Graph Data-Models and Semantic Web Technologies in Scholarly Digital Editing

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Graph Data-Models and Semantic Web Technologies in Scholarly Digital Editing

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Scholarly Music Editions as Graph: Semantic Modelling of the Anton Webern Gesamtausgabe

Stefan Münnich, Thomas Ahrend

Abstract

This paper presents a first draft of the ongoing research at the Anton Webern Gesamtausgabe (Basel, CH) to apply RDF-based semantic models for the purpose of a scholarly digital music edition. A brief overview of different historical positions to approach music from a graph-theoretical perspective is followed by a list of music-related and other RDF vocabularies that may support this goal, such as *MusicOWL*, *DoReMus*, *CIDOC CRM inf*, or the *NIE-INE* ontologies. Using the example of some of Webern's sketches for two drafted Goethe settings (M306 & M307), a preliminary graph-based model for philological knowledge and processes is envisioned, which incorporates existing ontologies from the context of cultural heritage and music. Finally, possible use-cases, and the consequences of such an approach to scholarly music editions, are discussed.

1 Introduction

Despite the seemingly irrefutable opinion that musicology is regarded as a "delayed discipline" (Gerhard 2000) due to the complexity of its subject-matter, scholarly music editions made the step into the digital age more than a decade ago.[1] Projects such as *Freischütz Digital* (2012*), Beethovens Werkstatt* (2014), or the *Digital Mozart Edition* (2006) have achieved fundamental milestones in the field of encoding musical information in XML-based formats (e.g., the format of the *Music Encoding Initiative* – MEI[2]) and have made significant contributions to both the theory of scholarly editing

[1] For a constitutive overview about the notion and concept of Digital (Scholarly) Edition see Sahle 2013, Pierazzo 2015, Driscoll and Pierazzo 2016, or Bleier et al. 2018. The diversity of the music philological landscape was cartographed in Emans and Krämer 2015; an in-depth discussion about the very nature of the *music philological question* was provided in Urbanek 2013. The transfer and application of digital methods to music editions has been fundamentally – in theory and practice – stimulated, discussed and developed during the last two decades by Joachim Veit and members of his research team (e.g. Veit 2006, Veit 2010, Veit 2015). A most comprehensive summary of the history, present and prospective of digital music philology can be found in Kepper 2011, a short repositioning in Acquavella-Rauch 2019, and in Kepper and Pugin 2017.

[2] See project website and latest specification of MEI (v4) in Music Encoding Initiative 2017 and Music Encoding Initiative 2018.

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and digital applications. However, the question arises (not only in the musical field) whether a *digital edition* should not be more than the mere conversion of a text into an XML format. The representation of semantic relationships and links between different areas of the editions, the overlap-free representation of non-hierarchical content, as well as the connection and interlinking with external data sets, are only some of the challenges that such an approach struggles to meet. Therefore, as early as 2009, Johannes Kepper considered whether "directed graphs are the more suitable data structure for encoding (music) texts than tree structures (and thus XML)" (Kepper 2009, 220). In the field of scholarly textual editions, some efforts were made in this direction (Kamzelak 2016, Wettlaufer 2018, or many other papers in the present volume). In the context of scholarly music editions, however, such an approach has, to date, hardly been tested. In order to pursue this desideratum, the Anton Webern Gesamtausgabe (University of Basel, CH) has the aim of researching and testing the scientific application of graph-based semantic models, in terms of RDF vocabularies,[3] for the purpose of a digital music edition. In this paper, we present a preliminary draft of this ongoing research: in section 2 we give a short overview of different historical positions to approach music from a graph-theoretical perspective, and a discussion of existing music-related and other, helpful, vocabularies; in section 3 we introduce a graph-based model for philological knowledge and processes, which is under active development within the project, in close cooperation with the Digital Humanities Lab Basel (DHLab) and the Swiss-wide National Infrastructure for Editions (NIE-INE). Incorporating existing ontologies from the context of cultural heritage and music, the possible interplay of these models is demonstrated using the example of some of Webern's sketches for two drafted Goethe settings from the 1930's (M306 & M307). The last section discusses possible consequences for the self-understanding of scholarly music editions if philological processes are considered as graphs.

2 Music as Graph

The idea to approach music from a graph-theoretical perspective has increasingly attracted attention since the mid-2000s in different areas:

On the one hand, graph-theoretical reflections have been applied to music in order to make its mathematical benefits available for music-analytical purposes.

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[3] The *Resource Description Framework* (RDF) is a "standard model for data interchange on the Web. […] RDF extends the linking structure of the Web to use URIs to name the relationship between things as well as the two ends of the link (this is usually referred to as a "triple"). Using this simple model, it allows structured and semi-structured data to be mixed, exposed, and shared across different applications. This linking structure forms a directed, labeled graph, where the edges represent the named link between two resources, represented by the graph nodes. This *graph view* is the easiest possible mental model for RDF and is often used in easy-to-understand visual explanations." (RDF Working Group 2014).

Fundamental developments in the field of mathematical music theory were realized in geometric approaches (e.g., Mazzola 1990; Mazzola 2002; Tymoczko 2011) or especially in transformational approaches combining both group theory and graph theory (e.g., Lewin 1987; Lewin 1990; Klumpenhouwer 1998). Following on from these approaches, more current studies are covering a wide range of subjects, including pattern matching (e.g., Szeto & Wong 2006), musical gestures (e.g., Mazzola & Andreatta 2007), tonal modulation (e.g., Walton 2010), or voice-leading (e.g., Rings 2011; Popoff et al. 2018).

On the other hand, graph-based knowledge models of music have been developed which contribute to the vision of a semantic web as it was proposed by Tim Berners-Lee and others around the year 2000 (Berners-Lee 1998; Berners-Lee et al. 2001). Formalized by (RDF-based) ontologies in terms of "explicit, formal specification[s] of a shared conceptualisation" (Studer et al. 1998, 184), the aim of these models was to enable a machine-readable description and connection of music metadata, especially in the context of music information retrieval (MIR), music recommendation systems, or music library cataloguing.[4] Despite these overall efforts, only a few major international projects such as *DoReMus*[5] in France or *Transforming Musicology*[6] in the UK have promoted "the enhancement of Semantic Web provisions for musical study […] augmenting existing controlled vocabularies (known as ontologies) for musical concepts"[7]. A comprehensive application of semantic web technologies to the modelling, enhancement, and transformation of human knowledge, as it has been discussed more and more in the humanities in recent years (e.g., Oldman et al. 2016), remains largely a desideratum in the domain of music,[8] and especially for scholarly music editions (Münnich 2018).

2.1 Existing Graph-Based Models for Musical Knowledge

When it comes to computer-based modelling of knowledge structures, it should be noted at the outset that each model can only be a reduced, simplistic, and imperfect *surrogate* for the considered part of the natural world, and that it can neither be all-

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[4] A comparison of music metadata schemas is given in Corthaut et al. (2008); an overview of (graph-based) symbolic music representation systems can be found in Simonetta (2018).

[5] Project website of *DoReMus* (http://www.doremus.org/) and the data access point of the *DoReMus* project (http://data.doremus.org/).

[6] Project website of *Transforming Musicology* (https://tm.web.ox.ac.uk/). Nurmikko-Fuller and Page 2016.

