# ALGORITHMS AND PROCEDURES
# COSCH WORKING GROUP 3
# REPORT ON ACTIVITIES 2012–14

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**ABSTRACT**: This interim report covers the activities of the Working Group 3 (WG3) of "Colour and Space in Cultural Heritage" (www.cosch.info), the COST Transdomain Action TD1201, supported by European Cooperation in Science and Technology CoST between 2012– 2016. The report covers the period from 2012 to 2014.

The ubiquity of algorithms embedded in everyday life for many who use technology has not, yet, allowed the non-expert users of systems any insight into their function and use. The work of this targeted workgroup seeks to assess, formalise and explain the range of algorithms in use in systems within cultural heritage. Certainly at times for the non-expert user of certain applications it is not apparent what algorithm is being used, and most importantly why it is being used. This paper aims to introduce a range of algorithms currently used in cultural heritage acquisition and measurement systems, offering explanations, and looking to develop recommendations and guidelines for use, depending on minimal spatial resolution and uncertainty values specified amongst a range of considerations; to inform users of the potential, output, constraints, preconditions and practical aspects related to the use of algorithms and procedures used to process digital data (both spectral and spatial data) and most importantly to structure knowledge about algorithms and procedures used in DCH in an ontology laying a foundation for an optimised and adapted use of algorithms and procedures for processing digital data by cultural heritage professionals.

## 1. INTRODUCTION

In Digital Cultural Heritage (DCH) one of the most challenging issues for non-expert users of certain acquisition technologies and experts is to understand at which processing stage(s) and why, for a given application, they have to use some algorithms and not others, and how to use these algorithms. To answer to these questions, experts in computer science and engineers need to:

- **Document** algorithms and procedures currently used in DCH in a critical review of the state-of-the art (step 1);
- **Develop recommendations and guidelines** about algorithms and procedures to be used depending on: — the minimal spatial resolution and uncertainty values specified; - the characteristics/types of physical cultural heritage objects and materials considered; — the conservation and documentation requirements (step 2);
- **Inform** users of the potential, output, constraints, preconditions and practical aspects related to the use of algorithms and procedures used to process digital data (both spectral and spatial data) (step 3);
- **Structure knowledge** about algorithms and procedures used in DCH in an ontology laying a foundation for an optimised and adapted use of algorithms and procedures for processing digital data by cultural heritage professionals (step 4).

To address these problems, Working Group 3 “Algorithms and Procedures” contributed to the development of two complementary documentation ontologies [1-3]:

- The COSCH Knowledge Representation model ($COSCH^{KR}$) (under construction) which represents the formal knowledge of experts and engineers working in the field of Cultural Heritage, is a hierarchy of concepts using a shared vocabulary to denote the types (e.g. technologies, instruments, algorithms), properties (e.g. sensitivity, accuracy, speed) and inter-relationships (e.g. acquisition geometry vs. accessibility of sites/objects, acquisition geometry vs. physical properties) of those concepts (Figure 1). Many organizations have tried to develop such documentation strategies from thesaurus standard documentation towards a documentation that is understandable by all CH experts. For example, the Getty Research Institute (http://www.getty.edu/) developed an ontology based on the W3C recommendations (see http://www.w3.org/TR/rdf-schema/). This ontology is organised as Linked Data (RDF triples). RDF (Resource Description Framework**,** http://www.w3.org/RDF/) is a standard language that encodes information using statements triples based on the following form: subject, predicate, object. We can also mention CIDOC CRM (CIDOC Conceptual Reference Model, see http://network.icom.museum/cidoc/working-groups/crm-special-interest-group/).

