Automating the preservation planning process: An extensible evaluation framework for digital preservation

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Abstract. The dominance of digital objects in today's information landscape has changed the way humankind creates and exchanges information. However, it has also brought an entirely new problem: the longevity of digital objects. Due to the fast changes in technologies, digital documents have a short lifespan before they become obsolete. Digital preservation, i.e. actions to ensure longevity of digital information, thus has become a pressing challenge. Different strategies such as migration and emulation have been proposed; however, the decision between available strategies and the evaluation of potential tools is very complex. Preservation planning supports decision makers in reaching accountable decisions by evaluating potential strategies against well-defined requirements. The analysis of the qualitative and quantitative performance of different migration tools for digital preservation has to rely on validating the converted objects and thus on an analysis of the logical structure and the content of documents.
Different approaches exist for analysing and characterising digital objects. However, the connection to the specific requirements and criteria that have to be considered in the evaluation procedure is yet unclear, and there is no automated and traceable way of linking these characteristics to the decision factors. Furthermore, an integration of preservation action, characterisation and planning is missing.
This paper presents an extensible integration architecture for automating the analysis and evaluation of potential preservation actions. We describe the problem context and the planning methodology underlying the approach. We then present an overall integration architecture and an extensible evaluation framework connecting requirements and criteria to measurable factors both in the environment and the digital objects themselves. We discuss the problems and expected benefits and outline the next steps towards implementing the proposed solution.

1 Introduction

The last decades have made digital objects the primary medium to create, shape, and exchange information. An increasing part of our cultural and scientific heritage is being created and maintained in digital form; digital content is at the heart of today's economy, and its ubiquity is increasingly shaping private lives.

The ever-growing complexity and heterogeneity of digital file formats together with rapid changes in underlying technologies have posed extreme challenges to the longevity of information. So far, digital objects are inherently ephemeral. Memory institutions such as national libraries and archives were amongst the first to approach the problem of ensuring long-term access to digital objects when the original software or hardware to interpret them correctly becomes unavailable [27].

A variety of tools performing preservation actions such as migration or emulation exist today; most often, there is no optimal solution. The complex situations and requirements that need to be considered when deciding which solution is best suited for a given collection of objects mean that this decision is a complex task. This multi-criteria decision making process is one of the key issues in preservation planning. Preservation planning aids has to evaluate available solutions against clearly defined and measurable criteria. This evaluation needs verification and comparison of documents and objects before and after migration to be able to judge migration quality in terms of defined requirements. It thus has to rely on an analysis of the logical structure of documents that is able to decompose documents and describe their content in an abstract form, independent of the file format. Moreover, there are a number of other factors to take into account, such as risk factors of object formats, cost models that influence the planning decisions, and changing constraints in environments and usage that imply a change in preferences and/or requirements.

Creating and maintaining the conceptual connection between these influence factors and the outcomes of decisions is a difficult process and a largely unsolved question. The effort needed to analyse objects, requirements and contextual influence factors is in many cases prohibitive. Furthermore, the evaluation of alternative action paths to arrive at accountable recommendations for a preservation action component is often costly.

This paper presents an evaluation framework that aims at automating this process and improving the traceability of influence factors in digital preservation decision making. An integration architecture brings together preservation planning with preservation actions, characterisation services, and the heterogeneous information sources and registries where these are described.

The article is structured as follows. We describe the context of work in the next section and the preservation planning methodology which forms the basis of our approach in Section 3. Section 4 presents the planning tool Plato which forms the technical background for implementing the described framework. Section 5 then outlines the integration architecture, while the last section discusses potential benefits and issues and outlines future work.

2 Related Work

Digital preservation is a pressing matter – large parts of our cultural, scientific, and artistic heritage are exposed to the risks of obsolescence. Trustworthiness is probably the most fundamental requirement that a digital repository preserving content over the long term has to meet. The Trusted Repository Audit and Certification Criteria as a widely recognised step towards standardisation and certification of digital repositories define a set of requirements to be followed in digital preservation processes [26]. At the heart of a preservation endeavour lies preservation planning. It is a core entity in the ISO Reference Model for an Open Archival Information System (OAIS) [12].