[7] Description of the *Transforming Musicology* project on its earlier, now no longer accessible website: https://web.archive.org/web/20170225090608/http://www.transforming-musicology.org/about/.

[8] Daquino et al. 2017 surveyed the "Landscape of Musical Data on the Web" in 2017 and have published their findings as a Linked Open Dataset: https://github.com/enridaga/musow. Their observation is "that a large amount of [musical] resources are not ready to be part of the Web of Data", identifying "the heterogeneity of large collections, the uncertainty in licensing, and the lack of large scale approaches to semantic lifting of musical resources and data publishing" as the main obstacles (Daquino et al. 2017, 67). Many thanks to Albert Meroño-Peñuela for pointing us to this survey.

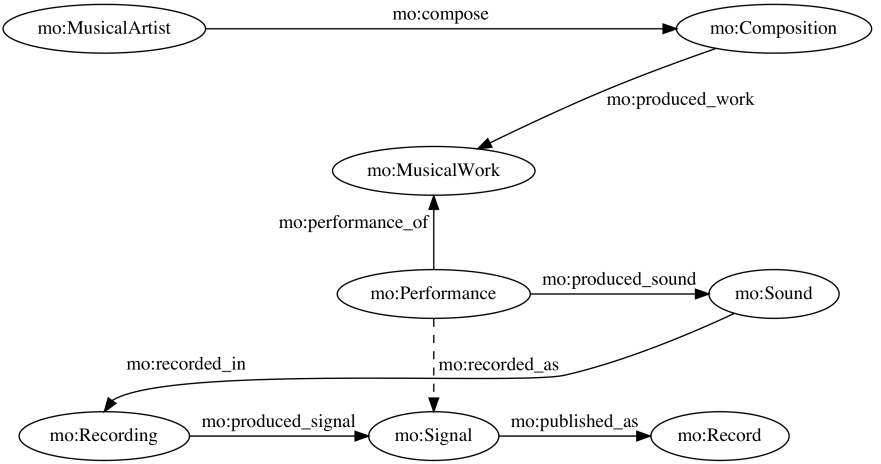

Figure 1. Excerpt (music production process) from the *MusicOntology*.

encompassing, nor finally conclusive (Davis et. al 1993; Stachowiak 1973). Thus, there is no single *correct* way, but rather multiple best possible ways of modelling, against which – up to a dead end, in case of doubt – the respective object of investigation, the questions to be applied to it, and one's own perspective, have to be tested.

Since as early as 2002, *MusicBrainz* has provided an online database of CD information that is stored and queried with unique identifiers (URIs) for artists, publishers, and albums, down to the track level. Although it does not offer any ontology in the narrower sense, *MusicBrainz* can be considered the first "semantic web service" for music-related information and it is still actively maintained and developed to date (Swartz 2002).

The *Music Ontology* (Raimond et al. 2013; motools 2013; motools 2007), which was developed at the Centre for Digital Music at the Queen Mary University of London in 2007, is widely used, especially in the field of MIR and music recommendation systems (Raimond et al. 2007; Sandler et al. 2009). Based on OWL, the Web Ontology Language, it is primarily concerned with statements on music production processes (like works, composers, performances, or recordings; see Figure 1). Its spin-offs and supplementary models (*timeline*, *event*, *keys*, *tonality*, *symbolic notation*, *chord*, *temperament*, *audio features*) allow the modelling and representation of further detailed musical information. Although it must currently be regarded as the de facto standard ontology for musical phenomena, the active development of the *Music Ontology* was discontinued in 2014.

The *MusicOWL – Music Score Ontology* (Jones et al. 2017a), which has been in devel-

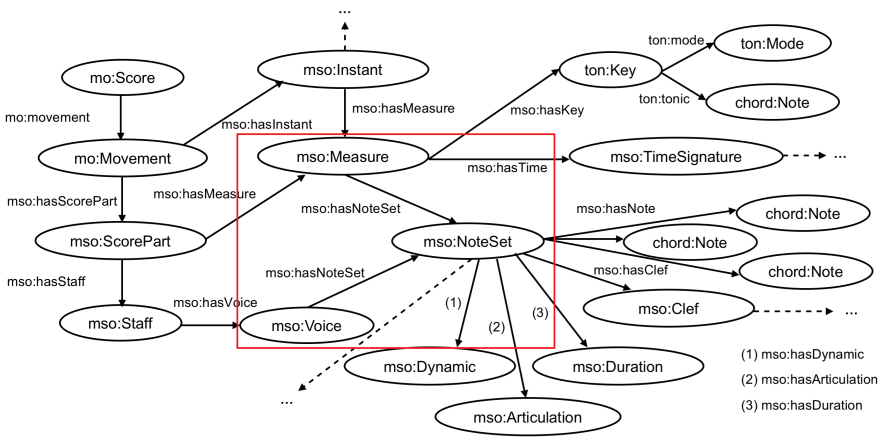

Figure 2. Excerpt from the *MusicOWL* ontology (mso) with integration of *Music Ontology* (mo), *Chord Ontology* (chord) and *Tonality Ontology* (ton).

opment at the University of Münster since 2017, is also based on OWL, but considers musical content beneath the level of musical scores, including elements such as parts, chords, notes, dynamics, articulations, measures, or voices (see Figure 2). Thereby, it reuses and expands the *Music Ontology* and its aforementioned supplementary models (Jones et al. 2017b). A very remarkable feature of the ontology is the overlap-free assignment of individual notes or chords, by means of a *NoteSet,* to both a certain measure or a certain part at the same time, which remains an intractable problem in XML-based encoding formats. Time will tell what the impact of *MusicOWL* will be, and that will be dependent on how well it handles or builds on existing standards. As an important first step, a (JAVA based) conversion tool from MusicXML to RDF, based on the *MusicOWL* ontology, already exists;[9] a corresponding module for the conversion of data encoded in MEI format would be most welcome in scholarly and philological contexts.

In addition, the *DoReMus* project has developed an ontology model that integrates and reuses the *MusicOntology*, *FRBRoo* (IFLA Working Group on FRBR/CRM Dialogue 2015), *CIDOC CRM* (CIDOC 2006), and the Europeana Data Model (EDM 2012), i.e., the main ontologies in the context of humanities (Achichi et al. 2015; Choffé & Leresche 2016). Thereby, a complex, mirrored, triangular modelling pattern, adapted from

[9] Github repository (https://github.com/jimjonesbr/musicowl). Another independent, but less documented approach to express MusicXML in RDF can be found in MusicML 2016. More information about the music interchange format MusicXML is provided in Good 2001. Latest specification in Good 2017.

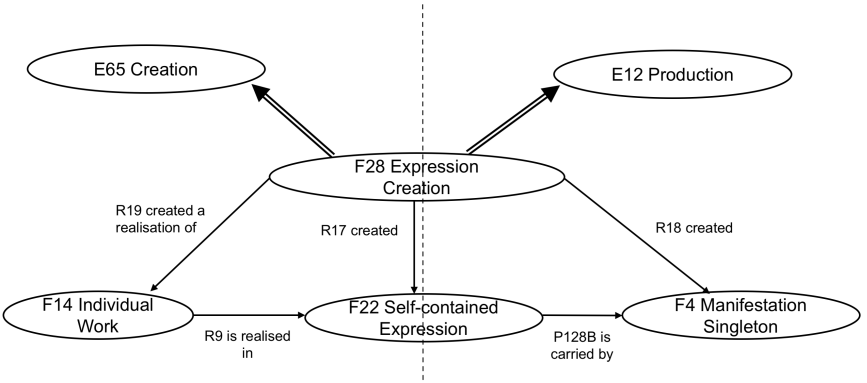

Figure 3. Mirrored triangular pattern in *FRBRoo*.

