rasdaman raster data management

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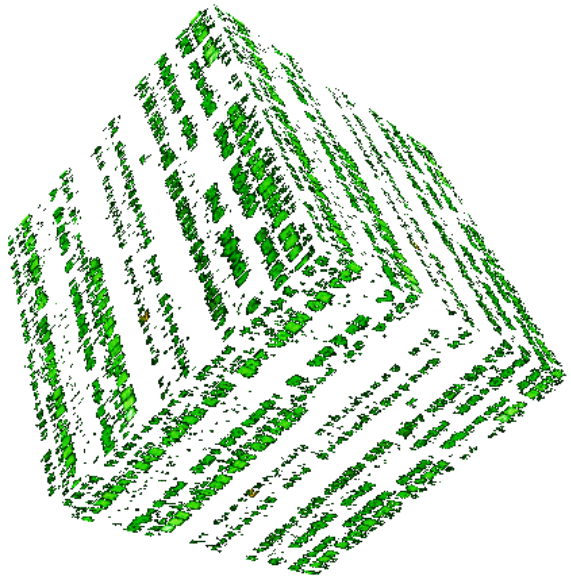


rasdaman

- the Agile Array Analytics Engine –

BOSS @ VLDB 2015

Kona, US, 04-sep-2015

Peter Baumann, Dimitar Misev

Jacobs University | rasdaman GmbH

[gamingfeeds.com]

Research supported by EU through EarthServer, PublicaMundi

Roadmap

- Introduction
- Installation
- Architecture
- Querying & Hands-on Session
- Wrap-up & discussion

Disclaimer:
This is a tutorial which has been presented at VLDB 2015. As such, it is supplementary material and not necessarily optimal for self-study. See www.rasdaman.org for ample ancillary material.

Introduction

BIG EARTH DATA

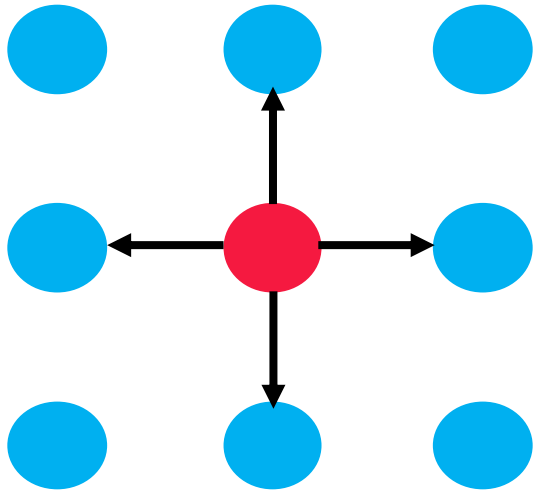
The Digitized Planet

Structural Variety in Big Data

- Stock trading: 1-D sequences (i.e., arrays)
- Social networks: large, homogeneous graphs
- Ontologies: small, heterogeneous graphs
- Climate modelling: 4D/5D arrays
- Satellite imagery: 2D/3D arrays (+irregularity)
- Genome: long string arrays
- Particle physics: sets of events
- Bio taxonomies: hierarchies (such as XML)
- Documents: key/value stores = sets of unique identifiers + whatever
- etc.

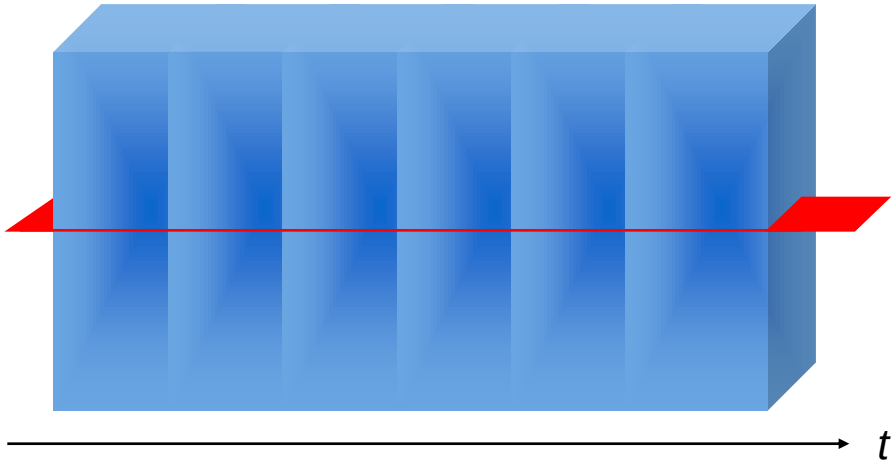
Array Analytics

- 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-D Euclidean neighborhood
  - Secondary: #dimensions, density, ...
- Operations: Linear Algebra++



[EDBT/ICDT Array Databases Workshop, 2011]

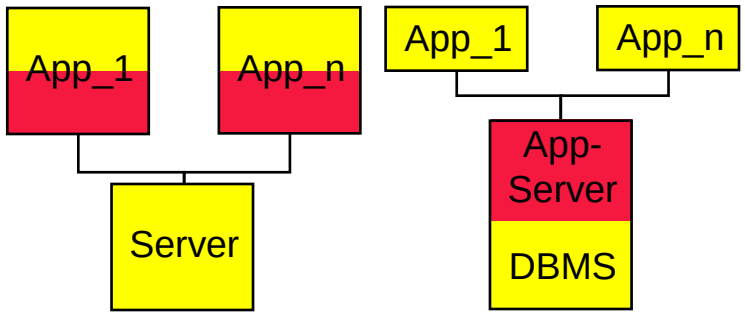
A Simple Example



- Divergent access patterns for ingest and retrieval
- Server must mediate between access patterns

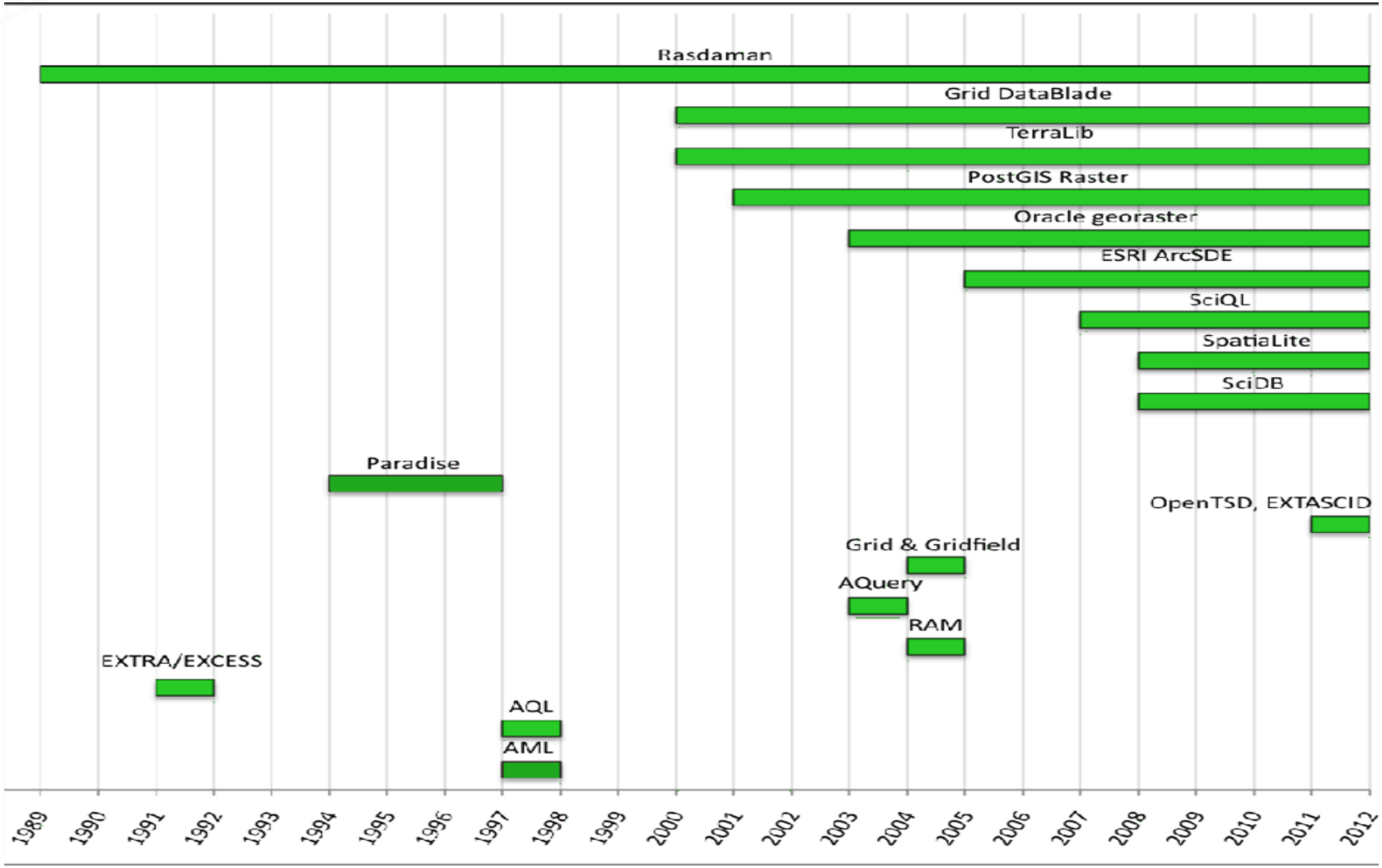
Why Array *Databases*?

