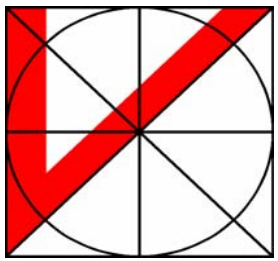
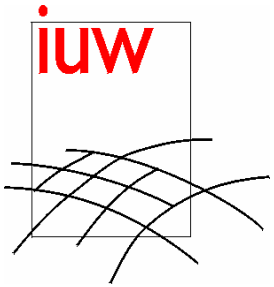
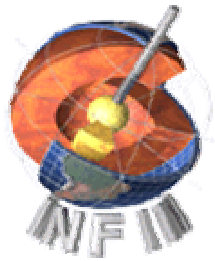
Spatio-temporal database support for long-period scientific data







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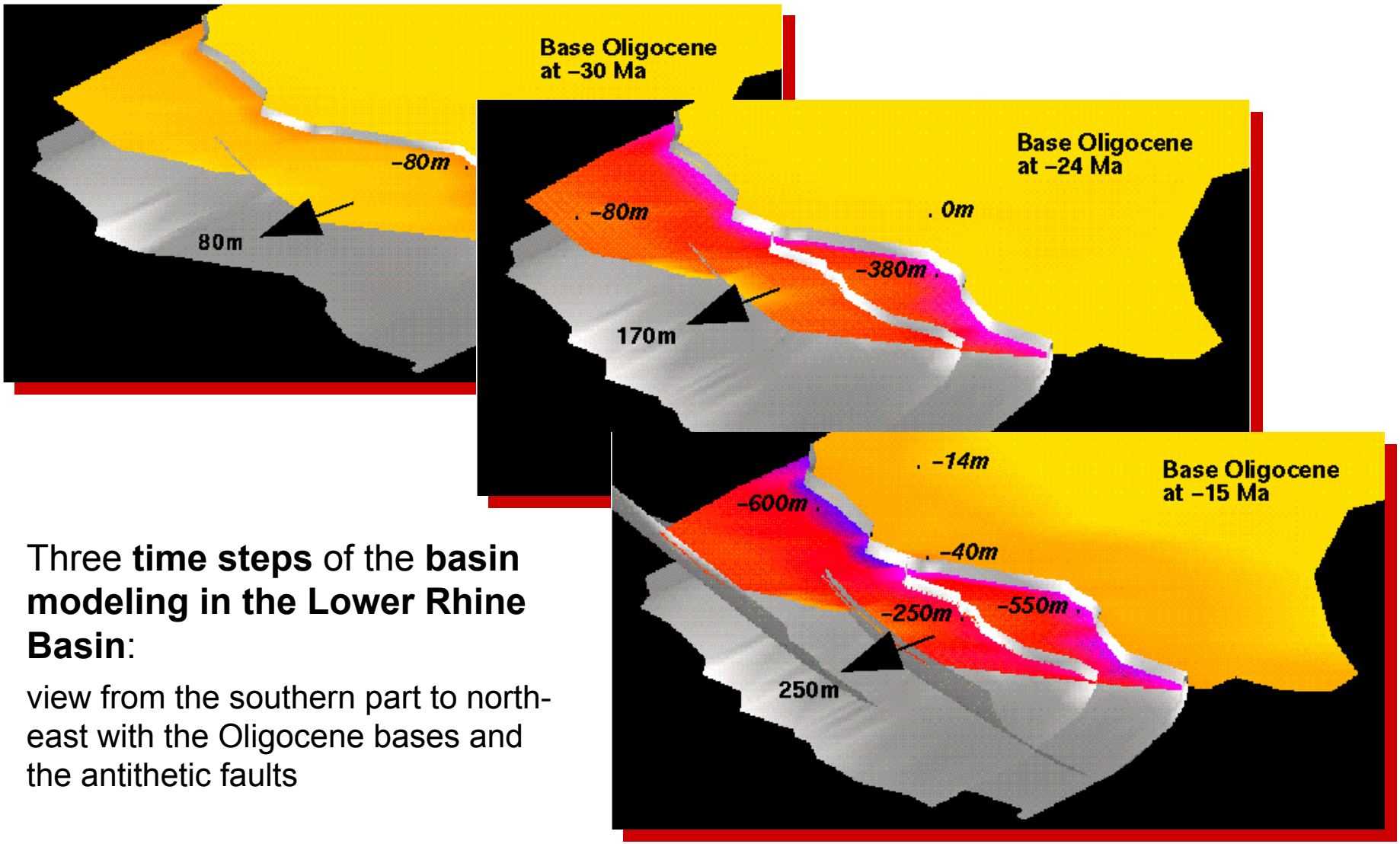
Objective: Database support for long-period scientific data, like used in geological applications

