TIME'13

MAKING *TIME* JUST AN OTHER AXIS IN GEOSPATIAL SERVICES

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JACOBS UNIVERSITY

EarthServer

Outline

A. Context

B. Concepts

C. Practical examples

D. CRS parametrization

E. *Conclusions*

A. Context

Geospatial Services

- **Open Geospatial Consortium**:
  interoperable, open and standard

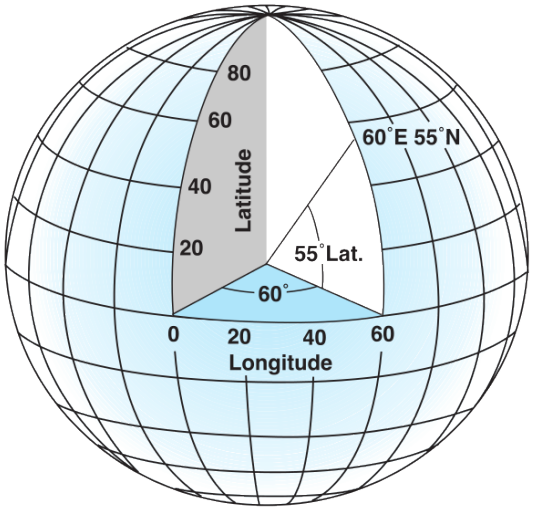
- Different <u>products</u>:
  raster- and vector-based, models, ...
- Different <u>domains</u>:
  metOcean, atmosphere, geology, land-use, ...

- One shared need: **time** as first-class citizen.

Coordinate Reference Systems

- Coordinate Reference System: **CRS**

  Ordered set of coordinates (tuple) that bind an object to a position on, e.g., Earth via a datum, uniquely.

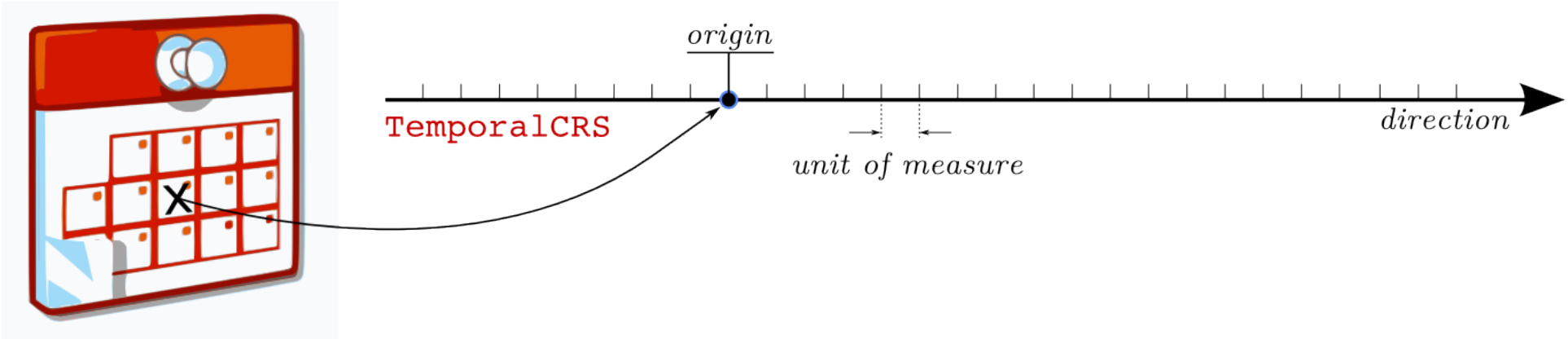


- Public catalogs of geospatial and planetary CRSs:
  EPSG registry, IAU2000, spatialreference.org, ...
- What about the temporal CRSs?
  ISO:19111 allows merged spatiotemporal reference systems.

Temporal CRSs

1D coordinate reference system used for the recording of time.

- Simple linear representation of time elapsed since an epoch.
- From timestamp to numeric notation.



