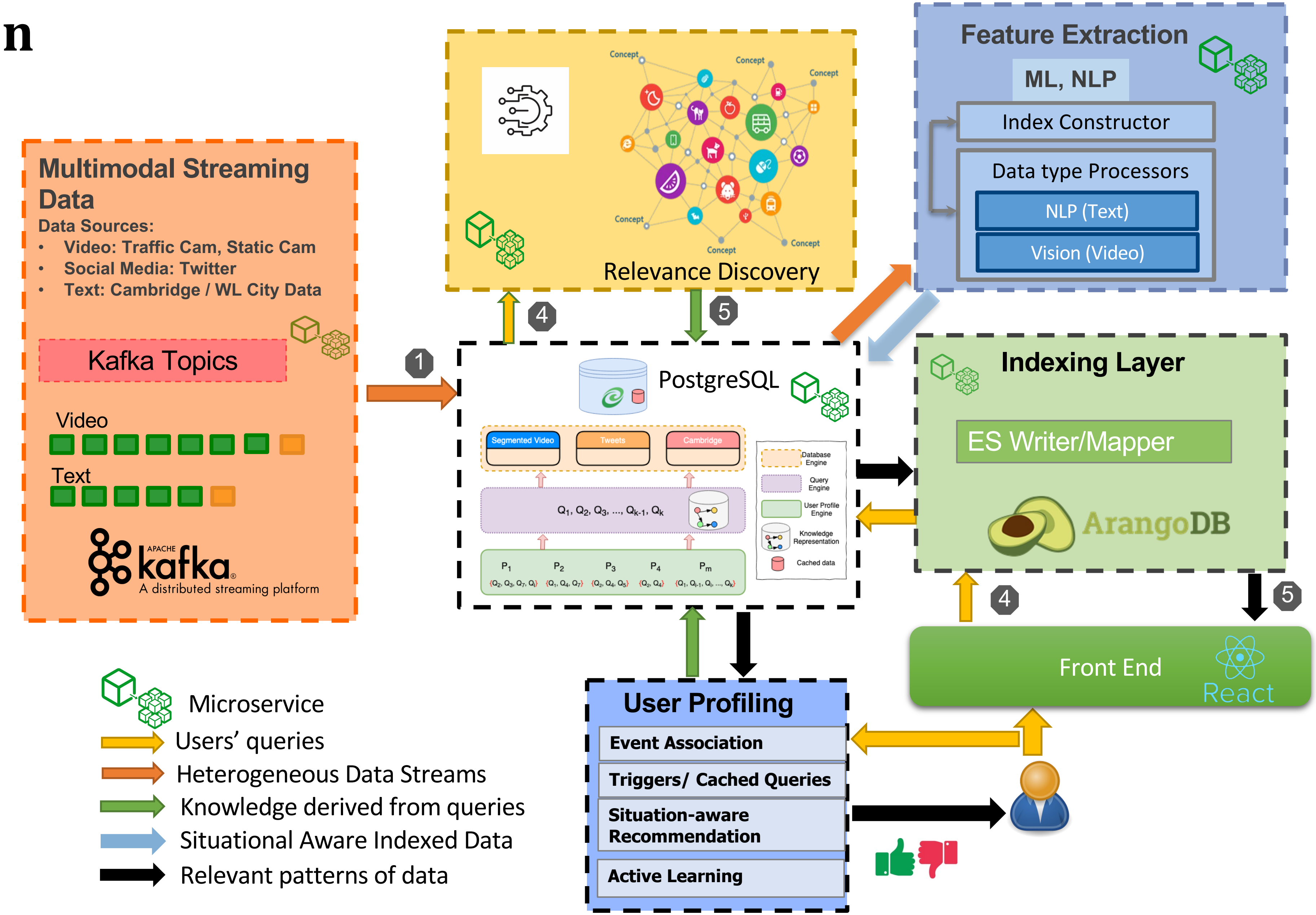
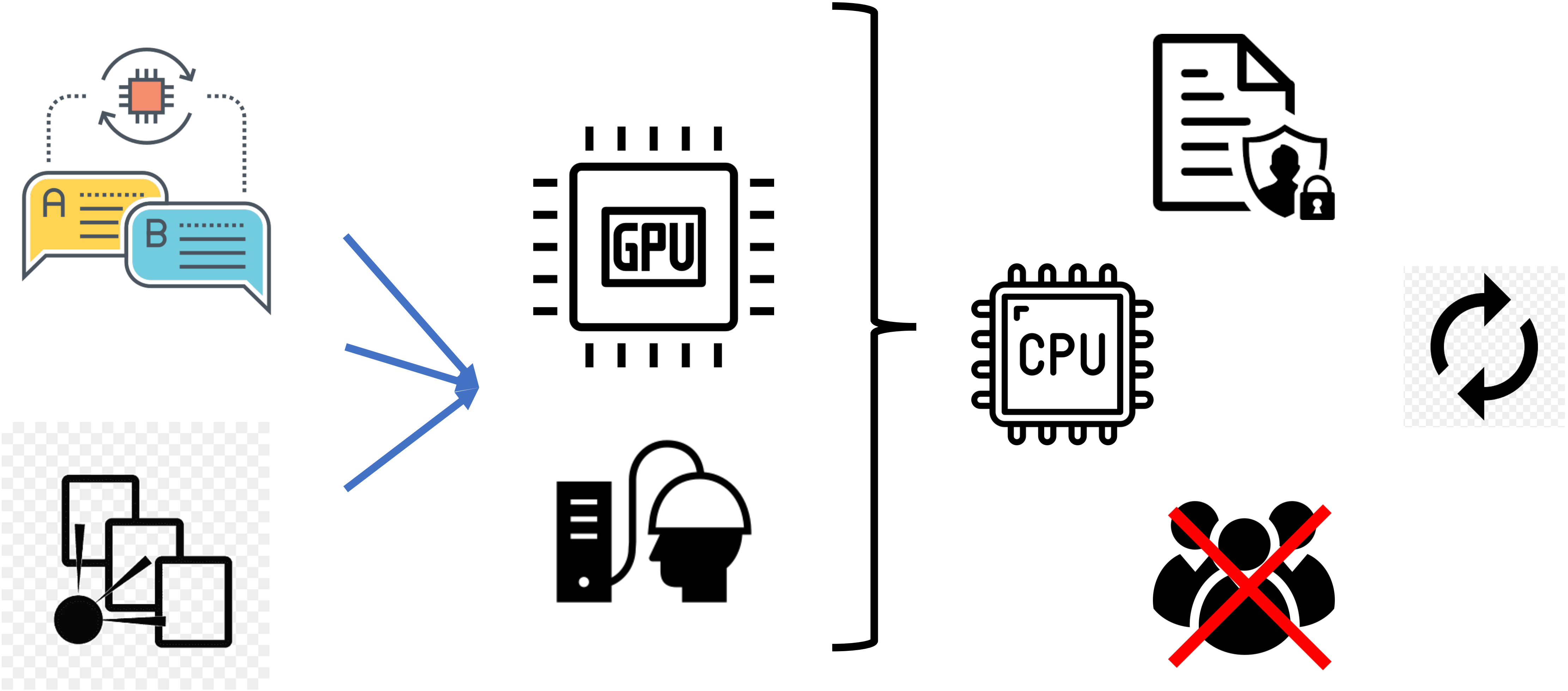


# Resource constrained Feature Extraction



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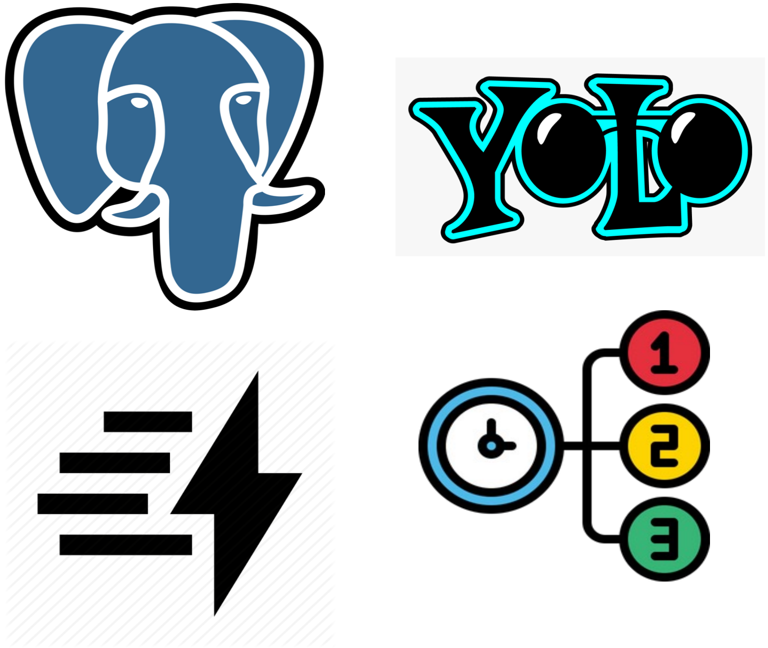
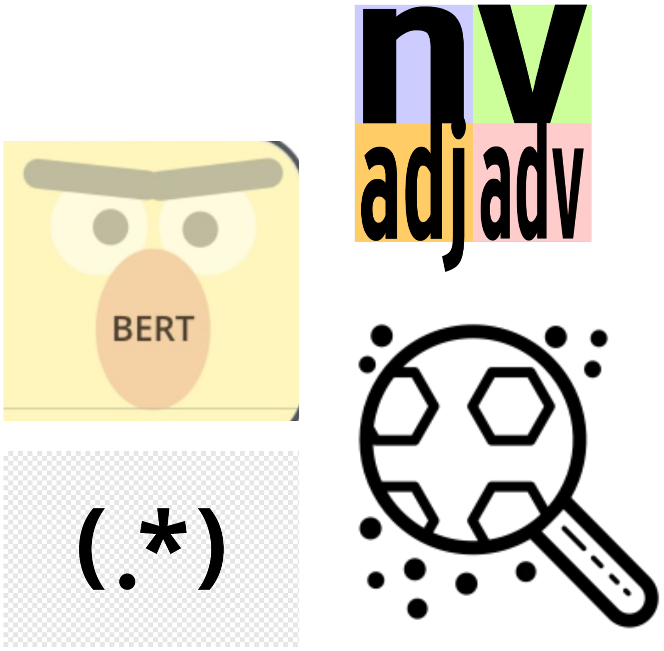



**Video and Image Feature Extraction**

- Priority System
- Object and Attribute Detection
- Heuristic Methods

**Text Feature Extraction**

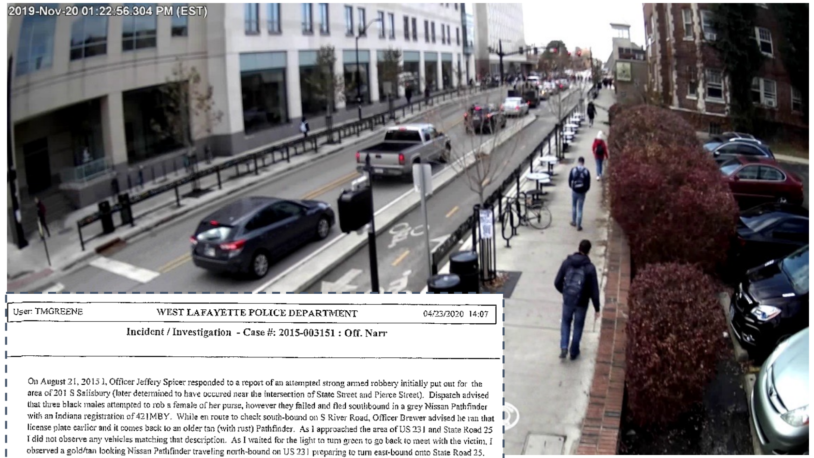
- Regular Expression
- Language Models
- PoS-based Classifiers

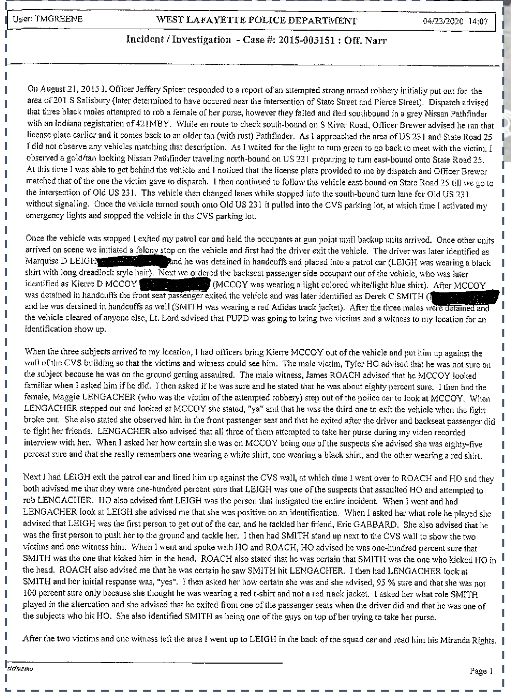
# Dataset

- Features for WLPD:

| Constant Attributes | Changeable Attributes | Other objects |
|---|---|---|
| Female | T-shirt | Car |
| Male | Shorts | Bicycle |
| White | Jeans | Truck |
| Black | Pants | Motorcycle |
| Hispanic | Jacket | Skateboard |
| Asian | Shoes | Backpack |

| Activity Recognition | Additional attributes |
|---|---|
| Smoking | Hair color |
| Running | Tattoo |
| Walking | Beard |
| | Bald |
| | Tall/short |
| | Headphones |



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stdnemo Page 1

# Video Feature Extraction with different CNN networks

- Pedestrian Attribute Recognition
  - Different Strategies on Convolutional Neural Network
    - Just CNN with Restnet50
    - 3D-CNN, CNN-RNN
    - CNN with Temporal pooling and attention network (to account for time dimension in videos)

**Performance Evaluation**

- Metrics:
  - accuracy
  - F1-score
- Dataset:
  - MARS (Motion Analysis and Re-identification Set)

**Table 7: Comparisons of recognition accuracy and F1 measure on MARS datasets(%).**

| Attribute | CNN (Resnet50)[6] | | 3D-CNN | | CNN-RNN | | Temporal Pooling[7] | | Temporal Attention[8] | | Color Sampling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | acc | F1 | acc | F1 | acc | F1 | acc | F1 | acc | F1 | acc | F1 |
| top color | 75.22 | 73.98 | 67.91 | 65.19 | 70.54 | 67.33 | 74.98 | 73.13 | 76.05 | 74.64 | 44.65 | 38.31 |
| bottom color | 73.55 | 54.09 | 59.77 | 36.56 | 67.71 | 44.44 | 71.69 | 47.84 | 70.15 | 46.89 | 45.26 | 15.88 |
| gender | 90.01 | 89.71 | 86.49 | 76.22 | 90.07 | 89.62 | 91.04 | 90.63 | 91.82 | 91.48 | - | - |
| average | 79.59 | 72.59 | 67.97 | 59.18 | 76.11 | 67.13 | 79.24 | 70.53 | 79.34 | 71.01 | 44.96 | 27.10 |

NORTHROP GRUMMAN

# Property Identification from Unstructured Text.

- Data Annotation
  - Gender, Race, Age, Hair Color, Clothing (jacket/pants/jeans) and their descriptions
  - Multiple persons are described in same document and annotated separately
- Wearing is evaluated on
  - Clothing Name
  - Clothing Description or Color Value

............

