UNIVERSITY OF COPENHAGEN

Declarative Cartography

In-Database Map Generalization of Spatial Datasets

P.K. Kefaloukos, M. Vaz Salles, M. Zachariasen

ICDE 2014 - Chicago, IL, USA

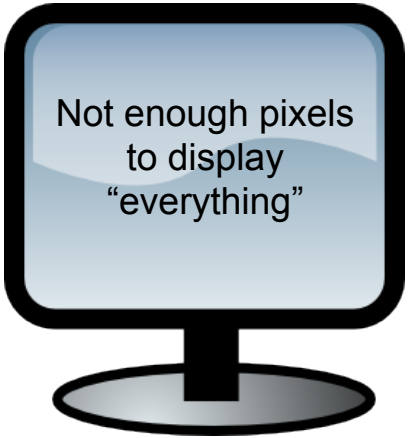
Creating zoomable maps

Maps should be

- Legible
- Representative
- Useful
- Zoomable

Basic challenge

Adapting data to scale of visualization medium



Basic challenge

We have to *choose*:

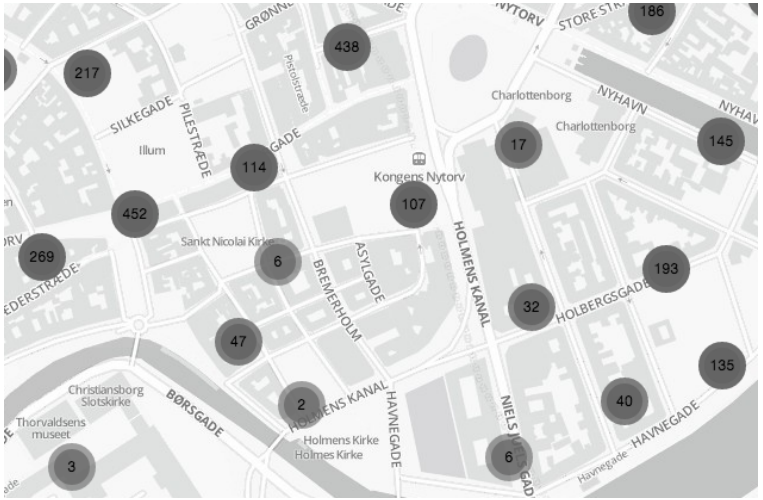
(1) *What* to display?

(2) *How* to display it?