The rising awareness of the urgency to deal with the obsolescence that digital material is facing has led to a number of research initiatives over the last decade. Research has mainly focussed on two predominant strategies – migration[25, 16] and emulation[20, 28]. Migration, the conversion of a digital object to another representation, is the most widely applied solution for standard object types such as electronic documents or images. The critical problem generally is how to ensure consistency and authenticity and preserve all the essential features and the conceptual characteristics of the original object whilst transforming its logical representation. Lawrence et. al. presented different kinds of risks for a migration project [15].

In contrast to migration, emulation operates on environments for objects rather than the objects themselves. Emulation aims at mimicking a certain environment that a digital object needs, e.g. a certain processor or a certain operating system. Rothenberg [20] envisions a framework of an ideal preservation surrounding for emulation. Recently, Van der Hoeven presented an emerging approach to emulation called *Modular emulation* in [28].

In principle, the selection problem in digital preservation can be seen as a domain-specific instance of the general problem of Commercial-off-the-Shelf (COTS) component selection [19]. The field of COTS component selection has received considerable attention in the area of Software Engineering. A comprehensive overview and comparison of methods is given in [17]. One of the first selection methods presented was the Off-the-Shelf-Option (OTSO) [13, 14]. It provides a repeatable process for evaluating, selecting and implementing reusable software components. OTSO relies on the Analytic Hierarchy Process (AHP) [22] to facilitate evaluation against hierarchically defined criteria through series of pairwise comparisons. Other methods include CRE[1] and PORE[18]. Most selection methods follow a goal-oriented approach [29] and conform to what Mohamed calls a 'General COTS selection process (GCS)' [17], an abstract procedure with the steps *Define criteria, Search for products, Create shortlist, Evaluate candidates, Analyze data and select product.*

The PLANETS preservation planning methodology[23] defines measurable requirements for preservation strategies in a hierarchical form and evaluates them in a standardised setting to arrive at a recommendation for a solution. The procedure is independent of the solutions considered; it can be applied for any class of strategy, be it migration, emulation or different approaches, and has been validated in a series of case studies [4, 7, **?**]. An OAIS-based analysis of the approach is shown in [24].

An important aspect of the evaluation process is the need for automatic validation and comparison of objects. A number of tools and services have been developed that perform content characterisation specifically for digital preservation. The National Library of New Zealand Metadata Extraction Tool[1] extracts preservation metadata for various input file formats. Harvard University Library's tool JHove[2] enables the identification and characterisation of digital objects. Collection profiling services build upon characterisation tools and registries such as PRONOM[3] to create profiles of repository collections [8]. The eXtensible Characterisation Languages presented in [6] support the automatic validation of document conversions and the evaluation of migration quality through a analysis and decomposition of digital objects into their constituting elements, thus representing them in hierarchical form in an abstract XML language.

Some approaches deal with distributed preservation architectures. Hunter [11] describes a distributed architecture for preserving composite digital objects using ontologies and web services. Ferreira [10] presents a system for performing format migrations based on pre-specified requirements.

The EU project 'Preservation and Long-Term Access via Networked Services' (PLANETS)[4] is creating a distributed service-oriented architecture as well as practical services and tools for digital preservation [9]. Based on a common conceptual framework, it is developing services for preservation action, characterisation, testing and planning.

3 The preservation planning workflow

The Planets preservation planning workflow as described in [23] consists of three main stages:

1. **Requirements definition** is the natural first step in the planning procedure, collecting requirements from the wide range of stakeholders and influence factors that have to be considered for a given institutional setting. This includes the involvement of curators and domain experts as well as IT administrators and consumers. Requirements are specified in a quantifiable way, starting at high-level objectives and breaking them down into measurable criteria, thus creating an *objective tree* which forms the basis of the evaluation of alternative strategies. Furthermore, as this evaluation would be infeasible on the potentially very large collection of objects, the planner selects representative sample objects that should cover the range of essential characteristics present in the collection at hand.
   While the resulting objective trees usually differ through changing preservation settings, some general principles can be observed. At the top level, the objectives can usually be organised into four main categories:
   - *Object characteristics* describe the visual and contextual experience a user has by dealing with a digital record. These characteristics are often referred to as *significant properties*. Subdivisions may be "Content",

[1] http://meta-extractor.sourceforge.net/
[2] http://hul.harvard.edu/jhove
[3] http://www.nationalarchives.gov.uk/pronom
[4] http://www.planets-project.eu

"Context", "Structure", "Appearance", and "Behaviour" [21], with lowest level objectives being e.g. the preservation of color depth, image resolution, forms of interactivity, macro support, or embedded metadata.
   - *Record characteristics* describe the technical foundations of a digital record, the context, interrelationships and metadata.
   - *Process characteristics* describe the preservation process. These include usability, complexity or scalability.
   - *Costs* have a significant influence on the choice of a preservation solution.

