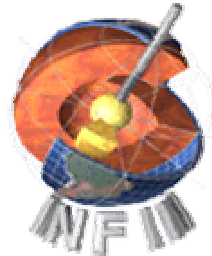
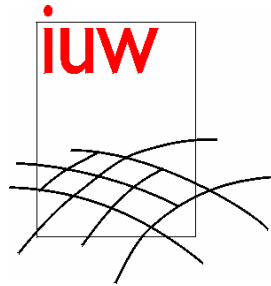
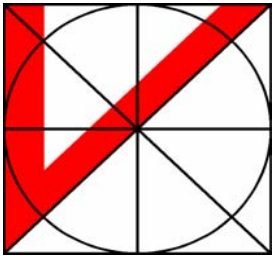


# Spatio-temporal database support for long-period scientific data



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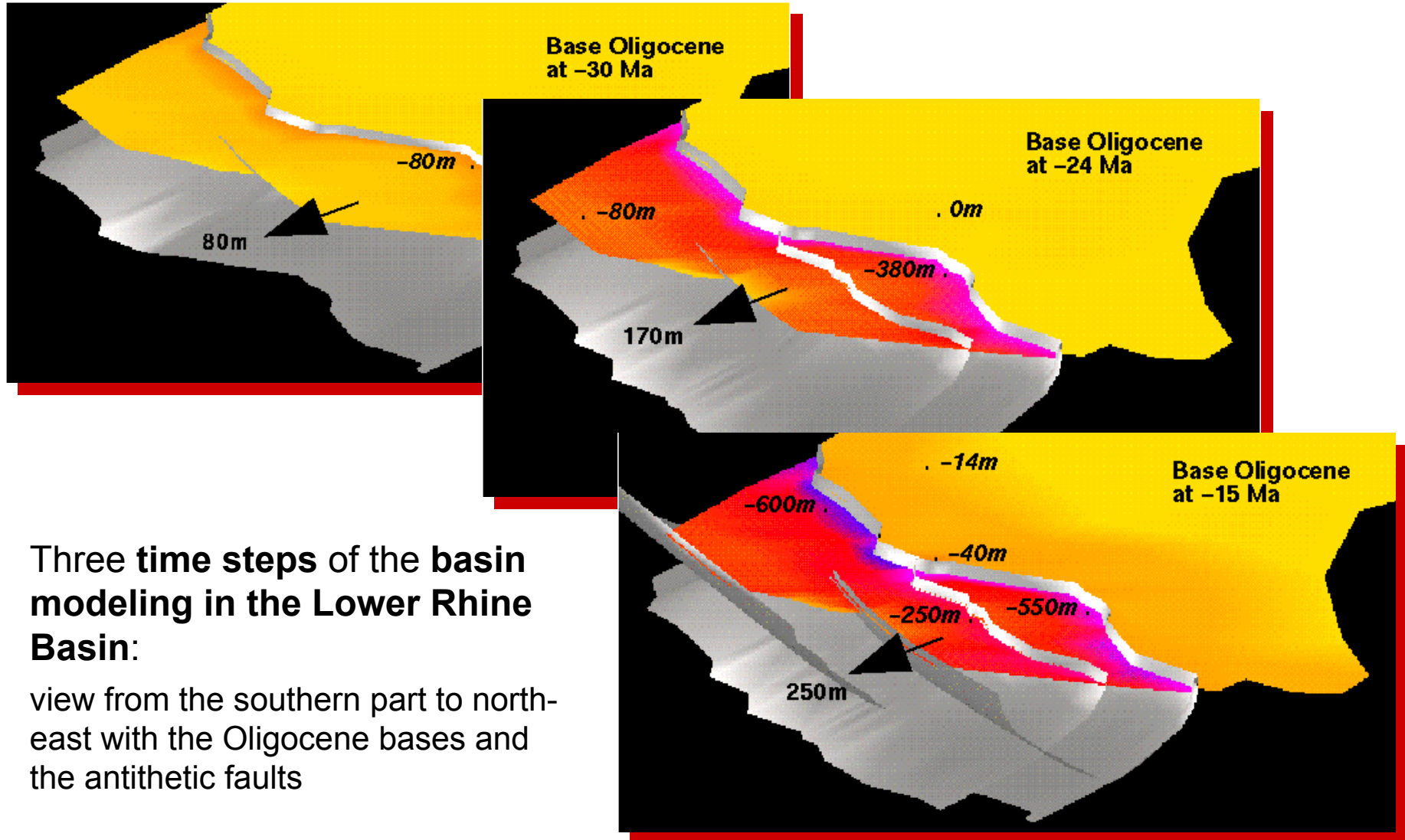
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# Objective: Database support for long-period scientific data, like used in geological applications