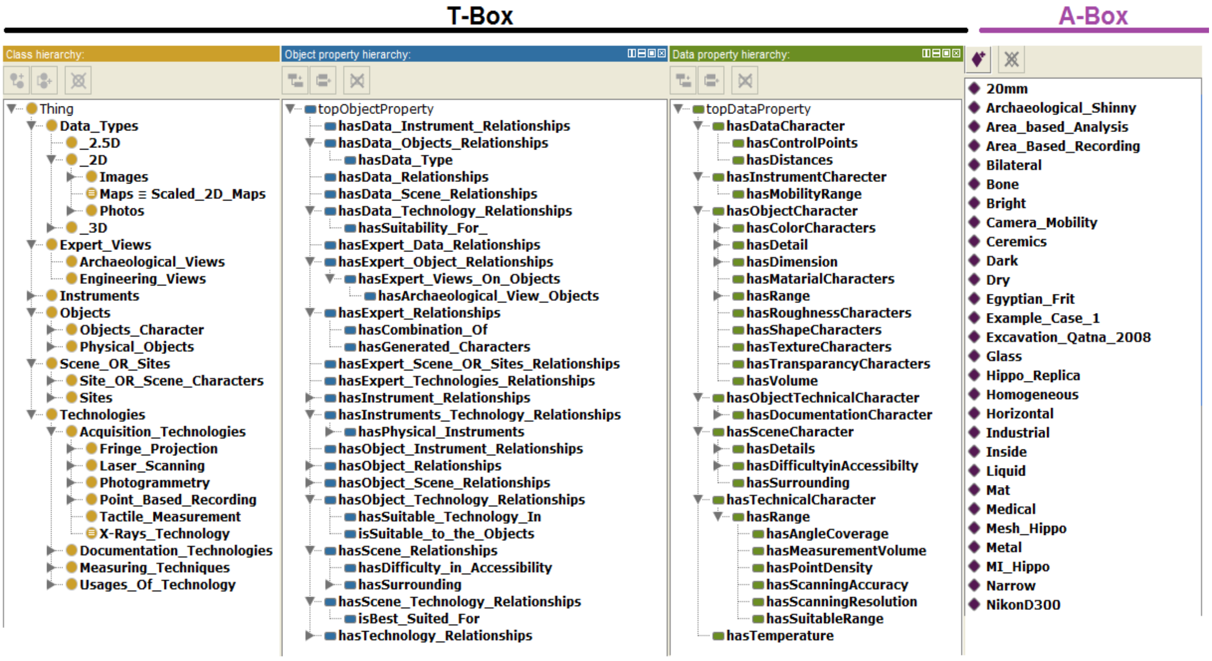



Figure 1. Structure of COSCH$^{KR}$ (i.e. the T-Box: concepts and relations) was defined using questionnaires filled by different domain experts. The assertion part of this ontology was further completed by other domain experts ((i.e.) A-Box: instances of concepts and relations). The focus of the first assertions was to demonstrate the process of query executions during different WG meetings. In a first step, the overall intention of the COSCH$^{KR}$ group was to focus on T-Box rather than on assertions. The version V2.0 of COSCH$^{KR}$ contains 120 concepts, 52 data type properties, 60 object properties and 49 individuals.

- The COSCH Algorithm Selection Module (COSCH$_{ASM}$) which formally represents the knowledge of computer vision experts as a hierarchy of algorithms using a shared vocabulary, understood by non-experts, to denote the types (e.g. calibration, registration, fusion), properties (e.g. accuracy) and inter-relationships (e.g. between parametric factors) of those algorithms [2].

WG3 contributed to the following COSCH general objectives:

- The development of guidelines for CH authorities concerning the specification of minimal spatial resolution/uncertainty values for a selected set of materials depending on the goal of the documentation, e.g. visualisation and condition assessment.
- The development of guidelines for users and technicians of the potential, output, constraints, preconditions and practical aspects of precise spectral and spatial instruments and of a wide list of algorithms.
- To lay a foundation for an optimised and adapted use of spectral and spatial techniques by CH Authorities.

The following sections summarise the main contributions proposed by this Working Group (WG3) for each steps defined above (step 1 to 4).

### 1.1 Exemplary Procedure: Colour/Spectral Calibration

To optimise the calibration accuracy of a given instrument, users have to know which are the parametric factors affecting the calibration accuracy (Figure 2). The main problem with calibration accuracy is that it is device dependent and application dependent. Thus, the calibration process used for a laser scanning system may differ from the calibration process used for point-based spatial recording, spatial fringe projection, spatial photogrammetry or tactile measurement. In this context, it is essential to:

- Identify what are the most important parametric factors for end users (depending of their needs and expectations), which have an influence on the calibration process;
- Determine what are the parametric factors common to several acquisition systems;
- Identify what are the main calibration / registration / fusion approaches that can be used to calibrate heterogeneous data.