Balanced restoration of structural basin evolution

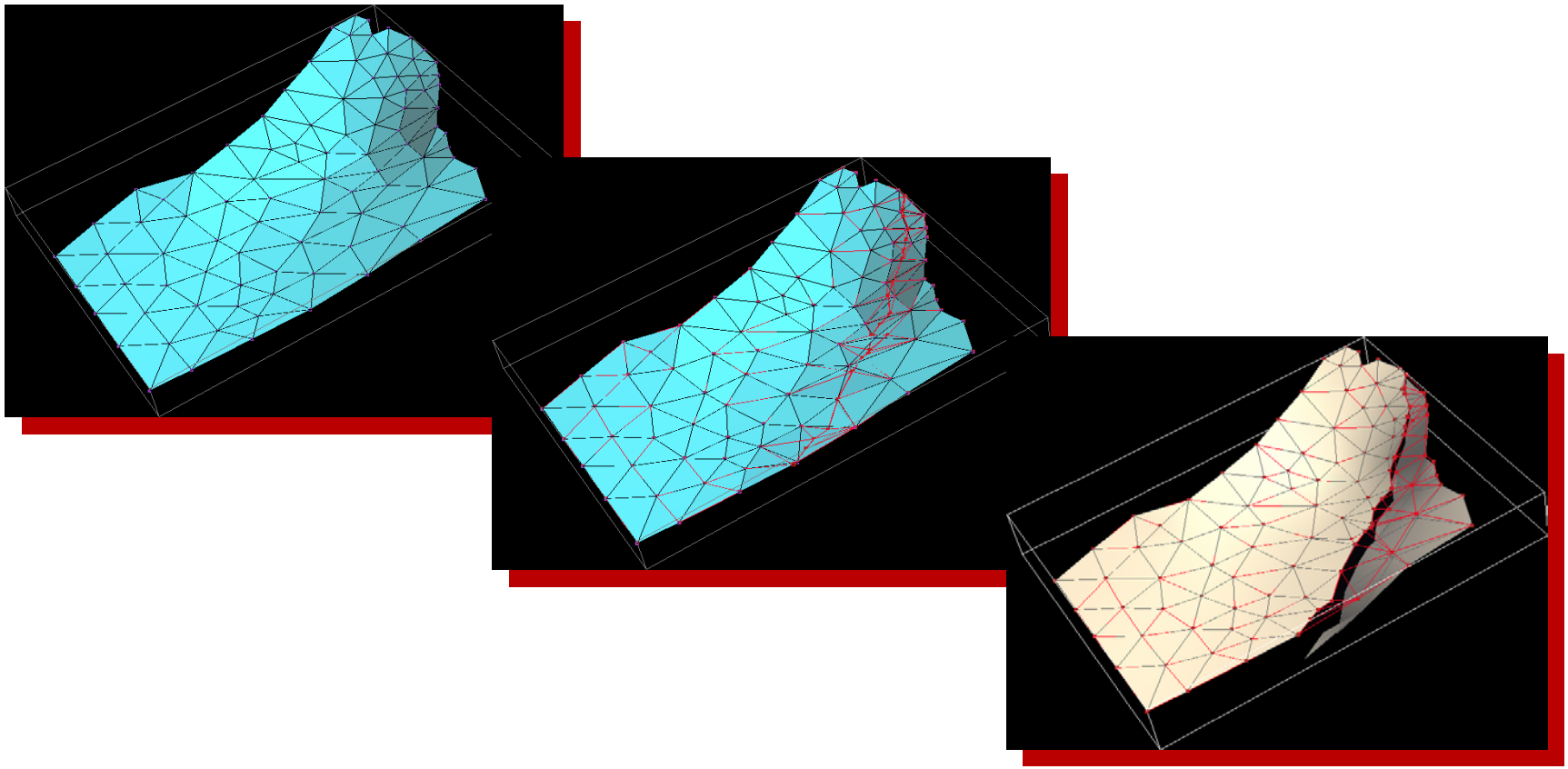


Three **time steps** of the **basin modeling in the Lower Rhine Basin**:

view from the southern part to north-east with the Oligocene bases and the antithetic faults

Conceptual model of continuously changing spatial data

Change in geometry and topology



Example for the change of the topology and geometry:

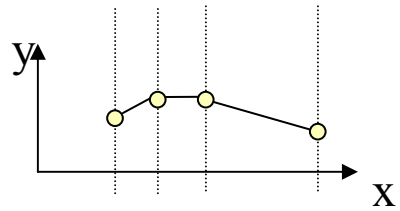
part of the Oligocene of the Lower Rhine Basin about 28 million years ago

Conceptual model
-- Design objectives

- Enabling **change in discretization**
- Separate meshes from vertices
  - Building several meshes from one set of vertices
  - **Automatic consistency** w.r.t. vertices
- **Spatio-temporal data structures**
  - Dynamic: *Insert, Delete, Update* operations on 4D geometries
- **Extending existing 3D data types with time**
  - Reuse of spatial functionality