Alternatives

Selection

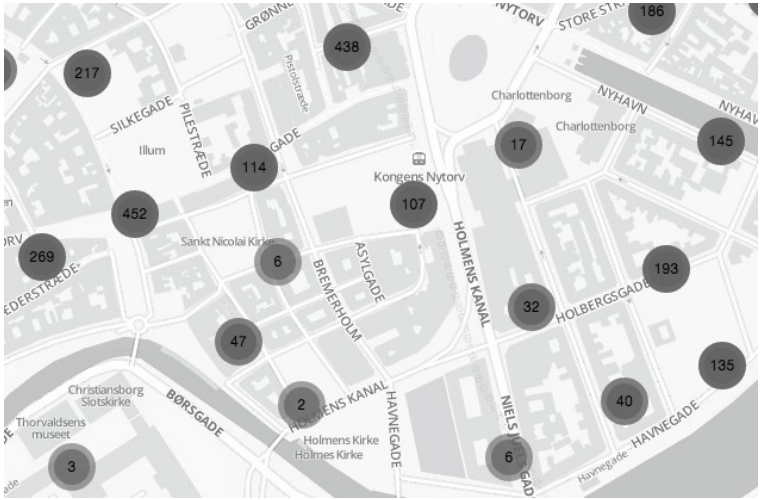
Aggregation



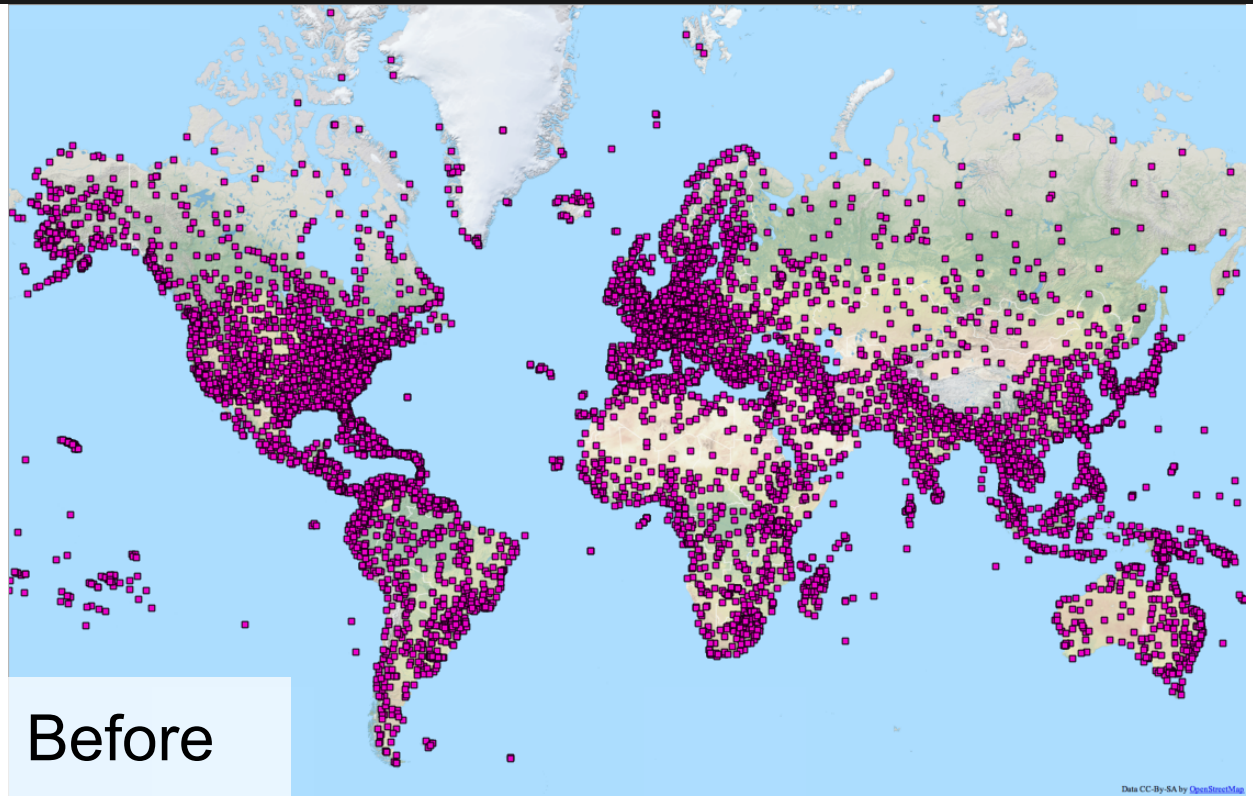
Alternatives

Selection (our work)