*Suspect was a white male, wearing buttoned-up shirt and blue jeans.*

.............

**Table 2: Performance Evaluation of Suspect Attribute Extraction from Incident Reports**

| Attributes | Gender | Race | Height | Wearing Attr-only | Wearing Attr-value |
|---|---|---|---|---|---|
| **Precision** | 0.94 | 0.94 | 0.72 | 0.93 | 0.92 |
| **Recall** | 0.73 | 0.73 | 0.57 | 0.65 | 0.87 |
| **F1-Score** | 0.82 | 0.82 | 0.63 | 0.77 | 0.90 |

# Human Attribute Extraction from Text (Incident Reports)

- Feature Extraction from Unstructured Text involves two steps
  - Candidate Sentence Extraction, using
    - Regular Expressions
    - Word2Vec
    - **Wordnet: Lexical Knowledge Base**
    - **Sentence BERT (SBERT)** NLI Classifier
  - Attribute Value Extraction from Candidate Sentence
    - For gender, race, height: we used Regular Expression search
    - For cloth-name and cloth-color, we used **Parts of Speech based heuristic methods**

*Suspect was a white male, wearing buttoned-up shirt and blue jeans.*

- We only focused on gender, race, height, and clothes as features in police incident reports, because
  - Frequency of each of these features in reports
    - Gender: 100%
    - Race: 97%
    - Height: 57%
    - Clothes: 78%
    - Weight, hair color: < 30%

# Feature Value Extraction

NORTHROP GRUMMAN

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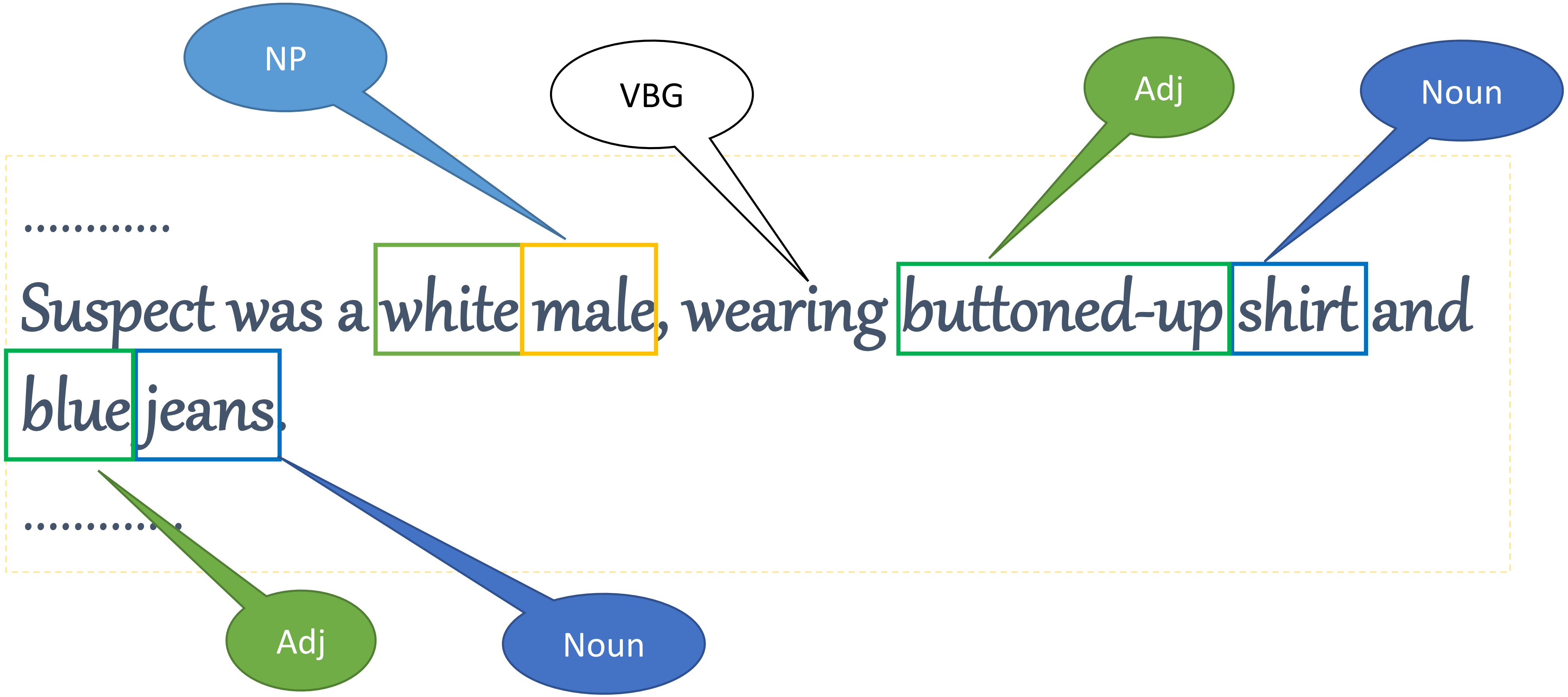
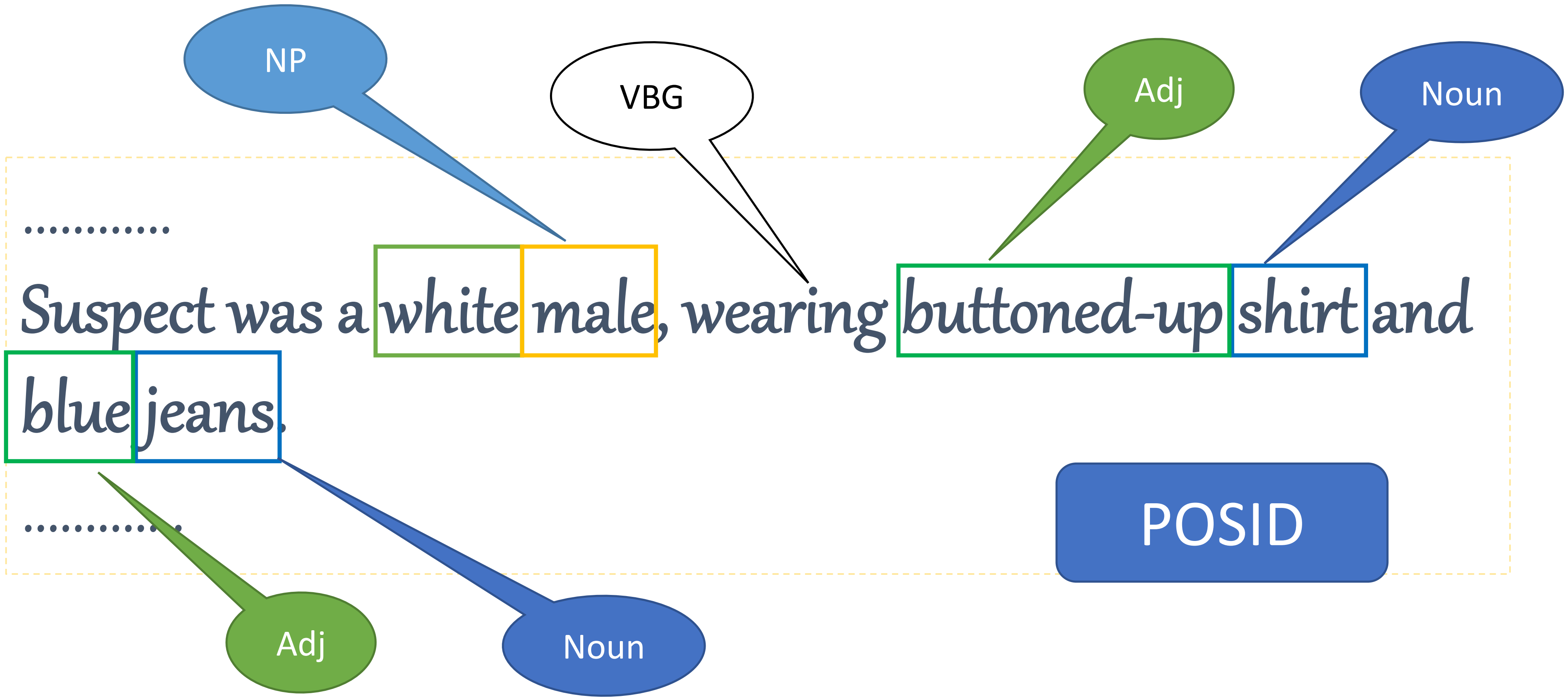


# Feature Value Extraction



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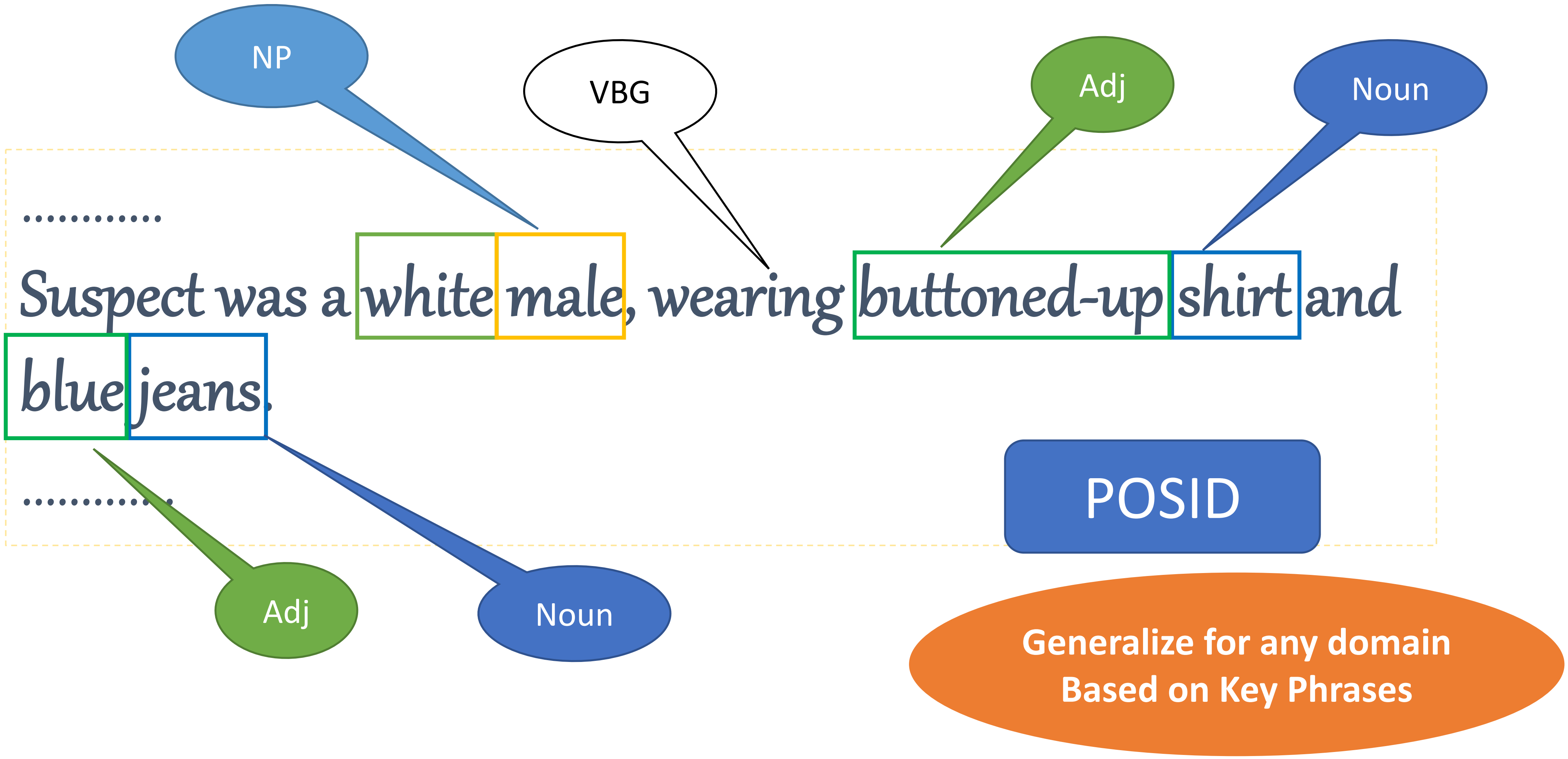
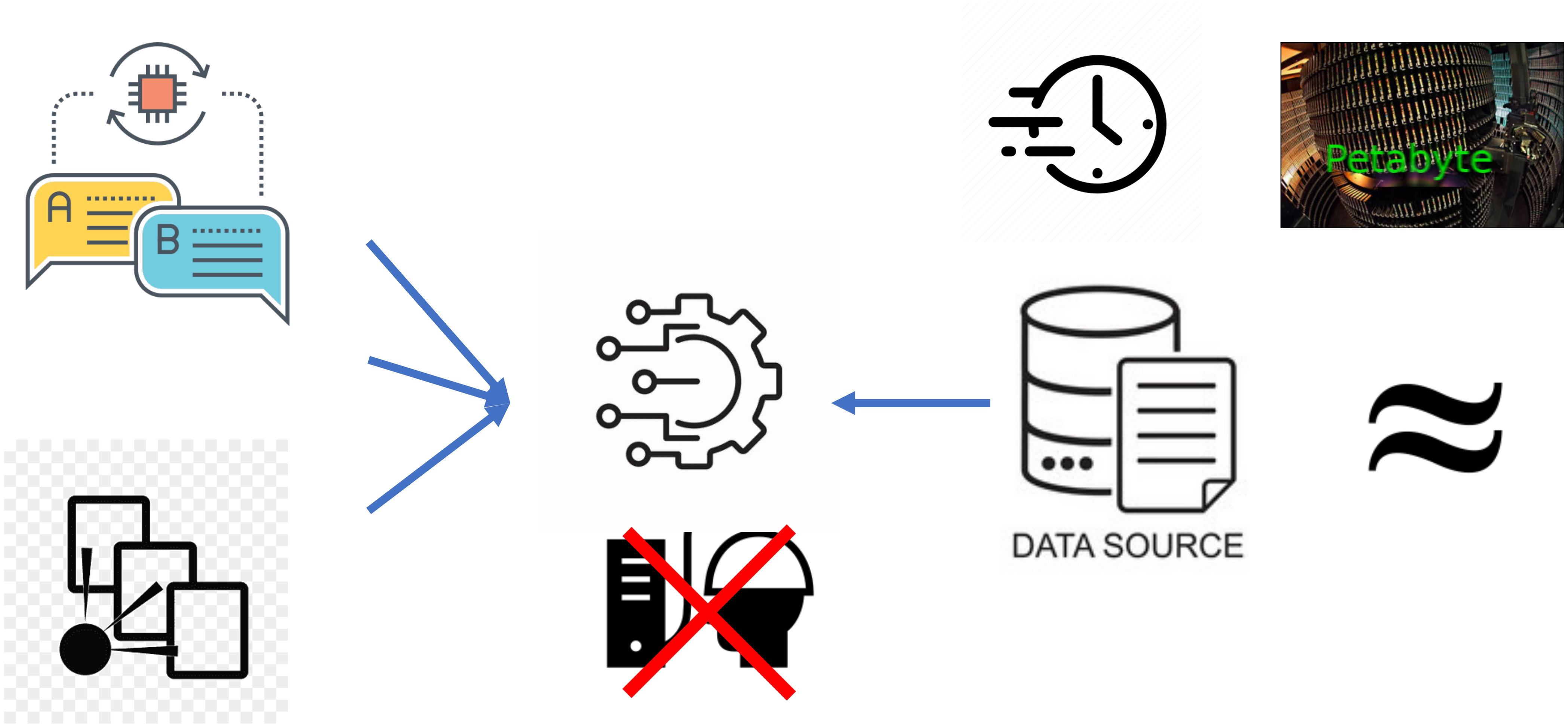
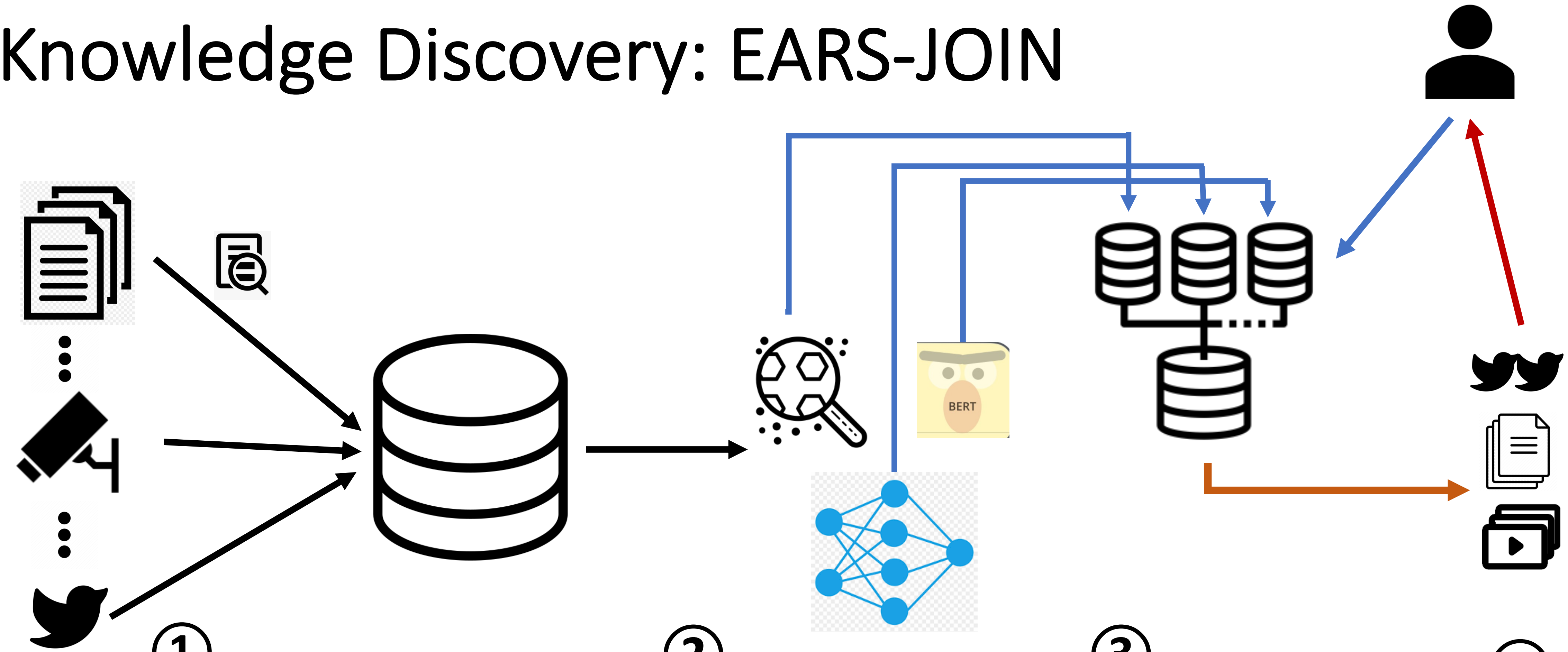