3D conceptual model extended by time
-- database type *MovingVertex*

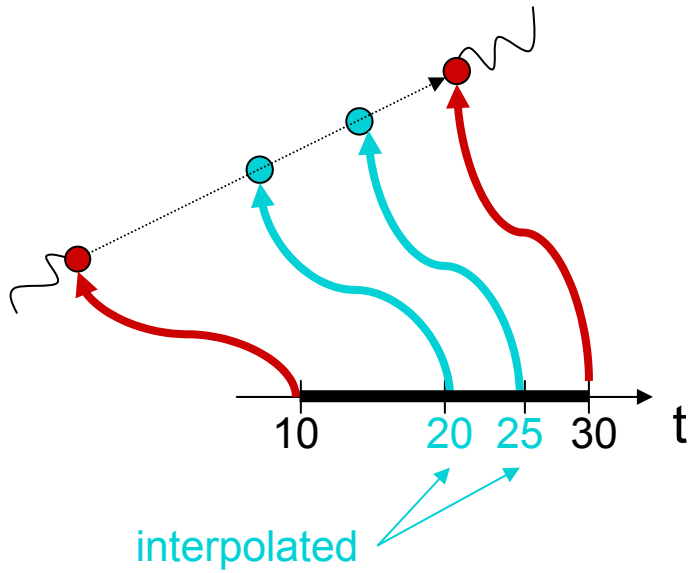
- *Time* isomorphic to the reals
  - Location and shape of geometries is a **function of time**
- Vertices move on their ***trajectories***



$$traj(v) = \{ loc_v(t) \mid t \in def(loc_v) \}$$

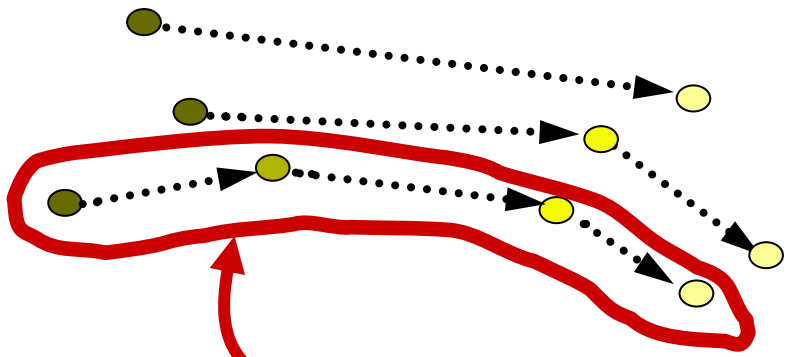
- **Properties of the model:**
  - Trajectory **piecewise linear**
  - **Change in direction** => Snapshot
  - Linear interpolation also w.r.t. time

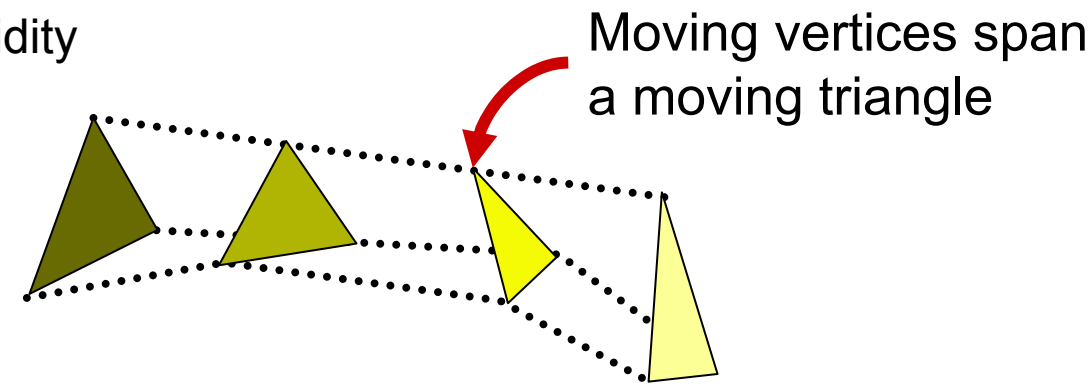
    => ***const velocity/no acceleration***
  - **Change in velocity** => Snapshot



-- Database type *TemporalSimplex*

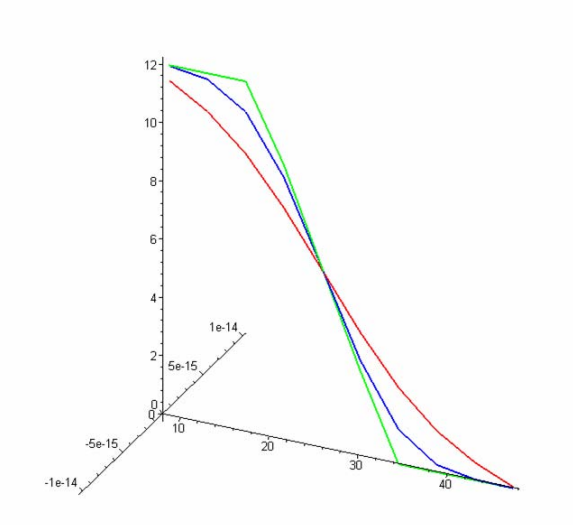
- Assemble **complex geometries** from moving vertices
  - Separates meshes from vertices
- A **moving simplex** comprises:
  - References to its moving vertices
  - Temporal interval of validity
- A **moving complex** comprises:
  - Set of moving simplexes
  - Temporal interval of validity
- **Integrity constraints!**