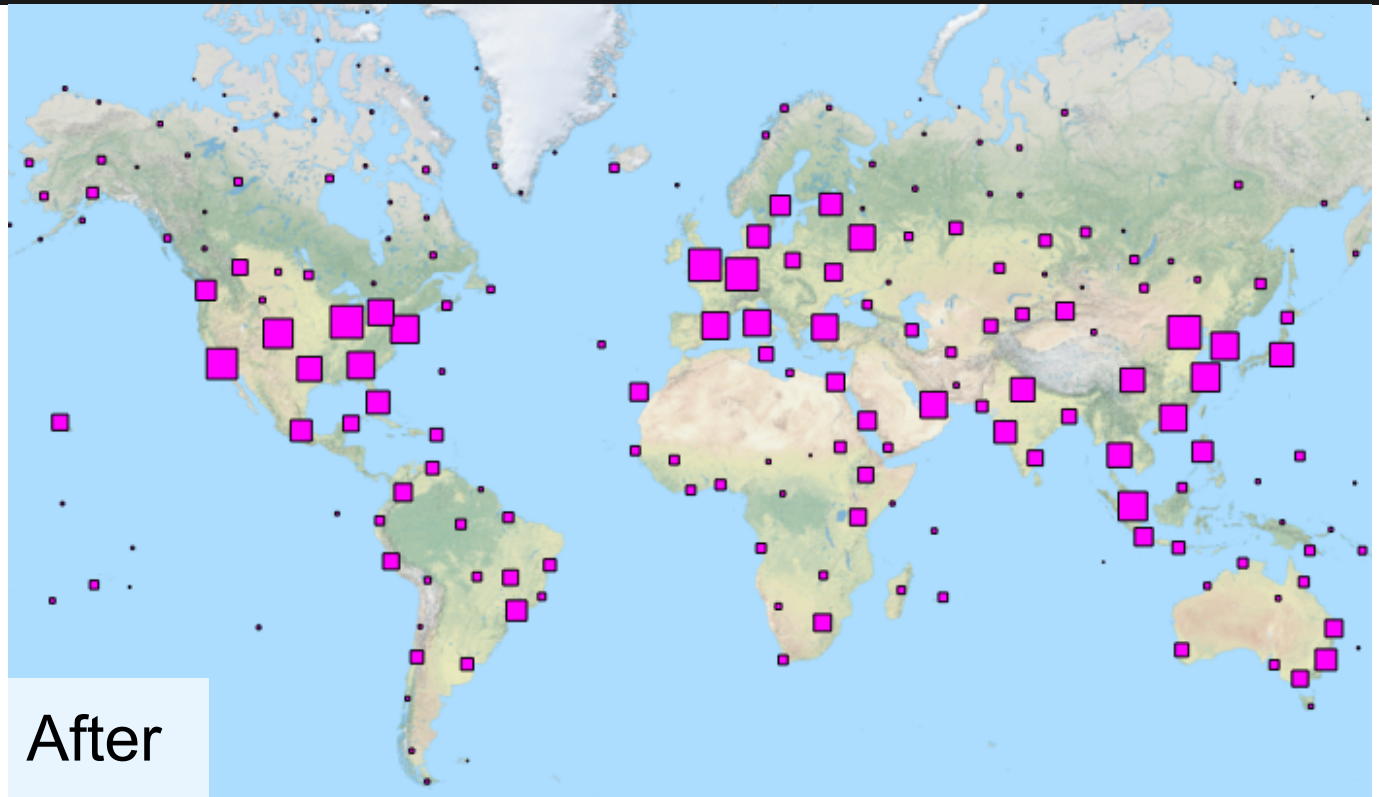
Aggregation



Selecting airports (example)



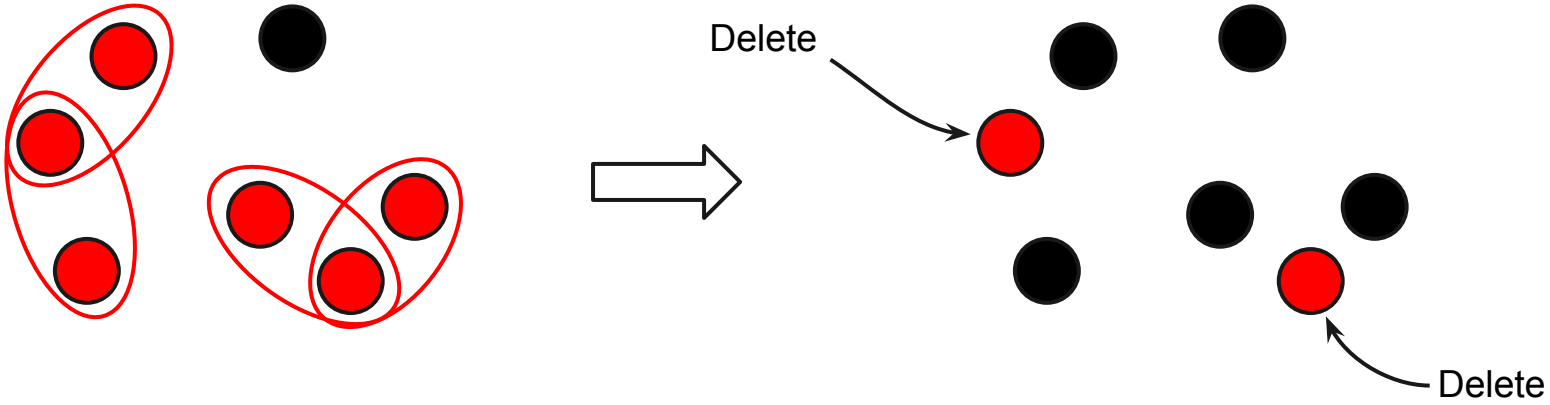
Selecting airports (example)



Selecting airports (example)

