→ HETEROGENEOUS MISSIONS ACCESSIBILITY

Design Methodology, Architecture and Use of Geospatial Standards for the Ground Segment Support of Earth Observation Missions

European Space Agency

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Design Methodology, Architecture and Use of Geospatial Standards for the Ground Segment Support of Earth Observation Missions

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To Eugenia, who had a strategy for ground segment interoperability.

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Foreword

The Heterogeneous Missions Accessibility (HMA) initiative is aptly titled. Earth observation (EO) systems are varied in design and purpose, reflecting their diverse missions and the diverse approaches conceived by their inventors, developers and promoters. The difficulty is that the societal, scientific and commercial values of these systems depend on whether or not their data and services can be readily published, discovered, assessed, processed and used by a broad set of users. EO data and service formats, observation capabilities, encodings and interfaces tend to be like foreign languages whose dissimilarities limit their usefulness. By involving key stakeholders, namely national space agencies, satellite or mission owners and operators, and industry the HMA initiative is successfully addressing this problem. Stakeholder collaboration has provided the forum to enable the harmonisation and standardisation process to make the ground segment services and related interfaces interoperable, accessible and useful to a wide range of stakeholders.

The Open Geospatial Consortium (OGC) manages an international consensus standards process for geospatial technology stakeholders. Participants in the HMA initiative have also been actively engaged in the OGC, contributing to the development of OGC standards and successfully aligning European EO systems with standards from the OGC, and related standards organisations such as those from the International Organization for Standardization (ISO). Through the participation of representatives from the HMA initiative and stakeholders from other organisations in Europe and other world regions, there is now a solid worldwide standards foundation for sharing EO data and online services. More work remains to be done, but the foundation is in place.

The common technical architecture described in this book provides a comprehensive guide to the use of international standards to enable a European EO system of systems. The book also illustrates how European EO assets become part of a larger EO network. The work of the HMA initiative provides an indispensable resource for organisations with EO assets that wish to connect to and build a truly local to global system of systems.

The importance of this work cannot be overstated. In this decade, humanity must confront looming crises involving climate, energy, natural resources, economics, environment and a rapidly expanding population. We desperately need to share information

about our world and work together if we are to better understand and find solutions to our shared problems.

Mark Reichardt
President & CEO
Open Geospatial Consortium

Preface

This book summarises the results of more than five years of coordination and harmonisation efforts, under the auspices of and with the cooperation of the Ground Segment Coordination Body in the critical area of ground segment interoperability.

This coordinated approach of at least two dozen European space and downstream industries, research centres and institutions has made, we believe, a significant contribution to the definition of interoperability and interaccessibility standards published within the Open Geospatial Consortium, and has brought together different national programmes and systems.

An immediate benefit has materialised in the context of the Global Monitoring for Environment and Security (GMES) Programme. This programme relies on a fleet of European Earth observation satellites, operated by various partners, including ESA Member States, commercial entities, a series of international mission operators and ESA.

The Heterogeneous Missions Accessibility standards have made a strong contribution to providing operational and sustainable user services. They have also helped to avoid unnecessary duplication in technologies, and to establish a well-coordinated, cost-effective and increasingly automated operations scenario.

Gunther Kohlhammer
Head of the Ground Segment Department
Earth Observation Programme
European Space Agency

Acknowledgements

This book provides a comprehensive overview of the standardisation results of the collaborative projects fostered by the Heterogeneous Mission Accessibility initiative. Hence, although the editors are the main authors of this book, it could not have been written without the immense and accurate work carried out by the various drafting, specification and implementation teams of the HMA initiative over a period of several years.

The editors cordially acknowledge the achievements of the individual team members and are very grateful for and impressed by their eagerness and attitude to converge complex technical approaches into one single, harmonised, interoperable and working solution.

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→ THE MOTIVATION FOR THE HMA INITIATIVE

1. The Motivation for the HMA Initiative

1.1 Is This Book for You?

There is a consensus in the software engineering community that complex software systems require sound and flexible architectures in order to enable stable and cost-effective operation, maintenance and evolution of the system. This demand is even greater when the software system to be designed is intended to work across organisational boundaries or even when different, independently developed systems (system of systems) need to interact with each other.

The current landscape of geospatial and industry standards from the Open Geospatial Consortium (OGC), International Organization for Standardization (ISO), the Organization for the Advancement of Structured Information Standards (OASIS) consortium and the guidelines from the European spatial data infrastructure initiative INSPIRE (Infrastructure for Spatial Information in the European Community) numbers hundreds of documents. This book has the objective of providing an outline of how to use those standards relevant for access to and interaction among heterogeneous Earth observation (EO) missions and in the interactions of the payload data ground segments with EO data exploitation for scientific purposes, (downstream) services and data integration or assimilation with *in situ* sensors.

If you are responsible for the design and implementation of a system of systems based on EO and geospatial data, then this book provides an insight into the kinds of geospatial interface standards available and their benefits. It also describes how the geospatial information needed by the service and downstream industries can be extracted by the payload data ground segment service interfaces within the EO space component.

Hence, the intended audiences of this book are:

- chief technology officers in the EO domain who have to decide on the role of geospatial standards in their system and software landscape;
- software architects and engineers who are required to conceive and develop EO software for payload data ground segments, data archives, applications and services;
- users and developers of EO scientific algorithms, software applications and services who want to look behind the scenes;

— experts from standards organisations such as ISO or OGC who need to know how geospatial standards are being applied, profiled and combined for EO purposes; and
— experts from other geospatial standards, such as *in situ* sensing or meteorology, who need to address geospatial interoperability problems outside their own domain.

Of course, such a book can only be an initial reading. Engineers who need to delve deeper into one or another service or information model are asked to look at the original literature. Both the list of references at the end of this book and the figures that try to illustrate their interdependencies may serve as guides.

1.2 Advantages of Standardisation and Interoperability

The motivation for harmonising the EO ground segment interface activity, which we refer to as the HMA initiative, can be linked to seven high-level objectives as formulated in Marchetti & Biancalana (2008):

1. To manage and reduce technical risks in EO systems and operations.
2. To manage and reduce the cost of EO systems and operations.
3. To establish the baseline for the development of the European space infrastructure in the context of the GMES Programme capable of harmonising and exploiting relevant national initiatives and assets.
4. To allow interoperability within and across organisations.
5. To increase competitiveness of the European space (and downstream) industry.
6. To maintain the leadership in EO systems and operations and avoid insurgence of undesired standards
7. To ensure that technology drivers for the European guaranteed access to space are led by European requirements

To maintain the standardisation effort required, we need to convince management and stakeholders by providing supporting arguments that address the costs and economic impacts of standardisation, and its impact on knowledge sharing and innovation. A large-scale example of the business growth that can come from standardisation is the Global System for Mobile Communications standard for mobile telephony adopted in Europe in 1987, and which is now used by two billion customers. Standards may be adopted for reasons

other than those of engineering or economics from the industry perspective. For example, the European Union has recently secured the commitment of industry to provide a common charger for mobile phones for the benefit of all users as well as reduce waste.

One of the standardisation costs is certainly the cost of the standardisation process itself, i.e. convening the stakeholders, collecting their requirements, designing the standard, fulfilling the need for the consensus building and approval process, testing the standard and implementing it.

Concerning the link between standardisation and economic growth, knowledge and innovation, two independent reports from France (AFNOR, 2009) and the UK (Swann, 2010) concur in their finding that standardisation supports economic growth, knowledge and innovation. Regarding innovation in particular, it has to be noted (Swann, 2010) that:

- standardisation helps to build focus, cohesion and critical mass in the formative stages of a market;
- standardisation codifies and diffuses state-of-the-art technology and best practice; and
- open standards are desirable to enable a competitive process of innovation-led growth.

1.3 The Challenge of Heterogeneous EO Missions

1.3.1 Description of the 'Big Picture'

The demand and the requirements for EO data have evolved dramatically over the last decade. The demand for and the volume of EO data have increased more than 10-fold, in line with the users' processing and analysing capabilities. In addition, more than 80% of users request and use data from more than one satellite.

This trend increases the challenge for EO satellite operators, space agencies and EO data providers to process the data and to offer access to different data as coherently and easily as possible. Last, but not least, it forces the parties to optimise the allocation of the available financial resources to handle an increasing number of EO missions through closer cooperation in ground segment development, operations and data exploitation.

Europe is addressing the monitoring and management of environmental changes through Global Monitoring for Environment and Security (GMES), the European programme for the implementation

of information services to support decisions concerning the environment and security. GMES services are based on observation data received from different EO satellites and on ground-based *in situ* information.

Furthermore, climate change is a major environmental, development and security issue that, left unaddressed, threatens a sustainable future. All EO missions play a vital role in systematically generating, preserving and giving access to long-term datasets of the 'Essential Climate Variables' (ECVs) to meet the needs of initiatives dealing with climate change.

The number of missions contributing to the establishment of the necessary observation capacity over Europe for critical services can easily exceed a dozen for each service. In the first instance, EO data users need easy and transparent access to these multiple sources of EO data. Until now, each mission was designed in an isolated manner and efforts were needed to harmonise the mechanisms for data access. In addition, interoperability is needed to reduce the burden on planners and operators. In short, a good level of interoperability across the mission ground segments is therefore required to address the challenges for the EO user and mission operator.

The objective of HMA is to establish harmonised access to data of heterogeneous EO missions. These missions range from national missions up to the ESA Sentinel missions[1] developed within the EU co-funded GMES Programme.

According to the Oxford dictionary, a mission in general is 'an expedition into space'.[2] More precisely, when applied to satellites, a mission encompasses the whole set of technologies, devices and software components in space and on Earth that accompany a satellite across all of its life-cycle phases and support the achievement of its intended objectives.

Heterogeneous EO missions pose the problem that each of them offers its own method and technology to search for access to and exploit the mission results in terms of software products, i.e. EO datasets or series of datasets, or images derived from these products. As illustrated in Fig. 1.1, these tasks are provided by ground segment services that may be called through corresponding interfaces by client applications, e.g. web portal applications or any other software components.

However, without a coordinated strategy and harmonised development, these ground segment services will all have different interfaces following the needs and business requirements of the

[1] *http://earth.esa.int/hma/objectives.html*
[2] *http://oxforddictionaries.com/view/entry/m_en_gb0525350#m_en_gb0525350*

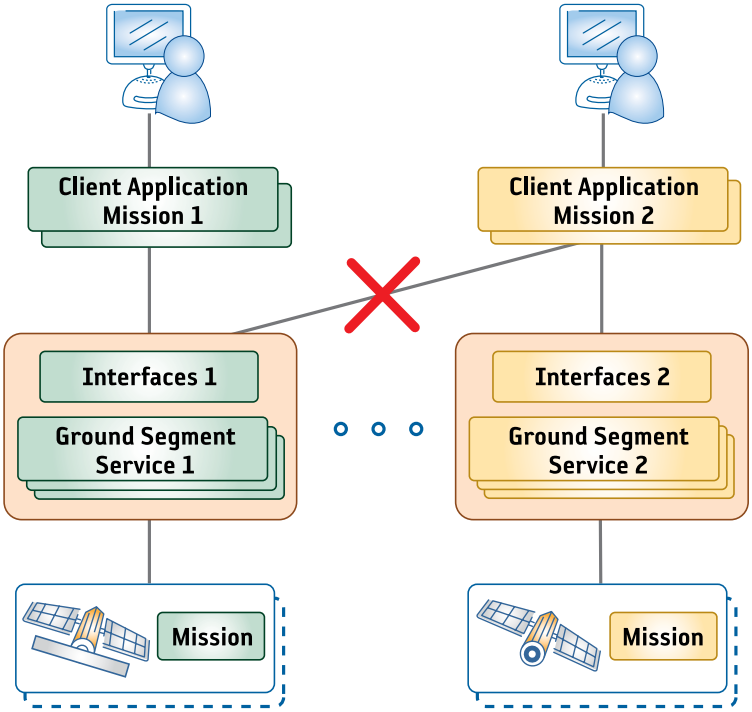


Figure 1.1. Access to EO mission products through ground segment services.

individual stakeholders. While this may not be a problem when accessing EO products from just one mission, it becomes difficult and tedious when EO products are required from multiple missions, or, even worse, when EO products from multiple missions have to be combined or processed together in order to provide higher-level services. A client application of one mission cannot call the ground segment services of another mission if their interfaces are not agreed upon.

Hence, there is a need to find and define a common technological foundation in order to harmonise the ground segment interfaces, or, in the language of software architects, to ensure interoperability between the ground segments.

According to a report from the European/Canadian Ground Segment Coordination Body (GSCB, 2009), the main project identified by the GSCB, when it started its work in 2005, was:

> related to interoperability from the point of view of inter-accessibility across heterogeneous missions. It aims at the joint definition and adoption of EO interoperability standards required to guarantee a seamless and harmonised access to

the heterogeneous EO data sets for the benefit of the scientific, commercial and GMES EO data users.

The resulting collaborative project was called Heterogeneous Missions Accessibility.

The initial step of HMA was 'to define the discovery, catalogue, ordering, EO instrument programming and data access and data delivery standards'. These standards should rely upon the experience gained from previous attempts and should follow to the maximum extent existing international standards.

The final objective of HMA, at least on but not limited to the technical level, is to leverage the idea of a service-oriented architectural style. This means that the individual ground segment systems should be loosely coupled by means of an HMA service network, whereby each individual ground segment system offers the functionality of its ground segment services through a set of well-defined harmonised HMA interfaces as shown in Fig. 1.2. However, although access through the HMA interfaces may be the preferred way according to the HMA objectives, each ground segment system still has the option to offer its services to mission-specific or provider-specific client applications by means of ground-segment-specific interfaces.

Note that client applications may be components of software systems that are run by other European institutions such as the European Maritime Safety Agency (EMSA) or the European Union Satellite Centre (EUSC). Or, they may comprise components of GMES core or fast-track services (see section 3.2.2) or components that are part of GEOSS environments (see section 3.2.4).

Finally, this approach leads to a system-of-systems architecture. There is no agreed definition of the term system-of-systems. Instead systems-of-systems are usually discussed in terms of their characteristics that distinguish them from other large and complex but monolithic systems (Usländer, 2010). The most distinctive characteristics of systems of systems are the independence of their component systems in terms of operation, management and evolution. This independence and the distribution of a system of systems over a large geographical extent result in an 'even greater emphasis on interface design than in traditional system architecting and engineering' (Maier, 1998).

Therefore, for the 'system of ground segment systems' it is the interface design of the ground segment services that is of major importance. Hence, the focus of this book is the description of the HMA interfaces from various perspectives as well as the technologies and concepts to engineer such systems of systems.

Several of the standards described in this book encompass a range of applications that exceed their proposed uses in satellite-

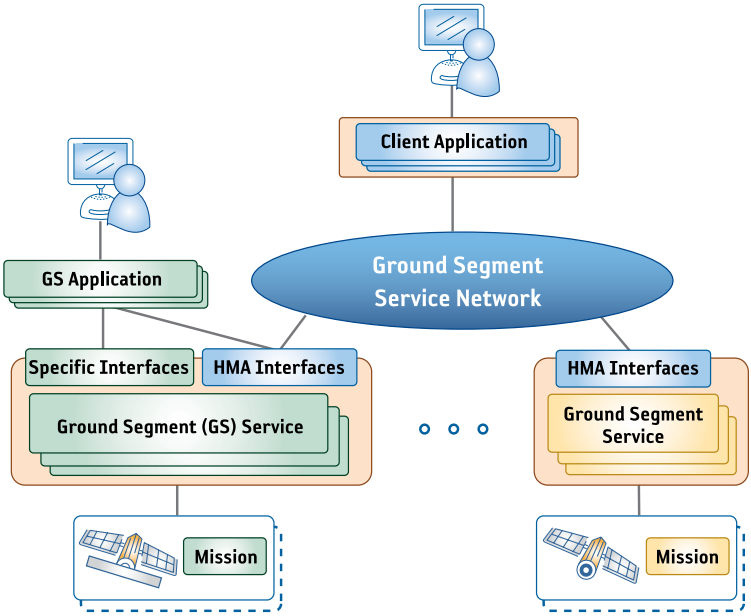


Figure 1.2. Ground segment system-of-systems approach.

based EO. These standards are generic in nature such that integration of *in situ* sensors, sensors mounted on flying or airborne or unmanned air vehicles with satellite-based sensors dedicated to EO is possible. In the following, we will limit ourselves to discussing the interoperability of satellite-based EO systems and corresponding ground segments.

1.3.2 The HMA Interfaces within the EO Ground Segment

The starting point (see Fig. 1.3) for any interaction within and across EO ground segments is the user, a generic customer of a space observation system. The user may also be a large-scale service receiving data from the ground segment. The user browses a catalogue and identifies products fitting his or her needs. The user then issues orders[3] for products. Products include a wide range of

[3] The 'order' service is the most common method to get an EO product from a ground segment. It should be noted that while this is very intuitive (e.g. for getting products from an optical high-resolution mission), there are other possible approaches when systematic or scientific products are of interest. The Linked Data initiative, for instance, addresses recommended best practice for exposing, sharing and connecting pieces of data, information and knowledge on the Semantic Web using uniform resource identifiers and the Resource Description Framework from the W3C.

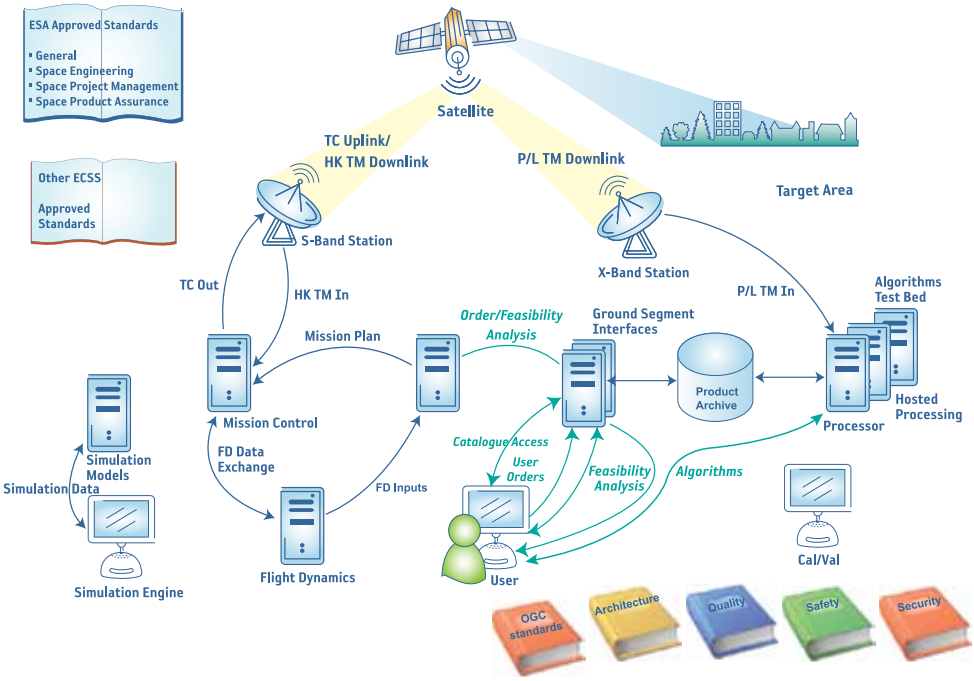


Figure 1.3. Ground segment subsystems and interfaces.

items (at different levels of processing) from single images/products to huge datasets (e.g. wide coverage, continuous or periodic monitoring, etc.; see Marchetti & Biancalana, 2008). For an outline of how the generic ground segment architecture relates to GMES coordinated data access, see Marchetti (2009).

Product orders may refer to:

— products already available in the product archive which are quickly delivered after retrieval and (possibly) processing; or
— products requiring the acquisition of new data triggering the process schematically described below.

Orders for the acquisition of new data are passed from user services to a planner entity. The planner builds a plan allocating the acquisition of new data by the satellite in the next period. The mission plan takes into account information coming from Flight Dynamics (FD)/Mission Control including satellite orbit, unavailability, etc. The planner sends the mission plan to the mission control entity which converts the plan into a set of telecommands (TCs) to be uplinked to the satellite during the

visibility periods. The set of uplinked telecommands also includes housekeeping telecommands for satellite maintenance and guidance. Mission Control receives and processes housekeeping telemetry (HK TM) coming from the satellite, mainly reporting satellite status and the TC results.

Mission Control interacts with Flight Dynamics to provide and receive data related to satellite maintenance and guidance.

During visibility periods the satellite (for simplicity a single satellite is shown, but the description can be extended to a constellation) receives the TC from the S-band antenna, executes them (immediately or at scheduled times) and downloads the housekeeping telemetry.

The uplinked TC include commands to download the data related to the acquired 'images'. The satellite downloads the data to the X-band station as payload telemetry (P/L TM) as soon as it is visible.

The payload telemetry acquired by the X-band station is transferred to the processor entities which generate the final products to be stored in the product archive and/or disseminated or delivered to the user, thus closing the loop that started with the product order. This download/generation schema includes near-real-time patterns where:

— data are acquired by the satellite and downlinked in a pipeline at the same time during visibility over the X-band station;
— data received at the X-band station are processed and are immediately delivered (electronically) to the user.

Moreover the EO ground segment scenario is supplemented by hosted processing for EO service-specific processing and algorithm test support environments dedicated to the support of scientific algorithm development and validation, calibration/validation (Cal/Val) systems and activities.

Needless to say, the above scenario has substantial variations when systematic missions (or constellations like, for example, the GMES's Sentinel-1 and Sentinel-2) are operated as the mission planning is reduced to very special cases. Furthermore, it must be remarked that the EO missions may relay the acquired data to data relay satellite(s) to shorten the delivery time to the processing centres and finally to the end users.

1.3.3 Stakeholder Perspective

The GSCB was established in June 2005. It is composed of Member-State agencies managing EO data ground segments.[4]

Various GSCB initiatives are being organised to foster the exchange of information among mission developers in Europe and Canada, the most important for interoperability being the HMA initiative. The GSCB partners who directly contributed to the HMA initiative are:

— ASI (Italian space agency)
— CNES (French space agency)
— CSA (Canadian space agency)
— DLR (German space agency)
— Eumetsat (European Organisation for the Exploitation of Meteorological Satellites)

GSCB shares expertise in the development and operation of payload ground segments of the missions listed in Table 1.1.

The GMES programme is the major European research and development programme for the establishment of a European capacity for EO. It is presented in more detail in section 3.2.2.

HMA standards are implemented within the GMES coordinated data access. Table 1.2 accounts for implementation of the HMA standards planned for completion by mid-2012.

Table 1.1. Agencies and their EO missions.

Agency/Operator	Origin	Mission
ESA	Europe	Sentinel-1, Sentinel-2, Sentinel -3, other GMES contributing missions
DLR	Germany	TerraSAR-X, TanDEM, EnMAP and third-party missions
ASI	Italy	COSMO-Skymed
CNES	France	SPOT, Topex-Jason and Pleiades
CSA	Canada	Radarsat-1, Radarsat-2 and Radarsat Constellation Mission (RCM)
Eumetsat	Europe	Meteosat First and Second Generation, MetOp, Jason-2 and third-party missions

[4] *http://earth.esa.int/gscb*

Table 1.2. Implementation of HMA interfaces (catalogue and order*).

Agency/Operator	Origin	Mission
ESA	Europe	Multimission
CNES	France	Pleiades
DLR	Germany	Multimission
DMCii/DEIMOS	UK, Spain	DMC
EUSI	Germany	World-View
RapidEye	Germany	Rapid Eye
e-Geos	Italy	COSMO-Skymed
Infoterra Germany	Germany	TerraSAR-X
SPOT Image	France	Multimission
MDA	Canada	Radarsat-2
Eumetsat	Europe	Multimission
VITO	Belgium	Proba-V
*Note: Not all the entities listed here are implementing the ordering service.		

1.3.4 User Expectations

The complexity of information management systems and ground segment architectures should be hidden from the user as much as possible. Indeed, their use should be intuitive and straightforward, i.e. they should behave similarly to other systems with objectives that the user is accustomed to. Known usage patterns should lead to expected results. This is not just a challenge to the system architect when designing the user interface, which is just one façade of a system, but also a question of a good overall design based on rigorous design principles.

An EO information and management system such as the one based on HMA interfaces should answer at least the following key questions in an easy-to-use way from the perspective of an end user:

- How can I participate in and exploit the system? This question leads to the functional package of management of user identities and authentication of users by means of log-in procedures.
- What is available in the system? This question leads to the functional package of searching for EO data products and collections on the one hand, but also searching for processing capabilities of such datasets on the other hand. In contrast to the search for documents on the World Wide Web, such a search request is usually targeted at structured data stored in databases or binary files whose meaning is stored in associated data and dataset descriptions. In the latter case it is targeted at the description of processing capabilities. However, users

often do not have knowledge of the entire interrelationships between different satellites and missions producing the data, and associated processing capabilities and responsible institutes providing the end product. Hence, there is a need for a means to describe the products and the capabilities in a user-friendly way and to enable fuzzy queries.

- How do I get EO datasets and data? EO data may not be immediately available, e.g. when the time reference lies in the future or the data need processing beforehand. This raises the following two questions:
  - How do I request and shape the EO data, or in general how do I process EO data? This question leads to the functional package of analysing the feasibility of a request on the one hand, and influencing, if possible, the data acquisition process (called programming or sensor tasking) on the other hand.
  - How do I order the EO data? This question leads to the functional package of specifying an order request, getting confirmation and waiting for delivery of the product. This requirement is similar to those of e-commerce systems.
- How do I access EO datasets and data? This question leads to the functional package of accessing the actual data in electronic form, once discovered, selected, ordered and available in the HMA-compliant ground segment. The data access may take place using simple file downloads over ftp or http or via a standardised service like the OGC's Web Coverage Service (WCS) allowing, for example, spatial subsetting and band selection.
- How do I view the EO data? This question leads to the functional package of rendering the data (viewing) in a form that is adequate for the end-user device by which the user accesses the HMA-compliant ground segment. This may be a 'simple' bitmap file in standard format but also a layer to be added to a cartographic (web) mapping system and visualised in the context of other geospatial data.
- How do I secure access to EO data? This question leads to the functional package of specifying access control rights for EO data and ensuring that only those users who have the necessary rights may create, read, write or delete EO datasets. The handling of this question is closely related to the first one (identity management) and needs a consistent technical approach.

Typically, when designing information systems, such user expectations need to be made concrete and refined as user stories and user requirements, e.g. in terms of use cases on multiple levels. The basic business use cases for HMA are presented in section 3.4 as part of the HMA Enterprise Viewpoint.

1.4 Understanding EO Missions

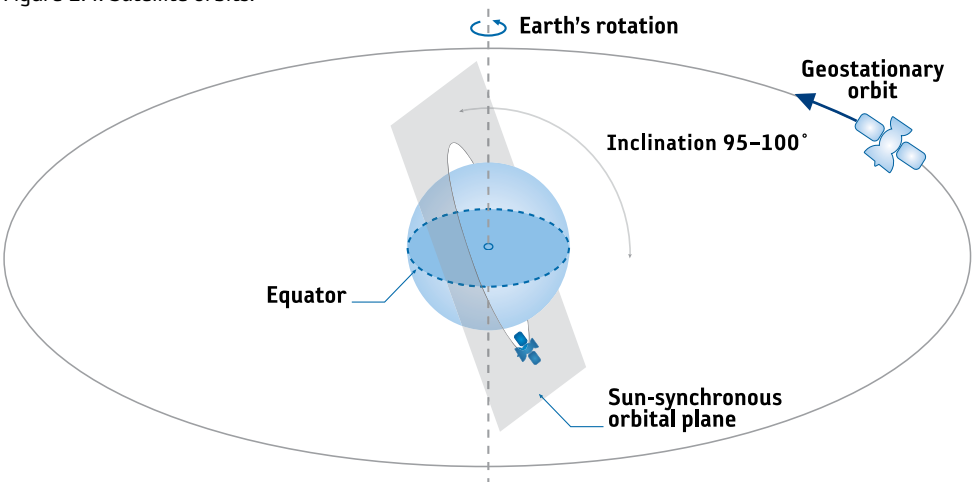
An overview of the terminology and concepts related to EO missions is beyond the scope of this book. We recommend Gomarasca (2009) as introductory reading which, with a geomatics perspective, provides an overview of EO, meteorological and global positioning systems (GPSs).

We will limit ourselves in the following to providing some background needed to establish a common terminology and understanding for concepts used within the various standards described in this book.

The satellites carrying the EO payloads fall into two large categories depending on some of the orbit characteristics: size, shape and inclination (Sellers, 2003), i.e. Sun-synchronous and geostationary. Sun-synchronous orbits are based on the right combination of sensor altitude (750–900 km), orbit shape (quasi-circular) and orbital plane inclination (95–100°). Sun-synchronous orbits permit exploitation of the Sun's illumination, and the time to revisit the same point on Earth spans two to four weeks. Geostationary satellites fly at an altitude of 36 000 km in an orbital plane passing through the equator. They observe the same Earth disc from a larger distance allowing for continuous monitoring as needed, e.g. in meteorological applications (Fig. 1.4).

EO products can be characterised at first glance by the characteristics of the observation payloads that generated the product. The payload carries the instrument that observes Earth. In the following we limit our description to the EO optical and radar instruments. However, we will see in the following chapters that

Figure 1.4. Satellite orbits.



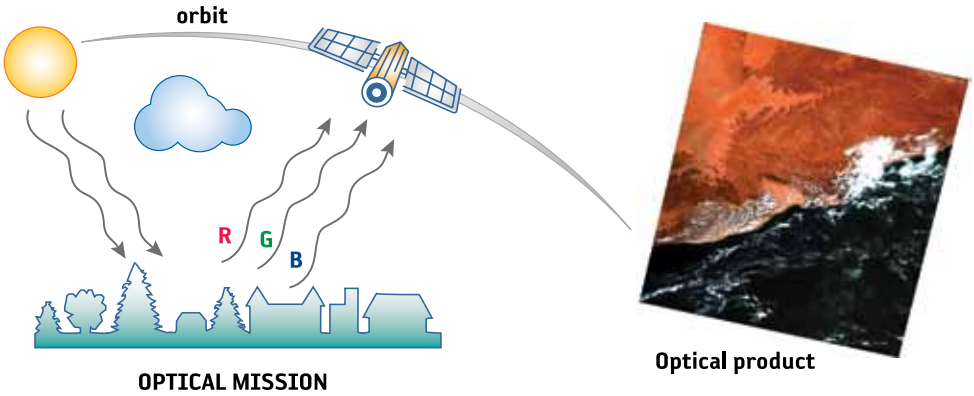


Figure 1.5. An optical mission.

the product metadata has been tailored to describe altimeters, limb-looking instruments and systematic products as well.

We will refer to the optical instrument when the payload is a passive sensor which detects the electromagnetic radiation originated by the Sun and reflected by Earth. This classification applies to payloads which detect the visible radiation (either panchromatic or in the three primary colours[5] red, green and blue), as well as to multispectral sensors spanning the visible to the near infrared. Optical missions (Fig. 1.5) are affected by the presence of clouds and therefore important information (metadata) associated with the product is the percentage of cloud cover.

We will refer to a radar instrument when the payload is active, namely synthetic aperture radar (SAR), where the electromagnetic impulses generated by the onboard emitter are collected by a large array antenna mounted on the satellite during its flight. The synthetic antenna matrix is composed of a physical array carried by the satellite, which becomes a matrix as the satellite moves around its orbit (see Fig. 1.6).

The active nature of the SAR payload enables the development of an EO product that is practically immune from cloud and other atmospheric effects and that works at night as well as in daylight. Normally SARs are sideways looking, and the electromagnetic radar signal can be polarised over vertical or horizontal planes. Then parameters like the antenna direction value and the signal polarisation become important parameters (metadata) specifically

[5] The Young–Helmholtz theory of trichromatic colour vision proposed that human colour vision is based on the combination of three kinds of receptors.

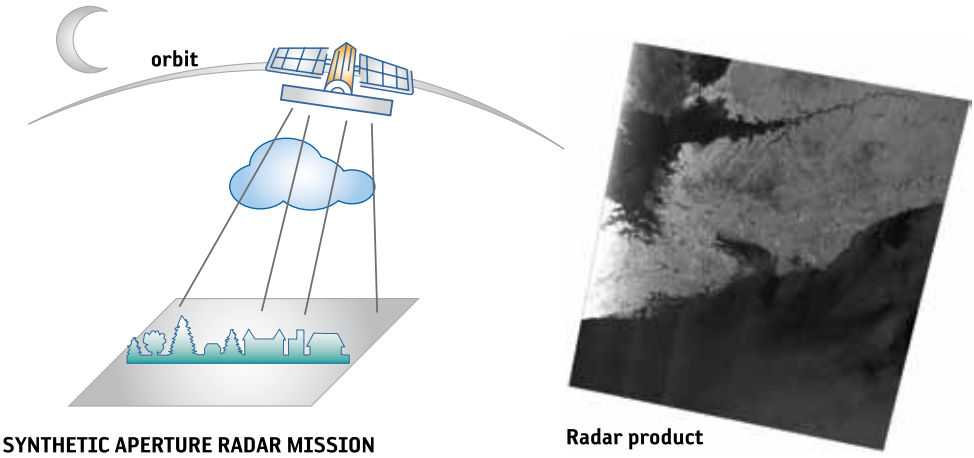


Figure 1.6. A SAR mission.

Figure 1.7. Use of EO product metadata to describe the product characteristics.

for SAR EO products. Figure 1.7 shows a practical example of the use of the EO product metadata to search for EO products on the Disaster Charter Catalogue supported by CNES via the mapshup client[6] (by courtesy of Jerome Gasperi, CNES).

[6] *http://mapshup.info*

The returned metadata identifies the kind of EO product, i.e. a product obtained by the SPOT satellite, which is a 'Scene' in SPOT's terminology. SPOT Scenes are EO products that undergo basic preprocessing qualified by their level, e.g. level-1A in our example. The preprocessing that leads to level-1A performs the radiometric correction of distortions due to differences in sensitivity of the elementary detectors of the viewing instrument. This additional information is intended for users who wish to do their own geometric image processing.[7]

1.5 Using This Book

The structure of this book largely follows the basic idea of describing a distributed system architecture from several viewpoints in order to highlight different aspects with a dedicated focus. The use of viewpoints is derived from the principle of abstraction as the heart of architectural specifications, i.e. the process of suppressing selected detail to establish a simplified model. The viewpoints enable the separation of concerns in a distributed system specification, whereby each viewpoint uses dedicated language constructs to express the viewpoint-specific concerns and decisions.

After the basic introduction and motivation in this chapter as to why HMA was started and what the general objectives are, the upcoming Chapter 2 provides a short introduction to the methodology used to describe the geospatial services and standards. It especially motivates the use of the ISO Reference Model of Open Distributed Processing (RM-ODP) (ISO/IEC 10746-1:1998) as the basic structuring guideline for this book, following other examples of previous and related research projects with similar objectives and motivation.

Consequently, Chapter 3 presents the Enterprise Viewpoint as lightweight reading of what a potential user expects from a service environment supporting heterogeneous missions. These expectations are expressed in terms of use cases.

The next two chapters provide more detailed descriptions of the technical concepts behind the proposed solutions. Chapter 4 describes the Information Viewpoint and as such presents the basic structure of all the data and metadata models used with their interdependencies and relationships between themselves and to international standards. Chapter 5 complements this by presenting the Service Viewpoint, i.e. a description of how the individual

[7] *www.astrium-geo.com/en/195-preprocessing-levels-and-location-accuracy*

operations are combined and aggregated into interfaces and services in order to fulfil the use case requirements described in the Enterprise Viewpoint. By their very nature, the services rely upon data and metadata models described in the Information Viewpoint. Hence, the order of reading these two chapters may depend upon the knowledge of the reader and the focus of interest.

Note that these descriptions are all abstracted from implementation issues. This book provides a conceptual architecture instead of a software architecture, as the conceptual approach will be the sustainable foundation for future work. Hence, this kind of information is much more adequate to be put into the form of a 'cookbook'. The reader interested in the Engineering and Technology Viewpoint is cordially invited to look at the original implementation specifications.

Finally, Chapter 6 closes with a conclusion and a high-level description of ongoing and future activities within and around the scope of heterogeneous missions accessibility.