FRBRoo, comes into play (Figure 3): on a conceptual level, a self-contained expression (*F22*) of an individual work (*F14*) is created in an expression creation event (*F28*). On a physical level, a manifest sign carrier is created – the so-called manifestation singleton (*F4*) – that carries the content of the self-contained expression. This segmentation of the concept of a *work* enables a highly complex modelling pattern of, and differentiated statements about, the creation process of a composition, and enables the repetition of this pattern on the level of performances, publications, recordings, or reception processes (Figure 4).

With *MELD* ("Music Encoding and Linked Data")[10], the British *Transforming Musicology* project has created a semantic framework that researches the "distributed real-time annotation of digital music scores" (in MEI format) with the help of semantic technologies. Here too, several existing models are reused, including *Music Ontology*, *FRBR* (Functional Requirements for Bibliographic Records; IFLA Study Group 1998), *SKOS* (Simple Knowledge Organization System; Miles & Bechhofer 2009), *PROV-O* (Provenance Ontology; Lebo et al. 2013), and *Web Annotation Ontology* (Sanderson 2017). The goal is the enrichment of MEI data with Semantic Web Annotations, which should guarantee a dynamic real-time communication between the participants of a performance situation (orchestra or band members), mediated by the musical score (Weigl & Page 2017; Kallionpää et al. 2017). The *MELD* framework is utilized by the EU-funded *TROMPA* project ("Towards Richer Online Music Public-domain Archives")[11] that aims to establish a digital platform to interlink, digitize and semantically enrich

[10] Github-Repository *MELD* (https://github.com/oerc-music/meld).
[11] Project website *TROMPA* (https://trompamusic.eu/).

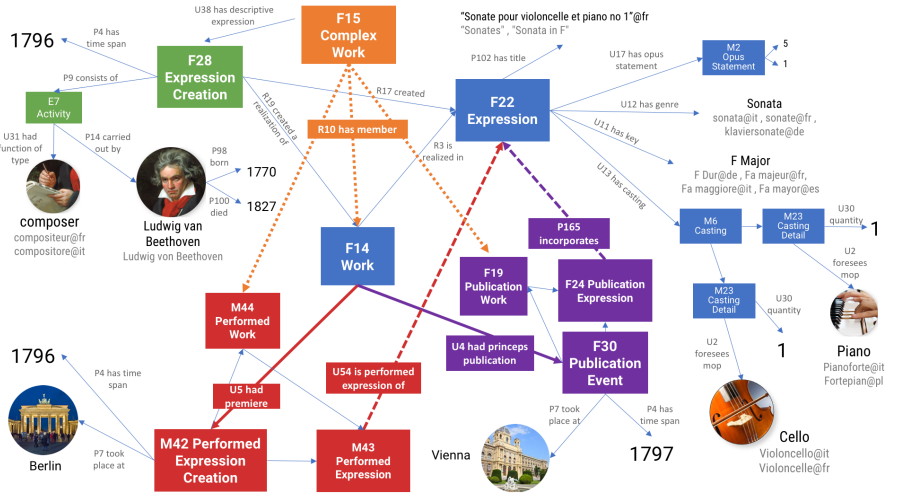

Figure 4. Excerpt from the *DoReMus* model with the separation of work (orange/blue), expression (blue) and expression creation (green) as well as their connection to performance (red) and publication (purple) processes by example of Beethoven's Cello sonata F-Major op. 5/1.

and annotate all forms of classical music in public domain, including scores in MEI format and sound recordings (Weigl et al. 2019; Goebl & Weigl 2019).

The *MIDI Linked Data* project researches the interconnection of "symbolic music descriptions [...] contained in MIDI files"[12]. Here, MIDI data are transformed to, and represented as, RDF graphs, with the help of a *MIDI Ontology* that captures the events (especially pitches, or instruments) of a MIDI file (Meroño-Peñuela & Hoekstra 2016a). A python-based converter allows for the lossless transformation from MIDI to RDF and back (Meroño-Peñuela & Hoekstra 2016b).

CHARM (Common Hierarchical Abstract Representation of Music) strives for an abstract representation of hierarchical musical structures. The concept developed in the early 1990s (Wiggins et al. 1989, Smaill et al. 1993) has been recently remodeled in a Semantic Web context (Harley & Wiggins 2015).

A no less ambitious project is *JazzCats* ("Jazz Collection of Aggregated Triples"),[13] which merges information on performances, recordings, and artists from three dif-

[12] Documentation of the *MIDI Linked Data* project, Github repository (https://github.com/midi-ld/documentation). Cf. also the project website: https://midi-ld.github.io/. The *Musical Instrument Digital Interface* (MIDI) is a control protocol for music devices and an industry standard since 1983. Its specifications can be found in MIDI Manufacturers Association (MMA) 2019.

[13] Project website *JazzCats* (http://jazzcats.cdhr.anu.edu.au/).

ferent jazz-related data sets (*Body & Soul*, *WJazzD*, and *LinkedJazz*), and links them together through concepts from the *Music Ontology* (Bangert et al. 2016; Bangert et al. 2018).

In 2016, the *Enhancing Music Notation Addressability* (EMA) project has introduced an Application Programming Interface (API) that facilitates "addressing and extracting specific portions of music notation published in machine-readable formats on the web" (Viglianti 2016, 57). Inspired by the URI-based mechanism and approach of the API of the *International Image Interoperability Framework* (IIIF) for images, the web service described by the Music Addressability API provides a standardized URI scheme, which can also be applied very effectively in graph modeling.

2.2 Other Helpful Models

In addition to generic top-level ontologies such as *FOAF* (Friend-of-a-Friend; Brickley & Miller 2014), *SKOS*, or the ontologies of the *Dublin Core Metadata Initiative* (DCMI 1995), which are extremely widespread due to the generality of their concepts, there are various models that are frequently used in connection with humanities, and that have been mentioned already in section 2.1: *CIDOC CRM* and the Europeana Data Model for Cultural Heritage (*EDM*), the bibliographic model *FRBRoo*, or *PROV-O* for provenance descriptions. Instead of these quite established models, we will concentrate in this section on two rather recent, and therefore less widely known, models: the first one is a whole series of ontologies that have been developed by the Swiss-wide project *National Infrastructure for Editions* (*NIE-INE*)[14]. These ontologies (Figure 5), adhering to the model theory of RDF and OWL Full, aim for a machine-interpretable, formal semantic expression of digital scholarly editions, providing a tremendous and highly interdependent range, from generic concepts (e.g., agent, event, human, organization), science-historical approaches (mathematics, philosophies, logic), to edition-specific (document, text-editing, text-structure, text, information carrier), or project-specific vocabularies (Kuno Raeber, Parzival, Atharvaveda, and others). Based on external ontologies (like the aforementioned) whenever possible, the *NIE-INE* ontologies apply event- and role-based modelling patterns (similar to, e.g., *CIDOC CRM*).