## Balanced restoration of structural basin evolution

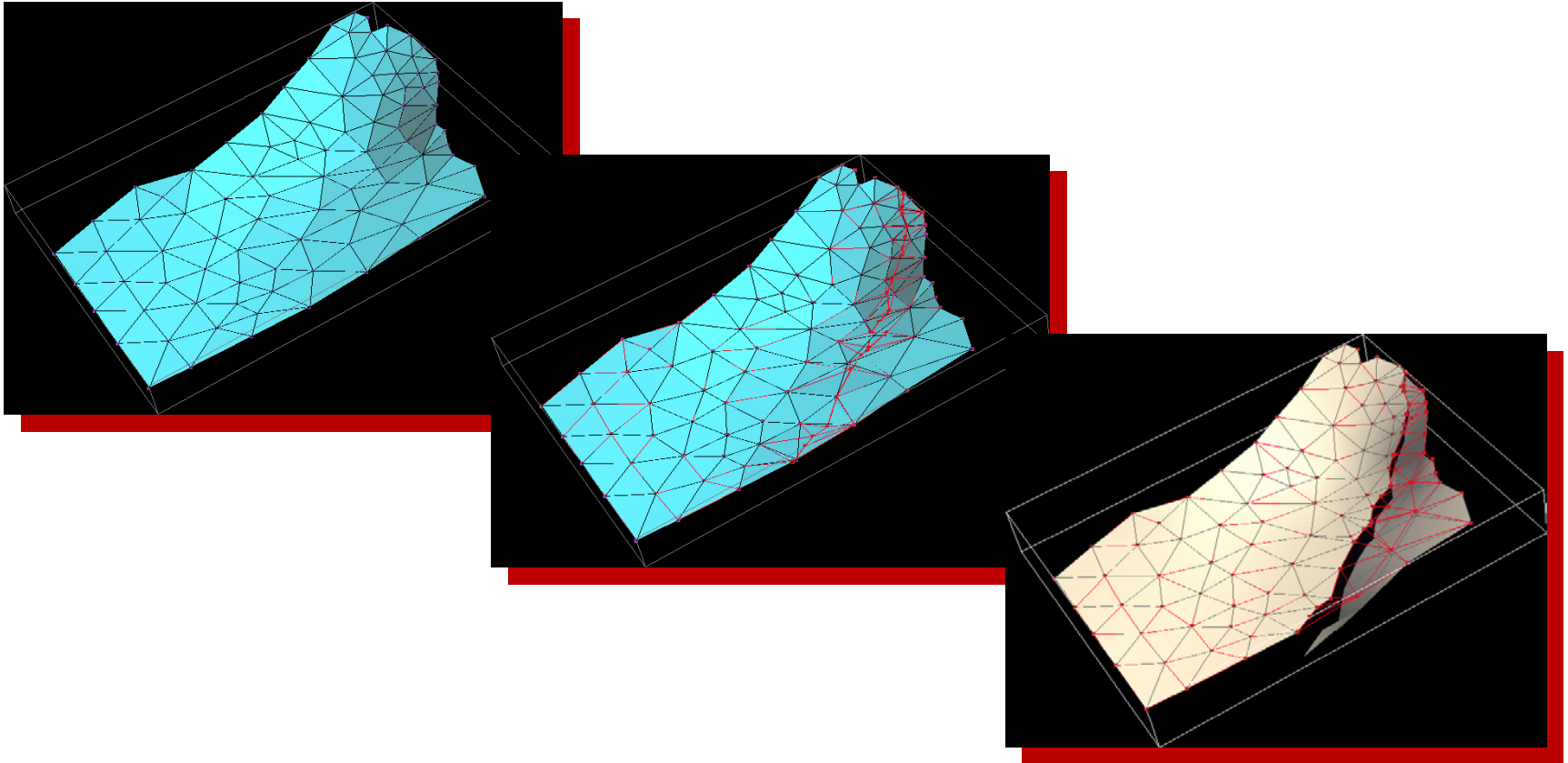


### Three time steps of the basin modeling in the Lower Rhine Basin:

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

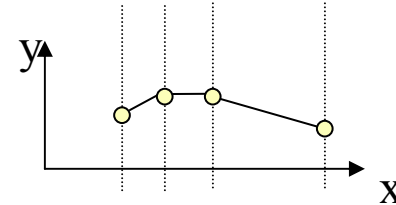
- Enabling **change in discretization**
- Separate meshes from vertices
  - ◆ Building several meshes from one set of vertices
  - ◆ **Automatic consistency** w.r.t. vertices
- **Spatio-temporal data structures**
  - ◆ Dynamic: *Insert, Delete, Update* operations on 4D geometries
- **Extending existing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

