# TDDD43

## Theme 2.2: Keyword Search in Databases

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# Keyword search

- Keyword search is a well known mechanism for retrieving relevant information from a set of documents.
  - **Google** is a familiar example !
- What about structured data?
  - Such as **XML** documents or **Relational Databases**?
- Current enterprise search engines in structured data requires:
  - **Knowledge** of schema
  - **Knowledge** of a query language
  - **Knowledge** of the role of the keywords
- Do users have all of the above **Knowledge** ?

# Keyword search in rel. DB

- Users need a simple system that receives some **keywords** as input and returns a **set of nodes** that together cover all or part of the input keywords as output.

- Relational databases can be modeled using **graphs**:
  - Tuples are **nodes** of the graph.
  - Foreign key relationships are **edges** that connect two nodes (tuples) to each other.

# Keyword search in rel. DB

**Cities**

| ID | Name | Country |
|---|---|---|
| 22 | Toronto | CA |
| 16 | New York | US |

**Organizations**

| ID | Name | Head Q. |
|---|---|---|
| 135 | UN | 16 |
| 175 | EU | 81 |

**Countries**

| Code | Name |
|---|---|
| CA | Canada |
| US | United States |

**Memberships**

| Country | Org. |
|---|---|
| CA | 135 |
| US | 135 |

# New York is Located in United States

**Cities**

| ID | Name | Country |
|---|---|---|
| 22 | Toronto | CA |
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| ID | Name | Head Q. |
|---|---|---|
| 135 | UN | 16 |
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**Countries**

| Code | Name |
|---|---|
| CA | Canada |
| US | United States |

**Memberships**

| Country | Org. |
|---|---|
| CA | 135 |
| US | 135 |

**Keywords** : "New York" "United States"

# New York hosts UN and Canada is a member

## Cities

| ID | Name | Country |
|---|---|---|
| 22 | Toronto | CA |
| 16 | New York | US |

## Organizations

| ID | Name | Head Q. |
|---|---|---|
| 135 | UN | 16 |
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## Countries

| Code | Name |
|---|---|
| CA | Canada |
| US | United States |

## Memberships

| Country | Org. |
|---|---|
| CA | 135 |
| US | 135 |

**Keywords** : “**New York**” “**Canada**”

# Keyword search in DBs

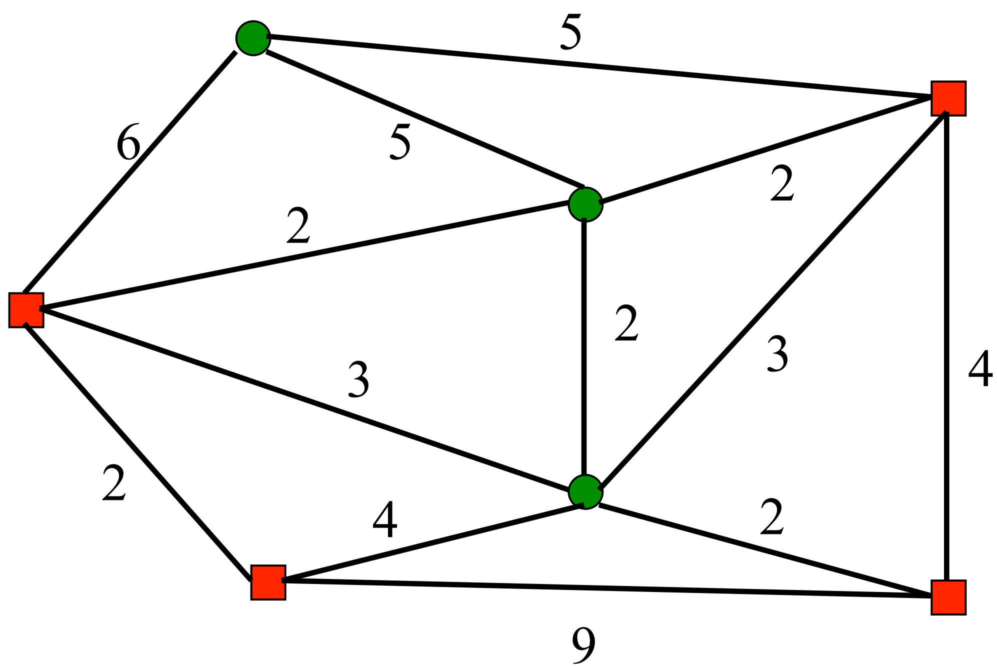
- Database is modeled as a graph where vertices can be objects, tuples, etc.) and edges reflect the relationship between vertices.
  - Undirected graph vs. directed graph
  - Weighted graph vs. un-weighted graph
  - Labeled edges vs. non-labeled edges

