Multi-disciplinary interoperability challenges

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Outline

- System of Systems approach and principles
- Brokering SOA (B-SOA)
- EuroGEOSS Operating Capacity
  - multi-disciplinary discovery and access brokers — including semantic search;

- Related research topics
  - Harmonizing netCDF-CF and ISO models - from ncML to ncML-G+
  - Uncertainty-enabled data (and services)
Rationale

- Contribution to the following Objectives
  - Formation and operation of an **Earth system science community**, based on **multidisciplinary knowledge integration**
  - Develop advanced digital earth infrastructures: **multi-disciplinary cyber(e)-Infrastructure**

- Interoperability across disciplines
  - **Semantic**
  - **Technical**
  - **Organizational**

- European and International Initiatives
  - **EU INSPIRE** (European SDI)
  - **GEO GEOSS**
INSPIRE and GEOSS approach

- **Implement a “system of systems”**
  - Consisting of *existing and future* information systems
  - *Supplementing but not supplanting* systems mandates and governance arrangements

- Build on *existing (autonomous) capacities*
  - Mediate (standard and non-standard capacities)
  - Interconnect (capacities) and Adapt connecting protocols

- Recognized *multi-disciplinary capacities* should provide:
  - Metadata to describe available spatial resources
  - Network (Access) services to
    - discover, transform, view and download spatial resources
    - invoke advanced processing services to support decision making
System of Systems principles

- Shift from technical interoperability towards conceptual composability
  - by recognizing and specifying interoperability arrangements
- Assure a low entry barrier for both resource Users and Producers
- Build incrementally on existing infrastructures (information systems) and incorporate heterogeneous resources
- Introduce distribution and mediation functionalities (i.e. brokering frameworks) for interconnect heterogeneous resources
  - Discovery, access, processing and chaining
Flexibility: different Interoperability levels

- Different interoperability levels - at different Infrastructures level
Flexibility: different Interoperability levels

- Different interoperability levels - at different Infrastructures level
- Four main infrastructure types

1. **Distributed Computing** Infrastructure
   - Distributed Capacity provision functionalities
Flexibility: different Interoperability levels

- Different interoperability levels - at different Infrastructures level
- Four main infrastructure types

1. **Geospatial Information** Infrastructure
   - Geospatial resources core functionalities

2. **Distributed Computing** Infrastructure
   - Distributed Capacity provision functionalities
Flexibility: different Interoperability levels

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- Four main infrastructure types
  1. **Thematic/Community** Infrastructures
     - SBA/CoP resources core functionalities
  2. **Geospatial Information** Infrastructure
     - Geospatial resources core functionalities
  3. **Distributed Computing** Infrastructure
     - Distributed Capacity provision functionalities
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Flexibility: different Interoperability levels

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- Four main infrastructure types

1. **Thematic/Community** Infrastructures
   - SBA/CoP resources core functionalities

2. **Digital Earth (Earth System Science)** Infrastructure
   - Earth science resources core functionalities

3. **Geospatial Information** Infrastructure
   - Geospatial resources core functionalities

4. **Distributed Computing** Infrastructure
   - Distributed Capacity provision functionalities
Flexibility: Interoperability Arrangements

- Interoperability Arrangements:
  - to shift from technical interoperability towards conceptual composability

- They must be able to
  - **align** (and where necessary to harmonize) the **heterogeneous** system **conceptual models**.
  - **connect autonomous systems** at **different** infrastructural **levels**
  - **avoid** tight coupling or **strong integrations** - only define how system components interface with each other
Interoperability Arrangements implementation

- **Need:**
  - to raise the level of abstraction and cope with systems complexity

- **Solution:**
  - Adapt SOA and MDA
  - Introduce brokering and mediation frameworks for managing resources
    - e.g. discovery, access, processing and chaining
Brokering SOA (B-SOA)

- For complex (large and heterogeneous) infrastructures, SOA archetype does not scale and is not flexible
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Present GCI framework
Brokering SOA (B-SOA)

- For complex (large and heterogeneous) infrastructures, SOA archetype does not scale and is not flexible.

