http://www.faculty.jacobs-university.de/pbaumann → publications

http://en.wikipedia.org/wiki/Array_DBMS

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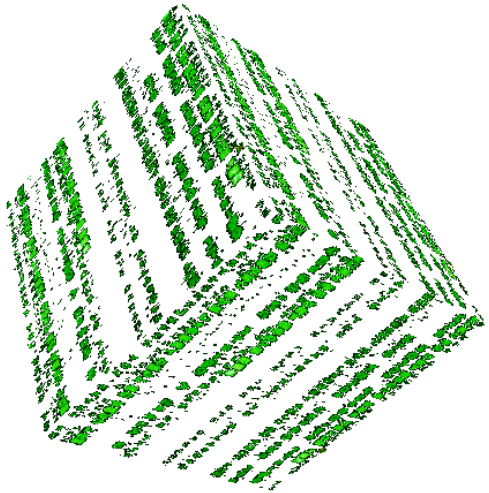

Array Databases

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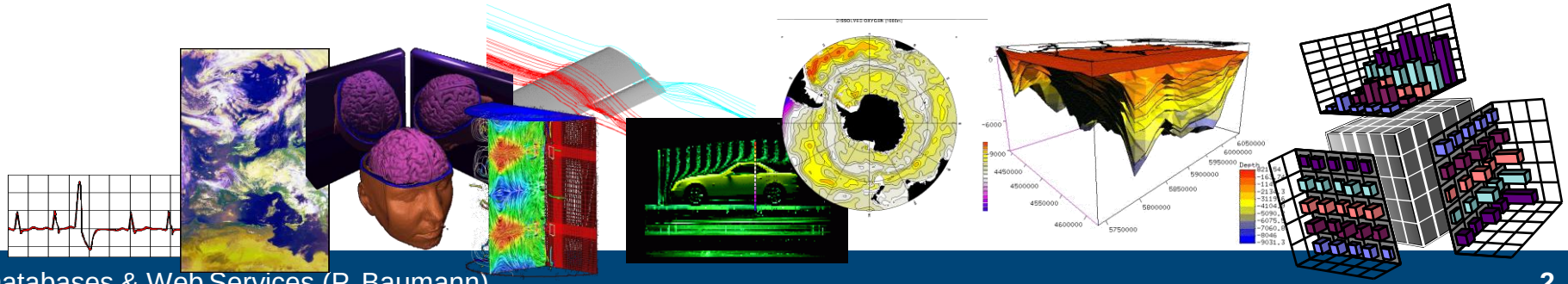
Who Needs Arrays?

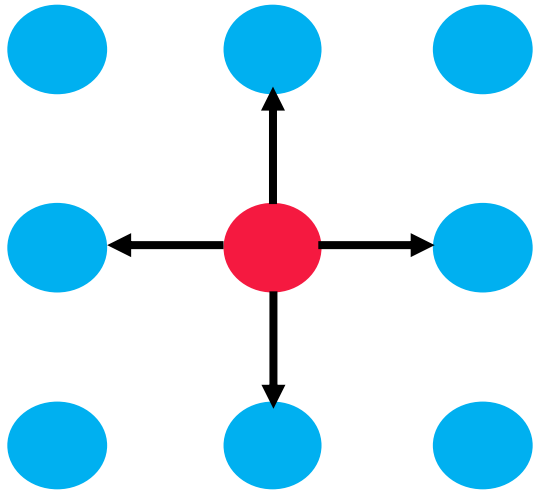
- Sensor, image, simulation, statistics data
  - **Earth:** Geodesy, geology, hydrology, oceanography, climate, earth system, ...
  - **Space:** optical / radio astronomy, cosmological simulation, planetary science, ...
  - **Life:** Pharma/chem, healthcare / bio research, bio statistics, genetics, ...
  - **Engineering & research:** Simulation & experimental data in automotive/shipbuilding/ aerospace industry, turbines, process industry, ...
  - **Management/Controlling:** Decision Support, OLAP, Data Warehousing, census, statistics in industry and public administration, ...
  - **Multimedia:** distance learning, prepress, ...
- „80% of all data have some spatial connotation“ [C&P Hane, 1992]