→ DESIGN METHODOLOGY

2. Design Methodology

2.1 Structural Approach

The methodology to structure the thinking and specification of the HMA initiative follows the principles of the RM-ODP (ISO/IEC 10746-1:1998). This is an international standard for architecting open, distributed processing systems. It provides an overall conceptual framework for building distributed systems in an incremental manner. The RM-ODP standards have been widely adopted: they constitute the conceptual basis for the ISO 19100 series of geomatics standards (normative references in ISO 19119:2005). Furthermore, RM-ODP was also employed for architectural specifications in the context of the OGC, e.g. the original OGC Reference Model (OGC 03-040) which laid the basis for the development of a series of OGC standards for geospatial services and information models, the Reference Model of the ORCHESTRA Architecture (RM-OA), which tailored it to environmental risk management applications (OGC 07-097), and the GIGAS methodology for comparative analysis of information and data management systems (OGC 10-028r1). These works on system architecture show that the proposed methodological approach is suitable for the design and analysis of individual systems, as well as of systems of systems as is the case within the context of the HMA initiative.

ISO/IEC 10746 specifies an architectural framework for structuring the specification of distributed systems in terms of the concepts of viewpoints and viewpoint specifications.

The viewpoints identify the top priorities for architectural specifications and provide a minimal set of requirements together with an object model to ensure system integrity. They address different aspects of the system and enable the 'separation of concerns'.

The five standard viewpoints are defined as follows:

1. The *Enterprise Viewpoint:* A viewpoint of the system and its environment that focuses on the purpose, scope and policies of the system. A description of the Enterprise Viewpoint is contained in Chapter 3.
2. The *Information Viewpoint:* A viewpoint of the system and its environment that focuses on the semantics of the information and information processing performed. A description of the Information Viewpoint is the subject of Chapter 4.
3. The *Computational Viewpoint:* A viewpoint of the system and its environment that enables distribution through functional

decomposition of the system into objects which interact at interfaces. Chapter 5 describes the Computational Viewpoint (here referred to as the Service Viewpoint; see below).

4. The *Engineering Viewpoint:* A viewpoint of the system and its environment that focuses on the mechanisms and functions required to support distributed interaction between objects in the system.
5. The *Technology Viewpoint:* A viewpoint of the system and its environment that focuses on the choice of technology in that system.

Descriptions of the Engineering and Technology Viewpoints are not given in this book because the risk of including outdated information is very high due to the dynamics of the software market and emerging tools under development in HMA-related research projects. The interested reader is referred to the latest information contained on the HMA wiki pages.[8]

The aspect of a distributed system resulting from the RM-ODP approach is handled by the concept of distribution transparency. Distribution transparency relates to masking from applications the details and differences in mechanisms used to overcome problems caused by distribution.

An RM-ODP-based approach has been selected for the design analysis of the architecture in the context of HMA because the primary objectives of RM-ODP are largely coherent with the HMA objectives:

— for the aspect of distributed processing shall be transparent to the user as far as possible and technically feasible;[9]
— provision of interoperability across heterogeneous systems, and
— hiding the consequences of distribution from systems developers.

However, as the HMA implementation within GMES will have the characteristic of a loosely coupled network of systems and services instead of a 'distributed processing system based on interacting objects', the RM-ODP concepts are not followed literally. The main difference is that the 'Computational Viewpoint' is referred to as the 'Service Viewpoint' in HMA following the suggestion of the RM OA (OGC 07-097).

[8] *http://wiki.services.eoportal.org*
[9] EO applications often have to deal with large datasets. Hence, in order to enable good response times the distribution of resources will sometimes not be fully transparent. For instance, it may be explicitly required to download large datasets from different sources to a central storage before a geoprocessing algorithm can be carried out. These aspects are further discussed in the context of cloud computing in section 6.1.3.

The proposed architecture follows the design principles of a geospatial service-oriented architecture (SOA). An SOA is an 'information technology architectural approach that supports the creation of business processes from functional units defined as services' (Zhang et al., 2008). For the HMA architectural analysis, the service-related definitions in the ISO series of standards on geographic information are adopted. Therefore, a service is a 'distinct part of the functionality that is provided by an entity through interfaces', whereby an 'interface is a named set of operations that characterize the behaviour of an entity' (ISO 19119:2005).

2.2 Design Approach for EO Applications

Following the concepts of geospatial SOAs, EO ground segments may be implemented as geospatial service networks by taking into account the constraints and rules of service platforms. A (geospatial) service network hereby comprises the set of networked hardware components and (geospatial) service instances that interact in order to serve the objectives of applications (OGC 07-097). In this context, the problem of the design of EO applications on top of such service networks boils down to the following general question of service-oriented design of information systems in the environmental and space domains (Usländer, 2010).

What parts of the required application are already provided by the capabilities of existing geospatial service networks in terms of

— service types ('which services are specified?'); and
— service instances ('which services are operational and usable?')?

Figure 2.1 relates the design of ground segment service networks to the domain of applications exploiting EO missions, the use cases, as well as the requirements and capabilities of a geospatial service network.

There is an EO domain that subsumes all the high-level business and organisational needs of the EO stakeholders concerned with the design, engineering, deployment, maintenance and use of EO missions. They are condensed and represented in the form of use cases that describe the desired behaviour of a system from the external perspective of a user and/or the stakeholders. The major generic use cases, from which the design of the HMA service networks is derived, are described in section 3.4 as part of the HMA Enterprise Viewpoint.

Capabilities of specified and deployed geospatial service networks are considered as basic building blocks of the targeted

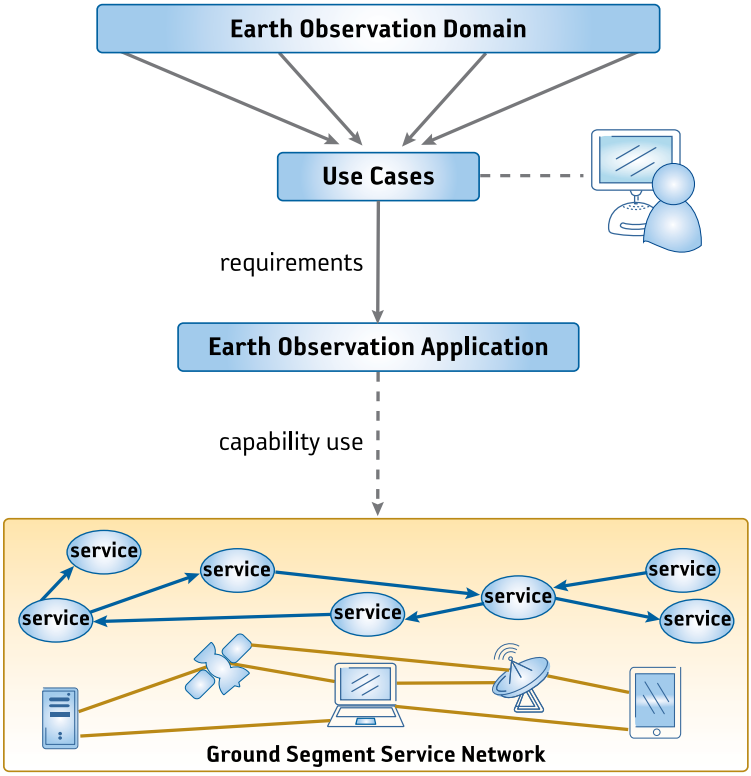


Figure 2.1. Design of EO applications on top of ground segment service networks

implementation of the EO application. The major capabilities are the HMA service types described in the Service Viewpoint in Chapter 5 and the HMA information models presented in the Information Viewpoint in Chapter 4.

As a result, EO applications are designed such that their generic parts are conceived as compatible increments to existing service capabilities. The design of an EO application should now be such that, on the one hand, it supports the use cases and, on the other hand, makes maximum use of those capabilities of HMA-compliant ground segment service networks that the user is allowed and enabled to access.

It is one of the purposes of this book to provide a comprehensive and coherent overview of the capabilities that exist in HMA-compliant ground segment service networks and that may thus be relied upon when designing EO applications.

→ ENTERPRISE VIEWPOINT

3. Enterprise Viewpoint

3.1 Architectural Guidelines

SOA is the predominant design paradigm for EO and environmental information systems (Coene & Gasser, 2007). The major SOA design principles (Erl, 2008), i.e. the loose coupling of functional entities (services) on the basis of an agreed service platform, their autonomy, reusability and composability, foster the use of SOA in geospatial information systems. SOA enables the sharing of geospatial resources, i.e. data and services with an explicit or implicit geospatial reference, their composition to higher-level entities and their use in geospatial applications possibly distributed across organisational and administrative boundaries. This is essential for EO and environmental information systems as natural phenomena are not limited to boundaries drawn by humans (Usländer, 2010).

However, an SOA for an open EO service environment cannot solely rely on existing design principles that are typically applied in commercial SOA environments. As in other geospatial service architectures (OGC 07-097) and sensor-based environments (OGC 09-132r1), HMA has been designed with the following architectural guidelines in mind:

- *Rigorous definition and use of concepts and standards:* The HMA initiative fosters rigorous use of proven concepts and standards in order to decrease dependence on vendor-specific solutions. This helps to ensure the openness of a sensor service network and support the evolutionary development process.
- *Loosely coupled components:* The HMA initiative supports the principle that the components involved in an EO service network be loosely coupled, in which case loose coupling implies the use of mediation to permit existing components to be interconnected without changes.
- *Technology independence:* The HMA initiative supports technology independence, development cycles and changes, as far as practically feasible. Accordingly it is possible to accommodate changes in technology (e.g. life-cycle of middleware technology, or protocol binding) without changing the selected standards, as the proposed standards are independent of specific implementation technologies (e.g. middleware, programming language or operating system).
- *Evolutionary development – design for change:* The HMA initiative is open to evolution of services and components, i.e. it should be possible to develop and deploy the proposed standards in an

evolutionary way. The HMA initiative (see section 1.3) is able to cope with changes of user requirements, system requirements, organisational structures, information flows and information types in the source systems.

— *Component architecture independence:* The HMA initiative has proposed standards that allow the architectural decoupling of the service network and EO missions and their payload ground segment infrastructure. The HMA initiative does not impose any architectural patterns on EO missions for the purpose of having them collaborate, and no EO mission should impose architectural patterns on the contributing missions in order to be considered HMA compliant. It is important here that an EO mission is seen as a black box, i.e. no assumptions about its inner structure are made when designing an HMA-compliant service network.

— *Generic infrastructure:* HMA-compliant services are independent of the application domain, i.e. they can be used across different thematic domains and in different organisational contexts. Ideally, any update of integrated components (e.g. EO missions, EO applications, services, the Semantic Web) requires no or only small changes to the consumers of HMA-compliant services.

3.2 Business Context and Related Initiatives

3.2.1 Overview

This section describes the major international projects and initiatives that directly or indirectly influence the design and development of HMA-compliant applications. This may be through the discussion, editing and promotion of technical specifications, but also through the development and validation of HMA-compliant architectural elements, components or services.

The following description presents European and global initiatives such as GMES, INSPIRE and GEOSS, but also standards organisations such as ISO, CEN, W3C, OASIS and OGC that are relevant in the HMA context. Readers interested in the meteorology information system implementation guidelines will find additional information at *www.wmo.int/pages/prog/www/WIS*

It was one of the primary objectives of the GEOSS, INSPIRE and GMES Action in Support (GIGAS) project to identify and define what is needed to enable a full integration of the architectures of the three initiatives via a consensus process in the light of the geospatial standards and their evolution. Hence, some of the material presented in this section is based on and derived from the 'Technology Watch' documents of the GIGAS project (GIGAS 2.2b, 2009).

3.2.2 GMES

The objective of GMES is to provide, on a sustained and operational basis, reliable and timely services related to environmental and security issues in support of public policy needs. GMES is an initiative led by the EU, in which ESA implements the space component and the European Commission (EC) manages activities for identifying and developing services.

In 2005 the 3rd Space Council confirmed the EC proposal for a phased implementation of GMES, starting with three GMES Fast-Track Services (FTSs). The GMES FTSs aim at establishing the following services:

— Land Monitoring Core Service, to be developed by the European research project *Geoland2*;[10]
— Emergency Response Core Service, to be developed by the European research project *G-Mosaic*;[11] and
— Marine Core Service, to be developed by the European research project *MyOcean*.[12]

Originally, for each of these services, an implementation group was set up by the EC with the objective of defining the scope, outputs, functions and architecture of the services and to make proposals for a governance scheme. In 2007, each implementation group produced an implementation report that provided guidelines for the implementation of the services and was used as guideline in the context of European research projects. Research was carried out on:

— Service chains, by implementing individual prototypes, tested over selected areas of Europe to make sure that they work satisfactorily. The funding is focused on the development of the processing chain and efforts to validate the concepts and the technologies and services developed.
— Development of GMES Downstream Services, with the goal of reaching self-sustainability. Such Downstream Services are positioned between multi-purpose services (see above) and a specific group of user clients, and take full benefit of the wide range of services by making extended use of the products made available by these clients.

[10] *www.gmes-geoland.info*
[11] *www.gmes-gmosaic.eu*
[12] *www.myocean.eu*

Products will be rolled out based on prototypes developed by the research projects mentioned above. The services will be made operational in order to meet the demand in terms of data volumes to be processed for full pan-European or global coverage and steady-state operation on a continuous basis, with the shortest possible response times.

At the end of 2011 the GMES services addressed six main thematic areas: land monitoring, marine environment monitoring, atmosphere monitoring, emergency management, security and climate change.

Support for the research on climate change will be provided by the three services on land monitoring, marine environment and atmosphere. All three will seek to provide added value on the essential climate variables. In addition, GMES will strive to support socio-economic analysis and the derivation of impacts.

The GMES services will rely on three categories of input data:

1. Space observation data will be provided by various satellite missions that are combined to form a GMES Space Component (GSC). The GSC is co-funded by ESA and the EC under a specific delegation agreement. The GSC also integrates data from other international or national contributing space missions and will provide these data through the 'GSC Data Access' (GSCDA) component.
2. *In situ* observation data will be provided by a network of observation infrastructures organised in different themes on the local, regional or national level. These networks are typically owned and governed by the EU Member States. The homogeneous and sustainable provision of these data poses a considerable challenge, which is being tackled under the leadership of the European Environment Agency (EAA). Beyond the firm expectation that INSPIRE Implementing Rules will be respected for data discovery and access, no details have so far been documented about network service implementation for *in situ* data.
3. Reference data, which fulfil a specific and complementary role compared with observation data, will be provided as a geographic or positional framework. These data include, among others, topographic data (including road networks, hydrography, digital elevation models, etc.) and data such as geological maps.

The latest information about GMES is available at *www.gmes.info*.

3.2.3 INSPIRE

INSPIRE is a legal instrument of the EC. It is driven by Directive 2007/2/EC of the European Parliament and of the Council establishing an 'Infrastructure for Spatial Information in the European Community' (EC, 2007), which entered into force on 15 May 2007. In addition, normative Implementing Rules and informative guidance documents on the aspects of metadata, interoperability of spatial data sets and services, network services, data and service sharing, and monitoring and reporting are or will be adopted.

The motivation for INSPIRE has been that the general situation on spatial information in Europe is one of fragmentation of datasets and sources, gaps in availability, lack of interoperability or harmonisation between datasets at different geographical scales and duplication of information collection. These problems make it difficult to identify, access and use data that are available. Fortunately, awareness is growing at national and EU level about the need for quality georeferenced information to support an understanding of the complexity and interactions between human activities and environmental pressures and impacts. The INSPIRE initiative is therefore timely and relevant but also a major challenge, given the general situation outlined above and the many stakeholder interests to be addressed.

INSPIRE is complementary to related policy initiatives, such as the EC proposal for a Directive on the reuse and commercial exploitation of public sector information. INSPIRE is ambitious. The initiative intends to trigger the creation of a European spatial information infrastructure that delivers to users integrated spatial information services. These services should allow users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an interoperable way for a variety of uses. Target users of INSPIRE include policy makers, planners and managers at European, national and local level and the citizens and their organisations. Possible services are the visualisation of information layers, overlay of information from different sources, as well as spatial and temporal analyses.

The implementation of INSPIRE requires technical arrangements that are summarised in Implementing Rules (and associated guidelines) on metadata, network services, data specifications, data and service sharing, and monitoring and reporting. These are briefly summarised in the following paragraphs.

EU Member States shall create metadata and keep it up to date. The metadata shall include information about:

— conformity with the Implementing Rules on interoperability;
— conditions for access and use of datasets and services;
— quality and validity;
— the public authorities responsible; and
— limitations on public access.

EU Member States shall make a network of the following services available to the public for datasets and services for which metadata has been created:

— Discovery Services (at no charge): search for spatial datasets and services on the basis of the content of the corresponding metadata and to display the content of the metadata.
— View Services (basically at no charge; however, there may be exceptions): to display, navigate, zoom in/out, pan or overlay viewable spatial datasets and to display legend information and any relevant metadata.
— Download Services: enabling copies of spatial datasets, or parts of such sets, to be downloaded and, where practicable, accessed directly.
— Transformation Services: enabling spatial datasets to be transformed with a view to achieving interoperability.
— Services allowing spatial data services to be invoked.

Moreover, the EU Member States shall ensure the technical possibility for public authorities:

— to link their spatial datasets and services;
— to restrict access to services;
— to make services available to third parties on request, under certain conditions; and
— to establish an INSPIRE geo-portal.

Concerning data sharing, the EU Member States shall adopt measures for the sharing of data and services between public authorities for public tasks relating to the environment without restrictions at the point of use. Note, however, that public authorities may license and/or charge other public authorities and European Community institutions provided that

— the measures are compatible with the objective of facilitating sharing between public authorities; and
— restrictions on licences and charges are the minimum necessary to ensure sustained availability and quality of the data and services.

When spatial data or services are provided to Community institutions for reporting obligations under EC law relating to the environment, then this may not be subject to charging. Member States shall provide the institutions and bodies of the Community with access to spatial datasets and services in accordance with harmonised conditions.

Furthermore, an Implementing Rule shall be adopted for interoperability and where practical for the harmonisation of spatial datasets and services. Examples for harmonisation needs are the classification of spatial objects or a common system of unique identifiers for spatial objects.

3.2.4 GEOSS

GEOSS[13] is an intergovernmental programme, coordinated by the Group on Earth Observations (GEO). GEOSS is a 10-year global programme that aims to provide to the broad environmental science and user community decision-support tools and support for the monitoring, analysis and modelling of various environmental phenomena through the integration of existing and future sources of EO information.

As of May 2011, 86 countries,[14] the EC and 61 organisations[15] participated in the GEOSS work plan. GEOSS aims to integrate EO systems into a global system that can be applied to various areas of environmental science and management. GEOSS is composed of a variety of systems (leading to a system-of-systems approach) including those for data collection, processing, discovery and dissemination.

Currently, the GEOSS work plan focuses on the following nine 'societal benefit areas' (SBAs), also called GEOSS themes:

1. reduction and prevention of disasters
2. human health and epidemiology
3. energy management
4. climate change
5. water management
6. weather forecasting
7. ecosystems
8. agriculture
9. biodiversity

[13] *www.earthobservations.org*
[14] *www.earthobservations.org/ag_members.shtml*
[15] *www.earthobservations.org/ag_partorg.shtml*

Interoperability arrangements ensure that the heterogeneous systems within GEOSS can communicate and operate. Data, information and service providers within GEOSS are guided by technical specifications for collecting, processing, storing and disseminating shared data, metadata and products. Interoperability arrangements in GEOSS are based on open standards, with a preference for formal international standards. Within the architecture, interoperability arrangements are registered in the GEOSS Standards and Interoperability Registry, after assessment by the Standards and Interoperability Forum (SIF).

3.3 Standards Organisations

Standardisation is key when aiming at open and interoperable software architectures and solutions. In the following a broad overview is given of the de jure and de facto standards organisations that specify and publish standards that serve as the basic building blocks for the design of the HMA architecture.

In order to give an overview, Fig. 3.1 shows the fundamental relationships and major contribution areas without going into detail. The individual standards are listed and explained in Chapters 4 and 5, which describe the HMA Information and Service Viewpoints, respectively.

3.3.1 ISO

ISO comprises a network of the national standards institutes of 157 countries, on the basis of one member per country, with a Central Secretariat in Geneva, Switzerland. The ISO Technical Committee TC 211[16] is the de jure international standards organisation in the field of digital geographic information. Its work aims to establish a structured set of standards for information concerning objects or phenomena (also called features) that are directly or indirectly associated with a location relative to Earth.

These standards specify methods, tools and services for the management of geographic data (including definition and description). This means to acquire, process, analyse, access, present and transfer such data in digital/electronic form among different users, systems and locations.

[16] *www.isotc211.org*

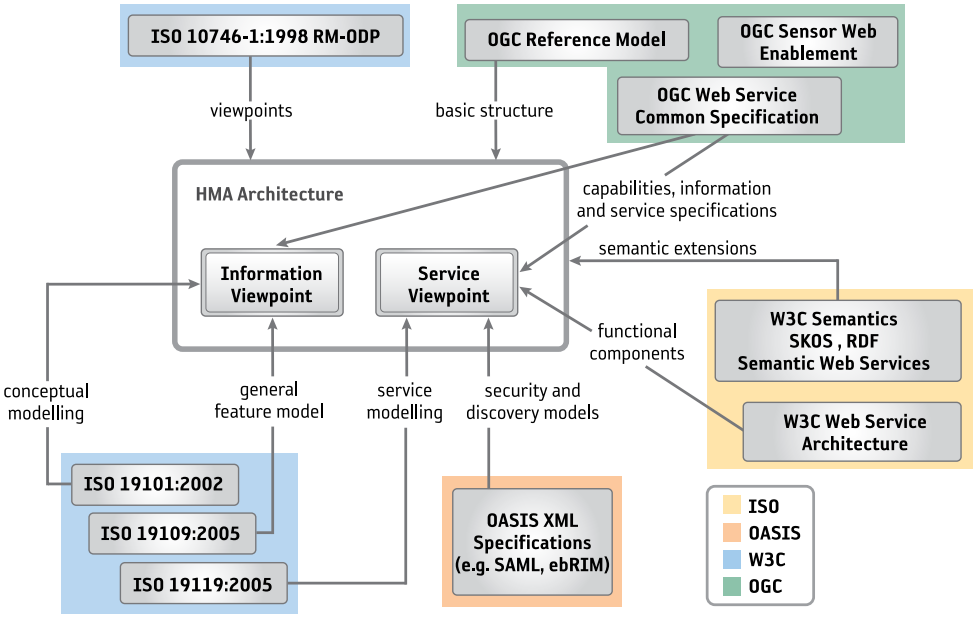


Figure 3.1. Basic contributions of standards organisations to the design of the HMA architecture.

The work of ISO TC 211 links to other appropriate (ISO) standards for information technology (IT) and data where possible, and provides a framework for the development of sector-specific applications using geographic data.

All ISO standards are accessible and can be obtained from national standards organisations or from the ISO central site in Geneva.[17]

In particular, ISO's RM-ODP (ISO 10746-1, 1998) sets the structural foundation for the description of the HMA architecture in terms of 'viewpoints' as already outlined in section 2.1. Furthermore, the series of ISO 19xxx standards provides guidance for the conceptual modelling of information and services and information, in particular the General Feature Model (GFM) as described further in section 4.2.3.

[17] *www.iso.ch*

3.3.2 CEN Technical Committee 287

CEN (European Committee for Standardization) is a major provider of European standards and technical specifications.[18] It is the only recognised European organisation for the planning, drafting and adoption of European standards in all areas of economic activity, with the exception of electrotechnology (CENELEC) and telecommunication (ETSI). CEN is organised into technical committees. Technical Committee 287 of CEN[19] deals with standardisation in the field of digital geographic information. It produces a structured framework of standards and guidelines, which specify a methodology to define, describe and transfer geographic data and services.

This work is carried out in close cooperation with ISO/TC 211 in order to avoid duplication of work. The ISO 191xx suite of standards has been adopted as European standards under the name EN ISO 191xx. The contents are identical, but they have a higher status and there are more obligations to use them.

The CEN standards support the consistent use of geographic information throughout Europe in a manner that is compatible with international usage. They support a spatial data infrastructure at all levels in Europe.

3.3.3 W3C

The W3C (World Wide Web Consortium) is an international community where member organisations, a full-time staff and the public work together to develop web standards.[20] W3C's vision for the web involves participation, sharing knowledge and thereby building trust on a global scale.

As HMA aims at a framework that allows designers to realise service networks that enable the sharing and exchange of EO data, information and knowledge, the basic W3C standards are applied to the HMA architecture specification, including the W3C approach of how to specify web service interfaces (in the Web Service Description Language, WSDL) and web service protocols (SOAP), as well as the eXtensible Markup Language (XML) as a platform-neutral and application-independent language to specify information models.

[18] *www.cen.eu*
[19] *www.centc287.eu/*
[20] *www.w3.org*

Furthermore, the latest W3C technologies and results targeted to evolve towards a Semantic Web are applied in order to improve the interoperability between HMA software components with respect to the meaning of terms and concepts.

3.3.4 OASIS

OASIS (Organization for the Advancement of Structured Information Standards) is a not-for-profit, international consortium that drives the development, convergence and adoption of open standards for the global information society.[21] OASIS promotes industry consensus and produces worldwide standards, e.g. for security, cloud computing, SOA, web services, emergency management and other areas.

OASIS members broadly represent the marketplace of public and private sector technology leaders, users and stakeholders. The consortium has more than 5000 participants representing over 600 organisations and individual members in 100 countries.

Originally, OASIS was founded in 1993 under the name SGML Open as a consortium of vendors (e.g. IBM and Microsoft) and users devoted to developing guidelines for interoperability among products that support the Standard Generalized Markup Language (SGML). OASIS changed its name in 1998 to reflect an expanded scope of technical work, including XML and other related standards.

The OASIS Reference Model for Service-Oriented Architecture (OASIS SOA-RA, 2008) specifies the common characteristics of SOAs, independent of a particular service platform implementation.

Among the long list of further OASIS standards, the HMA architecture basically adopts profiles of the OASIS security information models, in particular the Security Assertion Markup Language (SAML), Web Services Security (WS-security) and the eXtensible Access Control Markup Language (XACML) as described in section 4.7, and the generic and flexible approach on how to model metadata using the 'ebXML' Registry Information Model (ebRIM) as described in section 4.2.2.

[21] *www.oasis-open.org*

3.3.5 OGC

The OGC is an international consortium of companies, government agencies, research organisations and universities participating in a consensual process to develop publicly available interface specifications. These specifications support interoperable solutions that 'geo-enable' the web, wireless and location-based services, and mainstream IT. The specifications empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications.

The core mission of OGC is to deliver spatial interface and encoding specifications that are openly and publicly available for global use. This mission is achieved through organising interoperability projects, working towards a consensus, formalising OGC specifications, developing strategic business opportunities and standards partnerships, and promoting demand for interoperable products.

Furthermore, the following OGC working groups are of major importance for the HMA specifications:

- *Architecture:* The Architecture Domain Working Group addresses distributed computing architectural topics relevant to current or future OGC standards and specifications. The OGC Service Architecture (OGC 02-112), which is the same as ISO 19119 Geographic information – Services, and the resulting series of service and information model standards of the OGC Web Services are of particular relevance for HMA.
- *Sensor web enablement:* The goal of the Sensor Web Enablement (SWE) Working Group is to enable all types of web and/or Internet-accessible sensors, instruments and imaging devices to be accessible and, where applicable, controllable via the web. The vision is to define and approve the standards foundation for 'plug-and-play' web-based sensor networks. As instruments and detectors mounted on satellites fall into this category too, the SWE standards may also be applied to EO services and information models as defined in the HMA architecture.
- *Catalogue:* The Catalogue Working Group deals with the question of how to provide services that support the search for geospatial datasets and services. Such services require the formal specification of descriptions of datasets (dataset metadata) and the description of services (service metadata). Therefore, this working group works closely together with the Metadata Working Group.
- *Metadata:* The Metadata Working Group addresses issues related to how metadata must be specified in geospatial specifications fully to enable certain services in the OGC Service Architecture. This working

group maintains close correspondence with the ISO TC/211 metadata standard and the handling of metadata within OGC.

— *Coverages:* The Coverages Domain Working Group promotes and oversees the development of OGC Service Implementation Specifications for the exploitation of and access to coverage data, including images and other grid coverages. These coverage services support all aspects of image access and exploitation, in both rectified and non-rectified images.
— *CITE (Compliance and Interoperability Testing and Evaluation):* The CITE Subcommittee (CITE SC) comprises OGC members who are interested in the OGC Compliance Testing Programme. The Compliance Testing Evaluation Procedure is a set of steps used to evaluate a software product for proper implementation of an OGC standard.

3.3.6 ECSS

The ECSS (European Cooperation for Space Standardization) is an initiative established in 1993 to develop a coherent, single set of user-friendly standards for use in all European space activities concerning design and development.[22]

The set-up was in a spirit of true cooperation between European space agencies and European industry. Historically, the European space business had to support a multiplicity of different standards and requirements from the various space agencies in Europe. Although the agencies' requirements were essentially similar, the impact of the differences in standards was serious and led to higher costs, lower effectiveness and, moreover, a less competitive industry. Input into the ECSS comes from European space agencies and from industry.

3.3.7 Relationship with Other Ground Segment Standards

The state of play in the standardisation of ground segment interfaces for EO missions can be assessed (see Marchetti & Biancalana, 2008) by referring to Fig. 1.3. Here the interactions between the ground segment and satellite are schematically described as in section 1.3.1. The figure highlights the existing space standards, mainly from the ECSS, the overall EO process and the

[22] *www.ecss.nl*

interfaces where the harmonisation work within the HMA initiative is focused. Other relevant standards deal with architecture, quality, safety and security issues. The interoperable interfaces indicated in italics are the ones defined within the HMA initiative.

3.4 Business Use Cases

3.4.1 Introduction

HMA falls into the category of a service-oriented system. Hence, the development of client applications based upon the HMA services is a problem of service-oriented analysis and design (SOAD). In the literature numerous SOAD methodologies have been described and partly embedded in software development tools. The challenge is to choose a design methodology that brings together the requirements and the expert knowledge of users with the services and information offerings of existing information systems (here, the HMA services) and, in addition, explicitly obeys the guidelines and constraints of geospatial standards as side-conditions (here, the HMA service and information model specifications) (Usländer, 2010).

Most SOAD methodologies rely upon use case descriptions as one major result of the analysis of user requirements. In general, a use case models the behaviour of a system. When specified in detail, it may comprise a sequence of actions performed by the system to yield an observable result that is typically of value for one or more actors or other stakeholders in the system (Jacobson and Ng, 2005).

A use case expresses the functional, informational and qualitative requirements of a user (i.e. an actor or a stakeholder), whereby the functional requirements are represented by the 'sequence of actions', and the informational requirements cover the content of the 'observable result'. The qualitative needs encompass all the non-functional aspects of how the result is produced and the quality of the result which is important for the decision if the result is 'of value' to the user.

Therefore, the degree of abstraction and formalism, and the language, should be such that it is adequate for the domain of expertise of the stakeholders. To serve as an agreement, it should be understandable to the stakeholders but also precise enough. For the description of the HMA architecture in this book, the concept of use cases is applied in order to describe the high-level functional requirements that have motivated the design of the HMA architecture. This level of use cases is referred to as business use cases and is typically described in a technology-free notation. We use the Unified Modeling Language (UML) for this purpose,

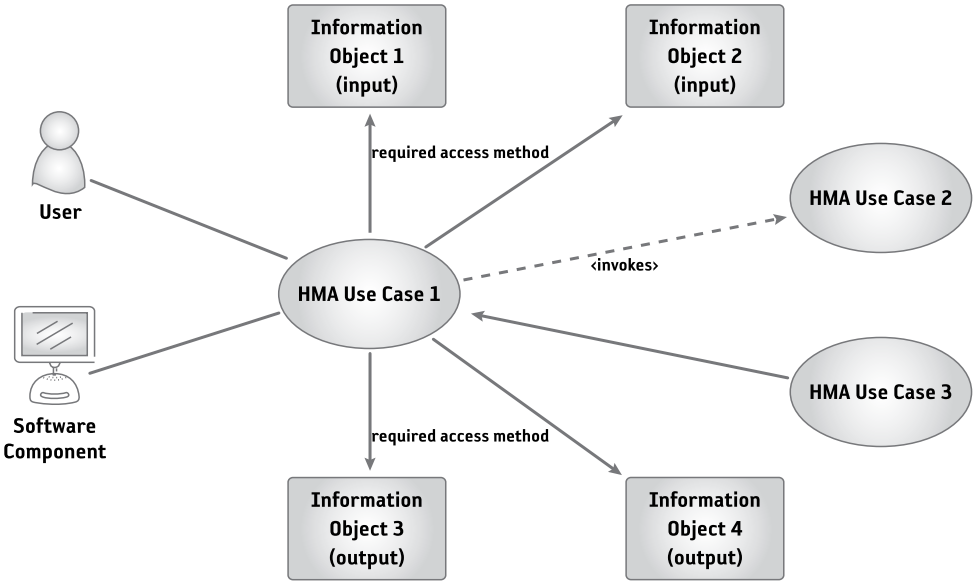
but by extending the UML use case notation with references to major information objects that are required to implement the use case. This small extension with respect to the traditional use case approach of Cockburn (2001) significantly facilitates the transition to the specification of the information model, but is still very easy to understand by thematic experts (Usländer & Batz, 2011).

Figure 3.2 shows the basic template that is used to present the HMA business use cases in the following sections.

Two major types of actors are distinguished: first, human end users (denoted as 'user' in the use case diagrams) that use a client application by means of its user interface; and second, 'Software Components' which represent a piece of software that invokes an HMA service by means of its (web) service interface.

Use cases need information objects as inputs. These are indicated in the upper part of the diagram together with the required access method, i.e. create, read, write or delete. Results of use cases are listed as information objects in the lower part of the diagram. Information objects may be related to each other. Furthermore, use cases may have relationships to other use cases. One use case may invoke another use case (which represents a dependency between use cases), or one use case may be a sub-variant of another.

Figure 3.2. Template for the presentation of the HMA business use cases.



Note, however, that these use case models as presented here only provide a structural overview without representing a sequence of actions (workflow). Such a workflow description would exceed the scope of this book, which focuses on giving a motivation and comprehensive overview of the HMA architecture.

The following business use cases are presented in the sections below:

— Authentication
— Authorisation
— Discovery of datasets, dataset series, sensors and services
— Data acquisition requests and feasibility analysis
— Product ordering
— Geospatial processing
— Access to and presentation of datasets

They represent the major functional requirements for the HMA architecture and are later on mapped to services in the HMA Service Viewpoint (see Chapter 5 and Fig. 5.1) and related information models in the HMA Information Viewpoint (see Chapter 4) derived from the identification of information objects.

3.4.2 Authentication

In SOAs, authentication concerns the identity of participants in an interaction, e.g. an exchange of data between the participants. Authentication refers to the means by which one participant can be assured of the identity of other participants (OASIS SOA-RA, 2008). In HMA, the business use case 'authentication' distinguishes between two variants of authentication as illustrated in Fig. 3.3:

— Authentication based on log-in data, i.e. the user performs a log-in procedure during which he or she enters a user name and a password.
— Authentication based on signed user names, i.e. there is a third party involved (a trusted identity provider) that has authenticated the user beforehand such that the user may already provide a signed user name.

In both cases, the authentication results in the delivery of authentication metadata, which describes 'assertions about identities' and is represented by a 'security token'. In each subsequent interaction with the system, the security token will be included in encrypted form to enable and enforce user-specific

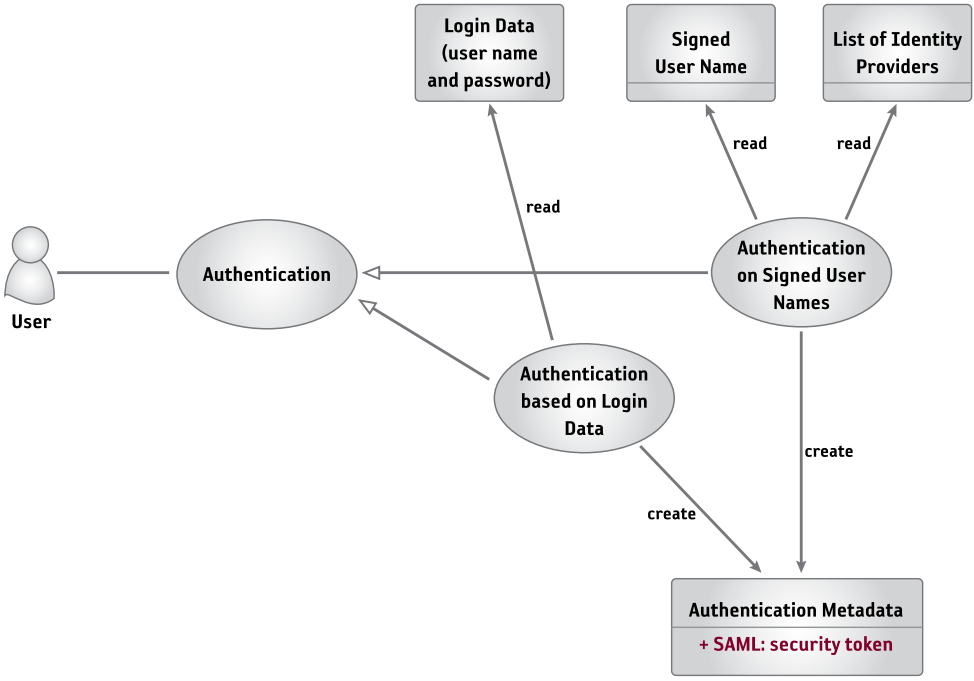


Figure 3.3. Business use case 'authentication'.

policies, e.g. for access control. As specified later in section 4.7.2, this security token will be encoded by means of the Security Assertion Markup Language (SAML).