# Challenge 2: Label Independent Data Integration



# Knowledge Discovery: EARS-JOIN



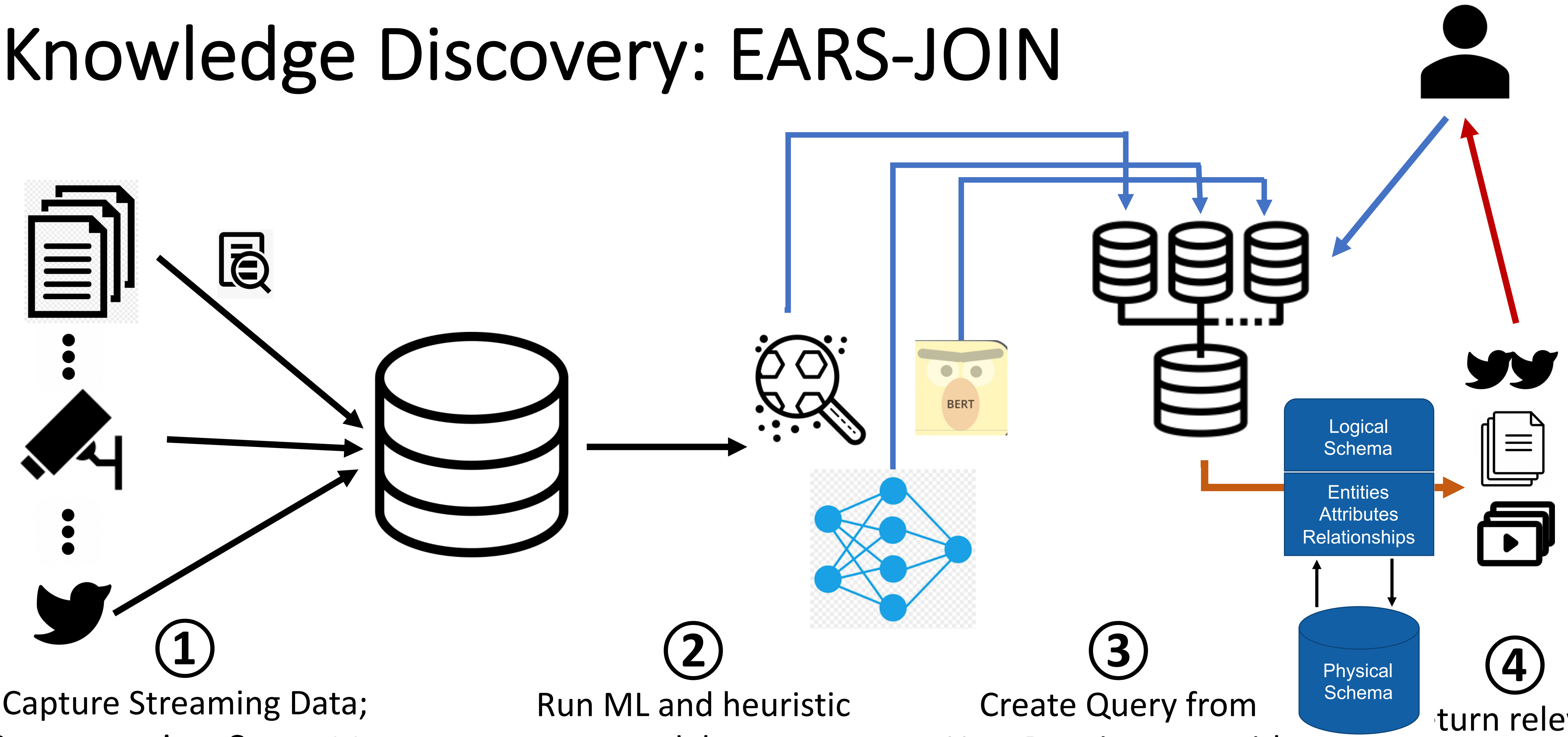

①
Capture Streaming Data; Pre-processing; Convert to MP4, txt; Store in Postgres
**(Data Capture and Data Storage)**

②
Run ML and heuristic models on video, text and tweets
**(Feature Identification)**

③
Create Query from User Requirement with DDL and return JOIN results w/ Predicate Matching
**(Data Fusion)**

④
Return relevant results to user's examples
**(Data Retrieval)**

# Knowledge Discovery: EARS-JOIN

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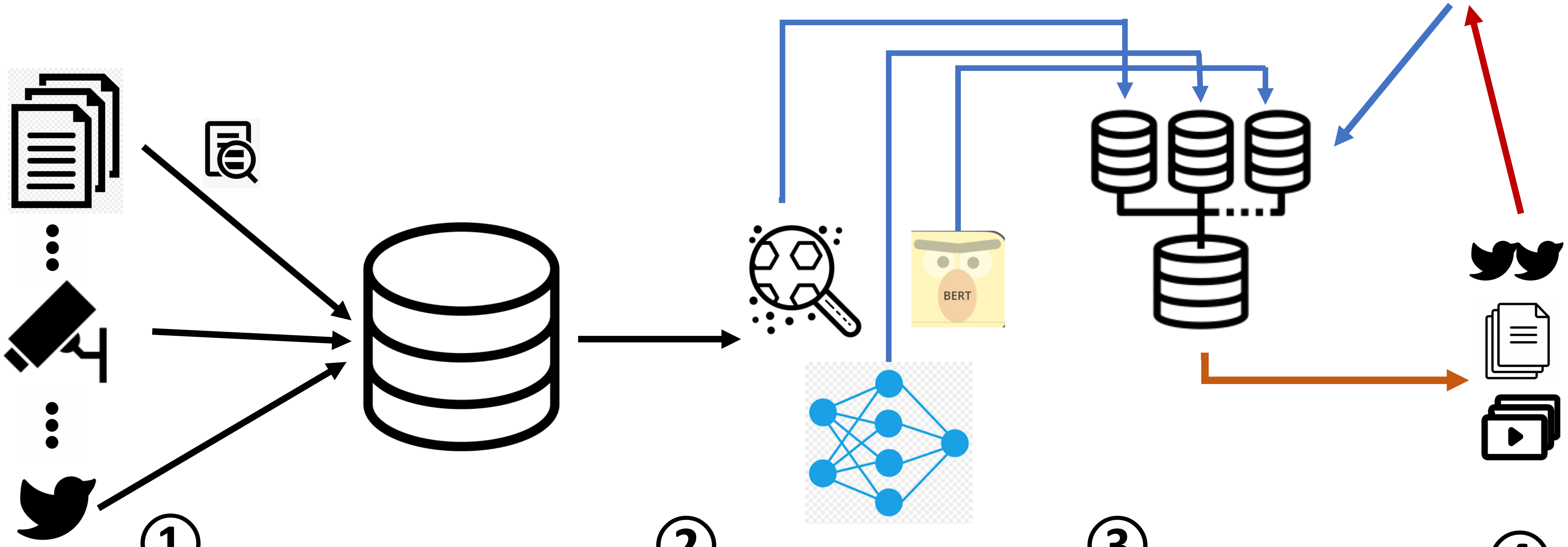
# Knowledge Discovery: EARS-JOIN

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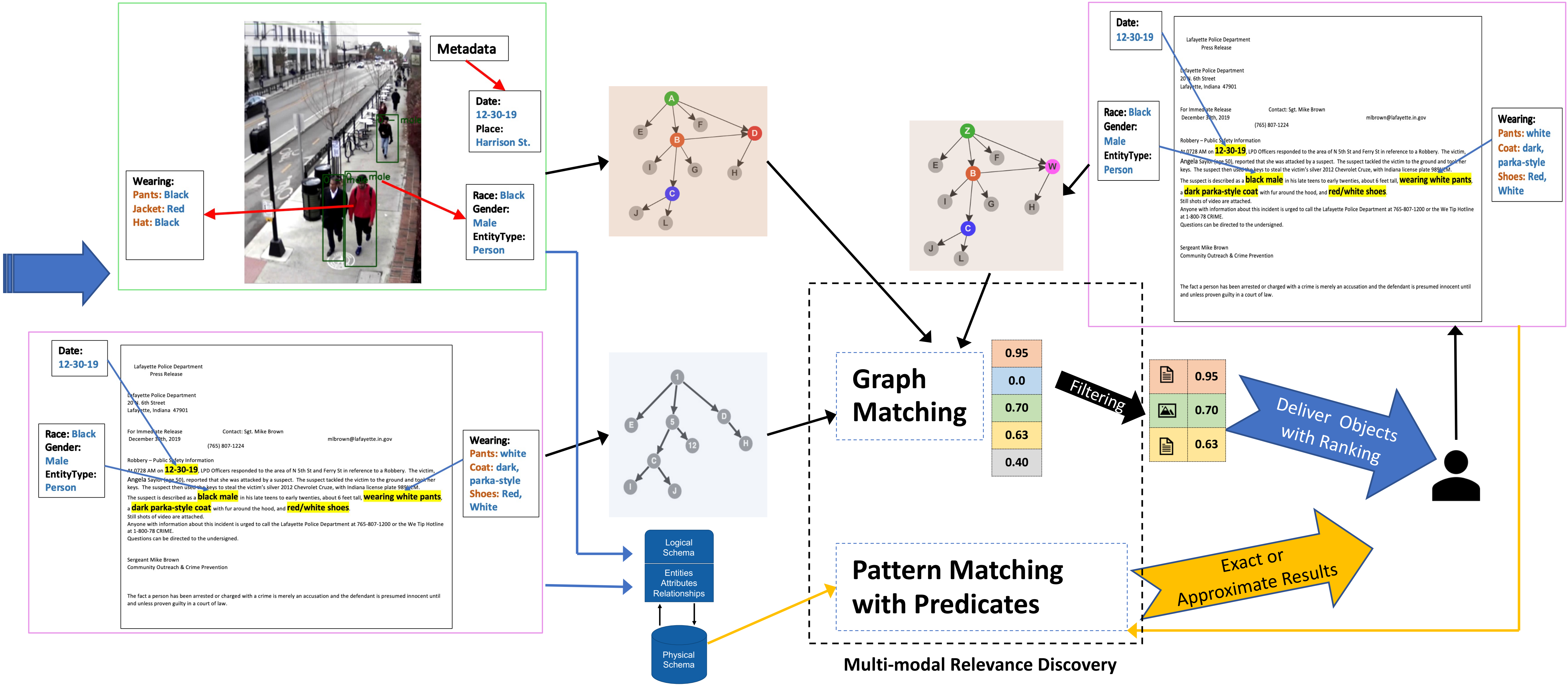
③ Create Query from User Requirement with DDL and return JOIN results w/ Predicate Matching **(Data Fusion)**