- Keywords → vertices in the graph
- Keyword search in DB → Steiner tree computation
- Ranked keyword search → ranked Steiner tree

# Steiner tree problem

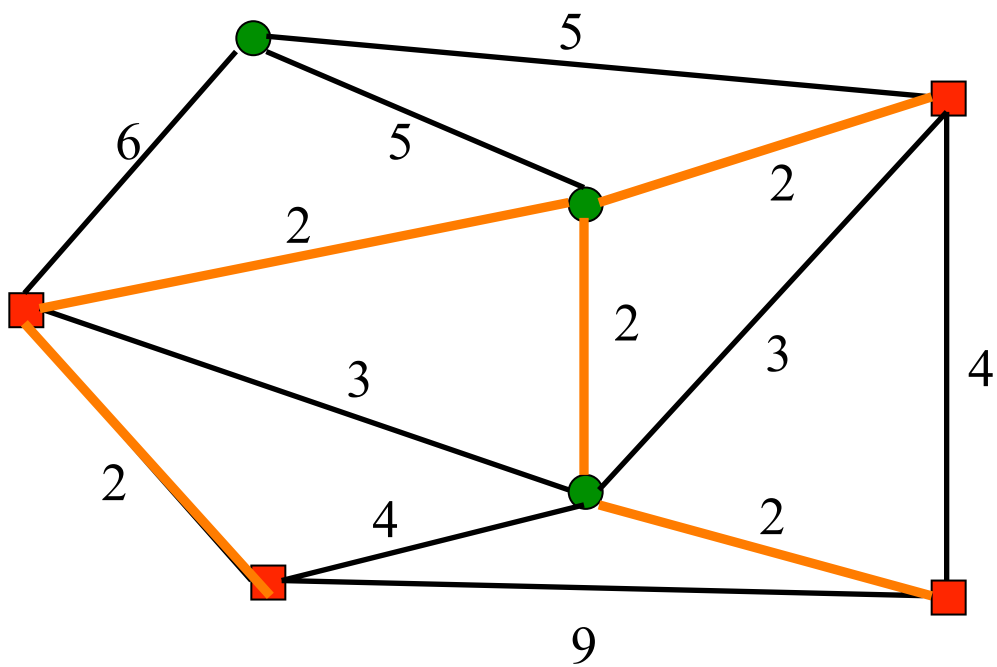
- Given a weighted graph $G = (V, E)$ of order $n = |V|$ and a set $S \subseteq V$ of $k = |S|$ to find a minimum cost sub-tree $T = T(S)$ of $G$ connecting (spanning) all terminal nodes.
  - Minimal cost → the sum of weights of the edges in $T$ is a minimum.

# Steiner tree example




 terminals

# Steiner tree example



# Special cases

- $k = 2$, STP is a shortest path problem between the two given terminals.
- $k = 3$, for three given points $z1$, $z2$ and $z3$, STP is to find a vertex $v$ that minimizes $d(v; z1) + d(v; z2) + d(v; z3)$
- $k = n$, STP is a minimal spanning tree problem (MSTP) of $G$

# Steiner tree: NP-hardness

- Steiner tree problem is hard.

The decision problem:

Given an undirected graph $G = (V,E)$, a subset $Y$ of $V$ and a value $i$, is there a Steiner tree $T$ spanning $Y$ with the length of $T$ which is shorter than $i$?

is NP-hard.