3.4.3 Authorisation

Authorisation concerns the legitimacy of an interaction. Authorisation refers to the means by which an owner of a resource may be assured that the information and actions that are exchanged are either explicitly or implicitly approved (OASIS SOA-RA, 2008). The business use case 'authorisation' is based on the result of the authentication use case as described above and illustrated in Fig. 3.4. Each service operation that is requested by a ground segment software component will include a security token.

This token has to be decrypted and verified. Then, identity-related policies such as those for access control may be carried out and enforced. Access control policies, i.e. a description of the actions a user may perform on certain information objects under various circumstances are specified in GeoXACML (Geospatial

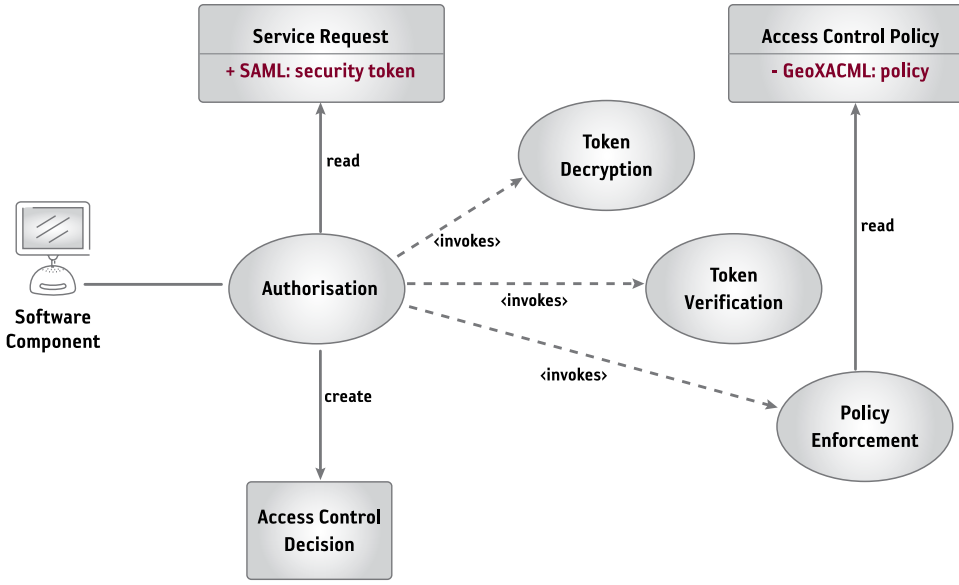


Figure 3.4. Business use case 'authorisation'.

extension of the eXtensible Access Control Markup Language) as described in section 4.7.3.

The 'authorisation' use case results in a decision on whether the service operation may be performed or not.

3.4.4 Discovery

The discovery use case deals with the question of how to find the EO resources (e.g. datasets, dataset series, services or sensors) of interest to a user. As in other application domains, such EO resources need to be described by some additional information, usually called metadata or meta-information.[23] Metadata informs about the major characteristics of a resource. Metadata elements are stored in metadata stores (e.g. realised by relational databases) and accessed through interfaces of dedicated services.

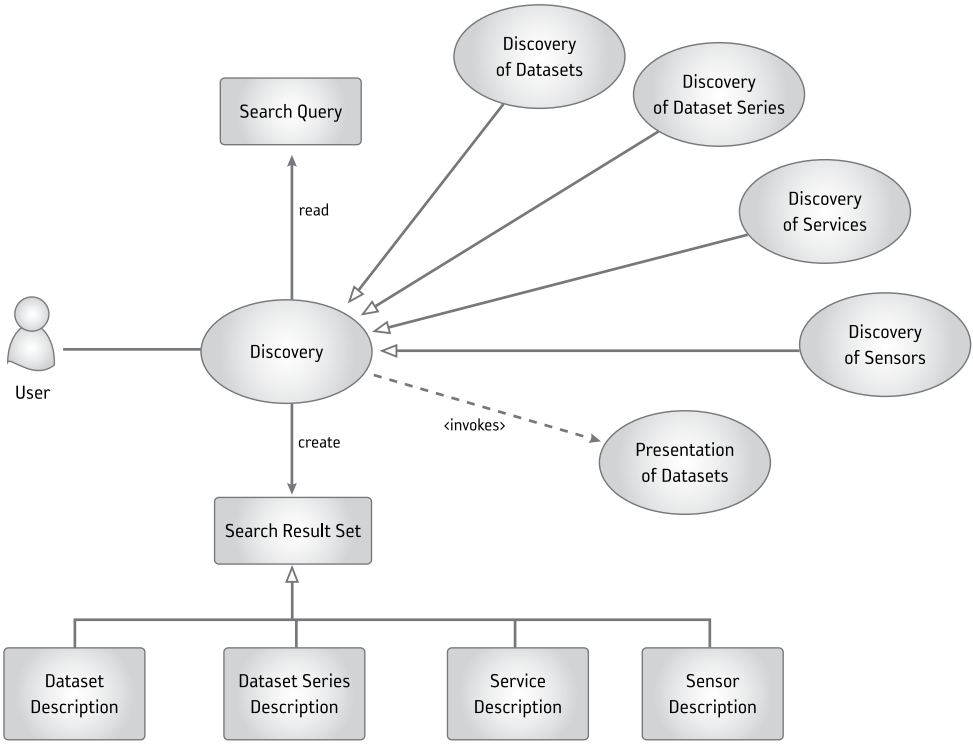
The goal for the end user is to discover those products that fulfil specific requirements according to his or her tasks. Essential requirements are, for instance:

[23] The terms metadata and meta-information are used here synonymously.

— region of interest;
— time interval;
— usage of a specific satellite and/or sensor;
— corresponding ground station; or
— additional attributes depending on the sensor type, e.g. cloud coverage.

As illustrated in Fig. 3.5, such requirements are entered as parameters in search queries. The discovery process delivers result sets that are specific to the resource types at which the search request has been targeted, i.e. it delivers descriptions (metadata elements) of datasets, dataset series, sensors and/or services. The user may then browse through these metadata records and select those with which he or she wants to continue the interaction with the HMA compliant services, e.g. access to the dataset itself as described in the use case below in section 3.4.8 or finding datasets belonging to a dataset series or activating the service etc. Furthermore, the selection

Figure 3.5. Business use case 'discovery'.



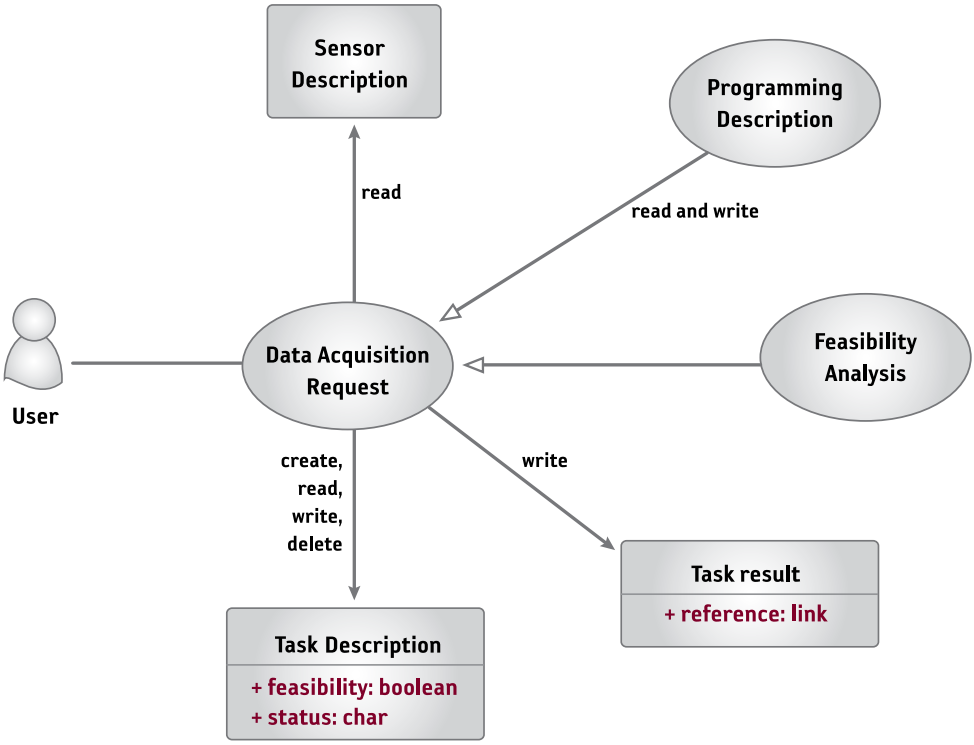
process may be supported by a presentation of datasets, e.g. in the form of a preview.

3.4.5 Data Acquisition Request and Feasibility Analysis

This use case deals with the question of how EO systems and sensors may be programmed such that the desired datasets may be accessed in future and further processed after their retrieval. The need for this use case as illustrated in Fig. 3.6 stems from the fact that data needs vary or may suddenly arise due to unforeseen events, e.g. emergency situations after natural disasters.

The user formulates a data acquisition request based upon known sensor capabilities that are available in sensor descriptions and drafts a programming description. The data acquisition request results in a task description. One option is to check and analyse the feasibility of the task before requesting its execution. Finally, the task

Figure 3.6. Business use case 'data acquisition request'.



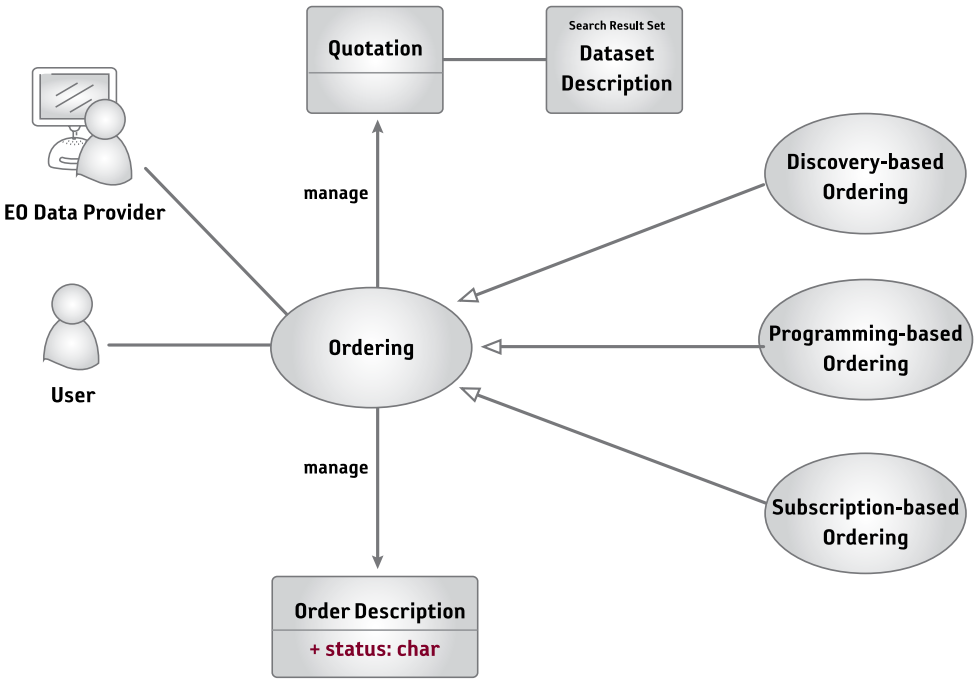


Figure 3.7. Business use case 'product ordering'.

description is forwarded to the EO management systems, which add feasibility and status information. Finally, when the task has been executed the task results are made available to the user, possibly including a link to access methods that enable dataset access.

3.4.6 Product Ordering

The use case 'product ordering' as illustrated in Fig. 3.7 allows the user to enter into a higher-level, possibly commercial relationship with the EO data provider. Higher-level here means that the user has the option to order products that he or she is used to in other commercial circumstances. This requires that EO products are offered and described by EO data providers in 'quotations' that include, among others, a description of the datasets offered, but also commercial information such as pricing and availability. Three variants of ordering may be distinguished:

1. discovery-based ordering whereby the order request results from a previous discovery use case (see section 3.4.4); or

2. programming-based ordering whereby the order request results from the programming of future data acquisitions; or
3. subscription-based ordering which allows users to specify orders for bulk products with given characteristics in certain areas of interest and periodically to receive these products as soon as they are available.

In all of these variants there is a need to create, read, write and delete order descriptions including status information.

3.4.7 Geospatial Processing

The datasets that may be retrieved through the EO systems are frequently not directly usable for the intended applications. For instance, the datasets may have to be processed to georeference and orthorectify them correctly, taking into account the terrain characteristics, to derive geophysical parameters, or there may be a need to combine several datasets and fuse their geospatial data elements. In general, there may be a need to process datasets by applying geospatial or geostatistical algorithms to them. This is the purpose of the geospatial processing use case as illustrated in Fig. 3.8.

In order to request such a geospatial processing task, the user has to describe the process to be applied and to provide the input

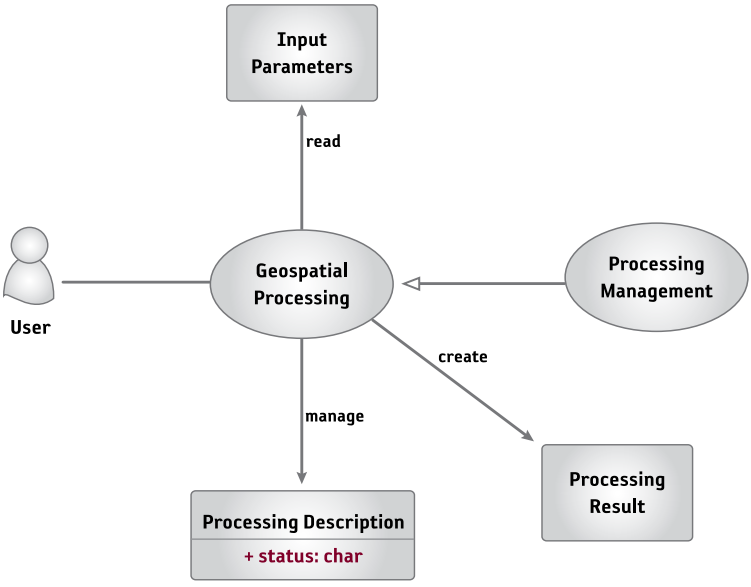


Figure 3.8. Business use case 'geospatial processing'.

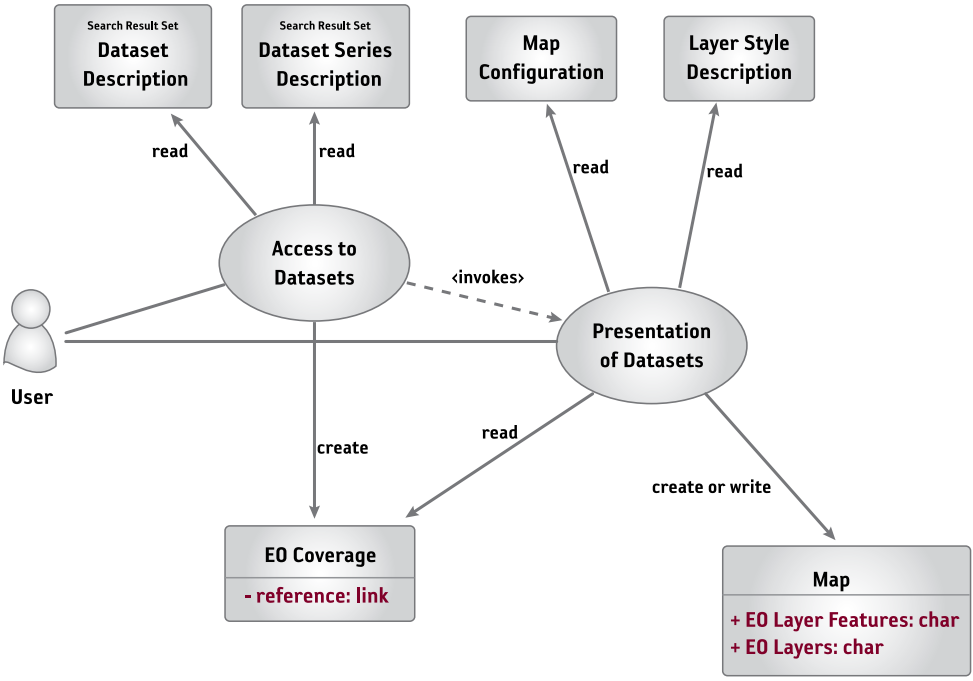
parameters for this process. There will be a means to manage the execution of the process, i.e. to start and possibly to monitor its status and to cancel it, e.g. if its execution does not terminate. Finally, the processing results must be made available to the user again.

3.4.8 Online Data Access and Presentation

Once a description (metadata entry) of a dataset or a dataset series has been selected from the search result set, i.e. it has been discovered and ordered, an EO user may want to access the dataset itself. This is covered by the use case 'access to datasets' as illustrated in Fig. 3.9. The user expects as a result references to the datasets, which, in EO environments, are typically available as coverages. A coverage hereby denotes digital geospatial information that represents (environmental) phenomena that vary in space or in time, or both.

A further important use case, which may also be invoked as part of the processing of the use case 'access to datasets', is the 'presentation of datasets'. EO datasets are typically presented in

Figure 3.9. Business use case 'dataset access and presentation'.



the broader context of a cartographic map, e.g. visualised in a Geographic Information System (GIS) component or a web mapping tool. In general, a map comprises geographic information rendered as a digital image file that is suitable for display on a computer screen. A map consists of one or several layers with individual styles, e.g. a legend that explains the meaning of the layer elements such as the colours of image pixels or symbols. The presentation use case covers the requirement to render an EO dataset to map layer information that may be visualised in a map context. Note that on-the-fly rendering may not always be possible for performance reasons. In this case, it should be possible to issue a rendering task asynchronously. Furthermore, it is often necessary to retrieve further information from such map layers, i.e. to access the attributes of individual features that are visualised in the map layer.

→ INFORMATION VIEWPOINT

4. Information Viewpoint

4.1 Overview

The Information Viewpoint specifies the modelling approach of all categories of information related to EO missions and, hence, that the HMA initiative has to deal with. This includes the thematic, spatial and temporal characteristics of the information elements as well as descriptive information about them, usually called metadata or meta-information.

When we talk about information modelling we mean the description of how information models should be structured, i.e. the set of rules and the notation that are used in order to define information objects and the relations among them. This provides the structure for the information that is being accessed and exchanged in a service network that follows the HMA initiative. The basic information objects that are relevant for HMA are illustrated in Fig. 4.1.

The major sources of information in EO systems are satellites, whereby, basically, a satellite is a '[hu]man-made object (such as a spacecraft) placed in orbit around Earth, another planet or the Sun'.[24] However, it is important to understand that in HMA the satellite itself is understood as one possible carrier of instruments, called a platform. In addition to EO satellite platforms there may also be other types of platforms such as unmanned aircraft vehicles.

An instrument is a technical entity that contains detectors, also called sensors. Sensors, in general, are entities that provide information about environmental phenomena at their output. In the EO context, sensors on board a satellite are typically radiometers and cameras that provide images (here, datasets consisting of a grid of values), but also active sensors like radar sensors or sounders.

An instrument is modelled in terms of its mode of operation (instrument mode), i.e. the sum of the configuration status information of the instrument and its detectors. Examples of such configuration information for remote sensing instruments are the across-track and along-track field of views, the swath width, the ground location accuracy, the revisit time, the number of bands and the list of detectors used for a particular instrument mode.

Instrument modes are associated with collections in the EO context. EO collections are collections of datasets sharing the same product specification. Note that these collections are also called EO

[24] See the ESA glossary at *www.esa.int/esaSC/SEMDL2S1VED_index_0.html*

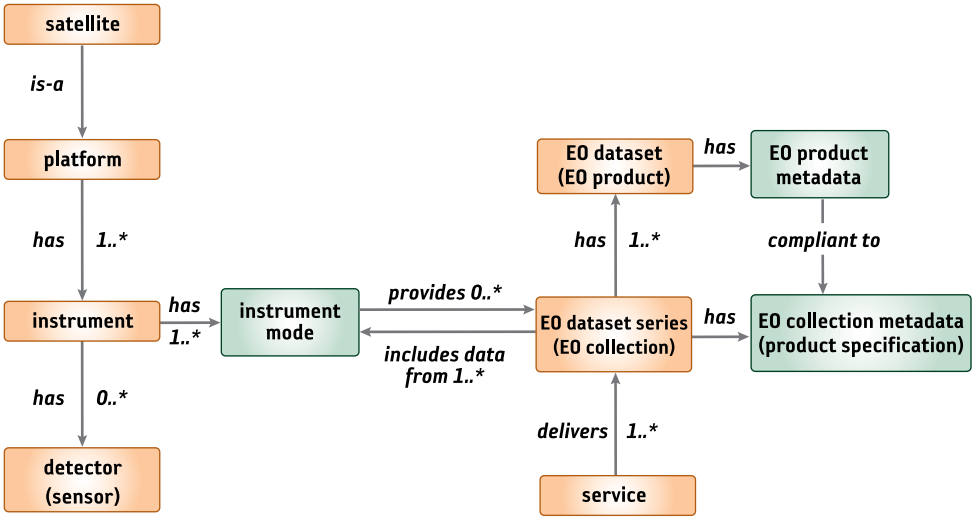


Figure 4.1. Major information categories in the HMA architecture.

dataset series as they may be mapped to 'dataset series' following the terminology defined in ISO 19113, ISO 19114 and ISO 19115.

An EO collection typically corresponds to a series of EO datasets (also called EO products) derived from data acquired:

— Either from an instrument in a dedicated mode on board a single satellite platform; or
— by a series of instruments, possibly from different satellite platforms, but in this case working in the same instrument mode.

Examples of EO dataset series are, for instance, datasets stemming from satellite platforms such as 'TerraSAR-X spotlight mode', 'ESA Envisat MERIS Full Resolution L1+2' or 'SPOT multispectral 10 m resolution'. The last example is presented in more detail when discussing metadata descriptions of such EO dataset series in section 4.3.2.

However, there is a tendency to group products into dataset series following other kinds of criteria such as range of resolution or product quality (e.g. snow collections or cloud-free collections).

HMA follows a service-oriented approach. This means that the access to EO collections is performed by means of services. A service hereby comprises a 'distinct part of the functionality that is provided by an entity through interfaces' (ISO 19119). An interface, in turn, is a 'named set of operations that characterize the behaviour of an entity' (ISO 19119).

HMA information modelling follows the systematic approach of a Model-Driven Architecture (MDA) as originated by the Object Management Group (OMG). MDA separates the specification of software concepts (information and functions) from the specification for the implementation of these concepts on a specific technology platform (Asadi & Ramsin, 2008). An MDA approach should thus improve the portability, interoperability and reusability of software. Applied to information models, this means that, in a first step, a platform-neutral information model, also called a conceptual model, is defined. Then, after selection of an implementation platform, this conceptual model is mapped to and encoded in a platform-dependent implementation model.

The OMG has defined a number of standards to support this approach. These are applied in HMA, too. For the platform-neutral information modelling, UML is of great importance. UML provides a standard modelling language for visualising, specifying and documenting software systems (Rumbaugh et al., 1998). Rules and guidelines on how to use UML for HMA information modelling are given in ISO/TS 19103:2005.

The most important encoding rules for the HMA information models are defined for XML schemas. XML is a set of rules for encoding documents electronically. It is defined in the XML 1.0 Specification under the auspices of the W3C. Furthermore, XML is mostly used for the encoding of request and response messages in OGC and W3C Web Services.

Figure 4.2 provides an overview of the most important specifications of information schemas and models that are applied in the HMA Information Viewpoint. It distinguishes between specifications on the conceptual level (typically in UML) and those on the implementation level (typically in XML). Furthermore, the figure illustrates encoding relations between specifications of different levels and also application and refinement relations between specifications within the same level.

The individual specifications are described in the following sections.

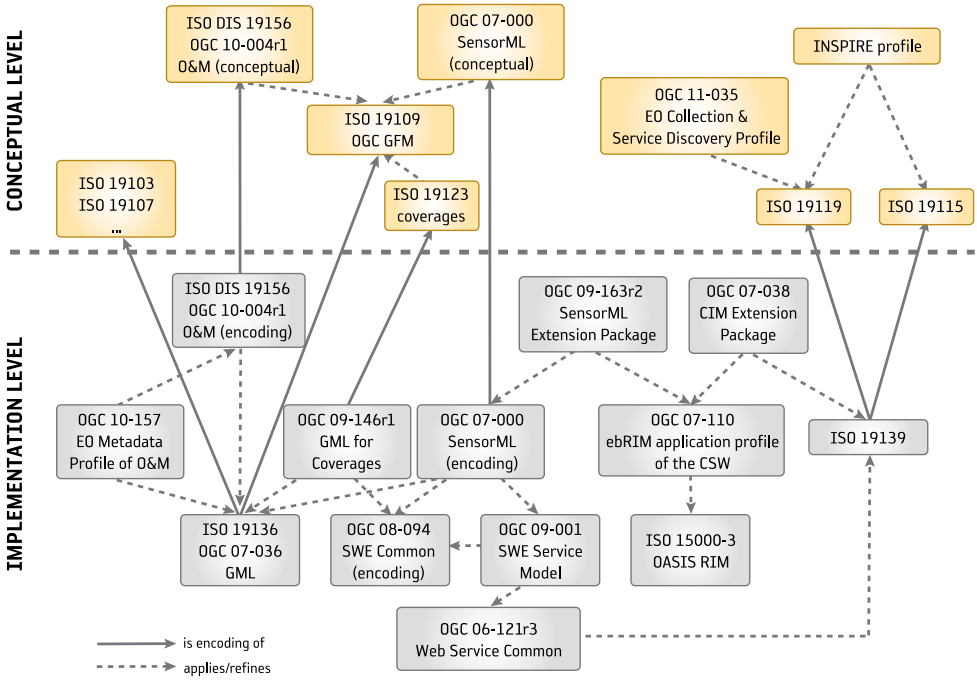


Figure 4.2. Overview of the HMA Information Viewpoint specifications.

4.2 Basic Information Models

4.2.1 OGC Web Service Common

OGC Web Services are self-describing in the sense that they return service metadata, also called capabilities, via their mandatory *GetCapabilities* operation. The structure of this service metadata is defined in the OGC Web Service Common specification, originally in version 1.1.0 with corrigendum 1 (OGC 06-121r9); now version 2 is the recommended version (see below). This encompasses all the data types, interfaces and mechanisms that are common to all OGC services and must be adhered to. It includes the contents, the parameters and the encoding of operation requests and responses.

The OGC Web Service Common document includes both platform-neutral and platform-specific specifications.

The platform-neutral specification is provided in textual form and associated UML class diagrams that are organised into 13 UML packages. Figure 4.2 illustrates the structure of the *GetCapabilities* package, which is the most important package of this UML specification. Many of the classes in this package are abstract,

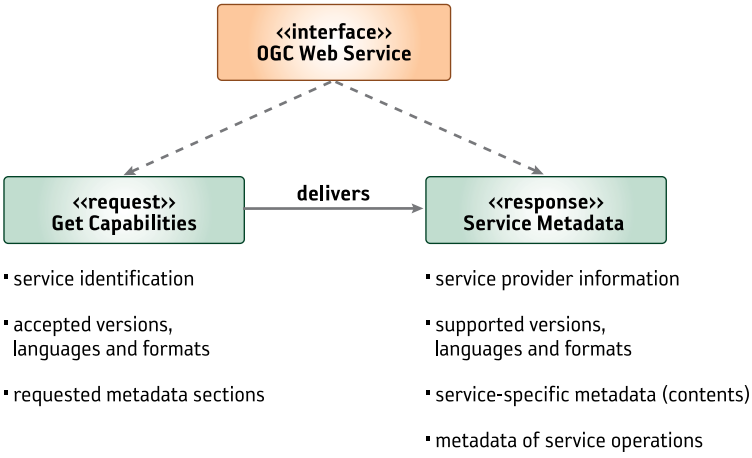


Figure 4.3. Basic structure of OGC Web Service Common.

because they are supposed to be specialised for each specific OGC Web Service. The mandatory GetCapabilities operation allows any client to retrieve metadata about the capabilities provided by any server that implements an OGC Web Service interface.

The *GetCapabilities* operation conveys the following information as request parameters:

— Abbreviation of the name of the service for which the capabilities are requested (e.g. WMS representing the OGC Web Map Service).
— Accepted versions: prioritised sequence of one or more specification versions accepted by the client. Together with the *version* parameter in the response (see below), this enables negotiations about versions between the client and the server.
— Accepted languages and formats: prioritised sequence of one or more languages for human-readable text (e.g. 'en-GB') and MIME-type formats (e.g. text/xml) accepted by the client.
— Requested metadata sections: names of those sections that are requested. The service metadata is structured into sections such that a client may choose the subset of the metadata of interest.

The normal response to the *GetCapabilities* operation is a service metadata document that primarily contains metadata about the specific server abilities, e.g. information about the specification version supported by the server. In addition, each service metadata document includes the following sections that are common to all OGC Web Services:

— The section service identification describes the responding server.

- The section service provider describes the organisation that operates the responding server.
- The section operations metadata provides metadata about the operations specified by this service and implemented by the responding server. This includes the URLs for the operation requests so that the client may invoke them directly.
- The section contents provides information about the data provided by this server, e.g. the name of the cartographic layers in the case of the OGC Web Map Service, or the geographical bounding box of the data provided by an OGC Web Feature Service. As may be seen by these examples, the contents and organisation of this section are specific to the type of OGC Web Service. Furthermore, whenever applicable, the information elements of this section are based on the MD_DataIdentification class specified in the metadata standard ISO 19115 (e.g. keywords to describe the responding server with commonly used or formalised word(s) or phrase(s)).
- The section languages lists the languages used in human-readable text provided by the responding server.

The OGC Web Services Common specification foresees that the specified platform-neutral operation requests can be encoded in many different ways, each appropriate to one or more specific platforms. Most of the HMA interface specifications use the XML encodings that are defined for a SOAP 1.2 transfer of operation requests.

Note especially that there is a version 2.0 of the OGC Web Services Common specification that was released in 2010 (OGC 06-121r9). One addition to this version was an informative annex that specifies how to map OGC Web Service (OWS) Common metadata to information elements of ISO 19119 (see section 4.4.1). For instance, it recommends that the ServiceProvider metadata element shall be mapped to the *SV_ServiceIdentification.PointOfContact* element of ISO 19119.

The need for this mapping arises from 'harvesting' applications that (periodically or on request) retrieve service metadata in order to feed ISO/OGC catalogue systems which are based upon ISO 19119 specifications. This is required, for instance, for INSPIRE-compliant catalogues.

4.2.2 OGC SWE Service Model

The OGC Sensor Web Enablement (SWE) Architecture (OGC 06-021r4) considers the Sensor Web to be a 'revolutionary concept towards achieving a collaborative, coherent, consistent, and consolidated sensor data collection, fusion and distribution

system'. As any kind of sensor, from a thermometer located in a fixed position to a complex hyperspectral sensor on an Earth-orbiting satellite, is encompassed by the OGC SWE approach, it is highly relevant for the HMA architecture.

In addition to dedicated services for the access and management of sensors (see their description in the HMA Service Viewpoint), the OGC SWE architecture defines information models that are specific to sensors and sensor-related processing (such as SensorML; see section 4.2.6).

The OGC SWE Service Model Implementation Standard (OGC 09-001) has been recently defined as a common foundation for SWE-related information models. This specification refines the OGC Web Service Common specification. It was drafted as part of the standardisation process of the second versions of the OGC Sensor Observation Service (SOS) and Sensor Planning Service (SPS) specifications.

Hence, in general, the OGC SWE Service Model serves as a baseline for the development of services that provide information from or about sensors. Furthermore, it specifies how sensor descriptions can be accessed and managed and is applicable for use cases in which sensors need to be managed through service interfaces. In order to enable asynchronous communication patterns, the OGC SWE Service Model supports publish and subscribe functionality for SWE services through the definition of recognisable event types, their encodings and associations to notification topics. This support relies upon the corresponding specifications of OASIS (WS-Topics) and W3C (WS-Addressing).

On the conceptual level the OGC SWE Service Model is structured into seven UML packages. Most of these packages define operation request and response types (e.g. *DescribeSensor*, *UpdateSensorDescription*) which are used in the most recent versions of the SWE services.

The packages that are most relevant for the HMA Information Viewpoint are the contents and the common packages:

- The *contents* package defines an *abstract offering* that contains metadata about a procedure and/or a sensor hosted by a service.
- The *common* package defines data types that are common to all other packages. In particular, this package contains the types that provide extension points for requests and responses of web service operations. This is highly relevant for OGC's new approach to define core and extension patterns for service specifications. This approach ensures that the core service functionality is defined in the base specification and extension specifications can define further functionality that integrates with the core.

Furthermore, the OGC SWE Service Model determines the following code values[25] that shall be used for identifying encodings defined in the OGC SWE Common Data Model Encoding Standard (OGC 08-094r1):

— *TextEncoding* shall be used for arbitrarily complex data using a text-based delimiter-separated values format;
— *XMLEncoding* shall be used for encoding structured data into a stream of nested XML tags;
— *BinaryEncoding* shall be used for encoding complex structured data using primitive data types encoded directly at the byte level.

Within the HMA architecture, the elements of the OGC SWE Service Model packages are especially used for the HMA Ordering Service (see section 5.5.4) and the HMA Feasibility Analysis Service (see section 5.4.3).

4.2.3 General Feature Model

The ultimate basis of the HMA information models is the ISO/OGC-defined General Feature Model (ISO 19109). The fundamental modelling unit of the General Feature Model is the concept of a feature. Features play a very important role in the design of EO applications as they represent entities in the universe of discourse of the users and stakeholders. In general, a feature is an abstraction of a real-world phenomenon (e.g. a river or a forest).

Features have properties which are usually attributes that describe the spatial, temporal or thematic characteristics of a feature. Schemata for describing features in terms of geometric and topological (ISO 19107) and temporal (ISO 19108) primitives are defined by the ISO. Features may be associated to each other. This is expressed in terms of the role properties of features as illustrated in Fig. 4.2.

For instance, a feature ‘sea surface temperature’ may be associated to another feature ‘Earth observation instrument’ with the role ‘observes’ on the instrument side and the role ‘is observed by’ on the side of the sea surface temperature. If required, the act of ‘observation’ may itself be modelled as a feature in order to describe observation properties, e.g. to start/stop observing or to configure observing periods. A feature with a geospatial attribute,

[25] Defined in the namespace *www.opengis.net/swe/2.0*

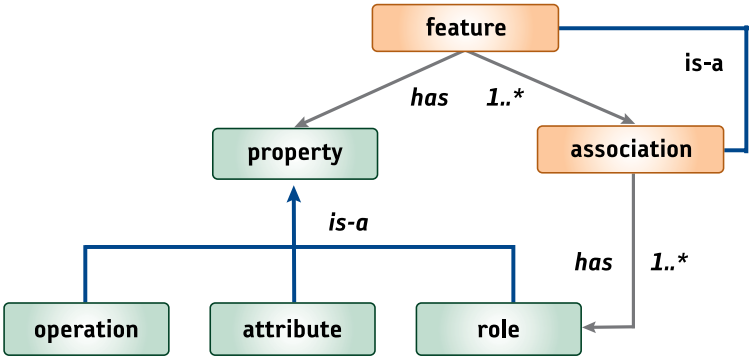


Figure 4.4. Basic structure of the OGC General Feature Model.

i.e. an attribute that describes a location relative to Earth, is called a geographic feature. In EO-based applications nearly all features are geographic features. They are the building blocks of project-specific application schemas, typically specified in UML and then mapped to XML (or GML; see below) in an engineering design step.