④ Return relevant results to user's examples **(Data Retrieval)**

# FemmIR – graph matching for data fusion

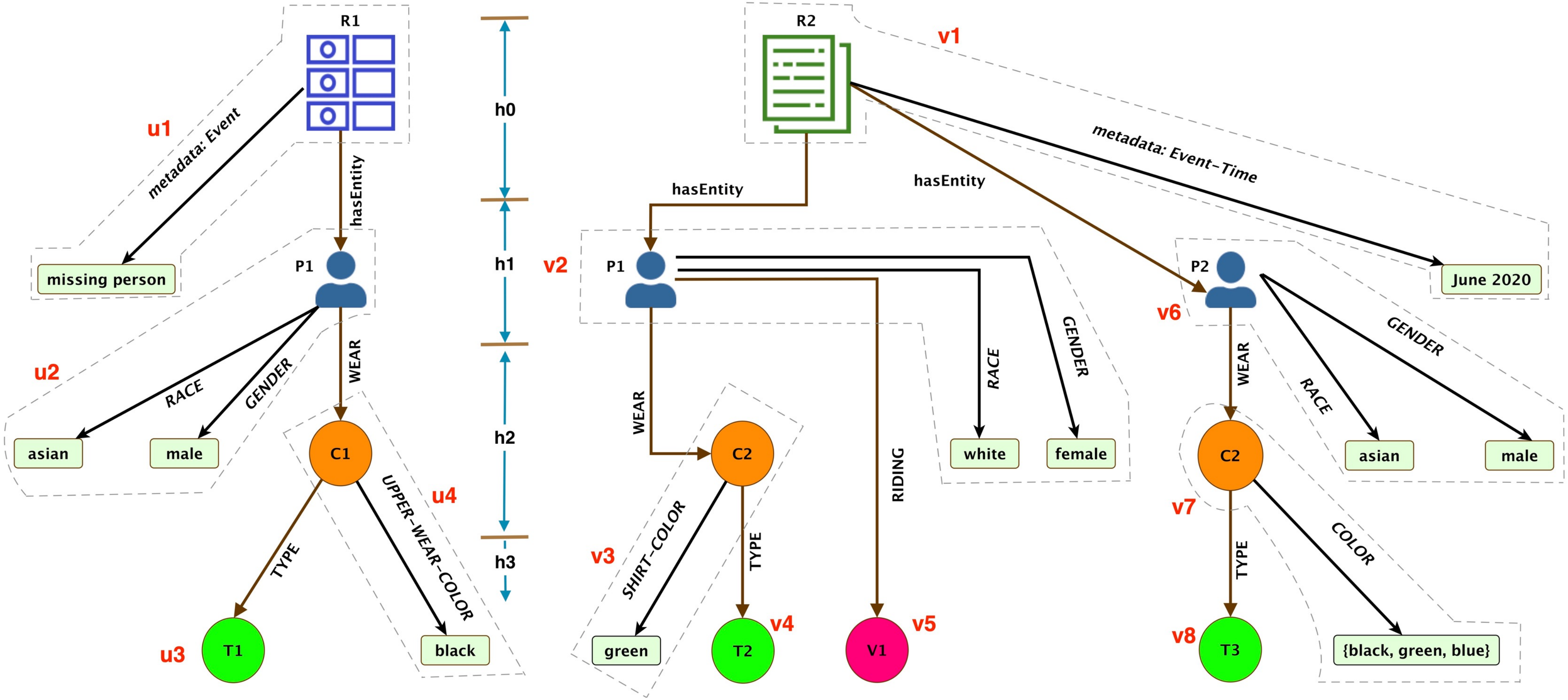
- With EARS, we extract data samples that are exactly matching with the given query features $F_2, F_6, F_i$
- *RQ1:* Some use cases require
  - Approximate matching, or
  - ranking of matching data samples
- *RQ2:* As we have seen in EARS, different data sources store features with different schema, and we would want to avoid manual schema mapping for each new data source
- FemmIR solves RQ1 by returning a ranking of the in-store data samples and by producing a similarity score for the streaming data samples with the query example
- FemmIR solves RQ2 by creating a graph representation for each data sample and encoding the graphs with graph convolution network (GCN)
  - GCN is representation-invariant

# Relevance Modeling and Data Fusion

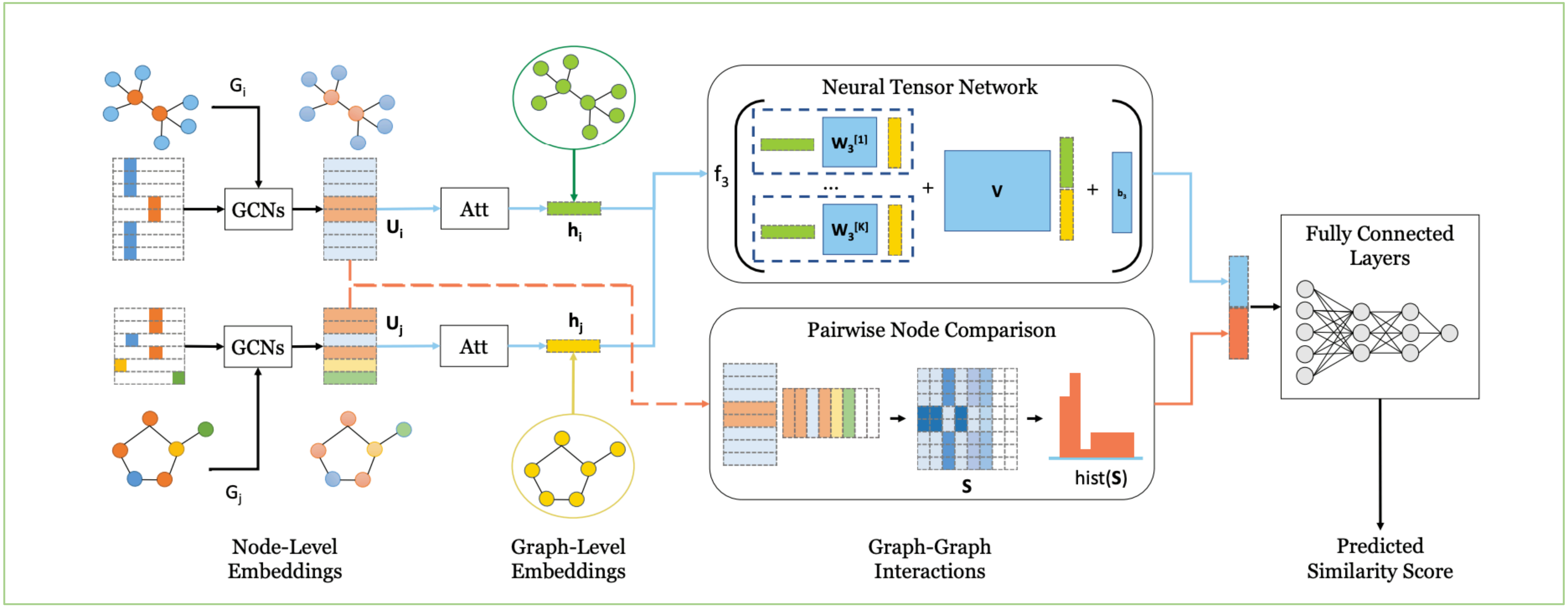


# Feature-centric Multimodal Information Retrieval (FemmIR): Graph Matching

- HARG
- Cost Matrix
- **Cumulative -Munkres**
- Content Edit Distance

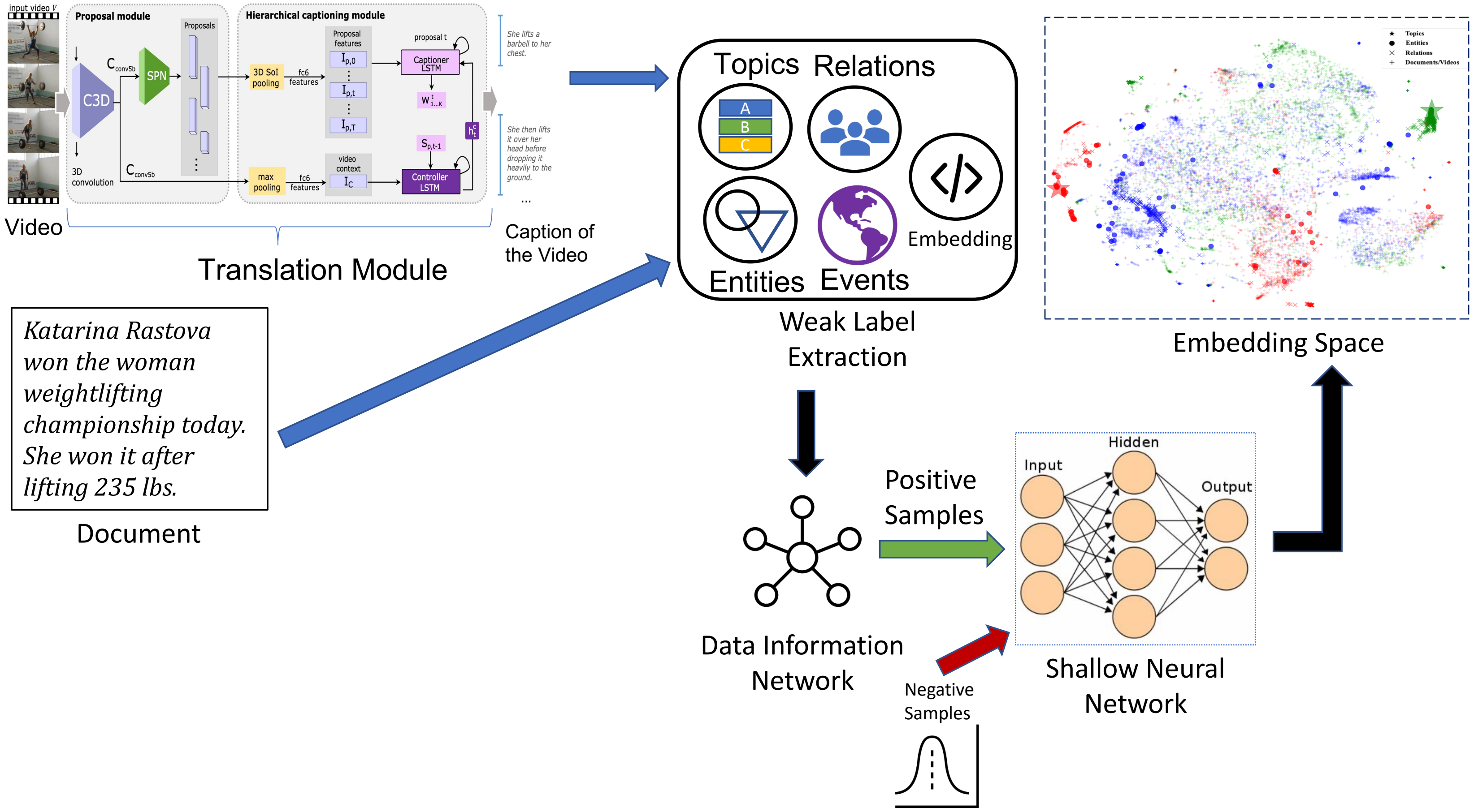


# SimGNN: A Neural Network Approach to Fast Graph Similarity Computation [6]

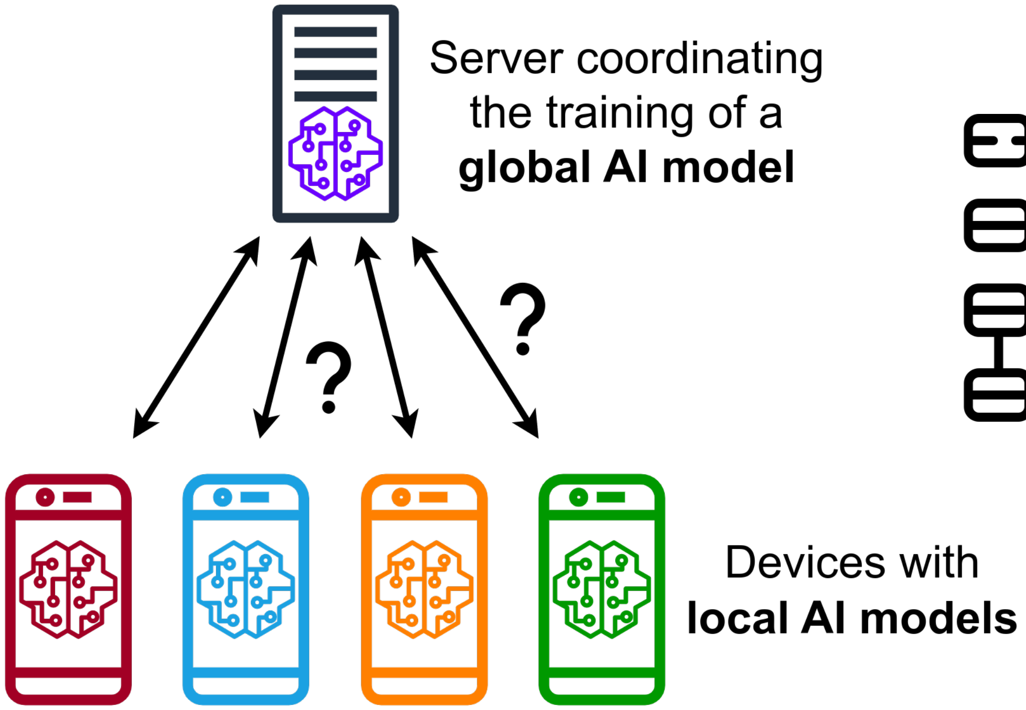


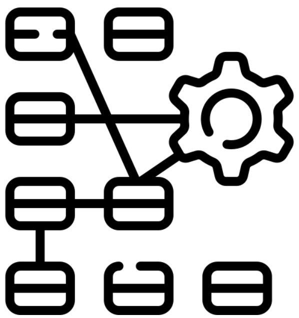
# Weakly Supervised Learning (WesJeM)

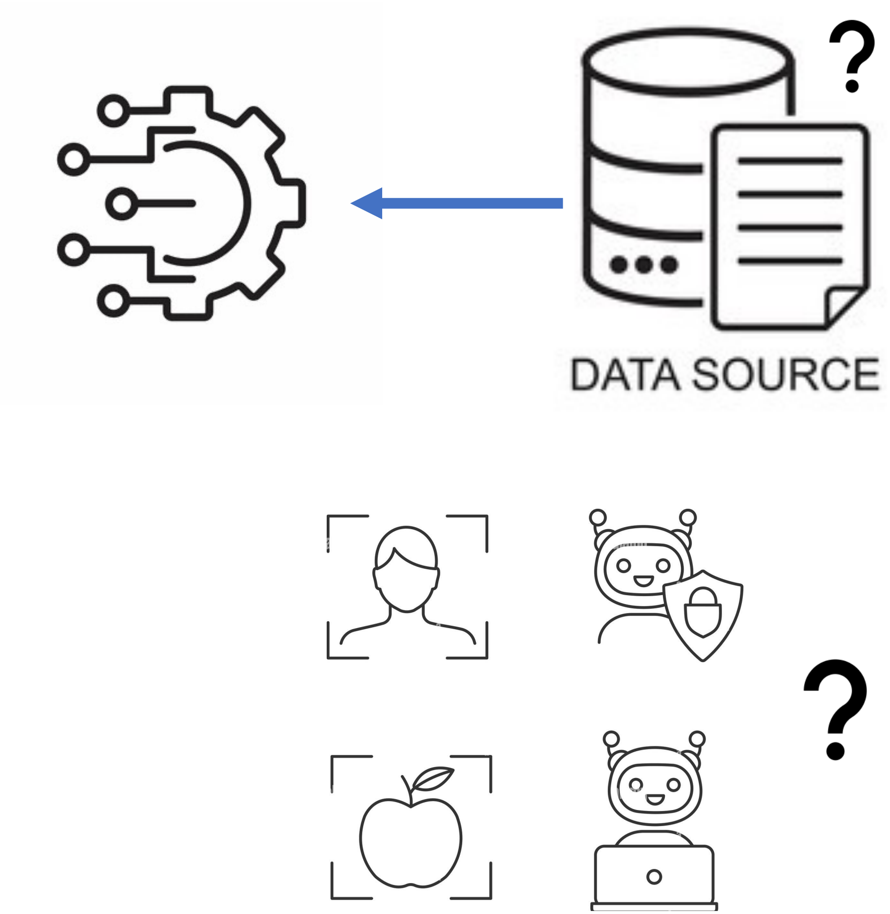
- translation to a textual representation
- weak feature labels extraction
- Data information network
- Connect data samples to features via interactions
- Contrastive Learning, by jointly embedding in a single space