Present GCI framework
The Broker/Mediator component

A Brokered-SOA proved to be more sustainable (i.e. flexible and scalable)

A more sustainable approach

(tens of thousands)

(hundreds)

(2-3)
B-SOA framework

- Extend the traditional SOA approach
- Address SoS complexity
  - Many heterogeneous systems
  - Flexibility to support future systems
  - Avoid tight coupling or strong integration
  - From technical interoperability to conceptual composability
Complexity to manage

Users

Cyber-Infrastructure

Providers

Space-based System
Air-based System
Cryosphere-based System
Land-based System
Ocean-based System

Health
Disasters
Weather
Energy
Water
Climate
Agriculture
Ecology
Biodiversity

Complexity to manage
Low Entry Barrier

Users


Complexity to manage

Providers


INTEGRATED
Low Entry Barrier for SBAs

- SBAs (and CoPs) systems
  - Remain autonomous
  - Remain unchanged – no new standard must be implemented, no new component or service must be implemented or deployed

- SBAs (and CoPs) may use their own standards to:
  - describe available spatial resources
  - publish accessible resources

- The multi-disciplinary infrastructure must
  - implement all the necessary mediation and brokering functionalities to interoperate with SBA systems avoiding strong integrations
  - Implement necessary semantic services to facilitate multi-disciplinary interoperability at the conceptual level
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The EuroGEOSS experience
Three Interoperability phases

I. Enable thematic interoperability & connections local to global

WP3: Forestry
WP4: Biodiversity
WP5: Drought

WP6: Cost benefit analysis

I. Enable thematic interoperability & connections local to global
Three Interoperability phases

I. Enable thematic interoperability & connections local to global

II. Enable multi-disciplinary interoperability

WP3: Forestry
WP4: Biodiversity
WP5: Drought
WP2: Multi-disciplinary interoperability
WP6: Cost benefit analysis
Three **Interoperability phases**

I. Enable thematic interoperability & connections local to global

II. Enable multi-disciplinary interoperability

III. Extend interoperability to other SBAs & systems
Multi-disciplinary Functionalities

Discover  Evaluate  Access  Use
Multi-disciplinary Functionalities

- Discovery broker
- Augmented (semantic) Discovery
- Web 2.0 resources discovery
Multi-disciplinary Functionalities

- Discovery broker
- Augmented (semantic) Discovery
- Web 2.0 resources discovery

Support to multiple clients
Multi-disciplinary Functionalities

- Discovery broker
- Augmented (semantic) Discovery
- Web 2.0 resources discovery

Support to multiple clients

Common Grid data access
Multi-disciplinary Functionalities

- **Discover**
  - Discovery broker
  - Augmented (semantic) Discovery
  - Web 2.0 resources discovery

- **Evaluate**
  - Support to multiple clients

- **Access**
  - Common Grid data

- **Use**
  - To lower GCI entry barrier
  - Use scenarios (AIP-3)
TO LOWER ENTRY BARRIER FOR MULTI-DISCIPLINARY CAPACITY
Step 1: Discovery

- «Service Providers»
  - Geospatial Resources

- Service Providers (Resource Servers)
  - CSW 2.0 Core
  - CSW 2.0 ebRIM/CIM O.1.9
  - CSW 2.0 ebRIM/EO O.2.5
  - CSW 2.0 ISO 1.0
  - Degree 2.2
  - GBIF
  - GDACS
  - GeoNetwork 2.2.0
  - GeoNetwork 2.4.1
  - GeoRSS 2.0
  - GI-cal 6.x
  - GI-cal 7.x
  - NetCDF-CF 1.4
  - OAI-PMH 2.0
  - OpenSearch 1.0
  - THREDDS 1.01-1.0.2
  - WCS 1.0
  - WCS 1.12
  - WFS 1.0.0
  - WFS 1.1.0
  - WMS 1.1.1
  - WMS 1.3.0
  - WPS 1.0.0
  - CCI

- SPARQL
- CSW
- OpenSearch
- WFS

(init Mask) Event – place - date
Step 1: Discovery

Implement Interoperability Arrangements

«Service Providers»
Geospatial Resources

...
Step 1: Discovery

«Service Providers»
Geospatial Resources

«Broker»
Catalog Discovery Broker

«Catalog Interface»
Published Interfaces

CSW

OGC

EuroGEOSS

A European Approach to GE OSS

SPARQL
CSW
OpenSearch
WFS
Step 1: Discovery

Implement Multi-disciplinary Interoperability Arrangements
Implement Subsetting & Transformation services