1: Cartographic constraints

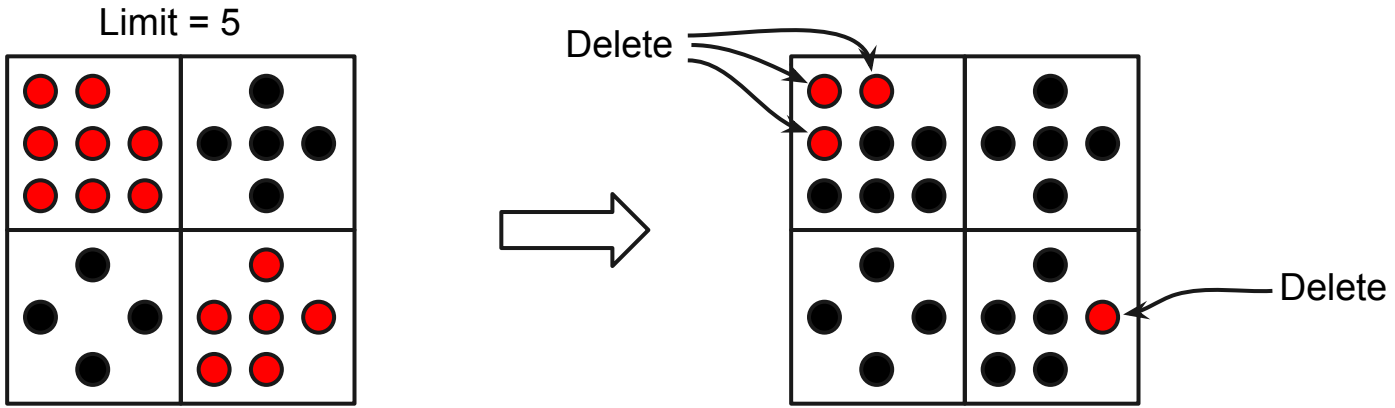
Proximity constraint: minimum distance between records (measured in pixels on screen)



Conflicts for proximity constraint

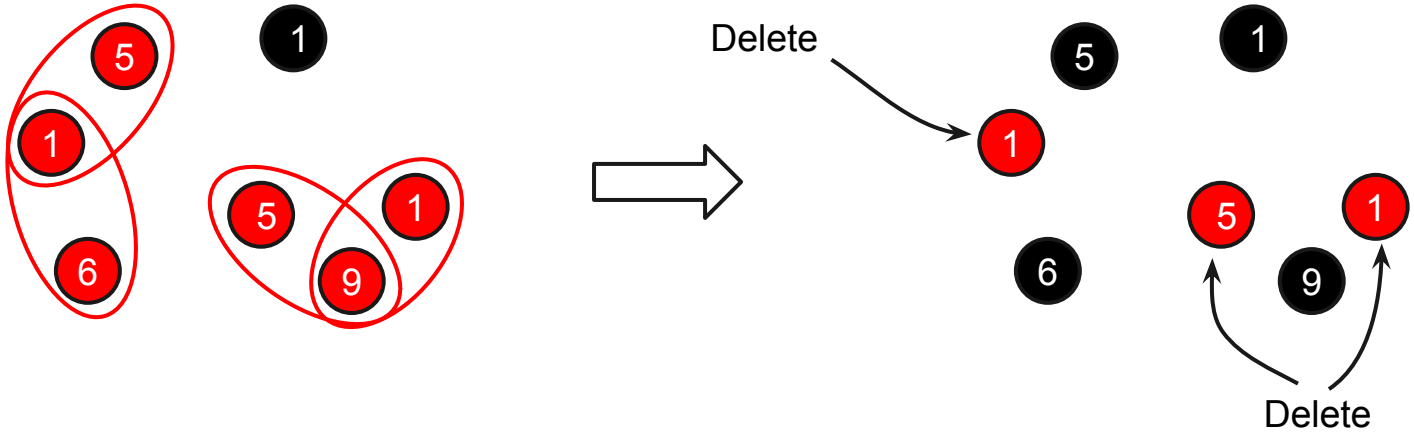
1: Cartographic constraints

Visibility: maximum records per unit area (within a map “tile”)