   The objective tree documents the individual preservation requirements of an institution for a given partially homogeneous collection of objects. An essential step is the assignment of measurable effects to the objectives. Wherever possible, these effects should be objectively measurable (e.g. € per year, frames per second). In some cases, such as degrees of openness and stability or support of a standard, (semi-) subjective scales will need to be employed. Strodl et. al. [23] report on a series of case studies and describe objective trees created in these.
2. The **evaluation of potential strategies** is carried out empirically by applying selected tools to the defined sample content and evaluating the outcomes against the specified requirements.
3. **Analysis of the results** takes into account the different weighting of requirements and allows the planner to arrive at a well-informed recommendation for a solution to adopt.
4. The final phase of **preservation plan definition** then uses the documented recommendation to define a concrete action plan for preserving the given set of digital objects[5].

The described workflow provides a solid, well-documented and well-tested approach of empirically evaluating potential solutions and defining concrete action steps. However, it is of considerable complexity and requires substantial effort, if not properly supported by according software. Curators and preservation planners do not have enough information and options at hand, they do not know potential strategies and are unsure how to model, quantify and measure their requirements. Morevoer, they find it very difficult to establish the complex relationships between technical, domain specific, and contextual influence factors and the impact they have on the decisions. Furthremore, researchers and tool developers are lacking a common framework of delivering, deploying, testing, distributing and putting to use algorithms and tools for analysis and characterisation, i.e. the analysis and comparison of object properties and the characterisation of actions.

Thus an automated platform is needed to support measurements, evaluation, and decision making. The planning tool Plato whose vision was described in [5] strives to provide full support for preservation planning endevaours following the described approach. It is a web-based software tool that guides the preservation planner through the workflow.

This paper describes how a pluggable evaluation architecture can be leveraged to integrate both information from diverse sources and services for preservation action and characterisation. We describe the overall integration architecture

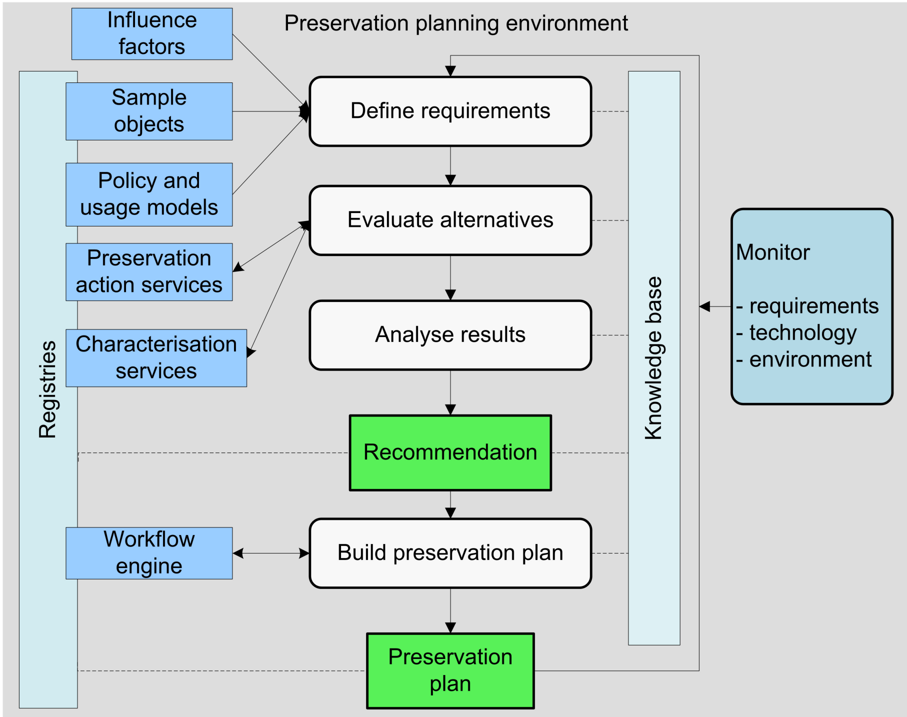

Fig. 1. Preservation planning environment

and then focus on automating the evaluation of requirements and criteria as they are defined in the objective tree. To this end, we propose a pluggable framework relying on *modellers, evaluators and comparators* to connect requirements and criteria to measurable and traceable properties and thus automate the planning procedure. Additionally, *watchers* are foreseen for continously monitoring environmental factors and constraints.