Step 1: Discovery

Implement Multi-disciplinary Interoperability Arrangements
Step 2: Access

«Service Providers»
Geospatial Resources

«Advanced Module»
Semantic Discov ery Broker

«Advanced Module»
Semantic engine

«Broker»
Geospatial Data Access Broker

«Broker»
Catalog Discov ery Broker

«Service Providers»
Web 2.0 resources

«Semantic Resources»
Thesauri

Gazzetters

SPARQL
CSW
OpenSearch
WFS
Step 2: Access

Implement Subsetting & Transformation services

«Service Providers»
Geospatial Resources

«Broker»
Geospatial Data Access Broker

«Broker»
Catalog Discovery Broker

CSW

OGC

Published Interfaces

+ CSW2.0.2.ebRIM/CIM0.1.9
+ CSW2.0.2.ebRIM/E00.25
+ CSW2.0.2.ISO1.0
+ GI-cal Extended interface 7.x
+ OAI-PMH2.0
+ OpenSearch-GENESIS-OR
+ OpenSearch1.1

GEOSS

EuroGEOSS
A European Approach to Geoss
Step 2: Access

Implement Subsetting & Transformation services

Underpin a common grid environment

<Broker>
Geospatial Data Access Broker

«Service Providers»
Geospatial Resources

«Catalog Interface»
Published Interfaces

OGC
International Organization for Standardization

CSW

EuroGEOSS
A European Approach to GEOSS

(edit Mask) Event – place - date
Step 2: Access

Geospatial Web resources.

What about Web 2.0 resources?

Implement Subsetting & Transformation services

Underpin a common grid environment

Implement Subsetting & Transformation services

Underpin a common grid environment

CSW

OGC

Published Interfaces

Catalog Discovery Broker

Geospatial Data Access Broker

"Service Providers" Geospatial Resources

"Broker" Catalog Discovery Broker

"Advanced Module" Semantic Discov ery Broker

"Advanced Module" Semantic engine

"Service Providers" Geospatial Resources

"Service Providers" Geospatial Resources

"Service Providers" Geospatial Resources

"Service Providers" Geospatial Resources
Step 3: Web 2.0 Resources

«Service Providers»
Web 2.0 resources

«Service Providers»
Geospatial Resources

«Broker»
Geospatial Data Access Broker

«Advanced Module»
Semantic Discov ery Broker

«Advanced Module»
Semantic engine

«Broker»
Catalog Discov ery Broker

«Service Providers»
Geospatial Resources

«Advanced Module»
Adapters

«Semantic Resources»
Thesauri

«Service Providers»
Gazzetters

SPARQL
CSW
OpenSearch
WFS

Step 3: Web 2.0 Resources

CSW

«CatalogInterface»
Published Interfaces

+ CSW 2.0 ebrIM/CIM0.1.9
+ CSW 2.0 ebrIM/E00.25
+ CSW 2.0 ISO1.0
+ GI-cal Extended Interface 7x
+ OAI-PMH2.0
+ OpenSearch GESI DR
+ OpenSearch1.1

EuroGEOSS
A EUROPEAN APPROACH TO GE OSS
Step 3: Web 2.0 Resources

Implement Web 2.0 Interoperability Arrangements
Step 3: Web 2.0 Resources

Implement Web 2.0 discovery Interfaces

Implement Web 2.0 Interoperability Arrangements
Step 3: Web 2.0 Resources

Well-structured geospatial queries

What about Semantic discovery for EO?