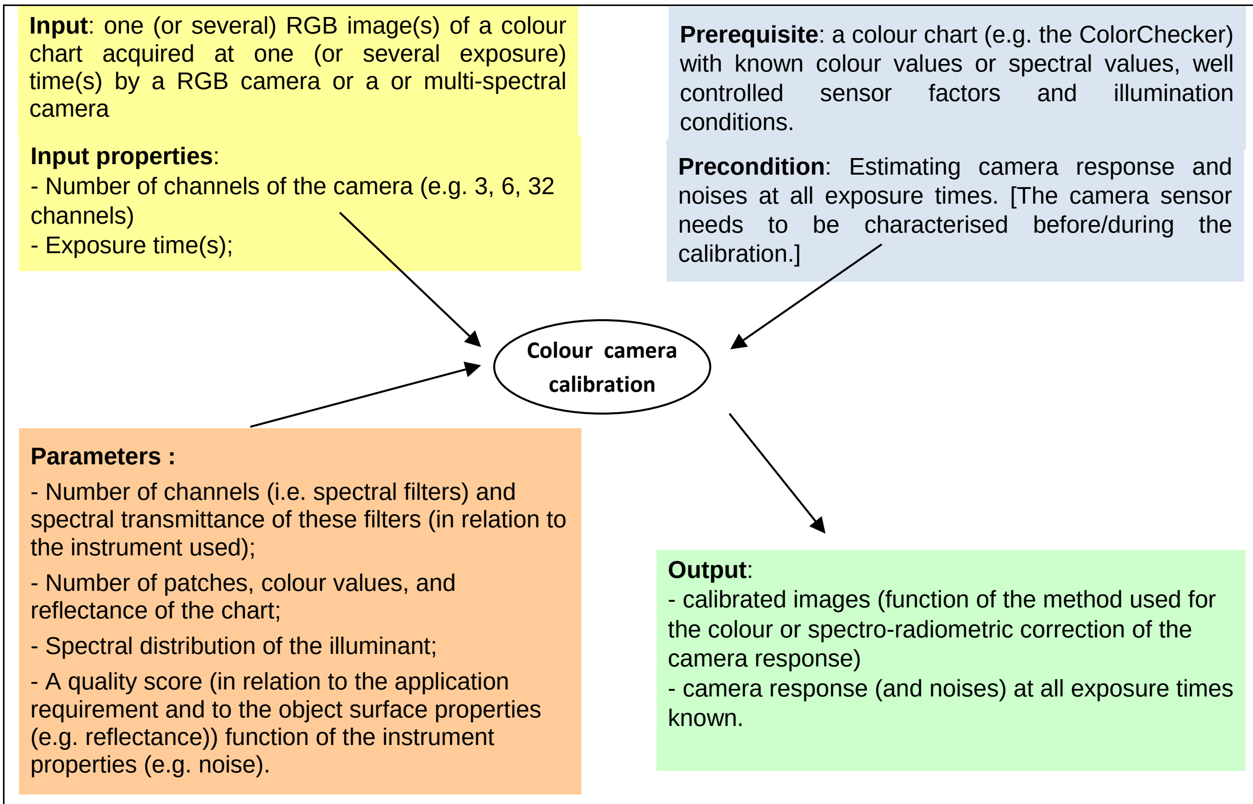



Figure 2. Parametric factors affecting the colour/spectral calibration accuracy. The influence of some parameters depends of the requirements of the application.

Other procedures already documented are listed in Table 1:

| | |
|---|---|
| 3D | HDR image generation<br>Panoramic cube generation<br>Camera calibration<br>Image orientation<br>3D data set registration<br>Image sequence orientation<br>Dense matching<br>3D camera calibration<br>Texture mapping<br>Orthorectification<br>Rectification<br>Point cloud meshing<br>Mosaicking |
| Multispectral / Hyperspectral | Dimensionality reduction<br>Calibration<br>Normalisation<br>Reflectance calculation |
| 3D + Multispectral | Image to 3D data registration<br>BRDF calculation<br>Rendering<br>Data fusion<br>Multi-angle registration |

Table 1. List of procedures documents by WG3.

**1.2 Exemplary algorithm: from spectral reconstruction to dimensionality reduction**

See Figure 3 below.