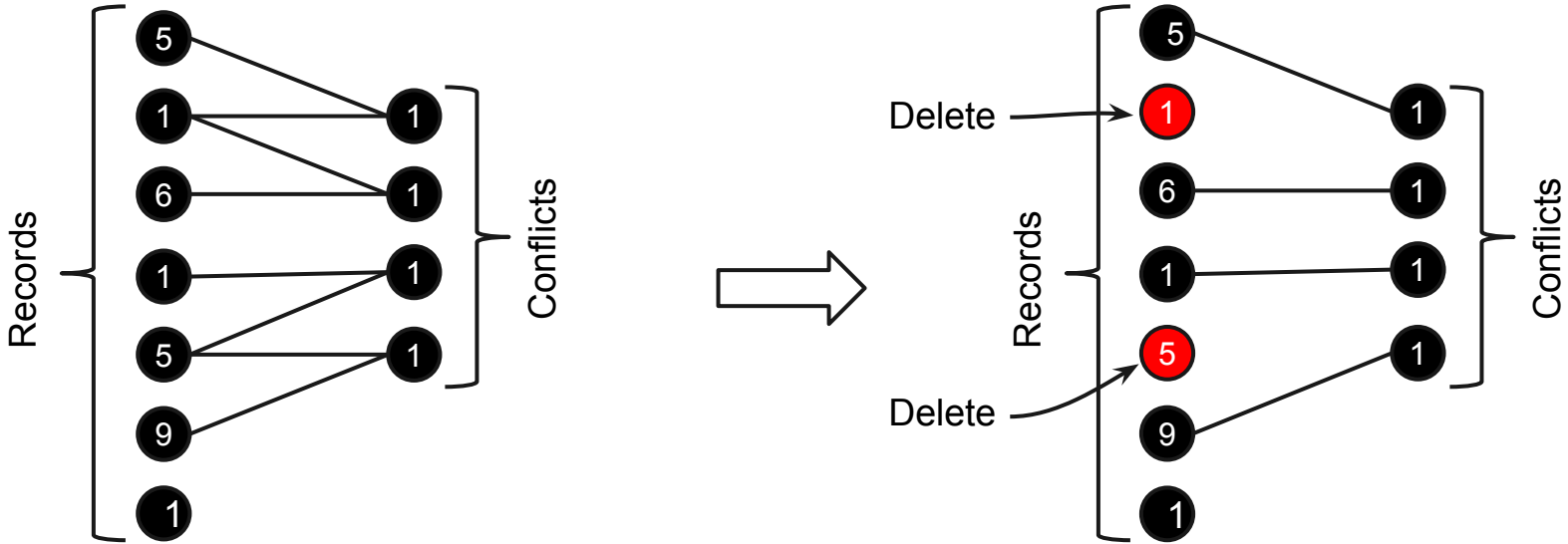
Conflicts for visibility constraint

2: Record weights



Adding weights may change selection

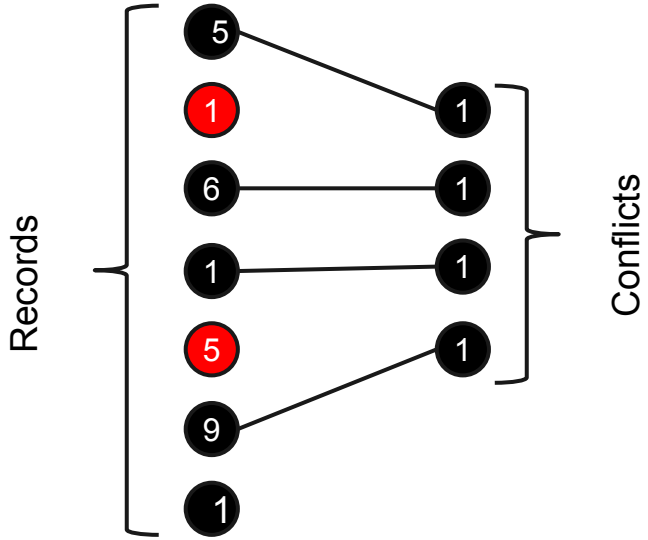
Optimization problem



Problem: delete minimum weight cover

Optimization problem

Set multicover problem (NP-hard)



User control

Creating maps is the job of data-journalists, bloggers, high-level programmers…

… not mathematicians

Declarative Cartography

```
GENERALIZE
    airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Cartographic Visualization Language (CVL)

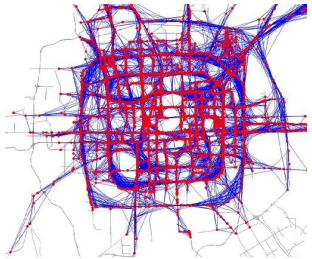
- Pronounced *“Civil”*
- State high-level goals:
  - Number of zoom-levels? (**`AT 18 ZOOM LEVELS`**)
  - Importance of records? (**`WEIGH BY`**)
  - Visual constraints? (**`SUBJECT TO`**)
- Compiles to SQL