# Challenge 3: Adaption to Open-world Novelties



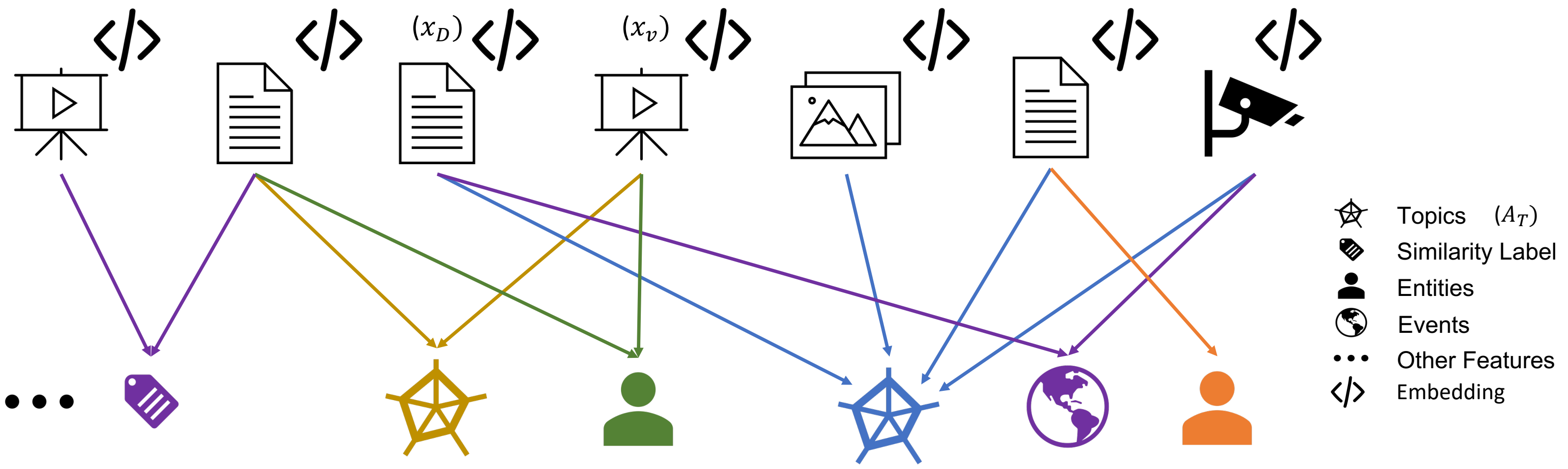


# Novelty Characterization in MMIR

- Covariate shift with change in application domain with the modalities for which translation module is available (covar-1).
- Prior probability shift with novel weak features (prior-1).
- Prior probability shift with no weak features (prior-2).
- Prior probability shift with novel relevance label (prior-3).
- Temporal concept drift with previously relevant data being non-relevant (concept-1).
- Covariate shift with new modality introduction (covar-2).

# Novelty detection in WesJeM

- ***Data information network*** is used to detect the changes during post-novelty inference.
- **Novel Instance.**
  - A test instance $x$ is novel if $G(V_{P_{tr+x}}, E)$ is different from $G\left(V_{P_{tr}}, E\right)$.
  - Considering a knowledge base for the weak features during training ($A_{tr}$), if weak features are absent in $A_{tr}$ during testing, the instance is novel.



# Domain Complexity Estimation for Distributed AI Systems in Open-World Perception Domain

- Dimensionality
  - Environment Complexity
  - ID
- Sparsity
- Heterogeneity

Domain Complexity Estimation

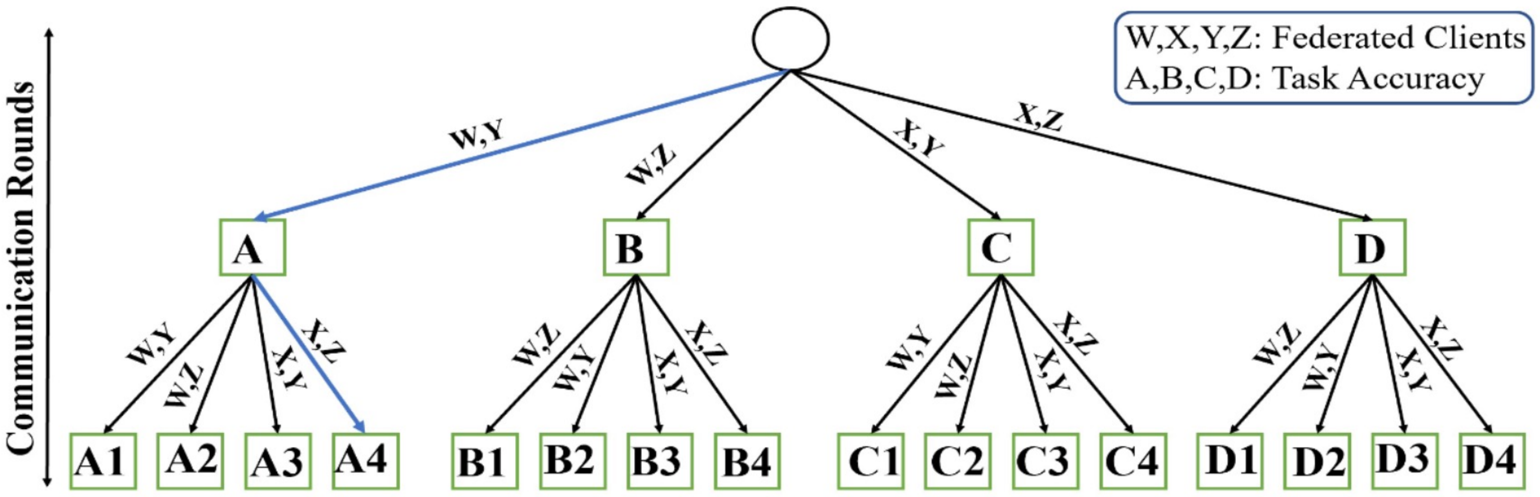
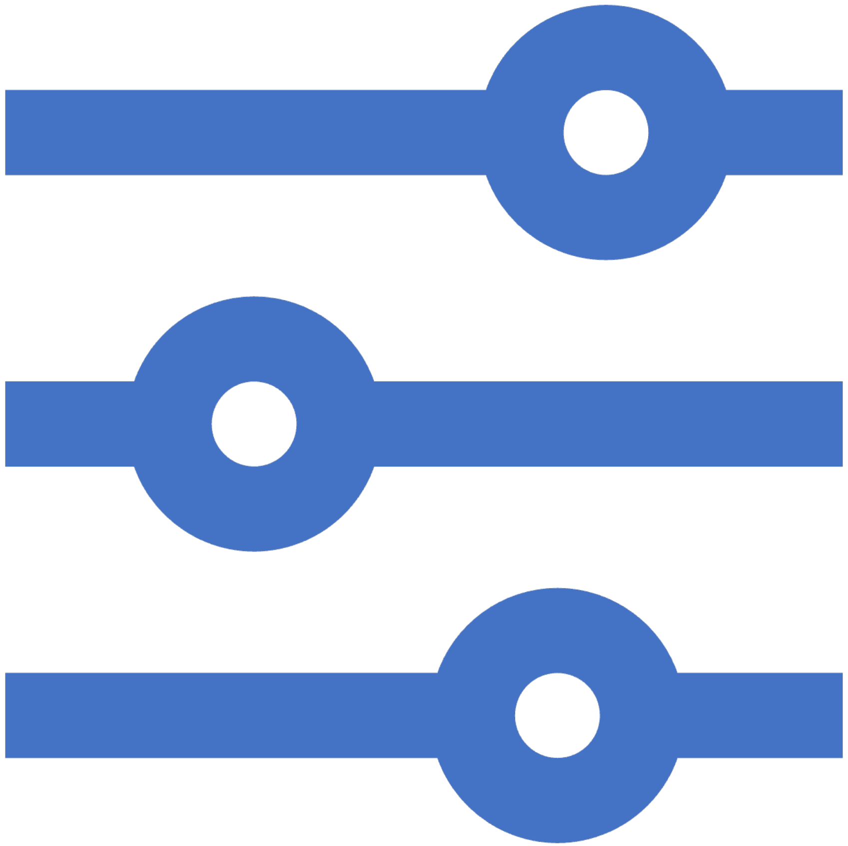



Figure 1: Federated Learning Tree

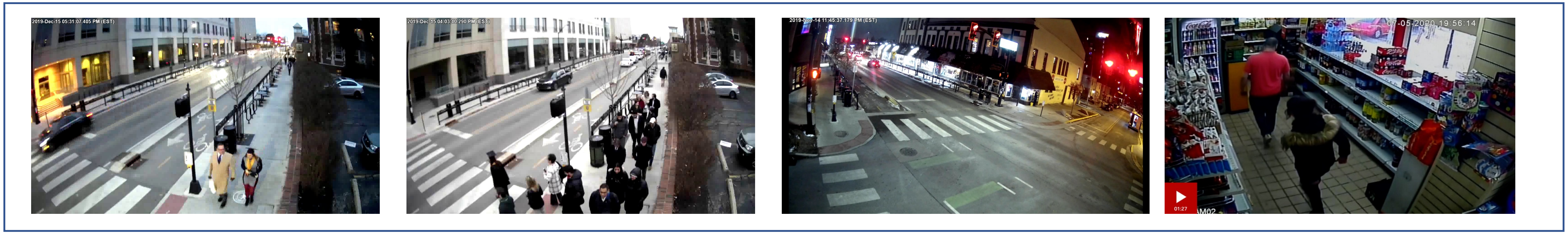
$$F(d, X) = \beta(\sqrt{x_1^2 + x_2^2 + \ldots. + x_n^2}) + (\frac{1}{m_1} + \frac{1}{m_2} + \ldots\ldots + \frac{1}{m_d})$$

# Applications



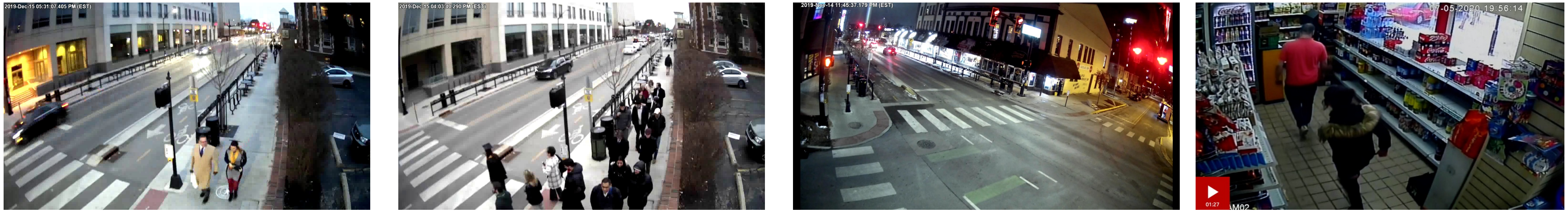
# Difficulty of Investigative Process

- Going through countless video feeds



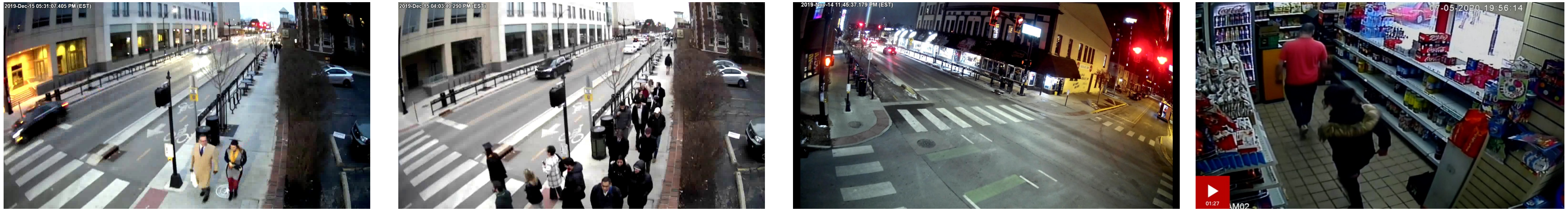
# Difficulty of Investigative Process

- Going through countless video feeds
- Human efforts for finding similar M.O.

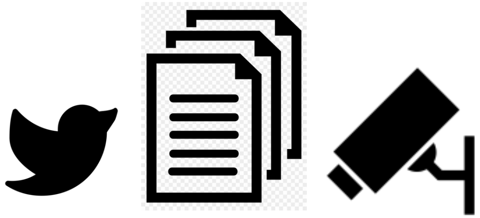


# Difficulty of Investigative Process

- Going through countless video feeds
- Human efforts for finding similar M.O.
- Finding same features throughout heterogenous sources



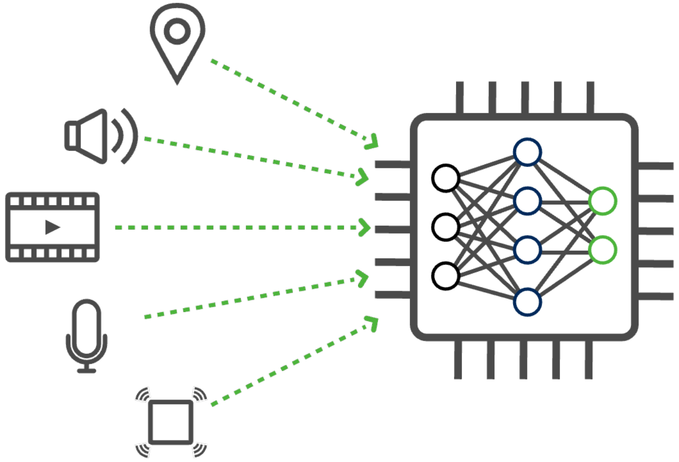
# Find-Them's Goals



Data Fusion

Automated Investigation

Diffusing Situation (w/ Mental Issues)



Feature Integration from Heterogeneous Sources

# Demo for Locating Missing Person


EXAMPLE APPLICATION DOMAIN: POLICE INVESTIGATION SYSTEM

# Similar System in Practice

- https://www.fbi.gov/services/cjis/ndex
- Unclassified national information sharing system that enables criminal justice agencies to search, link, analyze, and share local, state, tribal, and federal records.
- Strategic investigative information sharing system that fills informational gaps and provides situational awareness.
- **Analysts: Connecting the Dots**
- **Detectives: Linking Investigations**
- **Patrol Officers: Preparing for Encounters**
- **Regional Dispatchers: Increasing Officer Safety**

- incident, arrest, and booking reports; pretrial investigations; supervised released reports; calls for service; photos; and field contact/identification records.