CONCEPTUAL MODELLING

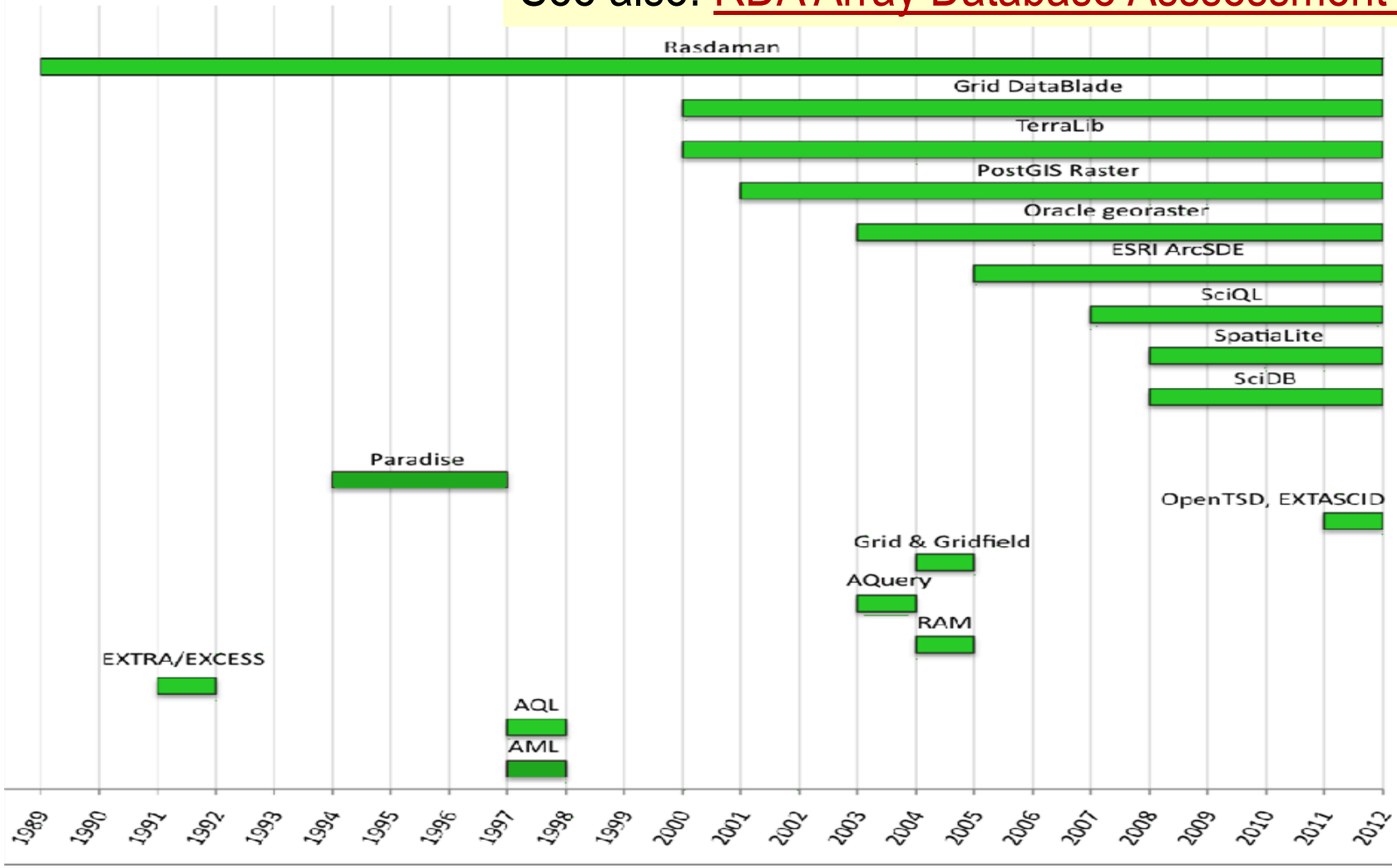
Array Analytics

- Array Analytics :=
  Efficient analysis on multi-dimensional arrays of a size several orders of magnitude above evaluation engine's main memory
- Essential data property: n-dimensional Euclidean neighborhood
  - Secondary: #dimensions, density, ...
- Operations: signal/image processing, Linear Algebra [M. Stonebraker], iterations