The following section describes the context of work by presenting the planning tool Plato and some of the existing and emerging services that need to be leveraged and connected to the evaluation procedure. We then describe the integration architecture in Section 5 and provide an outlook to future work in Section 6.

4 The planning tool Plato

The planning tool implements the preservation planning workflow described above and includes additional external services to automate the process. The software itself is a J2EE web application relying on open frameworks such as Java Server Faces and AJAX for the presentation layer and Enterprise Java Beans for the backend. It is integrated in an interoperability framework that

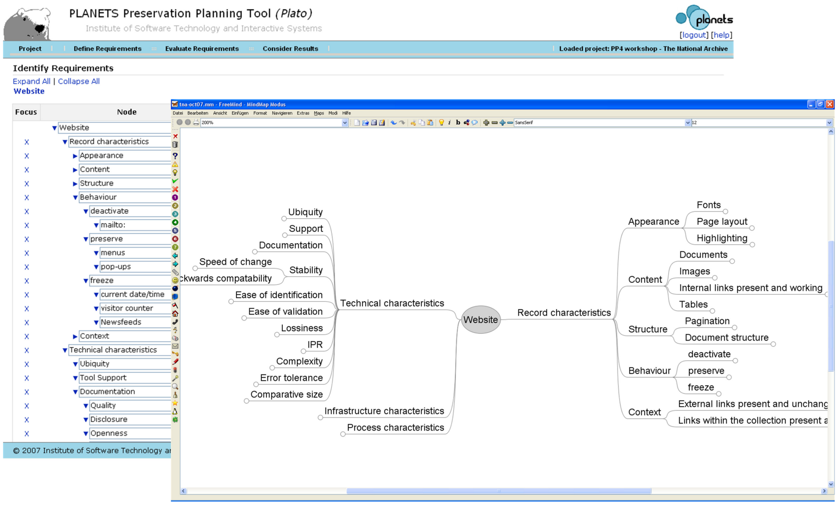

Fig. 2. Requirements definition in Plato

supports loose coupling of services and registries through standard interfaces and provides common services such as user management, security, and a common workspace. Based on this technical foundation, the aim is to create an interactive and highly supportive software environment that advances the insight of preservation planners and enables proactive preservation planning.

Figure 1 illustrates the preservation planning environment, putting the described workflow in the working context of services and registries as they are currently being implemented. It shows three main aspects: (1) Integrating registries for information discovery; (2) Integrating services for preservation action and characterisation of objects; and (3) Proactively supporting the planning with a knowledge base that holds reusable patterns and templates for requirements recurring in different planning situations.

The right choice of samples that are representative for the collection under consideration is essential, as any skewed representation might lead to wrong results. **Collection profiling services** based on characterisation services and format registries can inform the selection process and ensure the right stratification of samples. **Risk assessment services** can further assist by quantifying both the inherent risks of object formats and the salient risks present in the objects which are of particular relevance to a specific file format, such as the number of pages for some document formats or the presence of transparency layers in images.

The specification of requirements in a tree structure is often done in a workshop setting. This is supported by both a flexible web interface as depicted in Figure 2 and a direct tree import from mind-mapping software[5]. The knowledge

