3D Topography

A simplicial Complex-based Solution in a Spatial DBMS

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GIS-t lunch meeting January 18, 2008

TU Delft

Presentation outline

- Introduction
- Previous presentation (01-09-06)
  - Characteristics simplicial complex-based approach
  - Simplicial complexes applied to 3D Topography
  - Implementation details
- Update operations (feature insertion)
- Test data sets
  - Tetrahedronisation of models
  - Storage requirements, comparison to Oracle 11g polyhedrons
- Future research & conclusions

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Introduction (1/2)

PhD research within RGI-011

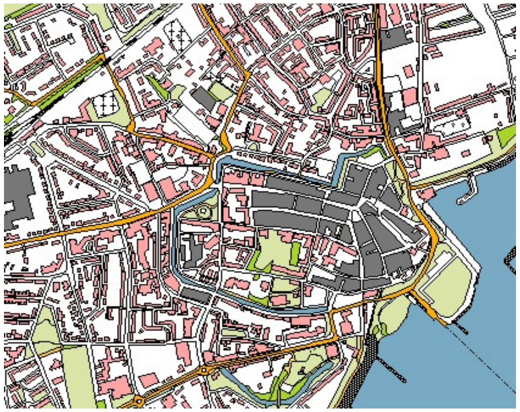
Objective RGI-011:

Enforcing a major break-through in the application of 3D Topography in corporate ICT environments due to structural embedding of 3D methods and techniques.

Research question my PhD:

How can a 3D topographic representation be realised in a feature-based triangular data model?

Introduction (2/2)



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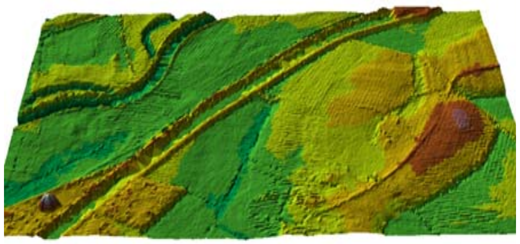

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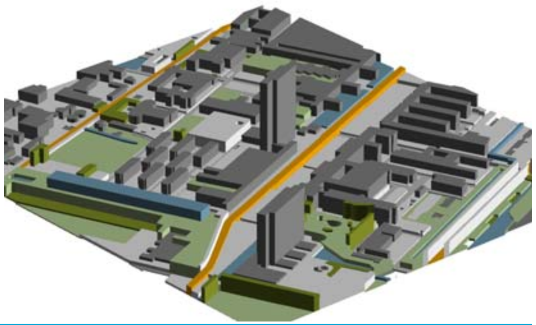

Two-step approach:

- How to develop a conceptual model that describes the real world phenomena (the topographic features)?
- How to implement this conceptual model, i.e. how to develop a suitable DBMS data structure?

Focus:

storage, analysis, validation

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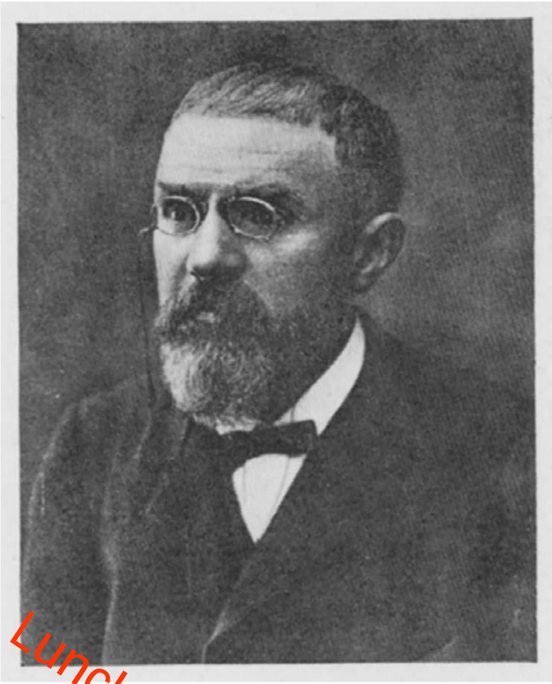
Previous presentation



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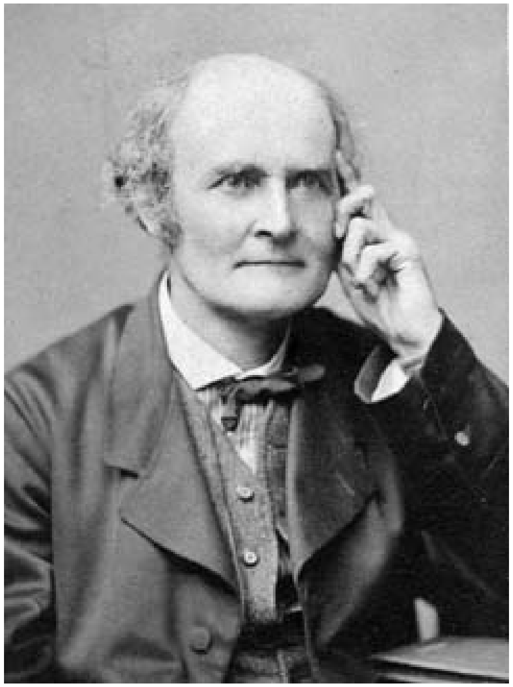

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= 3D GIS?

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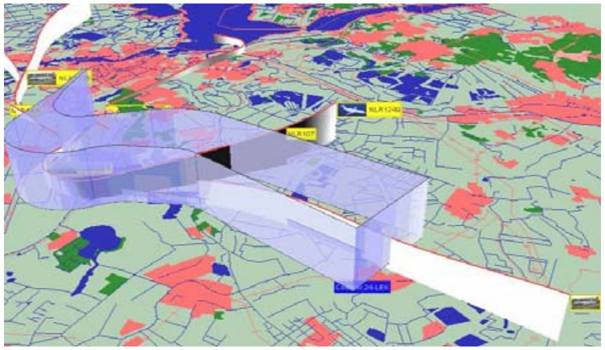
Previous presentation

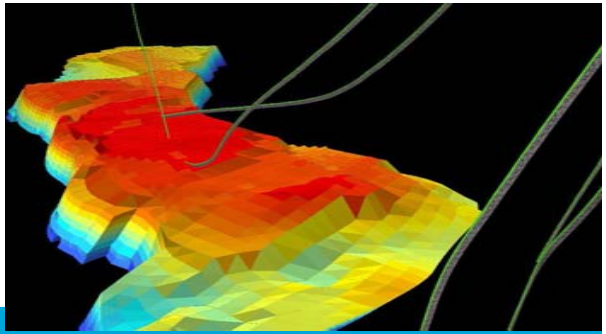
Characteristics sc-based approach (1/3)



Characteristic 1: Full decomposition of space

Two fundamental observations (Cosit'05 paper):

- ISO19101: a feature is an 'abstraction of real world phenomena'. These real world phenomena have by definition a volume
- Real world can be considered to be a volume partition (analogous to a planar partition: a set of non-overlapping volumes that form a closed modelled space)



Result: explicit inclusion of earth and air

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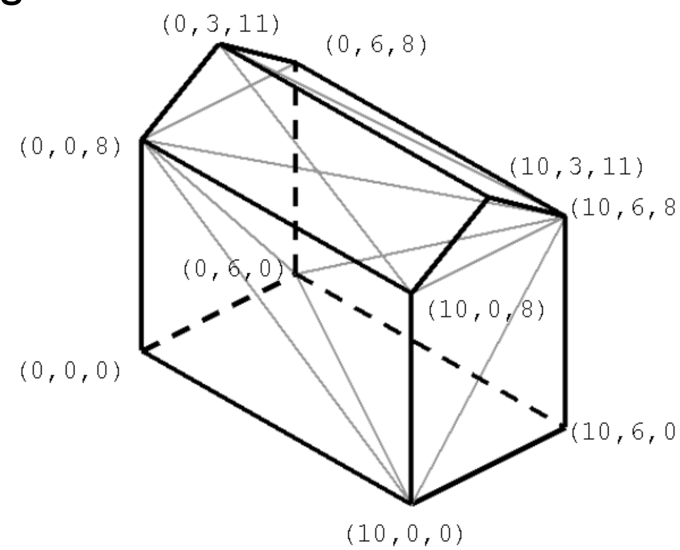
Previous presentation
Characteristics sc-based approach (2/3)

