The Potential of Geosensor Networks for Sustainable Management of Urban Areas

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Demands: rich information

- Information about environment
- Information about use of urban infrastructure
  - Traffic flow, pedestrian movement -> planning purposes
- Up-to-date
- Multi-purpose – variety of topics
- From high detail to overview
- 2D – 3D – temporal

- Currently acquired
  - By administration or private institutions
  - Dedicated themes by different institutions
  - In fixed update-cycles
  - Systematic coverage of areas

… on the way to ….

- Increasing availability of (spatial) information in the internet
- Google Earth, Microsoft acquire urban areas in high resolution
- More and more "unconventional sensors" are available
  - E.g. mobile phones can measure movement of cars -> detect traffic jams (TomTom-application)
  - Digital photography in internet
- Voluntary data acquisition, e.g. OpenStreetMap
- Geosensor Networks

Overview

- Geosensor Networks
- Collaborative data acquisition
- Collaborative data processing
- Summary and conclusion

Geosensor Networks

Geosensor Networks

- Very interesting topic, different aspects
- Miniaturization of sensors -> „smart dust“
- Communication between sensors
- Many sensors cooperate
- Global perception by cooperation
- Network can solve new tasks

Specifics

- Geodetic networks are well known …
- Geosensor Networks if
  - No fixed infrastructure
  - Setup of infrastructure is too expensive (or not possible)
- Properties:
  - Many sensors are used
  - Sensors are small and cheap
  - Self-organization and self-configuration
  - Robust
  - Extendable
  - Low energy consumption
  - Collaboration and data fusion
  - Redundancy -> fault tolerance

Geosensor Networks

- Common goal of sensors cannot be achieved by individual sensor alone
- Composition of sensor networks is adaptable
  - Idea: sensors are „spread out“ – in arbitrary arrangement
  - Sensors can move
  - Or: Sensors are fixed on moveable background
- No tasks specified for each member; tasks are derived from
  - Situation / context
  - Properties of sensors (measurements, computational power, communication, …)

Applications of Geosensor Networks

- Disaster management, e.g. earthquakes, hill slides, …
- Surveillance, risk management (buildings, technical devices, …)
- Military applications
- Traffic
- Glacier movements
- Human body
- Environmental information (e.g. temperature, pressure, humidity)

Problems

- Miniaturization
- Measurement capabilities (typical today: temperature, pressure, orientation, …)
- Energy
- Lifetime of sensors
- Communication vs. operations / calculations in sensor
- Capabilities of processors
- Programming / new-programming of sensors after they have been spread out

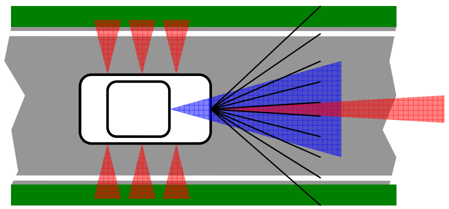
Contribution of Geodesy and Geoinformatics:

- Sensors and measurement systems
- Spatial data management and processing

Cooperative data collection

Future Cars

- More and more sensors in vehicle
  - GPS
  - Radar
  - Cameras (Mono, nightview)
  - camera (Stereo)
  - Radar
  - Laserscanner
  - ….



- Each vehicle is able to measure information about local environment
- Communication and cooperation to neighboring vehicles (and stationary infrastructure) leads to new possibilities

Mobile Mapping: Streetmapper @ ikg, Hannover

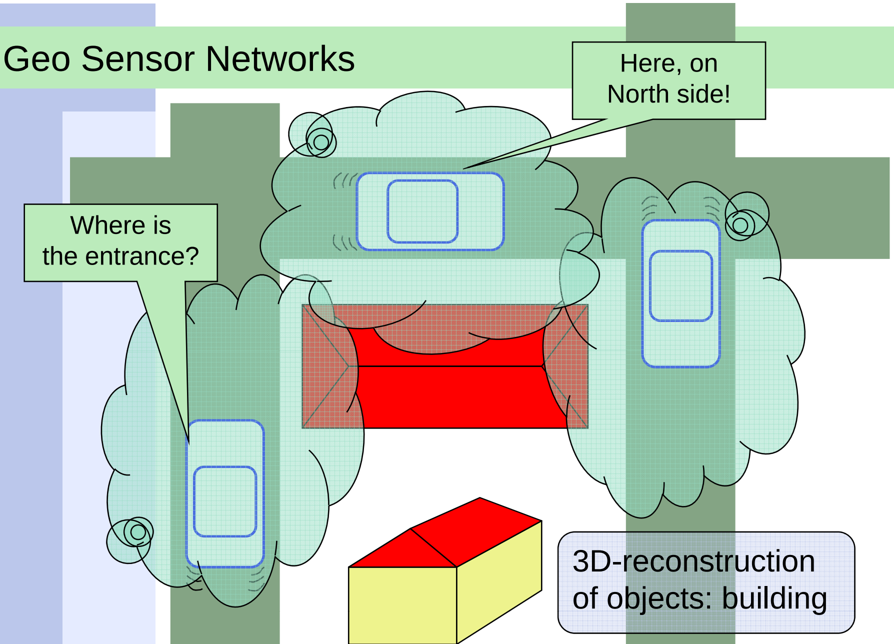
Königsworther Platz, Scandaten (3D Ansicht)

Google maps street view – 3D Data Capture (April 2008, Milano)