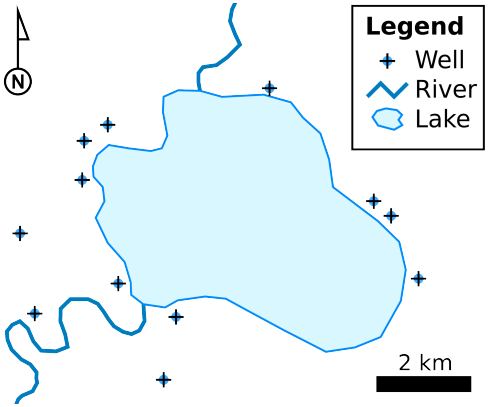
The OGC CRS Resolver

- OGC policy – every resource to be publicly available via **HTTP URI**:
  - *http://www.opengis.net/def/axisDirection/OGC/1.0/future*
  - *http://www.opengis.net/def/uom/OGC/1.0/radian*
  - *http://www.opengis.net/def/crs/EPSG/0/4326*
- OGC Naming Authority
- For OGC CRS resources:
  Semantic Coordinate Reference System Resolver
  (**SECORE**, Misev et al. 2012)
- HTTP URI → GML definition

GML: Geography Markup Language

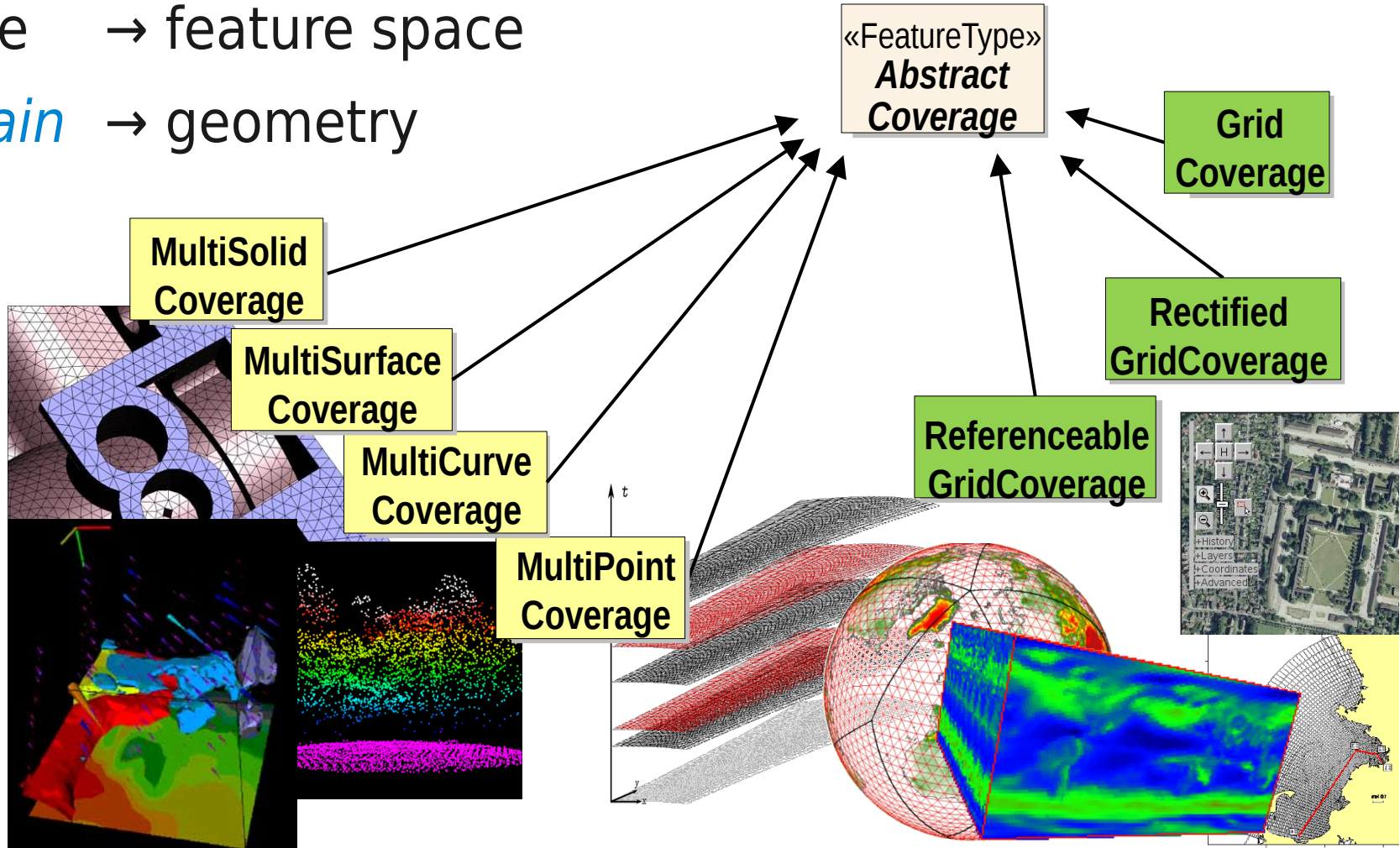
- XML grammar by OGC
- First truly public standard for spatial information.
- Geographic features:
  points, lines, curves, surfaces, solids, polygons, grids ...
- 1 feature → 1 CRS