Characteristic 2: constrained TEN

object boundaries represented by constraints

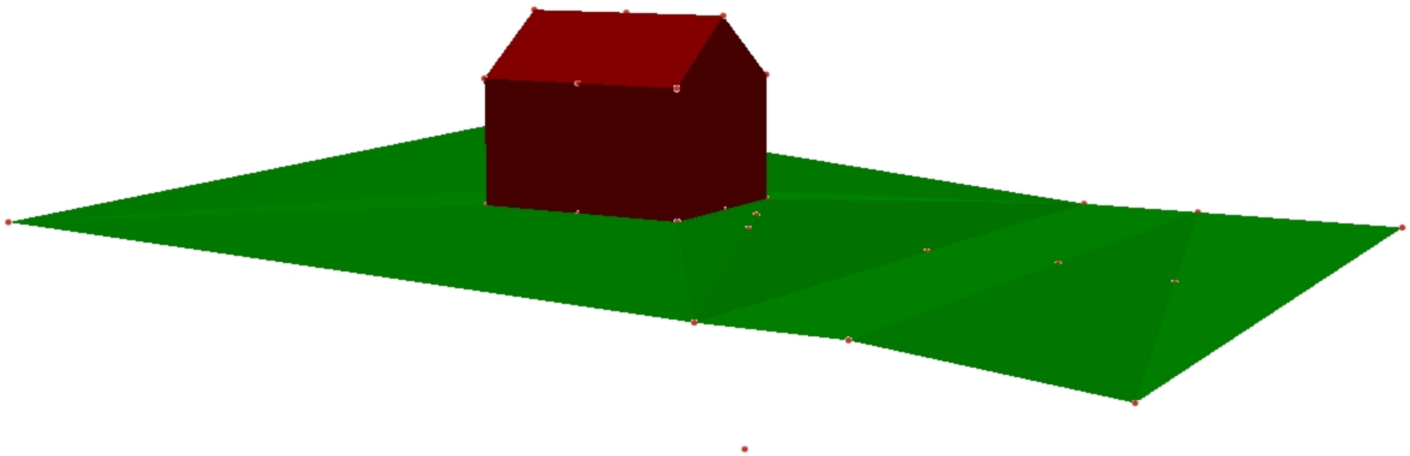


Advantages of TEN:

- Well defined: a n-simplex is bounded by n + 1 (n - 1)-simplexes.
- Flatness of faces: every face can be described by three points
- A n-simplex is convex (which simplifies amongst others point-in-polygon tests)

Previous presentation

Example: small data set



Previous presentation

Characteristics sc-based approach (3/3)

Characteristic 3: based on Poincaré simplicial homology

solid mathematical foundation (SDH'06 paper):

Simplex S_n defined by ($n+1$) vertices: $S_n = <v_0,\ldots v_n>$

The boundary ∂ of simplex S_n is defined as sum of *(n-1)* dimensional simplexes (note that 'hat' means skip the node):

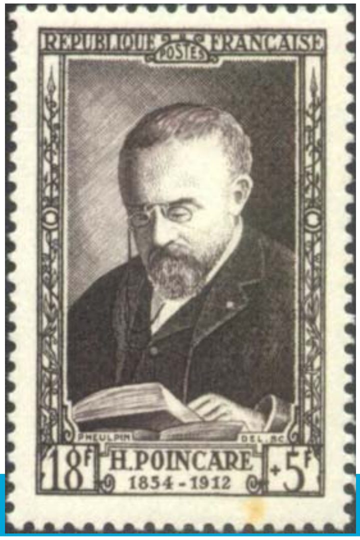
$$\partial S_n = \sum_{i=0}^{n} (-1)^i < v_0,\ldots,\hat{v}_i,\ldots,v_n >$$

remark: sum has n+1 terms

$S_1 = <v_0, v_1>$ $\quad\quad$ $\partial S_1 = <v_1> - <v_0>$

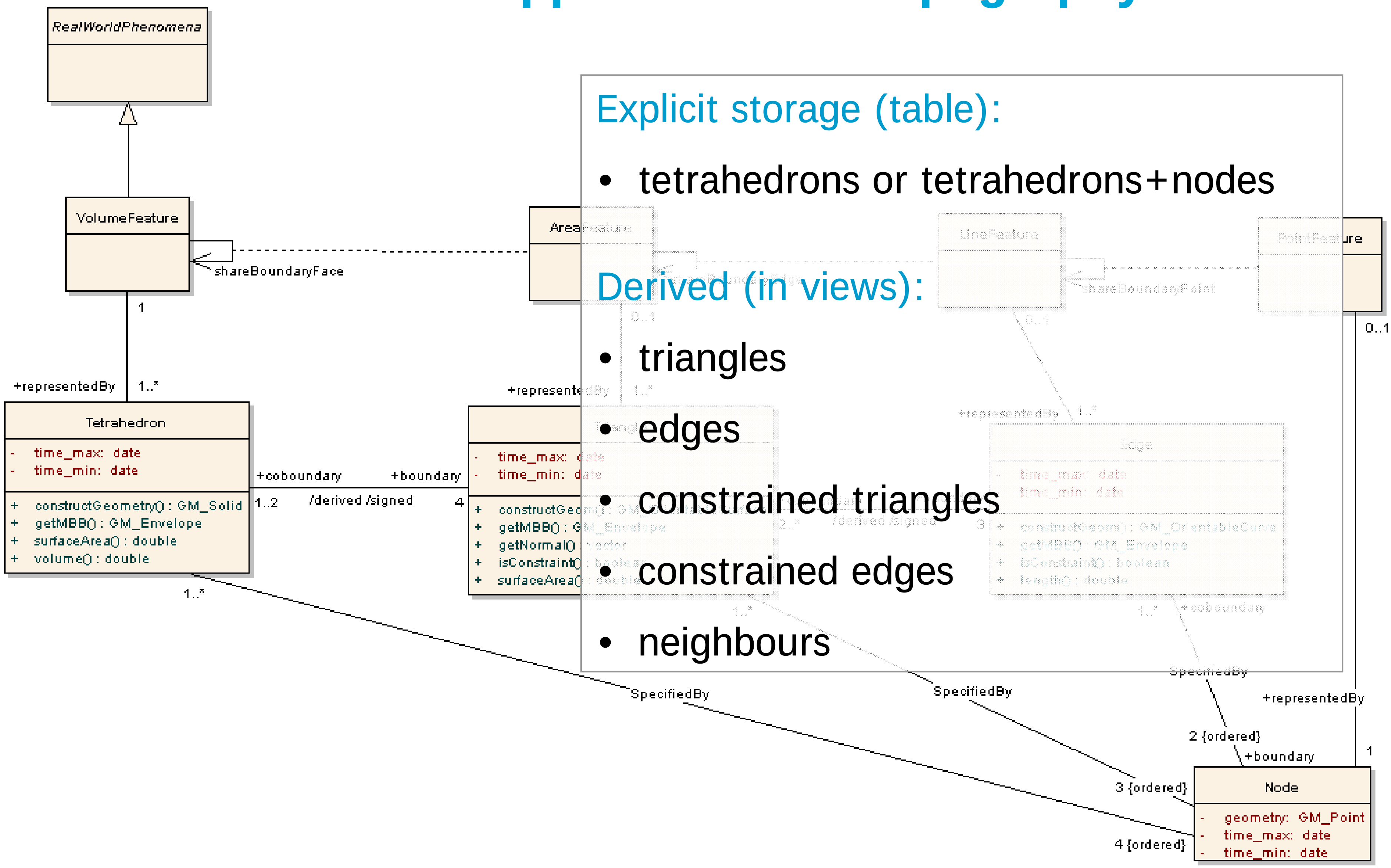
$S_2 = <v_0, v_1, v_2>$ $\quad\quad$ $\partial S_2 = <v_1, v_2> - <v_0, v_2> + <v_0, v_1>$

$S_3 = <v_0, v_1, v_2, v_3>$ $\quad\quad$ $\partial S_3 = <v_1, v_2, v_3> - <v_0, v_2, v_3> + <v_0, v_1, v_3> - <v_0, v_1, v_2>$



Previous presentation

SC-based approach to 3D topography



Explicit storage (table):

- tetrahedrons or tetrahedrons+nodes

Derived (in views):