Scanner x 3, Cameras

Quelle: Internet

Geo Sensor Networks



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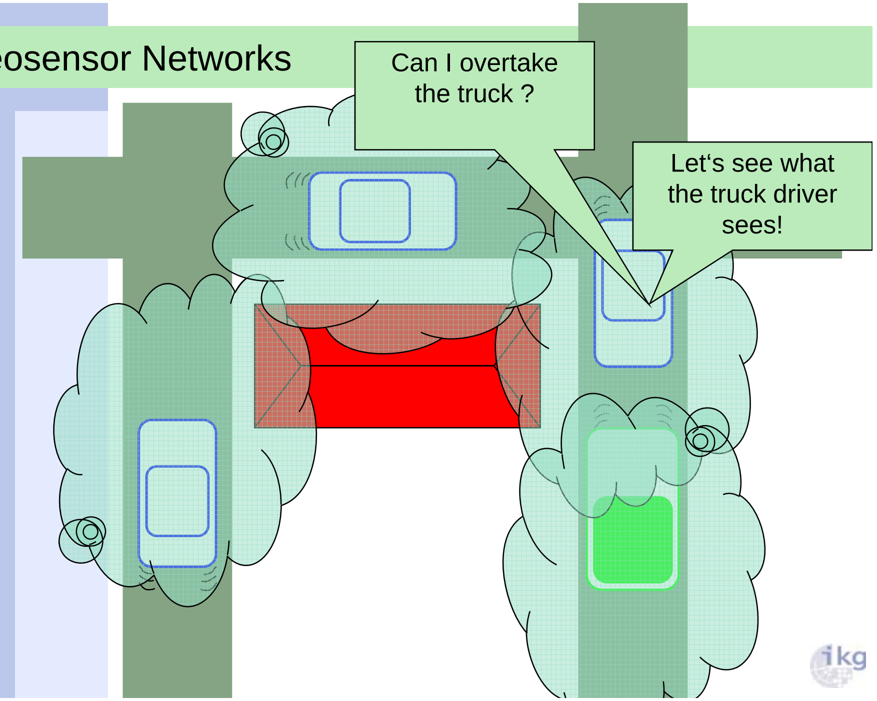
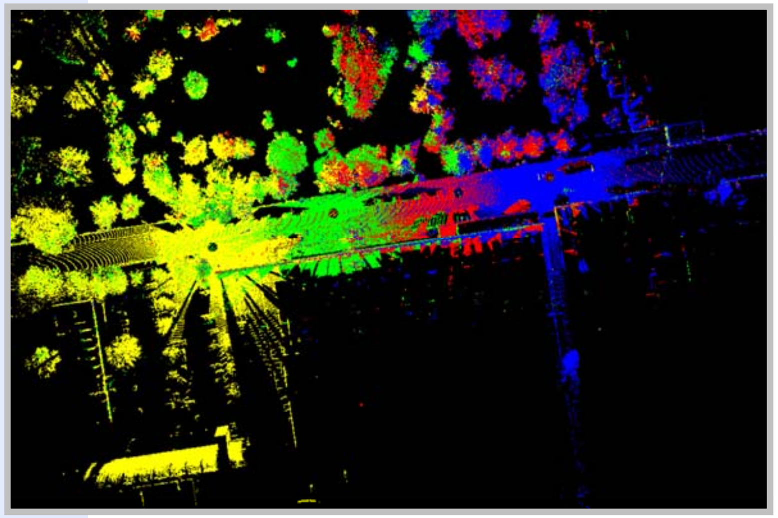
Geosensor Networks



Geosensor Networks: many sensors cooperating

- Extension of individual sensors' perception
  - „look around the corner"
  - Make others „transparent"
- Users can exploit information of others in order to
  - Determine state of road (e.g. in case of ice or oil-spills)
  - Find partners with similar interest in local environment
- Cooperative data capture and use
  - Cooperatively calculate model of environment (e.g. 3D-model of buildings)
  - Calculate 3D-environmental map for more precise positioning and navigation

„Map" from terrestrial Laser Data



Situation today and in near future

Different data are acquired by different users and sensors related to same spatial situation

- Different requirements
- Different objects
- Different richness in object descriptions
- Different scales
- Different quality
- Different time

Does this make sense ?

- No longer “one data set for all purposes”
- Benefits:
  - Only data is acquired, that is necessary for current application
    - No need to capture more than is needed
  - Incremental refinement / enrichment of information is possible
    - Mutual transfer of attributes
    - „averaging“ geometries
  - Reuse of information
  - Quality check, redundancy
    - Quality check by integration of data that have been acquired for different purpose

Requirements

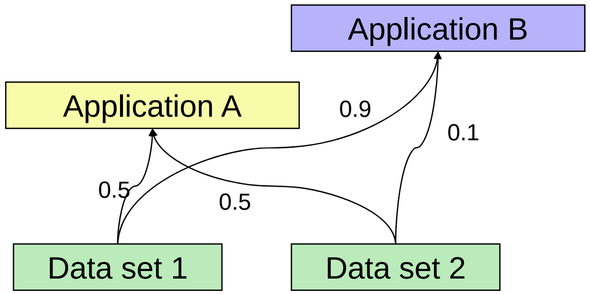
- Automatic integration and processing
- Semantic and geometric integration
- Integrated processing of distributed information

Data Integration and fusion

- Integration leads to derviation of new knowledge
- Data not necessarily fit exactly: both related to semantics and to geometry

Ideal:

- System that automatically selects adequate data sets for given tasks, integrates them and geometrically adapts them



Data Integration

Motivation

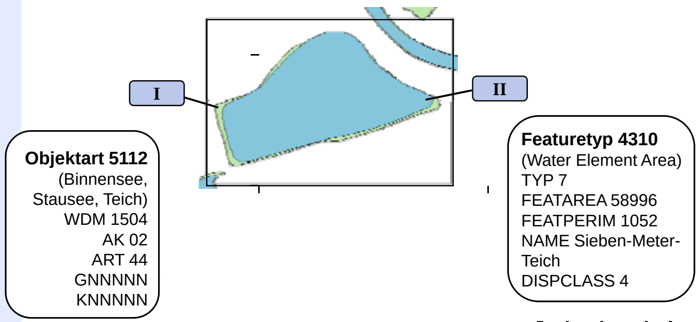
- Goal: find out data sets that fit to each other
- Example: search for water areas
  - They can be represented in different data sets; typically they are named differently
    - Wasser
    - Water
    - qh/W////
    - …
- Needed:
  - Understand meaning of data
    - Or better: use data in meaningful way
  - Meaning is coded in machine readable form: ontologies, i.e. concepts and relationships
  - Identification of corresponding concepts in different ontologies