Implement Web 2.0 discovery Interfaces

Implement Web 2.0 Interoperability Arrangements
Step 4: Augmented Discovery

«Service Providers»
Geospatial Resources

«Service Providers»
Web 2.0 resources

«Broker»
Geospatial Data Access Broker

«Broker»
Catalog Discovery Broker

Geospatial Resources

«Service Providers»
Adapters

Web 2.0 resources

«Semantic Resources»
Thesauri

«Service Providers»
Gazzetters

SPARQL
CSW
OpenSearch
WFS

«Advanced Module»
Semantic Discovery Broker

Semantic engine

«Advanced Module»
Semantic Discov ery Broker

(editable mask) Event – place – date
Step 4: Augmented Discovery

Implement Semantic discovery

«Advanced Module»
Semantic Discovery Broker

«Advanced Module»
Semantic engine

«Service Providers»
Geospatial Resources

«Service Providers»
Web 2.0 resources

«Service Providers»
Adapters

WFS

CSW

OpenSearch

«Semantic Resources»
Thesauri

«Service Providers»
Gazetteers

(edit Mask) Event – place - date
Step 4: Augmented Discovery

Implement Semantic discovery

Augment the Discovery Broker capacities

«Advanced Module»
Semantic Discovery Broker

«Service Providers»
Geospatial Resources

«Service Providers»
Web 2.0 resources

«Advanced Module»
Semantic engine

«Advanced Module»
Catalog Discovery Broker

«Semantic Resources»
Thesauri

«Service Providers»
Gazzetters

SPARQL
CSW
OpenSearch
WFS

«Broker»
Catalog Discovery Broker

«Service Providers»
Adapters

«Broker»
GeoSpatial Resources

«Broker»
Web 2.0 resources

«Broker»
Gazzetters

Semantic Discov ery Broker

Web 2.0 resources
Step 4: Augmented Discovery

Implement Semantic discovery

Augment the Discovery Broker capacities

Publish Semantic Discovery standard interface(s)
Step 4: Augmented Discovery

Implement Semantic discovery

Augment the Discovery Broker capacities

Publish Semantic Discovery standard interface(s)

Connect and Mediate heterogeneous Semantic resources
DISCOVERY (& ACCESS) BROKER
Provided Interfaces & Supported Resource types

Discovery (& access) Brokering Platform (GeoRSS support)
Brokering framework: new Resource types supported

- OAI-PMH 2.0
- DublinCore
- ISO 19139
- DIF 9.7.1 (Data Interchange Format)
- netCDF-CF 1.4
- THREDDS (1.0.1, 1.0.2)
- GDACS
  (Global Disaster Alert and Coordination System)
- WAF (Web Application Firewalls/FTP)
In collaboration with GENESIS

AUGMENTED (SEMANTIC) DISCOVERY
Semantic Augmentation

(Mediator)

Semantic Augmentation Component

Client

OpenSearch Extended Interface (semantic)
Semantic Augmentation

(Mediator)

Semantic Augmentation Component

Client

OpenSearch Extended Interface (semantic)
Semantic Augmentation

Client

OpenSearch Extended Interface (semantic)

Semantic Augmentation Component

(Mediator)

Adapter

Adapter

SKOS/RDF

Thesaurus A

Thesaurus B

Gazetteer

OGC

EuroGEOSS Meeting – JRC Ispra – 4-6 oct 2010
Semantic Augmentation

(Mediator)
Concepts discovery by semantic network browsing
Concepts discovery by semantic network browsing
COMMON GRID DATA ACCESS
Data Access

- Data Access functionality is composed of:
  - Data pre-processing functionalities to “normalize” data
    - Sub-setting (i.e. trimming, slicing)
    - Format conversion
    - CRS transformation
    - Data Interpolation
    - ….
  - Data Download functionalities
    - Synchronous and asynchronous downloads
    - RESTful and SOAP bindings
EuroGEOSS IOC
EuroGEOSS IOC

Sub-setting, Format conversion, CRS transformation, Interpolation
EuroGEOSS IOC

Sub-setting, Format conversion, CRS transformation, Interpolation

Client

WMS

WCS

WFS
EuroGEOSS IOC
EuroGEOSS IOC

Client

Sub-setting, Interpolation

WMS

WCS

WFS
EuroGEOSS IOC
EuroGEOSS IOC

Client

WMS

WCS

WFS

Sub-setting, Format conversion, Interpolation
EuroGEOSS IOC

Client

WMS

WCS

WFS

Sub-setting, Format conversion , Interpretation

(edit Mask) EuroGEOSS - date
EuroGEOSS IOC

Client

WMS

WCS

WFS
AOC: Requirements and Objective

• To develop an access framework which does not supplant but complete existing access systems/services
• A flexible framework to allow CoPs to use their pre-processing components/services – where required
• To be compliant with the INSPIRE transformation implementing rules
AOC: Requirements and Objective

- To develop an access framework which does not supplant but **complete existing access systems/services**
- A flexible framework to allow CoPs to **use their pre-processing components/services** – where required
- To be **compliant with the INSPIRE transformation implementing rules**

A broker system which implements the necessary mediations to make use of **existing and future data pre-processing services** – to “normalize” discovered data
Sub-setting, Format conversion, CRS transformation, Interpolation
Sub-setting, Format conversion, CRS transformation, Interpolation
Client