- triangles
- edges
- constrained triangles
- constrained edges
- neighbours

Previous presentation

Implementation details

$$\partial S_n = \sum_{i=0}^{n} (-1)^i < v_0, \ldots, \hat{v}_i, \ldots, v_n >$$

Boundary operator implemented in PL/SQL procedure

Procedure used to define views with triangles, edges, constrained triangles (object boundaries!), constrained edges, e.g.:

```
create or replace view triangle as
    select deriveboundarytriangle1(tetcode) tricode,
    tetcode fromtetcode from tetrahedron
    UNION ALL
    select deriveboundarytriangle2(tetcode) tricode,
    tetcode fromtetcode from tetrahedron
    UNION ALL
    ...
```

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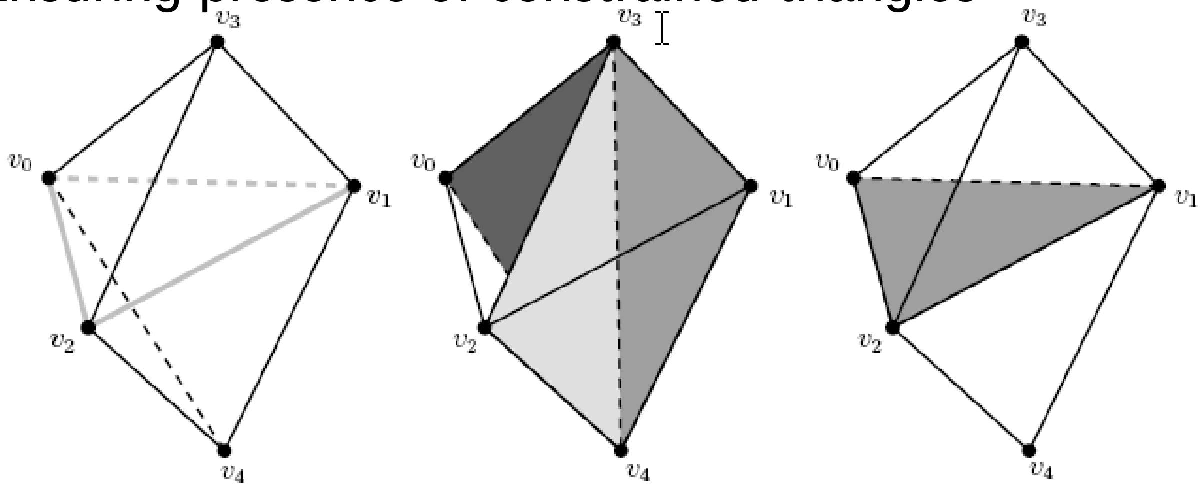
Update operations

Four steps in feature insertion

1. Feature boundary triangulation: input for step 2
2. Inserting constrained edges with new approach (following slides)
3. Ensuring presence of constrained triangles



4. Interior modelling + reclassifying tetrahedrons

Update operations

Insertion of constrained edge in a TEN

Usual approach: insert nodes, using flipping for edge recovery

Might fail in topographic TEN:

many constraints in close proximity ⟶ flipping not always possible

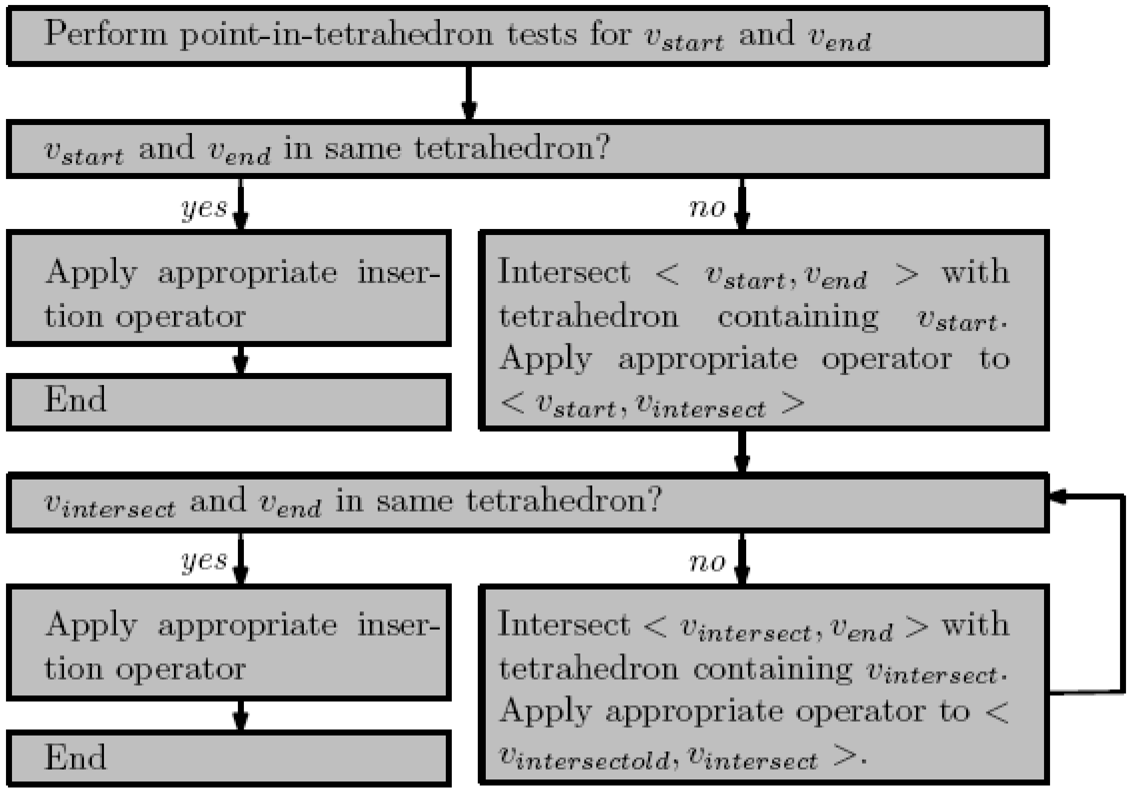
New approach: insert a complete constrained edge

Nine unique cases: *exhaustive + mutually exclusive*

Node lies on	Node	Edge	Triangle	Tetrahedron
Node	I_{00}	I_{01}	I_{02}	I_{03}
Edge	(I_{01})	I_{11}	I_{12}	I_{13}
Triangle	(I_{02})	(I_{12})	I_{22}	I_{23}
Tetrahedron	(I_{03})	(I_{13})	(I_{23})	I_{33}