Identification of corresponding concepts

- Manual identification based on analysis of individual concept descriptions, e.g. GiMoDig-Project (Harmonization of topographic data in Europe)
  - Definition and set up of „global schema“ of topographic information
  - Manual identification of correspondences and transformations of local schemata of countries to global schema
- Approach for automation: instance based reasoning
- Idea:
  - If two objects are located at same position in reality and have similar structure, then they also share semantic similarities
  - i.e.: exploitation of identical geometries to infer semantic correspondences

Instance based approach

- Geometric coincidence
  - Same spatial extent
  - And / or
  - Similar geometric properties
- Semantic correspondence
  - Two descriptions concerning same physical entity
  - -> relation between descriptions

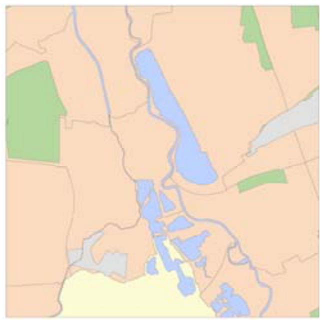


[Birgit Kieler]

Test data sets

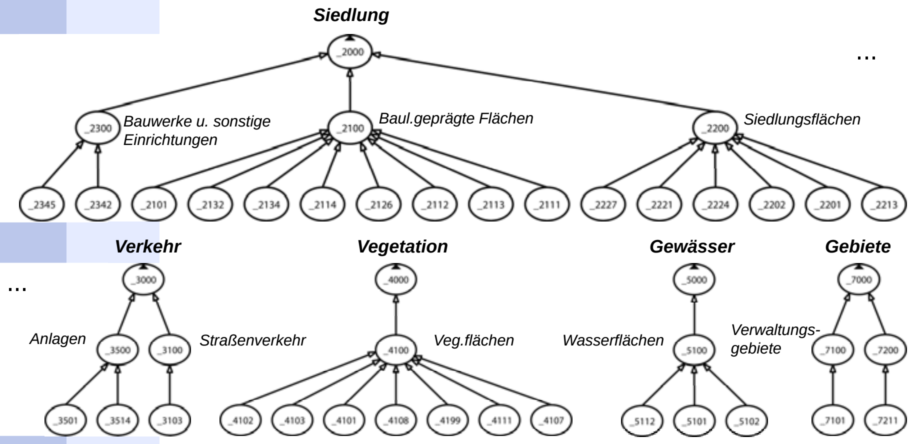
- ATKIS and TeleAtlas (GDF) → similar scale 1:25.000
- Test area: Hanover 25 km²
- Polygon-objects

ATKIS



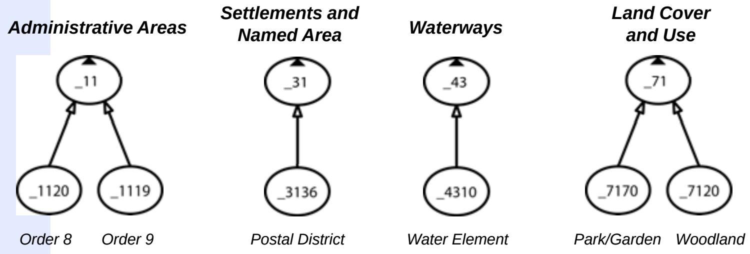
GDF

Ontology Representation: ATKIS



ATKIS

Ontology Representation: GDF



Which concepts from ATKIS correspond to which concepts from GDF ?

Methods to establish correspondences

- Matching of overlapping geometries
  - layer structure
  - Intersection
  - Area comparison
  - Statistical analysis

data set I		1	2	3
	A	N_{A1}	N_{A2}	N_{A3}
	B	N_{B1}	N_{B2}	N_{B3}
	C	N_{C1}	N_{C2}	N_{C3}
		data set II		

N: number of possible matching candidates

Intersection Matrix

ATKIS	1 (wa)	3 (wa)	4 (wa)	5 (wa)	7170 (lu)	9715 (lu)	3136 (pd)	7120 (lc)	1119 (a8)	1120 (a9)
2101		0,05			0,02	0,10	0,70	0,02	0,70	0,76
2111						0,01	0,24		0,24	0,26
2112						0,53	0,08		0,08	0,09
2113						0,01	0,07		0,07	0,08
2114							0,07		0,07	0,07
2126										
2132										
2134										
2201					0,01		0,04	0,01	0,04	0,05
2202			0,06	0,06			0,01		0,01	0,01
2213							0,03		0,03	0,03
2221										
2224			0,06	0,06			0,01		0,01	0,01
2227	0,01					0,01	0,06		0,06	0,06
2342					0,02		0,01	0,01	0,01	0,02
2345										
3103						0,01	0,02		0,02	0,02
3501					0,01	0,18	0,02	0,01	0,02	0,02
3514										
4101							0,01		0,01	0,01
4102			0,01				0,06		0,06	0,07
4103							0,04	0,01	0,04	0,05
4107					0,33		0,04	0,64	0,04	0,04
4108	0,02						0,01		0,01	0,01
4111										
4199	0,01									
5101	0,52	0,06					0,01		0,01	0,01
5102										
5112		0,46	0,31	0,09			0,06		0,06	0,06
7101	0,01	0,03	0,02	0,01	0,01	0,07	1,00	0,03	1,00	0,93
7211										