4.2.4 Geography Markup Language

The Geography Markup Language (GML) is an XML encoding for the transport and storage of geographic information. GML was originally developed within OGC and finally, as GML version 3.2.1 (OGC 07-036), was accepted as an ISO standard (ISO 19136:2007). The GML specification characterises GML in the following way: 'GML provides a variety of kinds of objects for describing geography including features, coordinate reference systems, geometry, topology, time, units of measure and generalized values.'

Hence, it describes both the spatial and non-spatial properties of geographic features. The GML schema is defined in accordance with the conceptual modelling framework used in the ISO 191xx series of international standards on geographic information:

— ISO 19103 – Conceptual schema language (units of measure, basic types) (ISO/TS 19103:2005)
— ISO 19107 – Spatial schema (geometry and topology objects) (ISO 19107:2004)
— ISO 19108 – Temporal schema (temporal geometry and topology objects, temporal reference systems) (ISO 19108:2004)
— ISO 19109 – Rules for application schemas (including the General Feature Model (GFM), see section 4.2.3) (ISO 19109:2005)
— ISO 19111 – Spatial referencing by coordinates (coordinate reference systems) (ISO 19111:2003)

— ISO 19123 – Schema for coverage geometry and functions (ISO 19123:2005).

Furthermore, GML defines the XML encoding, i.e. the syntax, mechanisms and conventions enabling an open, vendor-neutral framework for the description of geospatial application schemas for the transport and storage of geographic information in XML. This encoding is defined according to ISO 19118:2003 which specifies, in general, the requirements for defining encoding rules to be used for the interchange of geographic data within the ISO 191xx series of international standards.

4.2.5 Observation and Measurement Model

One extension of the General Feature Model (GFM) that is very relevant for EO applications is the OGC Observations and Measurement (O&M) Model (OGC 07 022). The O&M model is of core relevance for the access and interpretation of the data provided through sensors (detectors), being spaceborne, airborne, *in situ* or ex-situ sensors.

The observation is the kernel concept (Fig. 4.2). It is considered to be an 'an act associated with a discrete time instant or period through which a number, term or other symbol is assigned to a phenomenon'. The phenomenon is a property of an identifiable object, which is the feature of interest of the observation, i.e. the real-world object regarding which the observation is made.

The observation uses a procedure, which is often an instrument or sensor but may be a process chain, human observer, algorithm, computation or simulator. In the HMA architecture the capabilities of a sensor are defined in the Sensor Model Language (SensorML) (see section 4.2.6). The key idea is that the observation result is an estimate of the value of some property of the feature of interest, and the other observation properties provide context or meta-information for support.

An observation has the following characteristics:

— An *observation* is modelled as a feature type whose instances are created at a specific time point or time period, the 'phenomenon time', i.e. the time when the result applies to the feature of interest.[26] Applied to the EO domain, an observation is the act of acquiring, for example, an image of an observed area on the

[26] Previously also called the sampling time.

ground, i.e. the footprint of an acquisition. As this footprint is modelled as a feature of interest, the phenomenon time corresponds to the duration of the acquisition.
- The *observed property* identifies or describes the phenomenon for which the observation result provides an estimated value. It must be a property associated with the type of the feature of interest, e.g. the sea surface temperature if the feature of interest is a sea area.
- The *procedure* is the description of a process used to generate the result, i.e. the platform, instrument and detector (sensor) used in the acquisition of the observation, or the algorithm applied to a dataset in order to produce a processed result. It must be suitable for the observed property.
- A *result* of an observation may have been processed after its acquisition. The *result time* reflects the time when the result of the observation was produced.
- The *result* contains the value generated by the procedure. Note that the schema of the result data is not determined by the O&M model. The HMA architecture recommends a self-describing schema, e.g. by using the definitions of the OGC SWE Common Data Model specification (see section 4.2.2).
- An observation may have further meta-information, e.g. the responsible actor for the observation and an indication of event-specific quality.

In leveraging the liaison of OGC with ISO TC 211, the O&M model was submitted for standardisation as ISO 19156 – Geographic information – Observations and measurements. In 2011, it reached the status of an International Standard (ISO 19156:2011).

Considering the implementation view and the encoding, both GML (*gml:observation*) and the O&M model (*om:OM_observation*) define a data type observation. Conceptually, the O&M observation

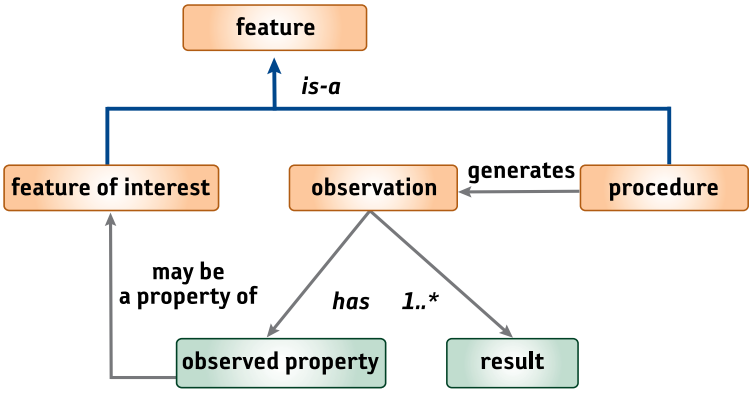


Figure 4.5. Basic structure of the OGC Observations and Measurement Model.

extends the GML observation by a link to the observed property and by adding further quality and time attributes, e.g. distinguishing between the time when the result applies to the feature of interest (phenomenon time) and the time when the result becomes available (result time).

Note that originally the EO products were described by applying the GML observation encoding (see OGC 06-080). However, as the O&M model has become increasingly important in the EO domain too, the GML schema has been replaced by the observation data type of the O&M model (see OGC 10-157r2). Note that there is a pending change request (OGC 08-114) for the GML 3.2.1 specification in general to deprecate the existing *gml:observation* and replace it with *om:OM_observation*.

Taking the O&M model as the general baseline for the EO and also for the non-EO communities, sections 0 and 0 describe how the metadata of EO datasets (products) and dataset series (collections) are defined, respectively.

4.2.6 Sensor Information Model

One further specification resulting from the OGC Sensor Web Enablement initiative is the Sensor Model Language (SensorML) (OGC 07-000). The main focus of SensorML is to define components associated with the measurement and post-measurement transformation of observations (in the sense of the O&M model described above).

The primary approach is that in SensorML all such components are modelled as processes. This includes components normally viewed as hardware, including transducers, actuators and processors (which are viewed as process components) and sensors and platforms (which are modelled as systems). All components are modelled as processes that take input, through which the application of an algorithm defined by a method and parameter values generates output. All such components can therefore participate in process chains. The process chains are themselves processes with inputs, outputs and parameters. Hence, SensorML can be viewed as a specialised process description language with an emphasis on application to sensor data.

The conceptual model for SensorML is defined in UML and is a refinement of the GFM (see section 4.2.3) as illustrated in the upper part of Fig. 4.6. This means that processes are specified as specialisations of features with the additional attributes of inputs, outputs and parameters. Processes are self-describing, which is expressed by metadata attributes. However, these meta-

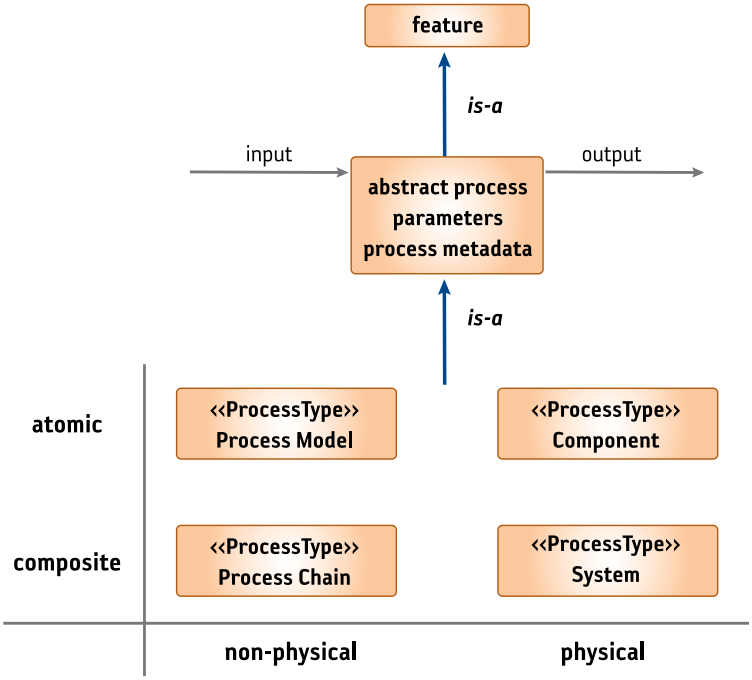


Figure 4.6. Basic structure of SensorML.

data attributes, while important for resource discovery, for the qualification of results, and for assistance to humans, are not considered essential for execution of the process within a process chain. All data or information required for actual execution of the process should be included within the inputs, outputs and parameter properties.

The lower part of Fig. 4.6 distinguishes between physical and non-physical processes, as well as atomic and composite processes. Non-physical process models, e.g. processes which can be treated as merely mathematical operations, are shown on the left, while physical process such as detectors, actuators and sensor systems models are shown on the right.

Hence, there are four types of process whereby the Component is the most important one for HMA:

1. An atomic non-physical process type is referred to as a *ProcessModel*. It is used to define more or less atomic pure processes that are expected to be used within more complex process chains (see below). A *ProcessModel* is characterised by a process method that provides the methodology by which input values are transformed to appropriate output values, based on the provided parameter values.

2. A *ProcessChain* is a collection of processes that are executable in a sequential manner to obtain a desired result. It is based on a composite design pattern and thus, while it consists of a collection of other processes, it is itself a process that can participate as a component within other process chains.
3. An atomic physical process type is called a *Component*. A *Component* either cannot be subdivided into smaller subprocesses, or can be treated as a single indivisible process. A *Component* can be considered as the real-world equivalent of a *ProcessModel*. A *Component* includes all the location and interface properties of a physical process and adds a method property that can describe the basis of physical processing of the component. A *Component* can participate as part of a *ProcessChain* or *System*. In HMA, a *Component* is used for the metadata model of EO instruments (see section 4.3.4).
4. Finally, there is the process type called *System*. In analogy to the relationship between a *Component* and a *ProcessModel* (see above), a *System* can be considered as the real-world equivalent of a *ProcessChain*. A *System* may include several physical and non-physical processes that all act to provide a certain set of *System* outputs, based on the *System* inputs and parameters. An example might be an airborne remote sensing system that may include, for example, a radiometric scanner (perhaps itself modelled as a *System*), as well as a GPS sensor and inertial momentum unit for reporting the location and orientation of the platform.

The SensorML conceptual model may be encoded as an application schema of the GFM in GML (see section 4.2.4).

Note that there is a change from SensorML version 1 to version 2 in the organisation of the specification contents. The SWE Common Data Model Encoding Standard (OGC 08-094r1) deprecates and replaces the 'SWE Common Conceptual Models' and the 'SWE Common XML Encoding and Examples' of version 1 of SensorML (OGC 07-000) from which they were extracted. These clauses will be removed from version 2.0 of the SensorML standard. The SWE Common Data Model Encoding Standard defines low-level data models for exchanging sensor-related data allowing applications and/or servers to structure, encode and transmit sensor-related datasets in a self-describing way. It is used to define the representation, nature, structure and encoding of sensor-related data.

4.3 EO Data Models

There are various data models that are used to describe elements of the HMA architecture or components of EO product acquisition systems. Figure 4.7 tries to illustrate in a simplified form the major EO data models (left-hand side) and what they describe (right-hand side). The boxes on the right correspond to the major information categories identified in Fig. 4.1. Each of these data models is explained in more detail in the following sections.

4.3.1 Metadata Model of EO Datasets

EO datasets (products) are characterised by information about the instruments and sensors on board satellites from which they originated and the geographic footprint of a satellite acquisition. However, additional attributes, such as the presence of cloud, haze, smoke or other atmospheric phenomena that were present at observation time and are reflected in the images, are necessary. The Earth Observation

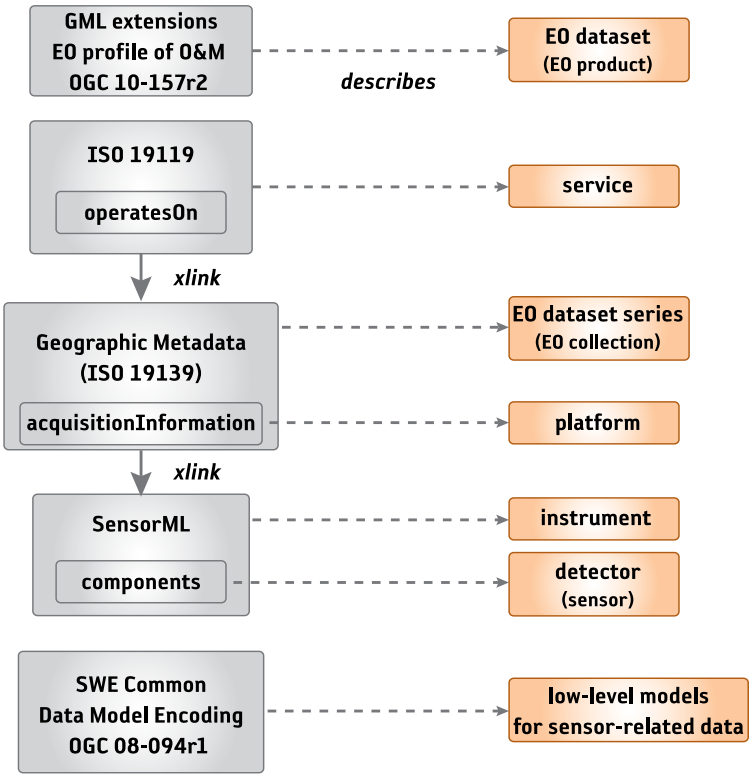


Figure 4.7. EO data models and what they describe.

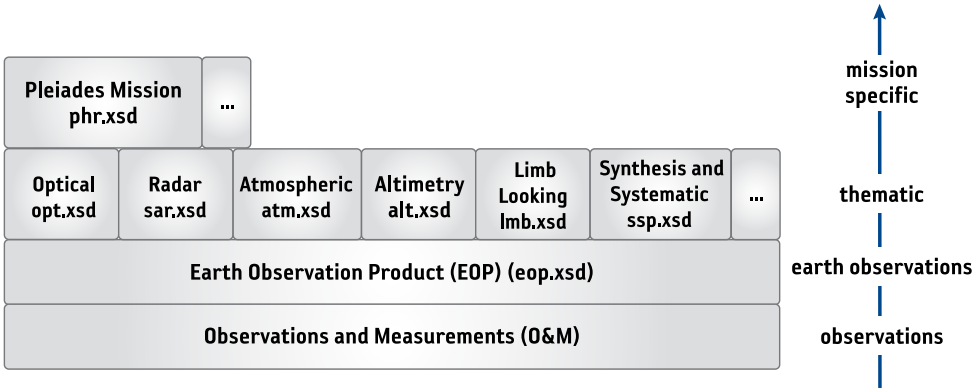


Figure 4.8. EOP type hierarchy.

Metadata Profile of Observations and Measurements (OGC 10 157r2) specifies a metadata model for this purpose.[27]

The resulting schemas are organised as extension layers of the basic concepts of the O&M model (see section 4.2.5) as illustrated in Fig. 4.8.

The O&M model (ISO 19156, see section 4.2.5) is the first general extension level of the generic GML elements. It focuses on the feature type observation with its linked concepts such as feature of interest and observed property as described above. It is followed by the Earth Observation Product (EOP) level which refines an observation into the feature type *earth observation*. It is described in the eop.xsd schema. An excerpt from the XML encoding of an EOP file is given in Fig. 4.9.

The figure shows information items relating to the acquisition time (*om:phenomenonTime*), the satellite platform (*eop:platform*), the onboard instruments and sensors (*eop:sensor*) and the geographical coverage of the data (*eop:footprint*).

The next specification level defines sensor-specific thematic schemas, leading to a product type hierarchy as shown in Fig. 4.8 and explained in Table 4.1.

On the highest layer, on top of the thematic layer, there are mission-specific extensions. An example is the phr.xsd schema that is dedicated to the high-resolution optical sensors of the French Pleiades mission.

[27] Note that originally the GML Application Schema for EO Products (OGC 06-080) was developed for the description of EO datasets (products).

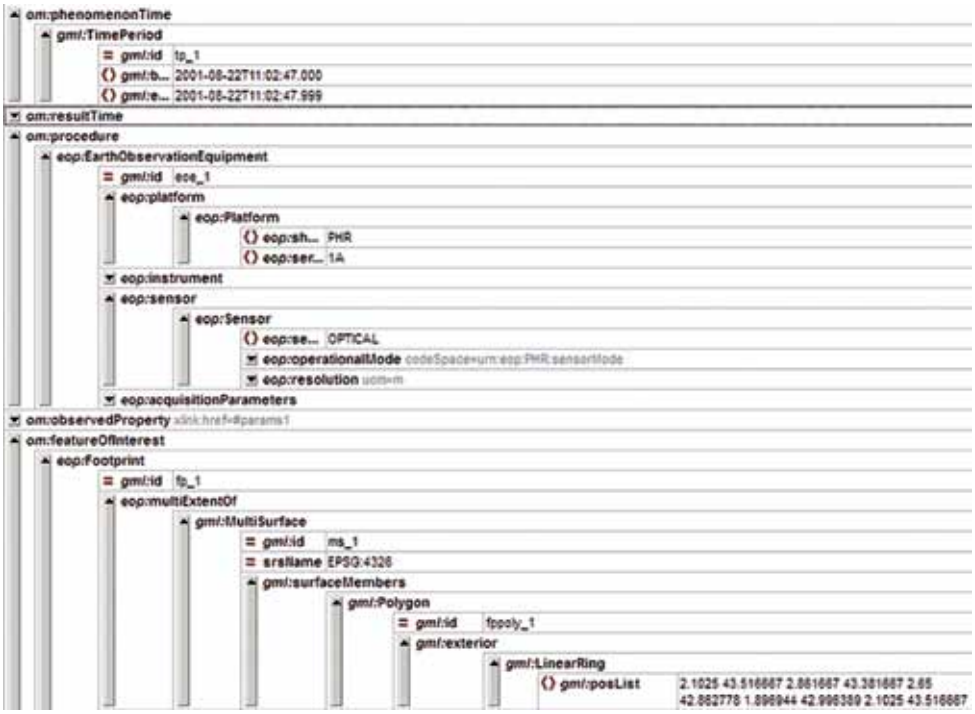


Figure 4.9. Example of an EOP file (excerpt).

Table 4.1. XML Schemas for EOPs

Schema name	Describes characteristics of
opt.xsd	High-resolution optical products
sar.xsd	Products created with SAR sensors
atm.xsd	Products created with atmospheric sensors
alt.xsd	Products created with altimetry sensors
lmb.xsd	Products created with limb-looking sensors
ssp.xsd	Synthesis and systematic products

The metadata model of EO datasets is applied for a number of use cases. A non-exhaustive list is given below:

— For the discovery of EO datasets: The search for datasets requires a description of datasets in terms of metadata elements. Hence, the metadata model of EO datasets is used in the EO Product Extension Package for ebRIM (OGC 10-189r2) because it provides an efficient encoding.

- For the description of feature attributes: When requesting attributes of features that are visualised in footprint layers of EO maps (using the *GetFeatureInfo* operation of the OGC Web Map Service) elements of the metadata model of EO datasets are used to describe them. Hence this model is included in the EO Application Profile of the OGC Web Map Service (OGC 07-063r1).
- For the description of coverages: When requesting EO coverages (using the *GetCoverage* and *DescribeCoverage* operation of the OGC Web Coverage Service, see section 5.6.3) elements of the metadata model of EO datasets are used to describe them in the operation result. Hence, the EO Application Profile of the OGC Web Coverage Service (OGC 10-140) specifies the preferred metadata format for EO coverages.
- Metadata may be potentially enclosed within an actual dataset (product) to describe georeferencing information. For instance, GMLJP2 (OGC 05-047r2, see below) defines how to store GML coverage metadata inside a JPEG 2000 file format.

Note that ISO 19115-2 defines extensions for imagery and gridded data and additional metadata elements dealing with the specifics of imagery data. However, GML and O&M were chosen over ISO 19115-2 because they handle modularity more easily. The content of the application schemas is still, at least partly, based on and mapped to metadata elements defined in ISO 19115 and ISO 19115-2.

4.3.2 Metadata Model of EO Dataset Series

The metadata of EO dataset series (collections) is described by means of ISO 19115 which comprises the ISO metadata standard for geographic information belonging to the series of ISO 191xx standards. ISO 19115 provides information on the identification, extent, quality, spatial and temporal schemas, spatial reference and distribution of digital geographic data.

For the description of collections the following elements from ISO 19115 are used:

- identifier
- description
- geographical and temporal extent
- common attributes

In addition, each collection is described by one or more keywords from keyword lists agreed by an Earth science community. Relevant sources for such lists are the terms defined by the GEneral

Multilingual Environmental Thesaurus (GEMET),[28] which is the reference vocabulary of the European Environment Agency (EEA), or the Earth science keyword list of the Committee on Earth Observation Satellites (CEOS) defined in the Global Change Master Directory (GCMD)[29] (Olsen et al., 2007).

ISO 19115 defines the abstract metadata schema using UML diagrams. The corresponding XML schema implementation, i.e. the XML encoding of the ISO 19115 conceptual information elements, is described in ISO 19139. It is called the Geographic MetaData (gmd) XML encoding.

Figure 4.10 shows an example of how the EO dataset series of SPOT satellites may be identified using the GMD encoding. Some of the XML elements are explained in the following:

- *gmd:dataStamp* indicates the date of the generation of the metadata entry (here, 11 June 2009)
- *gmd:metadataStandardName* and *gmd:metadataStandardVersion* provide information on the standard metadata schema used (here, ISO 19115 of 2003 with Corrigendum 1 of 2006).
- *gmd:citation* describes the entry in human-readable form. Here it states that the EO datasets comprise multiple spectral bands and have a geometric resolution of 10 m.
- *gmd:abstract* provides more details in human-readable form. Here it indicates that the images came from SPOT-1, -2, -3, -4 or -5 satellites with onboard instruments called High-Resolution Visible (HRV), High-Resolution Visible and Infrared (HRVIR), having one more band in the medium infrared, and High-Resolution Geometry (HRG), using the same spectral bands as HRVIR but with 10 m geometric resolution (Gomarasca, 2009).
- *gmd:MD_Keywords* comprise the major keywords that a user may use in order to search for such EO datasets. Here, there are two types of keyword:
  1. Keywords that identify the major applications for this EO dataset series. Here, these are ‘geology’ and ‘land cover’ applications. Hence, a user interested in such applications would use these terms to search for available EO datasets.
  2. Keywords that refer to the satellite provider (here, SPOT) and to the instrument type, e.g. HRVIR. It is expected that such keywords would be used by users with more technical expertise.

[28] *www.eionet.europa.eu/gemet*
[29] *http://gcmd.nasa.gov*

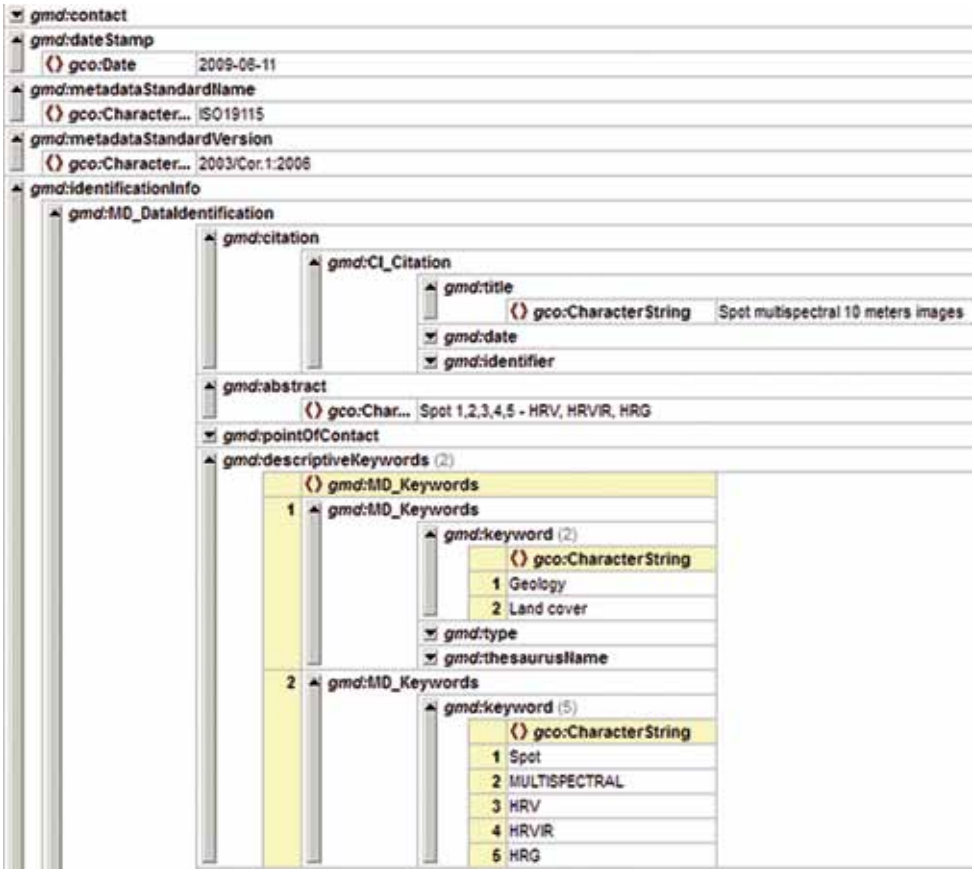


Figure 4.10. Example of the identification of dataset series for SPOT satellites.

Further XML elements provide more details about the satellite platforms and their instruments from which the datasets in this series have been acquired (*gmi:acquisitionInformation*).

Basically, there are two possible platforms: Platform 1 is a SPOT-5 satellite carrying two HRG instruments (see Fig. 4.11), whereas Platform 2 is a SPOT-4 satellite carrying an HRVIR instrument (see Fig. 4.12).

Going one step deeper, the XML element *gmd:identifier* refers to a more detailed description of the instruments that is provided in SensorML notation (see section 4.2.6).

EO collections may be of great interest within INSPIRE, too. Therefore, the INSPIRE Metadata Implementing Rules define profiles of ISO 19115 and ISO 19119. These profiles dictate the usage of some optional elements of ISO 19115 and ISO 19119.

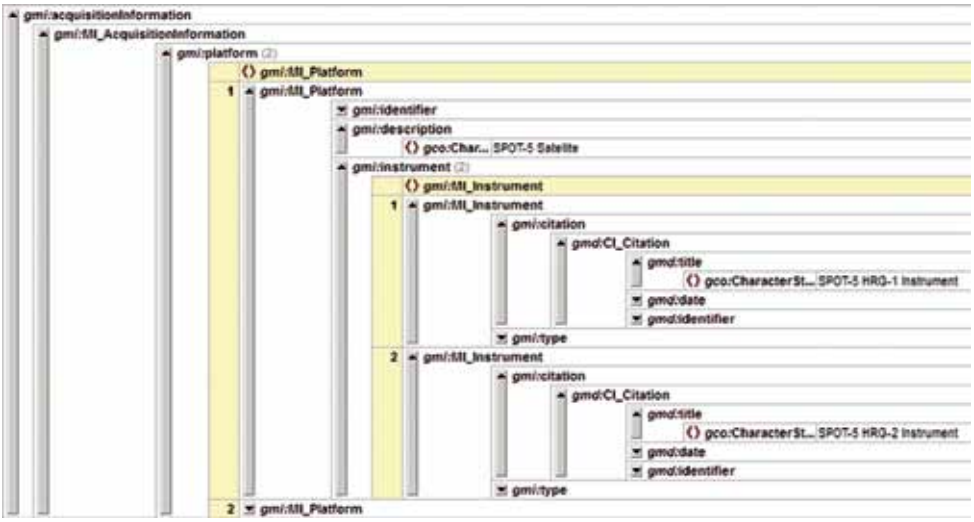


Figure 4.11. Example for the description of SPOT 5 instruments.

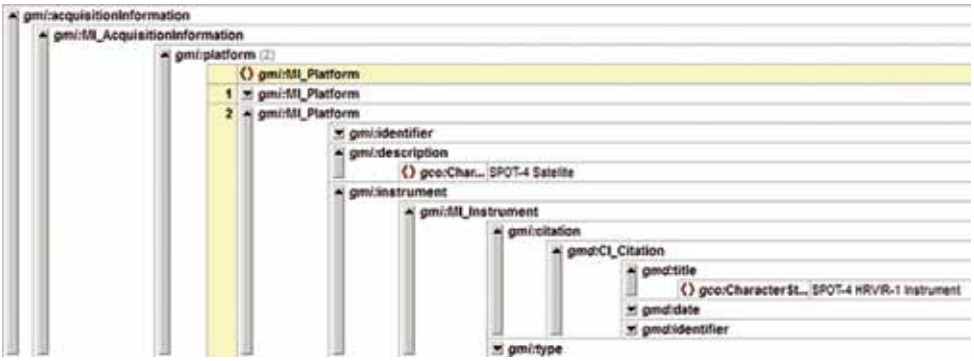


Figure 4.12. Example for the description of SPOT 4 instruments.

4.3.3 Metadata Model for the Presentation of EO Datasets

The presentation of EO datasets is performed through the OGC Web Map Service (WMS) as part of the HMA Online Data Access Service (section 5.4). However, as for all OGC services, the metadata model of a service, expressed in its capabilities, is of key importance for the proper use of the service as it reflects the specifics of the data types handled by the service. Defining a WMS metadata model that is dedicated to EO datasets (products) is therefore a prerequisite for

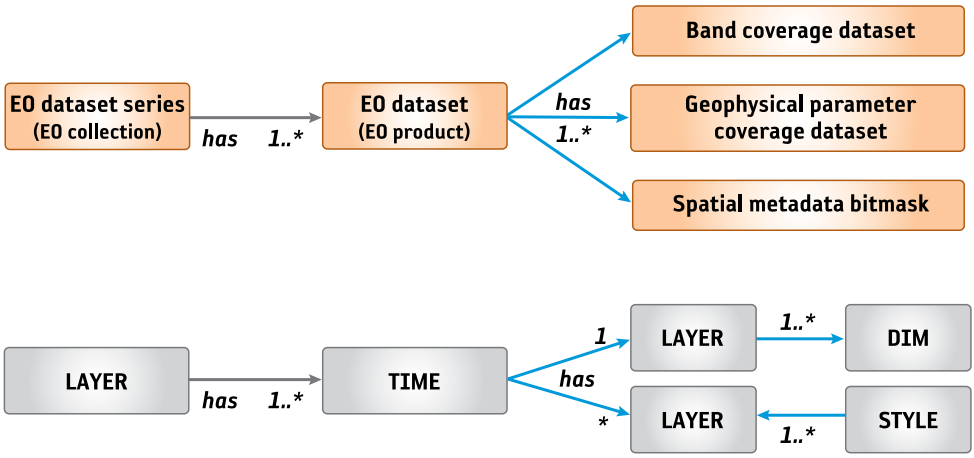
a WMS application profile allowing interactive viewing of all of the spatial information within EO products. This is the purpose of the metadata model of the OGC WMS application profile for EO products (OGC 07-063r1).

The handling of service metadata for EO products is closely related to the question of how multi-dimensional data is handled in a WMS instance (see Annex C of the WMS 1.3 standard (OGC 06-042)). The concept of dimensions hereby refers to:

— time, elevation and sample dimensions (e.g. wavelength bands or polarisations of electromagnetic radiation), whereby
— horizontal dimensions are expressed using a coordinate reference system (CRS) that is specific to each layer (i.e. basic unit of geographic information that may be requested from a WMS server).

Optional elements in WMS metadata declare available values along one or more dimensional axes applicable to a layer. For example, consider a server that offers daily satellite composite images of Earth, each element of the composite (representing one dimension) being accessible as an individual layer. If there were no rules on how to handle multiple dimensions, the number of layers would grow during the lifetime of the satellite because the server could give each layer a different name (e.g. by appending a string indicating the date to a base name). Hence, a more compact representation of the available dimensions is required in order to support the dataset discovery. The server may declare a single

Figure 4.13. Mapping of EO spatial information to elements of the WMS service metadata model (derived from OGC 07-063r1).



name for the layer and enumerate available times and wavelength bands in its service metadata.

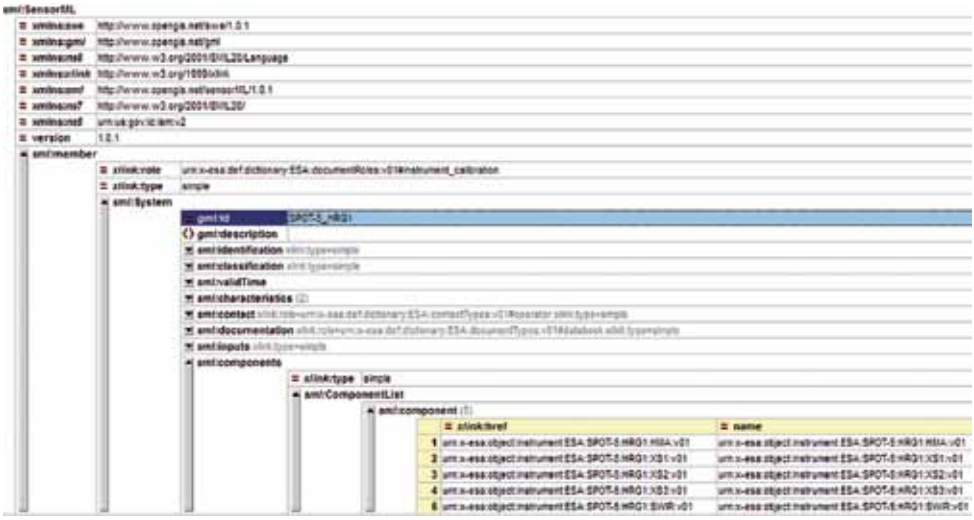
The basic idea of the WMS EO metadata model is illustrated in Fig. 4.13. Basically, it requires that a LAYER service metadata element shall be used to represent each dataset series/dataset type. For instance, all products of type 'MERIS instrument, Level-1b, Reduced Resolution' shall be described as a dataset series and represented by a single LAYER element in the service metadata of a WMS instance.

EO WMS instances shall support default maps of a given dataset series. Furthermore, the service metadata shall define a TIME dimension for each LAYER element with a value that defines the individual times or range of the available dataset. The use of other service metadata in the dataset series LAYER (e.g. nested layers, sample dimensions, styles) is optional but may be used to support the interactive browsing of EO products.

4.3.4 Metadata Model of EO Instruments

SensorML is used to describe the instruments of satellite and sensor systems used for the creation of EO products. The focus lies in the use of the Component part of the SensorML process types as introduced in section 4.2.6. Figure 4.14 shows excerpts from a SensorML file that provide more detailed information about the components used as part of the HRG instrument of a SPOT-5 satellite.

Figure 4.14. Excerpts from a SensorML description of a SPOT HRG instrument.



Note that two SensorML profiles have been defined that are relevant for HMA. The first one is dedicated to discovery and was therefore called a 'SensorML profile for discovery' based upon SensorML 1.0 (OGC 07-000). The second profile is based on the first one and is targeted at EO aspects. It was called the 'Earth Observation Sensor profile'. Originally, both profiles were contained in the ebRIM Application Profile of the OGC Catalogue Service (OGC 09-163r2), as chapter 12 and Annex B, respectively.

Now, these two profiles are being aligned with SensorML 2.0 (OGC 12-000). The first results are available as OGC 11-043 'SensorML 2.0 Extensions for Earth Observation Instruments and Platforms'.

Furthermore, there is also work being done on a SensorML Extension Package for the ebRIM Application Profile of the OGC Catalogue Service (OGC 09-163r2). This extension package may be used in the future to access EO dataset series metadata specified in SensorML. It describes the mapping of sensor metadata encoded in SensorML (according to the EO profile of SensorML) to an ebRIM catalogue structure (see the HMA Service Viewpoint in section 5.4).

Using this mapping it becomes possible to make sensors as well as SWE services discoverable through an OGC catalogue and thus achieve a better integration of sensors and sensor data into spatial data infrastructures.

Owing to the fact that the SensorML data model specifies the majority of its elements as optional, and as it allows the same information to be expressed in several, but differently structured ways, this document also contains a SensorML profile for discovery. This approach ensures that a minimum set of metadata is provided for every sensor in a common structure so that:

— on the one hand, automatic harvesting becomes possible; and
— on the other, all necessary metadata are present.