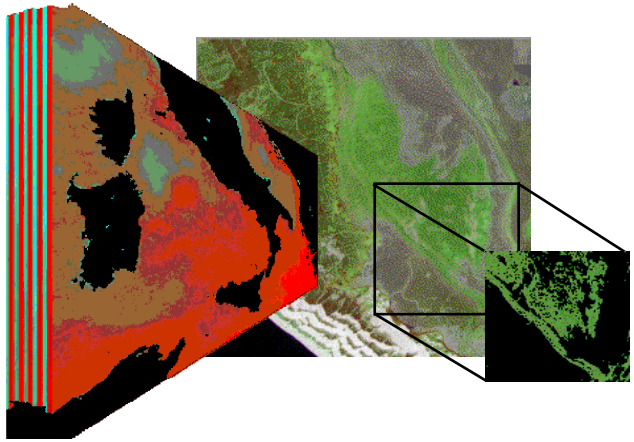
Early History of Array Databases

See also: RDA Array Database Asssessment WG



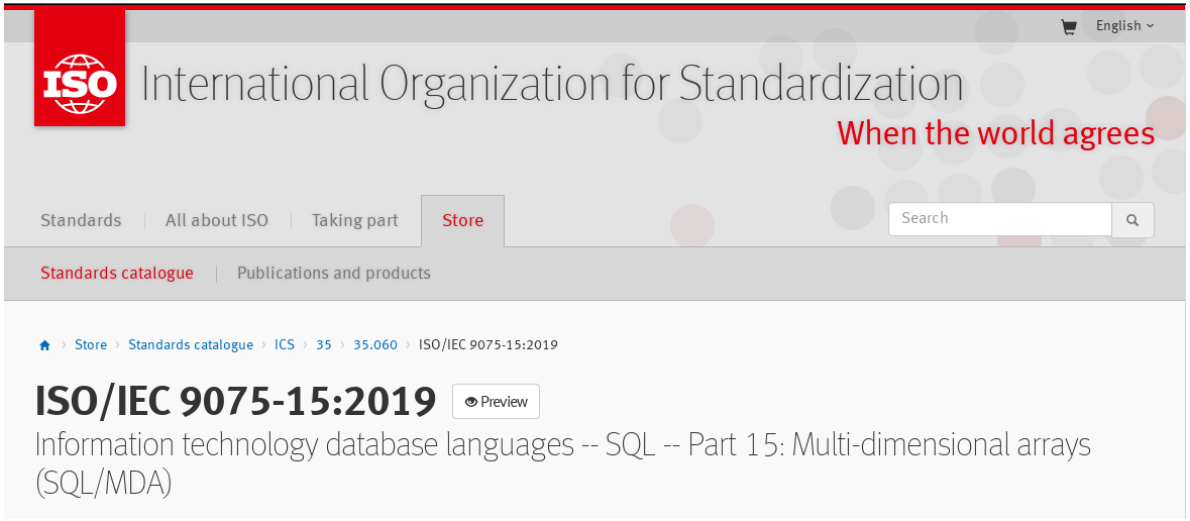
rasdaman

- „raster data manager“: SQL + n-D arrays
  - Scalable parallel “tile streaming” architecture
  - [VLDB 1994, VLDB 1997, SIGMOD 1998, VLDB 2003, …, VLDB 2016]
- Blueprint for stds, in operational use



Arrays in SQL

[SSDBM 2014]



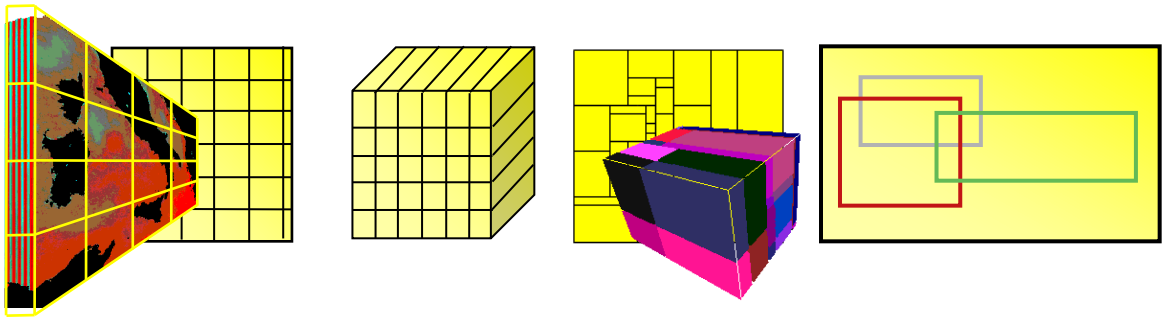

```
create table LandsatScenes(
    id: integer not null, acquired: date,
    scene: row( band1: integer, ..., band7: integer ) mdarray [ 0:4999,0:4999] )
```

```
select  id, encode(scene.band1-scene.band2)/(scene.band1+scene.band2)), „image/tiff“ )
from    LandsatScenes
where acquired between „1990-06-01“ and „1990-06-30“ and
          avg( scene.band3-scene.band4)/(scene.band3+scene.band4)) > 0
```