GDF

$$\frac{|I\_A \cap II\_1|}{|I\_A \cup II\_1|}$$

Intersection Matrix

ATKIS	1 (wa)	3 (wa)	4 (wa)	5 (wa)	7170 (lu)	9715 (lu)	3136 (pd)	7120 (lc)	1119 (a8)	1120 (a9)
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2202			0,06	0,06			0,01		0,01	0,01
2213							0,03		0,03	0,03
2221										
2224			0,06	0,06			0,01		0,01	0,01
2227	0,01					0,01	0,06		0,06	0,06
2342					0,02		0,01	0,01	0,01	0,02
2345										
3103						0,01	0,02		0,02	0,02
3501					0,01	0,18	0,02	0,01	0,02	0,02
3514										
4101							0,01		0,01	0,01
4102			0,01				0,06		0,06	0,07
4103							0,04	0,01	0,04	0,05
4107					0,33		0,04	0,64	0,04	0,04
4108	0,02						0,01		0,01	0,01
4111										
4199	0,01									
5101	0,52	0,06					0,01		0,01	0,01
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5112		0,46	0,31	0,09			0,06		0,06	0,06
7101	0,01	0,03	0,02	0,01	0,01	0,07	1,00	0,03	1,00	0,93
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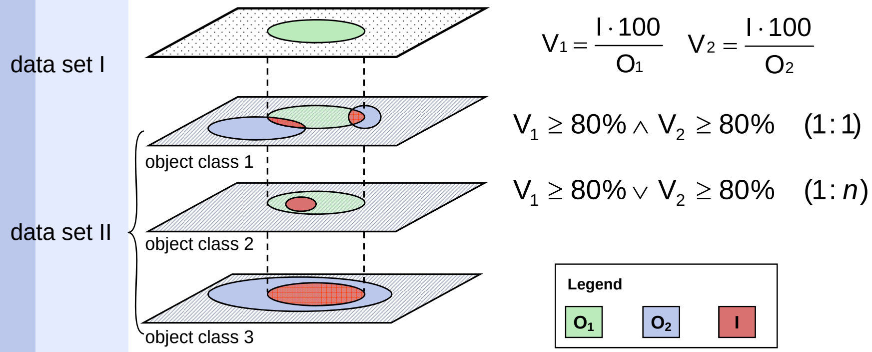
GDF

$$\frac{|I\_A \cap II\_1|}{|I\_A \cup II\_1|}$$

Matching of overlapping geometries



$$V_1 = \frac{I \cdot 100}{O_1} \quad V_2 = \frac{I \cdot 100}{O_2}$$

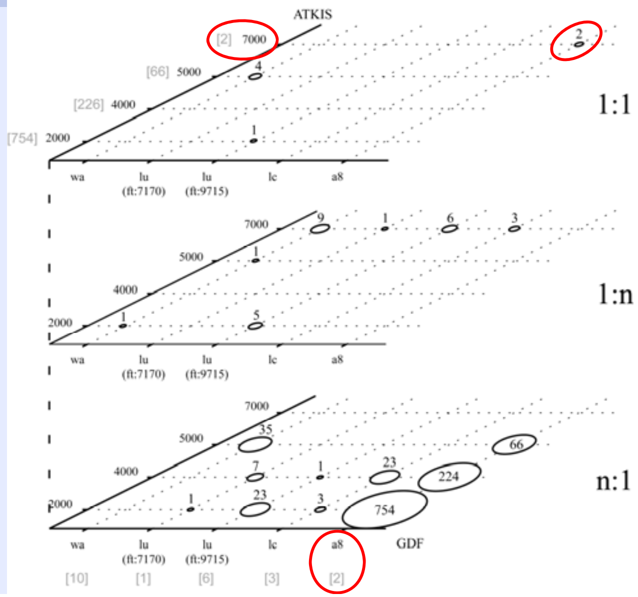
$$V_1 \geq 80\% \wedge V_2 \geq 80\% \quad (1:1)$$

$$V_1 \geq 80\% \vee V_2 \geq 80\% \quad (1:n)$$

Analysis of Correspondences

- Analysis of links
- Links on instance level reveal correspondences on concept level
  - 1 : 1 relationship → Equivalence ($X_1 \equiv X_2$)
  - 1 : n relationship → Inclusion ($X_1 \subseteq X_2$)
  - n : m relationship → Overlap ($X_1 \cap X_2 \neq 0$)
  - 1 : 0 relationship → Disjunction ($X_1 \cap X_2 = \varnothing$)