Another promising approach is the *CRMinf* Argumentation model, which was developed recently in the orbit of *CIDOC CRM* (Stead 2015; Doerr et al. 2015). It uses, inter alia, a pattern with a certain belief (*I2 Belief*), which assigns a corresponding truth value (*I6 Belief Value*) to a certain statement (*I4 Proposition Set*) as shown in Figure 6.

[14] Project website *NIE-INE* (https://www.nie-ine.ch) and Github-Repsitory *NIE-INE* (https://github.com/nie-ine). Authoritative publication of ontologies on http://e-editiones.ch. Cf. the paper of Roberta Padlina and Hans Cools in the present volume. The NIE-INE project was discontinued at the end of 2020.

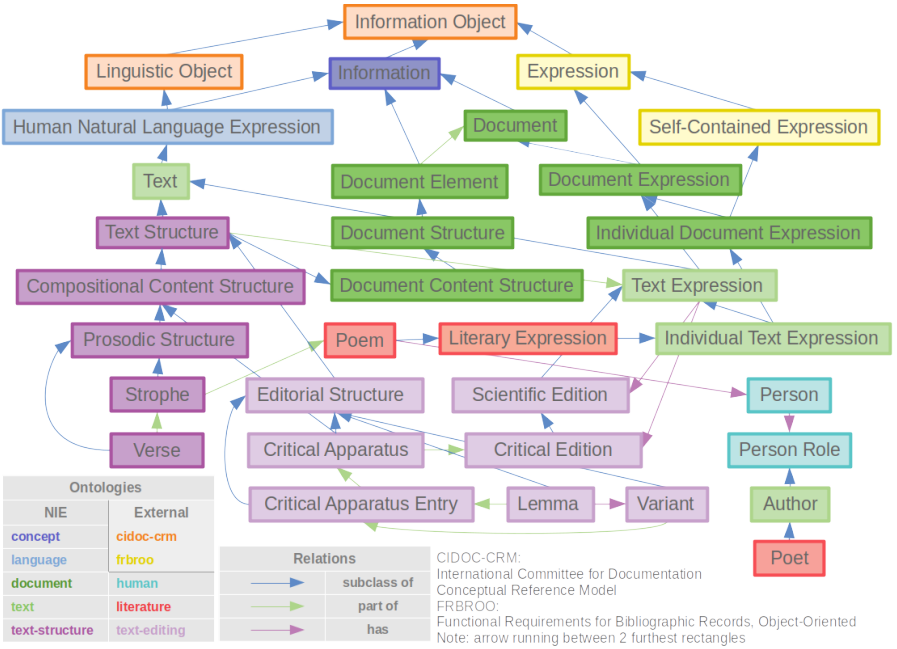

Figure 5. Core classes and properties of different ontologies from the NIE-INE project.

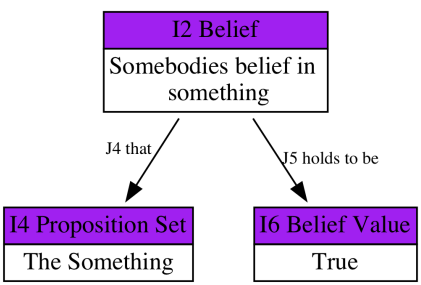

Figure 6. Belief Pattern in the *CRMinf* Argumentation Model.

This model could be particularly useful in the field of (digital) humanities, as it allows scholars to deal with uncertainty, doubts, hypotheses, or any kind of argumentative conclusion. However, so far only a few projects are known (like *ResearchSpace*[15], Oldman & Tanase 2018) that have applied this model comprehensively to an existing research question. Also, to gain the full potential of an argumentation model in the context of humanities, adding some time indicators to *CRMinf* should be considered ("I believe in something at a certain time"), as well as the possibility of using probability values, or at least a weighting of different beliefs.[16]

3 A Semantic Model for the Anton Webern Gesamtausgabe

The Anton Webern Gesamtausgabe (AWG 2015a; AWG 2015b) is working on a model that allows for a semantic representation of the philological knowledge compiled in the project (which is considered to be reusable for other music edition projects). As a so-called hybrid edition, located at the University of Basel, the AWG intends to make its digital parts available online with the help of the software framework *Knora* (Knowledge Organization, Representation, and Annotation), which is currently under development at the Digital Humanities Lab of the University of Basel.[17] (In addition, printed volumes will be published by Universal Edition in Vienna.) *Knora* allows one to supplement *Knora*-specific application models with project-specific ontology models of a certain granularity, which can be created, edited, and linked within the framework. In addition, facsimiles can be integrated, displayed, and annotated, in accordance with the IIIF standard (International Image Interoperability Framework Consortium 2019). For some time now, *Knora*'s predecessor, the virtual research environment *Salsah* (System for Annotation and Linkage of Sources in Arts and Humanities)[18], has been used productively as a database archive for context materials and for the document collection of the AWG. An area for daily editorial work, in which editors can create their critical reports and editions directly within the research environment, is currently under active development, also in close cooperation with the *NIE-INE* project (cf. section 2.2). A snapshot of the relationships between the various groups and projects involved is shown in Figure 7 in the form of an RDF graph, in which only classes or properties of the *FOAF*, *DCTerms* and *schema.org* (W3C Schema.org Community Group 2019) vocabularies are used. It goes without saying that the graph is not as limited as the figure conveys; according to the paradigm of an open world assumption, extensions and additions can be made at any point.

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[15] Project website *ResearchSpace* (https://www.researchspace.org/index.html).
[16] Thanks to Hans Cools and Roberta Padlina for pointing this out.
[17] Project website *Knora* (https://www.knora.org).
[18] Project website *Salsah* (https://www.salsah.org/). Schweizer & Rosenthaler 2014.

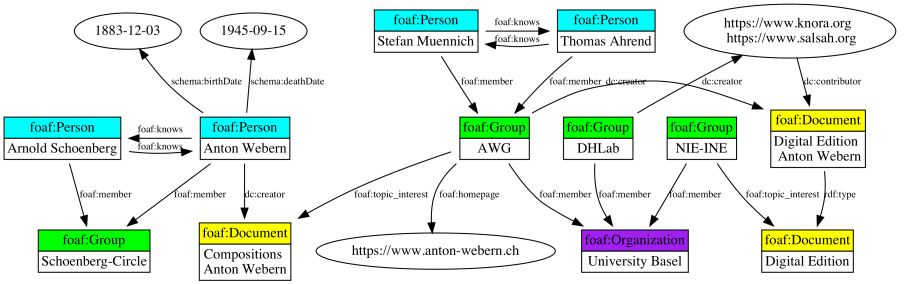

Figure 7. The Anton Webern Gesamtausgabe and some of its interrelations with historical and current groups, persons or matters of subjects.

Within this framework, the model of the AWG is being developed. Incorporating existing ontologies from the context of cultural heritage and music, this model will have a number of features: the separation of abstract works, self-contained expressions, and expression creation events (according to *FRBRoo*); the semantic embedding of these elements into their respective production, performance, or publication processes (according to *DoReMus*); the application of music-specific ontology models (*MusicOntology*, *MusicOWL*) and controlled vocabularies; as well as the integration of the *CIDOC CRMinf* Argumentation model, to deal with any kind of argumentative conclusion or uncertainty.