As a result, this extension package allows searching for sensors based on spatial criteria (i.e. an area for which sensor data are needed), temporal criteria (i.e. points in time for which sensor data are needed) and thematic criteria (i.e. phenomena for which sensor data are needed).

It should be noted that the different types of EO metadata, i.e. for datasets, dataset series, services and instruments, are interrelated. For instance, dataset metadata refers to the dataset series metadata via the '*ParentIdentifier*'. Also, the dataset series metadata may contain references to instrument modes modelled in SensorML exploiting ISO 19139 Part 2. The details of these information model

relationships are specified in a document called 'EO Collection and Service Discovery using the CS-W ebRIM Catalogue' (OGC 11-035).

4.3.5 EO Dataset Product Formats

In addition to the question of how to describe the characteristics of EO products, there is the question of how to encode an image that results from EO products.

Some EO missions, e.g. Pleiades and Sentinel, use JPEG 2000 as an encoding format for imagery (ISO/IEC 15444-1).[30] JPEG 2000 provides the ability to include XML data for a description of the image within the JPEG 2000 data file. This ability is exploited to use EO GML within JPEG 2000 images for geographic imagery. The encoding and packaging rules on how to use GML in JPEG 2000 are defined in the 'GML in JPEG 2000 for Geographic Imagery (GMLJP2) Implementation Specification' (OGC 05-047r2). Hence, GMLJP2 may be used as a standardised geographic image format that comprises, in addition to embedded information on geographic features, coverages, observations, topology, geometry, coordinate reference systems, units of measure, time, and value objects in a JPEG 2000 file.

One further aspect to consider is the requirement for EO data providers to archive EO datasets for a long period of time in the frame of the 'LTDP' (Long-Term Data Preservation) activities. This requires special attention to how the data and the information that accompanies them are preserved. In fact, from the point of view of the LTDP activities, there is both the need to convert the data regularly into new media technology to ensure their accessibility and avoid media obsolescence and the need to keep the alignment with relevant product metadata and specifications because they are fundamental for understanding and exploiting the data in years to come. In a multi-mission and multi-sensor environment, such data preservation activities may result in an increase in operational costs due to the potential proliferation of diverse and heterogeneous data formats. Early in 2004 ESA set up a project called HARM (Historical Archives Rationalization and Management), which aimed mainly at converting its historical datasets into a new single format, based on the latest technologies and standards and able to ensure the long-term preservation of its holdings. The format developed by the HARM project was named the Standard Archive Format for Europe (SAFE).[31]

[30] See also *www.jpeg.org/jpeg2000*
[31] *http://earth.esa.int/SAFE*

SAFE defines three models:

1. The SAFE Information Model is a kind of meta-model that specifies that a 'SAFE product' comprises product information including acquisition period, platform and instrument identification and product history, as well as product data/metadata including the EO datasets associated by dataset metadata such as orbital information, grid reference and quality information.
2. The SAFE Logical Model specifies the logical structure of SAFE products as a logical tree of 'content units'.
3. Finally, the SAFE Physical Model defines the physical structure (encoding) of a SAFE product in terms of a manifest file, the files for the content units (data and metadata) encoded as binary, ASCII or XML files, and the XML schema files.

SAFE uses the latest available technologies to achieve its goals of preserving the archived data in the long term, facilitating conversion into different formats, simplifying extraction from the archive and enhancing their utilisation by end users and/or processing systems.

Furthermore, SAFE is based on the XFDU (XML Formatted Data Units) standard under development by the CCSDS (Consultative Committee for Space Data Systems). In essence, SAFE is a profile of XFDU, but it restricts the XFDU specifications to specific utilisation in the EO domain.

The SAFE specifications, including a core and recommendations for specialisations, may be downloaded at *http://earth.esa.int/SAFE/specifications.html*

4.3.6 Coverage Model

Geographic information has usually been treated either as vector data or raster data (OGC 07-011).

Vector data deal with phenomena that are typically represented by a set of one or more geometric primitives, i.e. as points, curves, surfaces or solids. Each of these phenomena may be conceived of as a feature and, hence, its characteristics may be recorded as feature attributes in the sense of the GFM (see section 4.2.3).

However, data acquired by an EO sensor system typically deal with phenomena that vary continuously over space. It contains a set of values, each associated with one of the elements in a regular array of points (grid).

In ISO and OGC specifications, these types of data are conceptualised by 'coverages'. A *coverage* is defined as a function

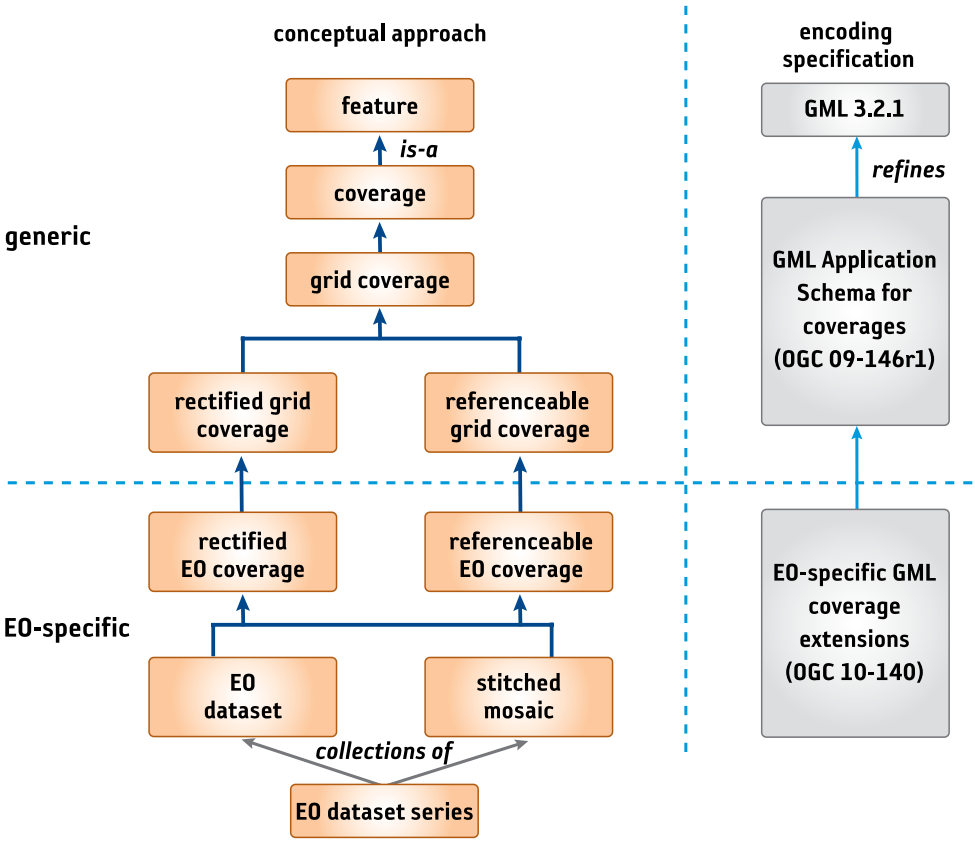


Figure 4.15. Conceptual and encoding of coverages.

from a spatial, temporal or spatio-temporal domain to an attribute range (ISO 19123:2005). Examples of coverage domains include raster files, triangulated irregular networks, point coverages and polygon coverages. Coverages are the prevailing modelling concepts in a number of application areas, such as remote sensing, meteorology and mapping of bathymetry, elevation, soil and vegetation. In HMA, coverages are used to model EO datasets (see section 4.3).

Figure 4.15 illustrates the relations between the conceptual modelling approach for coverages and their encoding specifications. In the context of the GFM, a coverage is a subtype of feature comprising multiple values for each attribute type.

Basically, a coverage associates a position within its domain to a record of values of defined data types. In the field of EO the *domain* is usually structured as a geometric grid of points, e.g. a grid of

pixels resulting from an imaging sensor in a satellite system. In this case, the coverage is called a grid coverage.

Furthermore, two grid coverage subtypes are distinguished:

1. A *rectified grid coverage* is a grid coverage that is based on a rectified grid. Hence, it puts a further constraint upon a grid coverage by requiring that the points of the grid are geometrically referenced, meaning that there is an affine transformation between the grid coordinates and the coordinates of an external coordinate reference system (ISO 19123:2005). Note that if the coordinate reference system is related to Earth by a datum, the grid is a *geo-rectified grid*.
2. A *referenceable grid coverage* covers the case when it is not possible to provide the transformation in an analytic form. As an alternative, the transformation may be provided as a table, relating the grid points to coordinates in the external coordinate reference system. Such a grid is classified as a referenceable grid. Again, if the external coordinate reference system is related to Earth by a datum, the grid is a *geo-referenceable grid*.

Coverage instances may be encoded using GML (see section 4.2.4 above). However, the definition contained in GML 3.2.1 has turned out to contain insufficient information to describe coverage instances in a flexible, interoperable and harmonised manner. To remedy this, OGC defines a GML Application Schema for coverages (OGC 09-146r1) applying some enhancements to the GML *Coverage* data type. For instance, it adds a mandatory element *rangeType* to carry information about the range value data structure of a *coverage*.

In addition, as illustrated in the lower part of Fig. 4.15, there is a further refinement necessary in order to model the specifics of EO datasets (section 4.3) and dataset series (section 4.3.2). This refinement is specified as part of the EO Application Profile of the OGC Web Coverage Service 2.0 Interface Standard (OGC 10-140; see section 5.6). It centres around the data structure of Earth Observation Coverages (EO Coverages) which have the following characteristics:

— They are derived either from a referenceable grid coverage (see above), leading to a referenceable EO Coverage, or from a rectified grid coverage, leading to a rectified EO Coverage.
— They are described by an EO metadata set on a higher semantic level, originally using the GML application schema for EO products (OGC 06-080), but now using the Earth Observation Metadata Profile of Observations and Measurements (OGC 10-157r2).

Based on this EO-specific coverage concept, three main data elements are defined:

1. An *EO Dataset* is a two-dimensional horizontal EO Coverage, which can represent, for example, a hyperspectral satellite scene. An EO Dataset can be a Rectified Dataset or a Referenceable Dataset, depending on the type of EO Coverage it is derived from.
2. A *Stitched Mosaic* is a collection of two-dimensional horizontal EO Coverages referred to as co-referenced EO Datasets. A Stitched Mosaic can be a Rectified Stitched Mosaic or a Referenceable Stitched Mosaic, depending on the type of EO Coverage it is derived from. A Stitched Mosaic can be interpreted (i.e. requested) as a single coverage.
3. An *EO Dataset Series* is a collection of coverages. An EO Dataset Series can refer to any number of Datasets and Stitched Mosaics. A Dataset Series is not a coverage by itself.

4.4 Resource Discovery

4.4.1 ISO Metadata Model for Services

One goal of HMA is to offer services, especially services processing EO datasets. The operations of these services may either be called by end users, or be embedded in service chains by software architects.

In the former case human-readable metadata is needed, which enables the system to answer questions like: ‘Look for an ordering service that allows me to order products of a specific collection with given characteristics.’

In the latter case machine-readable metadata is required and ISO 19119 is used for this purpose. ISO 19119 identifies and defines the architecture patterns for service interfaces used for geographic information and presents a geographic service taxonomy. Besides human-readable information, ISO 19119 also provides enough details to support machine-to-machine communications. The following information is defined for each service:

— properties of the service itself: service type, title, abstract, usage restrictions, region of interest, time period;
— information about the service owner: point of contact; and
— information about the service operations: name of the operation, connection end point and protocol binding and information about the operation’s parameters.

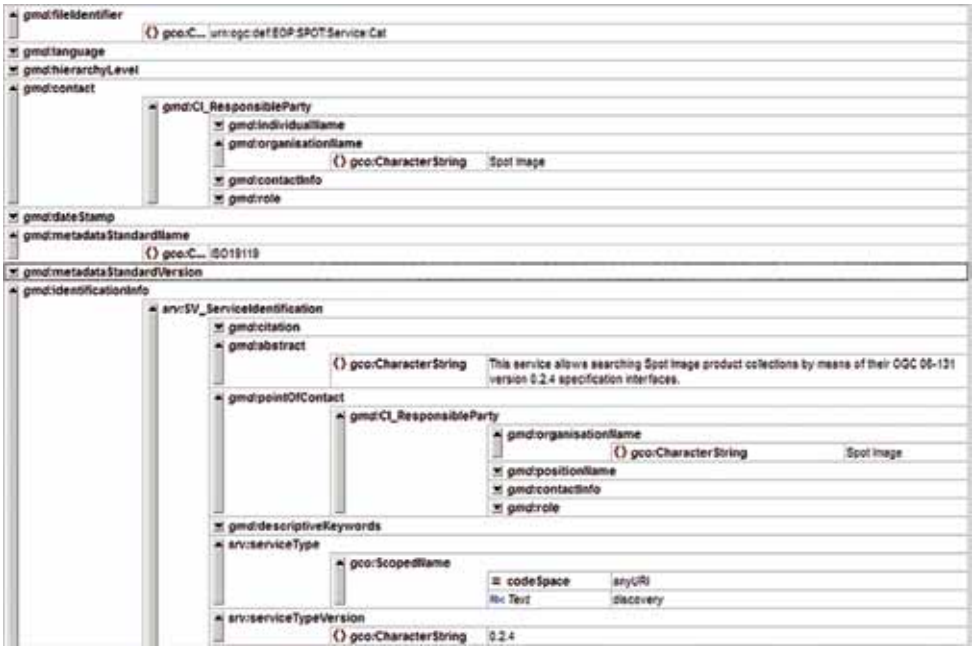


Figure 4.16. Example of a service metadata description of a catalogue service.

ISO 19119 only defines an abstract UML model. The corresponding XML schema is included in ISO 19139, as is the case for the XML encoding of ISO 19115.

Figure 4.16 shows an example of an XML encoding of ISO 19119 describing an HMA catalogue service which falls into the ISO 19119 service type 'discovery' (*srv:serviceType*). Here it is a catalogue service run by SPOT Image according to the OGC 06-131 specification in its version 0.2.4 (see section 5.4).

Furthermore, ISO 19119 offers the possibility to couple metadata about services with metadata about data. Referring to the example above, it may be used to couple the description of an EO catalogue service with specific EO dataset series (collections) provided by this catalogue service. This is realised by the XML link element *srv:operatesOn* as illustrated in Fig. 4.17. This link refers to file identifiers that describe EO dataset series. In the figure the reference to the file 'EOP:SPOT:MULTISPECTRAL_10m' is highlighted as this is the example used in section 4.3.2 to describe the metadata description of EO dataset series.

In order to enable interoperability between HMA and INSPIRE it is increasingly important to follow INSPIRE implementing rules for the description of EO services, too. As the INSPIRE rules propose a profile

srv:operatesOn (14)

	= xlink:href
1	http://earth.esa.int#urn:ogc:def:EOP:SPOT:ALL
2	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC
3	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_5m
4	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_5m_A
5	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_5m_B
6	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_10m
7	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_10m_P
8	http://earth.esa.int#urn:ogc:def:EOP:SPOT:PANCHROMATIC_10m_M
9	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL
10	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL_10m
11	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL_10m_J
12	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL_20m
13	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL_20m_X
14	http://earth.esa.int#urn:ogc:def:EOP:SPOT:MULTISPECTRAL_20m_I

Figure 4.17. Example of a link of service metadata to dataset series.

for ISO 19115 and ISO 19119, the schema to describe service metadata in HMA should be in line with the requirements of INSPIRE.

Hence, a minimal recommended subset of the ISO 19119 information model required for the discovery of EO services has been defined (see Fig. 4.18) in OGC document 11-035 called 'EO Collection and Service Discovery using the CS-WebRIM Catalogue'. As the title suggests, this subset is defined for the cataloguing of ISO Metadata (CIM) using the ebRIM Application Profile of CSW (OGC 07-038r3). It defines a mapping of the ISO 19139 metadata to the OASIS Registry Information Model (RIM) (see section 4.4.2) as used in the ebRIM Application Profile of the OGC CSW (OGC 07-110). Furthermore, it includes the 'coupling' of services with dataset series.

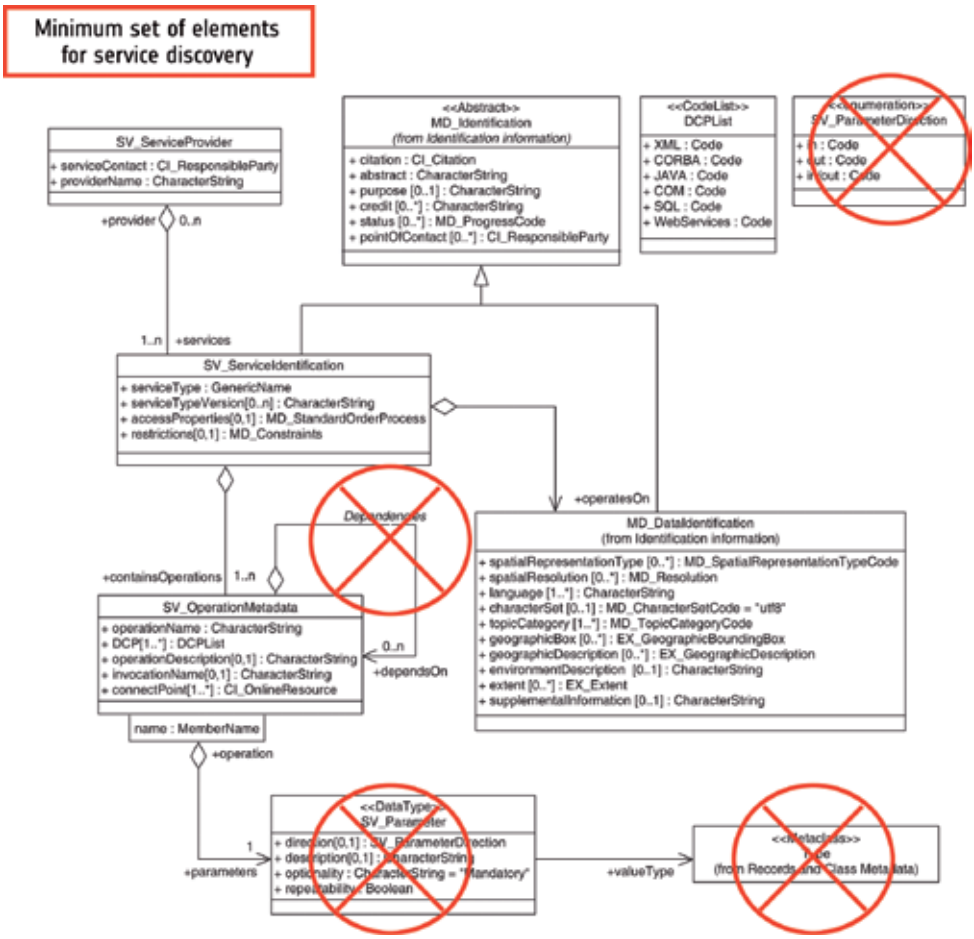


Figure 4.18. Minimal set of elements of ISO 19119 service metadata.

4.4.2 Registry Information Model

EO products are described by information objects whose structure follows the Earth Observation Metadata Profile of Observations and Measurements (OGC 10-157). Hence, the basic information object refers to the concept of an *earth observation* as a refinement of the generic concept of an *observation*.

Conceptually, these information objects are stored in the '*repository*' of a catalogue service. Each information object is then called a 'repository item'. However, for the purpose of discovery of the repository item, a metadata description of these information objects must be registered in the *registry* of a catalogue service. For

this purpose another information model is needed: the Registry Information Model (RIM). The RIM was originally specified by OASIS (OASIS ebRIM, 2005), and then submitted to ISO (ISO/TS 15000-3).

The registry contains *registry objects* which contain standardised metadata describing the repository items. Thus, the RIM defines types of metadata and contents that can be stored in a registry. A high-level view of this structure is shown in Fig. 4.19. The registry object serves as a common superclass for most classes in the information model. A subclass of the registry object is the extrinsic object, which is the primary metadata class for a repository item.

This information model has been applied to OGC Catalogue Services for the Web (CSW), leading to an ebRIM Application Profile of the OGC CSW (OGC 07-110) as described in the HMA Service Viewpoint in section 5.4. Furthermore, because it is extensible and versatile, this profile is suitable for supporting heterogeneous catalogues.

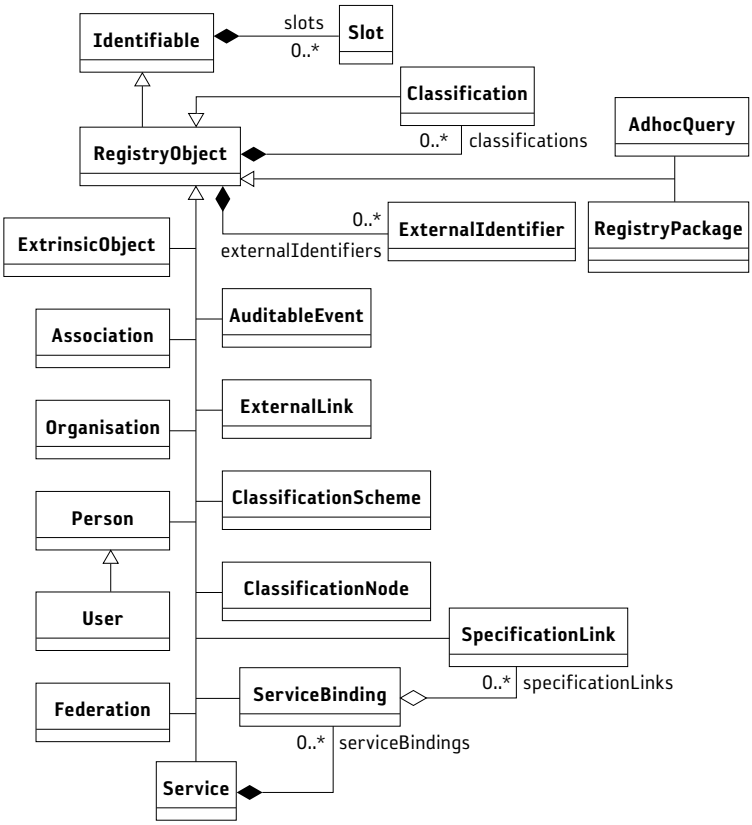


Figure 4.19. High-level view of the RIM.

Note that full support of all registry objects in queries and result sets as well as full support of all filter capabilities are often not possible for implementations, especially when the implementation acts as a proxy/façade in front of a legacy system or an existing catalogue service (e.g. a CIM Extension Package according to OGC 07-038). In order to cope with such restrictions conformance levels were defined. They restrict the number of registry objects which a catalogue implementing the conformance level has to deal with.

For integration into an INSPIRE service infrastructure it is sufficient to support a specific subset of the registry objects and filter capabilities. This subset of the CIM Extension Package can be fully mapped to equivalent objects and filter capabilities used within the INSPIRE catalogue specification. The subset is called CIM Extension Package Protocol Binding of INSPIRE Discovery Services and is currently proposed as an INSPIRE Conformance Class of the CIM Extension Package of the ebRIM Application Profile of the CSW (OGC 08-197r4). It may be interesting not only for the INSPIRE community, but also for other communities for which support of this subset is sufficient.

In the HMA system architecture the RIM is used and refined for the description of service metadata and dataset series (EO collections). This is outlined in the following two subsections.

4.4.2.1 RIM-based Metadata Model for Dataset Series

For the description of EO dataset series (collections) the extrinsic object *DataMetadata* is defined (see Fig. 4.20). It uses classification elements of ISO 19115:2003 such as:

- *SpatialRepresentationType*, which indicates the method that is used to represent geographic information in the dataset, e.g. vector data, grid data, textual or tabular data; or
- *TopicCategoryCode*, which provides a high-level thematic classification to assist in the grouping and search of available datasets, e.g. farming, climatology, elevation, environment, health or geoscientific information.

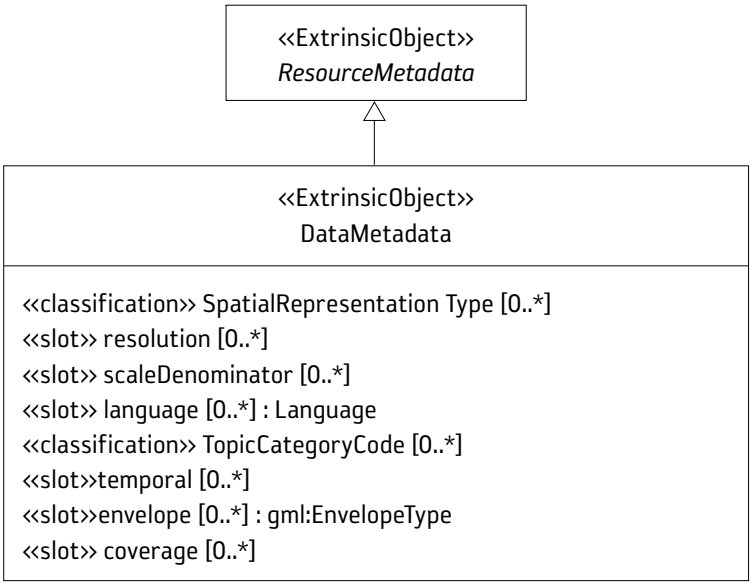


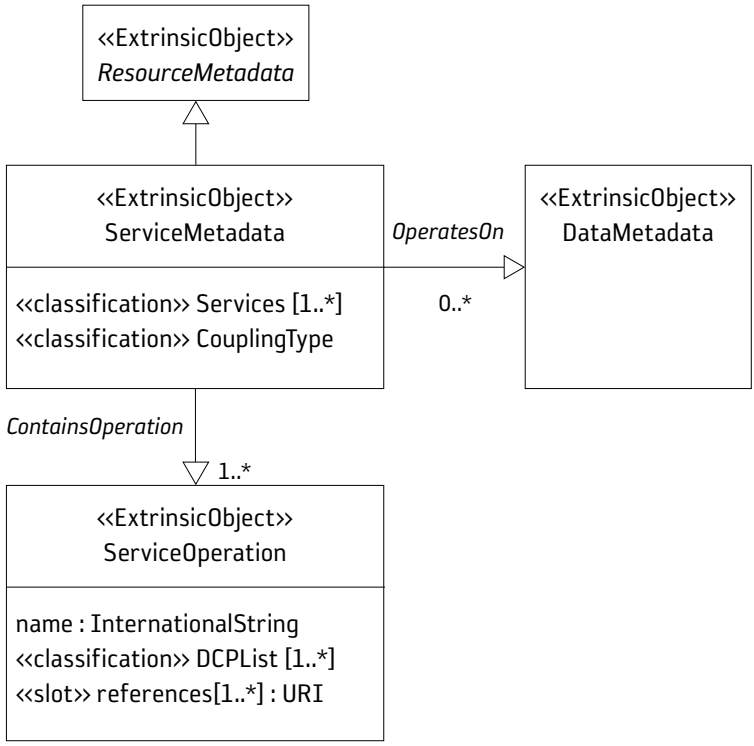
Figure 4.20. Extrinsic object representing metadata of dataset series.

4.4.2.2 RIM-based Metadata Model for Services

For the description of service metadata the extrinsic object *ServiceMetadata* is defined (see Fig. 4.21). In analogy to the *DataMetadata* extrinsic object (see above), it uses classification elements of ISO 19119:2005 such as:

- *Services*, which refer to the ISO 19119 geographic services taxonomy that distinguishes between:
  - Geographic human interaction services
  - Geographic model/information management services
  - Geographic workflow/task management services
  - Geographic processing services (spatial, thematic, temporal and metadata)
  - Geographic communication services.
- *DCPList*, which indicates the distributed computing platforms on which a service operation has been implemented, e.g. Java Enterprise Edition or Internet/http/Web Services.

Figure 4.21. Extrinsic object representing service metadata.



4.4.2.3 RIM-based Metadata Model for Datasets

Metadata for EO datasets is defined in the EO Metadata Profile of Observations and Measurements (OGC 10-157r2). The registration of these metadata elements in an ebRIM Application Profile of the OGC CSW (OGC 07-110) is defined in an separate document called 'Cataloguing Earth Observation Products for ebXML Registry information Model 3.0 based Catalogues' (OGC 10-189r2).

This document defines the extrinsic object *EOProduct* (see Fig. 4.22) which contains a set of attributes according to OGC 10-157r2. These attributes characterise EO products and are necessary for their discovery by means of a catalogue. Example attributes are:

— *parentIdentifier:* Identifier of the encompassing EO dataset series (collection).
— *acquisitionType:* Used to distinguish at a high level the appropriateness of the acquisition for 'general' use, whether the product is a nominal acquisition, special calibration product or other.

— *productType:* Describes the product type if mixed types are available within a single collection; this is a ground segment specific definition.
— *status:* Refers to product status (e.g. archived, acquired, cancelled, failed, planned, potential, rejected).
— *acquisitionDate:* Acquisition date time.
— *imageQualityDegradation:* Quality degradation percentage (i.e. uom='%').
— *imageQualityDegradationQuotationMode:* Indicator to know how the quality degradation percentage has been calculated.

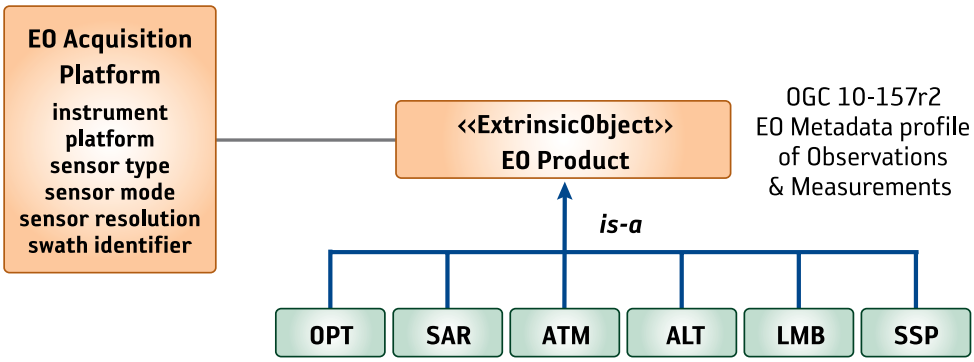
Figure 4.22 illustrates the structure of the EO product extrinsic object. It is related to information about the EO acquisition platform following the basic structure between HMA informational categories illustrated in Fig. 4.1. Furthermore, it shows the different variants of EO products according to the EOP type hierarchy visualised in Fig. 4.8.

4.4.2.4 RIM-based Metadata Model for Sensors

Metadata for EO sensors is defined in the Earth Observation Profile of SensorML (OGC 07-000) for Discovery (OGC 09-163r2 Annex B1). The registration of these metadata elements in an ebRIM Application Profile of the OGC CSW (OGC 07-110) is defined in the same document called 'SensorML Extension Package for the ebRIM Application Profile' (OGC 09-163r2).

As already mentioned in section 4.3.4, the EO Profile of SensorML is currently being aligned with SensorML 2.0 (OGC 12-000) and is available as draft document OGC 11-043 called

Figure 4.22. Extrinsic object representing EO products.



'SensorML 2.0 Extensions for Earth Observation Instruments and Platforms'. It is based on the 'Discovery Profile for SensorML' specification which is being defined by the OGC.

4.5 EO Product Order Model

The basic concept in the ordering of EO products is the order and its refinement in its three variants: product order, future product order and subscription orders.

Furthermore, as illustrated in Fig. 4.23, there are the following associated information items:

- Order options: Specify all possible valid combinations of options for ordering products of a specified EO product collection or for subscribing to a subscription.
- Order specification: Defines all parameters that a client has to specify when submitting an order (products/tasking request/subscription).
- Order item: Defines all parameters that a client has to specify for one item within an order (products/subscription).
- Order quotation: Describes the information provided in the order quotation such as price and contractual details.
- Order monitoring: Defines all parameters returned to the client when getting the status of submitted orders.
- Order item monitoring: Specifies the status information returned for product and subscription order items.

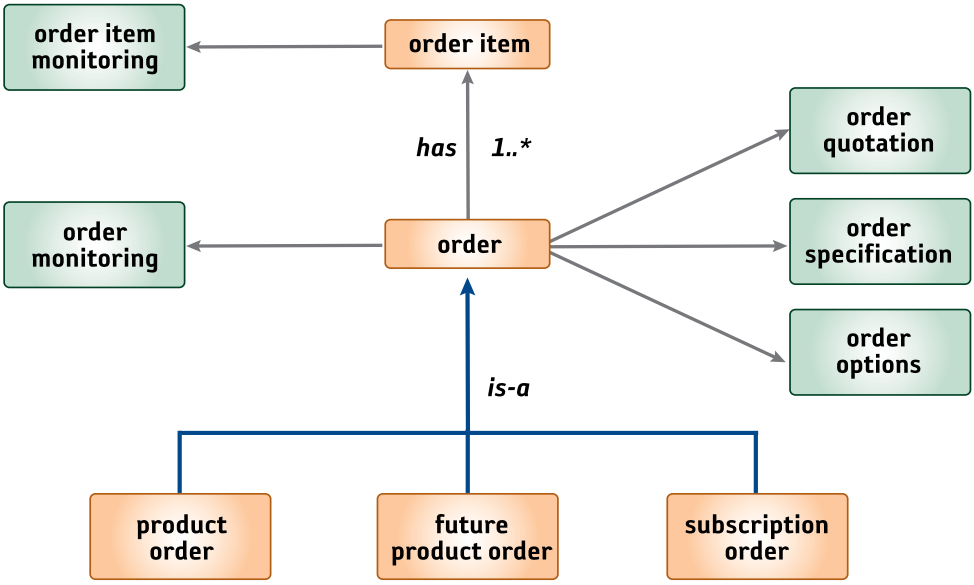


Figure 4.23. Conceptual model of EO product orders.

4.6 Semantic Annotations

The different types of HMA metadata models discussed in the previous sections enable the insertion of semantic annotations. Semantic annotations are additional information elements inserted into the metadata elements that refer to the concepts of a semantic model, e.g. an ontology. Ontologies are conceptual models that define concepts and their relations, together with constraints on these objects and relations (Alexiev et al., 2005). Ontologies represent shared knowledge, i.e. they represent a common understanding (consensus) of the discourse in the universe between the parties involved. The expressiveness of the knowledge representation language determines the classification of ontologies leading to an ontology spectrum that ranges from controlled vocabularies such as DublinCore[32] to semantic models defined by logic constraints. In the current HMA context, references to terms defined in thesauri are the most relevant ones. A thesaurus is a controlled vocabulary that adds relations between terms, e.g. synonyms and hypernyms. Major examples are the GEneral Multilingual Environmental Thesaurus (GEMET) of the European

[32] *http://dublincore.org*

Environment Agency (EEA) and the Earth science keyword list of the Global Change Master Directory (GCMD) (Olsen et al., 2007).

The purpose of semantic annotations in HMA is to define more precisely the meaning of a value or a type. Note that such semantic models may be multilingual, i.e. define term names in multiple languages, and may also define relationships with broader or narrower concepts. Such relationships may best be represented by the Simple Knowledge Organization System (SKOS) which is a common data model for sharing and linking knowledge organisation systems via the web (W3C SKOS, 2009).

In HMA, no assumption is made about the (formal) language and technology for defining the semantic model or the method to access the elements of the semantic model. In practice, W3C SKOS is frequently used for the definition of semantic models and W3C SPARQL or Linked Data principles[33] are used as the access method. How annotations are inserted into the different types of metadata models is defined in the document 'Semantic Annotations in OGC Standards' (OGC 08 167).

The following subsections give some examples of annotations related to several types of HMA metadata models as defined above.

4.6.1 Annotation of ISO 19139 Metadata Models

Semantic annotations of ISO 19139 metadata elements are typically used to annotate keywords which are contained in the dataset series (see section 4.3.2) or service metadata (see section 4.4.1). These annotations then point to the appropriate concepts defined in a semantic model. Figure 4.24 shows an XML extract that includes ISO 19139 keywords and associated references to the semantic model defined by the GCMD Earth science keywords as a SKOS representation.