<GML>



The Coverage

- Digital geospatial information representing <u>*n*-dimensional</u> space-time varying phenomena:
  - Range → feature space
  - *Domain* → geometry



Authors' context

- FOSS `rasdaman` developer
  http://rasdaman.org/
- EarthServer EU project
  http://www.earthserver.eu/
- OGC Web Coverage Service (WCS) implementation and standard proceeding.
- OGC Temporal Domain Working Group (DWG)
  - Public wiki *http://external.opengeospatial.org/twiki_public/TemporalDWG*
  - Mailing list *https://lists.opengeospatial.org/mailman/listinfo/temporal*

B. Concepts

Rationale

- Publicly available/resolvable indexing of time via GML temporal CRS, identified by HTTP URIs.
- Build a spacetime aquarium for OGC web services via CRS composition:

http://www.opengis.net/def/crs-compound?
1=http://www.opengis.net/def/crs/EPSG/0/4326&
2=http://www.opengis.net/def/crs/OGC/0.1/UnixTime

- Allow ISO:8601 timestamps for user interface.
- Refer to CRS dimensions by labels defined in their GML.

Some Related Works

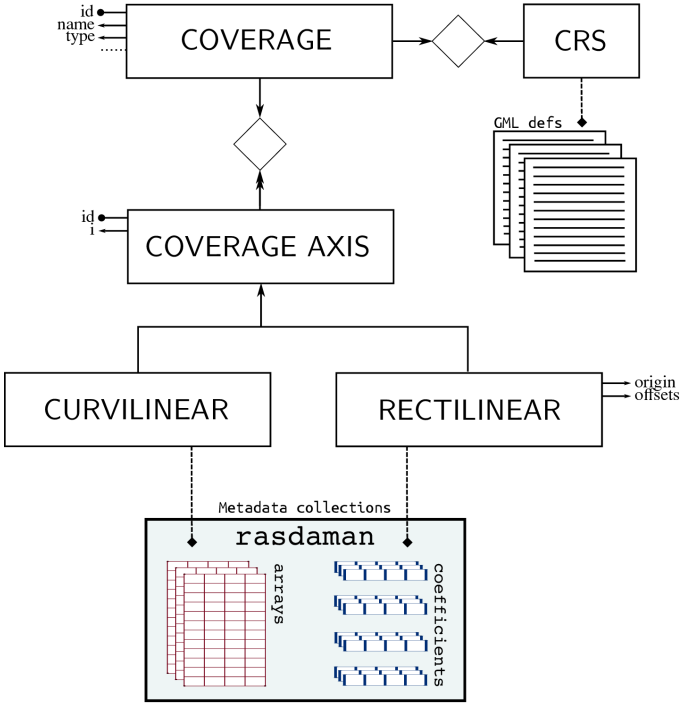
- Within OGC:
  - Web Map Service (WMS) TIME parameter
    (JD Blower et al. 2013)