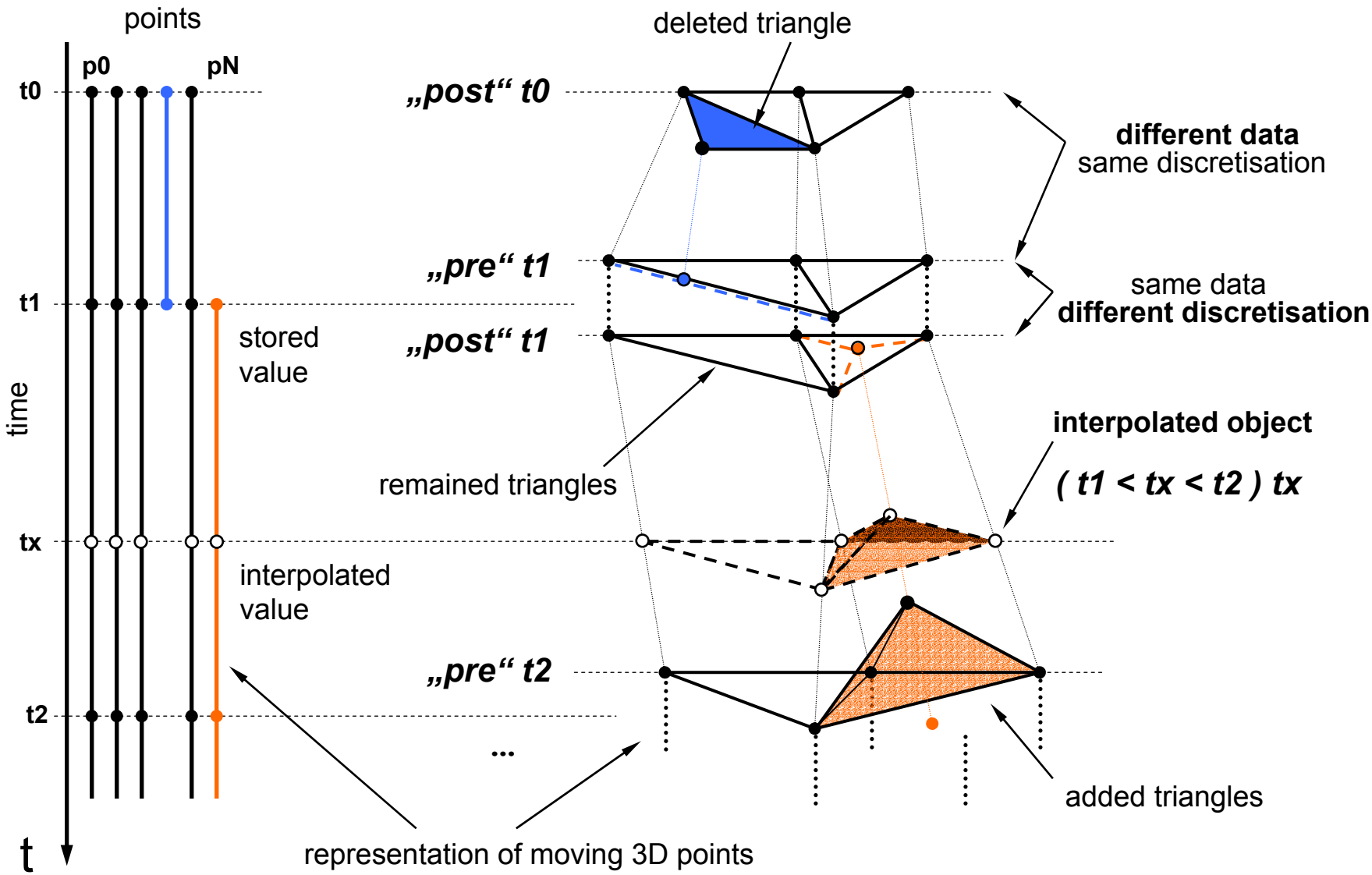
-- Database type *TemporalComplex*

- Given by a pair of:
  - Temporal interval of validity
  - List containing **references** to m*oving vertices*