ARCHITECTURE

Adaptive Partitioning („Tiling“)

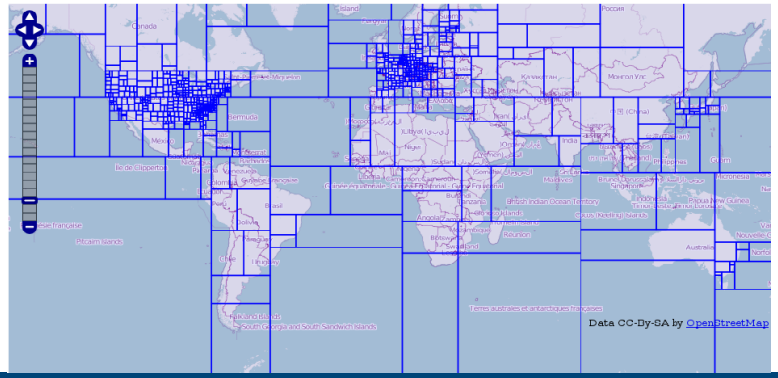
- Any tiling [Furtado 1999]
  - Cast into strategies



  - rasdaman storage layout language

```
insert into MyCollection
   values ...
   tiling
     area of interest [0:20,0:40], [45:80,80:85]
     tile size 1000000
     index d_index storage array compression zlib
```

- Why irregular tiling?

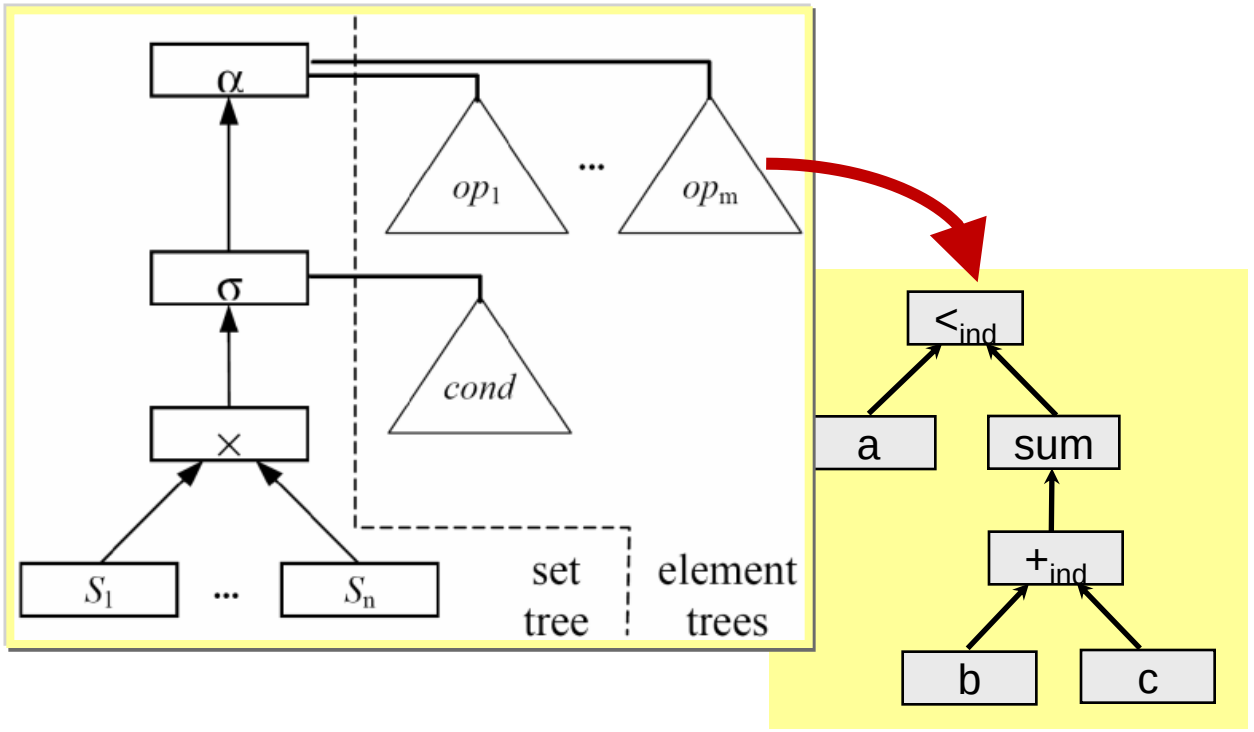


[OpenStreetMap]