# Use cases

- Feature analysis of heterogeneous data for personalized events.
- Fixed queries on data streams.

## Event dispatch

- Triggers an event when certain conditions are met.
- Tweet contains certain words and geolocation.
- Alert and dispatch the correspondent procedures/units

## Fixed queries

- Fixed queries on top of data streams.
- Cache queries and patterns in Query Engine.
- Aggregated query results from heterogeneous sources.

NORTHROP GRUMMAN

Accurate data, at the right place, and the right time.

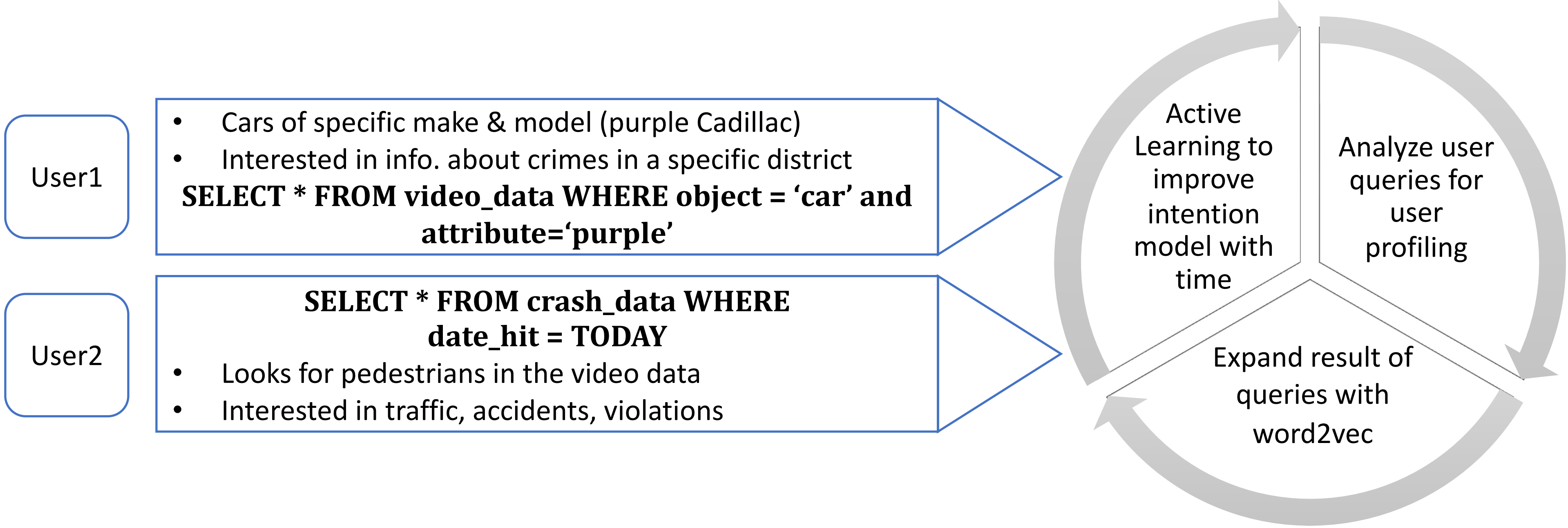
Complete data without noise

# Future Research Directions

# User Preference Modeling

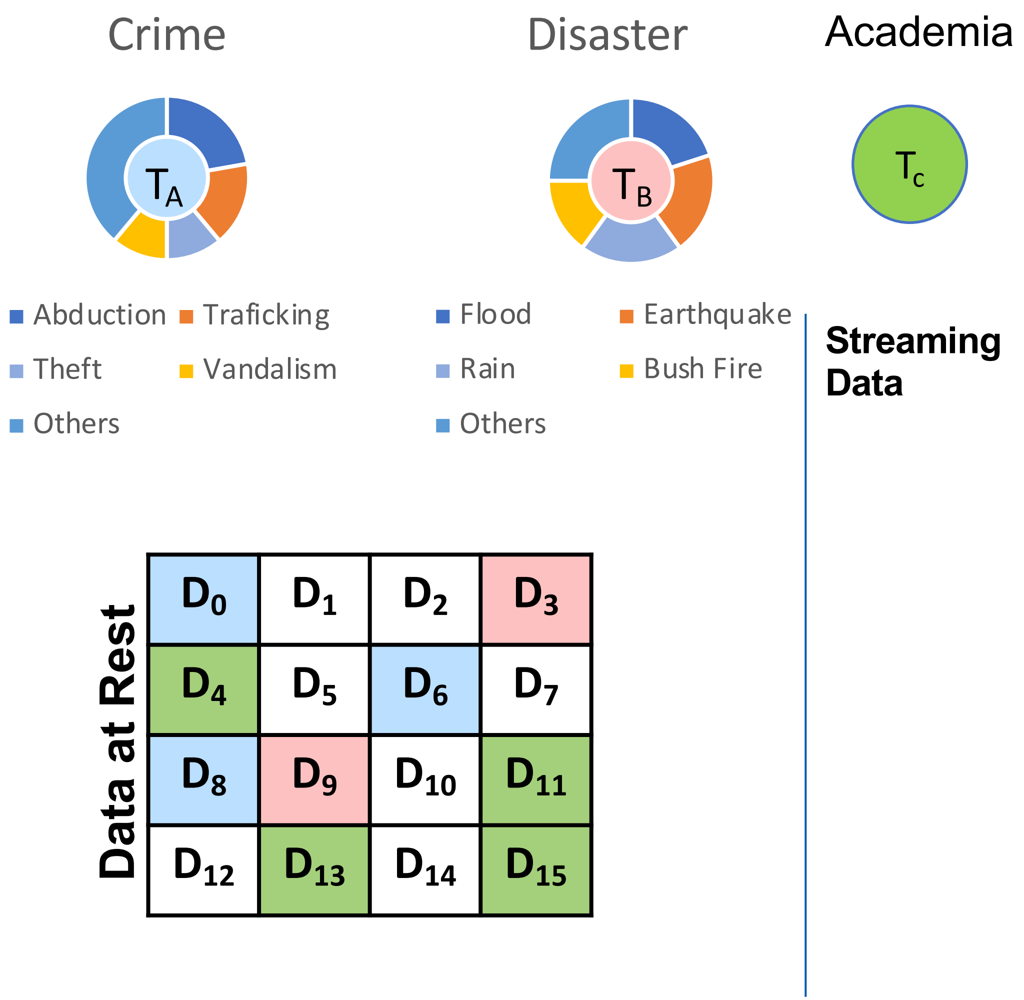
# User Modeling: Intention-aware Recommendation Engine

- Sends users streaming data that corresponds to their interests
- Builds User Profiles using the history of user queries
- Active Learning to narrow/expand intention model with more interaction
- Expands user queries with word embedding models to fetch relevant data from the database



# Multiple Data of Interest to Same User

- Extract **human-interpretable topics** from a data corpus
- Each topic characterized by features most strongly associated with
- Data as mixtures of topics that spit out features with certain probabilities.
- **No need to re-train**



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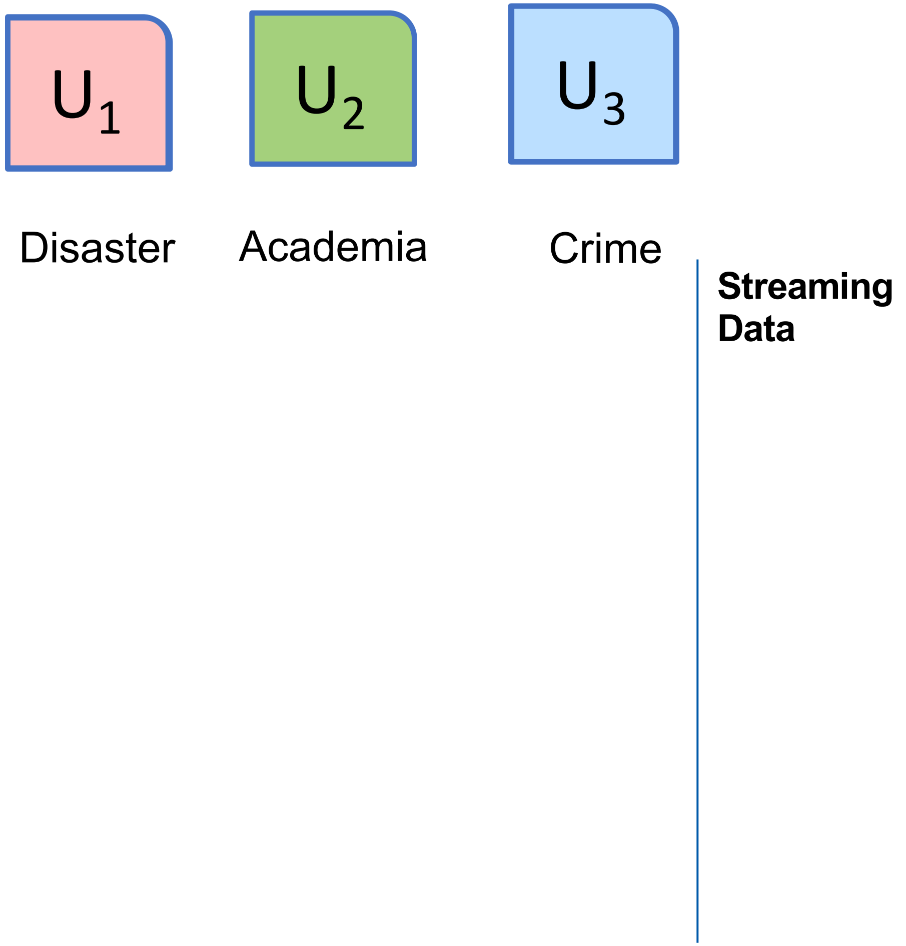

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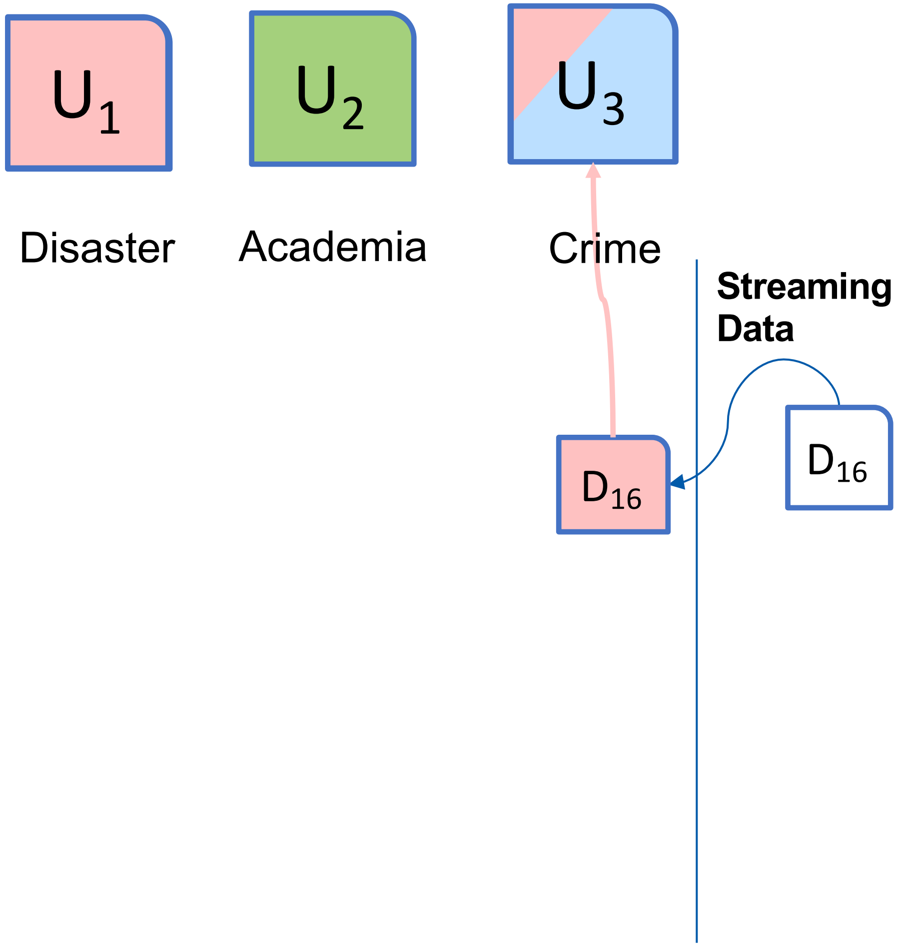

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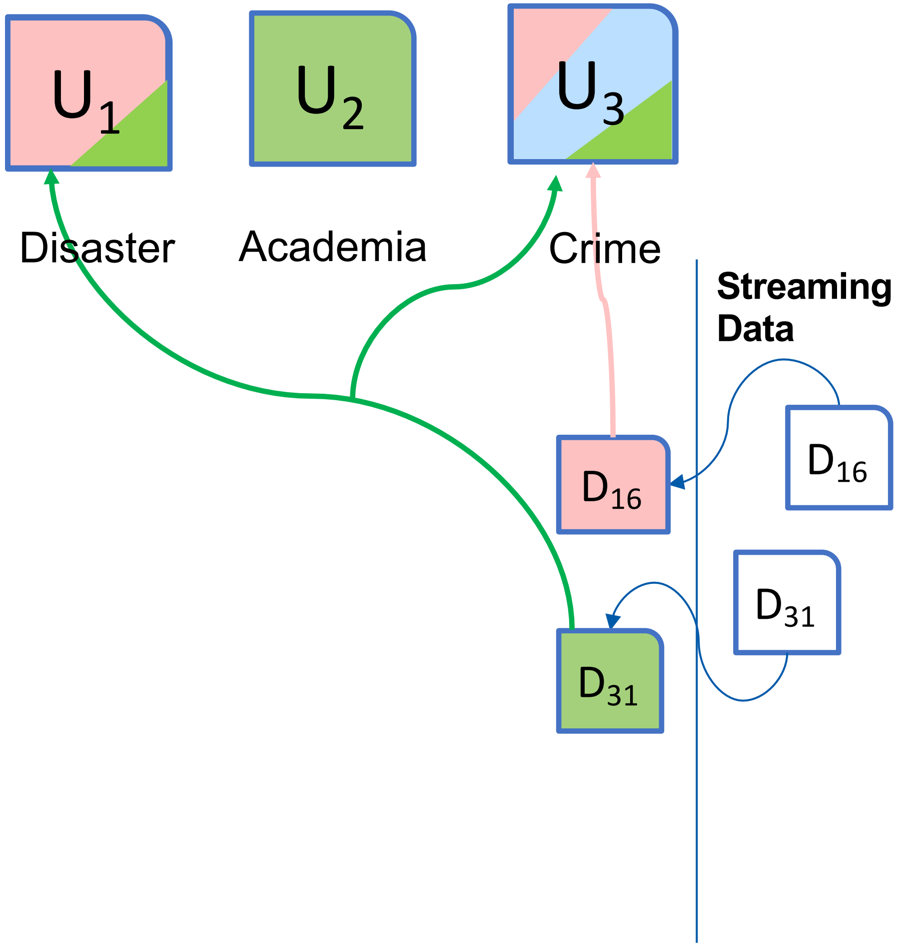
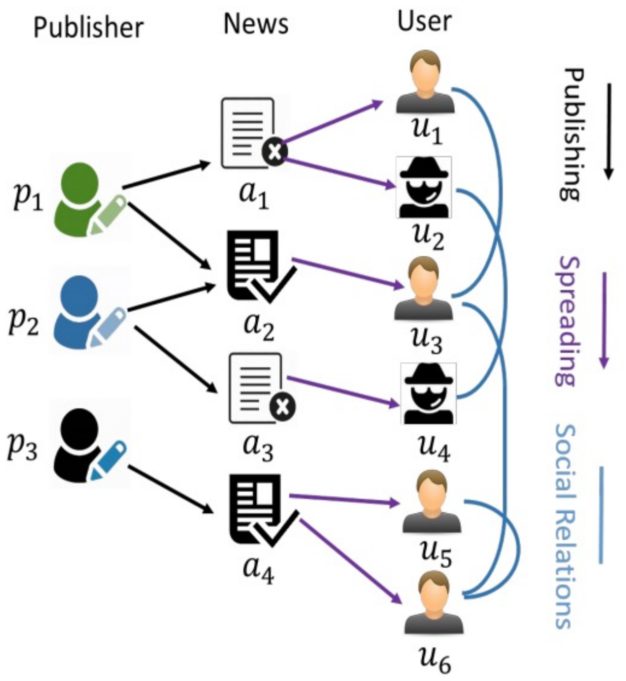