- Outside OGC:
  - R *gstat* and *spacetime* packages
    (E Pebesma 2012)
  - *PostTIME* PostgreSQL extension
    (https://github.com/52North/PostTIME)

✗ Max 1 temporal dimension ✗/✓ Time ≠ Space

Our Approach

- *n*-dimensional compound CRS
  - 1+ spatial CRS(s)
  - 1+ temporal CRS(s)
- Public resolvable resources identifiers
- Cross-standard: WCS, WMS, WFS, …

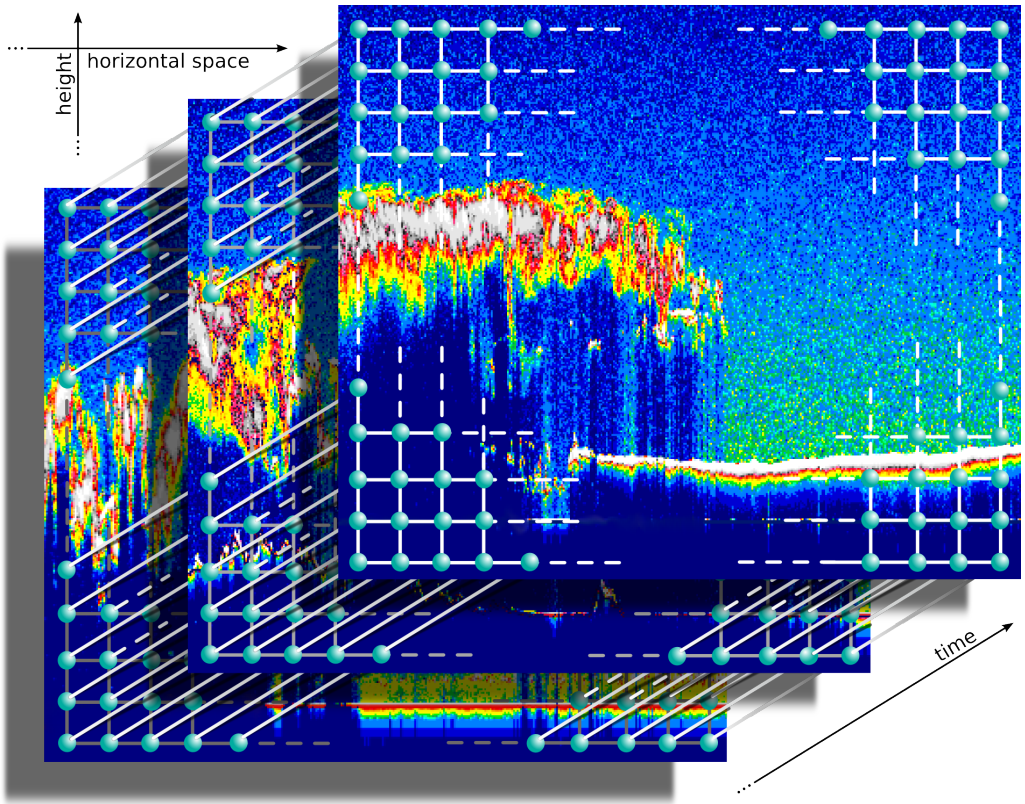


- Status:
  - α-implementation within OGC WCS service in *rasdaman*
  - some first temporal CRS definitions proposed to OGC-NA

C. Practical examples

Time Series of Images

- The dataset:
  - Temporal series of hourly 2D images starting from the end of the World, UTC 21 Dec 2012 00h00.
  - UTM spatial projection
  - Temporal reference: (e.g.) Unix time, hence t_0=1356044400 with a time spacing of 3600 [s].