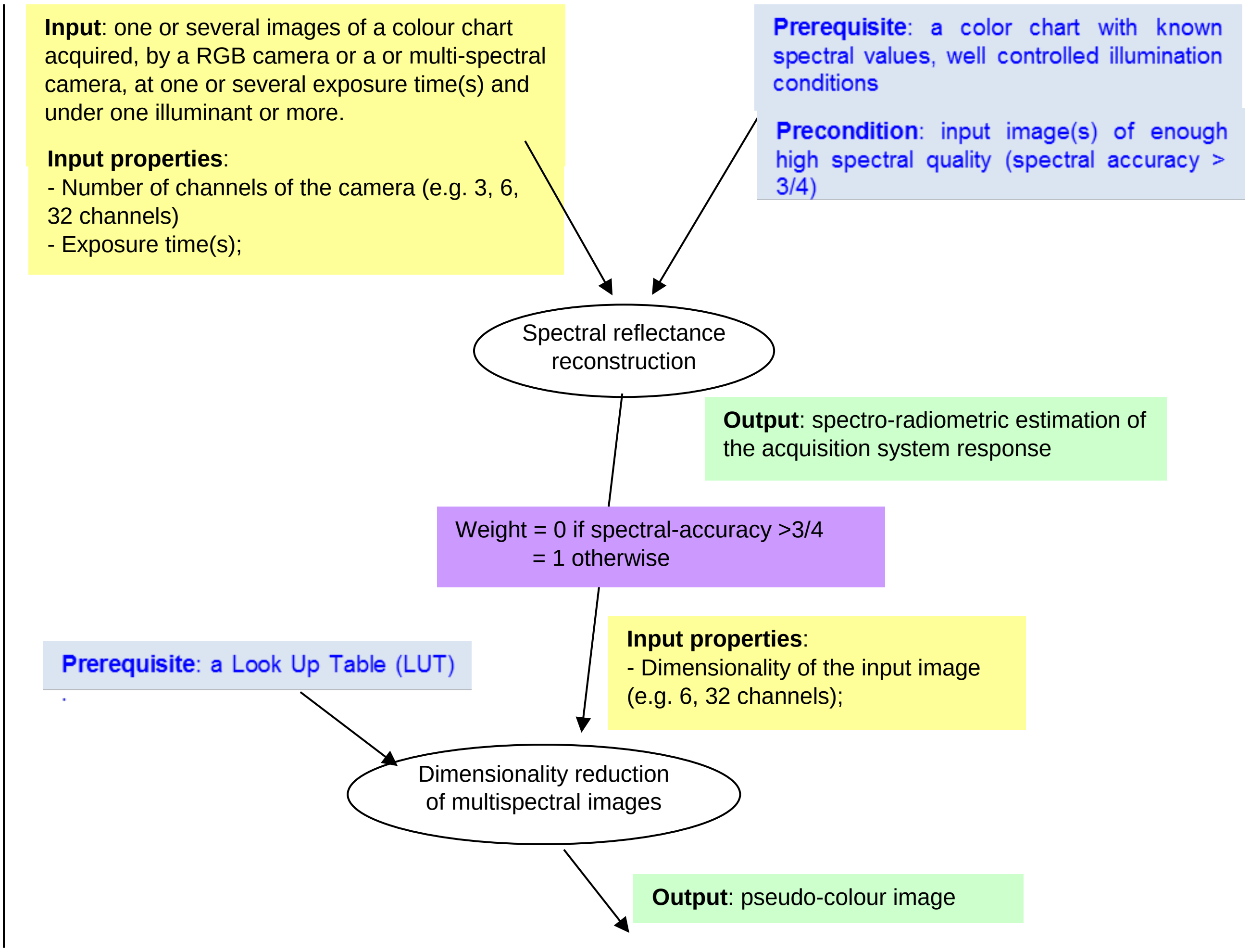



**Figure 3**: Parametric factors affecting the processing chain from spectral reconstruction to dimensionality reduction. The influence of some parameters (e.g. de weight w) depends of the requirements of the application.

Other algorithms (processing chains) documented are listed below:

- visualisation of a multispectral image on a RGB calibrated display after dimensionality reduction;
- fusion of 3D depth data with 2D perspective images (without correspondences) [Fröhlish, 2015].

## 2. REVIEW OF EARLIER RESEARCH

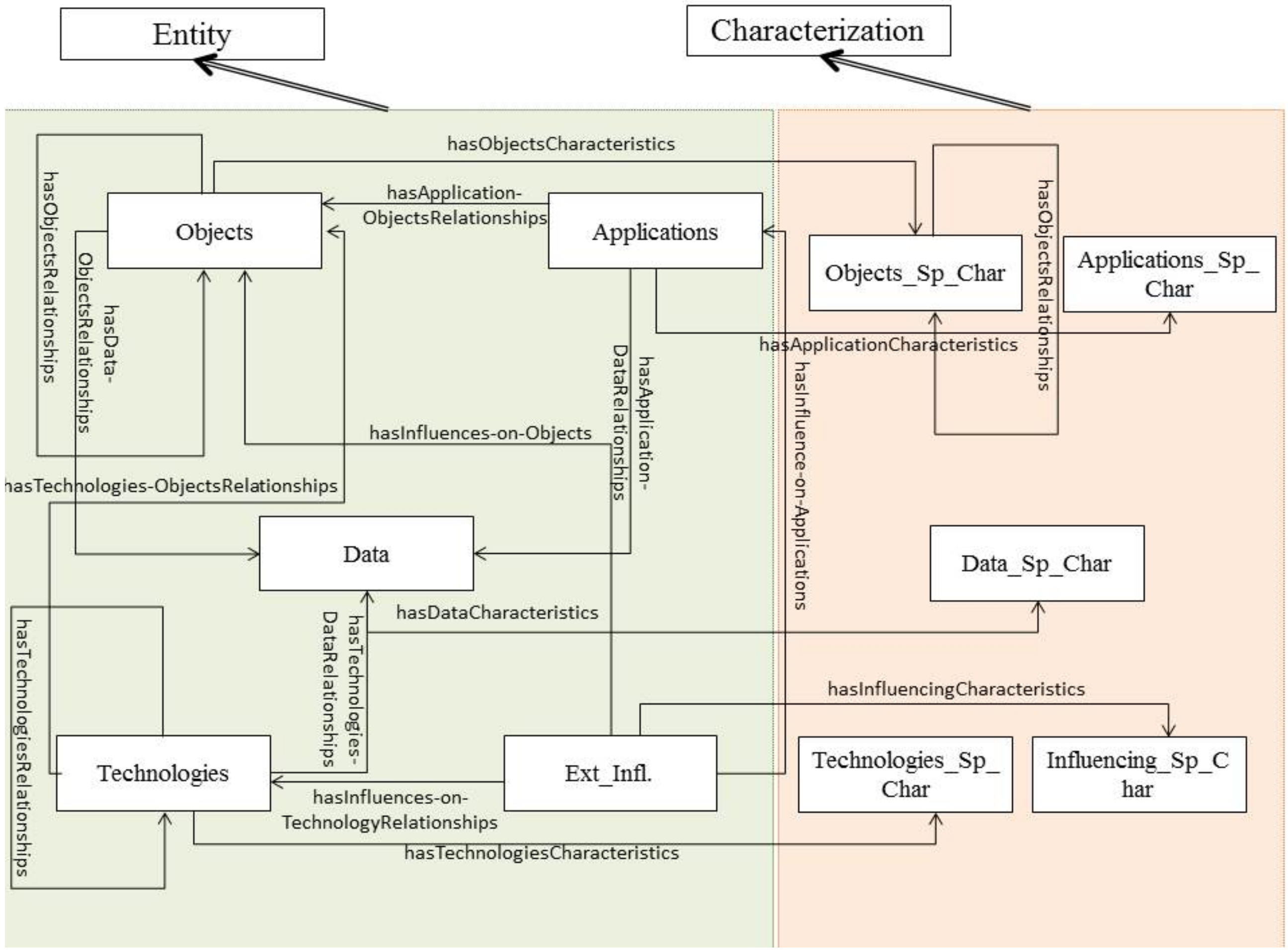
Very few research results have been published to provide to experts in Cultural Heritage a deeper knowledge of algorithms, procedures and flowcharts [Barazzetti et al., 2010] used in the domain [Pintus et al., 2014; Lo Brutto et al., 2012]; Santagati et al., 2013].