3.1 Graph-based model of philological knowledge and processes

Anton Webern's musical sketches for *Cirrus* M306, and for *Der Spiegel sagt mir: ich bin schön!* M307,[19] both unpublished fragments written in the summer of 1930 on poems by Goethe, shall serve as a starting point for the following discussion. Since M306 is conceptually a piano song, and M307 is, in most parts, a vocal composition, the two pieces are assigned to different sections of the edition (series II/3: Posthumous Choir Music, and series II/5: Posthumous Piano Songs). Each section contains its own general introduction, all the transcribed musical texts (sheets) of the section, and an overall critical report of the section (Figure 8). However, some sketches of M307 suggest a possible arrangement as a piano song, so the piece could be assigned to both sections. In most printed editions, assigning a piece to two different sections would hardly be conceivable, not least for reasons of space and cost. In a digital environment, however, the assignment does not have to be exclusive and can be designed to be flexible and multivariable.

[19] The M-number is referring to a cataloguing principle for Webern's oeuvre introduced by Hans Moldenhauer in Moldenhauer 1978.

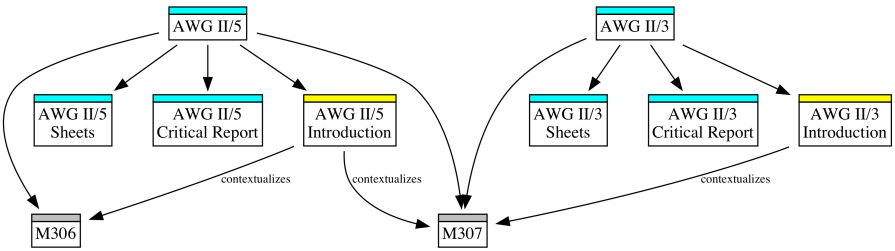

Figure 8. Assignment of different musical pieces (M306, M307) to different sections of the edition (AWG II/3 & II/5).

When looking at M307 a little closer (Figure 9), we see that the structure of the sections of the edition is mirrored on the level of the individual musical pieces: on a much more granular scale than the whole section, the musical pieces are equipped with a separate, more specific, introduction, their own specific transcribed musical texts (sheets), and a corresponding critical report. At the same time, these sub-sections are back-linked and contribute to their respective super-sections (indicated by dashed arrows). The critical report for M307 consists of an overview, a description, and an evaluation of the materials that are involved and considered sources for M307. In the case of an drafted-only composition like M307, these will be called sketch *complexes* (analogous to work complexes), i.e., the set of individual sketches (Sk1, Sk2, up to Sk7 in Figure 9) that can be identified on one or more certain pages (fol. 3v in Figure 9) of one or more physical sign carriers (Webern's sketch book no. 3 in Figure 9). It is this level of the sketch complexes where the actual philological work takes place: the source description describes the relevant sections of the physical sign carrier, the contents of which are transcribed in the sheets. The source evaluation evaluates the physical material in terms of a source, and defines the content and form of the text-critical comments (TkA), which are themselves philological annotations to the transcribed musical texts. Again, these sub-sections of the sketch complexes (sheets, source evaluation, and source description) are back-linked, and contributing to their respective super-sections (indicated by dashed arrows). As can be seen in Figure 9, the nodes in the graph have different functionalities: some of them are digital representations of a real world entity, either physical (like the sketchbook), or abstract (like the work complex M307, or its sketch complexes). These could be referred to as the actual points of interest of an edition (marked in grey). Other nodes (marked in yellow) stand for textual manifestations (like introductions, transcribed musical texts, source lists, evaluations, or descriptions) that are solely produced by the editors within the context of their philological work. The remaining nodes (marked in cyan)

represent digital *container* objects that need to be filled, either by the produced texts, or by backlinks from lower levels.

None of these philological issues is actually new or surprising compared to approaches in *traditional* editions. But in order to make philological knowledge accessible to machine-interpretable processing, it is necessary to explicitly name and model the operations from which it is shaped. One of the advantages of such graph-based modelling becomes evident in Figure 9. There is nothing to constrain the perspective from which an editor or user has to approach the content of an edition. Coming from the edition side, one could ask: Show me all sketches that are described in section II/5. Sk1 of M307 would be one of these sketches. From the material side, one could ask: Which entities in Sketchbook 3 have a source description? Here, too, Sk1 of M307 would be one of the returned items. Finally, one could merge the questions and ask: Show me all sketches that are described in section II/5 and are notated in Sketchbook 3. And again, Sk1 of M307 would be one of the results. Because of the explicit distinction between the level of the edition and the level of the (physical) material,[20] it becomes quite easy to switch perspectives without confusion or loss of orientation.

3.2 Connecting the model to the world

The proposed model is intended to be compliant with the application models of *Knora,* and to the framework of the *NIE-INE* ontologies. Besides the fact that the NIE-INE ontologies themselves are highly connected to *CIDOC CRM* and other existing ontologies, there are also various entry and connection points for the ontologies discussed earlier, in section 2 of this paper: *FRBRoo* via *DoReMus*, *MusicOWL* or CIDOC's *CRMinf*. Some of these connections are illustrated in Figure 11. According to *FRBRoo*, a physical sign carrier (the sketchbook in our example above) can be regarded as a F4 Manifestation Singleton, and the text objects produced by the editors as E31 Documents. In a way, the entity called M306 in the edition, as well as the corresponding sketch complexes associated with it, are documenting abstract works (M306 resp. first to nth sketch of M306). As already mentioned in chapter 2.1, these abstract works are represented in *DoReMus* (following *FRBRoo*) by a *F15 Complex Work* object and its corresponding member (a *F14 Individual Work*), which is realised in a *F22 Self-Contained Expression* that was created by an *F28 Expression Creation*. Following this path along the graph (marked in orange), the aforementioned digital representations of the abstract and the physical edition subjects become connected once more, this time not in terms of philological processes, but in terms of the creation processes of a musical piece. In this way, both the production processes and

[20] Peter Boot and Marijn Koolen called these two levels the *editable domain* and the *edition domain*, cf. their article in the present volume.