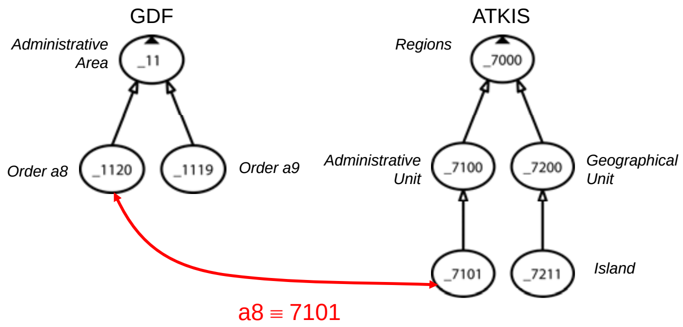
Analysis of 1:1-Correspondences



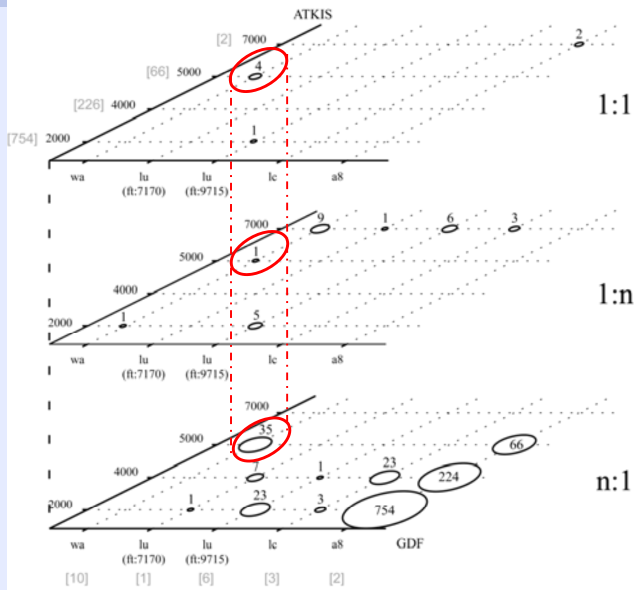
Analysis of Correspondences

- Equivalence ($X_1 \equiv X_2$)

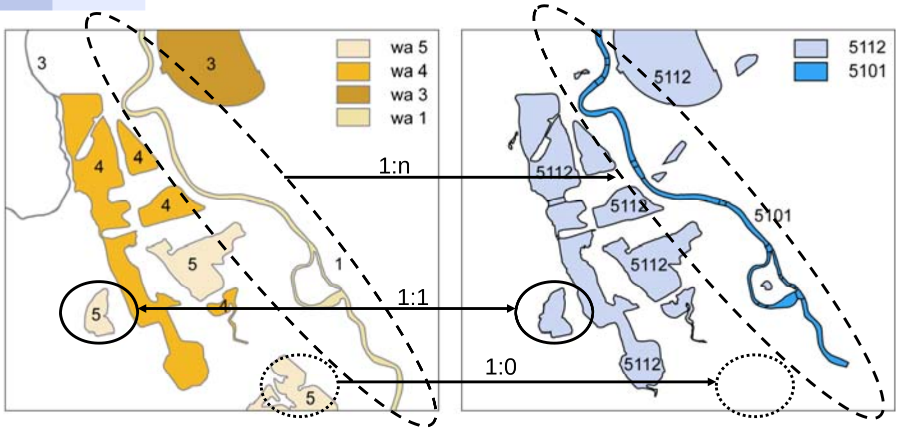
  → 1 : 1 relation



Analysis of Correspondences: wa <-> 5000



Analysis of Correspondences

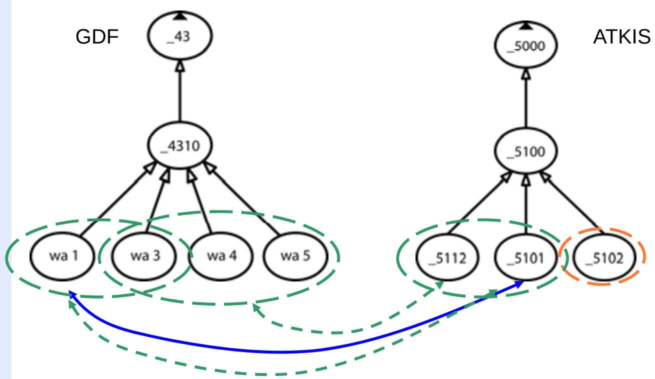


GDF

ATKIS

Analysis of Correspondences

- Inclusion ($X_1 \subseteq X_2$) → 1 : n relations
- Overlap ($X_1 \cap X_2 \neq 0$) → n : m relations
- Disjunction ($X_1 \cap X_2 = \varnothing$) → 1 : 0 relations

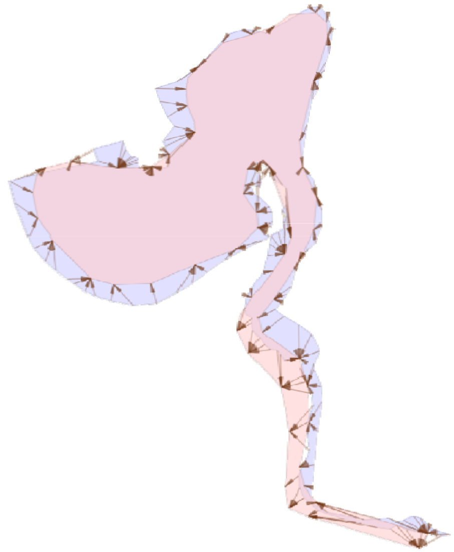


Benefits

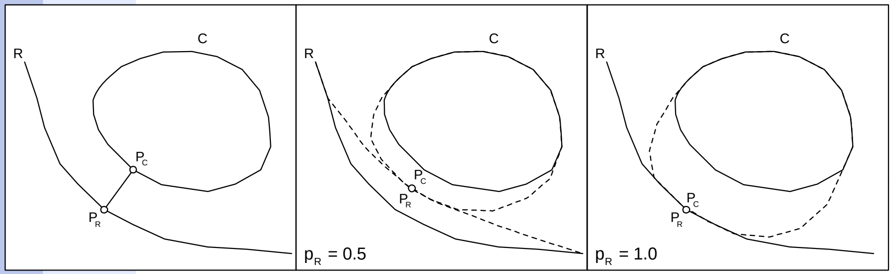
- Automatic identification of corresponding concepts in different ontologies
- Object instances reflect use of concepts and also context into which concepts are embedded

- Automation of data use
- Mutual data enrichment (e.g. by exchange of attributes between corresponding objects)
- Fusion of data sets for integrated analysis, e.g. using geometric morphing