# 3D conceptual model extended by time

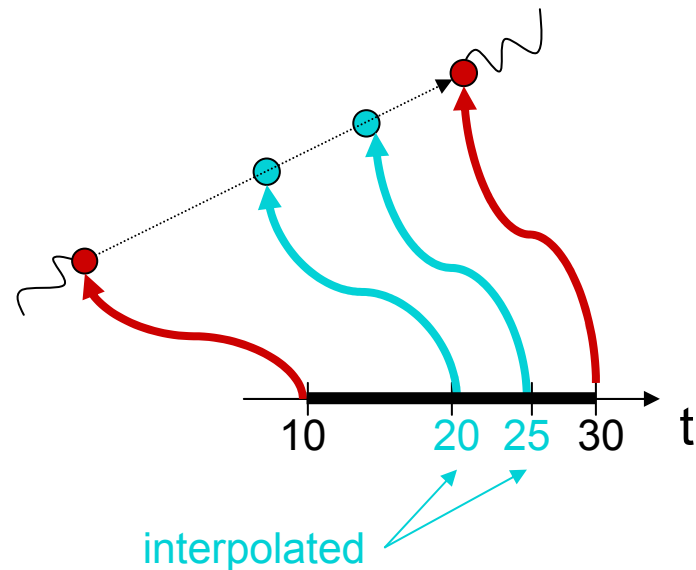
-- database type *MovingVertex*

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

$$\text{traj}(v) = \{ \text{loc}_v(t) \mid t \in \text{def}(\text{loc}_v) \}$$



- **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

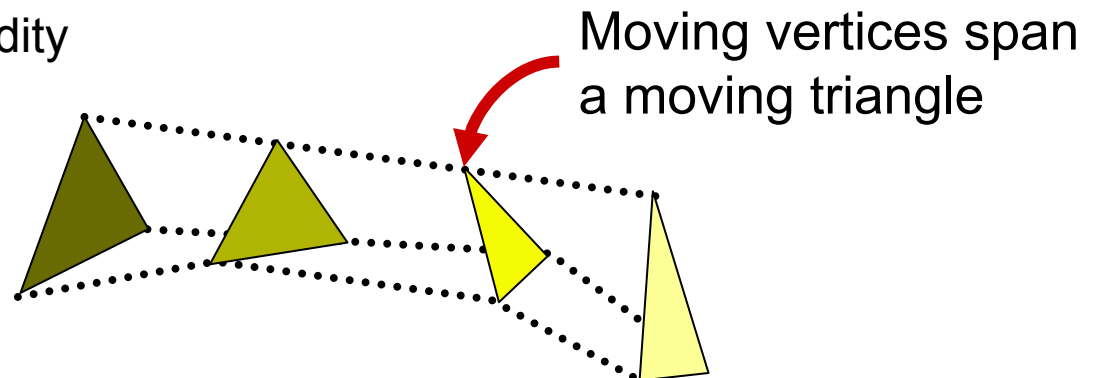
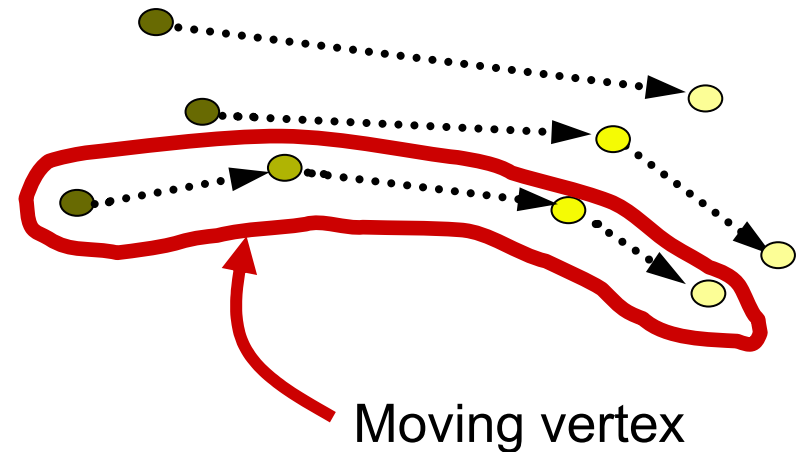
- ◆ Temporal interval of validity

- A **moving complex** comprises:

- ◆ Set of moving simplexes

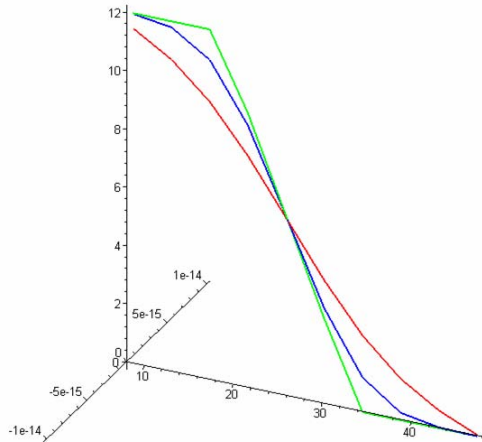
- ◆ Temporal interval of validity

- **Integrity constraints!**



## -- Database type *TemporalComplex*

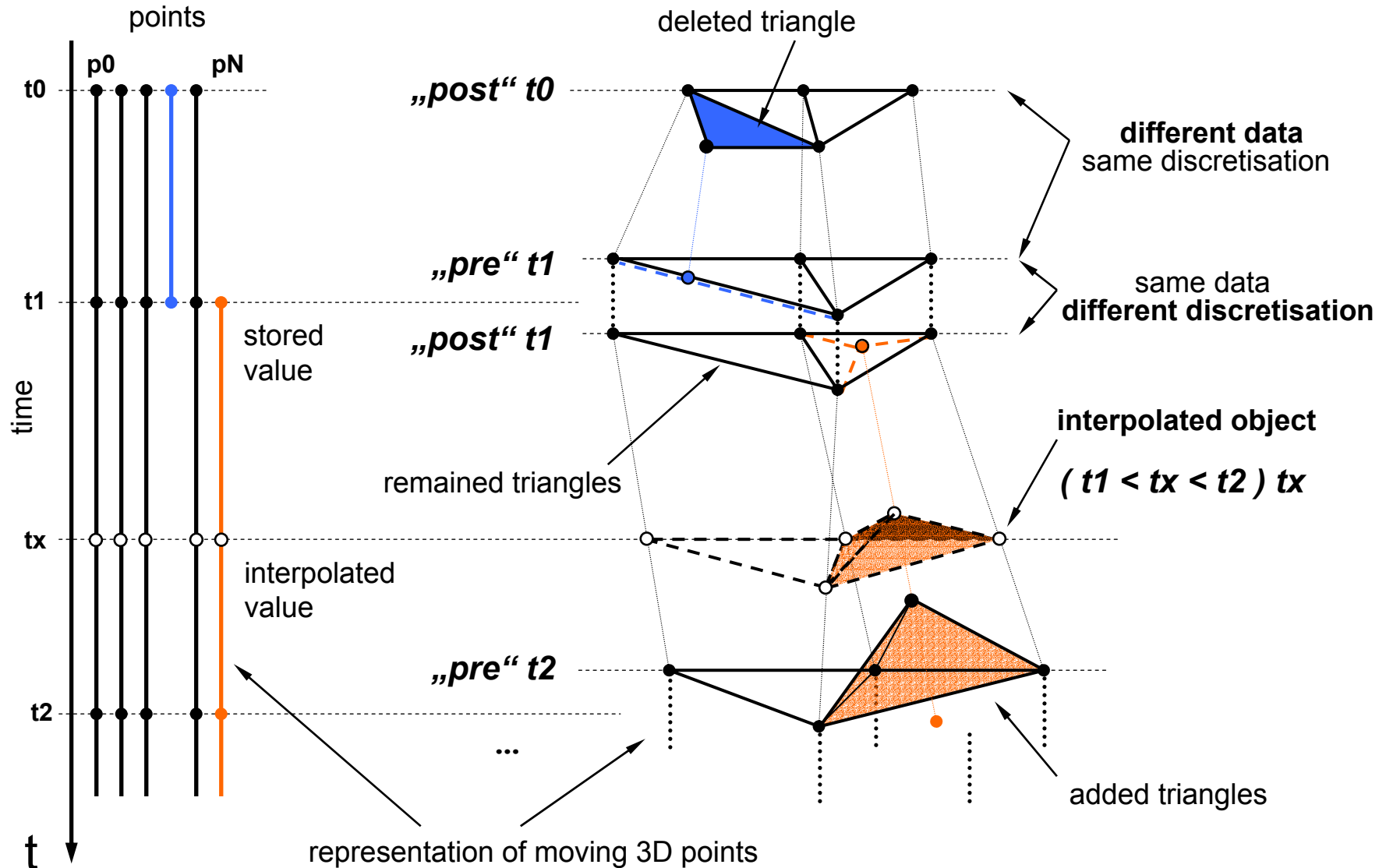
- Given by a pair of:
  - ◆ Temporal interval of validity
  - ◆ List containing **references** to moving *vertices*