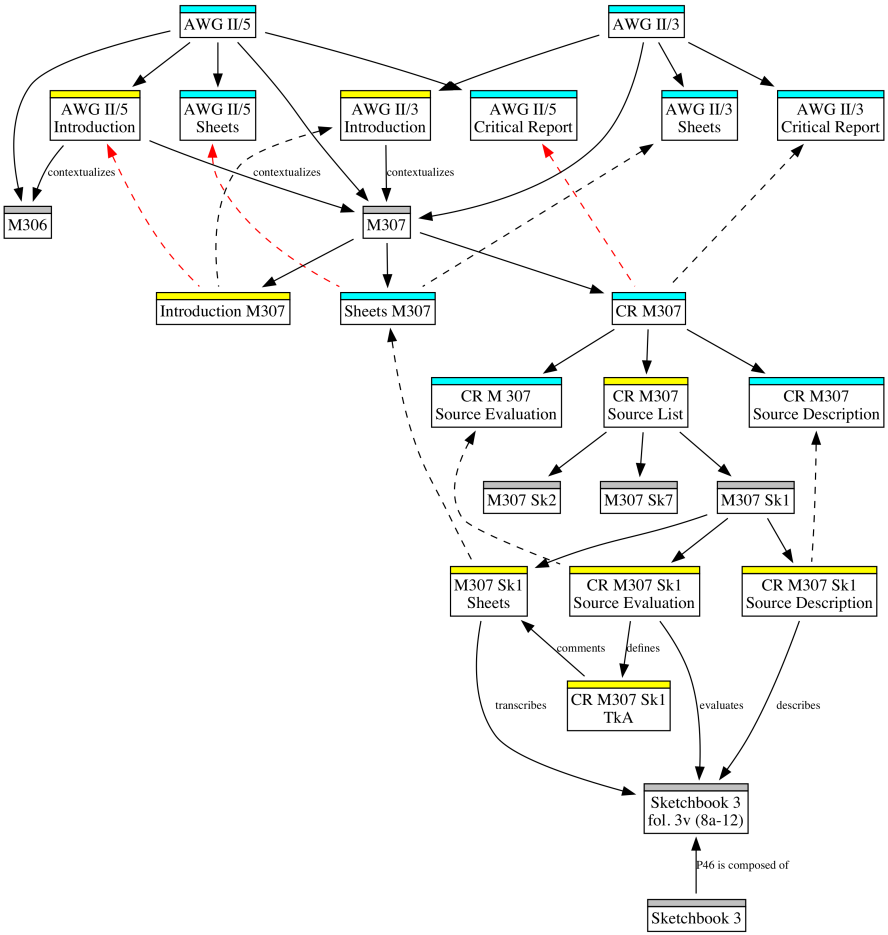

Figure 9. Philological processes concerning the sections of the edition and the material found in Webern's sketchbooks using the example of one sketch (Sk1) of M307.

reproduction processes of a piece, closely interacting with each other in an edition project, get interlinked and at the same time differentiated explicitly. Other sections of the *DoReMus* ontology including publications, performances, recordings, or reception processes can also be addressed here.

Regarding the transcribed musical texts, their status as a E31 Document can be further specified as a (digital) musical score. Utilizing the *Music Ontology* (*mo:Score*) and the *MusicOWL* ontology, this is the entry point for the highly detailed relationships on the level of music notation, as depicted in Figure 2 above. Following the approach of the *MELD* framework, these models can be used on top of a digitally encoded representation of the music score[21] to support the linking of the transcribed texts to philological observations, such as text-critical commentaries or alternative readings.

As already mentioned, the *CRMinf* Argumentation model can be particularly useful in the field of (digital) humanities. It allows scholars to deal with uncertainty, doubts, hypotheses, or any kind of argumentative conclusion. For graph-based scholarly digital editions, this model could take a genuine place in source evaluation: here, the ranking and relationships of the materials considered as sources are negotiated, their status is examined, and possible missing sources (*deperdita*) can be determined (Münnich 2019). In a final vision, however, it could be imagined that such a model could be applied to every single triple statement in the graph, in order to make the decision- and knowledge-making processes far more transparent. But this transparency would come at the price of the overall model quickly becoming much more complex. Figure 10 exemplifies a *simple* case, in which the conclusion of a scholar regarding two propositions (A & B) is accepted and adopted by a second scholar. The increasing complexity is easy to imagine if contradictions or scientific controversies and discourses are included in the modelling. But such complexity should be welcomed, as it allows scholarly argumentation in a digital context to overcome under-complexity or under-specification, which is induced by argumentatively restrictive or limited digital applications, and lags behind scientific standards and best practice.

3.3 Transforming philological knowledge

The example of some of Webern's sketches will be used to demonstrate how the idea of thinking about graphs and networks can influence the philological processes

[21] The AWG is in close contact (participation in workshops, conferences, development) and exchange with the MEI community, especially to clarify the question how a transcoding of the existing edited music texts (which are prepared with the music notation program *Finale* and available right now in MusicXML, PDF and SVG output format) into the MEI format would be possible. Since the philological findings and procedures require extensive manual intervention and adjustments to the *Finale* transcriptions, such transcoding can only be carried out to a certain extent (semi-)automatically. Until a technically feasible solution can be found within the capacities of the AWG in the medium term, the score texts will be embedded as SVG graphics within the online edition of the AWG.

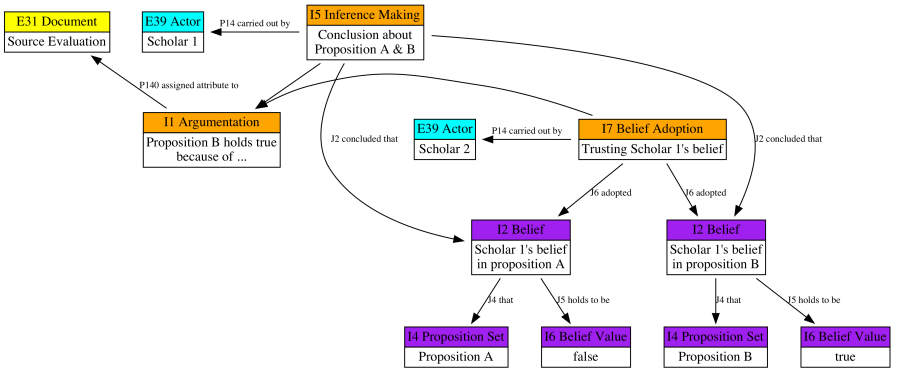

Figure 10. Example of an argumentative conclusion assigned to a source evaluation.

and the work of an edition project. Figure 12 shows a detail of folio 3^{v} in Webern's Sketchbook 3 on which the first sketches for *Der Spiegel sagt mir: ich bin schön!* M307 can be found.

One full page width sketch (Sk1) is accompanied by two smaller sketches above it (Sk1.1 and Sk1.2). From a philological examination, it becomes clear that Sk1.1 must have been created in parallel to the main sketch Sk1, since both sketches reflect and influence the changes of each other, without it being possible to determine which changes came first. We would call this a concomitant, accompanying relationship between the two sketches. In contrast, Sk1.2 must obviously have been created after finishing Sk1.1, since its first layer includes changes made in Sk1.1. This is what we would call a preceding, consecutive relationship. (It should be noted that Sk1.2 and Sk1 are in turn in a concomitant relationship to each other, i.e., here both sketches reflect and influence changes in the other.)

Going through the entire three pages in Sketchbook 3 that are related to M307, different working stages can be identified (Figure 13). They clearly start with an arrangement for four voices, then reduce the casting to three voices, before finally experimenting with the casting for one voice and piano, so transforming into a piano song, instead of a purely vocal composition. Additionally, different variants of the underlying twelve tone row can be found, as well as some paratexts that are connected to the start and end dates of the compositional process (between July 7^{th} and 9^{th} 1930).