```
GENERALIZE
    airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Input dataset, e.g:

- Points of interest (points)
- Running routes (lines)
- Animal territories (polygons)

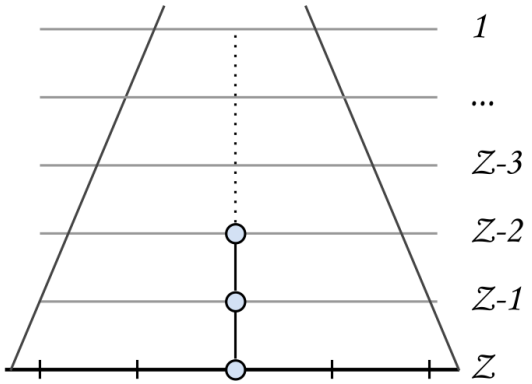


```
GENERALIZE
    airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Output dataset

- Output = input made “zoomable”



Zoom-consistency

```
GENERALIZE
    airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Weights

- Reuse SQL expressions as sub-language
- Evaluated for each row (once)

Anything that is a number

- random()
- x + y
- max (x, y)

```
GENERALIZE
    airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Constraints

- Referenced by name
- Parameterized

```
GENERALIZE
  airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

Constraints

- Referenced by name
- Parameterized

How are constraints defined?

- Let's look at proximity next

```
GENERALIZE
  airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
    num_departures
SUBJECT TO
    proximity 10
    visibility 16
```

Declarative Cartography

General syntax

- **CREATE CONSTRAINT**: give the constraint a name
- **NOT EXISTS**: define what a conflict is (`select cid, rid`)
- **RESOLVE IF DELETE**: define how to resolve a conflict (number of records to delete for conflict)

```
CREATE CONSTRAINT proximity AS
NOT EXISTS (
    /* select cid, ric ... */
)

RESOLVE cid IF DELETE (
    /* scalar query or integer */
)
```

Declarative Cartography

General syntax

- **CREATE CONSTRAINT**: give the constraint a name
- **NOT EXISTS**: define what a conflict is (`select cid, rid`)
- **RESOLVE IF DELETE**: define how to resolve a conflict (number of records to delete for conflict)

```
...
NOT EXISTS (
  SELECT
    l.{rid} || r.{rid} AS cid,
    Unnest(array[l.{rid}, r.{rid}]) AS rid
  FROM
    {level_view} l JOIN {level_view} r
  ON
    ST_Distance(
      l.{geom}, r.{geom}) <
      CVL_Resolution({z}, 256) * {param_1}
)
...
```

Declarative Cartography

General syntax

- **CREATE CONSTRAINT**: give the constraint a name
- **NOT EXISTS**: define what a conflict is (`select cid, rid`)
- **RESOLVE IF DELETE**: define how to resolve a conflict (number of records to delete for conflict)

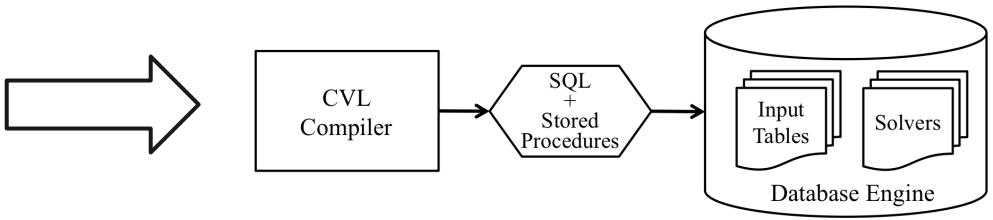
```
...
RESOLVE cid IF DELETE (
    1
)
```

Compiling CVL into SQL

```
CREATE CONSTRAINT proximity
AS
NOT
)
RESO
)
```

```
CREATE CONSTRAINT visibility
AS
NOT
)
RES
)
```

```
GENERALIZE
  airports TO airports2
WITH ID airport_id
WITH GEOMETRY wkb_geometry
AT 18 ZOOM LEVELS
WEIGH BY
       num_departures
SUBJECT TO
       proximity 10
       visibility 16
```



Using databases

- Spatial data typically managed in DBs
  - Option (a): Take data out of DB, process it, put it back
  - Option (b): Leverage database theory and technology to compute generalization *inside* DB (in-situ)
- We argue for option (b)
  - DBs are scalable and programmable
- However, DBs are not easy to program (unless you use CVL!)