Access Broker

WMS

WCS

WFS

EuroGEOSS
Client

Access Broker

Sub-setting, Format conversion, Interpolation

WMS
WCS
WFS

EuroGEOSS
Sub-setting, Format conversion, Interpolation

Client

Access Broker

MATLAB Web Service

WMS

WCS

WFS

(edit Mask) Event – place - date
IOC:
Client → Access Services

AOC:
Client → Access Broker → Access Services
Access Broker: the Context

Client → Access request

Discovery Broker

GetData request

INISPIRE Transformation Service

Access Broker

Registry

Access Broker → WMS, WCS, WFS

Client

Access request

CSW / OpenSearch

Format conversion

WPS

Interpolation

WPS

Reprojection

WPS

Reprojection

WCTS

Workflow

Kepler

Workflow

Taverna

Workflow

Open Modeller

Forecasting

MATLAB Web Service

...
Access Broker: the Context

Client → Access request

Discovery Broker

getData request

Access Broker

Registry

WMS → WMS

WCS → WCS

WFS → WFS

CSW / OpenSearch

INSPIRE Transformation Service

Specific CoP

Resampling

MATLAB Web Service

Format conversion

WPS

Interpolation

WPS

Reprojection

WPS

Workflow

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Taverna

Workflow

Open Modeller

Forecasting

MATLAB Web Service

Subsetting

WCTS

Reprojection

WPS

Interpolation

WPS

Format conversion

MATLAB Web Service
WEB 2.0 RESOURCES DISCOVERY
### Web 2.0 services considered

<table>
<thead>
<tr>
<th>Service Name</th>
<th>Available content type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twitter</td>
<td>short texts</td>
</tr>
<tr>
<td>Google Search API</td>
<td>Vector data (KML format)</td>
</tr>
<tr>
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<td>Raster data (photographs)</td>
</tr>
<tr>
<td>Picasa</td>
<td>Raster data (photographs)</td>
</tr>
<tr>
<td>Flickr</td>
<td>Raster data (photographs)</td>
</tr>
<tr>
<td>OpenStreetMap</td>
<td>Vector data (OSM format)</td>
</tr>
<tr>
<td>Wikimapia</td>
<td>Text (place names &amp; descriptions)</td>
</tr>
<tr>
<td>Geonames</td>
<td>Text (place names)</td>
</tr>
<tr>
<td>Geocommons</td>
<td>Raster and vector data (maps)</td>
</tr>
<tr>
<td>Wikipedia</td>
<td>Through Geonames</td>
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</table>

[Source: EuroGEOSS D2.6.1 (L. Díaz, C. Granell, O. Fonts, J. Gil)]
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Web 2.0 service Adaptors

**Web 2.0 Services**
- Toponyms: Geonames
- Vector: OpenStreetMap
- Multimedia: Flickr
- Short text: Twitter

**OWS Services**
- Catalog: CSW
- Vector: WFS
- Placenames

[Source: EuroGEOSS D2.6.1 (L. Díaz, C. Granell, O. Fonts, J. Gil)]
Web 2.0 service Adaptors

Web 2.0 Services
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Common interface:
OpenSearch(-geo) interface

[Source: EuroGEOSS D2.6.1 (L. Díaz, C. Granell, O. Fonts, J. Gil)]
Adaptors capabilities

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<td>Wikipedia</td>
<td>through Geonames JSON Wikipedia Search Web Service:</td>
</tr>
<tr>
<td></td>
<td>Response format: KML</td>
</tr>
<tr>
<td></td>
<td>Filter: Text search.</td>
</tr>
<tr>
<td></td>
<td>Paged results: NO</td>
</tr>
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</tr>
<tr>
<td></td>
<td>Response format: Atom + GeoRSS (Supported natively by API).</td>
</tr>
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Web 2.0 resources support

- Adaptor
- Geonames
- Twitter
- Flickr
- OpenStreet Map
- Wikipedia
- Geocommons

Discovery Broker

CSW/ISO

OpenSearch(-geo)
Flexibility: support heterogeneous Clients

• Any “standard” CSW or OpenSearch Client can be used to access the discovery capacity
  – GEO-portal
  – Geonetwork
  – ArcGIS / ArcExplorer
  – Web Browsers (via OpenSearch)
  – WorldWind
  – GI-go (thick) and its thin version: GI-portal
  – …..
USE SCENARIOS (AIP-3)
GEOSS AIP-3 Use Scenarios