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

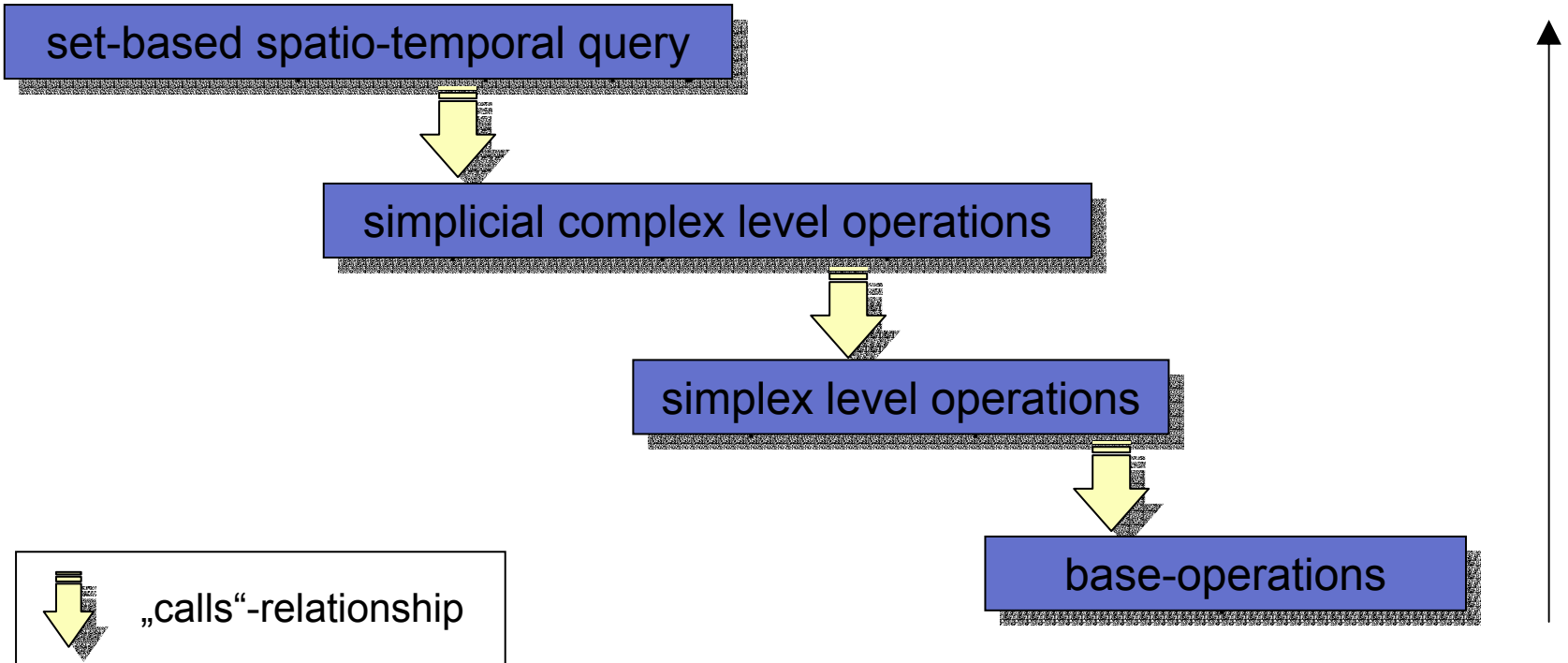
# Representing time-dependent simplicial complexes

## applying key-frame interpolation





# Hierarchy of operations

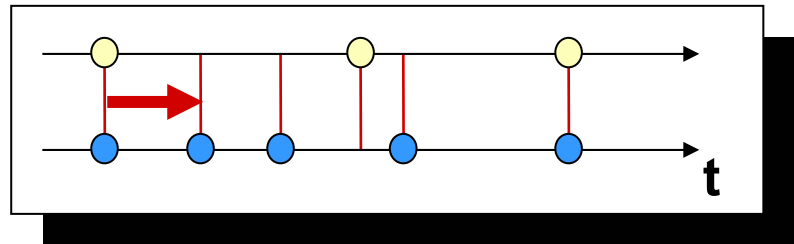
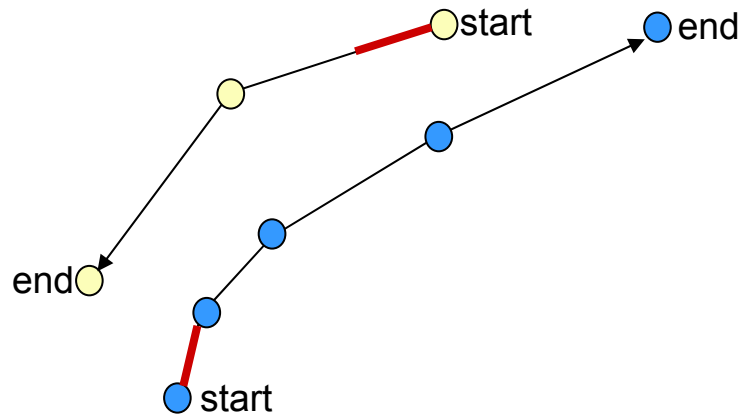