# *Explainability and Trustworthiness in Data Recommendation*

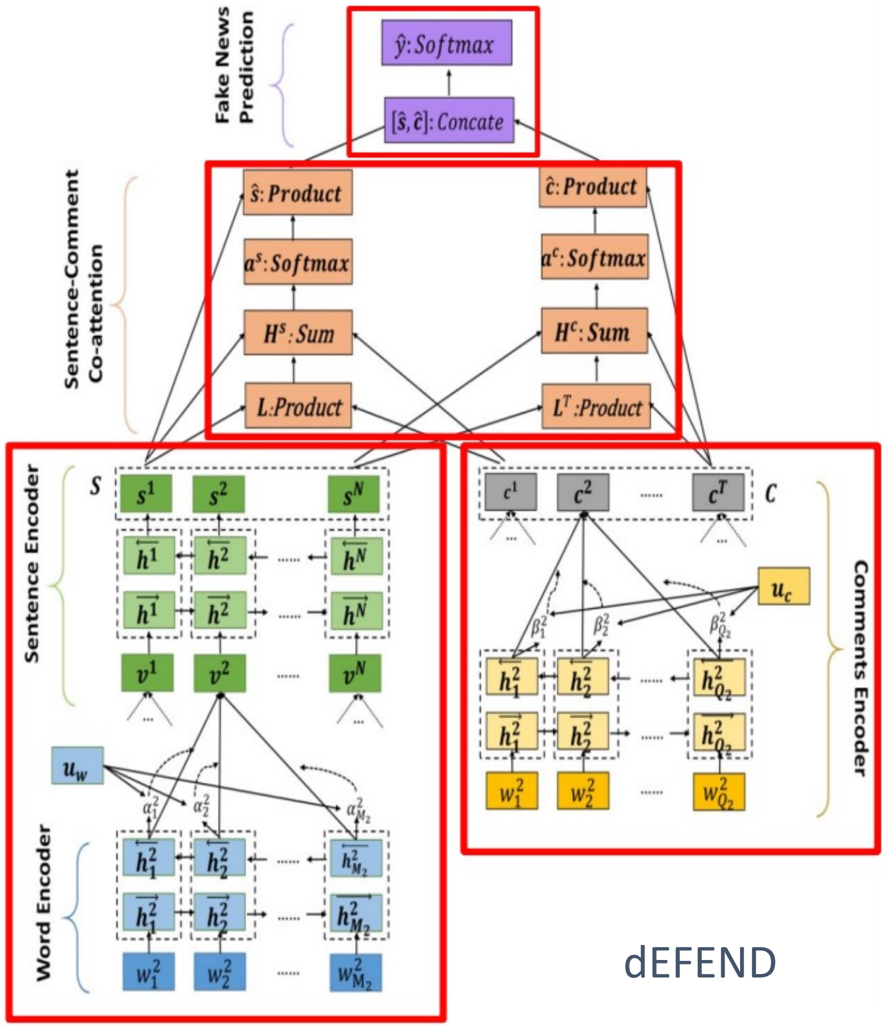
# Cross check integrity and credibility of multimodal data

- Detecting fake police leads/ tweets/ [report/ tip news articles] and explaining why it is detected as fake
  - Provide insights and knowledge to domain experts
  - Explainable features from noisy auxiliary information can further help detection performance

- Social context provides rich auxiliary information beyond news content [Tweets and Reports]
  - Goal: learn representations from the heterogeneous network
  - Jointly embedding reports/ news articles and social context
- Information from different modality can help to explain and detect authenticity of another [WeTip News and Tweets]
  - How to model content-content relations?
  - How to leverage authentic knowledge base structured information?



# Detection of information credibility with Explanation




dEFEND

- Learn representations for each modality of data
  - Different Attention Networks depending on the data type
- Select top explainable sentences and tweets through a co-attention network
- Detect fake leads with concatenated sentence and tweet representations as Classification task

Kai Shu, Limeng Cui, Suhang Wang, Dongwon Lee, and Huan Liu. ``dEFEND: Explainable Fake News Detection",   KDD 2019, August 4-8, 2019. Anchorage, Alaska.

# Long-term Plans

- *Privacy preserving Data Dissemination and Federated Learning*
- *Information Completion and Data Democratization*

# Potential Collaborations

| **Collaboration** | **Area** |
|---|---|
| Explanability and Trust | Multimodal information retrieval |
| Resource Management, Information Completeness | Disaster Resilience |
| Weak supervision, Credibility, User Modeling | Social media analysis and Big Data |
| Scalability and Unsupervised, **information credibility with explanation** | Situational Awareness |
| Adversarial robustness on artificial intelligence systems, optimization | Novelties in Learning Algo. |
| Pedagogy, Classroom Learning | Education and SoTL |

# CWU Research Program

- Collaborative Interdisciplinary Research
- Integrating Research with Coursework
  - thesis-based courses and project-based labs
  - early research training and offering students a taste of research, these courses will foster a collaborative spirit and enable students to publish papers and/or join my research team.
  - CS 420, CS 481, CS 489, CS 493, CS 498, CS 499
- Modular Research Approaches
  - realistic, short-term milestones and modular projects

# CWU Research Program

- Early Introduction to Research and Research Lab Design
  - Highline College Integration for 1st and 2nd years
  - 3rd and 4th years rotate for mentoring
- Inclusive and Supportive Environment
  - Growth focused
- Grant Writing and Project design
  - Clearly articulated and doable projects,
  - Clearly formulated hypothesis and research questions, and
  - a definitive plan for implementation and clear milestones.

DARPA
DEFENSE ADVANCED
RESEARCH PROJECTS AGENCY


Sandia
National
Laboratories

# Funding

# Grants and Proposals

- Vector DBMS proposal for NSF-planning
- DARPA ITM
  - to support building, evaluating, and fielding algorithmic decision-makers that can assume human-off-the-loop decision-making responsibilities in difficult domains, such as medical triage in combat.
  - Difficult domains are those where trusted decision-makers disagree; no right answer exists; and uncertainty, time-pressure, resource limitations, and conflicting values create significant decision-making challenges.
  - Other examples of difficult domains include first response and disaster relief
- DARPA TRIAGE
- Sandia - critical mission planning

# Past Collaborations

- Various interdisciplinary research centers and initiatives
  - Institute for Defense Analyses (IDA), Information Sciences Institute (ISI)
    → Novelties in Planning domain
  - MIT (Mike Stonebraker) and University of Michigan (Mike Cafarella)
    → Situational Knowledge on Demand

# Funding Opportunities

- NSF CAREER, CRII, EAGER, and ADVANCE awards, OSR young investigator programs from DOE, DARPA, AFRL, NASA, and other research awards.
- RUI and ROA for NSF proposals
- Private funding
  - Sigma Xi,
  - America’s seed fund,
  - American Summer/Short-Term Research Publication Grant, etc.

THANK YOU!

QUESTIONS?

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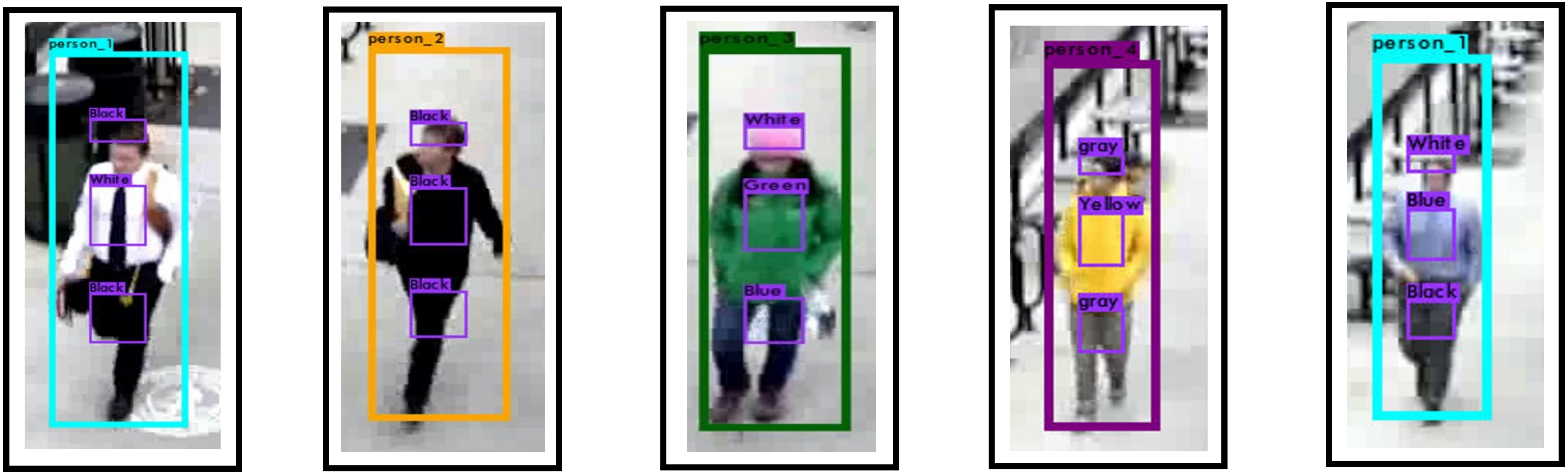
# Pedestrian color recognition in a single frame




- Sampling the pedestrian segmented body area
- Extracting the RGB value at every pixel
- Calculating the color distance to assign the pixel color
- Voting on the majority color of all the pixels to determine the color

Color distance ( △C) formula:

$$\bar{r} = \frac{C_{1,R} + C_{2,R}}{2}$$

$$\Delta C = \sqrt{\left(2 + \frac{\bar{r}}{256}\right) \times \Delta R^2 + 4 \times \Delta G^2 + \left(2 + \frac{255 - \bar{r}}{256}\right) \times \Delta B^2}$$

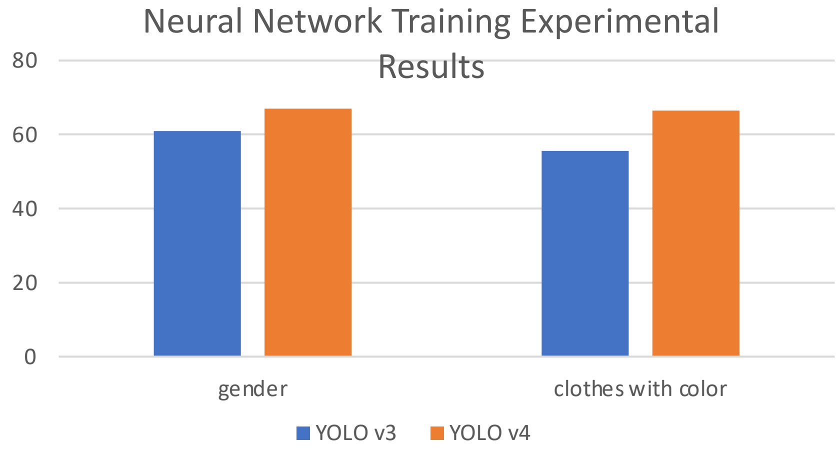
# Video Feature Extraction Evaluation

- Metrics used:

$$mAP = \frac{1}{|classes|} \sum_{c \in classes} \frac{\#TP(c)}{\#TP(c) + \#FP(c)}$$

**Mean Average Precision**

- Trained YOLO v3 and YOLO v4 on the 9400+ and 12200+ datasets with 6 classes to detect gender, clothes and color




- YOLO v4 with the largest dataset performed best

**Table 2: Performance Evaluation of persons in different colors from web images**

| Color | Precision | Recall | F1-Score |
|---|---|---|---|
| **Black** | 0.96 | 0.98 | 0.97 |
| **Purple** | 0.98 | 0.88 | 0.93 |
| **Red** | 0.92 | 0.92 | 0.92 |
| **Orange** | 0.96 | 0.88 | 0.92 |
| **Yellow** | 0.94 | 0.98 | 0.96 |
| **Green** | 1 | 0.92 | 0.96 |
| **Blue** | 0.96 | 0.96 | 0.96 |
| **White** | 0.91 | 0.96 | 0.93 |

- 8 color classes. Each class with 50 people
- precision and recall stats was calculated as 1 color vs other 7 colors

# Network Camera Information Analysis

- Pedestrian Attribute Recognition
  - Frames vs Videos
  - Different Strategies on Convolutional Neural Network

