Semantic Data Management

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Introduction and Motivation

VARIETY IN COMPLEX DATA ECOSYSTEMS

“WITHOUT DATA,
YOU’RE JUST
ANOTHER PERSON
WITH AN OPINION”

W. Edwards Deming, American Statistician

New Business Model: Instagram's Fable

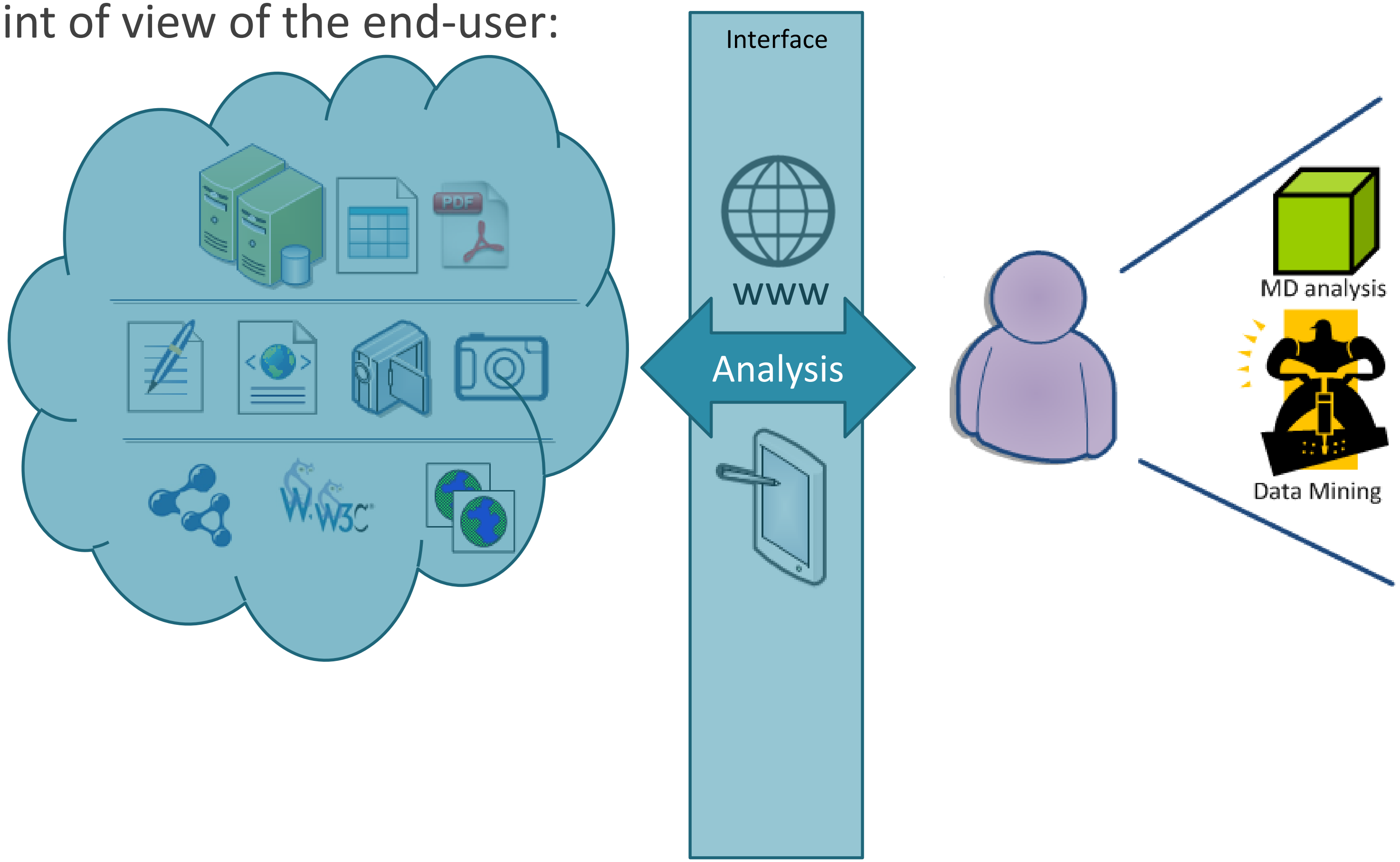
(xkcd.com)

Challenges of the Data-Driven Economy

FROM THE IT POINT OF VIEW

Data Analysis Democratisation

From the point of view of the end-user:



What is Big Data?