Time Series of Images : CRS

- CRS 3D coordinates' tuple:
  - Horizontal 2D UTM projection (over... Armenia?) with easting (E) and northing (N):
    CRS-s = *http://www.opengis.net/def/crs/EPSG/0/32638*
  - Temporal 1D Unix time dimension (unix):
    CRS-t = *http://www.opengis.net/def/crs/OGC/0.1/UnixTime*

- Assigning the <u>unique</u> CRS identifier to our dataset:
  - CRS = *http://www.opengis.net/def/crs-compound?1=<CRS_s>&2=<CRS_t>*

Time Series of Images : GML

- Unix time definition:
  linear counting of seconds elapsed since 1st Jan 1970 (no leap *s*).
- CRS resource name: “UnixTime”
- URI: *http://www.opengis.net/def/crs/OGC/0.1/UnixTime*
- Key GML elements in the definition:
- //TimeCS/axis/CoordinateSystem
  - /axisAbbreviation : “unix”
  - /axisDirection : “future”
  - @uom : “s” (seconds)
- //TemporalDatum
  - /origin : 1970-01-01T00:00:00Z

```
<TemporalCRS xmlns=[...] gml:id="Unix">
  <description>
    Seconds elapsed from Jan 1, 1970.
  </description>
  <identifier codeSpace="{codespace}">
     http://www.opengis.net/def/crs/OGC/0.1/UnixTime
  </identifier>
  <name>Unix time</name>
  <name>POSIX time</name>
  <timeCS><TimeCS id="s-CS">
    <identifier codeSpace="{codespace}">
      http://www.opengis.net/def/cs/OGC/0.1/Seconds
    </identifier>
    <axis>
      <CoordinateSystemAxis id="s-axis" uom="s">
        <identifier codeSpace="{codespace}">
          http://www.opengis.net/def/axis/OGC/0.1/seconds
        </identifier>
        <axisAbbrev>unix</axisAbbrev>
        <axisDirection codeSpace="{codespace}">
           Future
        </axisDirection>
      </CoordinateSystemAxis>
    </axis>
  </TimeCS></timeCS>
    <temporalDatum><TemporalDatum id="unix-TD">
      <identifier codeSpace="{codespace}">
        http://www.opengis.net/def/datum/OGC/0.1/UnixTimeDatum
      </identifier>
      <origin>1970-01-01T00:00:00Z</origin>
    </TemporalDatum></temporalDatum>
</TemporalCRS>
```

Time Series of Images : WCS req.

- WCS requests:
  - Time slice over a Region of Interest (RoI):

```
http://{WCS-server-host}/{path}?
    service=WCS&version=2.0.1&request=GetCoverage&
    coverageid=ARM-temperatures&
    subset=E(415000,500000)&
    subset=N(4430000,4530000)&
    subset=unix("2012-12-21T12:00:00")&
    format=application/gml+xml
```

Or: **unix**(1356087600)

  - Pixel history over a point location:

```
http://{WCS-server-host}/{path}?
    service=WCS&version=2.0.1&request=GetCoverage&
    coverageid=ARM-temperatures&
    subset=E(415000)&
    subset=N(4430000)&
    subset=unix("2012-12-21T00:00:00","2012-12-21T12:00:00")&
    format=application/gml+xml
```

Or: **unix**(1356044400,1356087600)

Time Series of Images : WCS resp.

```
… <gml:RectifiedGrid gml:id="<id>" dimension="3" srsName="{CRS}">
    <gml:limits>
       <gml:GridEnvelope>
          <gml:low>  66 260  0</gml:low>
          <gml:high>146 265 11</gml:high>
       </gml:GridEnvelope>
    </gml:limits>
    <gml:axisLabels>horizontal vertical t</gml:axisLabels>
    <gml:origin>
       <gml:Point gml:id="<id>" srsName="{CRS}">
          <gml:pos>414000 4430000 1356044400</gml:pos>
       </gml:Point>
    </gml:origin>
    <gml:offsetVector srsName="{CRS}">1000     0     0</gml:offsetVector>
    <gml:offsetVector srsName="{CRS}">   0  1000     0</gml:offsetVector>
    <gml:offsetVector srsName="{CRS}">   0     0  3600</gml:offsetVector>
</gml:RectifiedGrid> …
```

grid indexes

✓ *The temporal CRS defines an origin in time for these indexes.*

external CRS coordinates

✓ *Valid GML* (xsd:double)