- "classical“ database benefits for raster data:
  - data integration
  - flexibility
  - scalability
  - *...plus all further assets, like off-the-shelf tool support*



- Unfortunately database people have been soooo conservative
  - "images are matrices [...] which are stored as byte strings, ie, BLOBs"
  - „this is NOT SQL!“

A Brief History of Array DBMSs



first appearance in literature (not first implementation)

Array Analytics Research @ Jacobs U

- Large-Scale Scientific Information Systems research group
  - Flexible, scalable n-D array services
  - www.jacobs-university.de/lsis
- Main results:
  - pioneer Array DBMS, rasdaman
  - standardization: OGC Big Geo Data, ISO SQL

Hiring PhD students, PostDocs

rasdaman: Agile Array Analytics

- „raster data manager“: n-D arrays in SQL
  - [VLDB 1994, VLDB 1997, SIGMOD 1998, VLDB 2003, …]
- Array Algebra [NGITS 1998]
- Declarative, optimizable QL
- Scalable, parallel architecture
  - „tile streaming“

Installation

Options for Today

- Install from source: www.rasdaman.org
  - Prerequisite: Linux laptop
- Install RPM (CentOS 6, 7)
  - Prerequisite: Linux laptop
- Boot from USB stick
  - Prerequisite: laptop
- Run demo queries from browser
  - Prerequisite: laptop

Who wants what?

Coffee Break!

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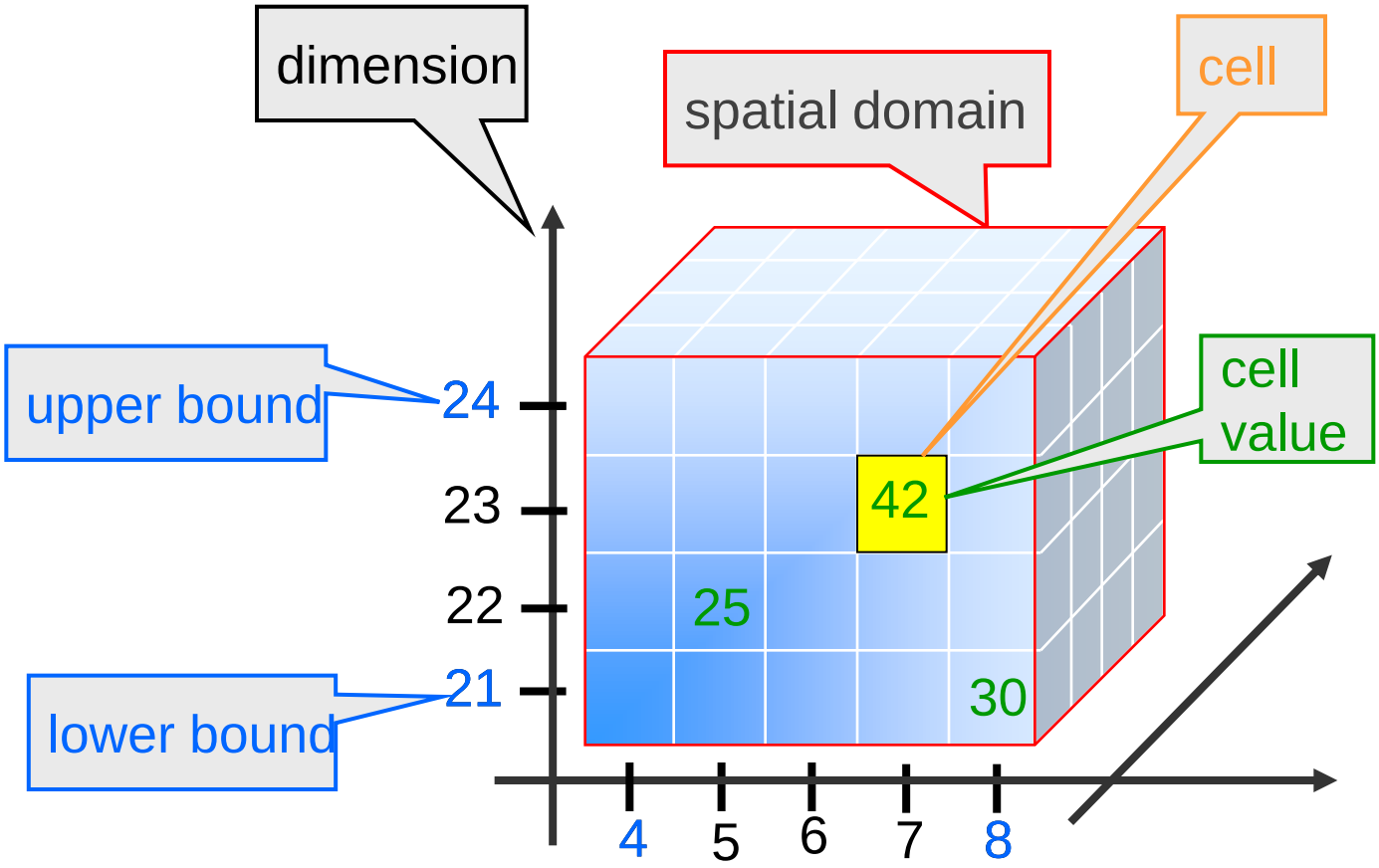
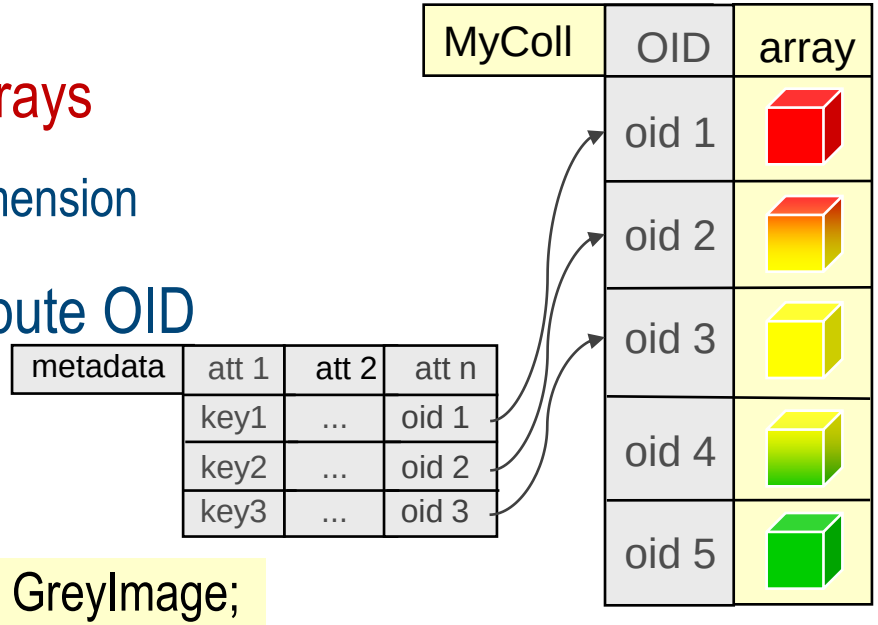
Query Language Intro