VOLUME

Veracity

Velocity

Value

vArIaBiLiTy

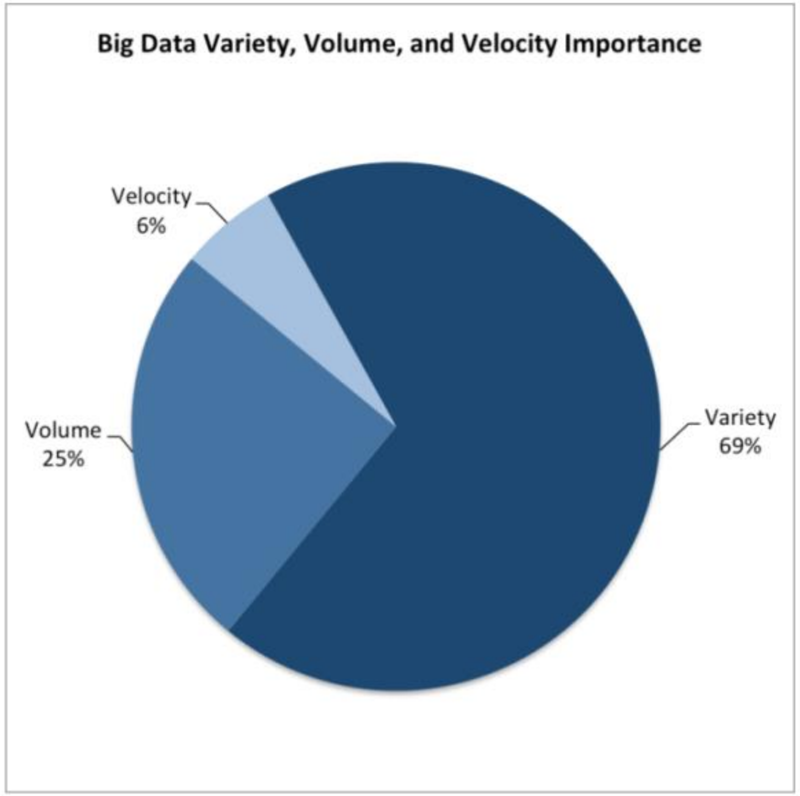
Variety

Today, the Focus is on Variety

That Big Data is synonymous with large volumes of data is a **myth**

"Rather, it is the ability to ***integrate*** *more sources of data than ever before — new data, old data, big data, small data, structured data, unstructured data, social media data, behavioral data, and legacy data"*

The Variety Challenge



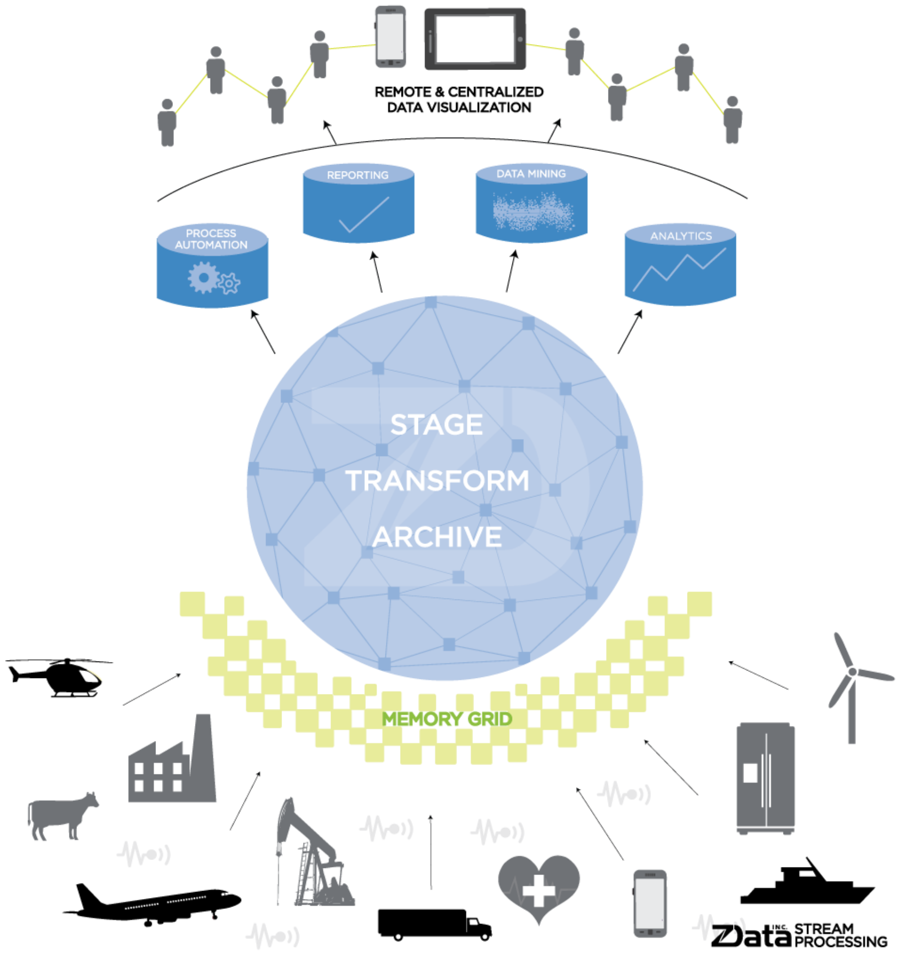
MIT Sloan Management Review (2016): http://sloanreview.mit.edu/article/variety-not-volume-is-driving-big-data-initiatives/