[5] `http://freemind.sourceforge.net`

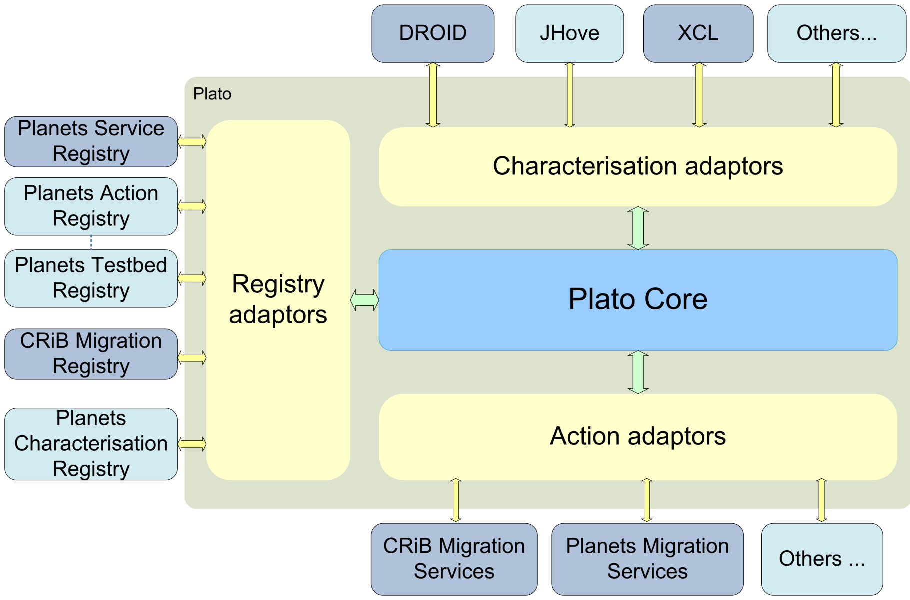

Fig. 3. Overall integration architecture

base provides recurring fragments and templates, such as process requirements for an archival institution or essential object characteristics for electronic documents in a library, to assist in the process of tree creation.

5 A pluggable evaluation framework

5.1 Introduction

While the preservation planning approach and the supporting planning tool outlined above provide considerable support and guidance, we need a link to existing tools and services performing preservation action and characterisation as well as a dynamic integration of information from different, partly heterogeneous information sources (registries). This section outlines an integration architecture and a pluggable framework for automating the evaluation of preservation actions in the described context.

Figure 3 shows the overall building blocks of the architecture. Three types of adaptor layers are needed:

1. **Registry adaptors** provide access to information sources. This primarily refers to registries holding information about preservation action tools and services, but also includes access to preservation characterisation registries that hold information such as risks of file formats.

2. **Action adaptors** are needed for accessing (remote) preservation action tools and services that come in different flavours and varying form. A number of migration services are available online that convert objects[3]. The Planets preservation action tool registry will contain extensive metadata and benchmark experiences from conducted preservation experiments.
   On the other hand, emulators can be a viable alternative in certain instances. Remote access to emulation can support the evaluation and the decision whether or not the additional effort for setting up an emulation environment is both feasible and valuable in a given planning situation.
3. Finally, **characterisation adaptors** access tools and services which can identify file formats, assess the risks of digital objects, extract some or all of their properties and compare these.

These characteristics extracted by the above mentioned characterisation tools and services can be of considerable heterogeneity and complexity. Moreover, the tools are just emerging and rapidly evolving. We thus propose a flexible pluggable architecture for the automated evaluation of objectives and criteria leveraging these services. The basic concept is to enable the dynamic attachment of 'plugs' to criteria in the objective tree, where a plug provides an evaluation value for a defined criterion. We identify three types of plugs:

1. **Comparators** are used for comparing significant properties of objects to validate that the application of a preservation action has not led to a breach of authenticity by destroying or changing a significant characteristic of the original object. To this end, they rely on characterisation tools and services and combine the outputs of these to evaluate changes in the resulting object.
2. **Evaluators** extract and analyse information about either an object or a preservation action tool and provide an evaluation value for a specific characteristic. This could be for example a risk assessment of a target file format when doing migration planning.
3. **Modellers** are used for specifying more complex relationships between key influence factors and their impact on outcomes and evaluation results. For example, cost factors can be combined in cost models to produce an estimate of the costs needed to implement a specific preservation strategy.

While comparators and evaluators need to rely on characterisation tools and services, modellers will mostl likely be largely independent of these. However, the key factors that are used within modellers might be subject to a monitoring process such as technology watch, as is outlined in Section 5.4.

5.2 Comparators

Validating the content of objects before and after (or during) a preservation action is one of the key questions in digital preservation.

While different tools are available, the main focus of our work are the characterisation tool JHove and the eXtensible Characterisation Languages [6] developed within the Planets project.