- In collaboration with the FP7 GENESIS project
- Biodiversity & Climate Change WG
  - **e-Habitat & Species Occurrences Use Scenario**
    - A web based decision-making tool for assessing environmental changes due to anthropogenic activities, including climate change
    - The development of the **modeling web service** for computing habitat similarities and irreplaceability allows the community to assess possible environmental consequences.
  - **Scientific patron: Gregoire Dubois (JRC)**
- Water (Drought) WG
  - **European Drought Observatory (EDO) Use Scenario**
    - Assessment of the drought situation in Europe
    - Multi-scale approach based on subsidiarity that integrates drought information from various scales
  - **Scientific patron: Stefan Niemeyer (JRC)**
Related Challenges:
From ncML to ncML-G+
Encoding Field View Content

Conceptual Approach
- Field View (Coverage types)

Conceptual Model & Metadata Model
- ISO 19123
- ISO 19115
- netCDF/CDM
- CF

Encoding Schema
- ISO 19139
- GML-Coverage
- ncML
Encoding Field View Content
Encoding Field View Content
Encoding Field View Content

Conceptual Approach
- Field View (Coverage types)
  - netCDF/CDM
  - CF

Conceptual Model & Metadata Model
- ISO 19123
- ISO 19115

Encoding Schema
- ISO 19139
- GML-Coverage
- ncML
- ncML-G+

O&M Field View products

THREDDS
- People
- Documents
- Data

stefano.nativi@cnr.it
Encoding Field View Content
ncML-G+

- Building on existing artifacts
  - ncML-Gml v. 0.5 specification and APIs
    - netCDF to ISO 19123 models mapping for regular grid data
  - ncISO
    - CF-netCDF to ISO 19115 models mapping for metadata

- Encode different coverage types
  - Regular grid data
  - Irregular grid data
  - Multi-point data
  - ....
Uncertain Types and Services
Rationale

• **Main objectives:**
  - Specify and Manage **Uncertainty of Scientific Data**
  - Assess and Control **Uncertainty Propagation** – e.g. in service chaining for models integration

• **Constraints:**
  - **minimize the impact** on the existing tools and processing schemas
  - **Re-use existing standards** as much as possible
Proposed approach

Introduce “uncertainty” types/elements

PROCEDURAL APPROACH

e.g. Java data types

PL Scientific Data Types
(e.g. netCDF Libraries)

Basic Data Types
Proposed approach

Introduce “uncertainty” types/elements

**PROCEDURAL APPROACH**

*e.g. Java data types*

- Basic Data Types
- Uncertanty

- PL Scientific Data Types (e.g. netCDF Libraries)

- Uncertainty properties described by the *UncertWeb vocabulary*
Proposed approach

Introduce “uncertainty” types/elements

**PROCEDURAL APPROACH**

*e.g. Java data types*

**DECLARATIVE APPROACH**

*e.g. XML data elements*

- PL Scientific Data Types
  
  (e.g. netCDF Libraries)

- Basic Data Types

- Uncertainty

- Uncertainty properties described by the
  
  *UncertWeb vocabulary*

- XML Scientific Data Types
  
  (e.g. ncML)

- XML Basic element Types
Proposed approach

Introduce “uncertainty” types/elements

**PROCEDURAL APPROACH**

- *e.g. Java data types*

  - PL Scientific Data Types
    - (e.g. netCDF Libraries)
  - Basic Data Types
  - Uncertainty

**DECLARATIVE APPROACH**

- *e.g. XML data elements*

  - XML Scientific Data Types
    - (e.g. ncML)
  - XML Basic element Types
  - Uncertainty

- Uncertainty properties described by the *UncertWeb vocabulary*

- Uncertainty Description based on the XML encoding of the *UncertWeb vocabulary* (e.g. UncertML)

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Proof-of-concepts

Different Scientific Data types are considered (i.e. Basic info encodings)

- XML encoded (e.g. GML, ncML)
- Binary encoded (e.g. netCDF, GRIB)
Example:

netCDF/ncML + (XML) uncertainty Info

netcdf avg_min_2050 {

dimensions:
    lat = 1285 ;
    lon = 2446 ;

variables:
    double lat(lat) ;
        lat:units = "degrees_north" ;
    double lon(lon) ;
        lon:units = "degrees_east" ;
    byte avg(lat, lon) ;
        avg:_FillValue = 0b ;