The Data Lake

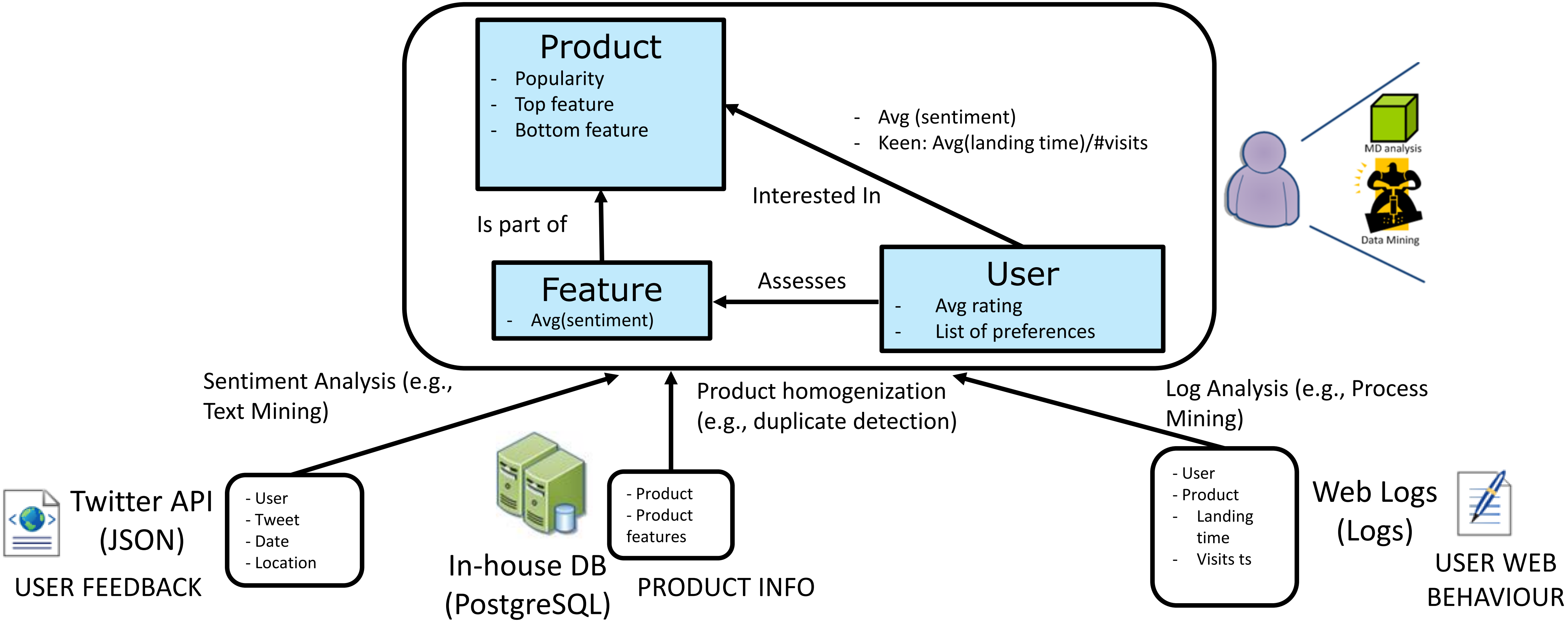
IDEA: Load-first, Model-Later

Modeling at load time restricts the potential analysis that can be done later (Big Analytics)

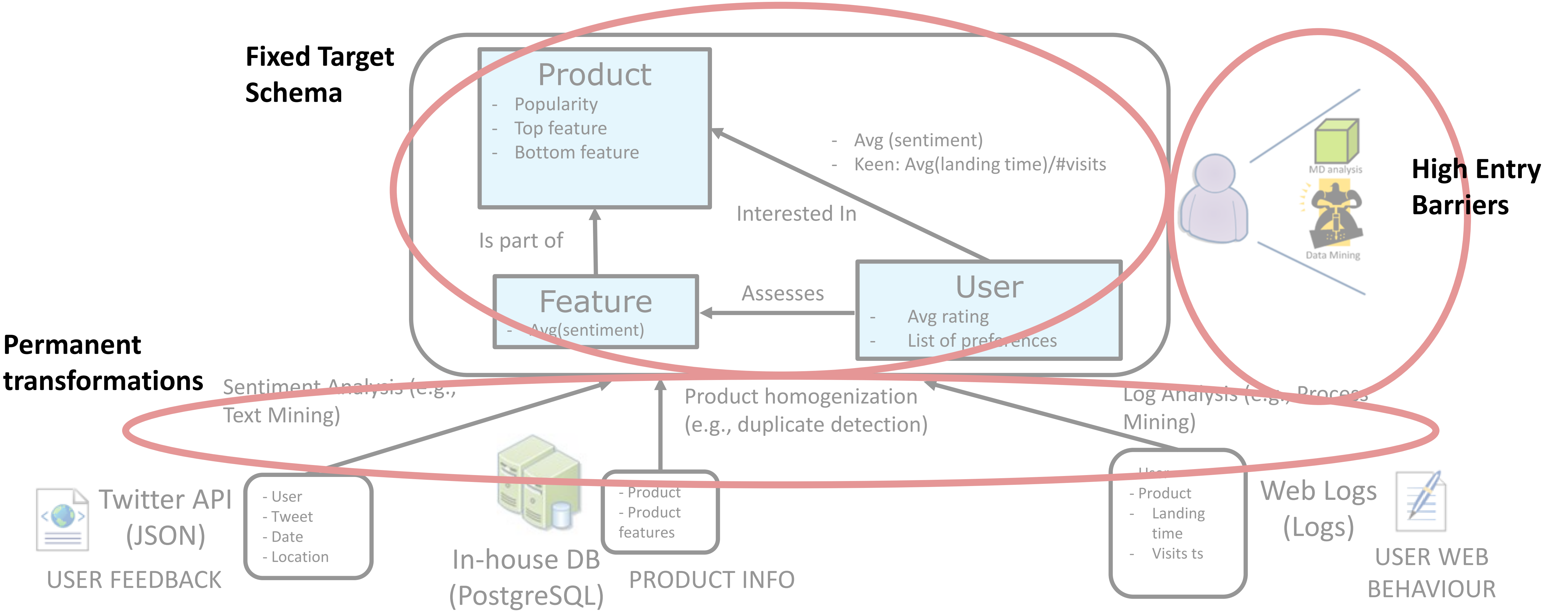
Store raw data and create on-demand views to handle with precise analysis needs



Model-First (Load-Later)