Allocating all (up to 13) of the larger and smaller sketches of M307 (here named Sk1 to Sk8) to these different stages results, almost automatically, in a graph-based visualization and orientation of the dependencies and interrelations between the

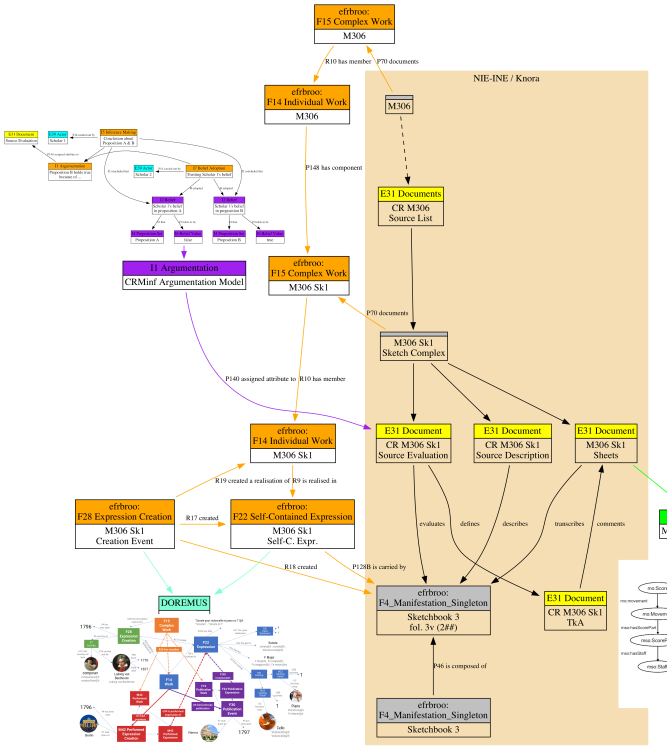

Figure 11. AWG embedded in the context of existing ontologies like *FRBRoo, DoReMus, MusicOWL*, or *CRMinf*.

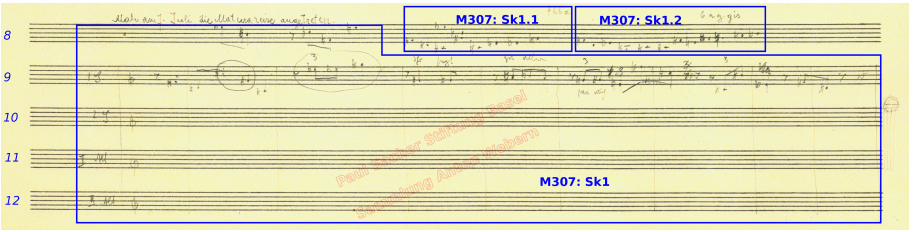

Figure 12. Folio 3^v of Webern's Sketchbook 3 with first sketches of M307 (detail of staves 8–12).

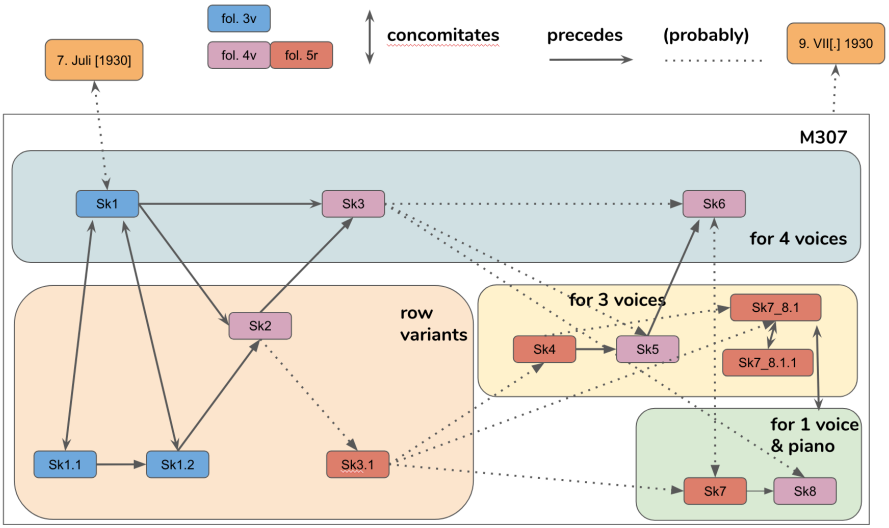

Figure 13. Philological *pathways* through Webern's M307. © Anton Webern Gesamtausgabe, 2019. CC-BY-NC-SA 4.0.

sketch complexes, as shown in Figure 13. Hereby, every established relationship (indicated by arrows in the figure) provides a short evaluation and explanation as to how the conclusion was reached by the editors. Expressed in RDF triples, all of this combines to form a graph-based source evaluation that allows for multiple *pathways*[22] through the different source materials involved. While the editors can provide their particular view and their particular *pathway*, other researchers and users could follow another path.

4 Conclusion

A quarter of a century after the first propositions and attempts to build a (then called) computer edition and its critical apparatus as an "hypertext presentation in the World Wide Web" (Peter & Wender 1997; Hoffmann et al. 1993), scholarly digital editions have adapted to the new possibilities and challenges of the technological and conceptual developments of the web. Among various approaches, XML-based solutions have played a crucial role for a long time. XML gains its full power in connection with

[22] The concept of *pathways* for digital (music) editions was recently proposed and discussed by Kepper and Pugin 2017, 362–363.

encodings of a document's structure. But it has its structural, conceptual and semantic limitations, like any artificial model, including RDF. But RDF, as with other graph-based approaches, provides another complementary perspective, and adds a level of differentiation that goes beyond the expressiveness of XML.

In this paper, we have tried to give another example of the potential of RDF-based modelling of philological knowledge. The possibilities for the representation of semantic relationships and the links between different areas of a scholarly digital (music) edition, the overlap-free representation of non-hierarchical content, as well as the connection, interlinking and interoperability with external data sets, appear to be the main advantages of such an approach. Of course, these structural possibilities could also be applied and continued beyond the scope of our example: thus, the indicated *pathways* through the sketches of Webern's M307 could be extended to paths through Webern's entire oeuvre, which then can be examined from within its historical context; ultimately, the presentation of a comprehensive music history would also be conceivable, progressing from the smallest surviving source materials, to larger musical or cultural perspectives.

Finally, we have to take into consideration that a graph-based, semantic approach to scholarly (music) editions is not only about using cutting-edge technology, it is about transforming philological knowledge into a machine-interpretable environment, and about changing the way in which we ourselves are enabled to think about philological and music historical processes.

5 Future Work

The proposed model for scholarly music editions is a work in progress, and a lot needs to be done: the classes and concepts to be re-used from external ontologies must be finally determined and applied to the model, especially those from the *Music Ontology*, *MusicOWL*, or from *DoReMus*. To take this step, the interlinking and interaction of the Knora models, the *NIE-INE* ontologies, and the *DoReMus* ontologies have to be further tested and investigated. On the level of music notation encoding, it would be great to see a closer connection between MEI format and *MusicOWL*. Hereby, the fundamental research and work of the *MELD* project will be of great assistance.

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Appendices

Biographical Notes

Thomas Ahrend (University of Basel, Switzerland – thomas.ahrend@unibas.ch) studied Musicology, Philosophy and Literary Studies in Frankfurt a. M. and Berlin. He received his MA 1996, and his PhD 2005 at Technische Universität Berlin with a dissertation on the instrumental music of Hanns Eisler. 1997–2010 member of the editorial staff of the Hanns Eisler Gesamtausgabe in Berlin. Since September 2010, member of the editorial staff of the Anton Webern Gesamtausgabe at Musikwissenschaftliches Seminar at University of Basel.

Peter Boot (Huygens ING, The Netherlands – peter.boot@huygens.knaw.nl) studied mathematics and Dutch language and literature; he wrote his PhD thesis about annotation in scholarly digital editions and its implications for humanities scholarship. He oversaw the creation of the digital edition of the letters of Vincent van Gogh. He is employed as a senior researcher at the Huygens Institute for the History of the Netherlands where he works, among other things, as a consultant in several edition projects.