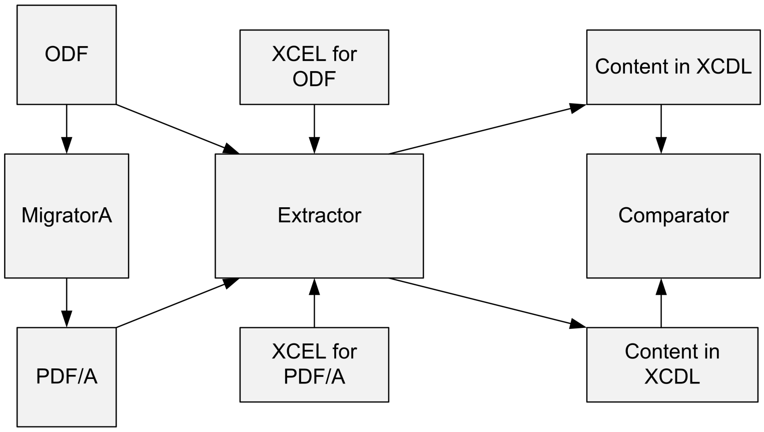

Fig. 4. Using XCL to compare migrated documents

Figure 4, taken from [6], shows a scenario for applying XCL in the context of format migration. After converting a document from ODF to PDF/A, the XCDL documents of the original and the transformed object can be compared using an interpretation software. A comparison tool ('Comparator') for XCDL documents is currently under development. Key objectives are the property-specific definition of metrics and their implementations as algorithms in order to identify degrees of equality between two XCDL documents. In its core functionality the comparator loads two XCDL documents, extracts the property sequences and compares them according to comparison metrics which are defined with respect to the types of the values in the value sets.

To allow the usage of this mechanism within the planning procedure, we need to connect characteristics and comparison metrics to the requirements and criteria defined in the objective tree. The different layers of this conceptual mapping are outlined in Figure 5, which spawns the bridge from objects and their characteristics to overall goals and how they can be broken down to more precise requirements and measurable criteria. The two trees need to be modelled in such a way that they can be connected; furthermore, comparison metrics and mapping structures are necessary to support the quantified and automated evaluation of criteria.

5.3 Evaluators

Evaluators provide characteristics of either objects or actions. A prime example for the first category is risk assessment of objects and object formats. Analysing the characteristics of preservation action services, such as measuring the performance of migration tools or services, falls into the second category.

Risk assessment services are being developed within the Planets project; an exemplary evaluation plug could leverage these services to perform risk assessment on the sample objects and their transformed counterparts. The risk assess-