# Dreyfuss-Wagner algorithm

- The Dreyfus–Wagner algorithm solves the Steiner tree problem for $S \subseteq V$ by dynamic programming.
- It computes optimal trees $T(X \cup \boldsymbol{v})$ for all $X \subseteq S$ and $\boldsymbol{v} \in V$ recursively.
  - Assume first that $\boldsymbol{v}$ is a leaf of the (unknown) optimal tree $T(X \cup \boldsymbol{v})$.
  - Then $\boldsymbol{v}$ is joined in $T(X \cup \boldsymbol{v})$ to some node $\boldsymbol{w}$ of $T(X \cup \boldsymbol{v})$ along a shortest path $P_{vw}$, such that either $\boldsymbol{w} \in X$ or $\boldsymbol{w} \notin X$. In both cases we have

$$T\,(X \cup \boldsymbol{v}) = P_{vw} \cup T\,(X \cup \boldsymbol{w})$$

# Dreyfuss-Wagner algorithm

- We can decompose

$$T(X \cup w) = T(X' \cup w) \cup T(X'' \cup w)$$

- for some nontrivial bipartition $X = X' \cup X''$.

- We may thus write

$$T(X \cup v) = \min(P_{vw} \cup T(X' \cup w) \cup T(X'' \cup w))$$

- where the minimum is taken over all $w \in V$ and all nontrivial bipartitions $X = X' \cup X''$.

# Algorithm

Algorithm (Dreyfus-Wagner algorithm)

Step 1: Compute $P_{wv}$ for all $w, v \in V$ .

Step 2: For $i = 2$ to $k - 1$,

For any $|X| = i$ and any $w \in Y$ , $v \in V \setminus X$

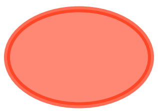
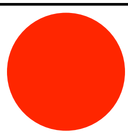
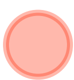
$$T(X \cup v) = \min P_{vw} \cup T(X' \cup w) \cup T(X'' \cup w).$$

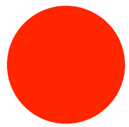
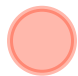
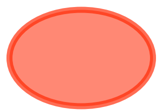
**Complexity:** $O(n \,.\, 3^k + n^2 \,.\, 2^k + n^3)$

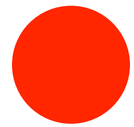
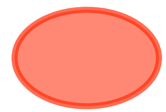
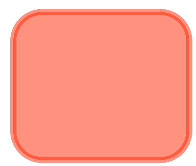
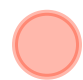
# Ranked queries

- Given a collection of objects, our goal is to find Top-k objects, whose scores are greater than the remaining objects.

# Example

| Object | Area ($x_3$) |
|---|---|
|  | 1 |
|  | 0.95 |
|  | 0.85 |
|  | 0.75 |
|  | 0.3 |
|  | 0.1 |

| Object | Roundness ($x_2$) |
|---|---|
|  | 1 |
|  | 1 |
|  | 0.5 |
|  | 0.2 |
|  | 0 |
|  | 0 |

| Object | Redness ($x_1$) |
|---|---|
|  | 1 |
|  | 1 |
|  | 0.67 |
|  | 0.6 |
|  | 0.5 |
|  | 0 |

Attributes

Grades

Every subsystem is sorted by the grade it holds

# Top-k object problem

- Naïve algorithm
- Basic Idea:
  - For for each object, use the aggregation function to get the score
  - According to the scores, get the top *k*.

- Problem: inefficiency
- Question:
  - Do we need to count the score for every object in the database?
  - Can we SAFELY ignore some objects whose scores are lower than what we already have?

# Fagin's algorithm

- Do Sorted access in parallel at all the lists
- Stop when we have *k* objects which appear in all the lists
- Calculate score value of all the objects
- Compute Top-k objects

# Example: Fagin's algorithm

**1** Objects appear in every list:

{ }

Objects seen so far:

{ , }

| Object | Redness ($x_1$) | Object | Roundness ($x_2$) | Object | Area ($x_3$) |
|---|---|---|---|---|---|
| | 1 | | 1 | | 1 |
| | 1 | | 1 | | 0.95 |
| | 0.67 | | 0.5 | | 0.85 |
| | 0.6 | | 0.2 | | 0.75 |
| | 0.5 | | 0 | | 0.3 |
| | 0 | | 0 | | 0.1 |

k = 3

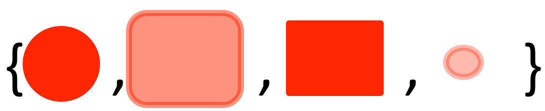
# Example: Fagin's algorithm

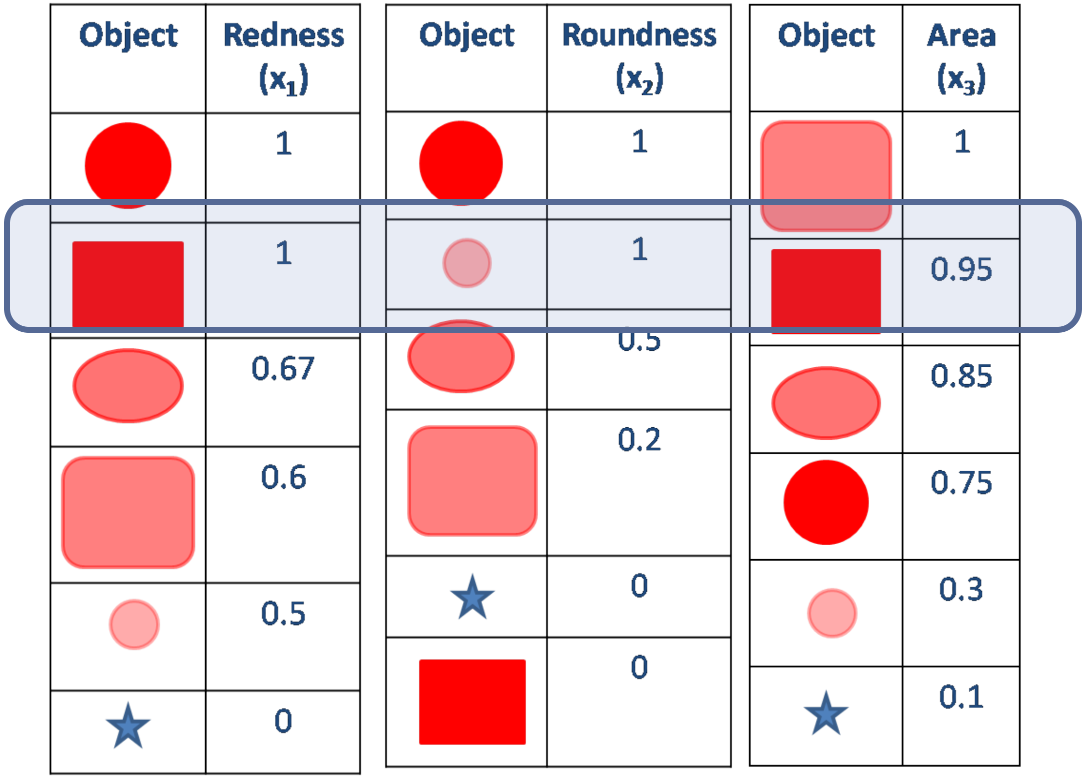
2

Objects appear in every list:

{ }

Objects seen so far:



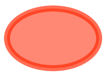



k = 3

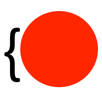
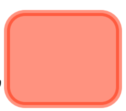
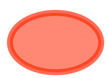
# Example: Fagin's algorithm

**3**

Objects appear in every list:

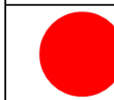
{  }

Objects seen so far:

{ , , , ,  }

| Object | Redness ($x_1$) |
|---|---|
|  | 1 |
|  | 1 |
|  | 0.67 |
|  | 0.6 |
|  | 0.5 |
|  | 0 |

| Object | Roundness ($x_2$) |
|---|---|
|  | 1 |
|  | 1 |
|  | 0.5 |
|  | 0.2 |
|  | 0 |
|  | 0 |

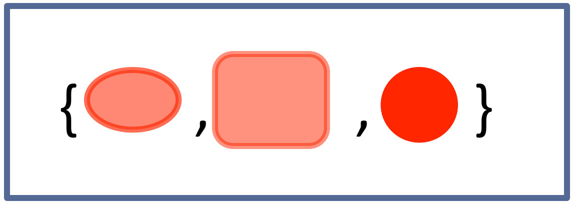
| Object | Area ($x_3$) |
|---|---|
|  | 1 |
|  | 0.95 |
|  | 0.85 |
|  | 0.75 |
|  | 0.3 |
|  | 0.1 |