Correspondences of object boundary



Adapation – different weights

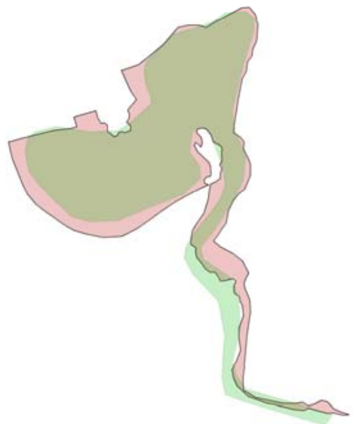


- p = 0.5 : intermediate geometry

- p = 1.0 : adaptation to one reference geometry

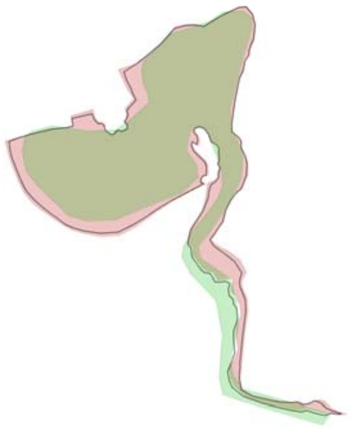
Interpolation

- Weights (Reference 1.0 : Candidate 0.0)



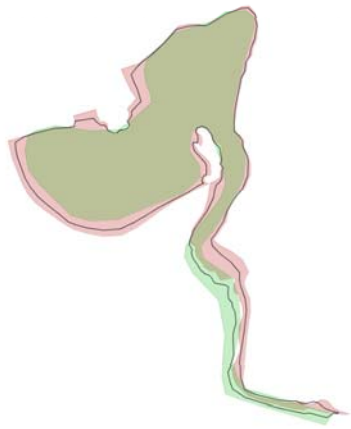
Interpolation

- Weights (Reference 0.8 : Candidate 0.2)



Interpolation

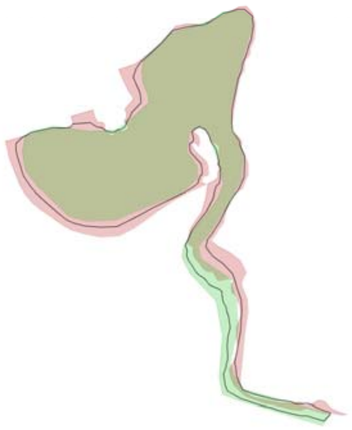
- Weights (Reference 0.6 : Candidate 0.4)



2009/fig

Interpolation

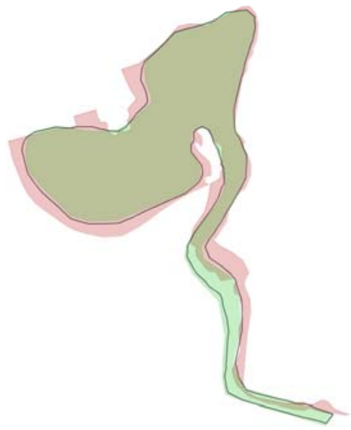
- Weights (Reference 0.4 : Candidate 0.6)



2009/fig

Interpolation

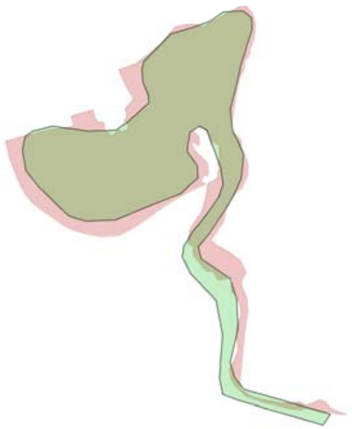
- Weights (Reference 0.2 : Candidate 0.8)



2009/fig

Interpolation

- Weights (Reference 0.0 : Candidate 1.0)

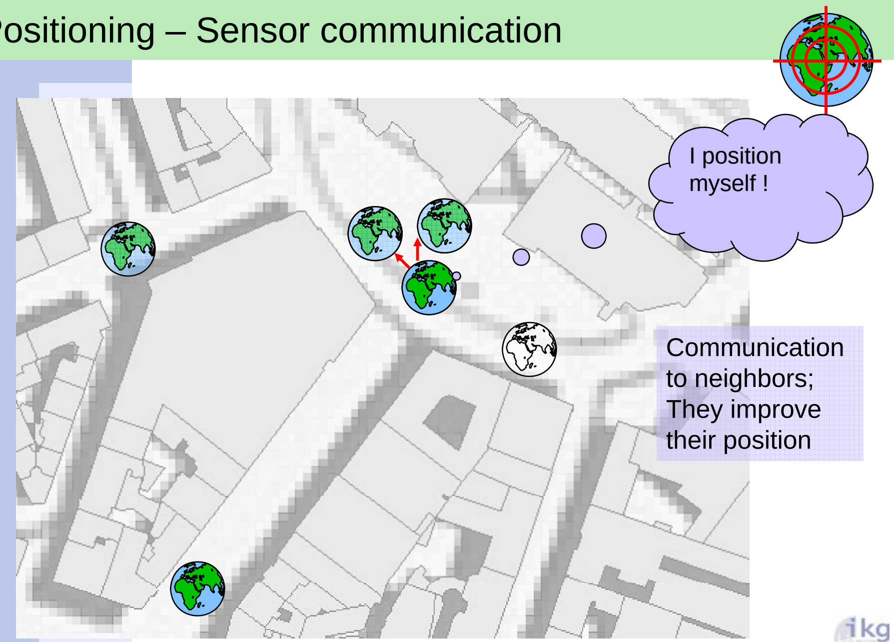


Quality analysis

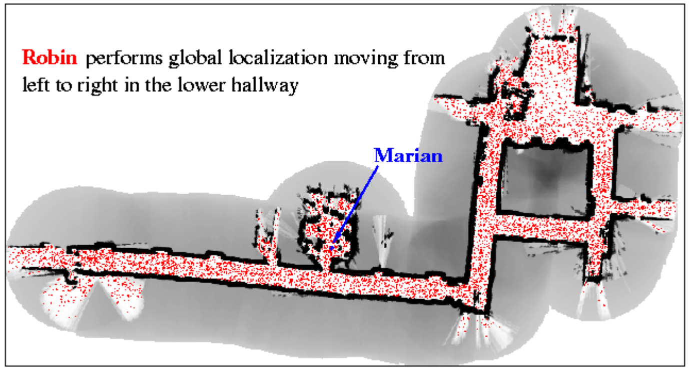
- Identification of deviations between data sets
- Large deviations give rise to
  - Different levels of detail
  - Different quality levels (e.g. acquisition with sensors of different quality)
- Integration of many measurements lead to quality improvement