Update operations

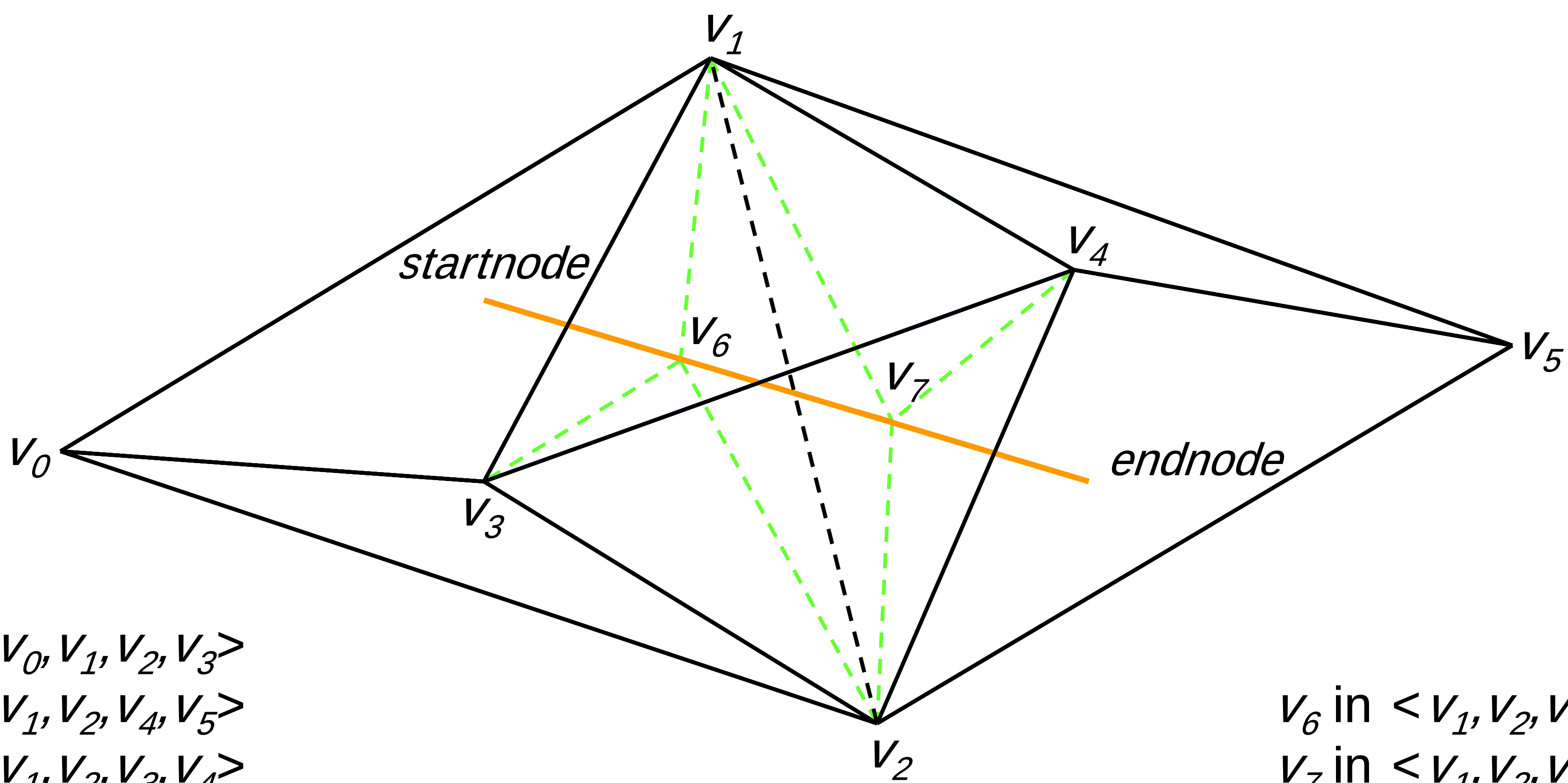
Insertion of constrained edge in a TEN



New approach: act as local as possible with minimal impact

Update operations

Example: constrained edge insertion



$<v_0, v_1, v_2, v_3>$
$<v_1, v_2, v_4, v_5>$
$<v_1, v_2, v_3, v_4>$

v_6 in $<v_1, v_2, v_3>$
v_7 in $<v_1, v_2, v_4>$

i.e. combination of intersection cases:
I_{23} - I_{22} - I_{23}

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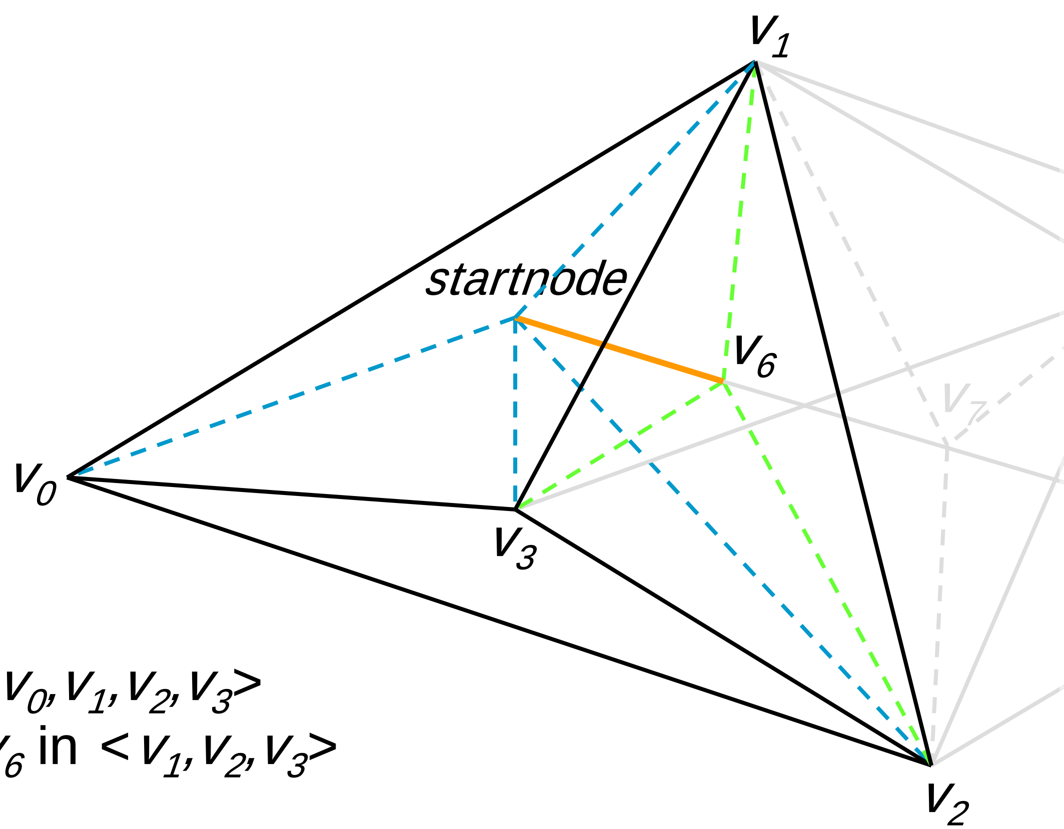
Update operations

Example: constrained edge insertion



$< v_0, v_1, v_2, v_3 >$

v_6 in $< v_1, v_2, v_3 >$

Tetrahedron split in six new tetrahedrons:

$< v_0, v_1, v_2,$ *startnode*$>$

$<$ *v0,*$v_1, v_3,$*startnode*$>$

$< v_0, v_2, v_3,$*startnode*$>$

$<$*startnode*$, v_6, v_1, v_2 >$

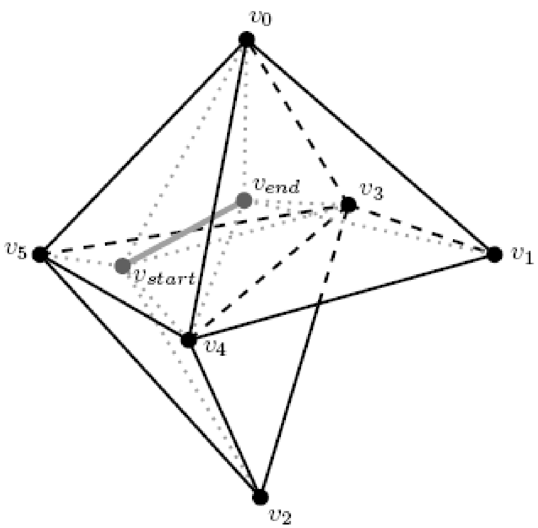
$<$*startnode*$, v_6, v_1, v_3 >$

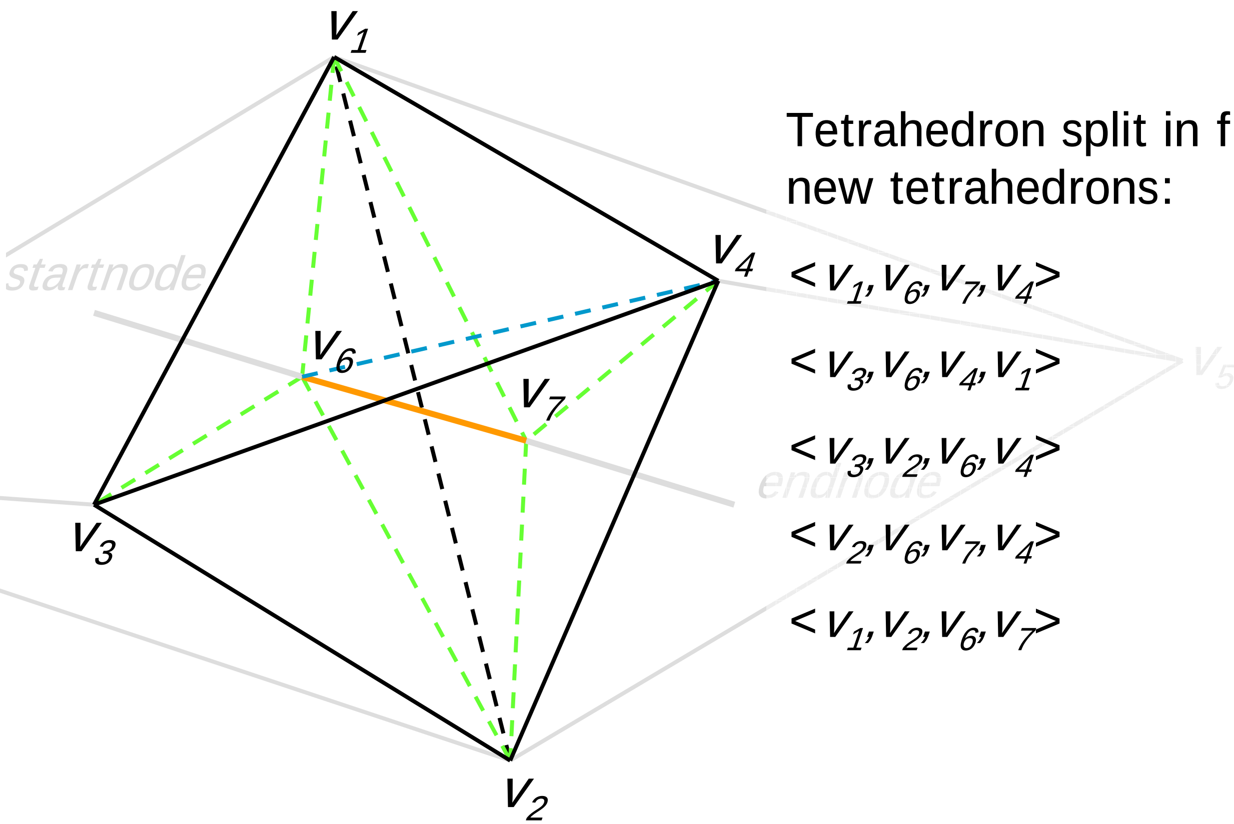
$<$*startnode*$, v_6, v_2, v_3 >$

![TU Delft]

Update operations

Example: constrained edge insertion





Tetrahedron split in five new tetrahedrons:

$<V_1, V_6, V_7, V_4>$

$<V_3, V_6, V_4, V_1>$

$<V_3, V_2, V_6, V_4>$

$<V_2, V_6, V_7, V_4>$

$<V_1, V_2, V_6, V_7>$

$<V_1, V_2, V_3, V_4>$
V_6 in $<V_1, V_2, V_3>$
V_7 in $<V_1, V_2, V_4>$

Update operations

Example: constrained edge insertion

Tetrahedron split in six new tetrahedrons:

$<v_2, v_4, endnode, v_5>$

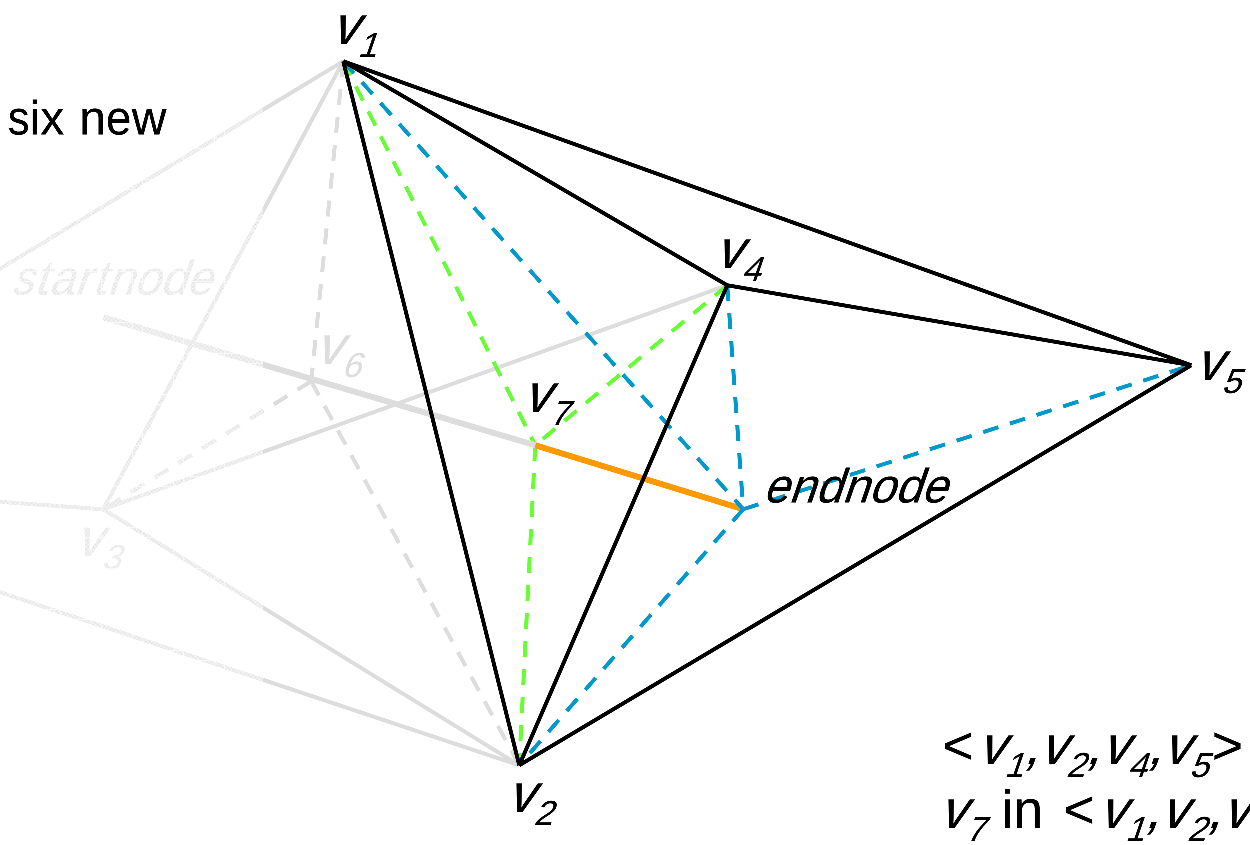
$<v_4, v_5, endnode, v_1>$

$<endnode, v_7, v_4, v_1>$

$<v_7, endnode, v_1, v_2>$

$<v_2, v_4, v_7, endnode>$

$<endnode, v_1, v_2, v_5>$



$<v_1, v_2, v_4, v_5>$

v_7 in $<v_1, v_2, v_4>$

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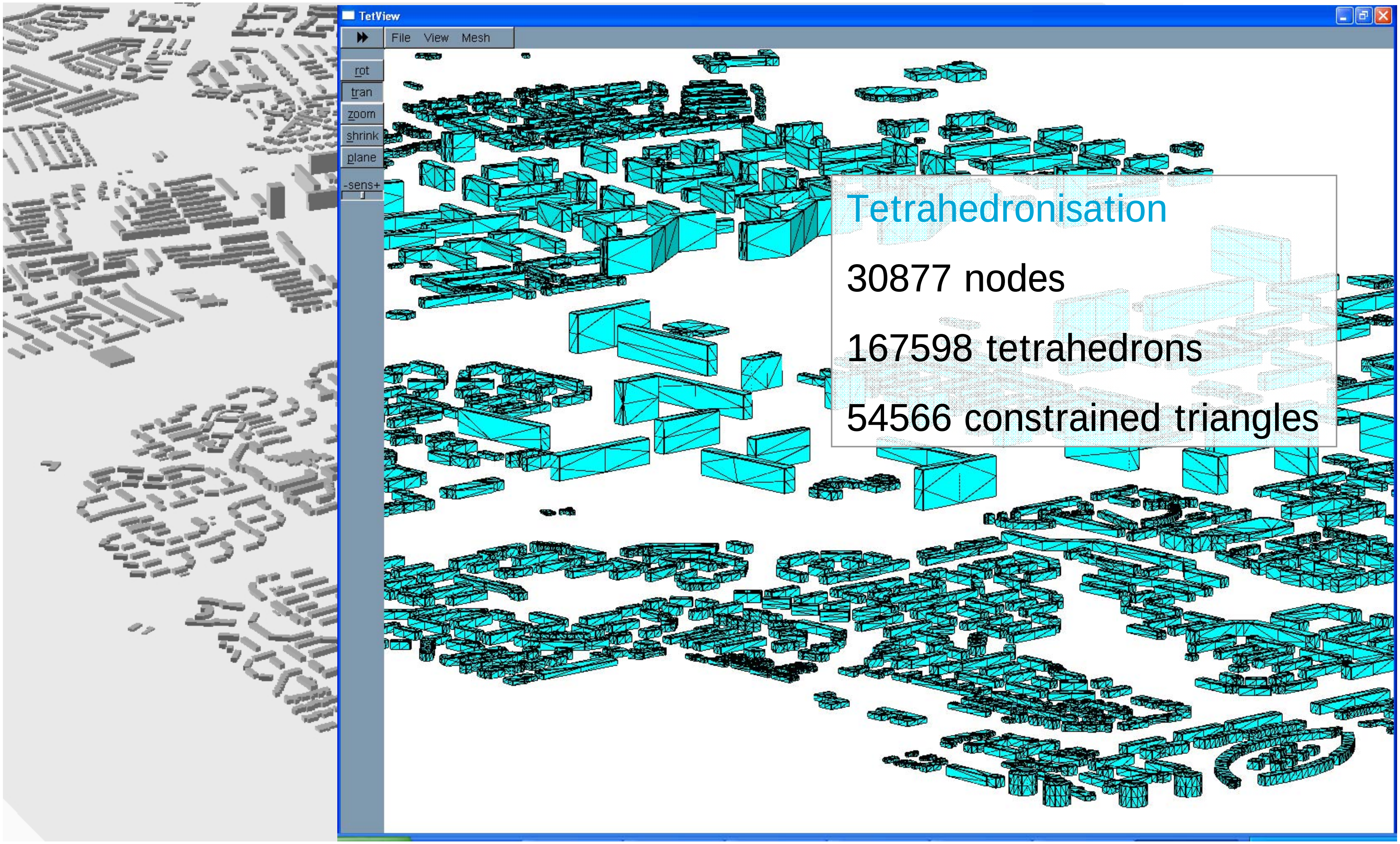
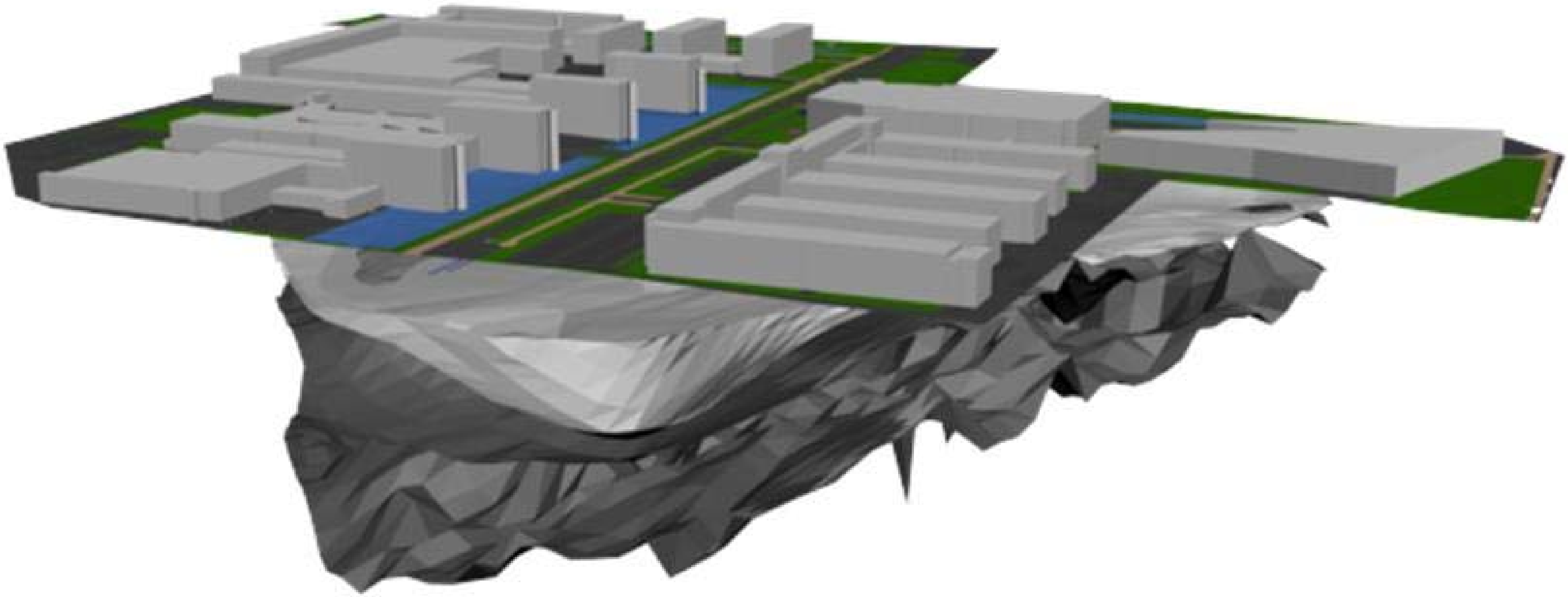
Test data sets (1/2)

Rotterdam data set

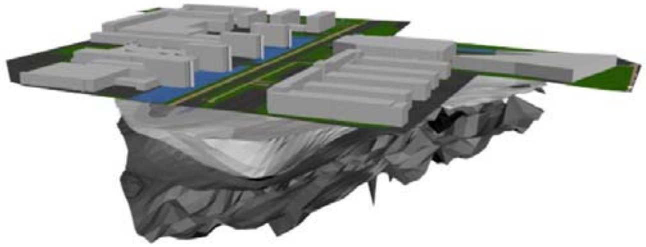


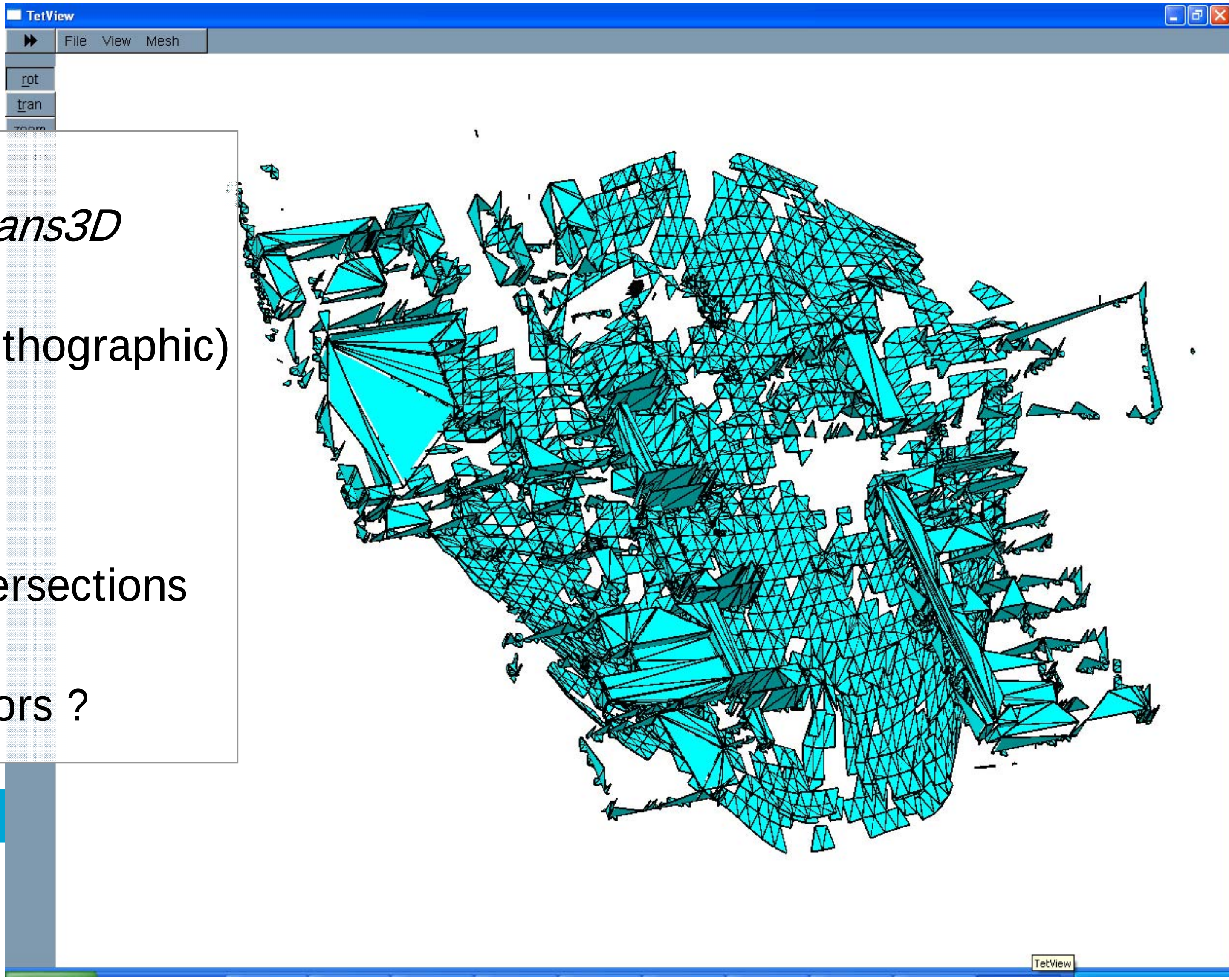
Test data sets (2/2)
Campus data set



Test data sets (2/2)