Most of the documentation and books published predominantly detail the methods or algorithms used with not enough detail on how to use these algorithms (questions arising include: How best to adjust parametric factors? What are the inter-relations between these factors?) Likewise, they do not sufficiently discuss the fact that the solution and flowcharts proposed are application dependent and data quality dependent. As an example, data accuracy depends on the resolution, the sensibility, the viewing field, and so on, of the sensor used and of the technology used, see COSCH interim report of WG2 [Sitnik and Hain, 2015]. As an example meanwhile, several colour calibration solutions were proposed to obtain accurate digitisation of object surface properties, e.g. specular or diffuse reflectance [Piccolo et al., 2015] very little research addresses colour accuracy issues related to 3D specular objects.

The main objective of WG3 is therefore to provide end-users a simple and understandable documentation of and for the main algorithms and procedures commonly used in Cultural Heritage applications. For example, how would you calibrate a colour acquisition system? As an illustration, the Khantaros's case study [COSCH, 2016] concerns this issue. This problem is also addressed by

WG1 [COSCH, 2016]. How may one fuse heterogeneous data? Within COSCH, this problem is addressed by specific COSCH Case Studies conducted at Germolles and on Roman Coins respectively [COSCH, 2016] The approach proposed (in development) aims to construct a structural frame which can be used by experts to enter their experience and views.

A limited number of knowledge models, such as the CIDOC-CRM [Alexiev, 2013] and the Europeana Data Model [Charles, 2014] have been proposed and discussed for content management and retrieval in Cultural Heritage [Boochs, 2014b]. In this interim report we will not survey these models, the reader is invited to explore this material — a survey [Kotthoff, L. 2012] and a literature review [Truong, 2013]. The main drawback of all these knowledge models is that they do not address techniques and technologies that are vital in any conservation and restoration activity. In contrast to these models the COSCH$^{KR}$ is structured in 6 top-level classes (Figure 4) to better integrate knowledge provided by technical experts.