**Table 7: Comparisons of recognition accuracy and F1 measure on MARS datasets(%).**

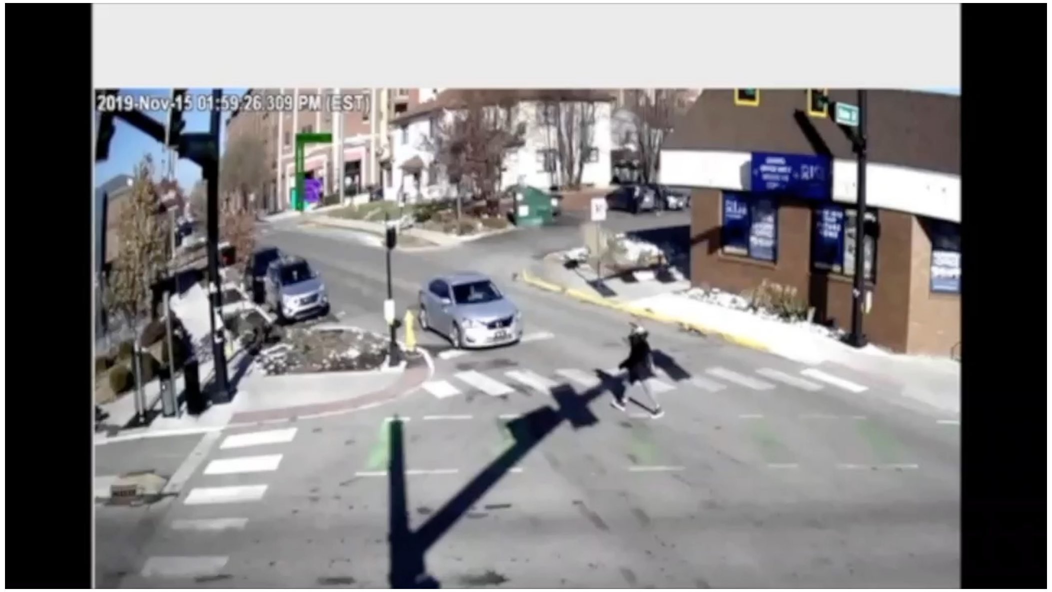
| Attribute | CNN (Resnet50)[6] | | 3D-CNN | | CNN-RNN | | Temporal Pooling[7] | | Temporal Attention[8] | | Color Sampling | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | acc | F1 | acc | F1 | acc | F1 | acc | F1 | acc | F1 | acc | F1 |
| top color | 75.22 | 73.98 | 67.91 | 65.19 | 70.54 | 67.33 | 74.98 | 73.13 | 76.05 | 74.64 | 44.65 | 38.31 |
| bottom color | 73.55 | 54.09 | 59.77 | 36.56 | 67.71 | 44.44 | 71.69 | 47.84 | 70.15 | 46.89 | 45.26 | 15.88 |
| gender | 90.01 | 89.71 | 86.49 | 76.22 | 90.07 | 89.62 | 91.04 | 90.63 | 91.82 | 91.48 | - | - |
| average | 79.59 | 72.59 | 67.97 | 59.18 | 76.11 | 67.13 | 79.24 | 70.53 | 79.34 | 71.01 | 44.96 | 27.10 |

# Pedestrian tracing in continuous frames

We can trace the walking trajectories of pedestrians by fusion the displacement and clothes color information

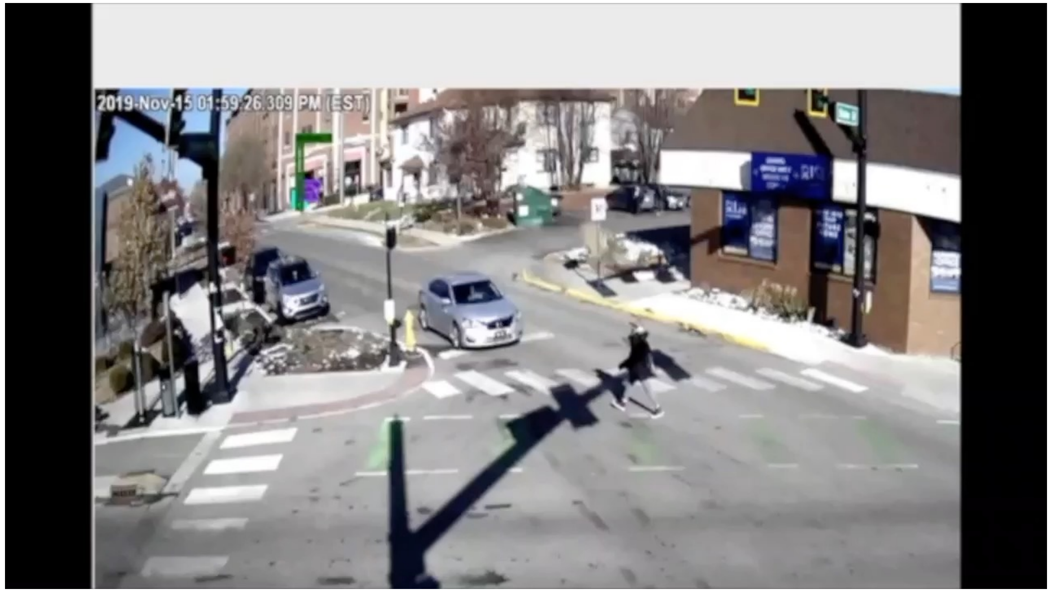
# Extracting relations between features, objects and entities
## Pedestrian tracing in continuous frames

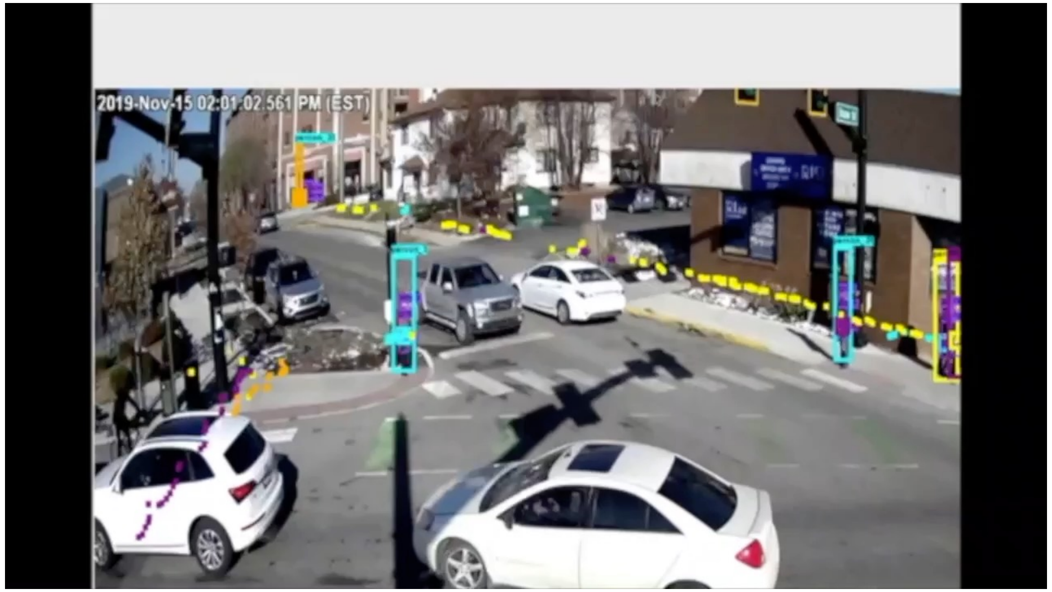
We can trace the walking trajectories of pedestrians by fusion the displacement and clothes color information



# Extracting relations between features, objects and entities
## Pedestrian tracing in continuous frames

We can trace the walking trajectories of pedestrians by fusion the displacement and clothes color information

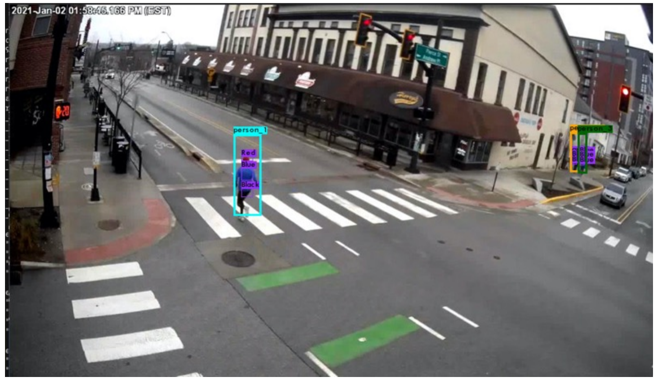


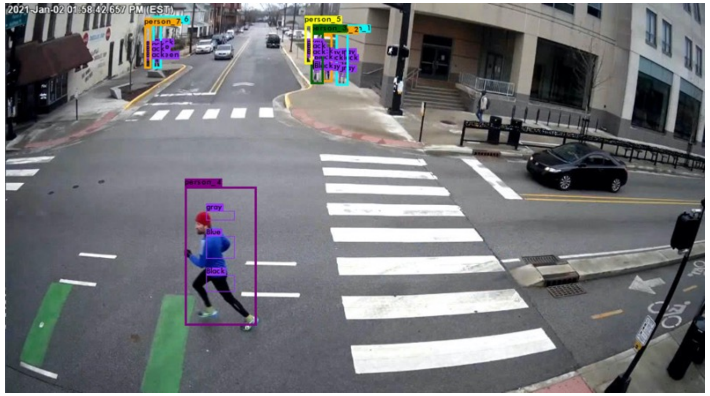
# Multi-camera Multi-locations

## We can trace the people from multiple cameras located at multiple locations

Camera 1 location A

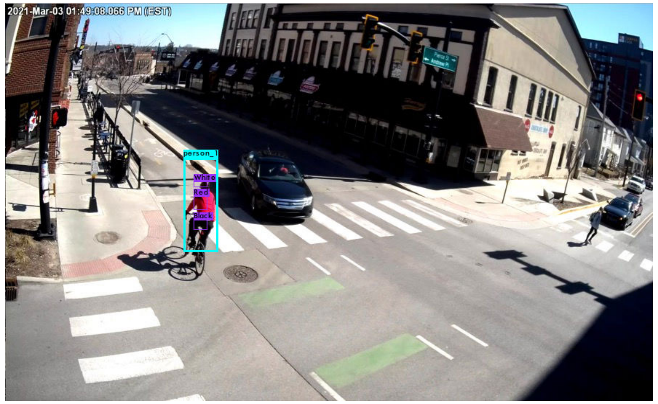


Camera 2 location A

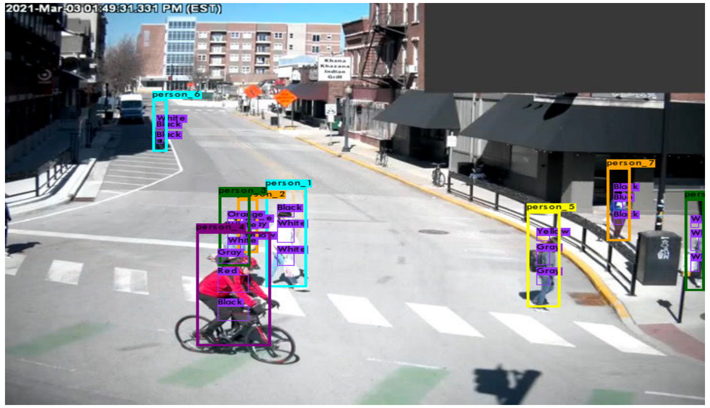


Camera 3 location A

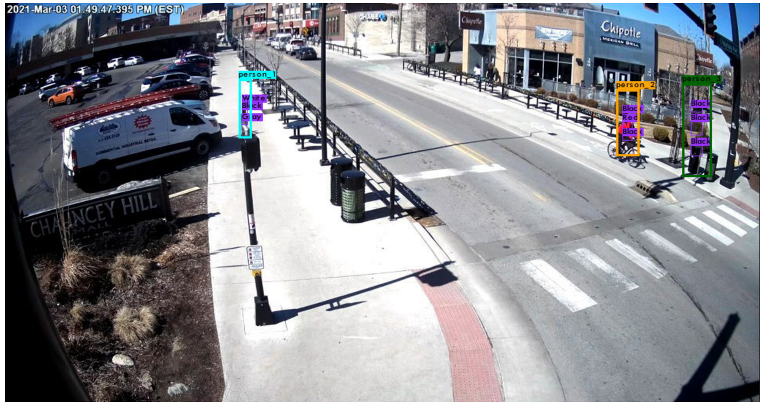
Camera 1 location B



Camera 2 location C



Camera 3 location D



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# Human pose detection

Pose detection allows the analysis on the people' behaviors across continuous frames

Walking pose tracing

Cycling pose tracing

# Weakly Supervised labels

- Representing data in terms of different structural features through which different modalities of data can be similar
- Structural representation of raw unstructured texts (with topics, entities, events, and relationships) allows readers to infer better knowledge
- Feature labels are generated automatically in two steps –
  - a textual description of each data sample is generated from any modality;
  - topics, entities, and events are extracted from the textual descriptions and are considered as weak labels for two reasons.
    - quality of the extracted structural units rely on the choice of the extraction models and can be noisy.
    - output generated from the modality specific textual descriptors can be ambiguous and noisy.

# Multi-task learning

- For each object, $o_i$ in the graph participating in relation $R$, $s_i^p$ and $s_i^n$ refers to positive and negative examples. $e_{o_i}$refers to the vector embedding of the graph object $o_i$ , and $y$ is the label.
- $y = 1$ for ($o_i$ , $s_i^p$ ) pairs and $y = 0$ for ($o_i$ , $s_i^n$ )

For each individual graph relation, R, we can define the learning objective as follows:

$$L_R = \sum_i L(o_i, s_i^p, s_i^n) \tag{1}$$

$$\begin{aligned} L(o_i, s_i^p, s_i^n) = \; & y \log sim(o_i, s_i^p)) + \\ & (1-y) \log(1 - sim(o_i, s_i^n))) \end{aligned} \tag{2}$$

where $sim(o_i, s_i^p) = \sigma(e_{o_i} \cdot e_{s_i^p})$;
$sim(o_i, s_i^n) = \sigma(e_{o_i} \cdot e_{s_i^n})$

# Learning objectives

- Features to Features $(A_T A_T\ / A_n A_n / A_{event} A_{event})$
  - Similar topics, named entities, or events with embedding value within a certain threshold, are placed together
- Data Sample to Data Sample $(x_D x_V\ / x_D x_D / x_V x_V)$
  - Positive pairs are selected by
    - Topics, Events and Entities, User Provided similarity labels, and Embedding
- Data Samples to Features $(x A_T\ / x A_{event} / x A_n)$
- Joint Object Function, $$L_{total} = \sum_{i \in O_s, O_s \subset O} \lambda_i L_i$$

  where $O$ is defined over all the objectives, weight $\lambda_i$ is set to 1.

# Reasoning Over the Data Information Network

$$Rel(a,b) = \frac{\sum_{i \in P(a,b)} w_i}{\sum_{b \in B} \sum_{i \in P(a,b)} w_i}$$

$$Rel(a,b) = sim(e_a, e_b)$$

$$Rel(f,b) = I * N_p(f,b)$$

- Weak Supervised Baseline
  - With the data information graph
  - #paths from one data sample to a given data sample or a given feature
  - counting the paths from one data sample to a given data sample or a given feature.

- *Similarity Based Score.*
  - Given a data sample, or a feature a and their embedding $e_a$ the relevance score with other data sample b with embedding $e_b$ is:

# Novelty Characterization

- Covariate shift with change in application domain with the modalities for which translation module is available (covar-1).
- Prior probability shift with novel weak features (prior-1).
- Prior probability shift with no weak features (prior-2).
- Prior probability shift with novel relevance label (prior-3).
- Temporal concept drift with previously relevant data being non-relevant (concept-1).
- Covariate shift with new modality introduction (covar-2).

# Novelty response

- pre-trained retrieval model from WeS-Jem
- three level training strategy
- With new modality introduction novelty, both image and LIDAR modality can be handled with the video translation module. Initial text embedding approaches can generate text embedding for any textual input for prior data shift.
- Linear embedding layers in WeS-JEm maps the OOD inputs into the pre-trained joint embedding space
- For (prior-2) novelty, when system relearns, only the (xx-embedding) objective functions remains active
- For novel modality introduction, a new translation method can be learned.
- User similarity labels provided by Relevance Feedback module have greater weights than old ones