Results

Tested two algorithms

- Static Greedy Algorithm (SGA):
  - sorting based heuristic, implemented in SQL
- Linear Programming Greedy Algorithm (LPGA):
  - linear programming approximation algorithm, implemented in PLPython and external LP solver

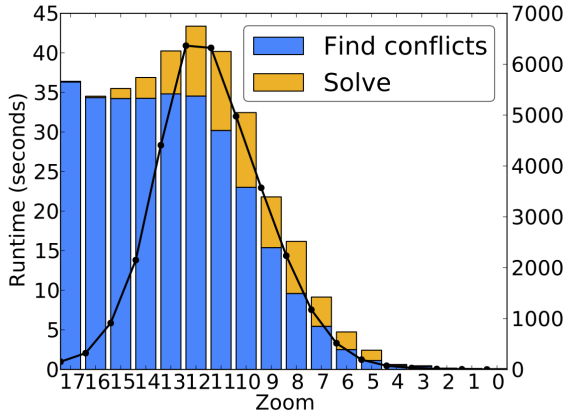
Results

Tested with one RDBMS

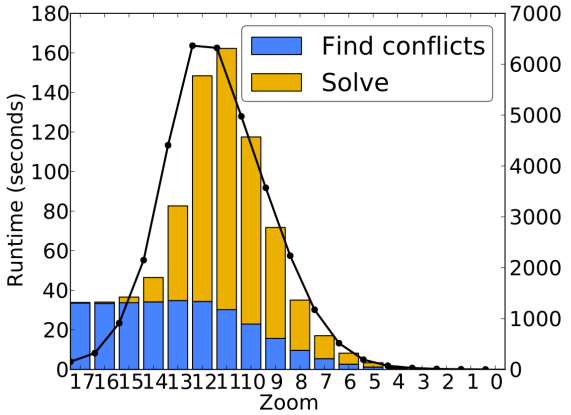
- PostgreSQL + PostGIS + Python + CVXOPT
  - Could be any database, e.g. a parallel one!

Results for points

- 500K points, tourist POI from OpenStreetMap



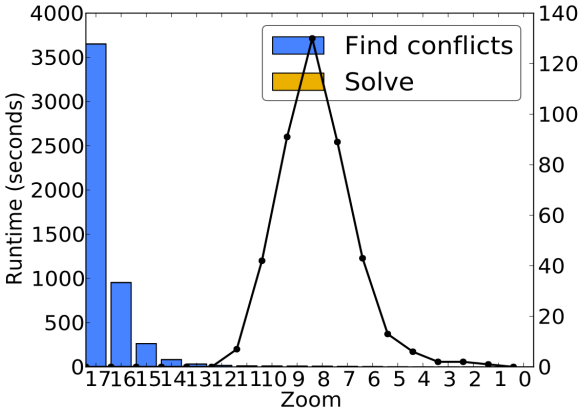
SGA + Visibility constraint



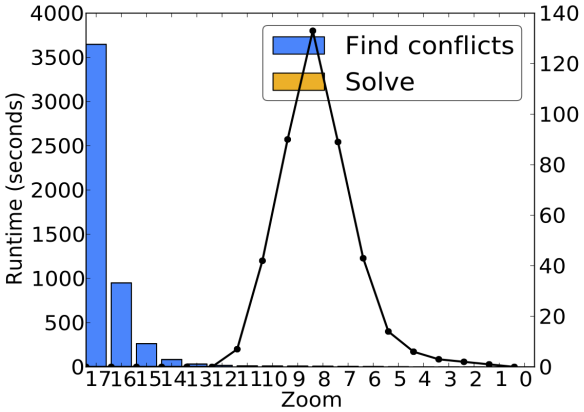
LPGA + Visibility constraint

Results for complex shapes

- 4K lines/4M points, rivers from OpenStreetMap



SGA + Visibility constraint



LPGA + Visibility constraint

Conclusion

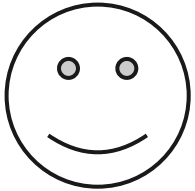
- Core idea
  - Compute: *what* data to display on a zoomable map
  - Delay decision on *how* to display it
- Conclusion on results
  - Overall: Running time dominated by computing joins when using efficient heuristic for selection
  - Points: SQL-based algorithms perform best
  - Complex shapes: Joins for complex shapes run *much* slower than joins for points