Query Processing

- Clear separation:
  set vs array trees
  - Arrays as 2nd order attributes
- Optimization
- Tile-based evaluation

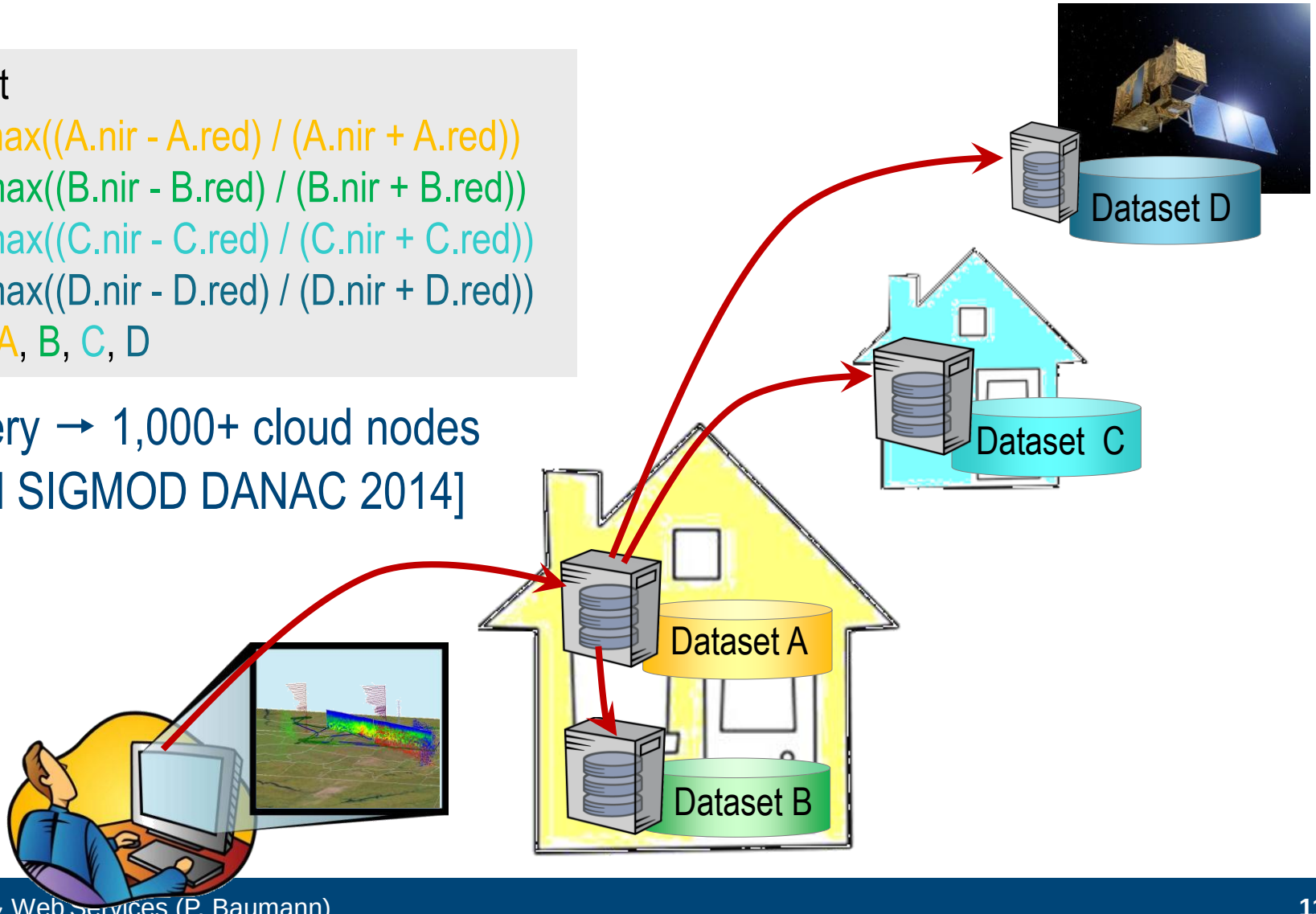
```
select a < sum_cells( b + c )
from   a, b, c
```



Parallel / Distributed Query Processing

```
select
      max((A.nir - A.red) / (A.nir + A.red))
    - max((B.nir - B.red) / (B.nir + B.red))
    - max((C.nir - C.red) / (C.nir + C.red))
    - max((D.nir - D.red) / (D.nir + D.red))
from A, B, C, D
```