...turn to crsName ?

gml:domainSet

```
{CRS} = http://www.opengis.net/def/crs-compound?
        1=http://www.opengis.net/def/crs/EPSG/0/32638&
        2=http://www.opengis.net/def/crs/OGC/0.1/UnixTime
```

✓ *Defined.*

Time Series of Images : ~~WCS resp.~~

```
… <gml:RectifiedGrid gml:id="<id>" dimension="3" srsName="{CRS}">
    <gml:limits>
        <gml:GridEnvelope>
            <gml:low>  66 260  0</gml:low>
            <gml:high>146 265 11</gml:high>
        </gml:GridEnvelope>
    </gml:limits>
    <gml:axisLabels>Long Lat t</gml:axisLabels>
    <gml:origin>
        <gml:Point gml:id="<id>" srsName="{CRS}">
            <gml:pos>4 45 2010-06-19T09:30:00+01:00</gml:pos>
        </gml:Point>
    </gml:origin>
    <gml:offsetVector srsName="{CRS}">0.01     0    0</gml:offsetVector>
    <gml:offsetVector srsName="{CRS}">    0  0.01    0</gml:offsetVector>
    <gml:offsetVector srsName="{CRS}">    0     0  P1H</gml:offsetVector>
</gml:RectifiedGrid> …
```

grid indexes

How are points in time indexed?

external CRS coordinates

Invalid GML (xsd:double)

...turn to crsName ?

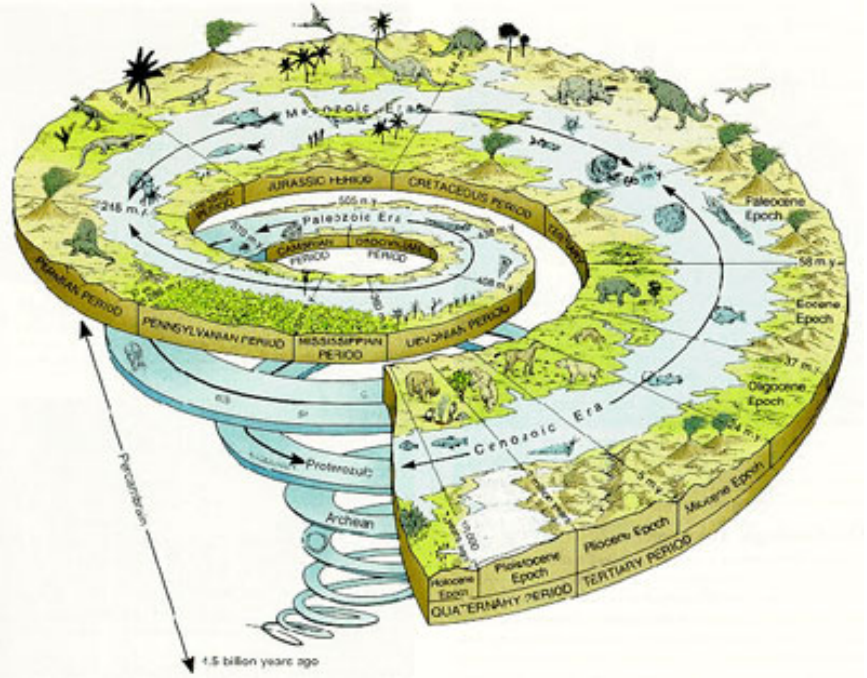
gml:domainSet

```
{CRS} = http://www.opengis.net/def/crs-compound?
        1=http://www.opengis.net/def/crs/EPSG/0/32638&
        2=http://www.opengis.net/def/crs/ISO/2004/8601
```

How to define it?