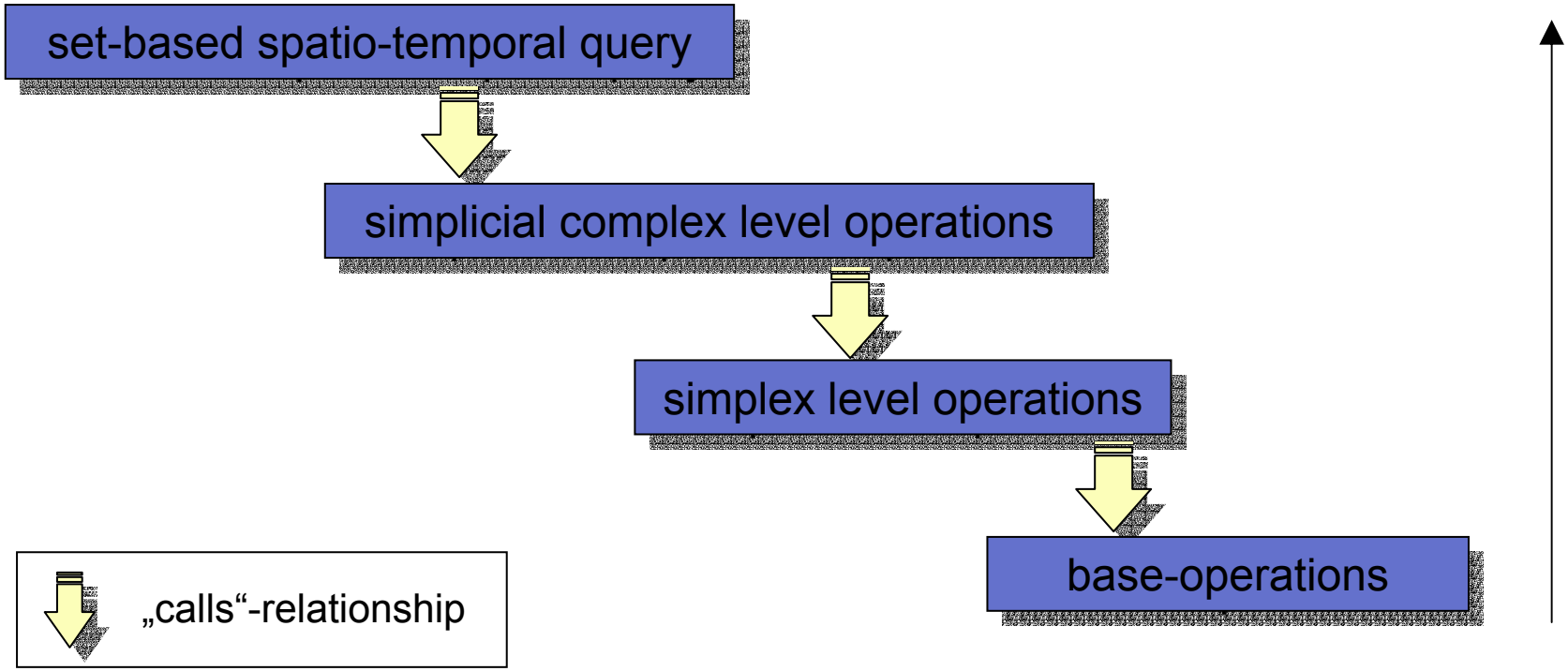


- Temporal interval of validity facilitates:
  - Remaining within the type system, e.g., after snapshot queries
  - Updates of snapshots

Representing time-dependent simplicial complexes
applying key-frame interpolation



Hierarchy of operations

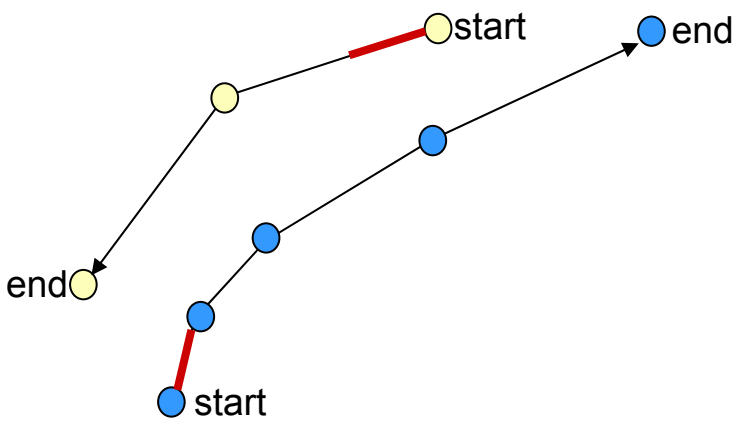


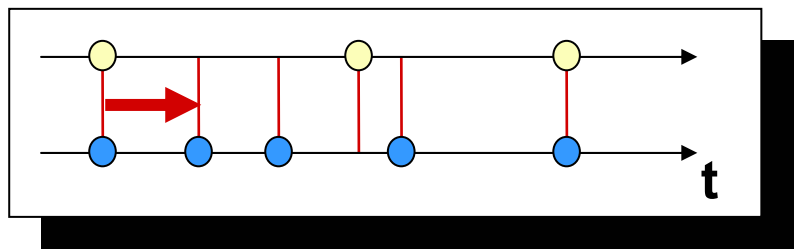
- Within this scenario:
  - Let proven concepts like geometric filter carry over from pure spatial setting
  - Support, e.g., through access methods

Examples for spatio-temporal operations:

Base operations on *temporal simplexes*

- Operations on a per-timestep basis not sufficient
- Geometric base operations
  - Analogues in the pure-spatial setting: e.g. segment/triangle Euclidean distance
  - O(1)-operations
- Operations involve two consecutive timesteps on the merged timeline of the two objects





Base operations in the scope of this work

***Minimum Euclidean distance* operation**

- Operands:
  - Spatial or spatio-temporal objects
- Types of operations:
  - Scalar function *min-dist*
  - Temporal function *when-min-dist*

***Intersection*-operations**

- Operand:
  - Plane or
  - Halfspace or
  - Bounding box

- **Types of operations:**
  - Boolean predicate ***intersects***
  - Temporal function ***when-intersects***
  - Object-generating function ***intersection***

Base operations on *temporal simplexes*

-- Implementing minimum Euclidean distance

- Definition: Minimum Euclidean distance $\min_{t \in T} \sqrt{\sum_{i=1}^{3} |\mathbf{x}_i - \mathbf{y}_i|^2}$
- Solution by:
  - **Parameterization of the simplex movement** (shared time parameter)

$$
\begin{aligned}
v(t) &= v_0(t) + \sum_{j=1}^{d} \lambda_j (v_j(t) - v_0(t)) \\
w(t) &= w_0(t) + \sum_{j=1}^{d} \kappa_j (w_j(t) - w_0(t))
\end{aligned}
$$