$k = 3$

# Example: Fagin's algorithm

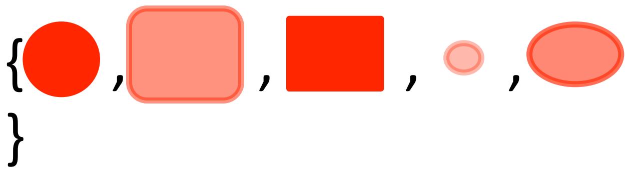
4

Objects appear in every list:



We got enough objects

Objects seen so far:



| Object | Redness ($x_1$) |
|---|---|
| | 1 |
| | 1 |
| | 0.67 |
| | 0.6 |
| | 0.5 |
| | 0 |

| Object | Roundness ($x_2$) |
|---|---|
| | 1 |
| | 1 |
| | 0.5 |
| | 0.2 |
| | 0 |
| | 0 |

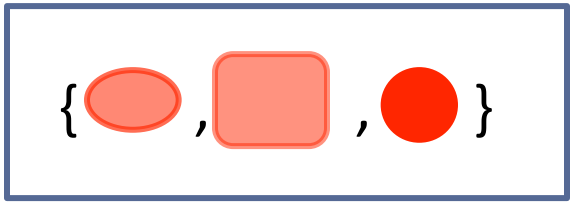
| Object | Area ($x_3$) |
|---|---|
| | 1 |
| | 0.95 |
| | 0.85 |
| | 0.75 |
| | 0.3 |
| | 0.1 |

k = 3

# Example: Fagin's algorithm

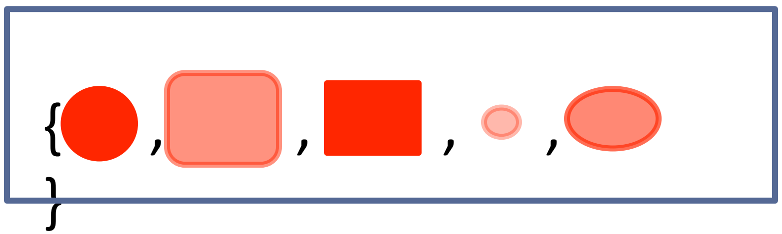
**4**

Objects appear in every list:



We got enough objects

Objects seen so far:



For all these, calculate the score and get the Top-k

| Object | Redness ($x_1$) | Object | Roundness ($x_2$) | Object | Area ($x_3$) |
|---|---|---|---|---|---|
| | 1 | | 1 | | 1 |
| | 1 | | 1 | | 0.95 |
| | 0.67 | | 0.5 | | 0.85 |
| | 0.6 | | 0.2 | | 0.75 |
| | 0.5 | | 0 | | 0.3 |
| | 0 | | 0 | | 0.1 |

k = 3

# Ranked Steiner tree with 3 terminals

- For three given points $z1$, $z2$ and $z3$, STP is to find a vertex $v$ that minimizes $d(v; z1) + d(v; z2) + d(v; z3)$

# Ranked Steiner tree with 3 terminals

| *v* | *d(v,z1)* |
|---|---|
| 12 | 1 |
| 256 | 3 |
| 9 | 4 |
| 55 | 6 |
| 137 | 7 |
| 474 | 8 |
| 987 | 10 |
| 33 | 12 |
| 787 | 15 |

| *v* | *d(v,z2)* |
|---|---|
| 256 | 3 |
| 345 | 13 |
| 678 | 14 |
| 347 | 16 |
| 55 | 17 |
| 890 | 18 |
| 235 | 25 |
| 57 | 32 |
| 564 | 35 |

| *v* | *d(v,z3)* |
|---|---|
| 999 | 20 |
| 64 | 21 |
| 954 | 22 |
| 332 | 23 |
| 256 | 24 |
| 55 | 24 |
| 687 | 26 |
| 1 | 37 |
| 33 | 40 |

Find the top-2 Steiner trees of terminals (z1, z2, z3)