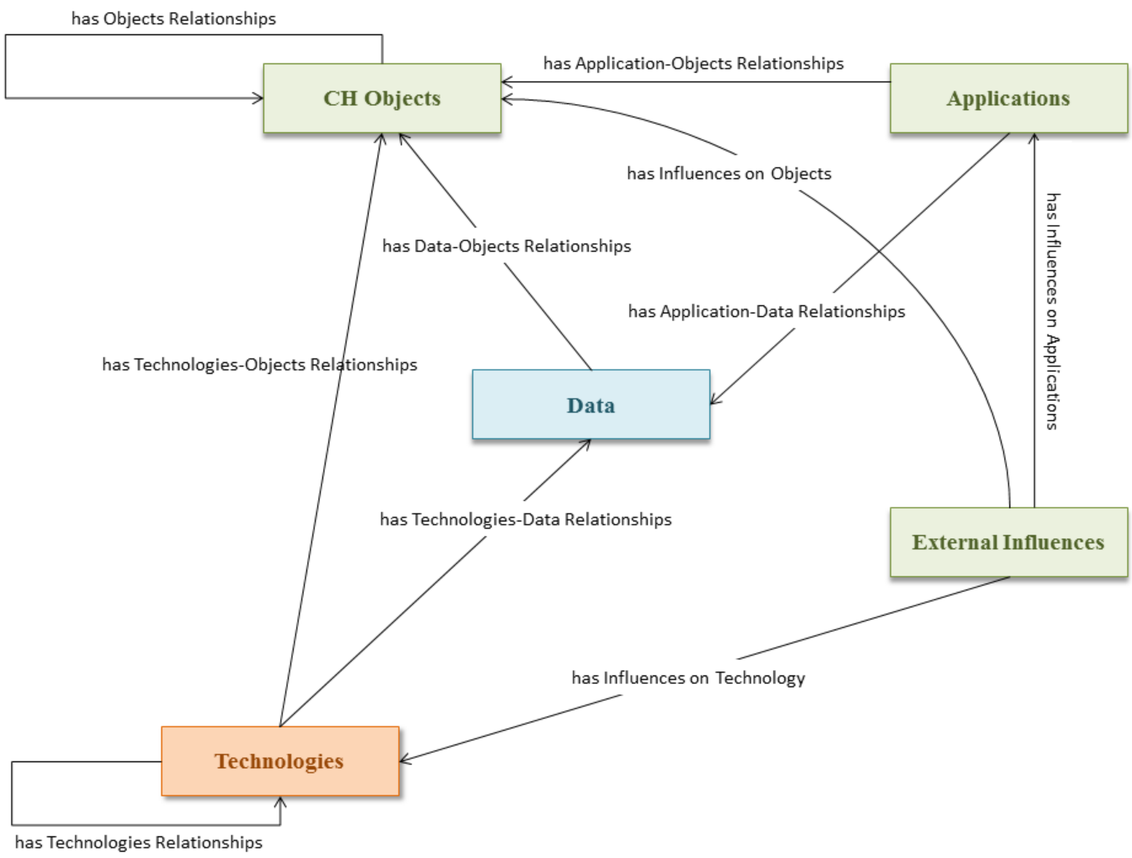



Figure 4. Structure of $COSCH^{KR}$

The conceptual principles used for the development of the $COSCH_{ASM}$ are based on the PhD thesis of Quoc Hung Truong [Truong, 2013].

## 3. STRUCTURED ANALYSIS / DISCUSSION OF THE RESEARCH QUESTION(S), CHOSEN APPROACH(ES) AND METHODS

Initially, WG3 consulted a variety of COSCH case studies (Roman Coins, Wall Paintings at Germolles, the Greek Khantaros) and other case studies related to other applications, to consider whether the structure of the $COSCH^{KR}$ is well adapted to describe the views and knowledge of experts in Cultural Heritage. As an example, the taxonomy hierarchy shown in Figure 5 illustrates how we categorise data acquisition systems. Some acquisition systems are not yet included in this taxonomy hierarchy.

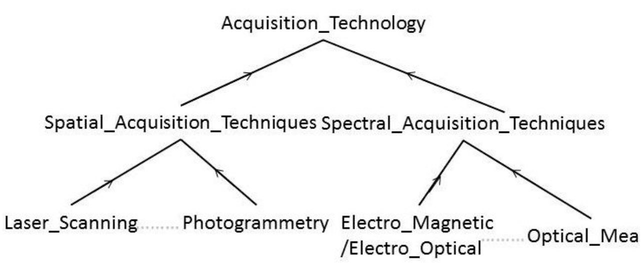



Figure 5. Simplified representation of the taxonomical hierarchy of data acquisition techniques used in different technical domains.

The $COSCH^{KR}$ is an evolving knowledge base which needs to be constantly extended to further application cases. The stepped process demonstrates the general ability of $COSCH^{KR}$ to link technology and application in typical cases, and that its structure is reliable. There are still some issues remaining to check/test in order to demonstrate that we are able to define rules in a reliable way that allows us to link technology and application.

One of the objectives of WG3 is to identify which data acquisition systems (instruments) and algorithms/procedures are missing in the $COSCH^{KR}$ and $COSCH_{ASM}$ (see example in Figure 6) and what are the properties/relationships that need to be added (see example in Figure 7). Likewise, another objective of WG3 was to identify missing procedures for the other top-level classes, such as the technologies class, and what properties and/or relationships need to be added there.