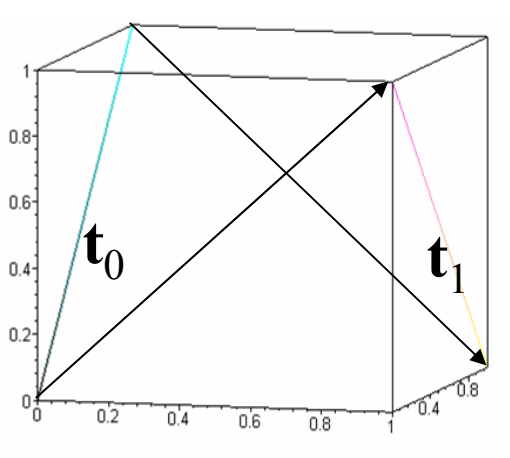
  - **Substitution** into Euclidean distance formula

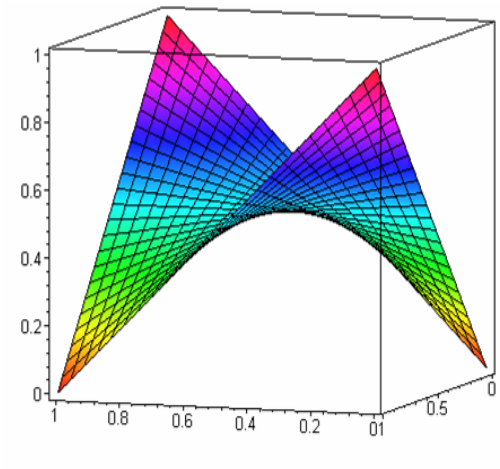
$$
dist = \sqrt{\sum_{i=1}^{3} |v(t, \lambda_1, \ldots, \lambda_{d_1}) - w(t, \kappa_1, \ldots, \kappa_{d_2})|^2}
$$

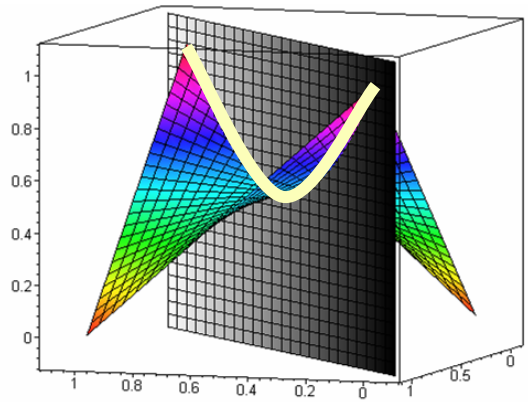
  - **Analytical search of minimum**
    - ↑ partial derivatives, solving system of equations

$$
\frac{\partial dist}{\partial t} = 0, \frac{\partial dist}{\partial \lambda_1} = 0, \ldots, \frac{\partial dist}{\partial \lambda_p} = 0
$$