Campus data set





DXF

↓ *AccuTrans3D*

STL

↓ (StereoLithographic)

TetGen

↓

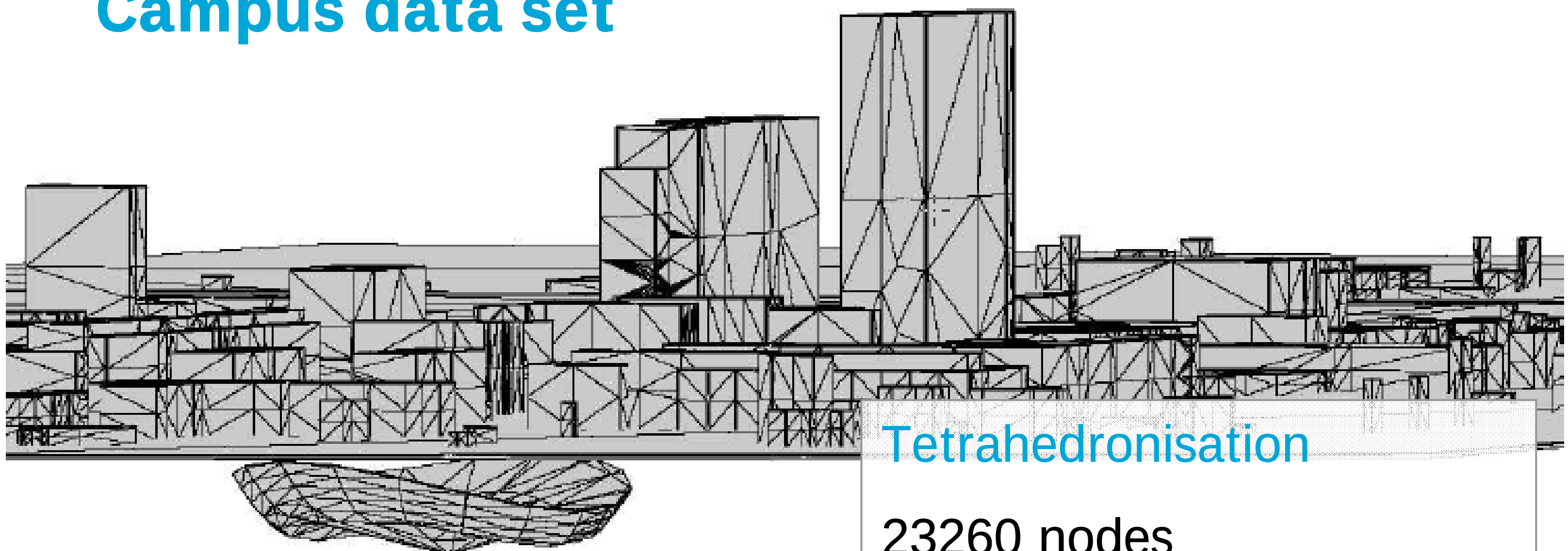
errors...

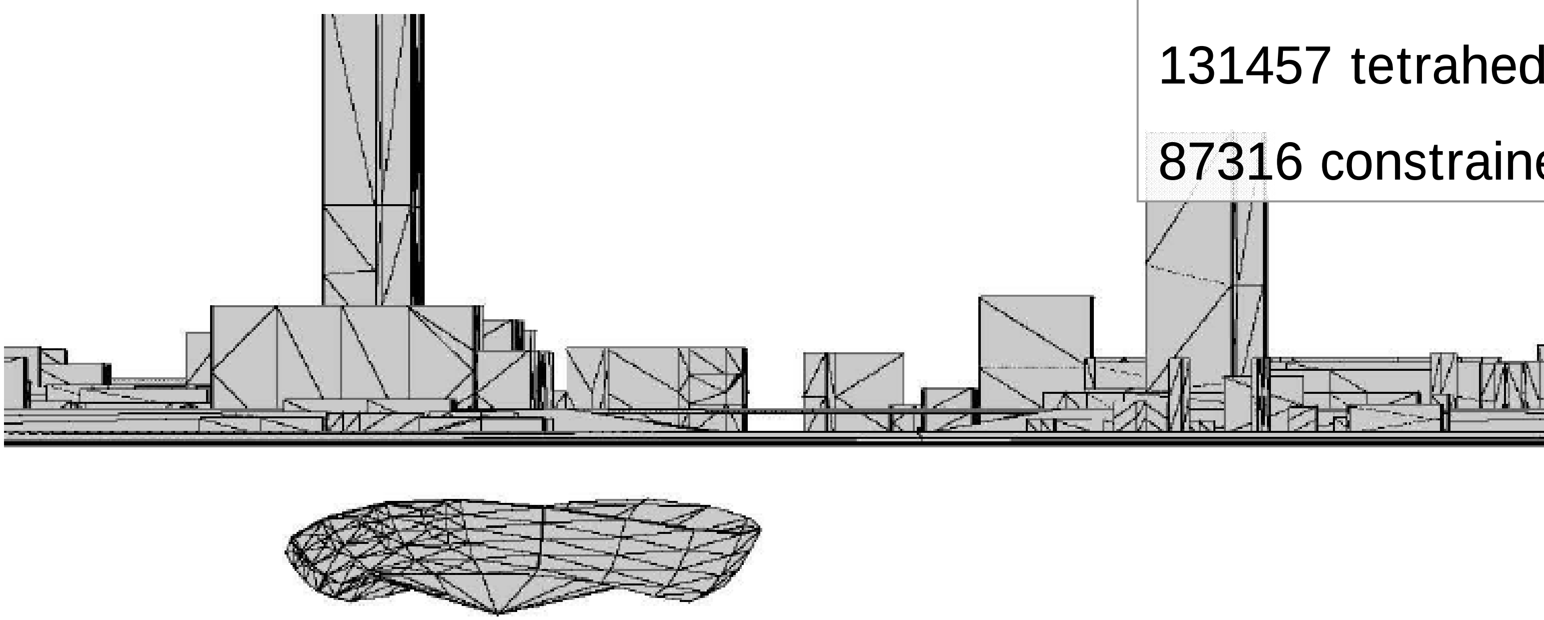
>50.000 intersections

round off errors ?

Test data sets (2/2)

Campus data set





Tetrahedronisation

23260 nodes

131457 tetrahedrons

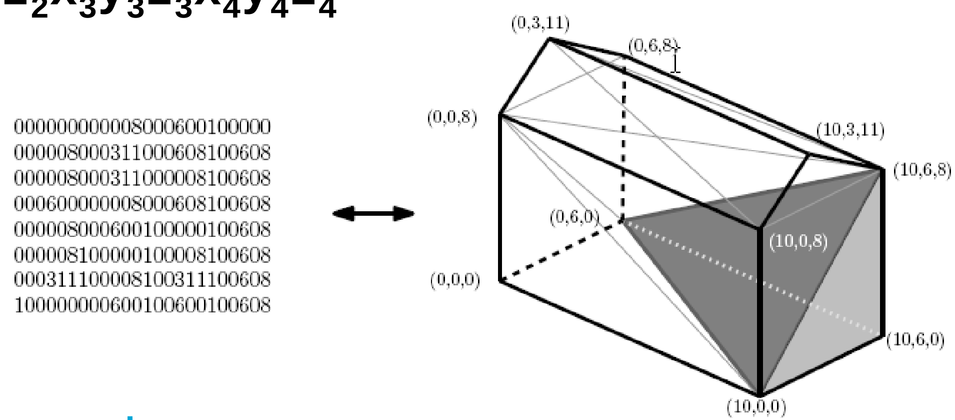
87316 constrained triangles

Data storage requirements (1/2)
Two alternative approaches

Coordinate concatenation:

describe tetrahedrons by node geometries:

$x_1y_1z_1x_2y_2z_2x_3y_3z_3x_4y_4z_4$



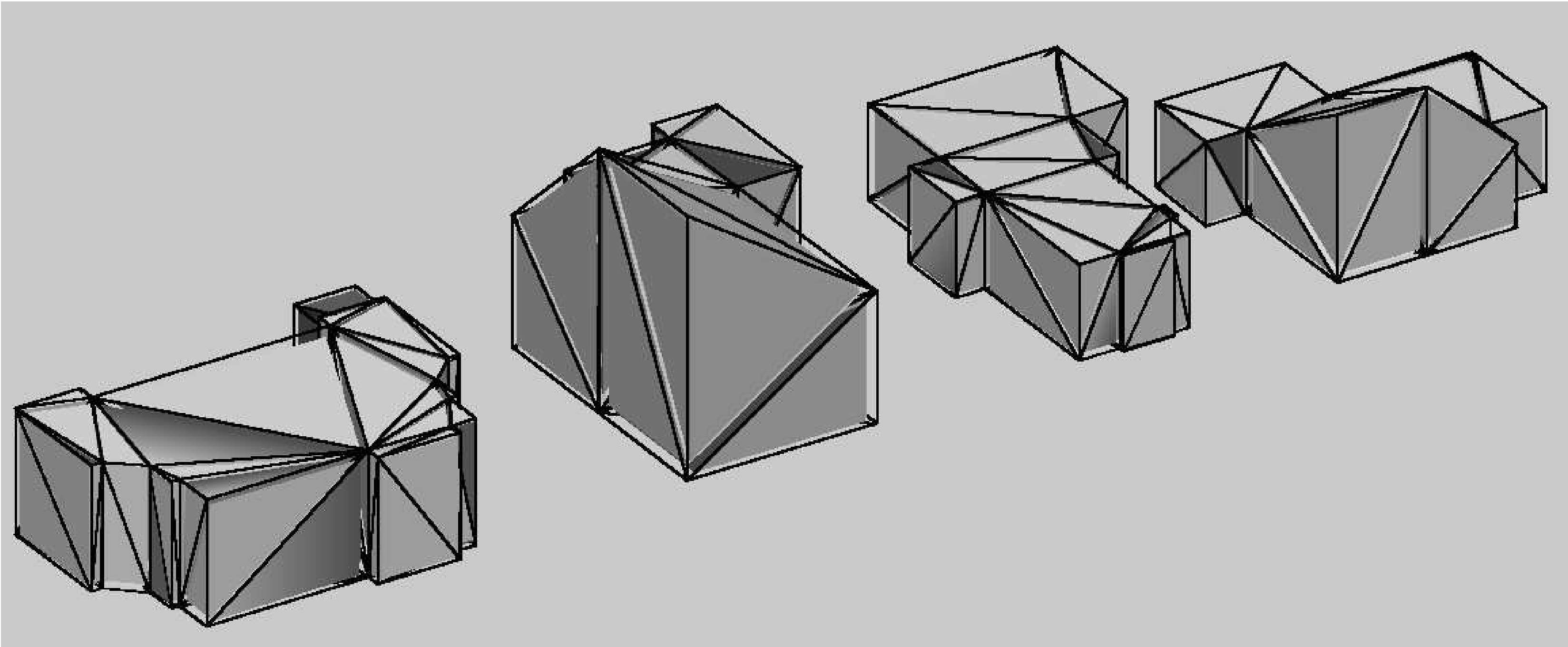
Identifier concateation:

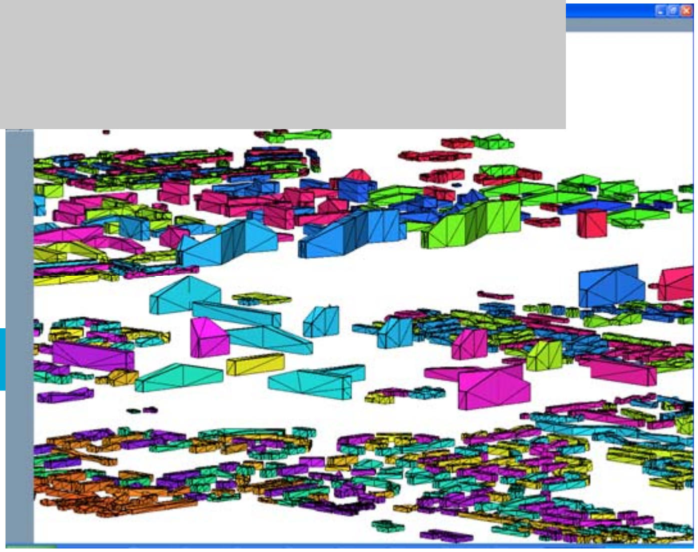
describe tetrahedrons by node id's:

$id_1id_2id_3id_4$ with $id_1{:}x_1y_1z_1$, $id_2{:}x_2y_2z_2$, etc.

Data storage requirements (2/2)

Comparing alternatives and polyhedrons





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Future research

Spatial clustering and indexing

Basic idea:

Why add a meaningless unique id to a node, when its geometry is already unique?

1 Bitwise interleaving coordinates → Morton-like code → sorting these codes → spatial clustering

2 Use as spatial index → no addtional indexes (R-tree/quad tree)

Objective: reducing storage requirements

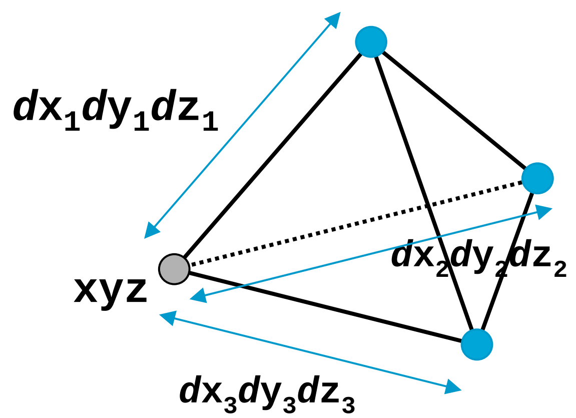
Future research

Coordinates vs. coord. differences

Four nodes of a tetrahedron will be relatively close:
only small differences in coordinates

Alternative tetrahedron description:

$\mathbf{xyz}\,dx_1dy_1dz_1dx_2dy_2dz_2dx_3dy_3dz_3$



Description is based on geometry
(so still unique) but smaller

Conclusions

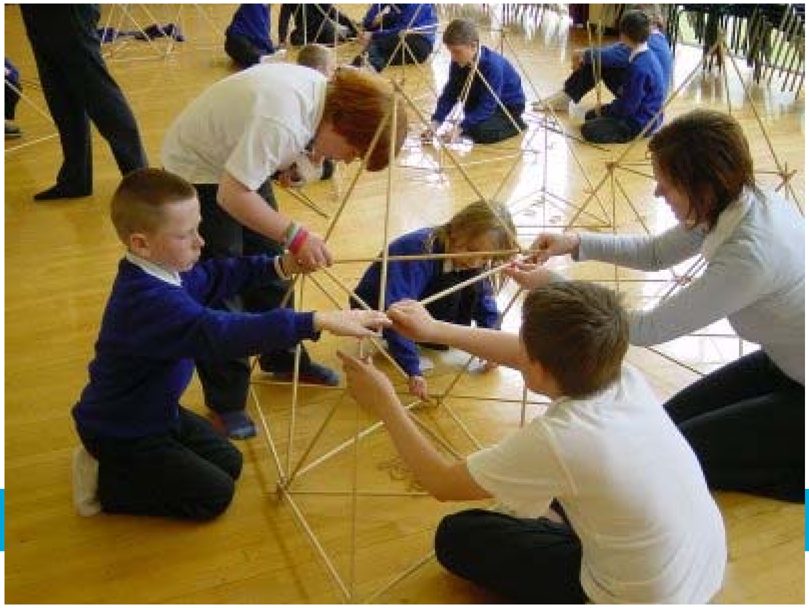
The PhD project results in a a new topological approach to data modelling, based on a tetrahedral network.

- Operators and definitions from the field of simplicial homology are used to define and handle this structure of tetrahedrons.
- Simplicial homology provides a solid mathematical foundation
- Simplicial homology enables one to derive substantial parts of the TEN structure efficiently, instead of explicitly storing all primitives.
- DBMS characteristics as the usage of views, functions and function-based indexes are extensively used to realise this potential data reduction.

Conclusions

- A proof-of-concept implementation was created:

  prevailing view that tetrahedrons are more expensive in terms of storage, is not correct when using the proposed approach (incl. proposed improvements (binary, delta's, etc.)



Using tetrahedrons is easy!

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Thesis defence

Thursday June 19, 2008 – 15.00 h

Keep the evening free…