Manuel Burghardt (University of Leipzig, Germany – burghardt@informatik.uni-leipzig.de) is head of the Computational Humanities Group at Leipzig University. He is interested in the use of digital tools and computational techniques to explore new modes of doing research in the humanities. His most recent areas of research are Sentiment Analysis in the Humanities, Drametrics, Computational Intertextuality, Computational Analysis of Movies and Series and Music Information Retrieval.

Toby Burrows (University of Oxford, United Kingdom – toby.burrows@oerc.ox.ac.uk) is a Senior Researcher in the Oxford e-Research Centre at the University of Oxford, and a Senior Honorary Research Fellow in the School of Humanities at the University of Western Australia.

Hugh Cayless (Duke University, USA - hugh.cayless@duke.edu) is Senior Digital Humanities Developer at the Duke Collaboratory for Classics Computing. Hugh has over a decade of software engineering expertise in both academic and industrial settings. He also holds a Ph.D. in Classics and a Master's in Information Science. He is one of the founders of the EpiDoc collaborative and currently serves on the Technical Council of the Text Encoding Initiative.

Hans Cools (University of Basel, Switzerland – 1961-2021) had a master degree in medicine and a specialization in orthopaedic surgery and traumatology (Universities of Ghent and Antwerp, Belgium, 1997), a bachelor's degree in physical

therapy, and a standalone degree in informatics (1999). Through various research and project management positions, in both companies and academic institutions, he gained expertise in different aspects of the Semantic Web technologies, focusing particularly on formal data modeling and machine reasoning. Those positions were in internationally collaborative research projects in a biomedical setting, mainly of the 5-7th EU Framework Program. Foremost in these projects were semantic interoperability and reusability of data. Since 2016, he worked in the humanities, as knowledge engineer, ontologist, and Semantic Web technology expert, at the University of Basel, as part of the NIE-INE project, which highlights scholarly editing. He (co-)published several articles, and gave workshops on the implementation of Semantic Web technologies in biomedicine and the humanities. He passed away in April 2021.

Francesca Giovannetti (University of Bologna, Italy – francesc.giovannett6@unibo.it) is a second-year PhD student in Digital Humanities at the Department of Classical Philology and Italian Studies, University of Bologna. She received an MA in Digital Humanities from King's College London and a second cycle degree in Digital Humanities and Digital Knowledge from the University of Bologna. She is interested in combining digital scholarly editing with semantic web technologies and in the use of digital technologies in education.

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Marijn Koolen (Royal Netherlands Academy of Arts and Sciences - Humanities Cluster, The Netherlands – marijn.koolen@gmail.coml) studied artificial intelligence and wrote his PhD thesis on using hyperlinks in information retrieval algorithms. He has worked on scholarly annotation for digital humanities research and on annotation-related information behaviour and information systems. He works as a researcher and developer at the Humanities Cluster of the Royal Netherlands Academy of Arts and Sciences, where he leads a project on developing annotation support within the *CLARIAH research infrastructure* project.

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Iian Neill (Digital Academy of the Academy of Sciences and Literature, University of Mainz - Iian.Neill@adwmainz.de) is a visiting researcher at the Digital Academy of the Academy of Sciences and Literature Department at the University of Mainz, Germany. He is the creator of Codex, a text annotation environment which uses standoff property annotation to generate entities in a graph meta-model. Codex is currently being used to produce a digital edition of the epistles of Hildegard von Bingen at the Digital Academy in Mainz.

Roberta Padlina (University of Basel, Switzerland – roberta.padlina@unibas.ch) studied medieval philosophy at the University of Fribourg, Switzerland, obtaining a doctoral degree in June 2020. She has twelve years of professional experience in the field of Digital Humanities, thanks to which she has been able to work closely with different actors involved in the online publication of open access research. Roberta has worked for several years for e-codices –Virtual Library of Manuscripts in Switzerland and currently coordinates the National Infrastructure for Editions (NIE-INE) project. Roberta's main focus is on the opportunities and challenges that the digital shift poses for traditional education and research institutions, including developing semantic web strategies for scholarly publications and cultural goods.

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Miller C. Prosser (University of Chicago, USA – m-prosser@uchicago.edu) earned his Ph.D. in Northwest Semitic Philology from the University of Chicago. His academic interests include the social and economic structure of Late Bronze Age Ras Shamra-Ugarit and the use of computational methods for philological and archaeological research. Miller is the Associate Director of the Digital Studies MA program at the University of Chicago where he teaches courses on Data Management and Data Publication for the Humanities. He also works as a

researcher at the OCHRE Data Service of the Oriental Institute of the University of Chicago where he consults with and supports research projects using the Online Cultural and Historical Research Environment (OCHRE). He has also worked as a tablet photographer for the Mission de Ras Shamra (Ugarit) and the Persepolis Fortification Archive Project, employing advanced digital photographic methods such as reflectance transformation imaging, photogrammetry, and high-resolution digital scanning.

Matteo Romanello (Université de Lausanne, Switzerland - matteo.romanello@unil.ch) is Ambizione SNF Lecturer at the University of Lausanne, where he conducts a project on the commentary tradition of Sophocles' Ajax. Matteo is a Classicist and a Digital Humanities specialist with expertise in various areas of the Humanities, including archaeology and history. After obtaining his PhD from King's College London, he worked as a research scientist at EPFL's DHLAB on the Linked Books and Impresso projects, before moving to his current position. He was also teaching fellow at the University of Rostock, researcher at the German Archaeological Institute, and visiting research scholar at Tufts University.

Sandra Schloen (University of Chicago, USA – sschloen@uchicago.edu) is the Manager of the OCHRE Data Service at the Oriental Institute of the University of Chicago, and is the co-designer and developer of the Online Cultural and Historical Research Environment (OCHRE). Trained in computer science and mathematics (B.Sc. University of Toronto; M.Ed. Harvard University), Sandra has spent over 30 years working with technology as a systems analyst, technical trainer, and software developer. A long association with colleagues in the academic community has enabled her to develop a specialty in solving problems in the Digital Humanities where challenges of data capture, data representation and data management abound. Specifically, she has served extensively as a database manager for several archaeological projects in Israel and Turkey, and supports a wide range of research projects at the Oriental Institute and at other universities.

Desmond Schmidt (University of Bologna - desmond.allan.schmidt@gmail.com) has a background in classical Greek philology, information security and eResearch. He has worked on several scholarly edition projects, including the Vienna Wittgenstein Edition (1990–2001), Digital Variants (2004–2008), the Australian Electronic Scholarly Editions project (2012–2013), the Charles Harpur Critical Archive (2014-) and a pilot edition of Gianfrano Leopardi's Idilli (2018-). He currently works on developing practical web-based tools for making, visualising and publishing digital scholarly editions.

Colin Sippl (University of Regensburg, Germany – colin.sippl@ur.de) is currently a project employee at the University Library of Regensburg. Since 2017, he has been working on extending the open access services of the Electronic Journals Library (EZB). More recently, he has started developing and setting up a digital repository for literature, artefacts and experiments relating to the early life sciences based on the Invenio framework. He specialised in textual data mining and the development of media services in the institutional domain.

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