The Multidimensional Data Model



The rasdaman Data Model

- Data model: tables of typed n-D arrays
  - Array type knows cell type, extent/dimension
- Original rasql: Array + system attribute OID
  - ODMG speak: „collections“ =relations
  - Typed; any C/C++ type for cells
  - Ex: typedef Marray< int, [0:255,0:*] > GreyImage;

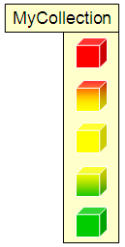


- ISO SQL/MDA (see later): tight DDL/DML integration with SQL
  - Ex:
```
create table LandsatScenes(
    id: integer not null, acquired: date,
    scene: row( band1: integer, ..., band7: integer ) array [ 0:4999,0:4999] )
```

will use rasql here

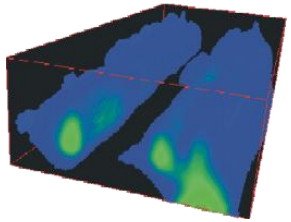
QL in a Nutshell

- Remember: tables with single, unnamed column of arrays



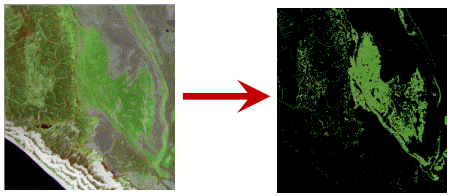
- trimming & slicing

```
select a[ *:*, 100:200, 10 ]
from AvgLandTemp as a
```



- result processing

```
select img * (img.green > 130)
from   NIR as img
```

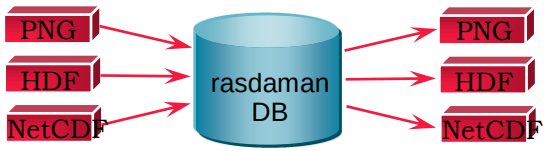


- search & aggregation

```
select mr
from   MRScan as mr, masks as m
where  some_cells( mr > 250 and m )
```

- data format conversion

```
select encode( a[*:*,*:*,10], "png" )
from AvgLandTemp as a
```



QL Foundation: Array Algebra

- Starting point: domain studies
  - ISO Computer Graphics Reference Model, Visualization Reference Model, image processing languages, AFATL Image Algebra, etc.
- Result: minimal algebra for model, QL, storage mapping, optimization
  - Array iteration implicit → no explicit loops → declarative, safe
- QL = SQL with array expression [VLDBJ1994, NGITS 1998]:
  - Array constructor -- build array & initialize from cell expression
  - Array condenser -- summarize over array, delivering a scalar
  - Array sorter – reorder array slices
  - *...all else can be reduced to these*

Array Algebra Ops: Constructor

- Define a new array (with extent), initialize cells

```
marray x in [0:99], y in [0:99]
values x+y
```

- Shorthands:
  - Subsetting (trim, slice):

```
a[ x0:x1, y0:y1, t ]
```

  - „induced“ operations: for every cell operation, offer same on arrays

```
a.red + 5
```

    - *cell component access*
    - *arithmetic, boolean, exponential, trigonometric ops,...*

Array Algebra Ops: Condenser

- Summarize over (part of) an array

```
condense +
over     x in [0:99], y in [0:99]
[ where  P ]
using    a[x,y]
```

- Shorthands:
  - usual suspects: *count, sum, avg, max, min, some, all*

```
max_cells( a )
```

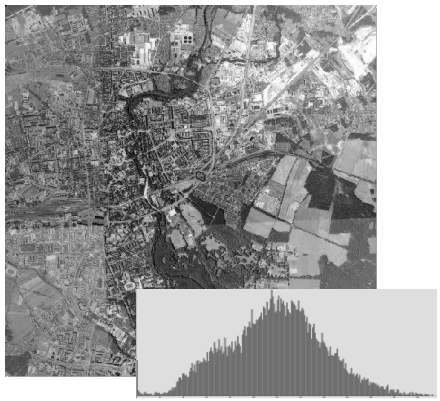
Sample Combinations

- Matrix multiplication (here for simplicity: self-join)

```
select marray i in [0:m], k in [0:p]
       values condense +
              over     j in [0:n]
              using    a [ i, j ] * b [ j, k ]
from   lena as a, lena as b
```

- Histogram

```
select marray bucket in [0:255]
       values count_cells( lena = bucket )
from   lena
```



Hands On Querying

Let‘s Get Hands On!

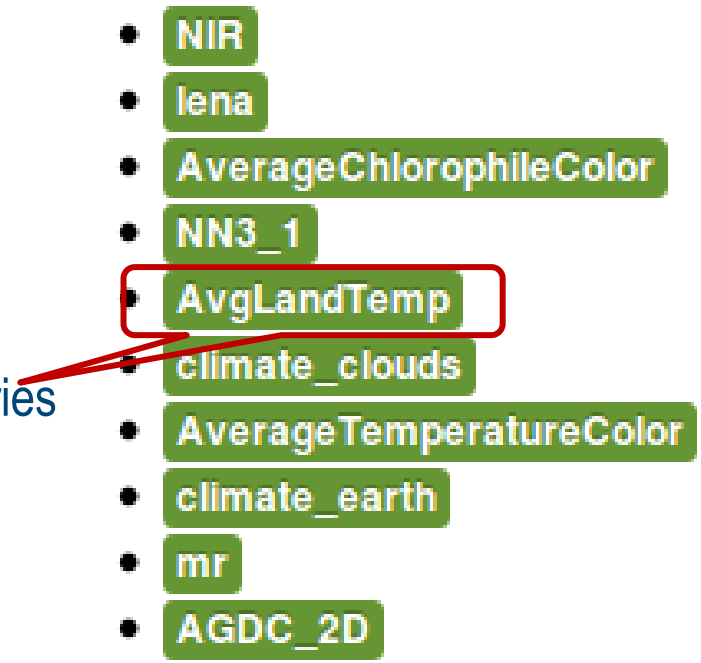
- Online:
  - http://standards.rasdaman.com/demo/client/rasql.php
  - For images: prefix query with image>>
  - For diagrams: prefix query with diagram>>
  - Otherwise (text output): no prefix
- USB sticks:
  - start_rasdaman.sh ⟶ open browser, see same page as above, continue as above
- Compiled from source: use command line:
  - start_rasdaman.sh
  - For images: $ rasql -q "select ... " --out image
  - Otherwise: $ rasql -q "select ... " --out string

What Data is Available?