Cooperative data processing

Positioning – Sensor communication



Collaborative positioning



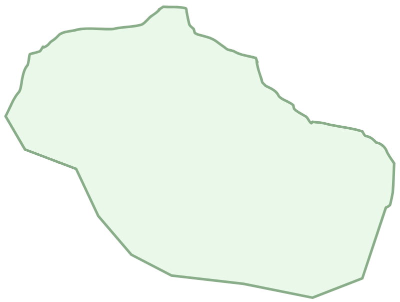
(animation)

Source: S. Thrun, Stanford

Collaborative Distributed Processing

- Local decision making to achieve intended global goal
- Prerequisite
  - Local processing capabilities
  - Local operations: algorithms that operate on local knowledge but can monitor geographic phenomena with global extents (<-> algorithms that operate on entire data sets)
  - Cooperation of sensors in local neighborhood (neighborhood size depends on communication range)
- Example:
  - Detection of boundaries of spatial phenomenon
    - E.g. temperature sink, movement (hill slide), …
  - Additional prerequisite: moving sensors

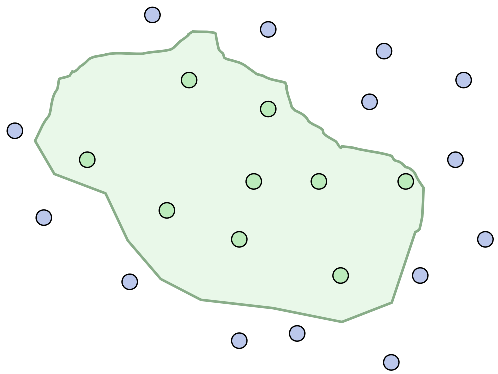
Spatial phenomenon



- Task: detect the boundary of the phenomenon using distributed sensor network

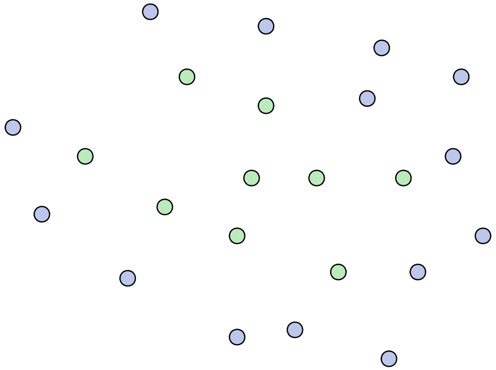
[Sester 2009]

Distributed Detection of Phenomenon Boundary



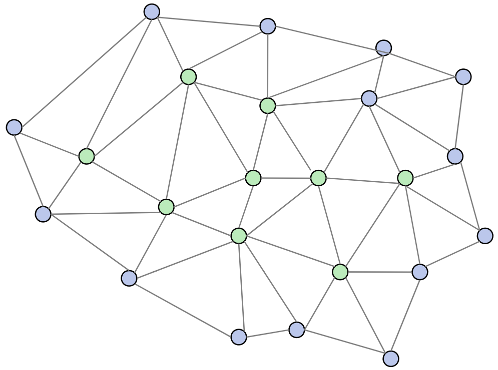
- Sensors are distributed and individually measure phenomenon (e.g. temperature, velocity, …)

Distributed Detection of Phenomenon Boundary



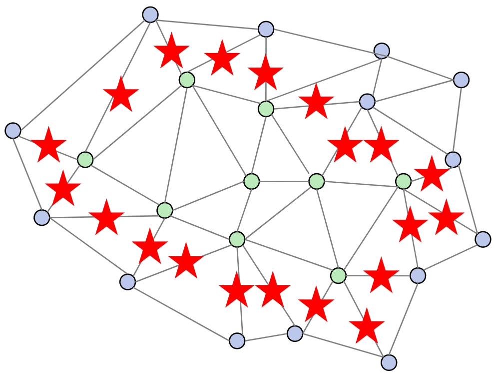
- Sensor distribution and measurement (here: binary):
  - Green: phenomenon detected
  - Blue: no phenomenon detected

Distributed Detection of Phenomenon Boundary



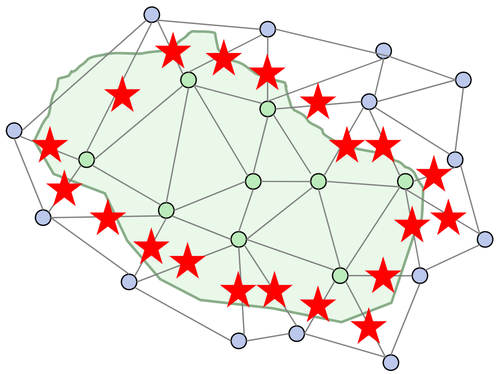
- Communication range of sensors (here: nearest neighbors)