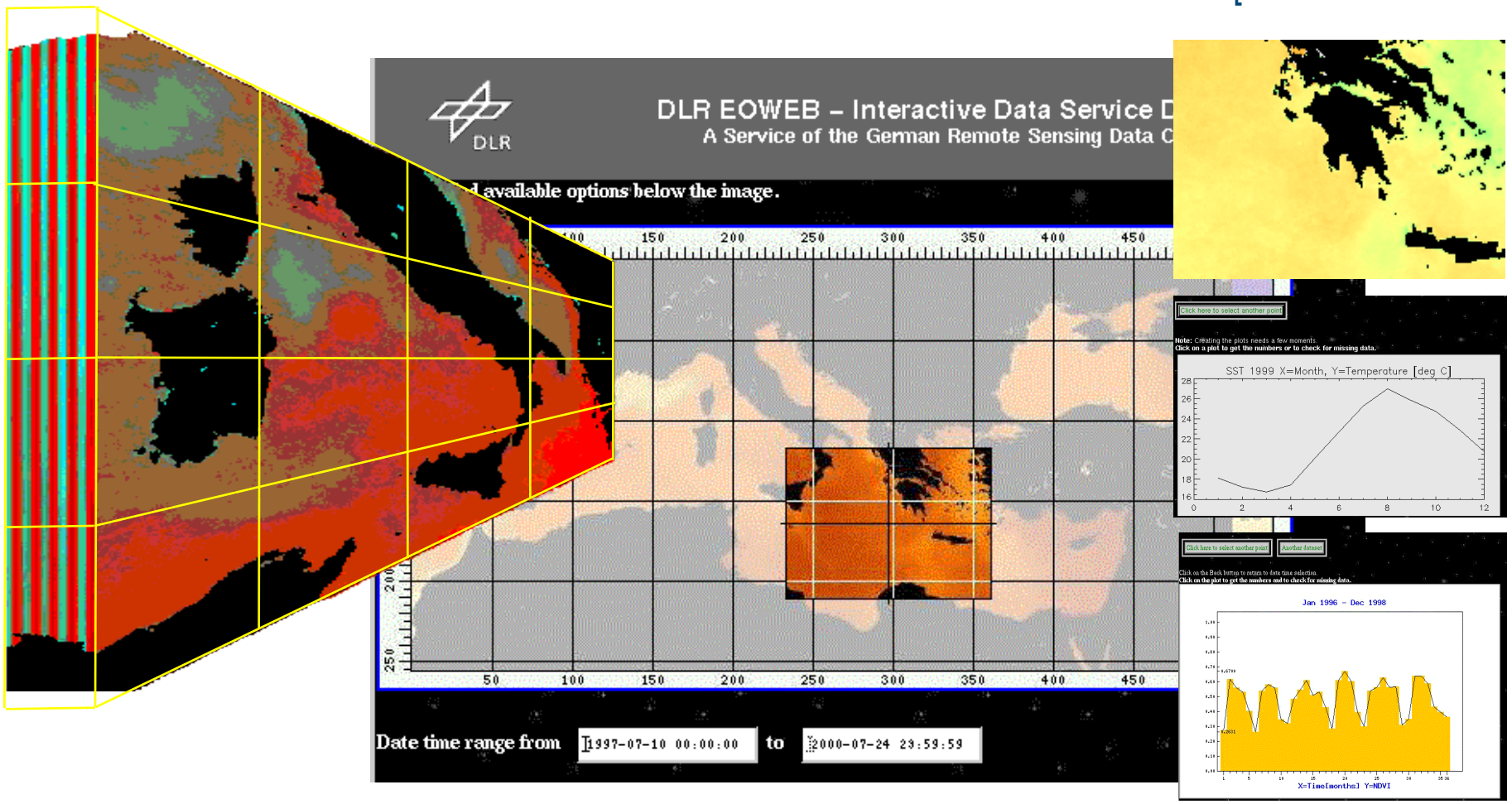
1 query → 1,000+ cloud nodes
[ACM SIGMOD DANAC 2014]



APPLICATIONS

Early 3-D Service on rasdaman

[Diedrich et al 2001]