- Within this scenario:
  - ◆ Let proven concepts like geometric filter carry over from pure spatial setting
  - ◆ Support, e.g., through access methods

# 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)

$$v(t) = v_0(t) + \sum_{j=1}^d \lambda_j (v_j(t) - v_0(t))$$

$$w(t) = w_0(t) + \sum_{j=1}^d \kappa_j (w_j(t) - w_0(t))$$

- ◆ **Substitution** into Euclidean distance formula

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

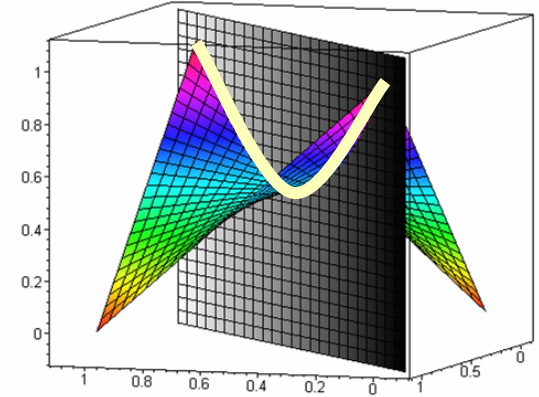
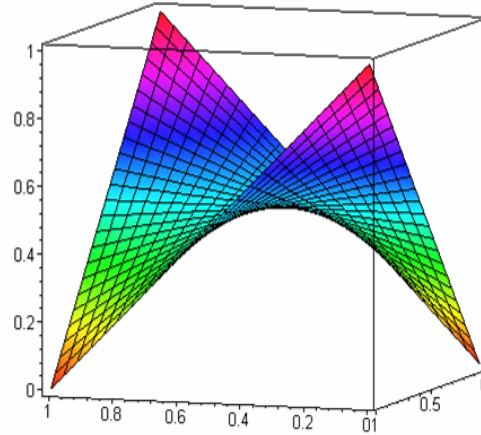
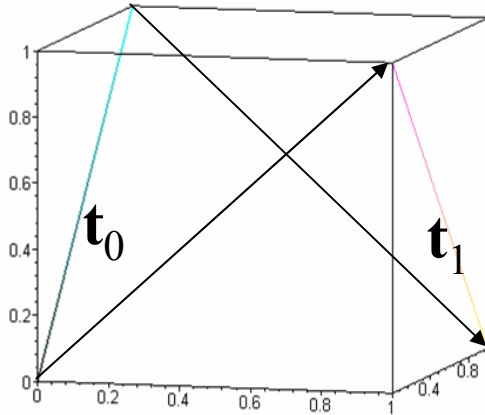
- ◆ **Analytical search of minimum**