- Collections hold array objects
- Get a list of available collections:

```
select c
from RAS_COLLECTIONNAMES as c
```

  - Virtual collection of 1-D char arrays
- In this tutorial:
  - Mostly using 3D global land temperature timeseries
  - Most collections contain 1 row



Array Schema & Other Information

- Get a list of available collections:

```
select c
from RAS_COLLECTIONNAMES as c
```

  - Virtual collection of 1-D char arrays

- oid() – array identifiers

```
select oid(c)
from AvgLandTemp as c
```

- sdom() – list of axis boundary intervals (ie, integer pairs)

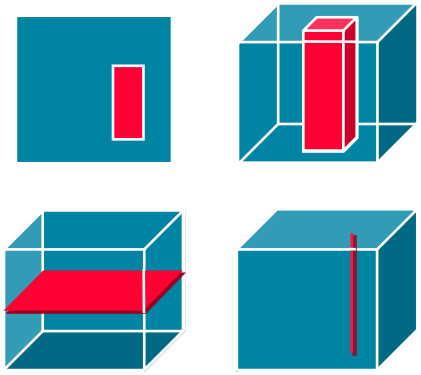
```
select sdom(c)
from AvgLandTemp as c
```

→ `[0:3599,0:1799,0:12]`

- dbinfo() – physical storage information

Trimming & Slicing

- Array subsetting:
  - Trim takes interval, retains dimension of result
  - Slice takes point, each slicing reduces dimension of result



- Ex (substitute numbers for x, y, t):
  - Single point (0D = scalar)

```
select c[ x, y, t ]
from AvgLandTemp as c
```

  - 1D timeseries

```
select c[ x, y, t1:t2 ]
from AvgLandTemp as c
```

  - 2D timeslice

```
select c[ *:*, *:*, t ]
from AvgLandTemp as c
```

Induced Operations

- = overloaded array cell operators, as aka shorthands
- Ex: „Convert all values from Celsius to Kelvin for one year at position x/y“

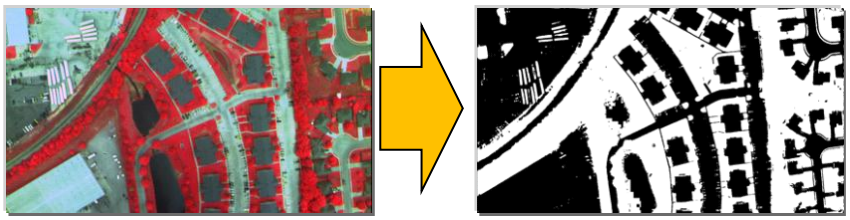
```
select encode( c[x,y,0:11] + 273.15, "csv" )
from AvgLandTemp as c
```

- Ex: Pixel-wise „band math“ in remote sensing

```
select encode( c.0 - c.1, "png" )
from NIR as c
```

- Ex: Real-life example: NDVI (vegetation index) from false-color image

```
select encode( (char) ((((float)c.0 - c.1) / ((float)c.0 + c.1)) > 0.7) * 255, "png")
from NIR as c
```



Induced Operations /contd.

- Conditional evaluation: SQL case statement, extended to arrays
  - Ex: „color code output based on cell values, null values as black (ie, transparent)“

```
select case
  when c[1600:2200,150:550,7] = 99999 then {255c,255c,255c}
  when c[1600:2200,150:550,7] < 18    then {0c,0c,255c}
  when c[1600:2200,150:550,7] < 24    then {0c,255c,0c}
  else                                     {255c,0c,0c} end
from AvgLandTemp as c
```

- In summary: all unary, binary, n-ary cell operations can be induced
  - record access, arithmetic, logarithmic, trigonometric, comparison, Boolean, cast, case

Array Construction /contd.

- Subsetting & induced ops expressible through basic array constructor, as per algebra:
- Ex: „2D 100x100 cutout in space, slice at time t=0“

```
select encode(
          marray x in [0:99], y in [0:99]
          values c[x,y,0],
          "png" )
from AvgLandTemp as c
```

- Ex: „1D array of bi-monthly average temperatures at a certain location“

```
select encode(
          marray t in [0:5]
          values (  c[1888, 369, 2*t]
                  + c[1888, 369, 2*t+1] ) / 2,
          "png" )
from AvgLandTemp as c
```

Aggregation

- First, shortcuts: *min_cells, max_cells, avg_cells, all_cells*, ...
  - Ex: „Minimum temperature of all months in first year, for location (100,200)“

```
select min_cells( c[ 100, 200, 0:11 ] )
from AvgLandTemp as c
```

- Next, basic condenser as per algebra
  - Ex: „Count number of months when average temperature over a particular area exceeds threshold“

```
select
  condense +
  over t in [0:4]
  where avg_cells( c[1800:1900, 300:400, t ] ) > 15
  using 1
from AvgLandTemp as c
```

User-Defined Functins (UDFs)

- external code dynamically linked into server, callable from query
  - Leverage existing libraries within rasql queries difficult to represent as queries
- rasdaman: UDF API = client API + auto-generated adapter → easy to use
  - integrated with server-side tile management, parallelization, ...
- Demo only available on self-installed version, not over Web; before running query compile UDF code:

1) Open terminal (Applications → Utilities → Terminal)
2) $ cd ~/rasdaman/share/rasdaman/udf
3) $ make && stop_rasdaman.sh && start_rasdaman.sh

- Ex: use OpenCV for histogram equalization on RGB image

```
select encode(
            cv.equalize_hist( c[0:999,0:999]/16) ), "png" )
from AGDC_2D as c
```

Cloud Demo

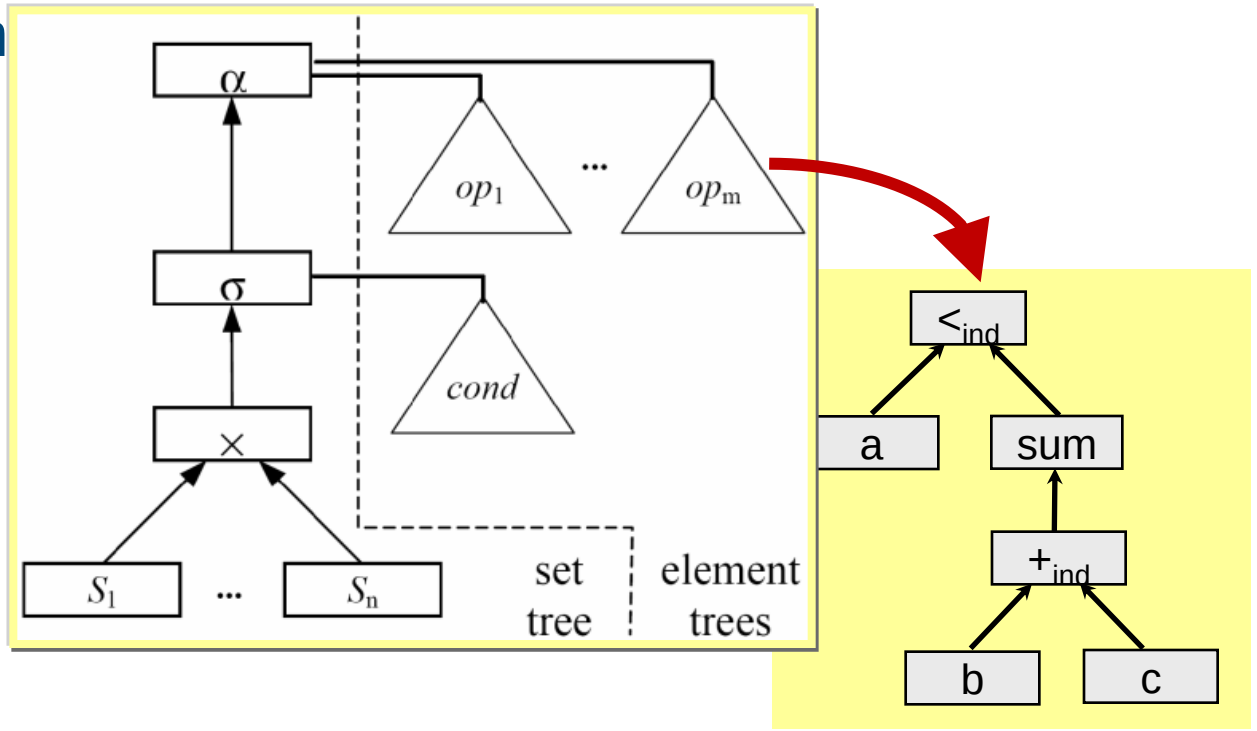
- Open URL shown
- 1 TB of Earth science timeseries data
- Run parallel queries in Amazon cloud