// global attributes:
    :Conventions = "CF-1.0" ;
}

uncert.web

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Example: netCDF/ncML + (XML) uncertainty Info

```xml
<?xml version="1.0" encoding="UTF-8"?>
<unc:NetCDF_Uncertainty xlink:type="extended">

  <unc:netcdf xlink:type="locator"
          xlink:locator="http://zeus.pin.unifi.it/angelini/UncertWeb/Data/avg_min_2050.nc#
                                               /netcdf/variable[@name=avg]"
          xlink:label="dataset"/>

  <unc:unc_description xlink:type="arc" xlink:from="dataset"
                      xlink:to="uncertainty"/>

  <unc:uncertainty xlink:type="resource" xlink:label="uncertainty">
    <un:Statistic>
      <un:parameters>
        <un:Parameter
          definition="http://dictionary.uncertml.org/statistics/mean">
          <un:value>3.2</un:value>
        </un:Parameter>
        <un:Parameter
          definition="http://dictionary.uncertml.org/statistics/variance">
          <un:value>0.25</un:value>
        </un:Parameter>
      </un:parameters>
    </un:Statistic>

  </unc:uncertainty>
</unc:NetCDF_Uncertainty>
```

netcdf avg_min_2050 {
  dimensions:
    lat = 1285 ;
    lon = 2446 ;
  variables:
    double lat(lat);
      lat:units = "degrees_north" ;
    double lon(lon);
      lon:units = "degrees_east" ;
    byte avg(lat, lon);
      avg:_FillValue = 0b ;

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        </un:Parameter>
        <un:Parameter>
          definition="http://dictionary.uncertml.org/statistics/variance">
            <un:value>0.25</un:value>
        </un:Parameter>
      </un:parameters>
    </un:Statistic>
  </unc:uncertainty>
</unc:NetCDF_Uncertainty>
```

```csharp
netcdf avg_min_2050 {
  dimensions:
    lat = 1285 ;
    lon = 2446 ;
  variables:
    double lat(lat) ;
      lat:units = "degrees_north" ;
    double lon(lon) ;
      lon:units = "degrees_east" ;
    byte avg(lat, lon) ;
      avg:_FillValue = 0b ;

  // global attributes:
    :Conventions = "CF-1.0" ;
}
```
Procedural Approach: the \textit{UncertainTypes definition}

- \textit{UncertaintyTypes} = new library of Data Types which include the Uncertainty Info

- \textit{UncertaintyTypes} = Basic (Data Types) + Uncertainty Info

- Basic (Data) Types = quantities for which the uncertainty is not specified
  - i.e. the PL (or library) data types
The concept of **UncertainType**, is a **BasicType** specialization:

- UncertainType “is a” BasicType
- An UncertainType includes additional information regarding its uncertainty.
The concept of **UncertainType**, is a **BasicType specialization**:

- UncertainType “is a” BasicType
- An UncertainType includes additional information regarding its uncertainty.
Sub-typing Issues

- OO programming language and encoding languages/models must support:
  - subtyping of base types

<table>
<thead>
<tr>
<th>ALLOWED</th>
<th>NOT ALLOWED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMAScript (JavaScript)</td>
<td>Java</td>
</tr>
<tr>
<td>Python</td>
<td>XML Schema</td>
</tr>
<tr>
<td></td>
<td>C++</td>
</tr>
</tbody>
</table>

- Operator overloading
Alternative approach

- To use an “association” relationship
- BasicType becomes a property of the associated UType

A prototype was developed for Java data types
Possible Integration in netCDF/CDM

To include the uncertain types in the supported *DataType* list

Update the APIs to work on such new (extended) *Datatype* entries
Possible Integration in netCDF/CDM

To include the uncertain types in the supported *DataType* list

Update the APIs to work on such new (extended) *Datatype* entries

Extended netCDF API (uncertainty DataTypes)
NetCDF API
Uncertainty API
Basic Data Types
Uncertainty
General picture: the Uncertainty propagation

- UncertainTypes (and Uncertain Algebra)
- Overall Dataset uncertainty
- Uncertainty Operations on Datasets
- Uncertainty metadata provided by Service (Uncertainty propagation through chaining)
General picture: the Uncertainty propagation

- UncertainTypes (and Uncertain Algebra)
- Overall Dataset uncertainty
- Uncertainty Operations on Datasets
- Uncertainty metadata provided by Service (Uncertainty propagation through chaining)

Uncertainty-driven discovery (service chaining)
Thank you for your attention!

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