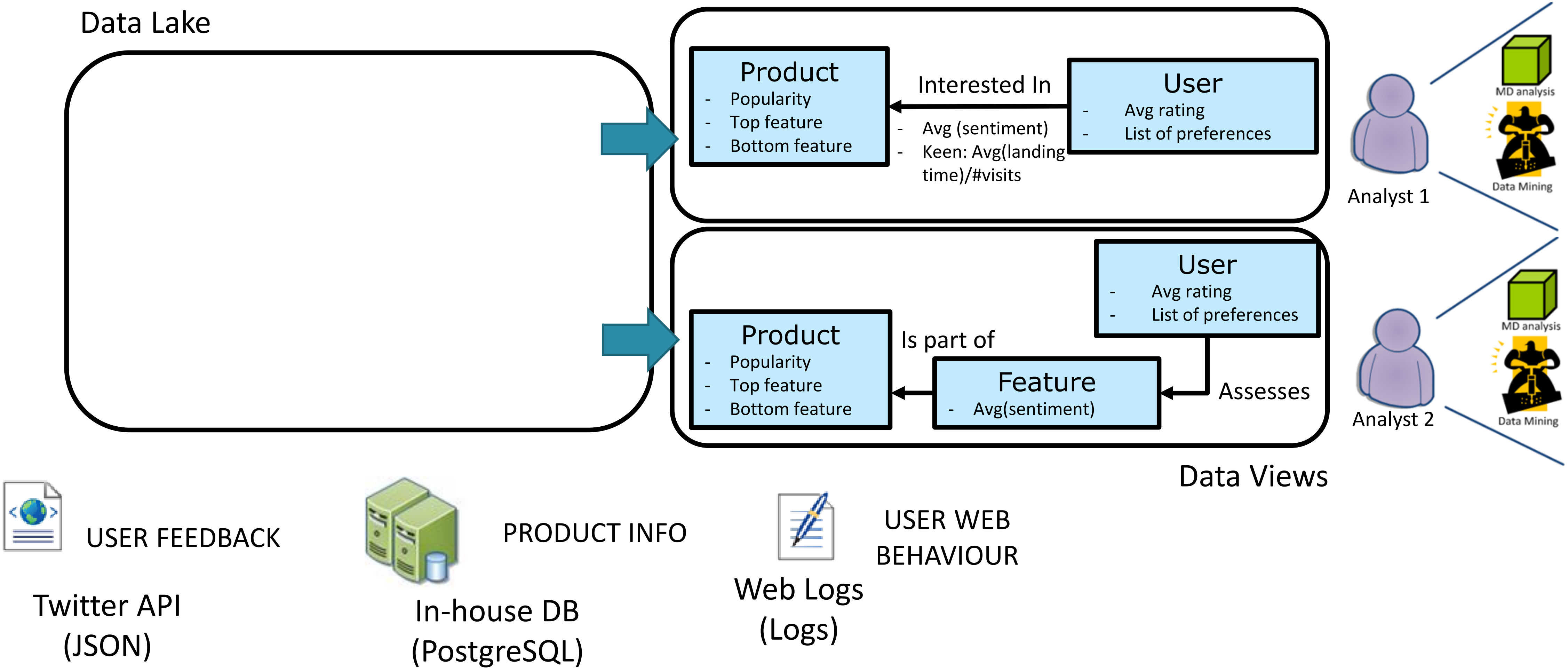


Drawbacks

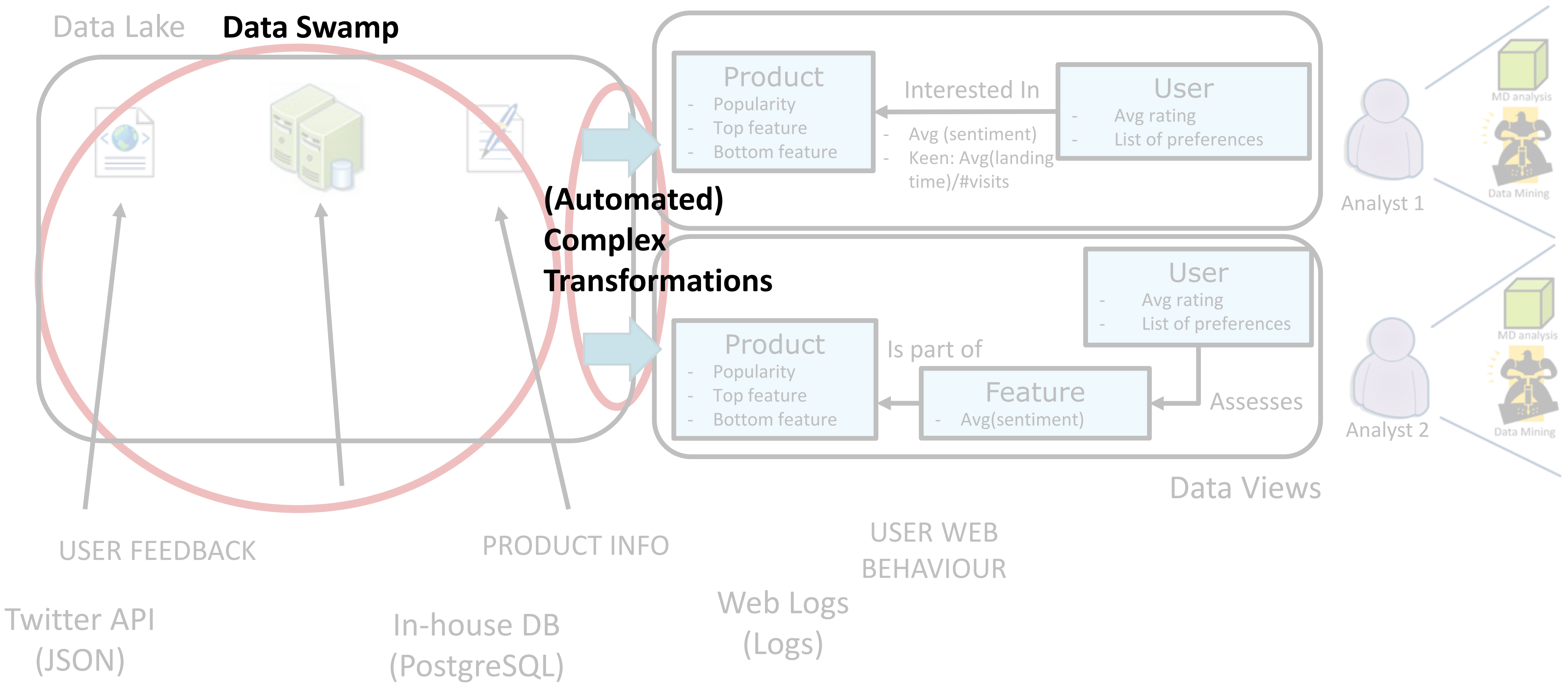


Fixed Target Schema
Product
- Popularity
- Top feature
- Bottom feature
- Avg (sentiment)
- Keen: Avg(landing time)/#visits
Interested In
Is part of
Feature
- Avg(sentiment)
Assesses
User
- Avg rating
- List of preferences
MD analysis
Data Mining
High Entry Barriers
Permanent transformations
Sentiment Analysis (e.g., Text Mining)
Product homogenization (e.g., duplicate detection)
Log Analysis (e.g., Process Mining)
Twitter API (JSON)
- User
- Tweet
- Date
- Location
USER FEEDBACK
In-house DB (PostgreSQL)
- Product
- Product features
PRODUCT INFO
- Product
- Landing time
- Visits ts
Web Logs (Logs)
USER WEB BEHAVIOUR