Architecture

Query Processing

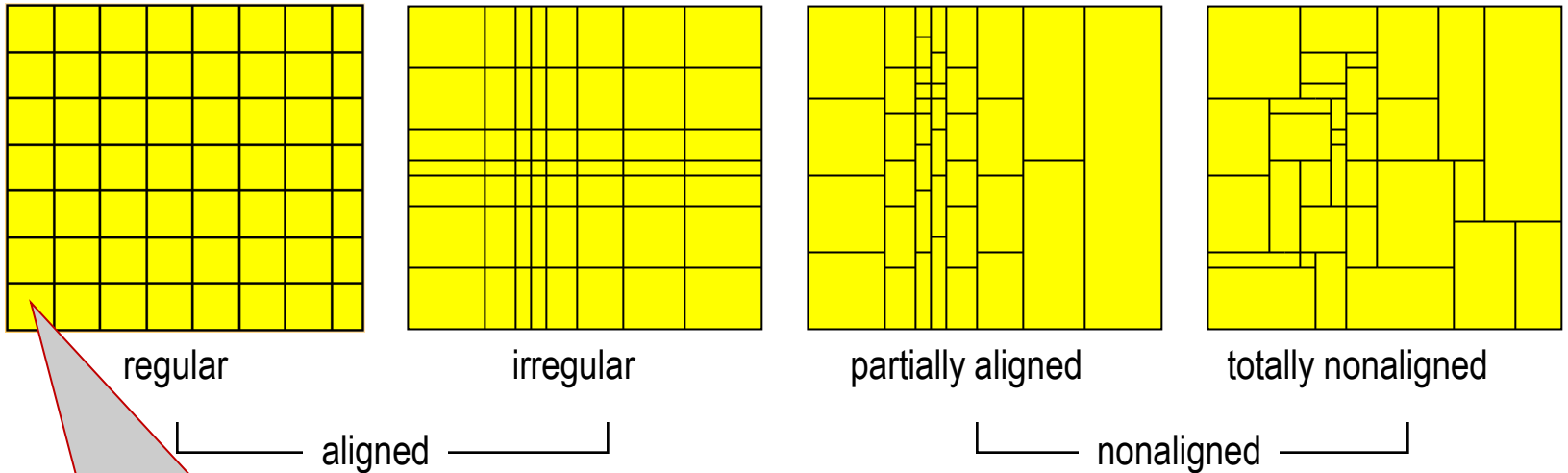
- Clear separation: set vs array trees
  - Arrays as 2nd order attributes
- Extensive optimization
- Tile-based evaluation

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



Tiling

- Goal: faster tile loading by adapting storage units to access patterns
- Approach: partition n-D array into n-D partitions („tiles“)
- Tiling classification based on degree of alignment [ICDE 1999]

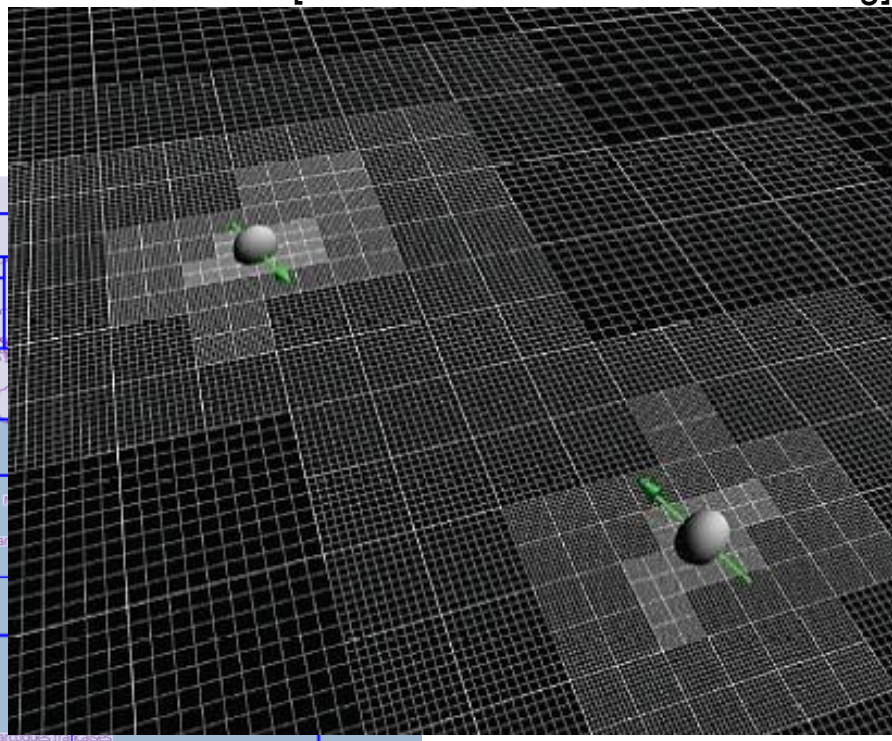


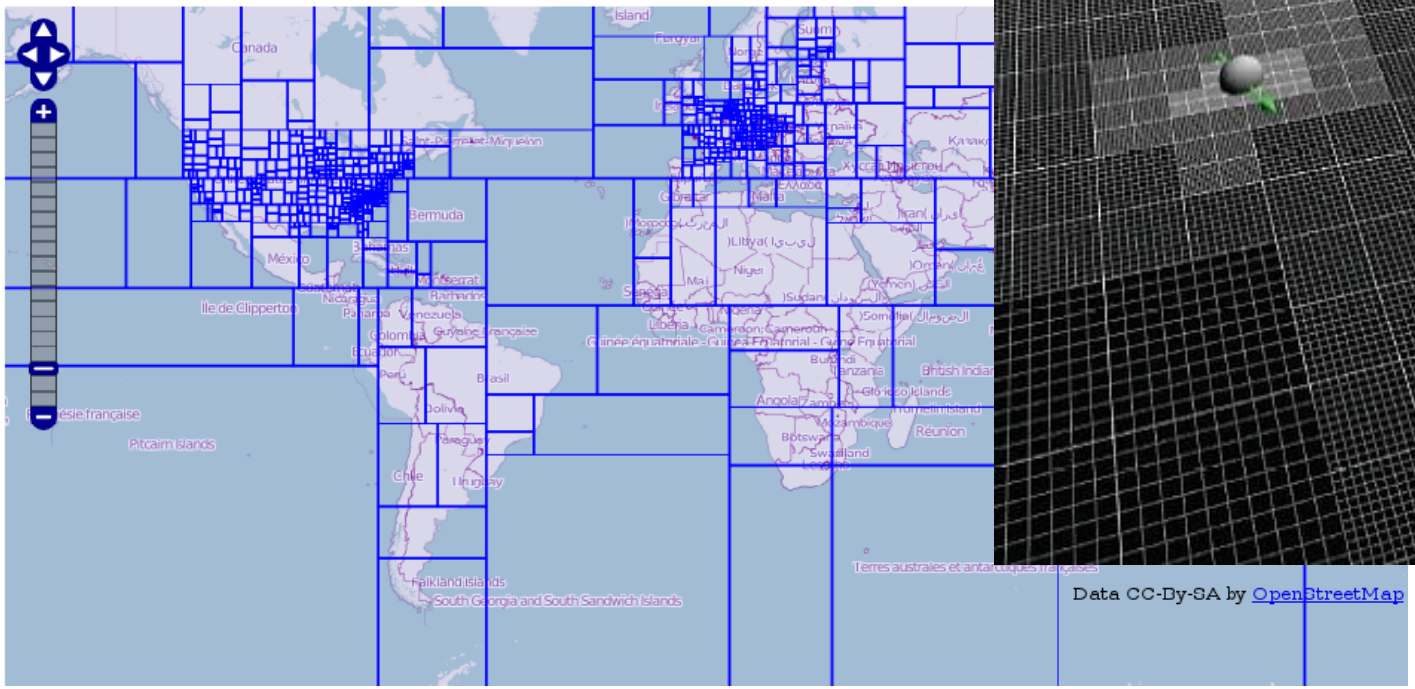
chunking [Sarawagi, Stonebraker, DeWitt, ...]