[33] *www.w3.org/designissues/linkeddata.html*

```
<gmd:descriptiveKeywords>
   <gmd:MD_Keywords>
      <gmd:keyword>
         <gmx:Anchor xlink:href='http://gcmd.gsfc.nasa.gov/skos#spectral_
engineering'>Spectral/Engineering</gmx:Anchor>
      </gmd:keyword>
      <gmd:keyword>
         <gmx:Anchor xlink:href='http://gcmd.gsfc.nasa.gov/skos#visible_
wavelengths'>Visible Wavelengths</gmx:Anchor>
      </gmd:keyword>
      <gmd:keyword>
         <gmx:Anchor xlink:href='http://gcmd.gsfc.nasa.gov/skos#visible_
imagery'>Visible Imagery</gmx:Anchor>
      </gmd:keyword>
      <gmd:type>
         <gmd:MD_KeywordTypeCode codeListValue='theme' codeList='http://www.
isotc211.org/2005/resources/codeList.xml#MD_KeywordTypeCode'/>
      </gmd:type>
      <gmd:thesaurusName>
         <gmd:CI_Citation>
            <gmd:title>
               <gmx:Anchor xlink:href='http://gcmd.gsfc.nasa.gov/skos/'>NASA/
Global Change Master Directory (GCMD) Earth Science Keywords. Version
6.0.0.0.0 </gmx:Anchor>
            </gmd:title>
            <gmd:date>
               <gmd:CI_Date>
                  <gmd:date>
                     <gco:Date>2008-02-05</gco:Date>
                  </gmd:date>
                  <gmd:dateType>
                     <gmd:CI_DateTypeCode codeList='http://standards.iso.
org/ittf/PubliclyAvailableStandards/
ISO_19139_Schemas/resources/Codelist/ML_gmxCodelists.xml#CI_DateTypeCode' code
ListValue='publication'>publication</gmd:CI_DateTypeCode>
                  </gmd:dateType>
               </gmd:CI_Date>
            </gmd:date>
            <gmd:identifier>
```

Figure 4.24. Semantic annotation of EO dataset series metadata.

4.6.2 Annotations of OGC Web Service Common Elements

Semantic annotations of OGC Web Service Common elements (see section 4.2.1) enhance the *Serviceidentification*. This metadata element is used in several data models, e.g. in service capabilities documents, in coverage offerings for an OGC Web Coverage Service (WCS) (section 5.6.3), as part of a layer description for an OGC Web Map Service (WMS) (see section 5.6.4) or in DescribeProcess response messages of an OGC Web Processing Service (see section 5.5.5).

Details on how this can be achieved may be found in the document 'Semantic Annotations in OGC Standards' (OGC 08-167).

4.6.3 Annotations of OGC SWE Common Elements

As specified in the OGC Policy Directives for Writing and Publishing OGC Standards (OGC 06-135r10), all new OGC identifiers issued for persistent public OGC resources shall be HTTP uniform resource identifiers (URIs). Both the HMA Feasibility Analysis Service (see section 5.5.3) and the HMA Ordering Service (see section 5.5.4) use OGC SWE Common identifiers (see section 4.2.2), as shown in the examples below. These identifiers can be considered as semantic annotations since they refer to the respective SKOS definitions using the Linked Data principles.

In the case of the Feasibility Analysis Service (Fig. 4.24), URIs identify tasking parameters in the SWE Common data structure. They have to be used without file extensions (e.g. *www.opengis.net/def/property/OGC-EO/0/IncidenceAngle*).

The extract in Figure 4.26 shows a definition of the concept *IncidenceAngle* referred to from the *DescribeTasking* response above. This excerpt also shows how the SKOS narrower relation is used to express that the two concepts *ElevationAngle* and *AzimuthAngle* are narrower in meaning (i.e. more specific) than the concept *IncidenceAngle*.

A similar approach is used by the HMA Ordering Service. The example in Fig. 4.27 shows an XML extract of a *GetOptions* response with a semantic annotation referring to the SKOS definition of *QualityOfService*.

```
<?xml version="1.0" encoding="UTF-8" ?>
- <soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/">
  - <soapenv:Body>
    - <sps:DescribeTaskingResponse xmlns:sps="http://www.opengis.net/sps/2.0" xmlns:xlink="http://www.w3.org/1999/xlink"
        xmlns:swe="http://www.opengis.net/swe/2.0">
      - <sps:taskingParameters name="CoverageProgrammingRequest">
        - <swe:DataRecord definition="http://www.opengis.net/def/property/OGC-EO/0/CoverageProgrammingRequest">
          - <swe:field name="QualityOfService">
            - <swe:DataRecord definition="http://www.opengis.net/def/property/OGC-EO/0/QualityOfService">
                <swe:label>Quality of Service</swe:label>
              - <swe:field name="PriorityLevel">
                - <swe:Category definition="http://www.opengis.net/def/property/OGC-EO/0/PriorityLevel">
                  - <swe:constraint>
                    - <swe:AllowedTokens>
                        <swe:value>STANDARD</swe:value>
                        <swe:value>HIGH</swe:value>
                      </swe:AllowedTokens>
                    </swe:constraint>
                    <swe:value>STANDARD</swe:value>
                  </swe:Category>
                </swe:field>
              </swe:DataRecord>
            </swe:field>
          - <swe:field name="RegionOfInterest">
            - <swe:DataChoice definition="http://www.opengis.net/def/property/OGC-EO/0/RegionOfInterest" updatable="false">
                <swe:label>Region of Interest</swe:label>
              - <swe:item name="Polygon">
                - <swe:DataRecord definition="http://www.opengis.net/def/objectType/ISO-19107/2003/GM_Polygon">
                  - <swe:field name="Exterior">
                    - <swe:DataArray definition="http://www.opengis.net/def/objectType/ISO-19107/2003/GM_Ring">
                      - <swe:elementCount>
                          <swe:Count />
                        </swe:elementCount>
                      - <swe:elementType name="Point">
                        - <swe:Vector referenceFrame="http://www.opengis.net/def/crs/EPSG/0/4326">
                          - <swe:coordinate name="Lat">
                            - <swe:Quantity axisID="Lat" definition="http://www.opengis.net/def/property/OGC/0/GeodeticLatitude">
                                <swe:uom code="deg" />
                              </swe:Quantity>
                            </swe:coordinate>
                          - <swe:coordinate name="Lon">
                            - <swe:Quantity axisID="Long" definition="http://www.opengis.net/def/property/OGC/0/Longitude">
                                <swe:uom code="deg" />
```


Figure 4.25. Semantic annotation of the *DescribeTasking* responseas part of the HMA Feasibility Analysis Service.

```
<rdf:RDF xml:base="http://www.opengis.net/def/property/OGC-EO/0/" xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#" xmlns:dc="http://purl.org/dc/elements/1.1/"
  xmlns:skos="http://www.w3.org/2004/02/skos/core#">
  <!-- ============================================ -->
- <rdf:Description rdf:about="http://www.opengis.net/def/property/OGC-EO/0/IncidenceAngle">
    <dc:creator>European Space Agency</dc:creator>
    <dc:creator>Spot Image S.A.</dc:creator>
    <dc:date>2010-11-23</dc:date>
    <dc:title>IncidenceAngle</dc:title>
    <dc:description>Planar angle between the zenith direction (straight up, along the local vertical) and the viewing direction of a
      scene</dc:description>
    <rdf:type rdf:resource="skos:Concept" />
    <rdfs:isDefinedBy rdf:resource="http://www.opengis.net/doc/IS/EOSPS/2.0" />
    <skos:prefLabel>Incidence Angle</skos:prefLabel>
    <skos:definition>Planar angle between the zenith direction (straight up, along the local vertical) and the viewing direction of a
      scene</skos:definition>
    <skos:inScheme rdf:resource="http://www.opengis.net/def/property" />
    <skos:narrower rdf:resource="http://www.opengis.net/def/property/OGC-EO/0/ElevationAngle" />
    <skos:narrower rdf:resource="http://www.opengis.net/def/property/OGC-EO/0/AzimuthAngle" />
  </rdf:Description>
</rdf:RDF>
```

Figure 4.26. Semantic model extract referred to from a *DescribeTasking* response.

```
<option>
  <swe:DataRecord>
     <swe:field name='QualityOfService'>
        <swe:Category updatable= 'false' optional='true'
            definition=
'http://www.opengis.net/def/order/OGC-EO/0/QualityOfService'>
           <swe:constraint>
              <swe:AllowedTokens>
                 <swe:value>STANDARD</swe:value>
                 <swe:value>RUSH</swe:value>
              </swe:AllowedTokens>
           </swe:constraint>
        </swe:Category>
     </swe:field>
   </swe:DataRecord>
   <grouping>Processing Option</grouping>
</option>
```

Figure 4.27. Semantic annotation of the *GetOptions* response as part of the HMA Ordering Service.

4.6.4 EO Metadata Profile Cataloguing

The second version of the EO metadata profiles is no longer based on GML 3.1 as described in section 4.3. This revision now takes advantage of the OGC SWE O&M standard which is both an ISO Draft International Standard and an OGC standard (section 4.2.5). The O&M model has also been selected by several groups in Annexes II and III of INSPIRE.

This new metadata profile also has an improved catalogue model for ebRIM-based catalogues. This new model follows the HTTP URI

policy rules of OGC (OGC 06-135r10). This leads to the situation where the properties now have identical names in OGC SWE, HMA ordering as well as OGC SPS standards.

```
<wrs:ExtrinsicObjectid='DS_PHR1A_20010822110247_TLS_PX_
E123N45_0101_01234' objectType='urn:ogc:def:objectType:OGC-
CSW-ebRIM-EO:2.0:EOProduct' mimeType='text/xml'>
  <rim:Slot name='http://www.opengis.net/def/property/OGC-
EO/0/Status'
           slotType='urn:oasis:names:tc:ebxml-
regrep:DataType:String'>
    <rim:ValueList>
         <rim:Value>ARCHIVED</rim:Value>
    </rim:ValueList>
  </rim:Slot>
  <rim:Slot
name='http://www.opengis.net/def/property/OGC-EO/0/
ImageQualityDegradation'
  slotType='urn:oasis:names:tc:ebxml-regrep:DataType:Double'>
    <rim:ValueList>
       <rim:Value>75.0</rim:Value>
    </rim:ValueList>
  </rim:Slot>
  <rim:Slot name='http://www.opengis.net/def/property/OGC-
EO/0/ParentIdentifier'
          slotType='urn:oasis:names:tc:ebxml-
regrep:DataType:String'>
    <rim:ValueList>
       <rim:Value>urn:ogc:def:EOP:ESA:EECF.ENVISAT_ASA_APx_
xS</rim:Value>
    </rim:ValueList>
  </rim:Slot>
  <rim:Slot name='http://www.opengis.net/def/property/OGC-
EO/0/AcquisitionStation'
        slotType='urn:oasis:names:tc:ebxml-
regrep:DataType:String'>
    <rim:ValueList>
       <rim:Value>TLS</rim:Value>
    </rim:ValueList>
  </rim:Slot>
  <rim:Slot name='http://www.opengis.net/def/property/OGC-
EO/0/BeginPosition'
    slotType='urn:oasis:names:tc:ebxml-
regrep:DataType:DateTime'>
    <rim:ValueList>
       <rim:Value>2001-08-22T11:02:47.000</rim:Value>
    </rim:ValueList>
  </rim:Slot>
  <rim:Slot name='http://www.opengis.net/def/property/OGC-
EO/0/LastOrbitNumber'
     slotType='urn:oasis:names:tc:ebxml-
regrep:DataType:Integer'>
     <rim:ValueList>
       <rim:Value>12</rim:Value>
     </rim:ValueList>
  </rim:Slot>
```

Using the same resolvable HTTP URI name for properties in different specifications adds a new dimension and semantic rigour to metadata. The meaning of a metadata property can now be easily resolved by simply following the link to get the definition of the property. Hence, the meaning of the property is assured throughout several specifications.

4.7 Identity and Access Management

4.7.1 Overview

According to the specification of the user management interfaces for EO services (OGC 07-118r8), the HMA architecture relies upon the security standards of OASIS for identity and access management. Their functional aspects are covered by the OASIS Web Service Security (WS-Security) standards that are defined in the HMA Service Viewpoint (section 5.3). Throughout the HMA architecture, they are basically applied for authentication and authorisation aspects. These two aspects are defined by the encompassing OASIS Reference Architecture for Service Oriented Architecture (OASIS SOA-RA, 2008) as follows:

- *Authentication:* This aspect concerns the identity of the participants in an exchange. Authentication refers to the means by which one participant can be assured of the identity of the other participants.
- *Authorisation:* This aspect concerns the legitimacy of the interaction. Authorisation here refers to the means by which an owner of a resource may be assured that the information and actions that are exchanged are either explicitly or implicitly approved.

From the informational point of view, the following languages are of major importance for these two aspects:

- The OASIS Security Assertion Markup Language (SAML) (OASIS SAML, 2006) is used to encode identities and related information. This is performed in 'SAML Assertions'.
- The OASIS eXtensible Access Control Markup Language (XACML) (OASIS XACML, 2010), including its geospatial extension GeoXACML (OGC 07-026r2), is used to define access control policies for the identities mentioned above.
- XML Encryption (W3C XML-Enc, 2002) specifies a process for encrypting data and representing the result in XML. According

to the requirements of the User Management Interfaces for Earth Observation Services (OGC 07-118r8), XML encryption shall be used to encrypt the SAML tokens based upon the AES-128 algorithm.

— XML Signature (W3C XML-Enc, 2002) provides XML syntax and processing rules for creating and representing digital signatures. According to OGC 07-118r8, the SAML token shall be signed following XML signature rules before it is encrypted.

The first two languages are described in the following subsections.

4.7.2 Assertions about Identities

SAML is a generic language for encoding security-related information (OASIS SAML, 2006). OASIS states that SAML consists of:

> building-block components ... which primarily permit the transfer of identity, authentication, attribute, and authorisation information between autonomous organizations that have an established trust relationship. The core SAML specification defines the structure and content of both *assertions* and *protocol* messages used to transfer this information.

Hence, one of the basic concepts of SAML is *assertions*. SAML *assertions* are applied to 'principals' which represent the identity of users. They carry 'statements about a principal that an asserting party claims to be true'.[34] These statements are expressed in terms of attribute–value pairs. Thus, for a given application domain, there needs to be a consensus about the attributes used and their meaning.

In the HMA architecture these attribute–value pairs are used for encoding information about identities. Hence an identity is a concept that is used to recognise a subject, i.e. a user or a software component in an application. Note that a subject may have several identities, e.g. a user may have several accounts with a user/password combination.

The OGC document 'User Management Interfaces for Earth Observation Services' (OGC 07-118r8) proposes a set of attributes to be included in an SAML token. As an example, the following set could be used:

[34] The concept of 'assertion' here is equivalent to the concept of 'claim' in WS-Trust.

— Id: unambiguous federated identity;
— c: country of origin;
— o: organisation;
— Account: account number;
— ServiceName: associated GMES services, e.g. Geoland2, MyOcean, etc., with which the user is affiliated;
— UserProfile: type of user (e.g. Commercial/GMES/Scientific).

Thus, an example of a list of attribute–value pairs could look as follows:

(Id=8580745, c=Italy, o=EnvAgency, Account=759, ServiceName=Geoland2, UserProfile='GMES')

The valid structure and contents of an assertion are defined by the SAML assertion XML schema. Assertions are usually created by an asserting party based on a request of some sort from a client to be consumed by a relying party, although under certain circumstances the assertions can be delivered to a relying party in an unsolicited manner.

The second SAML core concept is the *protocol*. It is used to build SAML-defined requests and return appropriate responses. The structure and contents of these messages are defined by the SAML-defined *protocol* XML schema.

The means by which lower-level communication or messaging protocols (such as HTTP or SOAP) are used to transport SAML protocol messages between participants is defined by the SAML *bindings*, the third SAML core concept.

Next, SAML *profiles* are defined to satisfy a particular business use case, e.g. the Web Browser SSO (Single Sign-On) profile. *Profiles* typically define constraints on the contents of SAML assertions, protocols and bindings in order to solve the business use case in an interoperable fashion.

Finally, by adding the complementary concepts of an authentication context and further configuration metadata, the six basic concepts of SAML are as illustrated in Fig. 4.28.

In the HMA architecture the following constraints for bindings and protocols apply:

— Messages shall conform to SOAP version 1.2 (W3C SOAP, 2007).
— Only SOAP messaging (via HTTP/POST or HTTPS/POST) with document/literal style shall be used.

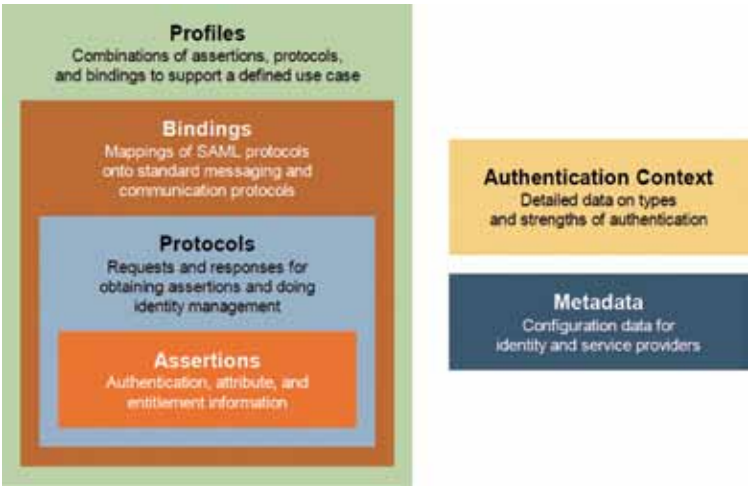


Figure 4.28. Basic SAML concepts (OASIS SAML, 2006).

4.7.3 Access Control Policies

XACML defined by OASIS (OASIS XACML, 2010) provides a language to encapsulate security rules in 'access control' policies. Its goal is to provide a common language through which an enterprise can manage all elements of its security policies for all components of its information systems in a standardised manner (Mazzoleni et al., 2008). In general, such an access control policy can be understood as a container of rules for access control. For instance, when a 'Policy Decision Poin' (PDP) has to decide if a service request may be operated by a service provider, it analyses a service request against the rules specified in an access control policy. Hence, if the same access control policies are used throughout the components of an information infrastructure, it is possible to manage the enforcement of policies in a consistent and to some extent interoperable way.

In the HMA architecture XACML and extensions such as GeoXACML are used as common languages to formulate access control policies.

4.7.3.1 XACML Basic Concepts

The following elements are relevant to understand the basic principles of XACML:

— *Policy:* A policy is a container for rules and other information, e.g. a general policy target or a particular rule-combining algorithm to support different matching policies for an authorisation request.

— *Rule:* A rule is the most elementary unit of a policy. A rule can be evaluated on the basis of its contents and the request. The main components of a rule are a rule target, an effect and a set of conditions that represent additional predicates specifying when the rules apply to a request.
— *Example:* 'User with the "guest" role cannot access high-resolution data' (extracted from OGC 07-118r8):

```
<Rule RuleId='urn:…:xacml:2.0:ex:ruleid:HL-IDM-500'
Effect='Deny'>
   <Description>
      User with the 'guest' role cannot access high-
      resolution data
   </Description>
   <Target>
      <Subjects>
         <Subject>
            <SubjectMatch
               MatchId='urn:…:xacml:1.0:function:string-
               equal'>
                  <AttributeValue
                     DataType='.../XMLSchema#string'>guest
               </AttributeValue>
               <SubjectAttributeDesignator>
                  AttributeId='urn:ogc:um:eop:0.0.4:saml:r
                  ole'
                  DataType='.../XMLSchema#string'/>
            </SubjectMatch>
         </Subject>
      </Subjects>
   </Target>
   <Condition>
      <Apply FunctionId='urn:…:xacml:2.0:function:double-
      greater-than'>
      <Apply FunctionId='urn:…:xacml:1.0:function:double-
      one-and-only'>
         <ResourceAttributeDesignator DataType='…/
         XMLSchema#double'
         AttributeId='urn:ogc:def:ebRIM-Slot:OGC-06-
         131:resolution'/>
      <Apply>
         <AttributeValue>
         DataType='…/XMLSchema#double'> resolution_
         threshold
         </AttributeValue>
      </Apply>
   </Condition>
</Rule>
```

— *Rule target:* The target defines the set of resources, subjects, actions and environment to which the rule is intended to apply. An XACML PDP verifies that the matches defined by the target are satisfied by the subject, resource, action and environment attributes in the request context, e.g. role. In summary, targets are used to determine which rules match the given request.

— *Effect:* The effect of a rule indicates the rule-writer's intended consequence of a 'True' evaluation for this particular rule. Two values are allowed: 'Permit' and 'Deny'.

XACML not only provides a language for policy specification, but also provides a method for evaluating a policy based on the values of the policy attributes that are associated with a request. A PDP is in charge of evaluating applicable policies and returning an authorisation decision.

The PDP works as follows. After receiving a request the PDP matches the request against the policies to determine the policies to be considered. Here, matching simply means the evaluation of the rule target as described above. In case one of the targets matches, the effect is either *permit* or *deny*. It is possible that there is more than one matching rule. In this case the defined combining algorithm is used to provide an authorisation decision, e.g. if the combining algorithm is *deny-overrides*, then one occurrence of a *deny* overwrites all occurrences of *permit*.

Furthermore, it is then up to the 'Policy Enforcement Point' (PEP) to enforce the stated authorisations, i.e. to make sure that they are applied to the handling of the service request.

4.7.3.2 GeoXACML: The Geospatial Extension of XACML

GeoXACML is an OGC Implementation Standard (OGC 07-026r2). It defines an extension to XACML for spatial data types and spatial authorisation decision functions. These data types and functions can be used to define additional geospatial constraints for XACML based policies:

— GeoXACML makes use of existing XACML extension points to be fully compatible with the XACML standard. This means that a 'GeoPDP' is able to evaluate not only GeoXACML decision queries but standard XACML queries as well.
— GeoXACML extends XACML by only one new data type, named 'urn:ogc:def:dataType:geoxacml:1.0:geometry'. It contains geometric data types described in the simple feature access specification of OGC (OGC 06-103r3).

Note that there are two extensions to the GeoXACML implementation specification: one that defines the GML encoding for GML version 2 (OGC 07-098r1); and one that describes it for GML version 3 (OGC 07-099r1).

The XACML extension points for data types are illustrated in the XML fragments in Figs 4.29–4.31 (OGC 09-132r1). As the *DataType* attribute is of type *anyURI*, the additional *geometry* data type can be used.

There are 34 new functions of two different conformance classes defined by GeoXACML, 19 of which belong to the conformance class BASIC and 15 to the conformance class STANDARD. These functions cover several aspects of geographic evaluation:

— Topological functions (conformance class BASIC)
— Bag functions (conformance class BASIC)
— Set functions (conformance class BASIC)
— Geometric functions (conformance class STANDARD)
— Conversion functions (conformance class BASIC)

A 'GeoPDP' has to implement all functions of conformance class BASIC to be considered a 'BASIC GeoXACML conformant PDP implementation'.

A 'STANDARD conformant PDP implementation' has to implement all functions of conformance class STANDARD in addition to all functions of conformance class BASIC.

The XACML extension point for function types is shown in Fig. 4.32. As the *FunctionId* attribute is of type *anyURI* any additional function may simply be used. In order to maintain the XACML conformance, GeoXACML does not define any additional or changed XSD schema elements.

```
<xs:element name="AttributeValue" type="xacml:AttributeValueType" substitutionGroup="xacml:Expression"/>
 <xs:complexType name="AttributeValueType" mixed="true">
  <xs:complexContent mixed="true">
   <xs:extension base="xacml:ExpressionType">
    <xs:sequence>
     <xs:any namespace="##any" processContents="lax" minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
    <xs:attribute name="DataType" type="xs:anyURI" use="required"/>
   <xs:anyAttribute namespace="##any" processContents="lax"/>
  </xs:extension>
 </xs:complexContent>
 </xs:complexType>
```

Figure 4.29. AttributeValue extension point of XACML.

```
<xs:complexType name="AttributeDesignatorType">
 <xs:complexContent>
  <xs:extension base="xacml:ExpressionType">
   <xs:attribute name="AttributeId" type="xs:anyURI" use="required"/>
   <xs:attribute name="DataType" type="xs:anyURI" use="required"/>
   <xs:attribute name="Issuer" type="xs:string" use="optional"/>
   <xs:attribute name="MustBePresent" type="xs:boolean" use="optional" default="false"/>
  </xs:extension>
 </xs:complexContent>
</xs:complexType>
```

Figure 4.30. Attribute-DesignatorType extension point of XACML.

```
 <xs:complexType name="AttributeSelectorType">
  <xs:complexContent>
   <xs:extension base="xacml:ExpressionType">
    <xs:attribute name="RequestContextPath" type="xs:string" use="required"/>
    <xs:attribute name="DataType" type="xs:anyURI" use="required"/>
    <xs:attribute name="MustBePresent" type="xs:boolean" use="optional" default="false"/>
   </xs:extension>
  </xs:complexContent>
 </xs:complexType>
```

Figure 4.31. Attribute-SelectorType extension point of XACML.

```
<xs:element name="Function" type="xacml:FunctionType" substitutionGroup="xacml:Expression"/>
 <xs:complexType name="FunctionType">
  <xs:complexContent>
   <xs:extension base="xacml:ExpressionType">
    <xs:attribute name="FunctionId" type="xs:anyURI" use="required"/>
   </xs:extension>
  </xs:complexContent>
</xs:complexType>
```

Figure 4.32. FunctionType extension point of XACML.

→ SERVICE VIEWPOINT

5. Service Viewpoint

5.1 Overview

The HMA Service Viewpoint describes how the functional requirements that were identified for an HMA-compliant system environment are realised in terms of services. Thus, a service is understood to be a distinct part of the functionality that is provided by an entity through interfaces (ISO 19119). In an HMA-compliant system environment, using today's Internet technology, a service is typically realised as a 'Web Service'.

In contrast, this section focuses on the conceptual level of the services. Figure 5.1 provides an overview of the major categories of functional requirements and their mapping to categories of HMA services. The introduction of HMA service categories promotes the categorisation of services and therefore enables the definition of a service taxonomy.

The functional requirements correspond to the primary use cases as presented in section 3.4 as part of the HMA Enterprise Viewpoint.

In standards organisations and major project initiatives service types are classified into service taxonomies, i.e. they are grouped with respect to characteristics and usage patterns. In

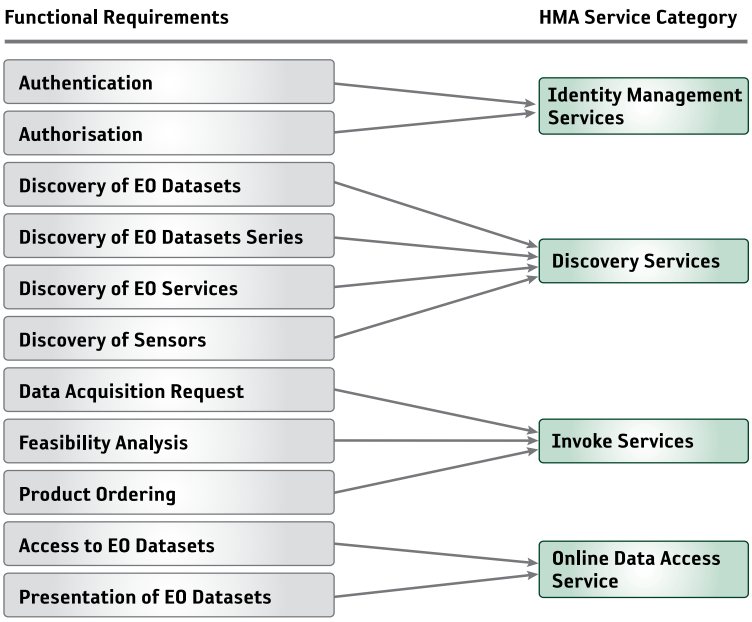


Figure 5.1. Mapping of functional requirements to HMA service categories.

Table 5.1. HMA service categories.

HMA service category	ISO 19119 service taxonomy	INSPIRE service types	Section
Identity Management Services	Geographic model/ information management services	–	5.3
Discovery Services	Geographic model/ information management services	Discovery Service	5.4
Invoke Services	Geographic processing services	Invoke Service	5.5
Online Data Access Services	Geographic model/ information management services	Download Service and View Service	5.6

particular, this approach facilitates the comparison of information management systems that are based upon service-oriented architectures (OGC 10-028r1). In table 5.1 the HMA service types are listed and mapped to the service taxonomies proposed by the ISO Geographic Information Services (ISO 19119) and the INSPIRE Network Services Architecture (INSPIRE NSA, 2008).

Furthermore, the table references the section in which the respective service type is described in more detail. For each service, an overview and a description of the service operations is given, grouped into interfaces. Furthermore, each service description illustrates which of the information models presented in the HMA Information Viewpoint are used. However, the next section first of all introduces the service (meta-)model used in HMA and its link to the information (meta-) model.

5.2 Service Model

The basis for the modelling of the HMA Service Viewpoint is provided by the two concepts of service and interface as illustrated in Fig. 5.2. The modelling unit for services is the concept of an interface (OGC 09-132r1). HMA services, more precisely their types, are defined by the collection of the interface types that they support. As an interface type defines the externally visible behaviour, an HMA service is in fact defined by the functionality that it provides to the external world.

A service may have several interfaces and an interface may be applied in several services. For instance, the metadata of services, also called capabilities, may be specified in a service metadata interface which is common to all services. It delivers a self-description of a deployed service component. An example is the OGC Web Service Common Implementation Specification (OGC 06-121r9) as introduced

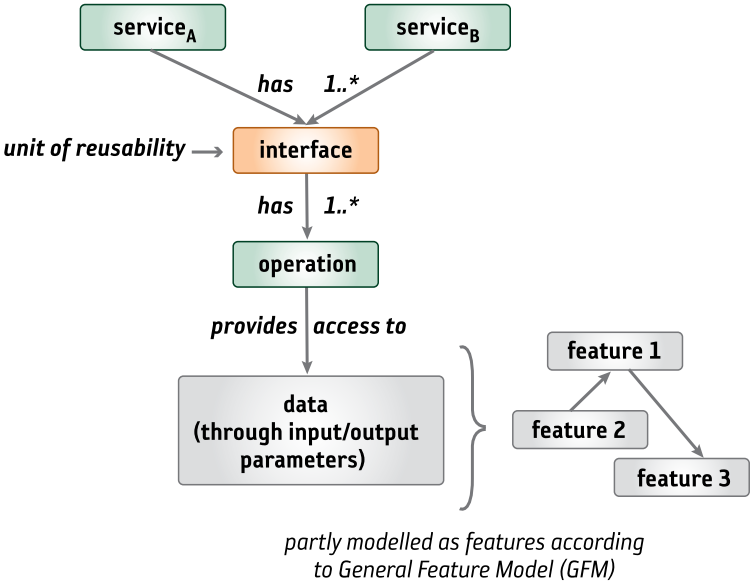


Figure 5.2. Service model used in the Service Viewpoint.

in section 4.2.1. An interface has one or more operations which in turn may have one or more (input and output) parameters through which it provides access to data. The operations and the parameters provide the link to the General Feature Model (GFM) (see section 4.2.3) as both may be properties of features.

5.3 Identity Management Services

5.3.1 Overview

The HMA Identity Management Services comprise the specification of the interfaces and operations that are required to authenticate and authorise users in EO service networks following HMA specifications. This means the following:

- On the one hand, they support the authentication process. Authentication verifies that a potential partner in a conversation is entitled to represent a person or an organisation, or, as stated by the SOA reference architecture (OASIS SOA-RA, 2008), one participant can be assured of the identity of other participants.
- On the other hand, the HMA Identity Management Services provide the means to authorise the legitimacy of an interaction between the participants such that an owner of a resource may

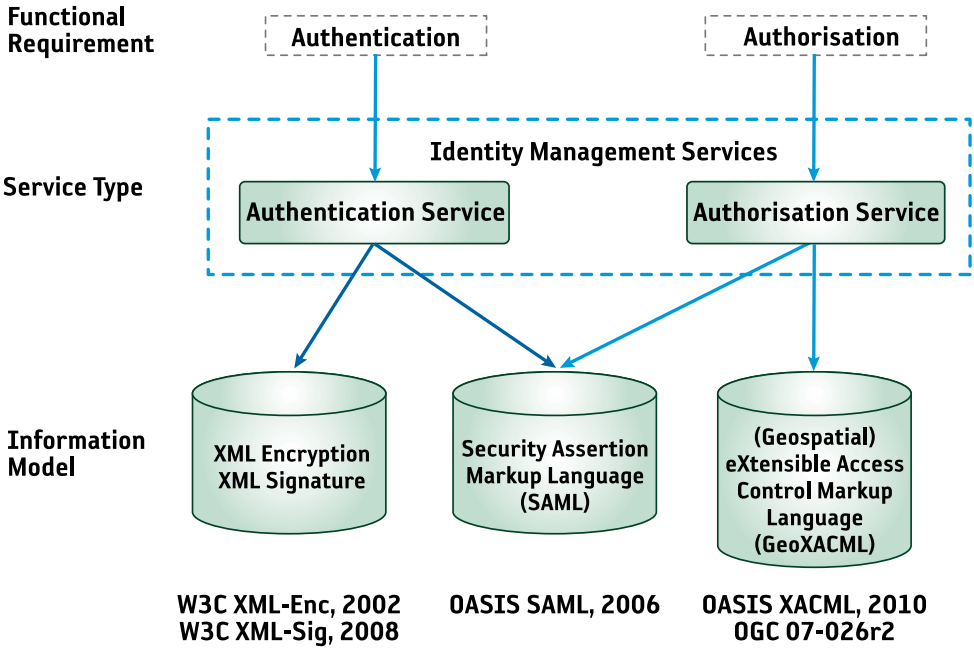
be assured that the information and actions that are exchanged are either explicitly or implicitly approved (OASIS SOA-RA, 2008).

The basic service standard upon which the HMA Identity Management Services rely is the OASIS WS-Trust specification (OASIS WS-Trust, 2007). WS-Trust is an extension of the WS-Security specification (OASIS WS-Sec, 2006) which defines the basic mechanisms for secure SOAP-based messaging with respect to message content integrity and confidentiality. In order to secure communication between two parties, they must exchange security credentials, e.g. security tokens.

Basically, WS-Trust defines methods for issuing, renewing and validating such security tokens. The HMA Identity Management Services, however, just use a small part of these methods called the Security Token Service (STS). The STS issues SAML-based security tokens when called with user credentials. Furthermore, it defines the constraints upon the message structure required for authorisation of the execution of service requests in HMA service networks.

HMA specifies the following types of Identity Management Services:

Figure 5.3. Usage of information models by HMA Identity Management Services.



— Authentication Service to fulfil the functional requirements of authentication.
— Authorisation Service to fulfil the functional requirements of authorisation.

Both are described further in the following sections.

5.3.2 Relevant Information Models

As illustrated in Fig. 5.3, the HMA Identity Management Services rely upon the following two information models that are both specified by OASIS:

1. Security Assertion Markup Language (SAML) (OASIS SAML, 2006). As described in section 4.7.2, SAML is used in general to encode identities and related information. Here, its purpose is to encode security tokens unambiguously to identify authenticated users.
2. eXtensible Access Control Markup Language (XACML) (OASIS XACML, 2010). As described in section 4.7.3, XACML is used in general to encapsulate and specify security rules in the form of 'access control' policies. Here its purpose is to specify the conditions that must hold in order to decide if a service request comprising an SAML security token may be relayed to a service provider. Geospatial conditions, e.g. access to the EOs of a given region, are expressed by means of GeoXACML (see section 4.7.3.2) which is a geospatial extension of XACML defined by OGC.
3. XML Encryption (W3C XML-Enc, 2002) and XML Signature (W3C XML-Sig, 2008).

According to the User Management Interfaces for Earth Observation Services (OGC 07-118r8), the encryption algorithm used for the SAML token shall be the AES-128. This requires that the token is encrypted using the asymmetric RSA encryption algorithm with the public key of the relying party, i.e. the entity that shall enforce the access control policies based on the token's assertions. The resulting value is added to the message, using the XML Encryption (W3C XML-Enc, 2002).

5.3.3 Description of the Authentication Service

This service is described in Table 5.2.

Table 5.2. Description of the Authentication Service.

Name	Authentication Service

Standard service specifications	User Management Interface for EO Services (OGC 07-118r8) relying upon:
	— WS-Trust 1.3 (OASIS WS-Trust, 2007)
	— SAML (OASIS SAML, 2006)
	— OASIS WS-Security (OASIS WS-Sec, 2006) with its two profiles:
	  – Web Services Security UsernameToken Profile 1.1 (OASIS WS-SecUserToken, 2006)
	  – WS-Security SAML Token Profile (OASIS WS-SecSAMLToken, 2006)

Description	This service supports the authentication process in the context of the OASIS Access Control Design pattern. It specifies the following interface: — Security Token Service (STS): supports the authentication process based upon WS-Trust 1.3. Furthermore, it specifies a constraint upon any service request in an HMA service network to include an SAML token in the message header.
STS Interface	
Request Security Token (RST) (with 'issue' action)	Allows clients (called requestors) to retrieve authentication metadata from a nominated identity provider. The RST Response (RSTR) is an XML document containing authentication metadata about the authentication process and the requestor (the authenticated user). The authentication metadata is returned as a signed and encrypted SAML token (see section 4.7.2) such that the client is unable to decrypt the content of the encrypted SAML token. There are two variants of this operation, depending on whether the STS provider itself takes the role of the identity provider or may at least access the identity provider (case 1), or the identity was already provided by another service provider before calling this operation (case 2): 1. The SAML token is generated by the STS provider from the user name and password information given by the requestor in the RST operation. Optionally, the RST contains the address of the nominated identity provider (which may be the STS itself). 2. The SAML token is generated by the STS provider from a signed user name. This indicates to the STS provider that the authentication has already been performed by an external identity provider beforehand. The signature enables the STS provider to check the trustworthiness of the request. For this purpose, the STS provider contains a list of public keys of all the identity providers that it trusts.