Base operations on *temporal Simplexes* -- Example *intersection*

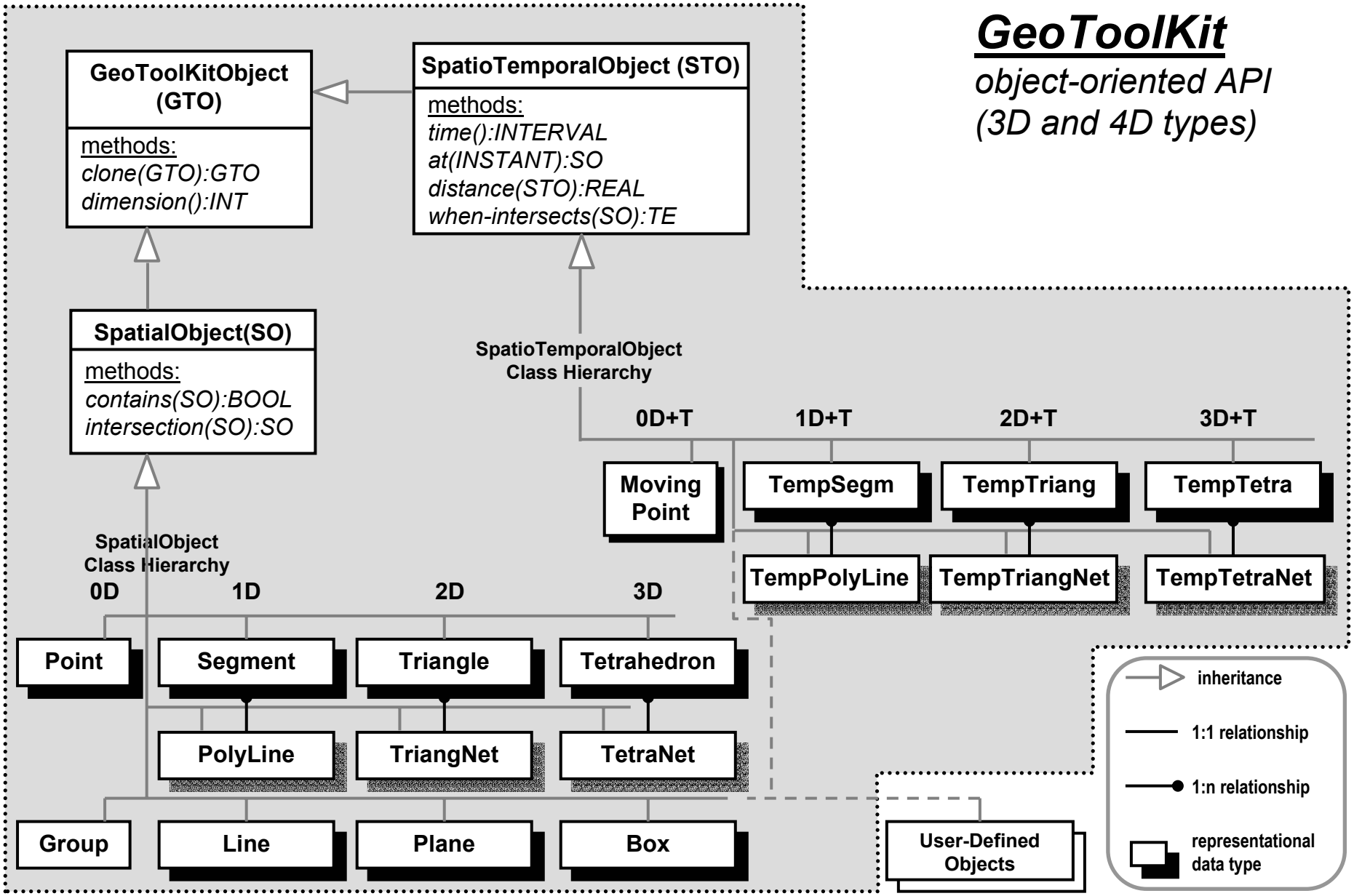




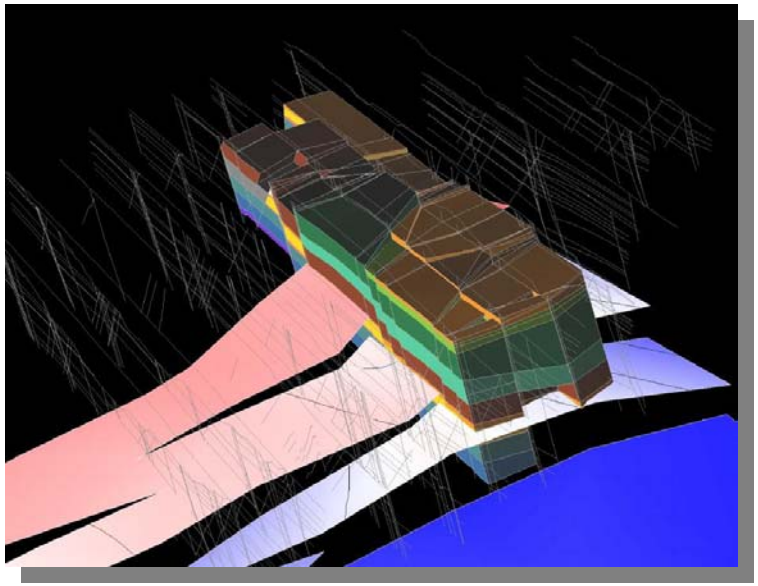


- Model is not closed under *intersection*
- Contrast to purely spatial model: Approximation must be performed by query system

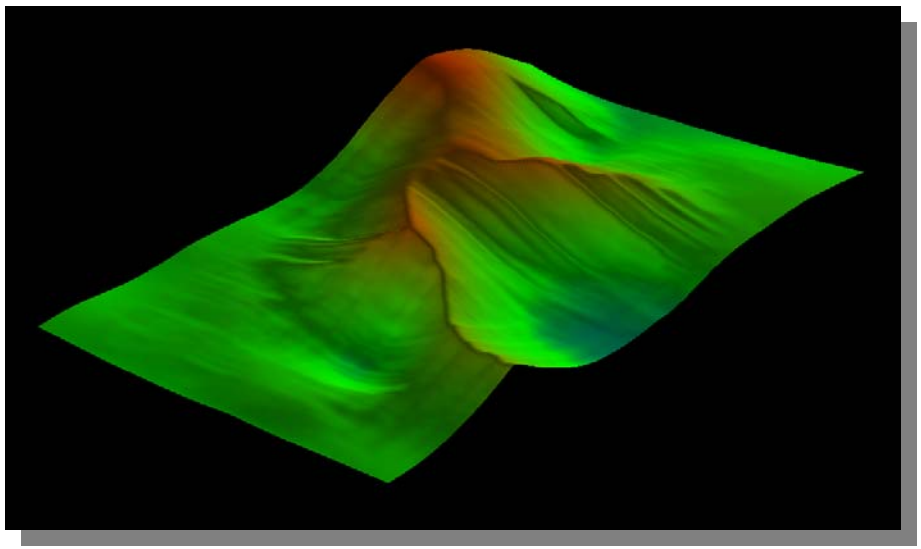
System architecture: Extending GeoToolKit