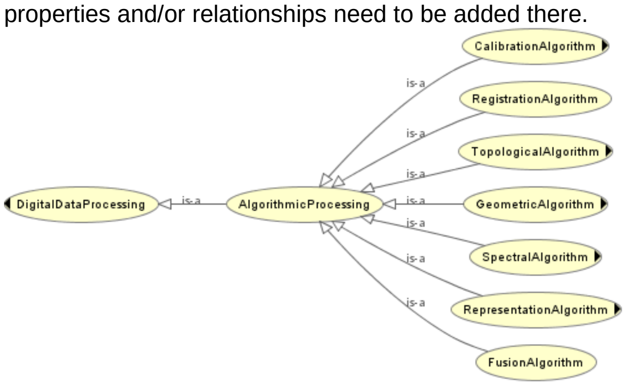



Figure 6. Structure of $COSCH_{ASM}$

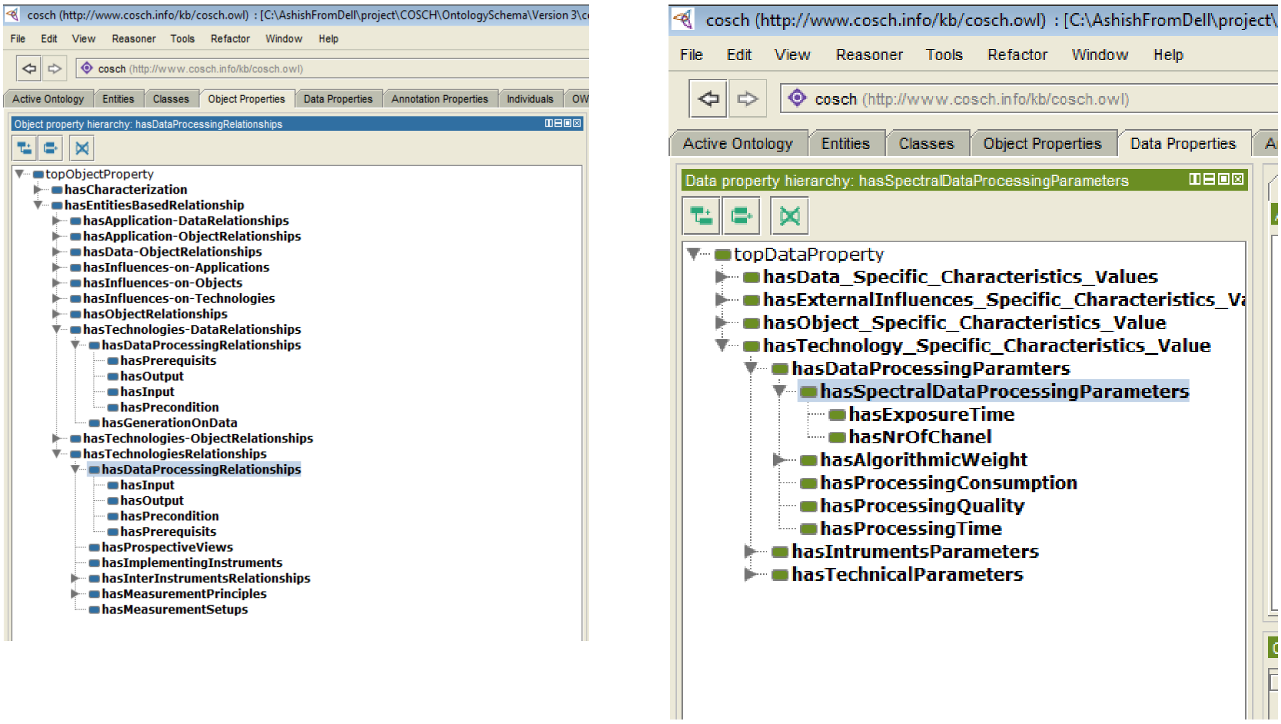



Figure 7. Examples of properties/relationships linking COSCH$^{KR}$ and COSCH$_{ASM}$

Another objective was to enrich the sub-classes and rules already defined by adding new sub-classes and rules between sub-classes/classes and by improving the current relationships identified (Figure 8). The first difficulty here is to check that all relationships, concepts, etc. identified are valid (that needed to be done manually by experts). The second difficulty is to add new relationships to the COSCH$^{KR}$ and to update it. This ontology is not yet complete and needs to be further updated. Furthermore, we need to demonstrate that it can be flexible, i.e. that it will be able to manage alternate scenarios rather than the variety of those used for the case studies.

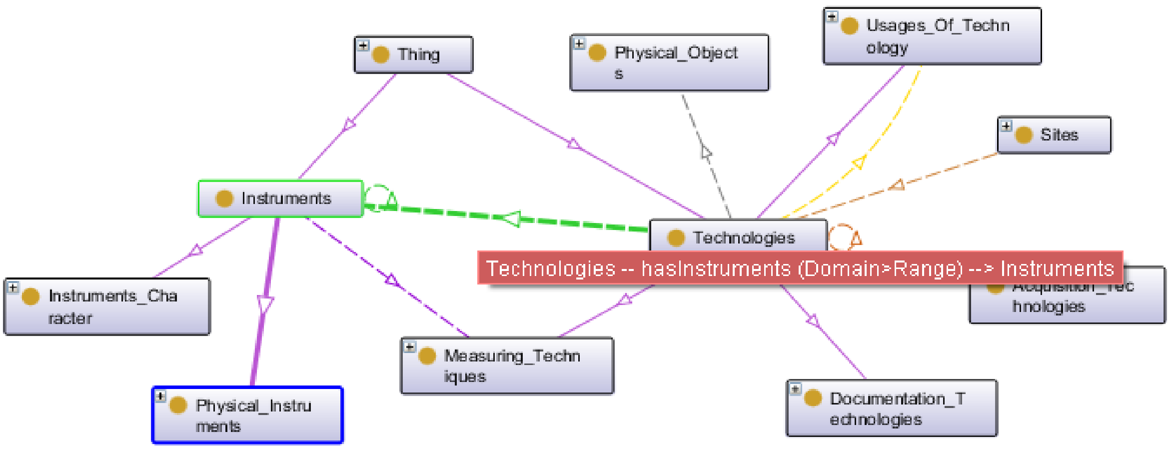



Figure 8. Sub-graph of COSCH$^{KR}$ associated to the concepts 'Technology' and 'Instruments'. Continues lines refer to property 'subClassOf' and dotted lines refer to other properties.

The next objective will be to enrich the COSCH$^{KR}$ ontology, e.g. either by using an ontology alignment approach or an automatic ontology population approach [Bennamar, 2015; Buono, 2015] from expert views, particularly from the knowledge that we can get from the COSCH case studies. Next focus will be to find an approach to solving the following issues:

- how to analyse these contents and
- how to generate rules from these contents.

This task may require extensive work from domain experts. The primary tasks performed by WG3 comprise:

- Theoretical analysis and practical investigation of typical and necessary processing tasks and their potential or

real impact on quality and information content of results (PT3);
- Support/help for WG1 and WG2 to theoretically identify and practically explore important characteristics of instruments and their potential impact on data quality, usability and information content with respect to typical surfaces (PT1);
- Support/help for WG4 and WG5 to select typical applications and/or objects to be subject of implementation of optimal processing chains, from data capture up to the final results, guided by all the interdisciplinary expertise available to COSCH (PT4).