Geologic Time

- The dataset:
  - Temporal series of hourly 2D model outputs of geological units starting from the Eocene, i.e. 34 millions years ago.
  - Lat/Long spatial reference
  - Temporal reference: e.g. defining a "*how many millions of years ago*" time CRS.



Geologic Time : CRS

- CRS 3D coordinates' tuple:
  - Horizontal 2D geographic CRS with latitude (Lat) and longitude (Long):
    CRS-s = *http://www.opengis.net/def/crs/EPSG/0/4326*
  - Temporal 1D chronometric geologic CRS (mya):
    CRS-t = *http://www.opengis.net/def/crs/OGC/0.1/GeologicTime*

- Assigning the <u>unique</u> CRS identifier to our dataset:
  - CRS = *http://www.opengis.net/def/crs-compound?1=<CRS_s>&2=<CRS_t>*

Geologic Time : GML

- Geologic time definition:
  linear counting of megaannum elapsed from *today*.
- CRS resource name: “GeologicTime”
- URI: *http://www.opengis.net/def/crs/OGC/0.1/GeologicTime*
- Key GML elements in the definition:
- //TimeCS/axis/CoordinateSystem
  - /axisAbbreviation : “mya”
  - /axisDirection : “past”
  - @uom : “Ma” (megaannum)
- //TemporalDatum
  - /origin : 0001-01-01T00:00:00Z

```
<TemporalCRS xmlns=[...] gml:id="GeologicTime">
  <description>
    Millions of years, backwards in time.
  </description>
  <identifier codeSpace="{codespace}">
     http://www.opengis.net/def/crs/OGC/0.1/GeologicTime
  </identifier>
  <name>Chronometric geologic time</name>
  <timeCS><TimeCS id="s-CS">
    <identifier codeSpace="{codespace}">
      http://www.opengis.net/def/cs/OGC/0.1/Mya
    </identifier>
    <axis>
      <CoordinateSystemAxis id="ma-axis" uom="Ma">
        <identifier codeSpace="{codespace}">
          http://www.opengis.net/def/axis/OGC/0.1/mya
        </identifier>
        <axisAbbrev>mya</axisAbbrev>
        <axisDirection codeSpace="{codespace}">
           Past
        </axisDirection>
      </CoordinateSystemAxis>
    </axis>
  </TimeCS></timeCS>
    <temporalDatum><TemporalDatum id="gt-TD">
      <identifier codeSpace="{codespace}">
     http://www.opengis.net/def/datum/OGC/0.1/GeologicTimeDatum
      </identifier>
      <origin>0001-01-01T00:00:00Z</origin>
    </TemporalDatum></temporalDatum>
</TemporalCRS>
```

D. CRS parametrization

Why Parametrization?

- Avoiding *axes* labels **conflicts**:
  - Establish “hidden” template GML definitions of *concrete* (temporal) coordinate reference systems.
  - parametrized CRS definitions that enable (at least) axis reference customization of their concrete *target* templates.

- *Example:* 5D meteorological simulations with real and simulation time axis.
  - Template:
    ~~http://www.opengis.net/def/crs/OGC/0.1/UnixTime~~
    http://www.opengis.net/def/crs/OGC/0.1/.UnixTime-template
  - Parametrizations:
    http://www.opengis.net/def/crs/OGC/0.1/UnixTime?axis-label=”real-date”
    http://www.opengis.net/def/crs/OGC/0.1/UnixTime?axis-label=”simulation-date”

Templates and Parametrizations

```
<ParameterizedCRS xmlns=[...] gml:id="Unix-param">
  <parameters>
    <parameter name="axis-label">
      <value>unix</value>
      <target>//gml:TimeCS/gml:axis/gml:CoordinateSystemAxis/gml:axisAbbrev</target>
    </parameter>
  </parameters>
  <identifier>http://www.opengis.net/def/crs/OGC/0.1/UnixTime</identifier>
  <targetCRS xlink:href="http://www.opengis.net/def/crs/OGC/0.1/.UnixTime-template"/>
</ParameterizedCRS>
```