Distributed Detection of Phenomenon Boundary



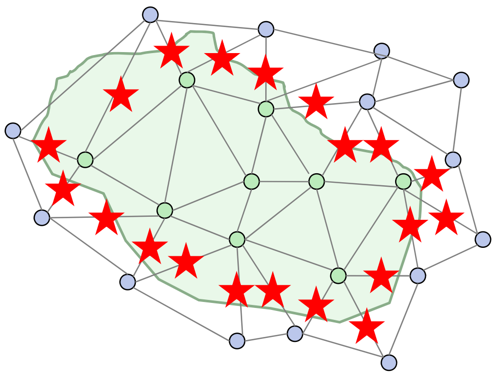
- Simple interpolation of boundary

Distributed Detection of Phenomenon Boundary



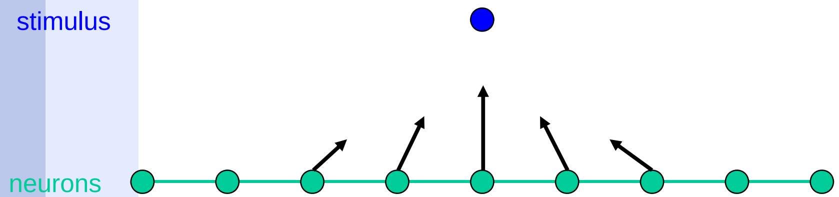
- Not exactly reflects true boundary

Distributed Detection of Phenomenon Boundary

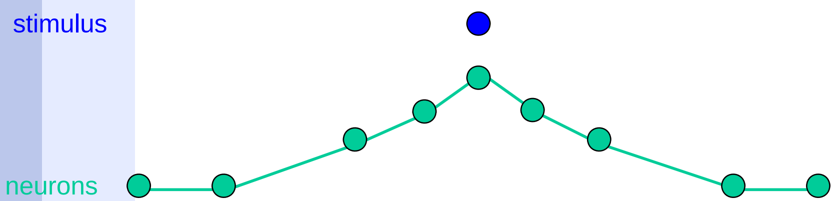


- Idea: use Self Organizing Network (Neural Network) to approximate the boundary

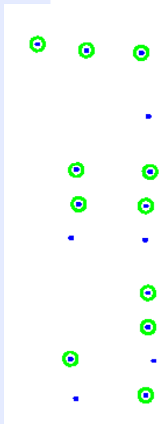
Principle of Self Organizing Network



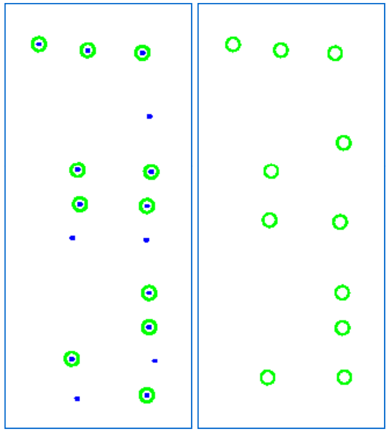
Principle of Self Organizing Network



Example – linear structure

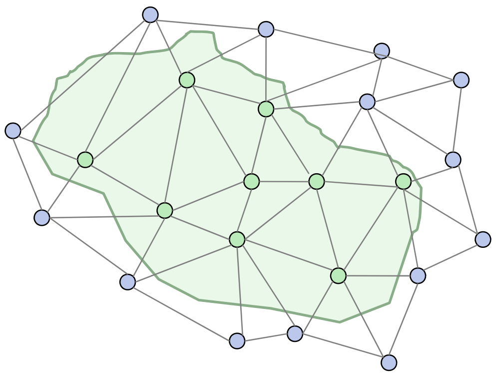


animation



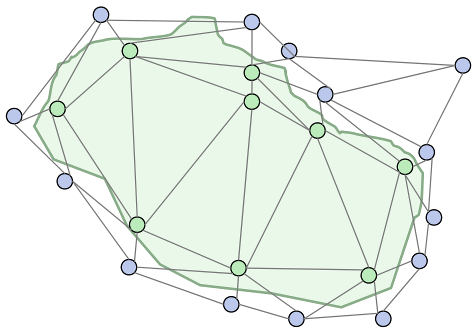
start situation final situation

Distributed Detection of Phenomenon Boundary



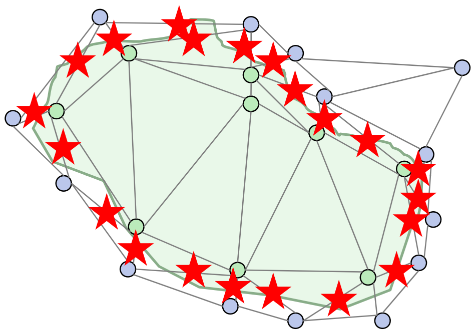
- Before SOM-adaptation

Distributed Detection of Phenomenon Boundary



- After SOM-adaptation
  - Sensors move towards phenomenon boundary
  - Sensor distribution is more dense at boundary

Distributed Detection of Phenomenon Boundary



- Result: better approximation of boundary

Summary and Conclusion

Geo-Sensor Networks: challenges and benefits

- Challenges:
  - Heterogeneous data
  - Heterogeneous quality
  - Heterogeneous coverage
  - Heterogeneous data types: from low-level to high-level information, e.g. raw Lidar points to GIS-data
- Benefits:
  - Highly timely information -> “instant information”
  - Scalability
  - Redundancy – fault tolerance:
    - System does not depend on one sensor
  - Multi-purpose use of data (beyond original acquisition purpose)

Outlook on future research topics

- Continuous blur between data acquisition and processing
- On-the-fly data interpretation based on uncertain and incomplete knowledge
- Privacy issues
  - How can I both use the crowd-collected services but not give away my privacy ?
- Interoperability
  - Seamless integration and fusion of information
- Quality
  - Assure and propagate quality measures of data and and processes