Name	Authentication Service
	Notes: 1. The authentication interface of an external identity provider (case 2) need not necessarily comply with the RST operation as described in the HMA Identity Management Service. For instance, it may rely upon single sign-on systems such as OpenAM[35] or Shibboleth.[36] 2. The STS shall be able to deliver the SAML token formatted both as a SAML version 1.1 (default) or version 2.0. For this purpose, the standard WS-Trust TokenType element of RST shall be used to indicate in the RST operation the requested SAML version. 3. The STS should be able to deliver the SAML token formatted for different Relying Parties (i.e. consumers or destinations). The standard WS-Trust wsp:AppliesTo element of RST shall be used to indicate the Relying Party in the RST operation.
Any interface of a service provider	
any service request	Each service request by the client includes the SAML token in the message header, i.e. in the case of the SOAP, encoded as a WS-Security element in the SOAP header. Both synchronous and asynchronous service requests, based on WS-Addressing (W3C WS-Addr, 2006), are supported. Note that the WS-SecurityPolicy standard (OASIS WS-SecPolicy, 2007) shall be used for the specification of the WSDL files that describe the signature of the Web Services to be called. For instance, WS-SecurityPolicy specifies how to encode the SAML token and the encryption algorithm in a SOAP header such that the Web Services are self-describing. WS-SecurityPolicy is based upon the policy concept of W3C that refers to domain-specific capabilities, requirements and general characteristics of entities in a Web-Services-based system (W3C WS-Policy, 2007).

[35] *www.forgerock.com/openam.html*
[36] *http://shibboleth.internet2.edu*

5.3.4 Description of the Authorisation Service

This service is described in Table 5.3.

Table 5.3. Description of the Authorisation Service.

Name	Authorisation Service
Standard service specifications	User Management Interface for EO Services (OGC 07-118r8) relying upon: — WS-Trust 1.3 (OASIS WS-Trust, 2007) — XACML (OASIS XACML, 2010) — GeoXACML (OGC 07-026r2) — OASIS WS-Security (OASIS WS-Sec, 2006)
Description	This service supports the authorisation process in the context of the OASIS Access Control Design pattern. It specifies the following interface: — Policy Enforcement Point (PEP), specified by constraints on each Web Service request in an HMA service network.
PEP Interface	
any service request	The PEP is not specified in terms of a Web Service interface but as a list of functions to be carried out in order to check if a service request may be forwarded to a service provider or not. A PEP implementation shall: 1. Check the existence of a SAML token in a service request. 2. Decrypt it. 3. Verify it (especially its signature and expiry time). 4. Enforce the access control policies. Hence, the PEP decides whether to accept or refuse the service request or to reroute it. In addition to the analysis of the SAML token, this decision is based on the content of the message body and the applicable policies encoded as (Geo)XACML information (see section 4.7.3). Note that the PEP approach is non-invasive, which means that it is independent of the implementation of the service provider.

5.4 Discovery Services

5.4.1 Overview

This section describes the services of the HMA service architecture which are necessary to fulfil the discovery use cases described in section 3.4.4. Basically, there are four types of HMA Discovery Services supporting three different functional requirements:

1. The *Dataset Discovery Service* supports access to the metadata of EO datasets (products).
2. The *Dataset Series Discovery Service* supports access to the metadata of EO dataset series (collections) and services.
3. The *Service Discovery Service* supports access to the metadata of EO services.
4. The *Sensor Discovery Service* supports access to the metadata of EO sensors.

As illustrated in Fig. 5.4, the specifications of the HMA Discovery Services are all extension packages of an application profile of the OGC Catalogue Services Implementation, Version 2.0.2 (OGC 07-006r1), which is usually also referred to as the OGC Catalogue Service for the Web (CSW).

These extension packages are determined by the information models (metadata models) that describe the resources to be discovered, i.e. datasets, dataset series, services and sensors. In HMA, the fundamental decision was taken that the basic structure of the ebXML registry information model (ebRIM) (see section 4.4.2) is used to describe these resources. Hence, all HMA Discovery Services are founded upon the CSW application profile called the CSW-ebRIM Registry Service (OGC 07-110).

Depending on the resource type to be discovered (datasets, dataset series, services and sensors), four different HMA Discovery Services are specified:

1. The Dataset Discovery Service is specified as an extension package for the ebRIM Application Profile that is dedicated to EO products (OGC 06-131r6).
2. The Dataset Series Discovery Service is specified by Cataloguing of ISO 19915 Metadata (CIM) using the ebRIM application profile of CSW (OGC 07-038).
3. Analogously, the Service Discovery Service is specified by Cataloguing of ISO 19919 Metadata (CIM) using the ebRIM application profile of CSW (OGC 07-038).
4. Finally, the Sensor Discovery Service is specified in an extension package for the ebRIM application profile that is dedicated to EO sensors (OGC 09-163r2). It is defined by a mapping of sensor metadata encoded following the SensorML profile for discovery (see section 4.3.4) to the ebRIM structure within an OGC Catalogue.

Note that in addition to the above server-to-server interfaces (i.e. dedicated to programmatic access by software components), a simple Internet Discovery Service is available as well. It allows

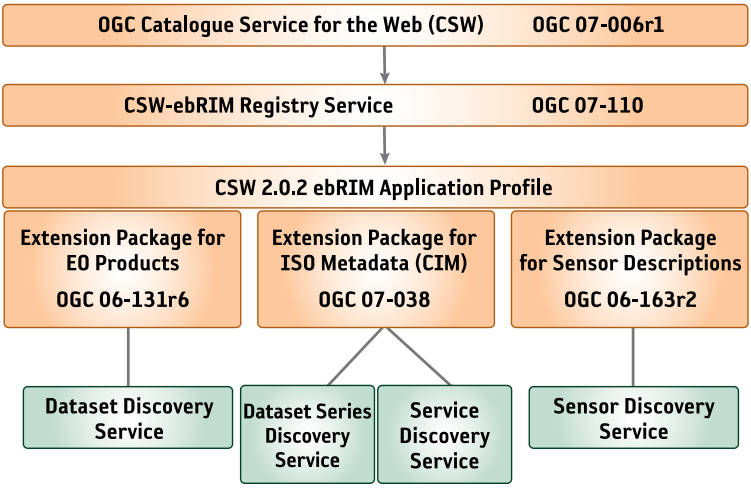


Figure 5.4. Catalogue service support for the HMA Discovery Services.

the discovery of resources using an enhanced textual search. This interface aims to provide a 'mass market' interface to repositories of EO resource metadata that is dedicated to human access.

The Internet Discovery Service is specified by the OpenGIS OpenSearch Geospatial Extensions (OGC 09-084r1) which is, conceptually, independent and complementary to the OGC CSW), but may be mapped to the OGC CSW service interfaces as one implementation option.

A further evolution of this specification is being prepared by OGC as 'OpenSearch GeoSpatial and Temporal Extensions' (OGC 10-032r3) which is an extension of OpenSearch 1.1. This document will supersede OGC 09-084r1. In this proposal, a request returns Atom 1.0.[37] An important difference to the HMA Discovery Services is that it is not based on SOAP, which implies that HMA Identity Management should be applied (see section 4.7) using a web SSO checkpoint mechanism as explained in Chapter 8 of OGC 07-118r8, and supported by Shibboleth,[38] OpenAM[39] (formerly OpenSSO) or other web SSO implementations.

In addition to the above extensions, an 'OpenSearch Extension proposal for Earth Observation Products'[40] has been put forward. In this EO extension, the names of additional search parameters

[37] Atom is the name of an XML-based web content and metadata syndication format. See *www.atomenabled.org/developers/syndication/* for further information.
[38] *http://shibboleth.internet2.edu/*
[39] *www.forgerock.com/openam.html*
[40] See the GENESI-DEC website at *www.genesi-dec.eu/news/?id=117*

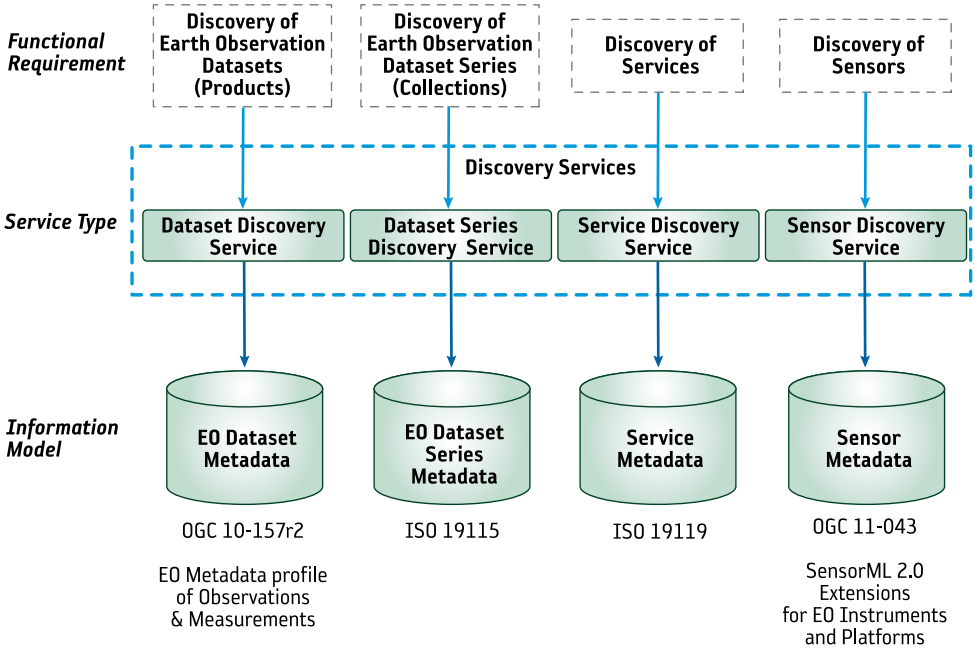
have been aligned with the OGC 06-080 standard. It defines platform, sensorType, instrument, resolution, orbitNumber, acquisitionStation, processingCentre, processingSoftware and processingDate as additional search parameters. This extension would typically return results of type HTML or Atom, but in principle EO product metadata in a GML representation according to OGC 06-080 or OGC 10-157r2 could be returned as well.

For simplicity, this special type of discovery service is not contained in the figures on the HMA Discovery Services.

5.4.2 Relevant Information Models

Figure 5.5 illustrates the connections between the four types of discovery services and the information models specified in the HMA Information Viewpoint (Chapter 4):

Figure 5.5. Usage of information models by the HMA Discovery Services.



1. The Dataset Discovery Service relies upon the EO profile of the O&M model (OGC 10-157r2) as presented in section 4.3.1.
2. The Dataset Series Discovery Service relies upon a subset of ISO 19115 and its mapping to the ebRIM information model as presented in section 4.4.2.1.
3. The Service Discovery Service relies upon a subset of ISO 19119 and its mapping to the ebRIM information model as presented in section 4.4.2.2.
4. The Sensor Discovery Service relies upon the 'EO Profile of SensorML for Discovery' as presented in section 4.3.4.

Note that, in addition, there is a dependency on the identity and access management information models as some of the Discovery Services require the inclusion of the SAML token to filter access (see section 4.7.2).

5.4.3 Description of the Discovery Services

These services are described in Table 5.4.

Table 5.4. Description of the Discovery Services.

Name	Discovery Services
Standard service specifications	— OGC Catalogue Services Implementation, Version 2.0.2 (OGC 07-006r1) — OGC Catalogue Services for the Web (CSW) – ebRIM Registry Service, Part 1: ebRIM profile of CSW (OGC 07-110)
Description	The Discovery Services are based upon implementations of the OGC CSW. Catalogues are intended to store metadata describing resources published by providers and allow clients to find these resources (OGC 10-189r2). These resources metadata are organised in catalogues according to specific data models, in this case based upon the RIM. The CSW ebRIM Registry Service is a profile of the OGC Catalogue Services Implementation, Version 2.0.2. It applies the following CSW interfaces to the OASIS ebXML RIM: — Service Metadata Interface: Provides information about both common and EO-specific capabilities. — Registry Service Interface: Provides the catalogue operations.
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an instance of the HMA Discovery Service.
Registry Service Interface	
DescribeRecord	Returns information model(s) and type definitions supported by the catalogue.
GetRecords	This is the search operation of the catalogue. It returns all or some items in a result set.
GetRecordsById	Returns a representation of a registry object by its identifier.
GetDomain (optional)	Returns a description of the value domain for a specified data element or request parameter.
GetRepositoryItem	Returns a repository item corresponding to an intrinsic object.
Harvest (optional)	Realises the pull style of registration of catalogue content. A resource is retrieved from a remote location and inserted into the catalogue.
Transaction (optional)	Allows direct insertion, update or deletion of catalogue content.

As mentioned above, there are extension packages for the CSW-ebRIM application profile, depending on the resources to be discovered:

— one extension package (OGC 10-189r2, formerly OGC 06-131r6) is dedicated to the discovery of datasets (products);

— another (OGC 07-038) is dedicated to the discovery of dataset series (collections) and services; and
— one last extension package (OGC 09-163) is dedicated to the discovery of sensors.

These extension packages comprise the same set of operations. They differ only in the use of metadata models as described in the following subsections.

5.4.4 Description of the Dataset Discovery Service

The discovery of datasets (products) is achieved by a CSW extension package of the ebRIM application profile that is dedicated to EO products (OGC 06-131r6). This extension package relies upon the EO Metadata Profile of Observations and Measurements (OGC 10-157r2) (see section 4.4.2.3). It ensures that the EO products profile supports access to product metadata.

The HMA system architecture defines this profile as a standardised interface for the Catalogue Service. Documents describing EO products using the EO Metadata Profile of Observations & Measurements are made accessible as repository items and can be discovered using the metadata elements of the RIM structure. Note, however, that in most cases these documents are generated on-the-fly as most catalogues are implementations of gateways to legacy catalogues using other internal formats.

5.4.5 Description of the Dataset Series Discovery Service

Dataset series are described by means of an RIM-based metadata model, i.e. dedicated extrinsic objects of RIM are specified. The extrinsic object specification relies upon elements of ISO 19115 (section 4.4.2.1). Hence, dataset series metadata documents are made available as repository items and can be discovered using the metadata elements of the RIM structure.

Consequently, dataset series are discovered by means of the CSW-ebRIM Profile for the Cataloguing of ISO Metadata (OGC 07-038), usually referred to by the acronym CIM. The CIM profile extends the OASIS ebRIM Registry Service for the management of ISO 19115 metadata. This is done via the mapping of ISO 19115 to the RIM structure (see section 4.4.2).

It should be noted that dataset series can also be discovered by first discovering sensors (see section 5.4.7) and, second, based upon

the discovered sensor metadata, finding the associated dataset series. Indeed, the dataset series and sensor metadata are related and this relationship is available inside the ebRIM model used for discovery as well.

5.4.6 Description of the Service Discovery Service

HMA services are described by means of an RIM-based metadata model, i.e. dedicated extrinsic objects of RIM are specified. The extrinsic object specification relies upon elements of ISO 19119 (section 4.4.2.2). Hence, service metadata documents are made available as repository items and can be discovered using the metadata elements of the RIM structure.

Consequently, services are also discovered by means of CIM – the CSW-ebRIM Profile for the Cataloguing of ISO Metadata (OGC 07-038) – extending the OASIS ebRIM Registry Service for the management of ISO 19119 metadata. This is done via the mapping of ISO 19119 to the RIM structure (see section 4.4.2).

Note especially that the original specification of the CIM profile does not address the requirements of INSPIRE. Therefore a dedicated INSPIRE conformance class for this CIM profile has been formulated (OGC 08-197r4). It summarises the conceptual work on the interoperability between CIM and the INSPIRE Discovery Service (INSPIRE DS). The 'INSPIRE Conformance Class' of the CIM EP restricts the number of *RegistryObjects*.

As for future developments, the discovery use case for end users foresees a cascading catalogue architecture, where the Catalogue Service of a higher level forwards requests to Catalogue Services in the ground segment level. To support this functionality, further specification work is needed on the OGC CSW Catalogue Service for supporting asynchronous interactions with Catalogue Services such that partial results may already be returned before an integrated query result from all underlying catalogues is available. Further change requests for the support of distributed environments have been formulated in OGC and will be taken into account for the next version of the OGC Catalogue Service Implementation Specification: CSW 3.0 (OGC 08-086).

5.4.7 Description of the Sensor Discovery Service

The discovery of sensors is achieved by a CSW extension package for the ebRIM application profile that is dedicated to sensor descriptions (OGC 11-043). The elements of these sensor descriptions

are extensions of SensorML 2.0 that are dedicated to EO instruments and platforms as described in section 4.4.2.4.

5.4.8 Description of the Internet Discovery Service

This lightweight discovery service (Table 5.5) can be used to discover any of the above resource types based on a simple HTTP GET request, which is a textual search using search terms possibly extended with some structured search criteria such as a bounding box (bbox), geometry, user identity (uid), latitude (lat), longitude (lon), radius, relation or name.

Table 5.5. Description of the Internet Discovery Service.

Name	Internet Discovery Services
Standard service specifications	— OpenGIS OpenSearch Geospatial Extensions Draft Implementation Standard (OGC 09-084r1)[41] — OASIS OpenSearch – Search Web Services searchRetrieve Operation: Binding for OpenSearch, Version 1.0 (OASIS OpenSearch, 2008)
Description	The Internet Discovery Service is based upon implementations of the Geospatial Extensions of OpenSearch. Catalogues are intended to store metadata describing resources published by providers and allow clients to find these resources. The interface is an extension of the OpenSearch 1.0 specification. It defines the following interfaces: — Service Metadata Interface — Registry Service Interface
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an instance of the service. This is done through an OpenSearch Description Document which contains a URL template and advertises the available response formats. It instructs a client application on how to issue queries to the service. The URL template represents a parameterised form of the URL.

[41] This document will be superseded by OGC 10-032r3, which also includes temporal extensions.

Name	Internet Discovery Services
Registry Service Interface	
GetRecords	This is the search operation of the catalogue. It returns all or some items in a result set according to the MIME type corresponding to the URL used. The URL to be used to perform the search is defined as a template in the OpenSearch Description Document. In this template, the search clients are to replace the parameters (e.g. searchTerms, startPage, geo:bbox, etc.) by actual values. Preferred formats for results are XML, KML (Keyhole Markup Language), and GeoJSON[42], a geospatial extension of the JavaScript Object Notation that allows the programmer to encode a variety of geographic data structures such as Point, LineString, Polygon, MultiPoint, MultiLineString and MultiPolygon.

5.5 Invoke Services

5.5.1 Overview

The purpose of the Invoke Services is three-fold:

1. They allow client applications actively to request the future acquisition of data products by spaceborne EO systems. The intention is to support the programming process of EO sensor systems that can be supported by many satellite data providers, most of which have existing facilities for the management of these programming requests.
2. They support the ordering of EO datasets. Three basic use cases are considered:
   (a) Discovery-based ordering: The order request results from dataset collections that have been discovered by a client through a search in a catalogue based upon the Dataset Discovery Service (see section 4.4.2.1 and section 5.4.4).
   (b) Programming-based ordering: The order request results from the programming of future data acquisitions.
   (c) In addition, they support the subscription to EO products. This means that the service allows clients to specify orders for bulk products with given characteristics in given areas of interest and to receive these products periodically as soon as they are available.

[42] *http://geojson.org*

3. They support the invocation of any kind of (geospatial) information processing, e.g. the execution of simulation models or geostatistical calculations of observations and measurements.

In the HMA Invoke Services such programming, ordering and processing requests are conceptualised in the term 'task' and specified by means of tasking request and associated tasking parameters. The target system for which such a task is defined is referred to by the general term asset. In an HMA service network an asset, in most cases, refers to (EO) sensors; however, it may also refer to simulation components as a kind of 'virtual sensor'. Therefore, the more general term asset is used.

In addition to the management of tasks the service also enables checking in advance whether or not a task may be executed at all by a service instance, depending upon its current state and its associated resources, e.g. the asset itself but also operators, support units, radio links, etc. This check is called feasibility analysis. Furthermore, at the same time as requesting a feasibility check, the potential task can be reserved. A successful task reservation blocks all resources required to execute the task for a certain amount of time. This is useful for ensuring that assets from different services can be tasked together.

HMA specifies the following types of Invoke Services:

— Feasibility Analysis Service (including the function to request future data acquisition and programming).
— Ordering Service.
— Processing Service.

These are further described in the following subsections.

Technically, the HMA Invoke Services are defined as compatible extensions of the OGC Sensor Planning Service (SPS) Implementation Standard, Version 2.0 (OGC 09-000) resulting in the EO-SPS Version 2.0, the SPS Earth Observation Satellite Tasking Extension (OGC 10-135) and the OGC Web Processing Service 1.0 (OGC 05-007r7). The EO-SPS defines data models as well as additional service operations that can be used, for example, for the tasking of spaceborne EO systems (assets).

5.5.2 Relevant Information Models

The HMA Invoke Services rely upon the following information models as illustrated in Fig. 5.6:

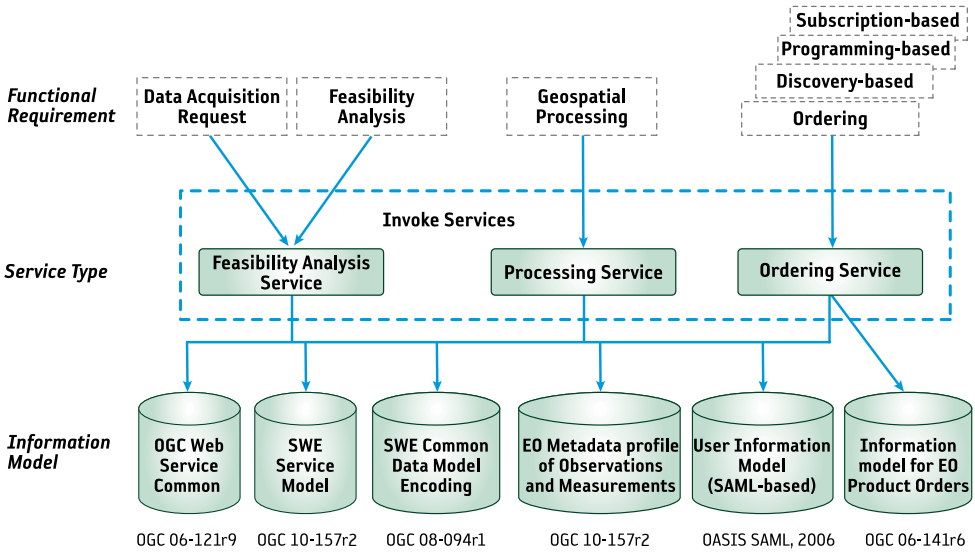


Figure 5.6. Usage of information models by HMA Invoke Services.

1. OGC Web Services Common Standard v2.0 (OGC 06-121r9) as presented in section 4.4.1.
2. SWE Service Model Implementation Standard v2.0 (OGC 09-001) as presented in section 4.4.2.
3. Earth Observation Metadata Profile of Observations and Measurements (OGC 10-157r2) as presented in section 4.2.5.
4. SWE Common Data Model Encoding Standard v2.0 (OGC 08-094r1). As described in the note at the end of section 4.2.6, the elements of this information model were extracted from SensorML Version 1 (OGC 07-000) where they were originally defined.
5. User management information model with SAML-based assertions about identities as presented in section 4.5.2.
6. Information model for EO Product Orders (OGC 06-141r6) as presented in section 4.4.2.4.

5.5.3 Description of the Feasibility Analysis Service

This service is described in Table 5.6.

Table 5.6. Description of the HMA Feasibility Analysis Service.

Name	Feasibility Analysis Service
Standard service specifications	— Sensor Planning Service Interface Standard 2.0 Earth Observation Satellite Tasking Extension, Version 2.0 (OGC 10-135) — Sensor Planning Service Implementation Standard, Version 2.0 (OGC 09-000)
Description	The Feasibility Analysis Service is defined as an extension of the OGC Sensor Planning Service (SPS). The OGC SPS provides a standard interface to task any kind of sensor to retrieve collection assets (i.e. sensors and other information-gathering assets). Furthermore, a client can either determine collection feasibility for a desired set of collection requests for one or more sensors/platforms, or submit collection requests directly to these sensors/platforms. Different kinds of assets with differing capabilities as well as different kinds of request processing systems are supported. The EO-SPS application profile is flexible enough to handle the variety of programming needs of most EO satellite systems. This means in particular the ability to support different configurations to access the different stages of planning, scheduling, tasking, collection, processing, archiving and distribution of requests, and the resulting observation data. The Feasibility Analysis Service provides its functionality through the following interfaces: — Service Metadata Interface: Provides information about both common and EO-SPS-specific capabilities. — Tasking Status Interface: Provides information about sensors and the status of the tasking of EO sensors. — Tasking Management Interface: Provides a set of operations to task EO sensors.
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an EO-SPS instance. This operation also supports negotiation of the specification version being used for client–server interactions. Moreover, the content section of this operation contains the list of sensor identifiers provided by the EO-SPS instance.
Tasking Status Interface	
DescribeSensor	Allows the client to obtain a description of the sensors supported by the current SPS. The mission can decide on the level of detail provided in such a description. This operation should return metadata for EO sensors as described in section 4.3.4.

Name	Feasibility Analysis Service
DescribeTasking	Allows a client to request the information that is needed in order to send GetFeasibility (for a feasibility study), Submit, Update and Reserve (for tasking the asset) requests. The response contains a description of the input (tasking parameters) and optionally the output parameters included in status reports.
DescribeResult Access	Allows a client to retrieve information on how and where data produced by the sensor can be accessed. The server response may contain links to any kind of data and not necessarily through an HMA Online Data Access Service, whereby this is the desired option.
GetSensor Availability (optional EO-SPS extension)	Provides information on the availability of the sensor. An EO system may not be available over a period of time for different reasons such as workload, maintenance, etc. This operation allows the client to obtain a preview of the periods of availability of a sensor before a feasibility study is requested. The granularity of the information provided is up to the data provider, which can choose to describe its exact workload or simply list approximate periods of availability.
GetStatus	Allows a client to receive information about the current status of the requested task. The response contains a progress report, the content of which is defined in the DescribeTasking response.
Tasking Management Interface	
GetFeasibility	Informs a client about the feasibility of a programming (tasking) request. Depending on the sensor type offered by the EO-SPS instance, the SPS server action may be as simple as checking that the request parameters are valid and are consistent with certain business rules, or it may be a complex operation that calculates the usability of the sensor to perform a specific task at the defined location, time, orientation, calibration, etc.
Submit	Submits a programming (tasking) request. Depending on the selected sensor, it may perform a simple modification of the sensor or start a complex mission.
Cancel (optional)	Allows a client to request cancellation of a previously submitted task.
Update (optional)	Allows a client to update a previously submitted task.
Reserve (optional)	Reserves a task for a future execution triggered by a Confirm operation. A reservation lasts for a certain amount of time and can be committed during this timeframe.
Confirm (optional)	Used to commit a reserved task. By committing a reserved task the EO-SPS starts to execute the task, possibly at a later time.
Validate (optional EO-SPS extension)	Used by a client to indicate to the EO-SPS server that an acquisition is satisfactory and thus to stop collecting new images for this area. This operation is necessary as several acquisition attempts are sometimes necessary to obtain a satisfactory result, e.g. in the case of optical satellites over zones with a tendency to be cloudy.

5.5.4 Description of the Ordering Service

This service is described in Table 5.7.

Table 5.7. Description of the HMA Ordering Service.

Name	Ordering Service
Standard service specifications	— OGC 06-141r6 (Ordering Services for Earth Observation Products Interface Standard) v1.0.0; aligned with — Sensor Planning Service Implementation Standard, Version 2.0 (OGC 09-000)
Description	The Ordering Service supports the ordering of EO datasets (products). Its interfaces are analogous to those of the Feasibility Analysis Service as both rely upon the operations of the OGC SPS. The Ordering Service only supports a subset of the SPS operations. These operations are interpreted according to the two basic use cases of discovery and programming-based product ordering: — Service Metadata Interface: Provides information about both common and specific capabilities and service options. — Ordering Status Interface: Provides information about the product ordering status. — Ordering Management Interface: Provides operations for product ordering management (submit and cancel).
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an HMA Ordering Service instance.
GetOptions	Allows clients to retrieve the options for issuing an order: — in case of product ordering it returns the options for ordering a specific type of product; — in case of ordering from tasking requests it returns the processing and delivery options for ordering the future products coming from the tasking request; — in the case of subscriptions it returns the possible parameters to set for specifying the scope of the subscription (e.g. the area of interest, expiration date, etc.).

Name	Ordering Service
GetQuotation (optional)	Allows the client to get a quotation of either the order or the tasking request or the subscription to be issued. As the response time of this operation may vary quite considerably, the operation supports several interaction models. It may be carried out in the following ways: — As a synchronous request/response interaction, i.e. the quotation is directly returned in the response of the GetQuotation request. — As an asynchronous interaction via notification, i.e. the client provides a call-back operation (GetQuotationResponse) which is called by the server when the quotation is available. — As a synchronous interaction via monitoring, i.e. after the first activation, in which the client specifies all order parameters, the client has to repeat it until the server is able to return the quotation. — As an off-line interaction, i.e. the quotation is delivered via a separate messaging system, e.g. electronic mail.
Ordering Status Interface	
DescribeResult Access (optional)	According to the SPS, this operation allows a client to retrieve information on how and where data produced by an asset can be accessed. The HMA Ordering Service uses this operation to access the ordered products in the case of an online delivery.
GetStatus	Allows a client to receive information about the current status of the requested task, here the submitted orders or the status of subscribed subscriptions.
Ordering Management Interface	
Submit	According to the SPS, this operation allows a client to submit a programming (tasking) request. The HMA Ordering Service uses this operation either to submit an order for products (selected from an EO catalogue or resulting from a programming request), or to subscribe to an EO product. Typically, this operation is asynchronous in that the client has to implement a call-back operation (SubmitResponse) in order to get the result.
Cancel (optional)	Allows a client either to ask for the cancellation of an already submitted order or to cancel a product subscription. Typically, this operation is asynchronous in that the client has to implement a call-back operation (*CancelResponse*) in order to get the response.

5.5.5 Description of the Processing Service

Currently, the Processing Service just provides core functionality to describe and execute processing operations. It is being extended to support additional 'transactional' use cases such as the deployment of processes, data and auxiliary data. These extensions will be aligned with the forthcoming OGC Web Processing 2.0 specification. In order to provide a comprehensive presentation, these extensions

are already included (according to current knowledge) in the service description in Table 5.8 but marked as V2.

Table 5.8. Description of the HMA Processing Service.

Name	Processing Service
Standard service specifications	— Web Processing Service, Version 1.0 (OGC 05-007r7) — Corrigendum for OpenGIS Implementation Standard Web Processing Service (OGC 08-091r6) V2: — Web Processing Service: Core Operations Implementation Standard, Version 2.0 (to be published) — Web Processing Service: Enhanced Operations Implementation Standard, Version 2.0 (to be published) — Web Processing Service: Transactional Operations Implementation Standard, Version 2.0 (to be published) — Web Processing Service: Processing on Demand Operations Implementation Standard, Version 2.0 (to be published) — Pending change requests to be assessed by the WPS 2.0 Standards Working Group including: – OGC 08-123 WPS-T Discussion Paper – OGC 09-109 change request – methods for controlling, and checking the status of asynchronous process
Description	The Processing Service supports on-demand processing of EO datasets. It provides its functionality through the following interfaces: — Service Metadata Interface: Provides information about both common and WPS-specific capabilities. — Processing Core Interface: Provides information about the executable processing operations and the operation to start their execution. V2: — Processing Enhanced Interface: Enables the retrieval of status information about an executing process and to cancel the process. — Processing Transactional Interface: Enables the dynamic deployment and undeployment of a process by means of a process description and a deployment profile. — Processing on Demand Interface: Supports the deployment and undeployment of auxiliary data and the means to get an execution trace.
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of a WPS instance. This operation also supports negotiation of the specification version being used for client–server interactions.

Name	Processing Service
Processing Core Interface	
DescribeProcess	Requests and receives detailed information about one or more processing operation(s) that can be executed by an execute operation, including the input parameters and formats, and the outputs.
Execute	Executes a specified processing operation implemented by the Processing Service, using provided input parameter values. The process can be executed synchronously or asynchronously. In the latter case, the client can retrieve the processed values at the specified location.
Processing Enhanced Interface (V2)	
GetStatus	Retrieves information about the current status of a process. Such information includes the progress of an executing process.
Cancel	Allows a client to terminate execution of the specified process.
Processing Transactional Interface (V2)	
DeployProcess	Dynamically deploys a process along with its description and deployment profile in a WPS service instance. The deployment profile document contains (an archive with) the process executables along with any other relevant information required to execute the process.
UndeployProcess	Dynamically undeploys a previously deployed process. The corresponding process description and deployment profile are removed.
Processing on Demand Interface (V2)	
DeployData	Dynamically deploys auxiliary data needed by one or several processes along with a description and deployment profile in a WPS service instance. The deployment profile document contains (an archive with) the auxiliary data.
UndeployData	Dynamically undeploys previously deployed auxiliary data. The corresponding data description and deployment profile are removed.
DescribeData	Provides detailed information about (one or several) previously deployed auxiliary data. In particular ISO 19139 metadata related to the auxiliary data is provided.
GetAudit	Retrieves the process execution trace in two forms. The short form provides a trace of all the processing that was spawned by a given process instance (e.g. a workflow) and is needed to discover (recursively) a processing tree/ hierarchy (e.g. nested workflows). The long form provides the full execution trace of a given process instance.

5.6 Online Data Access Services

5.6.1 Overview

The HMA Online Data Access Service supports the access and presentation (viewing) of EO datasets. This is achieved by two HMA services that are defined as application profiles of generic OGC Web Service specifications dedicated to EOs:

1. Download Service: an EO application profile of the OGC Web Coverage Service (EO-WCS) dedicated to the access of EO datasets (OGC 10-140).
2. View Service: an EO application profile of the OGC Web Map Service (EO-WMS) dedicated to the presentation of EO datasets (OGC 07-063r1).

The Download Service is designed to provide an efficient retrieval of EO datasets. In order to save bandwidth on network and storage space on the client side it supports subsetting, i.e. it enables the retrieval of just those parts of EO datasets that are of interest for a specific purpose. The requested parts may be defined by spatial and/or temporal constraints ('bounding boxes') as well as by band constraints.

In addition to the OGC WCS 2.0 core functionality (OGC 09-110r3) the HMA Online Data Access Service requires the implementation of the following extensions:

— subsetting based on wavelength bands;
— scaling and interpolation;
— support of the EPSG Coordinate Reference Systems (CRS);
— support of at least one of the WCS 2.0 coverage format encodings, such as GeoTIFF, Network Common Data Form (NetCDF) or JPEG 2000; and
— support of at least one of the WCS 2.0 protocol binding extensions GET/KVP or SOAP.

Note that an implementation of this WCS application profile may use conventional back-end interfaces to data archive servers such as a file transfer mechanism based upon the Internet File Transfer Protocol (FTP). This, however, is not part of any of the specifications and represents an implementation-specific detail.

Furthermore, note that the WCS 2.0 specification is based on the core and extension model for OGC specifications. Since currently not all extensions are available fully to support the EO-WCS, a transitional provision has been applied. It states that for each specification not yet available the WCS 1.1 Corrigendum 2 (OGC 07-067r5) shall apply until the respective specifications are officially adopted by OGC. This transition mechanism ensures that EO-WCS implementations will be functional and interoperable by adhering to OGC standards.

By utilising the appropriate parameters (i.e. scaling via size or resolution) in *GetCoverage* requests, an EO-WCS-enabled client may provide a View Service based directly on an EO-WCS.