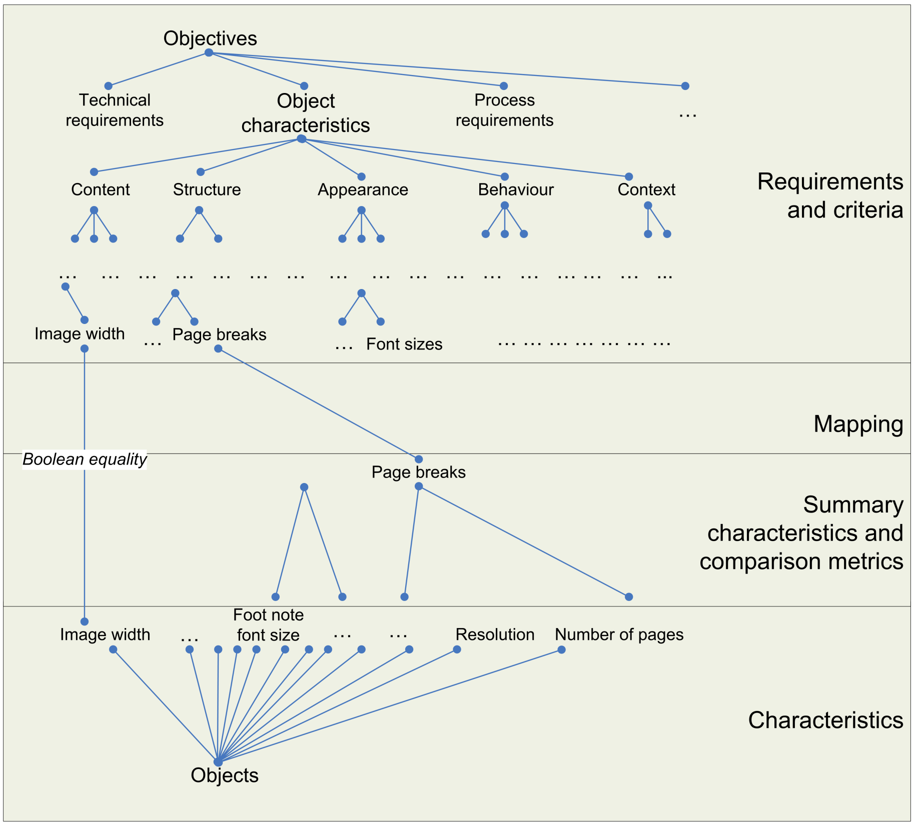

Fig. 5. Connecting object properties to objectives and criteria

ment service in the Planets characterisation framework addresses two categories of risks: (1) General risks of formats, such as complexity or lack of documentation, and (2) Risks that can apply to objects of a certain kind. For example, Word documents with more than 1000 pages may be much more difficult to preserve than short documents.

5.4 Modellers and Watchers

The previous sections have outlined how to analyse, characterise and compare digital objects and actions. This section describes how complex relationships between influence factors can be represented and suggest a mechanism for supporting the assessment of change impact.

Our approach uses **modellers** as the third category of plugs to connect influence factors such as cost factors to criteria in the objective tree. For example, cost factors can be combined through different cost models such as the LIFE and

LIFE2 models[2] to calculate an estimate of the costs of preserving one object for a specified time span.

While evaluators and comparators rely on input from characterisation services, modellers might be used as input to a different category of plugins. **Watchers** extract information from the environment, thus monitoring the environment with respect to specific parameters that influence preferences and decisions. The most prominent example in this context is technology watch, where aspects such as the distribution of file formats are monitored and warnings can be raised when specific thresholds are exceeded.

Watchers are an important basis for continuous monitoring and iterative planning as shown in Figure 1. To this end, thresholds could be defined on various levels that trigger an alert when exceeded. The input parameters to the modeller plugs mentioned above could then be captured, modelled and monitored as well through watchers, leading to a continuous recalculation of the modeller plugs. These in turn can trigger an alert leading to a re-evaluation of preservation solutions and a possible update of the preservation plan.

6 Discussion and Outlook

This paper outlined a flexible and extensible evaluation framework for automating the preservation planning procedure. The concept builds on a solid preservation planning methodology and aims at improving both automation of the workflow and traceability of key influence factors to ensure their impact can be assessed. It consists of an integration architecture and a series of so-called *plugs* which can be attached to criteria for measuring key influence factors that impact preservation planning decisions. We described the main architecture, discussed which issues we deem critical for the successful implementation of this framework, and outlined the next steps in this direction.

The main issues foreseen in completing this work are threefold.

1. The correct trade-off between flexibility and generality on one side, and the specific information needs of algorithms on the other side, can be difficult to find. Similarly, the timely availability of input information needed for the evaluation at the right point in time can be difficult. For example, benchmarking migration services will imply that benchmark results are captured as metadata during service execution; these metadata need to be analysed by the evaluation plug.
2. Related to this, the availability and quality of characterisation services integrated through the evaluation framework is critical to the final quality of the resulting evaluation processes.
3. The mapping between characteristics and requirements needs to bridge the conceptual gap between intellectual properties and technical characteristics.

A thorough conceptual basis is needed to tackle these issues; on the technical level, rapid prototyping can ensure that concepts are validated in an early stage. The successfully implemented architecture should lead to a series of benefits:

– Improved automation of the planning procedure, leading to a considerable reduction in the effort needed to create a preservation plan.
– Improved quantification and understanding of influence factors, leading to a better traceability and improved change impact assessment. This also creates a basis for a continuous monitoring of influence factors through watch functions.
– Researchers and tool developers until now often do not know which kinds of characteristics are significant and need to be extracted and compared automatically. Moreover, they are lacking a common framework of delivering, deploying, testing, distributing, and putting to use algorithms and tools for characterisation, specifically for the comparison of object properties and the characterisation of actions.
  The completed framework can serve as an integration framework for developing advanced services for preservation characterisation and comparison algorithms.
– Analysis of existing and missing services can serve as a gap analysis pointing at problems and thus providing a research agenda for supporting the evaluation of preservation services.

The next steps in developing the described framework are as follows.

– Analyse existing objective trees and their criteria to verify the completeness of the approach with respect to potential influence factors;
– Build prototypical implementations of each type of plug; and
– Build a software infrastructure that supports the dynamic integration of plugs.

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