During the first two years of the COSCH project, WG3 mainly worked on:

Registration processes (acquisition, filtering and view integration).
Integration of multi-sensor data.

### 4. MAIN FINDINGS

WG3 defined a template form to characterise a list of algorithms used in CH. This template specifies: input, output, risks, required parameters/information, preconditions and prerequisites, quality measure, user interaction and possible next step(s) related to an algorithm [Boochs et al., 2015]. For each form, the knowledge provided by experts in computer vision were defined so as to be understandable by Cultural Heritage domain expert users who have limited knowledge in computer vision. The data provided by these forms will be integrated in the $COSCH_{ASM}$ using the graph of data defined below.

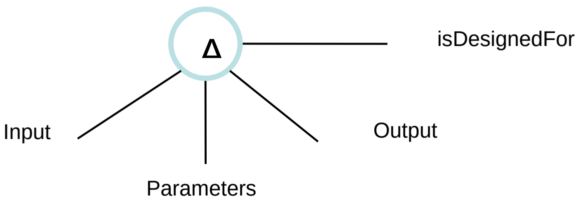



Figure 9. Graph of data corresponding to the algorithm A [Truong, 2013] e.g. colour calibration.

Twenty two algorithms are now documented (PT3 Task st3.2, see Table 1). These documents address problems related to the parameterisation process, the evaluation process, the learning process, and so on. (PT3 Task st3.1). As an example please see [Boochs et al., 2015].

Simultaneously, WG3 also wrote a draft report on data access and format (PT3 Task st3.3) and another draft report on commercial software for 3D creation models from multiple images and enhancement models of 3D data.

The COSCH Algorithm Selection Module ($COSCH_{ASM}$) has been defined to formally represent several processing chains used in Cultural Heritage as a hierarchy of algorithms (Figure 9) to denote the types (from acquisition to visualisation), properties (e.g. accuracy) and inter-relationships (e.g. between parametric factors) of algorithms used for a given task (e.g. 3D reconstruction of a Greek vase in the Khantaros case study exemplar). The main specificity of the $COSCH_{ASM}$ is that it is intended to be used by end-users (who are non-experts in computer vision) in order to help them to find/select the best sequence of algorithms corresponding to their application. As this selection depends on the object and scene/environmental characteristics, on the acquisition instruments and measurement technologies used, the $COSCH_{ASM}$ is directly linked to the $COSCH^{KR}$.

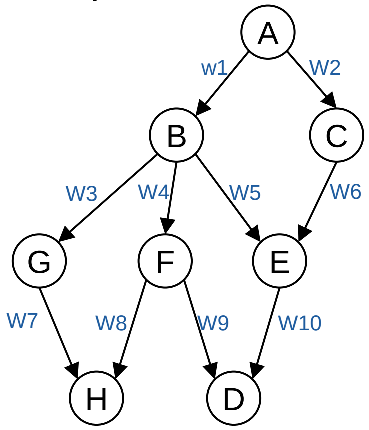



Figure 10. Graph of relationships between algorithms, with priority weights [Truong, 2013].

In a first step, from a few examples, WG3 members tried to identify/define the rules, relationships, which define a sequence of algorithms. As an example see Figure 10.

### 5. RECOMMENDATIONS FOR THE FUTURE WORK OF COSCH

The contributions presented in the paper [Boochs et al., 2015] summarise the initial work performed by the WG3 task force in Cork, in February 2015, to provide knowledge to end-users about:

- the behaviour of algorithms and about the relationships between algorithms output and data input (related to technologies and instruments used, and objects and scenes processed);
- the potential and the real impact (on quality and information content of results) of typical processing algorithms.

The next step will be to:

- Improve upon the first documentation completed;
- Document a higher number of algorithms, with a focus on some classes of algorithms (e.g. fusion of 2D colour/spectral images with 3D images – PT3 Task st3.2)
- Document a higher number of sequences of algorithms (i.e. all steps of a processing chain) commonly used in Cultural Heritage (from the case studies supported by COSCH).
- Weigh the algorithms graph depending on the requirements defined by the user (e.g. time, consumption and quality constraints) and on the quality of results (e.g. efficacy, robustness and accuracy) that algorithms can provide.
- Propose a method to automatically populate $COSCH^{KR}$. One that could be achieved from an automatic textual

analysis of papers related to the CH domain. This will be one of the topics to be discussed during the next WG3 taskforce meeting at Budapest, Hungary.

The WG3 will also work on challenging issues related to:

- the parameterisation process and the learning process to exploit in an optimal way the data and the knowledge structured in the $COSCH_{ASM}$.
- the establishment of conceptual and practical frameworks for multisensory data acquisition, its implementation, and evaluation (PT5). During the CCIW'2015 special session on "Color in Digital Cultural Heritage" co-organised by COSCH several presentations addressed this issue (see http://cciw2015.univ-st-etienne.fr/Program-CCIW15.html).

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