EarthServer

JACOBS UNIVERSITY

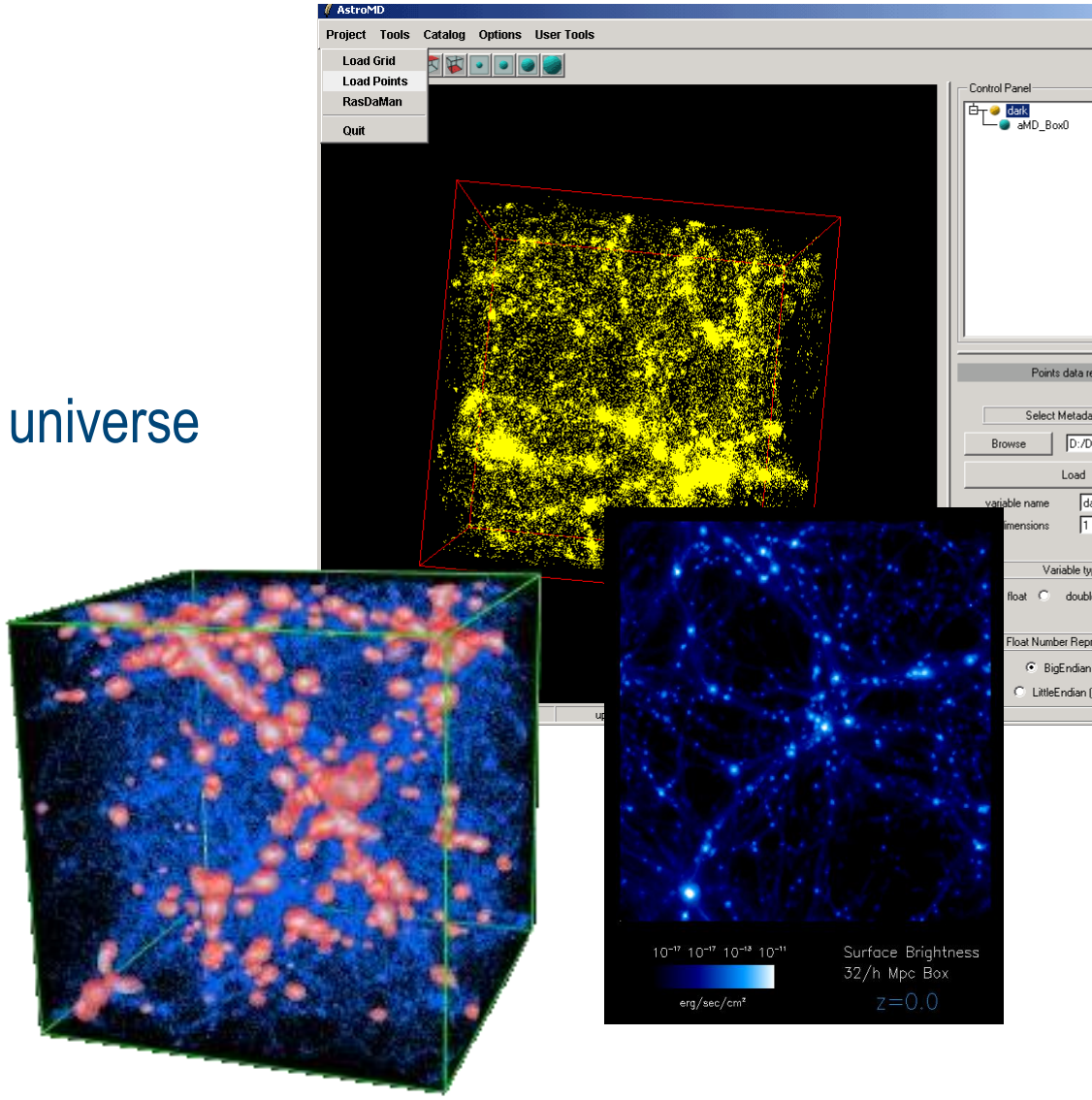
- Agile Analytics on x/y/t + x/y/z/t Earth & Planetary datacubes
  - EU rasdaman + US NASA WorldWind
  - Rigorously standards as c/s APIs
  - 100+ Petabyte
- 10+ data centers
  - participation free & open