↑ partial derivatives, solving system of equations

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

# Base operations on *temporal Simplexes*

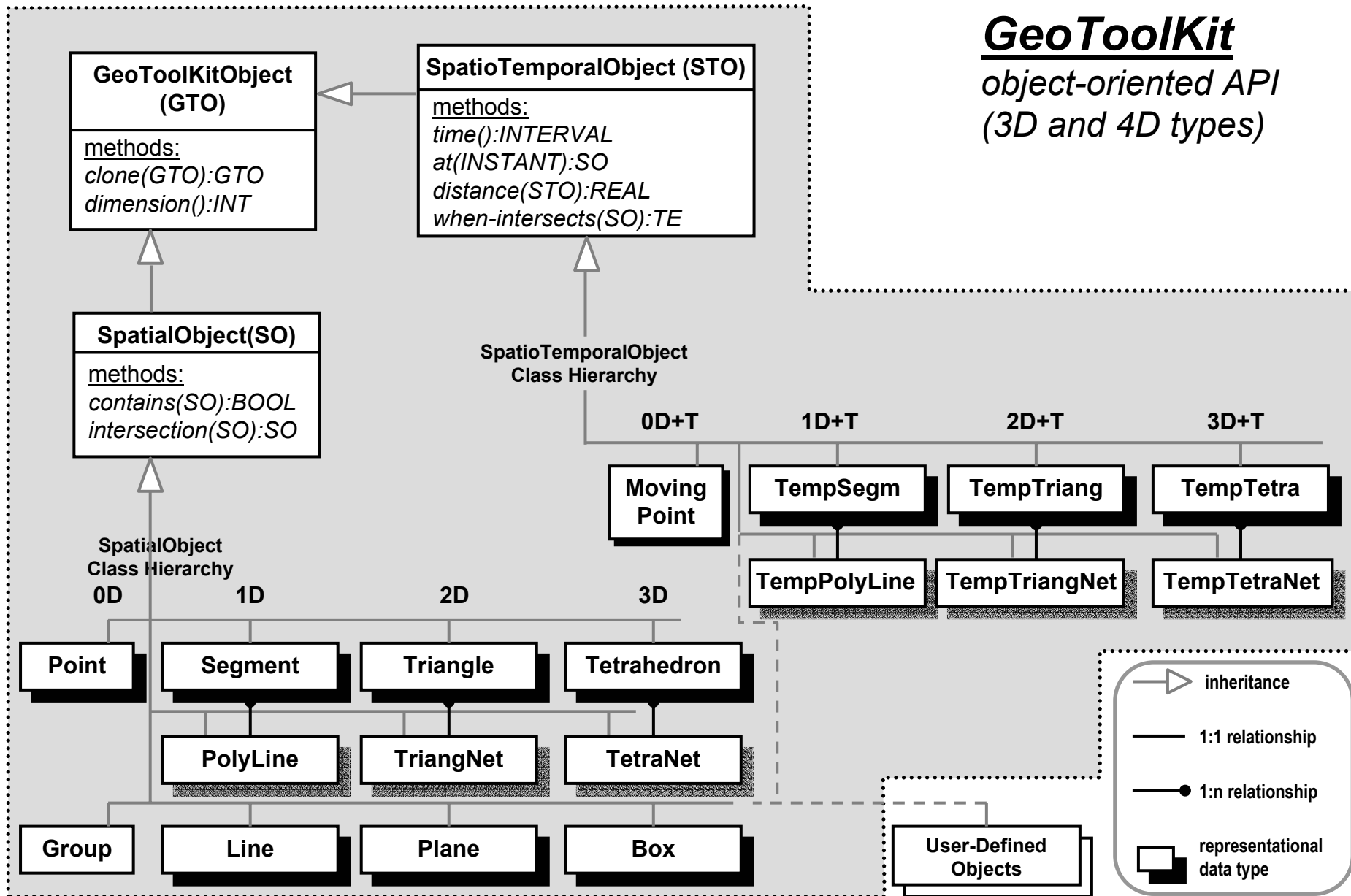
## -- Example *intersection*



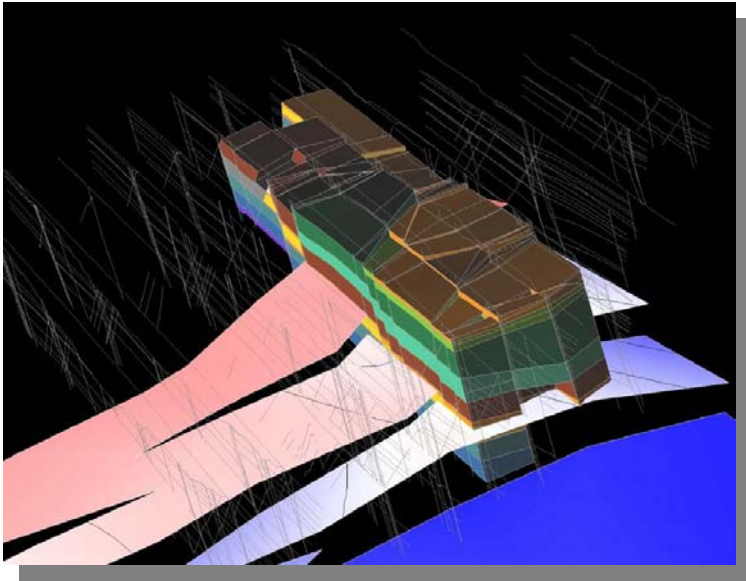
- Model is not closed under *intersection*
- Contrast to purely spatial model: Approximation must be performed by query system

# System architecture: Extending GeoToolKit

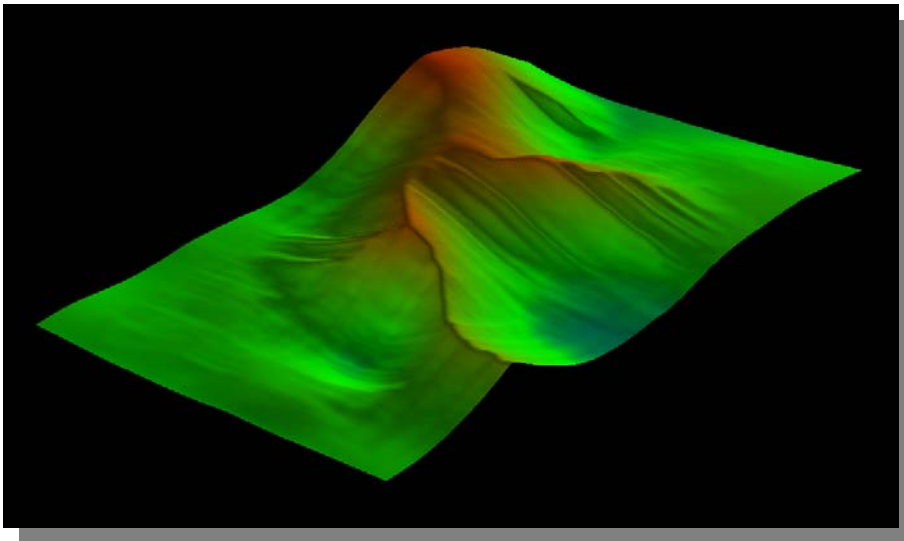
**GeoToolKit**  
*object-oriented API*  
*(3D and 4D types)*