Why Irregular Tiling?

- e-Science often uses irregular partioning

[Centrella et al: scidacreviews.org]



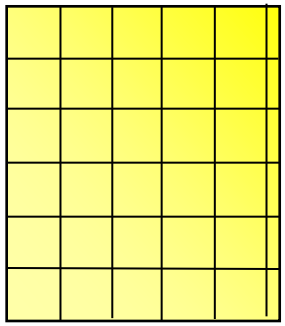


[OpenStreetMap]

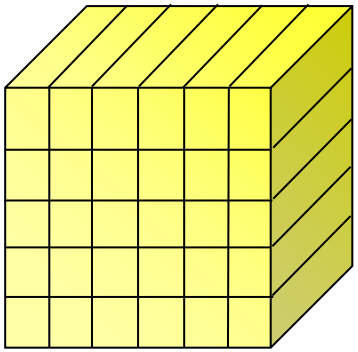
Adaptive Tiling

- Sample tiling strategies [ICDE 1999]:

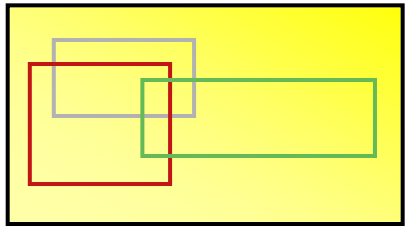
regular



directional



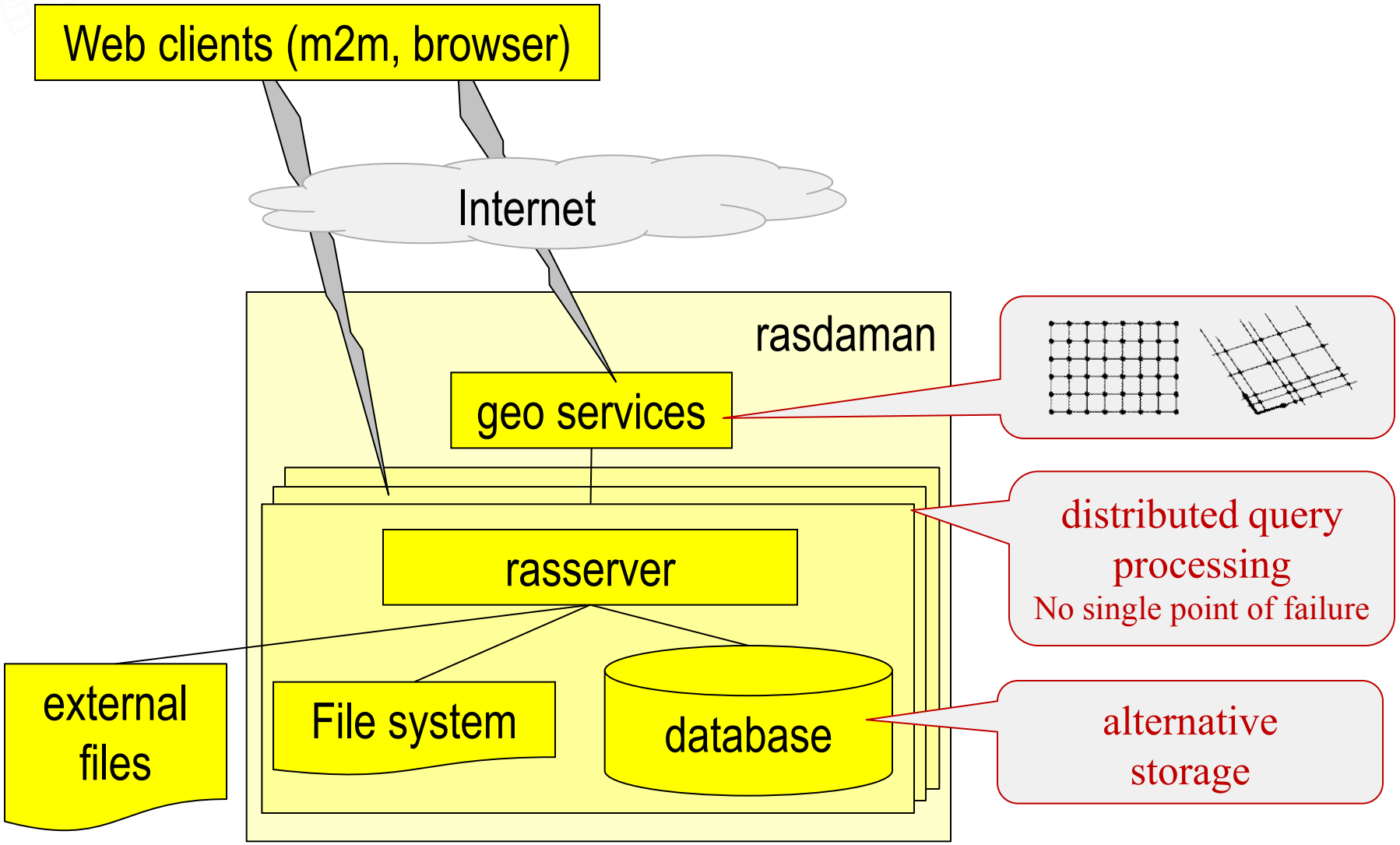
area of interest



- rasdaman storage layout language [SSTDM 2010]

```
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
```