- Previous *UnixTime* definition turns to hidden *.UnixTime-template*.
- This will be targeted by the above proposed `ParametrizedCRS` definition, *UnixTime*, giving the possibility to customize the axis label directly in the URI identifier of the CRS:

http://www.opengis.net/def/crs/OGC/0.1/UnixTime → *label* = "unix"
http://www.opengis.net/def/crs/OGC/0.1/UnixTime?axis-label="time" → *label* = "time"
http://www.opengis.net/def/crs/OGC/0.1/UnixTime?axis-label="model" → *label* = "model"

An Example

- **Daily numerical simulations of meteo features (5D grid)**
  - (ordered) compound of one spatial and two temporal CRSs:

```
{CRS} = http://crstest.opengis.net:8080/def/crs-compound?
      1=http://crstest.opengis.net:8080/def/crs/EPSG/0/4327&
      2=http://crstest.opengis.net:8080/def/crs/OGC/0.1/UnixTime?axis-label="real-time"&
      3=http://crstest.opengis.net:8080/def/crs//OGC/0.1/UnixTime?axis-label="model-time"
```

  - OGC WCS request:

```
http://{WCS-server-host}/{path}?
    service=WCS&version=2.0.1&request=GetCoverage&
    coverageid=relative-humidity&
    subset=real-time("2012-03-30T12:30:00")&
    subset=model-time("2012-03-30T12:30:00","2012-03-30T18:00:00")&
    subset=Long(9.15,10.95)&
    subset=Lat(44.25,45.05)&
    subset=h(100)&
    format=application/gml+xml
```

E. *Conclusions*

Summary

- Seamless integration of the temporal dimension(s) for geospatial web services.
- Interoperability : OGC–compliant framework.
- FOSS.
- Actionable HTTP URIs
- Flexibility :
  - Arbitrary epoch and temporal resolution
  - ACME can publish URIs of own CRS definitions

    http://www.acme.com/def/crs/Bill/0/4326
    http://www.acme.com/def/crs/Bill/0/SecondsFrom2000

Still...

- Coordinate reference systems are *simple* tools.
- Proposed framework is just a cornerstone.
  Time has many more facets:
  - Different calendars → $Ab\ urbe\ condita$ ...
  - Calendar types → solar, sidereal ...
  - Leap seconds → no more linear counting

→ beyond CRS capabilities

Next Steps

- Consolidate public temporal CRS *definitions* that to OGC Naming Authority.
- Consolidate *implementation* of OGC WCS service with temporal support to:
  - scientific community (FOSS `rasdaman` users)
  - *EarthServer* lighthouse applications
- Proceed *discussion* and provide guidance and best-practices at the OGC Temporal DWG.

Acknowledgements

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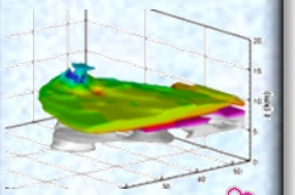
Cryospheric Science
landcover mapping

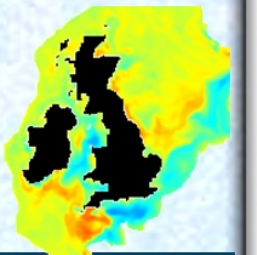
Airborne Science
high-altitude long-endurance drones

Atmospheric Science
climate variables

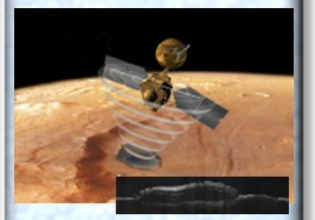


Geology
geological models

Oceanography
marine model runs + in-situ data



Planetary Science
Mars geology



Does the time bother you?
I get bothered by the time.
Not so much the time itself,
but the people!
..bother me, for the time.

– George Carlin, “Again!” 1978.

THANKS
for the attention