The View Service is dedicated to the presentation of EO datasets and is defined as an application profile of the OGC WMS. Using

OGC WMS technology to present EO datasets for evaluation is not straightforward as EO products often contain far more information than can easily be presented in a single, static view. The WMS profile for EOs allows for basic (default) representation of and interaction with EO products in an interoperable way. It is, for instance, important to potential users that they can evaluate EO products prior to ordering and (if desirable) purchase.

5.6.2 Relevant Information Models

The HMA Online Data Access Service relies upon the following information models as illustrated in Fig. 5.7:

1. The service metadata model is compliant with OGC Web Service Common (OGC 06-121r9), see section 4.2.1.
2. The modelling approach of coverages complies with the definitions of ISO/OGC (ISO 19123, OGC 07-011) as described in section 4.2.5.
3. GML Application Schema for Coverages (OGC 09-146r1) as described in section 4.2.5 as well.
4. GML Application Schema for Coverages (OGC 09-146r1) relies upon the definition of the OGC SWE Common Data Model (OGC 08-094r1) as described in section 4.2.2.
5. GML extensions for EO-specific aspects of the modelling and handling of coverages are defined in the section 'EO data model' of the Earth Observation Application Profile of the OGC WCS 2.0 itself (OGC 10-140). For instance, when a coverage is downloaded by a *GetCoverage* or *DescribeCoverage* operation of the WCS 2.0 (OGC 09-110r3), the response contains a metadata element following the Earth Observation Metadata Profile of Observation and Measurements (OGC 10-157r2) that describes the coverage. The structure of this metadata element is defined in OGC 10-140.
6. For the presentation of EO datasets the metadata model of the OGC Web Map Service application profile for EO products (OGC 07-063r1) is used. In particular, it supports the handling of multi-dimensional data as described in section 4.3.3.
7. When the *GetFeatureInfo* operation of the EO Application Profile of WMS (OGC 07-063r1) is applied to the outline (footprint layer), it shall return metadata whose structure follows the Earth Observation Metadata Profile of Observation and Measurements (OGC 10-157r2) as described in section 4.3.1.

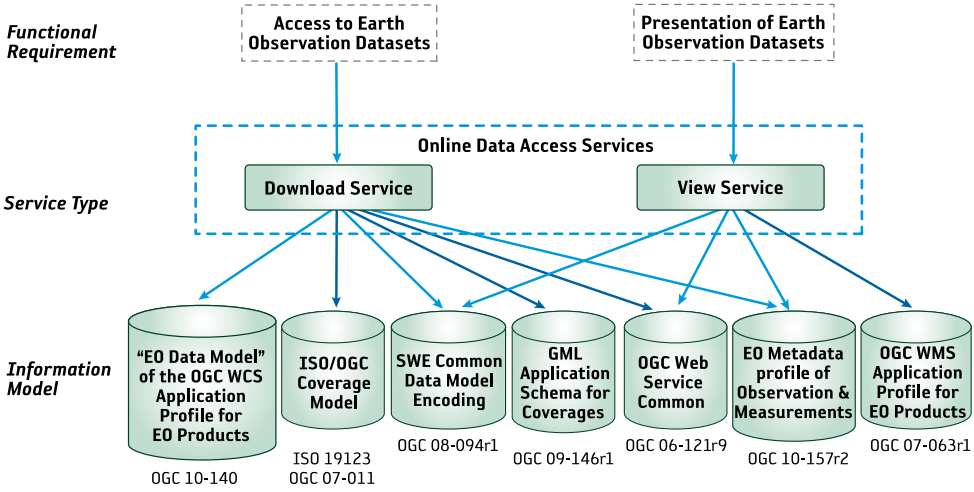


Figure 5.7. Usage of information models by HMA Online Data Access Services.

5.6.3 Description of the Download Service

This service is described in Table 5.9.

Table 5.9. Description of the HMA Download Service.

Name	Download Service
Standard service specifications	OGC Web Coverage Service 2.0: Application Profile – Earth Observation (OGC 10-140). This application profile requires that, in addition to the WCS 2.0 core functionality (OGC 09-110r3): — at least one protocol extension (e.g. GET/KVP or SOAP) and — at least one coverage format encoding (GeoTIFF, NetCDF or JPEG 2000) shall be supported.
Description	The Download Service supports access to EO datasets. It comprises the following interfaces: — Service Metadata Interface: Provides information about both common and specific capabilities. — OGC Web Coverage Service (WCS) Application Profile – Earth Observation Interface: Specialises the generic OGC WCS interface for an efficient retrieval of EO datasets by adding additional requirements (additions and constraints).
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an HMA Download Service instance. In addition to OGC WCS 2.0, the capabilities document defined by this application profile allows the inclusion of DatasetSeriesSummary elements besides the usual CoverageSummary elements in the Contents section which identifies those dataset series that are provided by the WCS instance.
WCS Interface for EOs	
DescribeCoverage (WCS core)	Allows a client to request detailed metadata on selected coverages that are offered by a server. The metadata comprises information about the domain and the range of coverage as well service-specific parameters. EO-WCS adds the mandatory inclusion of EO metadata following the Earth Observation Metadata Profile of Observation and Measurements (OGC 10-157r2) for each coverage. In addition, the server may indicate which GML functions can be used to retrieve range values at given coverage locations and application-specific metadata.

Name	Download Service
GetCoverage (WCS core)	Allows a client to request a coverage defined by selected range properties at a selected set of spatio-temporal locations (e.g. specified by means of a bounding box). Usually, the response is a data structure whose type is the same subtype of *gmlcov*: *AbstractCoverage* that the requested coverage has. Alternative encoding types are pure GML (not recommended for EO coverages), some well-known data formats (such as GeoTIFF, JPEG 2000 or NetCDF), or as a GML envelope together with a separate file in some well-known coverage data format (e.g. GML envelope with enclosed GeoTiFF as multipart/related file). As an extension to WCS 2.0, EO-specific metadata elements are returned. In particular, a provenance entry is appended to the lineage record to denote that the processing of the *GetCoverage* step was performed.
DescribeEO CoverageSet (EO application profile)	Submits a Dataset Series, Stitched Mosaic, or Dataset identifier together with a spatio-temporal subsetting criterion ('bounding box'). The response to a successful request on a Dataset Series consists of a (possibly empty) set of descriptions of Datasets and Stitched Mosaics and a (possibly empty) set of descriptions of Dataset Series. The response to a successful request for a Stitched Mosaic consists of a (possibly empty) set of descriptions of Datasets. In any case, the result items are those which are (i) referred to by the object submitted and (ii) matched by the bounding box. The type of matching – contains or overlaps – is specified in the request.

5.6.4 Description of the View Service

This service is described in Table 5.10.

Table 5.10. Description of the HMA View Service.

Name	View Service
Standard service specifications	OGC Web Map Service (WMS) level-1 profile[43] for EO products (OGC 07-063r1). Basically, this application profile refines the WMS metadata model and defines some additional constraints on the use of the operations defined by the OGC WMS Version 1.3 (OGC 06-042).
Description	The View Service supports the presentation of EO datasets. It comprises the following interfaces: — Service Metadata Interface: Provides information about both common and specific capabilities. — OGC WMS Interface with additional constraints defined by its application profile for EO products.
Service Metadata Interface	
GetCapabilities	Informs the client about both common and specific capabilities of an HMA View Service instance. The EO-specific aspects of the WMS capabilities are defined by the WMS application profile for EO products (OGC 07-063r1). For instance, it requests that for EO datasets a LAYER service metadata element shall be used to represent each dataset series/dataset type. For example, all products of type 'MERIS instrument, Level-1b, Reduced Resolution' would be described as a dataset series and represented by a single LAYER element in the service metadata of a View Service instance.
WMS Interface for EOs	
GetMap	Returns a map of spatially referenced geographic and thematic information as an image document. Map-specific request parameters determine the list of desired layers and their styles, the corners of the bounding box in which the layers should be positioned, the coordinate reference system used as well as the colour of the background. Some characteristics of the output image may be determined by the client application. They comprise the desired output format, the width and height of the image (in pixels) as well as whether the map background should be made transparent or not. Furthermore, there are two optional parameters elevation and time that allow the client to refine the request if some geographic information is available at multiple elevations (e.g. ozone concentrations at different heights in the atmosphere) or at multiple times (e.g. an optical satellite photo taken on different dates).

[43] Level-1 profiles provide only specific use cases without extensions or changes.

Name	View Service
	Note that the OGC Styled Layer Descriptor (SLD) specification defines a mechanism for user-defined symbolisation of feature data instead of layers and styles. In this case, an SLD-enabled WMS retrieves feature data from an OGC Web Feature Service (WFS) and applies explicit styling information provided by the user in order to render a map.
GetFeatureInfo (optional)	Returns information about the features rendered in a certain point of a map layer as a document. The request must specify the attributes of the query point (x and y coordinates of the point in the image coordinate system, the layer name and the number of features for which information is expected) as well as a copy of the (GetMap) request that generated the image.[44]

[44] This is required because the WMS instance behaves in a stateless manner.

→ OUTLOOK AND CONCLUDING REMARKS

6. Outlook and Concluding Remarks

6.1 Selected Examples of Next Steps

This 'HMA cookbook' relies upon HMA specifications that are available and agreed upon as of 2011. Implementations of the present HMA architecture either are operational in practice or have a prototype status.

Apart from operational tests, adaptations to new technologies, as well as the problems of how to govern the maintenance process of HMA specifications (see section 6.2) and how to optimise the implementations in order to deal efficiently with large datasets, there are some significant conceptual questions which still need research to be considered as new or extended elements of the HMA architecture.

This outlook for the next steps of HMA can only cover a small portion of what will happen. The following points have been selected:

- *Conformance testing and reference implementations:* Online conformance testing should help organisations to check conformance of their implementations with the corresponding HMA specifications. This is discussed in section 6.2.1.
- *Ontology access and management:* If ontologies are used more and more in the EO community to improve semantic interoperability, how can they be included in the SOA? This is discussed in section 6.2.2.
- *Processing service and cloud computing:* Processing on demand is a breakthrough in support of the scientific research process, in the processing of global datasets and in the validation of algorithms for scientific missions (Pinto et al., 2011). See section 6.2.3.
- *Service-oriented analysis and design (SOAD) methodologies:* If the HMA architecture is used as a 'standard' geospatial service platform to realise future EO requirements, there is a need for an agreed methodology of how to develop new applications on the basis of the HMA capabilities. This is discussed in section 6.2.4.

6.1.1 Conformance Testing and Reference Implementations

The OGC Compliance and Interoperability Testing and Evaluation Initiative (CITE),[45] is an ongoing initiative that develops tests for

[45] *http://cite.opengeospatial.org*

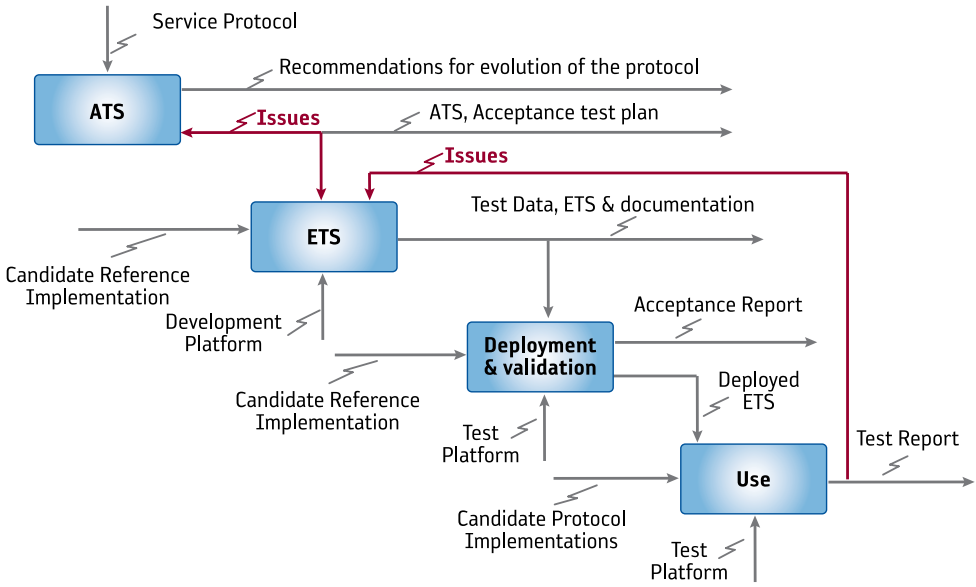


Figure 6.1. CITE tests for OGC-based protocols

OGC standards, and makes these tests available for online testing over the Internet. As part of the HMA initiative, efforts are under way to make online tests available to the community for the various OGC specifications adopted by HMA and corresponding reference implementations. [46]

The OGC compliance testing consists of the definition of an Abstract Test Suite (ATS) which defines the appropriate test design, and test cases which are subsequently implemented using an OGC-defined test script language called 'CTL' (Conformance Test Language). The ATS can typically be found in the OGC specification document itself as a separate chapter. The resulting set of executable test scripts is called the 'Executable Test Suite' (ETS) in OGC jargon. CTL is defined as an OGC specification (OGC 06-126r2), and past and current HMA projects are contributing CTL tags for support of SOAP and asynchronous communication based upon WS-Addressing. In addition, HMA projects are implementing the ETS in an open-source OGC test script interpreter called 'TEAM engine'.

Figure 6.1 illustrates how the ATS and ETS artefacts that are typical for OGC compliance testing fit into a typical software life cycle as defined by the ECSS.

[46] *http://rssportal.esa.int/tiki-index.php?page=Open%20Software*

6.1.2 Ontology Access Service

The use of Semantic Web technologies has already been described in section 4.6 under the heading 'Semantic Annotations'. Semantic annotation pursues an approach to specify the meaning of elements in a data or metadata element by pointing to the concepts of an ontology, or at least an agreed vocabulary. It is based upon the assumption that an ontology represents the shared knowledge of a community, e.g. a thematic expert group or an international expert initiative, in terms of a 'conceptualisation'. However, since on the one hand there is no single ontology for a given thematic domain, and, on the other hand, ontologies undergo changes and have to be maintained, it is necessary to provide the means to access and manage ontologies and integrate these means into an SOA.

For the HMA architecture this topic is discussed in the software design document of the HMA-related research project 'Semantic Web Mediated Access Across Domains (SMAAD)' (Coene & Jacques, 2011). It revisits the idea of an Ontology Access Service and a Thesaurus Access Service (OGC 07-097) and interprets them in the context of the HMA service environment and the latest technological developments.

The basic role of the Ontology Access Service was to 'support the read access to the specification of a logical ontology and to export or import a complete specification of a logical ontology into an ontology store', whereas the Thesaurus Access Service 'supports read and write access to a thesaurus that may be multi-lingual'. Thus, a thesaurus is understood to be 'a variant of an ontology restricting the relations used to a priori relationships between terms, e.g. questioning whether the meaning of two terms is similar, broader, or narrower'.

SMAAD encompasses both aspects under an HMA Ontology Access Service that is categorised as a geographic model/information management service as defined in the ISO 19119 geographic services taxonomy (see Table 5.1). However, as a first step, it assumes that the underlying ontology is restricted to a thesaurus expressed according to the Simple Knowledge Organization System (SKOS), i.e. an application of the Resource Description Framework (RDF)[47] that is targeted at defining concepts,

[47] RDF is based on the idea of making statements about resources (in particular, web resources) in the form of subject–predicate–object expressions. These expressions are known as triples in RDF terminology. The subject denotes the resource, and the predicate denotes traits or aspects of the resource and expresses a relationship between the subject and the object. A collection of RDF statements intrinsically represents a labelled, directed graph (*http://en.wikipedia.org/wiki/Resource_Description_Framework*).

their labels (i.e. expressions that are used to refer to concepts in natural language) and simple relations between concepts such as *broader*, *narrower* and *related* that further contribute to defining the meaning of a concept.

Following this basic assumption, the HMA Ontology Access Service will have the following characteristics:

- The standard interfaces to the SKOS-based thesaurus are the query language SPARQL (SPARQL Protocol And RDF Query Language) (W3C SPARQL, 2008) or resolvable URIs adhering to the Linked Data principles as an example. Most forms of SPARQL query contain a set of triples which are like RDF triples except that subject, predicate and object may each be a variable.
- The resulting 'SPARQL service' (also called SPARQL end point) is described by the metadata elements of the SPARQL 1.1 Service Description (W3C SPARQL-Serv, 2012). It denotes, for instance, the subset of the supported SPARQL language (e.g. *Query and Update*) and the format of the query result format.
- The metadata describing the thesaurus and its access methods is expressed as a Vocabulary of Interlinked Datasets (VoID) (W3C VoID, 2011). VoID is an RDF schema vocabulary for expressing metadata about RDF datasets. It is intended as a bridge between the publishers and users of RDF data, with applications ranging from data discovery to cataloguing and archiving of datasets. In addition to DublinCore metadata elements, it provides, for instance, structural metadata such as statistical information about the total number of entities, properties, classes and triples contained in the dataset.
- Furthermore, an instance of an HMA Ontology Access Service may expose an OpenSearch 1.1 interface (OpenSearch.org) to support textual searches. The OpenSearch end point returns a list of SKOS concepts and their relevance encoded according to the OpenSearch Relevance extension.[48]

Currently, the SMAAD project applies this approach to the thesaurus information provided by the EEA's GEMET and the Earth science keyword list of the GCMD (Olsen et al., 2007).

[48] *www.opensearch.org/Specifications/OpenSearch/Extensions/Relevance/1.0*

6.1.3 Processing Services and Cloud Computing

Several missions already apply grid computing and cloud computing solutions in their ground segment infrastructure to handle computation-intensive processing as close to the data as possible, thereby avoiding data transfers of large EO products and offering full scalability. A well-known example of such a processing infrastructure is ESA's Grid Processing on Demand (G-POD) infrastructure. It is an operational generic processing environment where specific data handling applications can be seamlessly plugged in for processing available EO products. Coupled with high-performance and scalable computing resources managed by grid and cloud computing technologies, it provides the necessary flexibility for building a virtual application environment with rapid accessibility to data, computing resources and results (Lee et al., 2011). It relieves[49] scientists who want to develop and run their algorithms on large amounts of EO data from the tasks of collecting and storing the data and orchestrating execution of the algorithm.

The HMA Processing Service presented in section 5.5.5 is applied as a façade to such a processing infrastructure, which can be based on the Globus toolkit or any other grid middleware supporting SAGA.[50] This will allow scientists to deploy (auxiliary) data and processes through this interface on the missions' computing infrastructure and retrieve processing results.

The next step is to use the same HMA Processing Service façade in front of a hybrid cloud which will then offer spatial Data as a Service (DaaS). The HMA Processing Service can thus be used for accessing processing capabilities in a (geospatial) cloud, such as G-POD. This is also discussed in the recent OGC White Paper 'OGC Standards and Cloud Computing' (OGC 11-036).

6.1.4 Analysis and Design Methodologies for HMA Applications

Although a reference architecture such as HMA is essential for enabling and improving the interoperability of EO services, it is not enough to guide the design of EO client applications based upon HMA. Moreover, a design methodology is required that guides the individual

[49] The full list of services and algorithms supported, success stories, procedure for access and examples are available at *http://wiki.services.eoportal.org*

[50] *A Simple API for Grid Applications*, Open Grid Forum (OGF) document GFD-R-P.90 (Jha et al., 2001).

activities of the design process and explicitly considers the service capabilities and side-conditions of HMA (Usländer et al., 2010).

There are currently numerous methodologies for SOAD, but none of them has so far reached the status of an agreed methodology in the SOA community (Kohlborn et al., 2009) or even the geospatial services community. One of the biggest challenges is the transition between the business and organisational aspects of a service-oriented approach and their realisation at the technical level, e.g. as web services, especially when aiming at reusing as much as possible the capabilities of existing service platforms, e.g. the HMA services, either at the specification level as service types, or even at the implementation level as service instances.

A design methodology for HMA client applications should be tailored to the geospatial domain. This means that such a SOAD methodology should contain knowledge about HMA information and service models, guidelines and constraints of geospatial architectures, e.g. interfaces of OGC service types. One example of such a design methodology that specifically addresses the need for a service-oriented design under these side-conditions has been proposed by Usländer (2010), whose design methodology called SERVUS is tailored to the design of information systems based upon geospatial service-oriented architectures (such as HMA) and the modelling of use cases and capabilities as resources. It describes individual design activities that are interconnected by a common modelling environment that contains the Enterprise, Information and Service Viewpoints of HMA.

6.2 How Changes to the Standards Are Managed

In order to manage the evolution and changes to the defined HMA standards, ESA, together with other relevant EO mission and data owners (national agencies, European institutions), have defined the HMA Architecture Working Group (AWG), which operates under the auspices of the Ground Segment Coordination Body (GSCB). The AWG coordinates and shares its findings with the OGC, the primary forum for the standardisation of the geospatial ground segment interfaces, and with other coordination and standardisation entities such as the CCSDS (Consultative Committee for Space Data Systems) and CEOS (Committee on Earth Observation Satellites), and it carries out regular consultations with industry and commercial missions.

Current participants in the HMA AWG, in addition to ESA, are national mission owners such as: ASI, CNES, CSA and DLR. Furthermore, Eumetsat participates in order to ensure data access

and interoperability with meteorological missions. Other participants include the EUSC (European Union Satellite Centre) as an EU institutional user of EO data, while EC-JRC ensures alignment to the INSPIRE Implementing Rules.

Other organisations might be involved depending on the use they make of the standards, like commercial data distributors or the European Maritime Safety Agency (EMSA) that has decided to use the HMA standards in the implementation of its infrastructure. The AWG tracks, collects and discusses[51] requests for changed or new requirements, coordinates future standardisation work and makes proposals for the adoption of new standards. The actual standardisation work is performed instead within the various standards working groups of the OGC.

6.3 Concluding Remarks

The potential of products that result from EO missions may only be exploited to the full if the underlying technology to discover, order and access them is easy to use, dependable, sustainable and interoperable by design. The latter points, sustainability and interoperability, require an information and communication technology (ICT) that is agreed upon in a community comprising the EO product providers, because no single provider alone can offer all the products with all the required characteristics for all regions of Earth's surface. However, in the very dynamic ICT world and market such an agreement is only possible if the architectural approach is based on internationally agreed standards, either de facto ones prepared and established by industrial communities and organisations or, even better, de jure standards such as those of ISO or CEN.

The approach of HMA motivated and presented in this book is an ambitious one that was initiated by the Ground Segment Coordination Body (GSCB, 2009) and driven by ESA to enable the interoperable use of EO products despite the heterogeneous underlying software and system environments of the individual providers.

Of course, such an architecture will never be static as both requirements and technological capabilities are changing constantly. However, there must be a reliable conceptual foundation, an architectural framework, that guides the direction of the technological evolution. It is the purpose of this book to describe this framework in a comprehensive manner.

[51] Most of the discussion material is publicly available as wiki pages and forum discussions in the Join & Share area at *http://rssportal.esa.int*

As a structural guideline the book uses the ISO Reference Model of Open Distributed Processing (RM-ODP), thus addressing the problem that a complex software and system architecture can only be understood if viewed from several perspectives in parallel. Furthermore, as the contents of a book should be of value beyond ICT product life cycles, its scope is restricted to a description of the Enterprise, Information and Service Viewpoints of HMA.

The Enterprise Viewpoint describes the business context, the standards organisations involved, the stakeholders and the most important functional requirements of HMA users. The requirements are expressed as 'use cases' which cover the following aspects:

- Authentication of users: How to identify the users?
- Authorisation: How to control the access?
- Discovery: How to search for the desired products and resources?
- Online Data Access: How to access the products?
- Data Acquisition Request: How to influence the data acquisition process?
- Geospatial Processing: How to process the products once discovered and accessed?
- Product Ordering: How to order the products that are offered?

The architecture based on HMA interoperability standards has to fulfil these requirements in a technology-independent manner. The most promising approach today is by applying the design principles of service orientation. Hence, HMA defines in its Service Viewpoint the following services as functional units with well-defined interfaces, all based upon existing or emerging standards of ISO or OGC:

- Identity Management Services for authentication and authorisation.
- Discovery Services for EO resources such as datasets, dataset series, services and sensors.
- Invoke Services to process information, perform feasibility analysis of product queries and order products.
- Online Data Access Services to download and view the products.

However, agreement on service interfaces is not sufficient for interoperability. Services just provide the 'verbs of the communication language', the headers of the messages. What is required in addition is agreement on the 'subjects and objects', i.e. agreement about the structure and contents of the messages. This means defining the Information Viewpoint in terms of data and information models and languages on how to express them (meta-models). The agreement of such languages and information models is a tedious task as, on the one hand, common terms and

vocabularies have to be found, and, on the other hand, they are highly interrelated. As for the services, HMA aims to define all information models such that they reference international standards for all resources covered by the services.

The remaining Engineering and Technology Viewpoint descriptions not addressed here may be found in complementary HMA specifications on the web maintained by the HMA community. In particular, we refer to the HMA wiki[52] that delivers the latest information about ongoing projects and includes references to the latest specifications in the form of an HMA Configuration Management Table.

[52] *http://wiki.services.eoportal.org/*

→ ANNEXES

Acronyms

ASCII	American Standard Code for Information Interchange
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ATM	Atmospheric (GML extension)
ATS	Abstract Test Suite
AWG	Architecture Working Group
Cal/Val	Calibration/Validation
CCSDS	Consultative Committee for Space Data Systems
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CENELEC	Comité Européen de Normalisation Electrotechnique (European Electrotechnical Standardization Committee)
CEOS	Committee on Earth Observation Satellites
CIM	Cataloguing of ISO Metadata
CITE	Compliance and Interoperability Testing and Evaluation
CNES	Centre National d'Etudes Spatiales (French Aerospace Center)
CRS	Coordinate Reference System
CSA	Canadian Space Agency
CSW	Catalogue Services for the Web
CTL	Conformance Test Language
DaaS	Data as a Service
DIS	Draft International Standard
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ebRIM	ebXML Registry Information Model
ebXML	Electronic business using XML
EC	European Commission
EC-JRC	European Commission Joint Research Centre
ECSS	European Cooperation for Space Standardization
ECV	Essential Climate Variables
EEA	European Environment Agency
EMSA	European Maritime Safety Agency
Envisat	Environmental Satellite (operated by ESA)
EO	Earth Observation
EO-SPS	Earth Observation Satellite Tasking Extension for the SPS
EO-WCS	Earth Observation profile of WCS
EO-WMS	Earth Observation profile of WMS
EOP	Earth Orientation Parameters/Earth Observation Product (GML extension)
EPSG	European Petroleum Survey Group
ESA	European Space Agency
ETS	Executable Test Suite
ETSI	European Telecommunications Standards Institute
Eumetsat	European Organisation for the Exploitation of Meteorological Satellites
EUSC	European Union Satellite Centre

ftp	File Transfer Protocol
FTS	Fast-Track Service
GCMD	Global Change Master Directory
GEMET	GEneral Multilingual Environmental Thesaurus
GEO	Group on Earth Observation
GeoJSON	JSON Geometry and Feature Description
GEOSS	Global Earth Observation System of Systems
(Geo)TIFF	Tagged Image File Format (for georeferenced information)
GeoXACML	Geospatial extension of the eXtensible Access Control Markup Language
GFM	General Feature Model
GIGAS	GEOSS, INSPIRE and GMES Action in Support
GIS	Geographic Information System
GMD	Geographic MetaData XML (encoding of ISO 19115)
GMES	Global Monitoring for Environment and Security
GML	Geography Markup Language
GMLJP2	GML in JPEG 2000 for geographic imagery
G-POD	Grid Processing On Demand
GPS	Global Positioning System
GS	Ground Segment
GSC	GMES Space Component
GSCB	Ground Segment Coordination Body
GSCDA	GSC Data Access
HARM	Historical Archives Rationalization and Management
HK TM	Housekeeping Telemetry
HMA	Heterogeneous Missions Accessibility
HRG	High-Resolution Geometric (instrument on SPOT-5 satellites)
HRV	High-Resolution Visible
HRVIR	High-Resolution Visible and Infrared (instrument on SPOT-4 satellites)
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ICT	Information and Communication Technology
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organization for Standardization
IT	Information Technology
JPEG 2000	Image compression standard and coding system format created by the Joint Photographic Experts Group in 2000
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
KVP	Key Value Pair binding
LTDP	Long-Term Data Preservation
MDA	Model-Driven Architecture
MERIS	Medium-Resolution Imaging Spectrometer (instrument on Envisat)
MIME	Multipurpose Internet Mail Extensions
NetCDF	Network Common Data Form
O&M	Observations and Measurements

OASIS	Organization for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
OGF	Open Grid Forum
OMG	Object Management Group
OPT	Optical (GML extension)
OWL	Web Ontology Language
OWS	OGC Web Service
PDP	Policy Decision Point
PEP	Policy Enforcement Point
PHR	Pleiades High Resolution (GML extension)
P/L TM	Payload Telemetry
RDF	Resource Description Framework
RIM	Registry Information Model
RM-OA	Reference Model of the ORCHESTRA Architecture
RM-ODP	Reference Model of Open Distributed Processing
RST	Request Security Token
RSTR	RST Response
SAFE	Standard Archive Format for Europe
SAGA	Simple API for Grid Applications
SAML	Security Assertion Markup Language
SAR	Synthetic Aperture Radar
SBA	Societal Benefit Area
SC	Subcommittee
SensorML	Sensor Model Language
SERVUS	Design methodology for information systems based upon geospatial SERVice-oriented architectures and the modelling of USe cases and capabilities as resources
SGML	Standard Generalized Markup Language
SIF	Standards and Interoperability Forum
SKOS	Simple Knowledge Organization System
SLD	Styled Layer Descriptor
SMAAD	Semantic Web Mediated Access Across Domains
SOA	Service-Oriented Architecture
SOAD	Service-Oriented Analysis and Design
SOAP	Simple Object Access Protocol[53]
SOS	Sensor Observation Service
SPARQL	SPARQL Protocol And RDF Query Language
SPOT	Système Pour l'Observation de la Terre (CNES satellite series)
SPS	Sensor Planning Service
SSO	Single Sign-On
STS	Security Token Service

[53] Original meaning of the acronym SOAP. Since SOAP version 1.2 (W3C SOAP, 2007), the acronym is no longer written out but used as a proper name.

SWE	Sensor Web Enablement
TC	Telecommands
TEAM	Test, Evaluation And Measurement
TM	Telemetry
UDDI	Universal Description, Discovery and Integration
UML	Uniform Modeling Language
URI	Universal Resource Identifier
URL	Uniform Resource Locator
VoID	Vocabulary of Interlinked Datasets
W3C	World Wide Web Consortium
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WPS	Web Processing Service
WPS-T	Transactional Web Processing Service
WSDL	Web Service Description Language
XACML	eXtensible Access Control Markup Language
XFDU	XML Formatted Data Units
XML	eXtensible Markup Language

Glossary

Access control (OGC 09-132r1)
Ability to enforce a policy that identifies permissible actions on a particular resource by a particular subject.

Application (OGC 09-132r1)
Use of capabilities, including hardware, software and data, provided by an information system specifically to satisfy a set of user requirements in a given application.

Application domain (OGC 07-097)
Integrated set of problems, terms, information and tasks of a specific thematic domain that an application (e.g. an information system or a set of information systems) has to cope with. Note: One example of an application domain is Earth observation.

Application profile (ISO 19101, ISO 19106)
Set of one or more base standards and – where applicable – the identification of chosen clauses, classes, subsets, options and parameters of those base standards that are necessary for accomplishing a particular function.

Architecture (of a system) (ISO/IEC 10746-2:1996)
Set of rules for defining the structure of a system and the interrelationships between its parts.

Assertion
Statements about a principal that an asserting party claims to be true. Note: Equivalent to the concept of 'claim' as used in OASIS WS-Trust (2007).

Asset (OGC 09-000)
An available means of collecting information. Note: synonym of sensor.

Atom (www.atomenabled.org/developers/syndication)
Name of an XML-based web content and metadata syndication format, and an application-level protocol for publishing and editing web resources belonging to periodically updated websites. All Atom feeds must be well-formed XML documents, and are identified with the application/atom+xml media type.

Authentication (OASIS SOA-RA, 2008)

Concerns the identity of the participants in an exchange. Authentication refers to the means by which one participant can be assured of the identity of other participants.

Authorisation (OASIS SOA-RA, 2008)

Concerns the legitimacy of the interaction. Authorisation here refers to the means by which an owner of a resource may be assured that the information and actions that are exchanged are either explicitly or implicitly approved.

Claim

Declaration made by an entity (e.g. name, identity, key, group, privilege, capability, etc.).

Collection (OGC 09-000)

Act of gathering information.

Credential

Information used as proof of identity (e.g. a password).

(Earth observation) Collection

Datasets sharing the same product specification. A collection typically corresponds to the series of products derived from data acquired by a sensor on board a satellite and having the same mode of operation.

Coverage (OGC 07-011)

Feature that acts as a function to return values from its range for any direct position within its spatio-temporal domain.

A feature that associates positions within a bounded space (its spatio-temporal domain) to feature attribute values (its range). GIS coverages (including the special case of Earth images) are two- (and sometimes higher-) dimensional metaphors for phenomena found on or near a portion of Earth's surface. A coverage can consist of a set of features or feature collections. Earth images are seen as grid coverages that contain features whose geometries are of type 'set of cells' or 'set of pixels' (surfaces).

Dataset (OGC 10-140)

Observations obtained by satellite instruments.

Dataset series (ISO 19113, ISO 19114, ISO 19115)

Collection of datasets sharing the same product specification. In HMA, the term is used as a synonym for a collection of (Earth observation) data. When applied to coverages (OGC 10-140), it identifies a collection of Earth observation coverages.

Discovery (derived from W3C: *www.w3.org/TR/2004/NOTE-ws-gloss-20040211/#discovery*)

Act of locating a machine-processable description of a resource that may have been previously unknown and that meets certain functional, informational or qualitative criteria. It involves matching a set of functional and other criteria to a set of resource descriptions.

Earth observation coverage (OGC 10-140)

Coverage conformant with the OGC WCS EO Application Profile (OGC 10-140), i.e. among others, restricted to 2D rasters. A rectified grid coverage or a referenceable grid coverage having an EO metadata record and a WGS84 bounding box.

Feature (OGC 07-097derived from ISO 19101)

Abstraction of a real-world phenomenon (ISO 19101) perceived in the context of an application.

Interface (ISO 19119)

Named set of operations that characterise the behaviour of an entity. The aggregation of operations in an interface, and the definition of interface, for the purpose of software reusability. The specification of an interface includes a static portion that contains the definition of the operations. The specification of an interface includes a dynamic portion that contains any restrictions on the order of invoking the operations.

Lineage record (OGC 10-140)

Data structure documenting an operation that has been applied to the coverage it is part of.

Layer (OGC 07-063r1)

Basic unit of geographic information that may be requested as a map from a server.

Map (OGC 07-063r1)
Portrayal of geographic information as a digital image file suitable for display on a computer screen.

Mission (EN 13701:2001)
Specific task, duty or function defined to be accomplished by a system.

Observation (OGC 07-022)
Act of observing a property or phenomenon, with the goal of producing an estimate of the value of the property.

Observed property (derived from OGC 07-022r1)
Identifier or description of the phenomenon for which the observation result provides an estimate of its value.

Ontology (Alexiev et al., 2005)
Ontologies are conceptual models that define concepts and their relations, together with constraints on those objects and relations. An ontology represents shared knowledge, i.e. it represents a common understanding (consensus) of the universe of discourse between the parties involved.

Operation (ISO 19119)
Specification of a transformation or query that an object may be called to execute. An operation has a name and a list of parameters.

Policy (derived from OASIS SOA-RM (2006))
Representation of a constraint or condition on the use, deployment or description of a resource.

Portrayal (ISO 19117)
Presentation of information to humans.

Security token
Represents a collection (one or more) of claims.

Sensor (OGC 09-132r1)
Entity that provides information about an observed property at its output. A sensor uses a combination of physical, chemical or biological means in order to estimate the underlying observed property. At the end of the measuring chain electronic devices produce signals to be processed.

Sensor system (OGC 09-132r1)

System whose components are sensors. A sensor system as a whole may itself be referred to as a sensor with its own management and sensor output interface. In addition, the components of a sensor system are individually addressable.

Stitched mosaic (OGC 10-140)

Two-dimensional horizontal Earth observation. It is composed of one or more (non-overlapping) subsets of co-referenced datasets.

System (ISO/IEC 10746-2:1996)

Something of interest as a whole or as comprising parts. Therefore a system may be referred to as an entity. A component of a system may itself be a system, in which case it may be called a subsystem.

Task (OGC 09-000)

(Conceptual) Resource that represents an assignment in a sensor planning service. It includes the (possibly empty) set of tasking parameters.

Tasking (OGC 09-000)

Parameterising an asset; can be done by sending one or more tasking requests.

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