Architecture



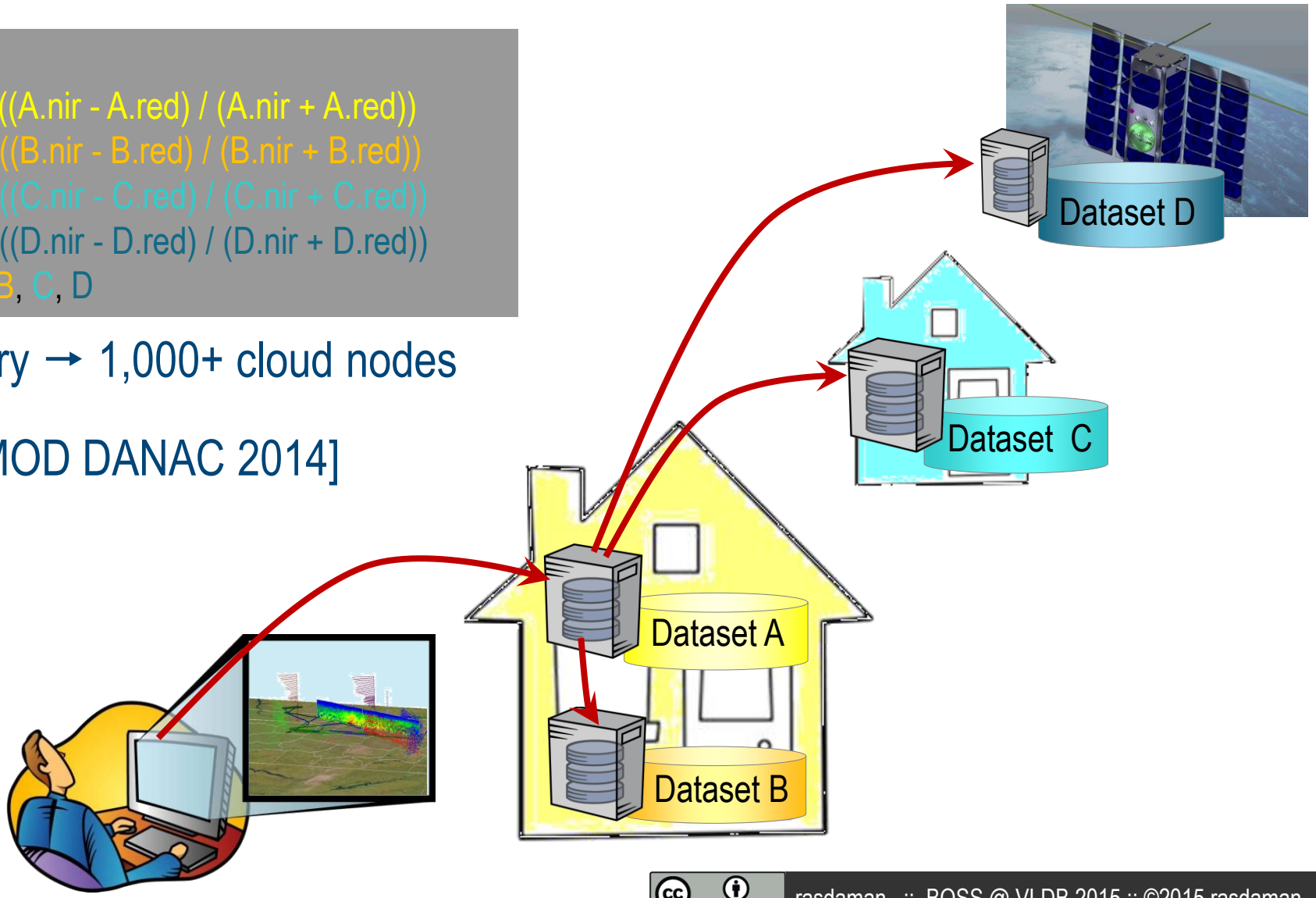
[SSTD 2013]

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

[SIGMOD DANAC 2014]



Parallel / Distributed Query Processing

- Online demo at http://earthlook.flanche.net/vldb_cloud_demo
  - ~1TB of 3D Landsat 5 time series data (2003-2011) over ACT area
  - 6 bands: blue, green, red, nir, mir1, mir2 (in rasql 0, 1, 2, ...)
  - distributed over 9 Amazon nodes

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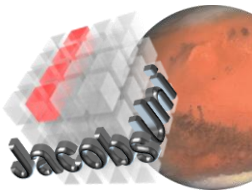
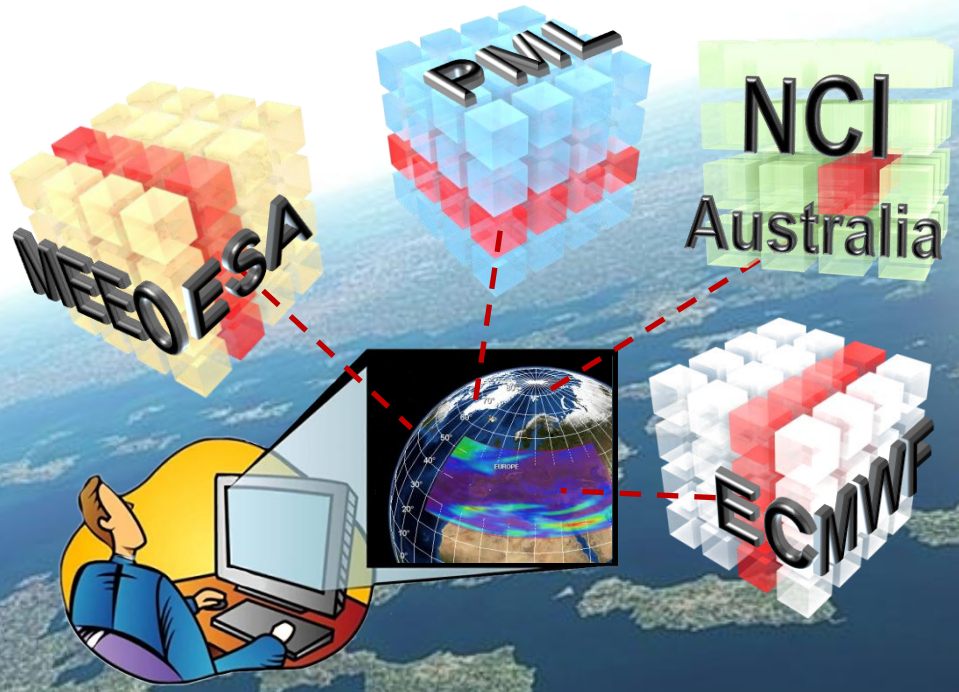
Wrap-Up & Discussion

EarthServer: Datacubes at Your Fingertips

- Operational Agile Analytics on 1+ Petabyte space/time datacubes
  - Earth Science (3D sat image timeseries, 4D weather); Planetary Science
- Based on & extending rasdaman
  - integrated data/metadata search
  - performance enhancements
- Intercontinental initiative: EU+US+AUS
- www.earthserver.eu

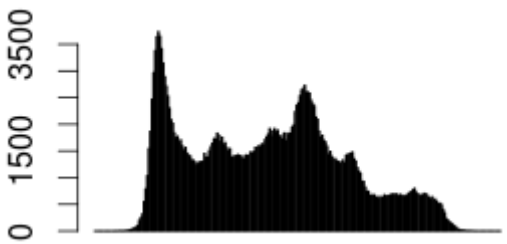


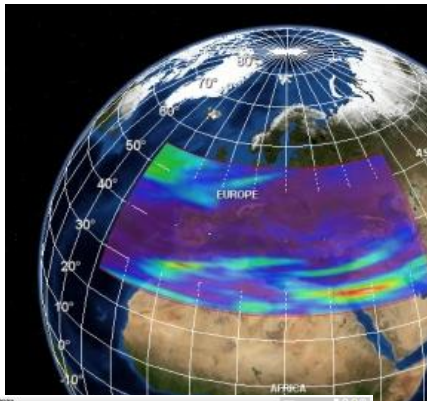


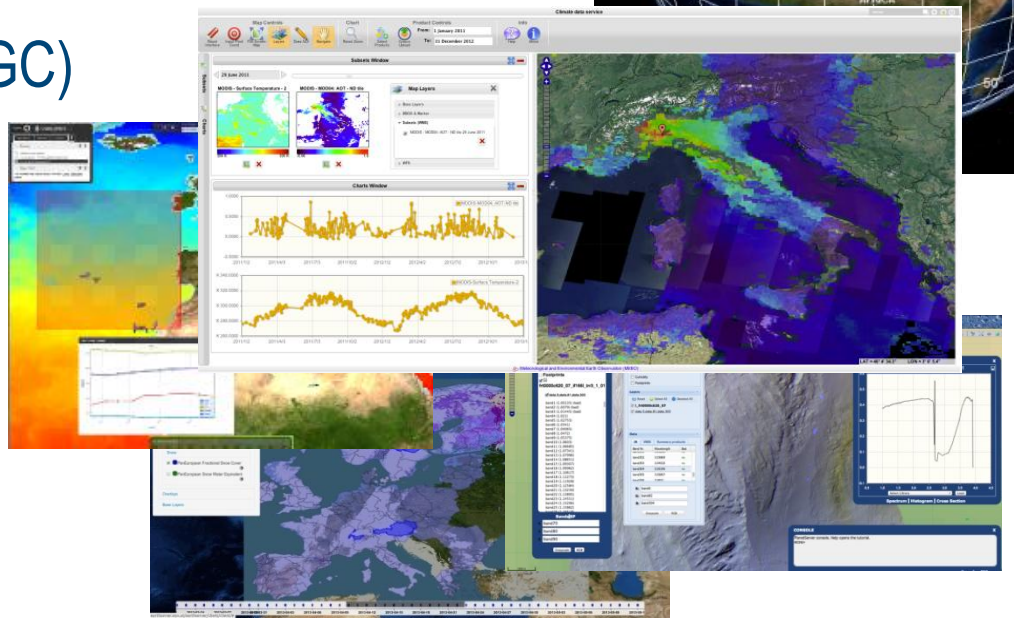
Co-funded by the European Union

Science & GIS Tool Interfacing

- General-purpose scientist tools:
  - Python, R, Java, C++
- Geo tools:
  - MapServer, GDAL, QGIS, OpenLayers, NASA WorldWind, ...
- Open Geospatial Consortium (OGC)
  Web Coverage Service (WCS)
  Core Reference Implementation
  - OGC‘s „Big Geo Data“ standard