www.earthserver.xyz

Co-funded by the European Union

Cosmological Simulation

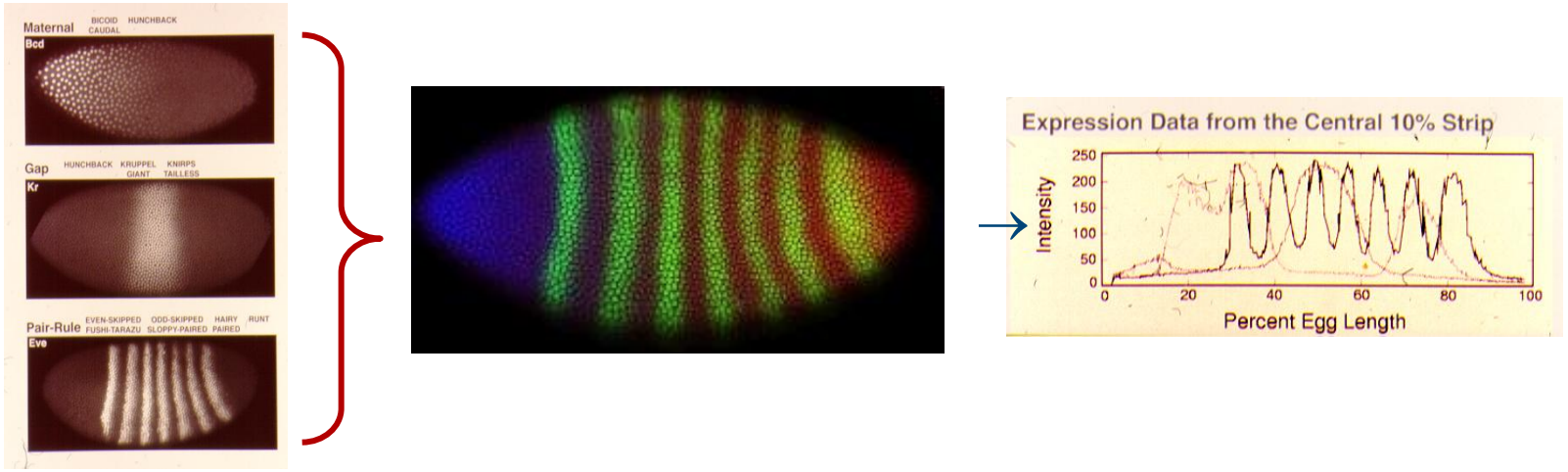
- Modelling domain: 4D
- Results: 3D/4D cutouts from universe
- Screenshots: AstroMD
  [Gheller, Rossi 2001]



Gene Expression Analysis

http://urchin.spbcas.ru/Mooshka/
[Samsonova et al]

- Gene expression = reading out genes for reproduction
- Research goal: capture spatio-temporal expression patterns in Drosophila

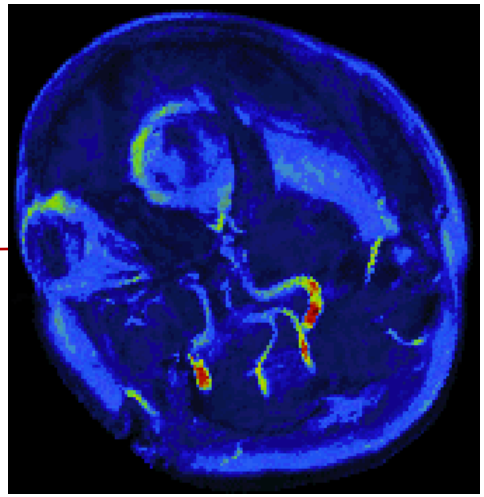


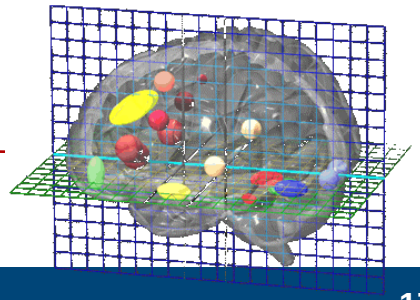

```
select encode( scale( {1c,0c,0c}*e[0,*:*,*:*]
                    +{0c,1c,0c}*e[1,*:*,*:*]
                    +{0c,0c,1c}*e[2,*:*,*:*], 0.2 ), „image/jpeg“ )
from EmbryoImages as e
where oid(e)=193537
```

Human Brain Imaging

- Research goal: structural-functional relations in human brain
- Experiments → activity patterns (PET, fMRI)
  - Temperature, electrical, oxygen consumption, ...
  - → lots of computations → „activation maps“
- Example: “*a parasagittal view of all scans containing critical Hippocampus activations, TIFF-coded*.“

```
select tiff( ht[ $1, *:*, *:* ] )
from   HeadTomograms as ht,
       Hippocampus as mask
where  count_cells( ht > $2 and mask )
       / count_cells( mask )
       > $3
```





`$1` = slicing position, `$2` = intensity threshold value, `$3` = confidence

WRAP-UP

Summary

- Arrays are core data structure next to sets, graphs, hierarchies
  - sensor, image, simulation, statistics datacubes
- Array DBMS for declarative queries on massive n-D arrays
  - rasdaman
- Issues:
  - enhancing distributed processing
  - iterative methods
  - ...