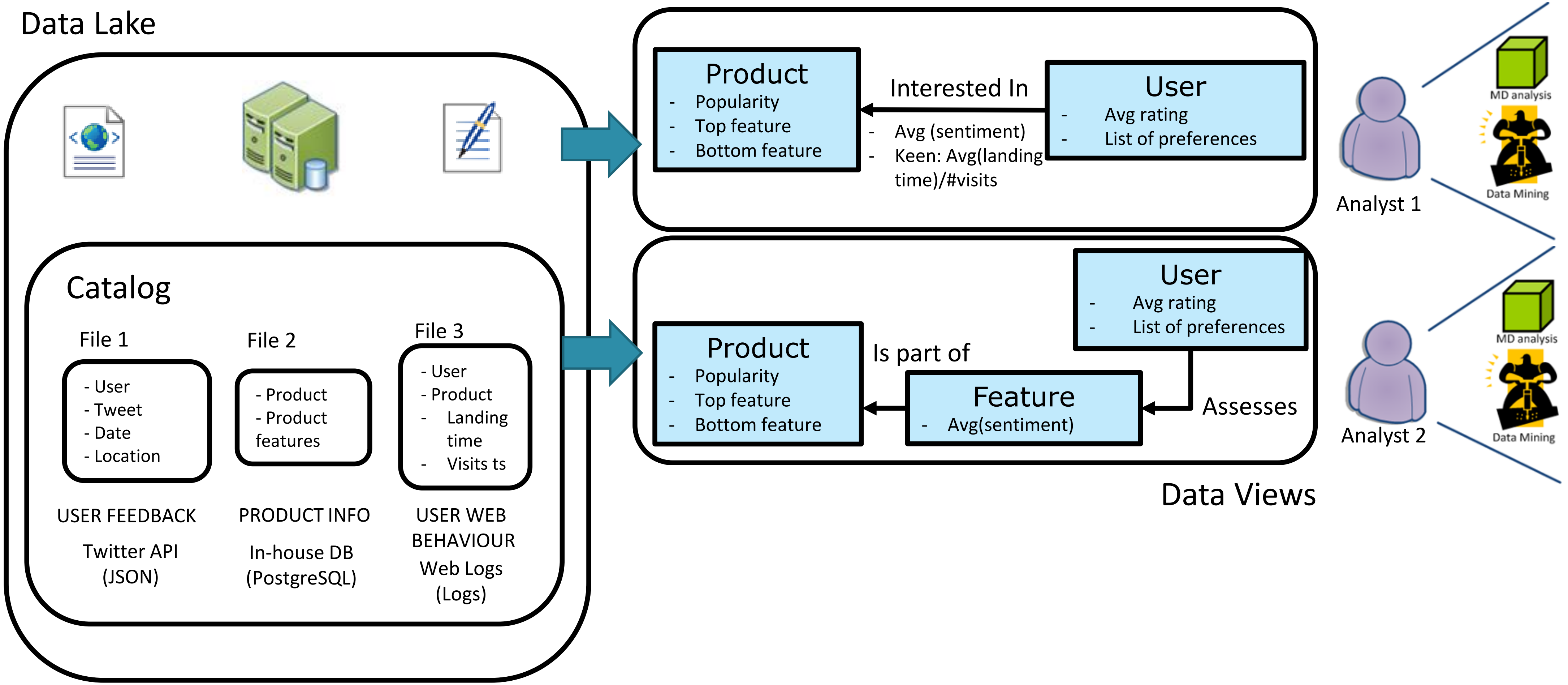
Load-First Model-Later



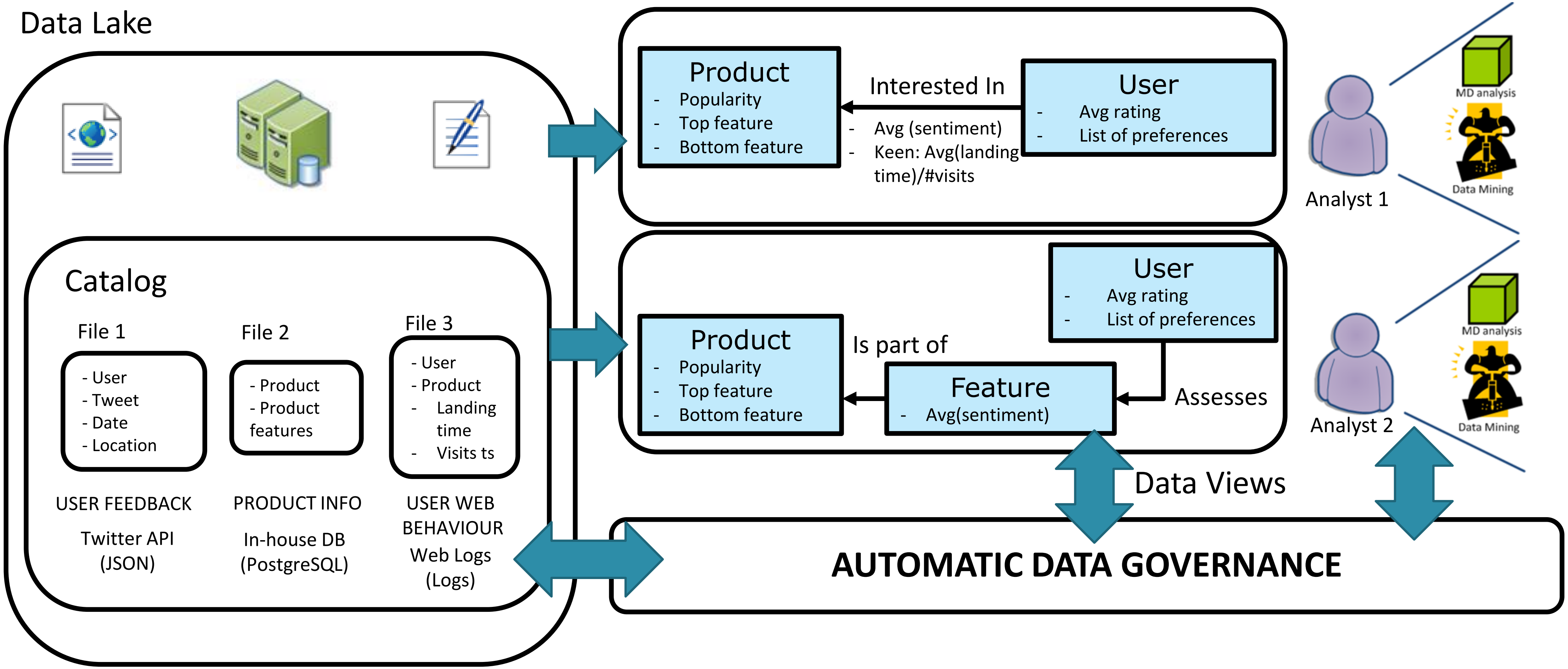
Drawbacks


Data Lake
Data Swamp
(Automated) Complex Transformations
Product
- Popularity
- Top feature
- Bottom feature
Interested In
- Avg (sentiment)
- Keen: Avg(landing time)/#visits
User
- Avg rating
- List of preferences
Analyst 1
MD analysis
Data Mining
User
- Avg rating
- List of preferences
Product
- Popularity
- Top feature
- Bottom feature
Is part of
Feature
- Avg(sentiment)
Assesses
Analyst 2
MD analysis
Data Mining
Data Views
USER FEEDBACK
PRODUCT INFO
USER WEB BEHAVIOUR
Twitter API (JSON)
In-house DB (PostgreSQL)
Web Logs (Logs)

From Data Swarms to Semantic Data Lakes



From IT-Centered to User-Centered



Data Variety:
Graphs to the Rescue

Graph Data Model in a Nutshell

Occurrence-oriented

- It is a schemaless data model
  - There is no explicit schema
  - Data (and its relationships) may quickly vary
- Objects and relationships as first-class citizens
  - *An object o relates (through a relationship r) to another object o'*
    - *Such relationship is often known as a triple (o r o')*
  - Both objects and relationships may contain properties
- Built on top of the graph theory
  - Euler (18th century)
  - More natural and intuitive than the relational model to deal with relationships

Notation (I)

A **graph** *G* is a set of nodes and edges: *G (N, E)*

N - **Nodes** (or vertices): *n1, n2, … Nm*

E - **Edges** are represented as pairs of nodes: (*n1, n2*)

- An edge is said to be **incident** to *n1* and *n2* (also, *n1* and *n2* are said to be **adjacent)**
- An edge is drawn as a line between *n1 and n2*
- **Directed edges** entail direction: <u>**from**</u> *n1* <u>**to**</u> *n2*
- An edge is said to be **multiple** if there is another edge exactly relating the same nodes
- An **hyperedge** is an edge inciding in more than 2 nodes

Types of graphs:

- **Multigraph**: If it contains at least one multiple Edge
- **Simple graph**: If it does not contain multiple edges
- **Hypergraph**: A graph allowing hyperedges

Notation (II)

Size (of a graph): #edges

Degree (of a node): #(incident edges)

- The degree of a node denotes the node adjacency
- The neighbourhood of a node are all its adjacent nodes