Examination with geological and artificial datasets

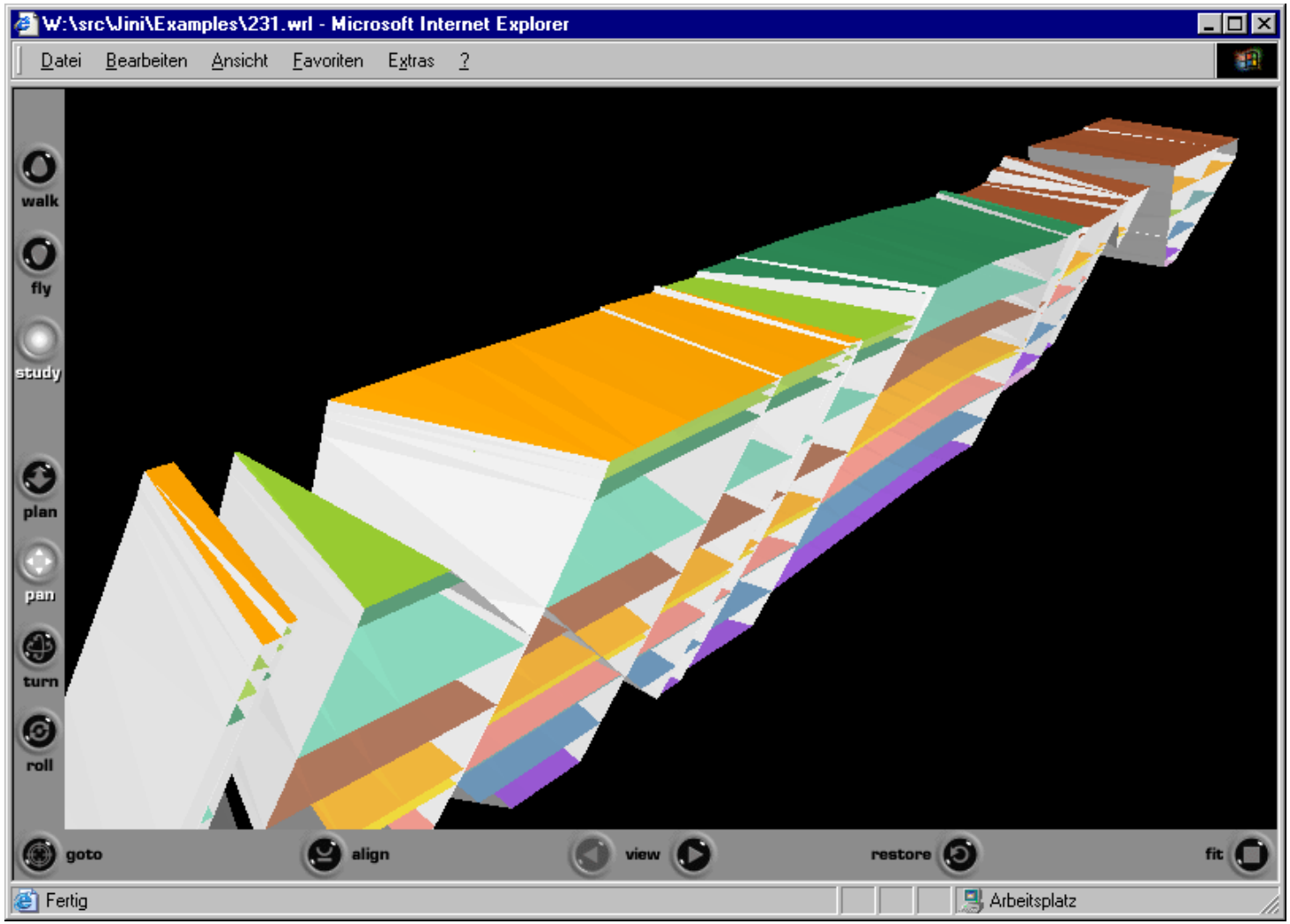


3D model “Bergheim”
(visualized by the 3D modelling tool gOcad®)



Automatical generation of artificial landform data

Result of a temporal database query from the Bergheim model



(visualized in the VRML browser Cortona™ ®).

Summary and future work

- **Conclusions**
  - Need for spatio-temporal database types and operations
  - Spatio-temporal operations
    - metric queries (minimum Euclidean distance)
    - intersection-queries
  - Applications

- **Future Work**
  - Enhance existing operations through **geometric filters** and **index support**
  - **Extend conceptual model**: more operations on spatio-temporal types
  - **New applications** (kinematics of landform)

Sponsors and contact information

- **Sponsor: German Research Foundation (DFG)**
  - Graduate Research Centre 437 "*Landform*"
  - **http://slide.giub.uni-bonn.de/Kolleg/welcome.html**

- Examples taken from joint research between 1994-2001 with Agemar Siehl's group (Geological Institute) within the Collaborative Research Centre SFB 350

  http://www.sfb350.uni-bonn.de
  http://www.geo.informatik.uni-bonn.de/software/geotoolkit

  - DFG joint project "Interoperable GIS" (IOGIS)

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