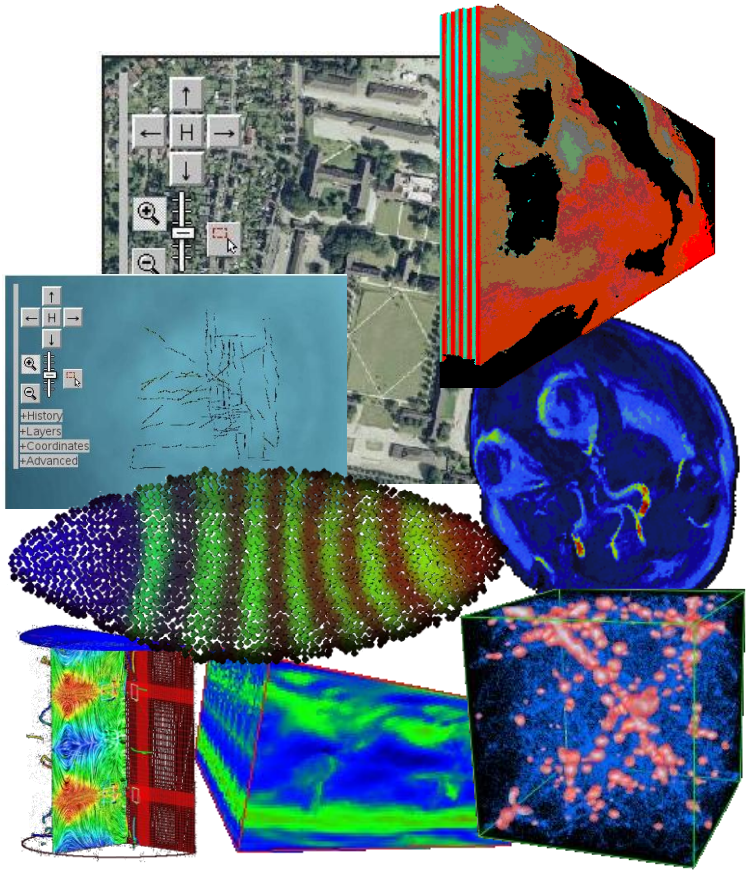






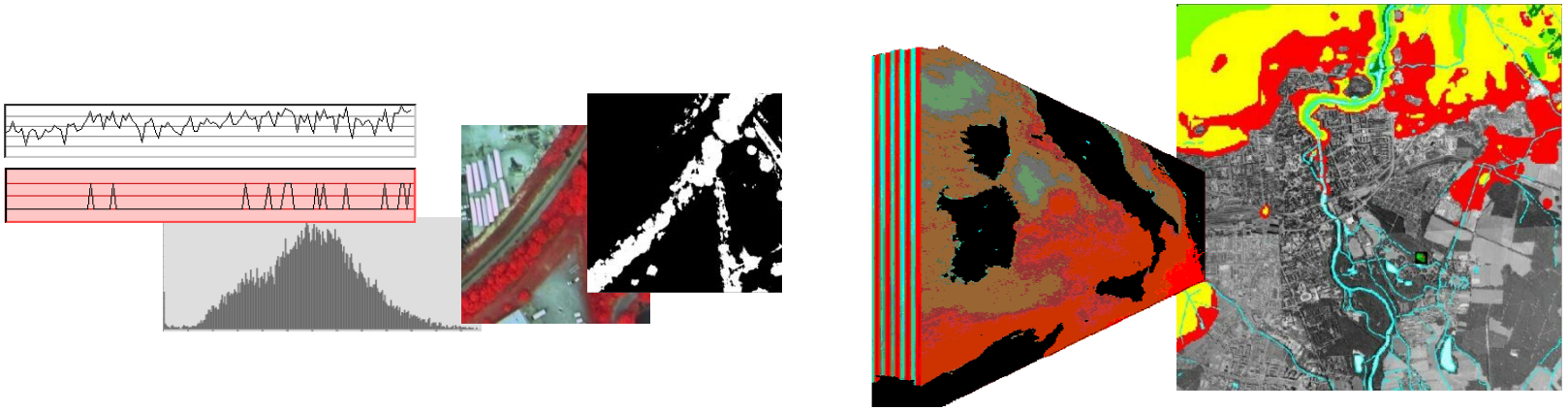
Domains Investigated

- Geo
  - Environmental sensor data, 1-D
  - Satellite / seafloor maps, 2-D
  - Geophysics (3-D x/y/z)
  - Climate modelling (4-D, x/y/z/t)
- Life science
  - Gene expression simulation (3-D)
  - Human brain imaging (3-D / 4-D)
- Other
  - Computational Fluid Dynamics (3-D)
  - Astrophysics (4-D)
  - Statistics (n-D)

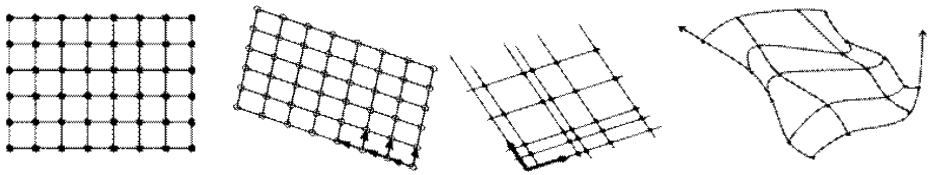


Standardization: Geo Raster QL

- OGC Web Coverage Processing Service (WCPS)



- high-level geo raster query language; adopted 2008
  - Integration with XQuery
  - Geo semantics → variety of grid types:



[VLDB 2003, SSDBM 2009, SSDBM 2010, Geoinformatica 2010]

Standardization: SQL

[SSDBM 2014]

ISO/IEC JTC 1/SC 32

Date: 2014-06-04

WD 9075-15:2014(E)

Information technology — Database languages — SQL —

Part 15:
Multi-Dimensional Arrays (SQL/MDA)

ISO/IEC JTC 1/SC 32/WG 3

The United States of America (ANSI)

Technologies de l'information — Langages de base de données — SQL —

Partie 15: Tableaux multi-dimensionnels (SQL/MDA)

```
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.nband1+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
```

„one size does not fit all“

...holds for the above sentence, too.

We need to inspect every case individually,
and arrays fit nicely into SQL world.

NB: Geo world desperately tries to get away from silos,
striving for (logical) data integration

Conclusions

- Array Analytics: support for a core category of „Big Data“ in sci & eng
  - Sensor, image, simulation, statistics data
  - Signal/image processing, statistics, Linear Algebra
- DBMSs contribute flexibility, scalability, information integration, ...
- rasdaman: pioneer ADBMS, in industrial use
  - PB of operational databases, 1,000+ nodes
  - OpenHub: rasdaman community @ 10m US$ value
- See us:
  - www.rasdaman.org, www.jacobs-university.de/lsis, www.earthserver.eu

[Dali]