Out-degree (of a node): #(edges leaving the node)

- Sink node: A node with 0 out-degree

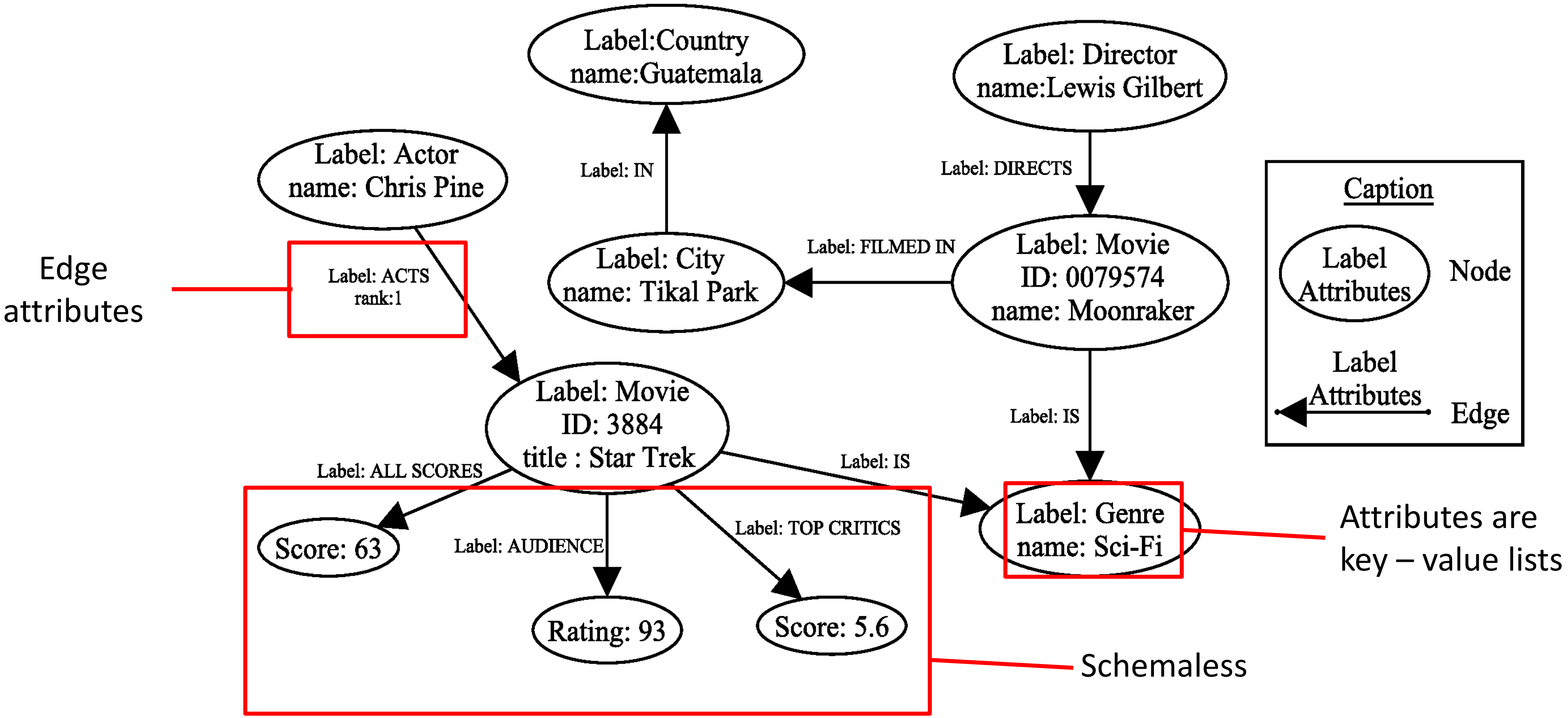
In-degree (of a node): #(incoming edges reaching the node)

- Source node: A node with 0 in-degree

Cliques and trees are specific kinds of graphs

- **Clique**: Every node is adjacent to every other node
- **Tree**: A connected acyclic simple graph

Example



Label:Country
name:Guatemala
Label: Director
name:Lewis Gilbert
Label: Actor
name: Chris Pine
Label: IN
Label: DIRECTS
Caption
Edge
attributes
Label: ACTS
rank:1
Label: City
name: Tikal Park
Label: FILMED IN
Label: Movie
ID: 0079574
name: Moonraker
Label
Attributes
Node
Label
Attributes
Edge
Label: IS
Label: Movie
ID: 3884
title : Star Trek
Label: ALL SCORES
Label: IS
Score: 63
Label: AUDIENCE
Label: TOP CRITICS
Label: Genre
name: Sci-Fi
Attributes are
key – value lists
Rating: 93
Score: 5.6
Schemaless

Showcasing Graphs

Crossing data from social networks it is possible to identify a graph like the one that follows:

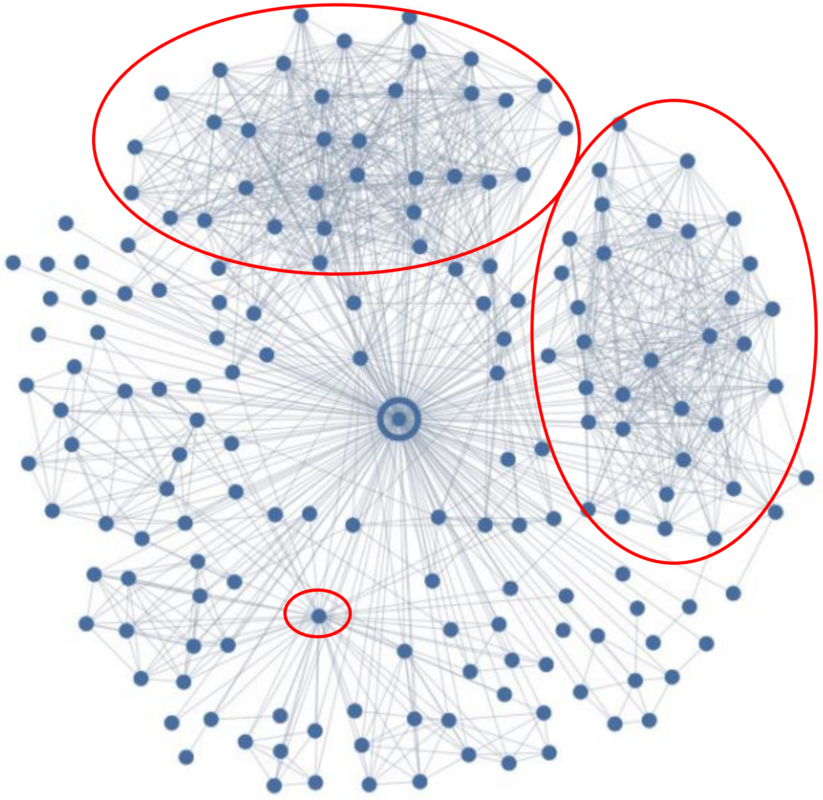
- In the centre there is a specific person *P*
- The rest are *P* connections and connections among them

Using sociology techniques…

- We can identify *P social foci*:
  - Dense clusters of connections, representing relationships
  - Typically, college friends, coworkers, relatives, etc.
- The *significant other* can be identified by a high *dispersion* rate
  - Highly connected with *P* connections,
  - But with a high dispersion degree wrt *P* social foci

Hypothesis: when the node with higher dispersion degree Identified is not the partner, this couple is likely to split up in a period of 60 days

L. Backstrom, J. Kleinberg. Romantic Partnerships and the Dispersion of Social Ties: A Network Analysis of Relationship Status on Facebook https://arxiv.org/pdf/1310.6753v1.pdf



Graph Data Models and Data Analytics

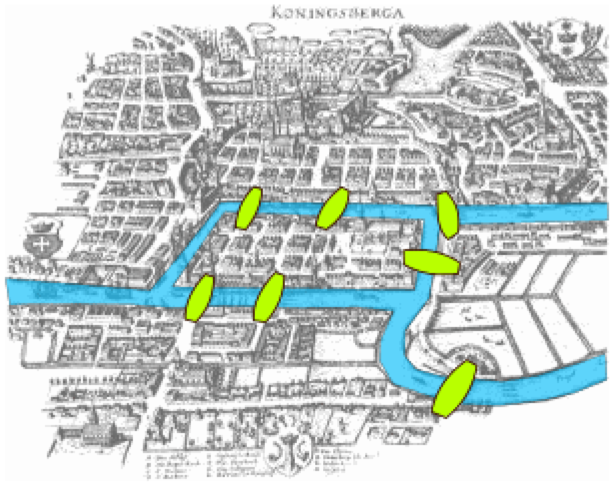
From a data management point of view:

- They are extremely flexible
- Schemaless by definition
- **Data and metadata are stored together** (i.e., data with annotations)
  - *Thus, we say that they store semantic (i.e., together with its meaning) data*
- Custom annotations facilitate data governance

Graphs are not only about data variety

From a data analytics point of view:

- Allow to exploit the data structure topology
  - Shortest path, centrality measures, community detection, etc.
- Graph data analytics is deterministic (i.e., by default non-probabilistic)
- Plenty of advances to enable probabilistic analysis on top of graphs
  - For example. graph embeddings and Graph Neural Networks (GNNs)



Seven Bridges of Koningsberg
(the born of graph theory)

Graph Data Models

What is a Graph Data Model?

Graph data models are composed of data structures, constraints and operators:

Data Structures

- Nodes
- Edges
- Attributes
- Etc.

Constraints

- From a data structure point of view: nodes and edges are disjoint
- From a schema point of view: schemaless

Operators

- Graph operators (grounded in the graph theory): pattern matching, reachability, neighbourhood, etc.
  - For these operations: graphs are translated into mathematical structures (!)
- Algebraic operators (coming from databases): selection, projection, join, union, aggregation, etc.
- Probabilistic operators (ML-based operators): prior a transformation of the graph into a vectorial representation

Graph Data Models

Two main families:

- **<u>Property Graphs</u>**
  - Born in the database field
  - Not predefined semantics
  - Follow a Closed-World assumption
  - Generate data silos
  - Algebraic operations on top of traditional graph operations
- **<u>Knowledge Graphs</u>**
  - Born in the knowledge representation field
  - May assume the Open-World assumption
  - Facilitate data sharing and linking
  - Two main families
    - RDF and RDF(S)
      - Born in the semantic web field
      - Vocabulary-based pre-defined semantics
      - Combine traditional graph operations, algebraic operations and simple reasoning operations
    - Description Logics (DL)-based languages (e.g., OWL)
      - Representation of (subsets of) first-order logic
      - Pre-defined semantics based on logics
      - Reasoning operations grounded in logics

Summary

Graphs are the perfect canonical data model to tackle data variety:

- Semantic expressiveness,
- Semantic relativeness

As a result, data and metadata (semantic annotations on data) are stored together

- Data is stored with its meaning
- Machine-readable metadata opens the door to automatic data management

Main graph families

- Property graphs
- Knowledge graphs

Thanks! Any Question?