Conclusion

- Pros:
  - Domain Specific Languages make databases easier to program
  - Database engines can compute a concrete selection that matches a high-level goal expressed in DSL
  - Databases can work on data in-situ
- Cons:
  - Running time must improve
  - Selection dependent on algorithm

Conclusion

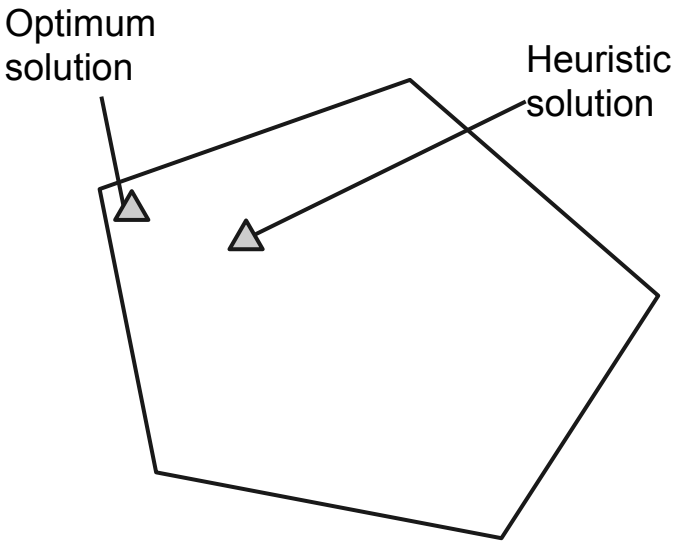
- Future work
  - Improving running time (in-memory, parallelism)
  - Improve salience function (static weights too crude)
  - Improve syntax (constraints are hard to define)
  - Improve expressibility (e.g. relax zoom-consistency)

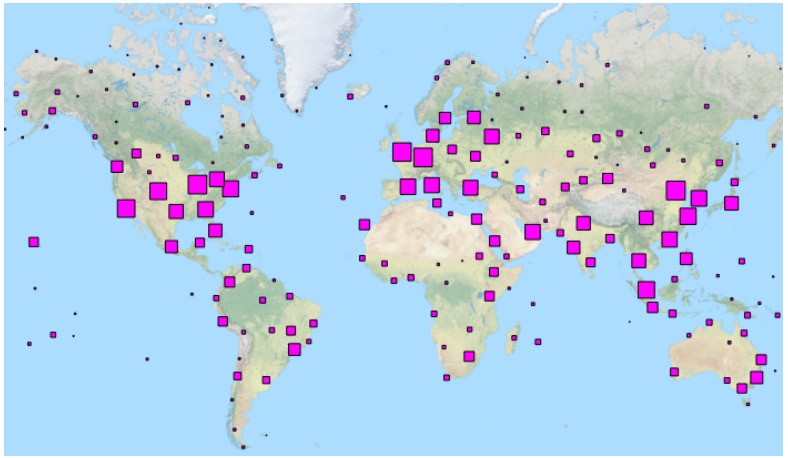


Thank you

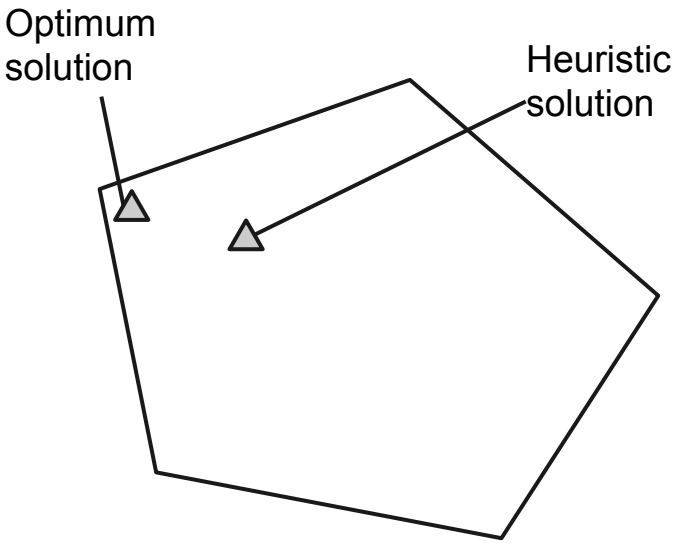
BACKUP SLIDES

Algorithm matters!





Algorithm matters!



Which airport to keep?