# Examination with geological and artificial datasets

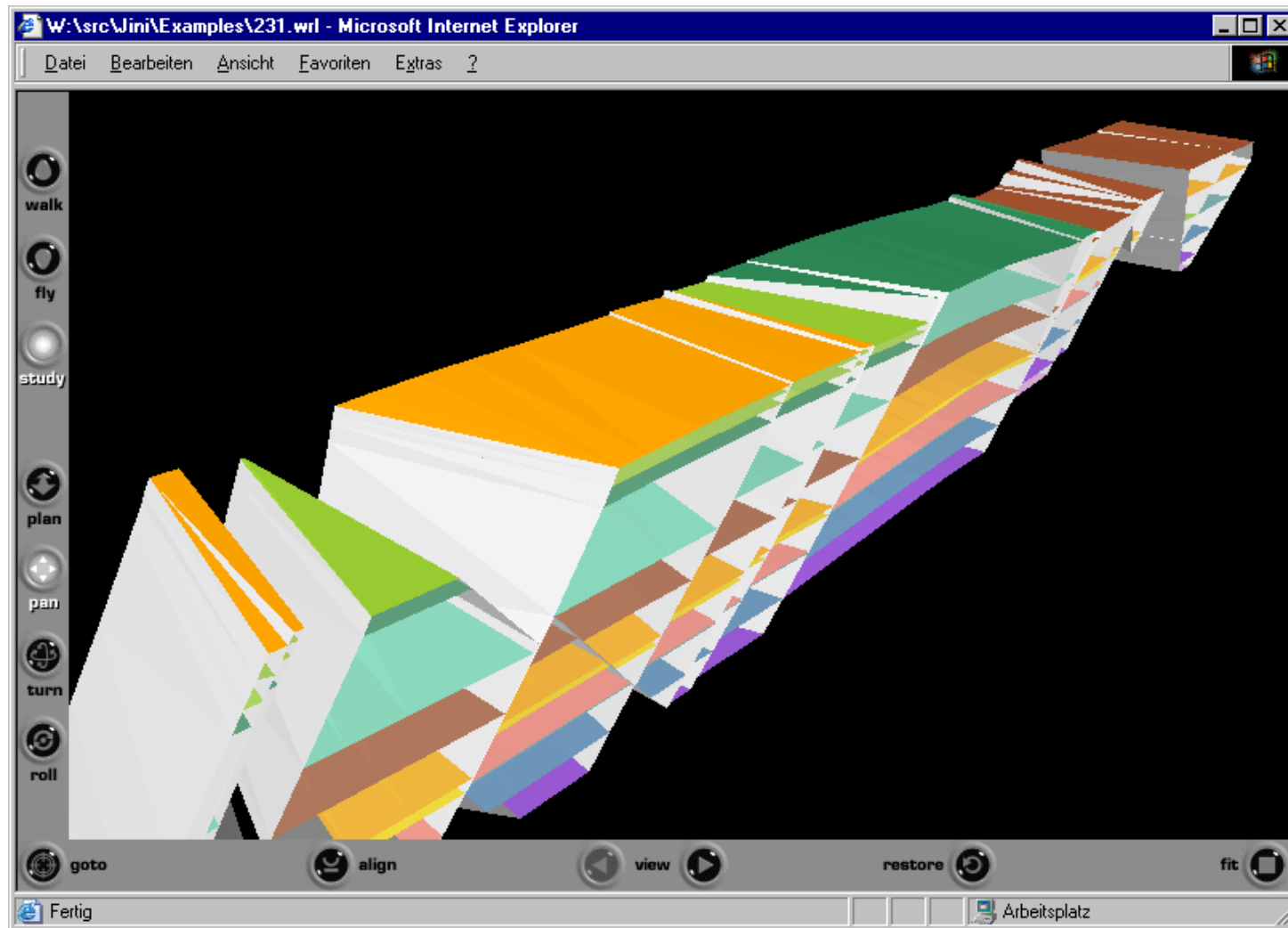


3D model “Bergheim”  
(visualized by the 3D modelling tool gOcad®)



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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