Playing with a Web of Music: Connecting and Enriching Online Music Repositories[1]

David M. Weigl and Werner Goebl (University of Music and Performing Arts Vienna)

Towards Richer Online Music Public-Domain Archives

Classical music represents both a treasured cultural heritage and a living, contemporary tradition, perpetuated and continuously reinterpreted through practice, performance, scholarly analysis, and listening enjoyment. Music libraries and archives assemble, preserve, and organize classical music resources for retrieval, but currently underserve the more dynamic aspects of our interactions with this repertoire. Enriching these interactions is important in order to engage, broaden, and diversify the classical music audience, thus sustaining this tradition.[2]

The EU Horizons 2020-funded TROMPA project[3]—Towards Richer Online Music Public-domain Archives—is addressing this challenge by combining music information retrieval (MIR) technologies and crowd-sourcing approaches to publish, interlink, contextualize, and augment public-domain classical music resources.[4] Building on large existing music repositories, TROMPA provides services for the discovery, enhancement, and contribution of musical scores, recordings, analyses, and interpretations, applying

1 This publication incorporates and expands on text from "Interweaving and enriching digital music collections for scholarship, performance, and enjoyment" by authors David M. Weigl, Werner Goebl, Tim Crawford, Aggelos Gkiokas, Nicolas F. Gutierrez, Alastair Porter, Patricia Santos, Casper Karreman, Ingmar Vroomen, Cynthia C. S. Liem, Álvaro Sarasúa and Marcel van Tilburg, presented at the 6*th* *International Conference on Digital Libraries for Musicology* (2019). DOI: 10.1145/3358664.3358666

2 Melenhorst and Liem, "Put the Concert Attendee in the Spotlight."

3 *Trompa*. https://trompamusic.eu

4 Weigl and Goebl, "Interweaving and Enriching Digital Music Collections."

open, standard web and MIR technologies to ensure reusable, reproducible, reinterpretable, scalable, and sustainable access to the data produced.

Within the project, we are building an infrastructure around publicly licensed music resources on the Web, adhering to FAIR principles of making data Findable, Accessible, Interoperable, and Reusable.[5] Digital encodings of musical scores play a central part, both as resources of primary interest and as structural frameworks for interlinking multimodal musical representations.

In this chapter, we provide an overview of the TROMPA project. Then, in section 2, we situate its origins within the heritage of three multi-institutional predecessor projects focusing on technologically enriched classical music concert experiences, digital music scholarship, and semantic Web technologies. We present several major Web repositories of publicly licensed music content in Section 3 before describing TROMPA's data infrastructure for interconnecting and enriching such repositories in Section 4. Section 5 describes five user types targeted by specialized Web applications under development as part of the project, as well as considerations pertaining to privacy and data ownership arising when users enrich and generate new music resources through their interactions with these applications. Section 6 introduces the Music Encoding Initiative and its XML schema underlying the dynamic digital scores forming the basis of TROMPA's user-facing applications. Finally, we characterize the Companion for Long-term Analyses of Rehearsal Attempts (CLARA), a TROMPA Web application serving the needs of instrumental players engaged in music practice, in Section 7; we then offer conclusions and future perspectives in Section 8.

Background

TROMPA builds on a number of previous wide-ranging, multi-institutional research projects around the interlinking and enrichment of music resources in a variety of use cases.

5 Wilkinson, "The FAIR Guiding Principles for Scientific Data Management and Stewardship."

Performances as Highly Enriched aNd Interactive Concert eXperiences (PHENICX)

PHENICX was an international collaborative research project funded under the European Union's Seventh Framework Programme. Motivated by notions that technological developments in the current digital age could offer new opportunities to make symphonic classical music more accessible to broader audiences, the project had two main focus areas.[6] Research was performed both into improving the audiovisual analysis techniques necessary for enabling multimodal enrichment, and into finding ways to make such enrichments engaging and useful for the intended broader audiences.

Though producing impactful demonstrations of technologically enriched concert experiences,[7] scalability was limited in part by the expensiveness of processes required to generate clean and well-structured input data (e.g., digital score encodings, score-aligned performance recordings) assembled under the supervision of human experts. In TROMPA, we are addressing this limitation through crowd-sourcing components that more scalably incorporate human insight into enrichment activities, while placing greater emphasis on the use of standardized Web technologies and FAIR data practices facilitating reuse of the data we generate beyond the confines of the project.

Transforming Musicology

This wide-ranging UK-based AHRC-funded project included a focus on semantic linking of musical resources and workflows, demonstrating how scholars might take fuller advantage of the possibilities for presentation, analysis and discovery inherent in a Web of digital resources organized as Linked Data.

Methods for capturing scholarly practice in terms of workflow were studied as an exercise in the semantic approach by analyzing and comparing the steps needed to achieve useful results in a number of music(ologic)al

---

6 Gómez, "PHENICX;" Liem, "Innovating the Classical Music Experience in the PHENICX Project."

7 E.g.: Arzt, "Artificial Intelligence in the Concertgebouw;" Gasser, "Classical Music on the Web-User Interfaces and Data Representations;" Melenhorst et al., "A Tablet App to Enrich the Live and Post-Live Experience of Classical Concerts;" Sarasúa Berodia, "Mapping by Observation."

tasks.[8] Other work in the SLICKMEM and SLOBR projects immediately preceding Transforming Musicology investigated the problems of aligning multiple datasets compiled with inconsistent formats or standards.[9] Subsequent follow-up projects have focused on the application of tools and workflows assembled under Transforming Musicology toward multimedia scholarly publishing and access to music digital libraries.[10]

Fusing Audio and Semantic Technologies for Intelligent Music Production and Consumption (FAST)

FAST was a multi-institutional UK EPSRC-funded project at the intersection of audio processing technologies, studio science, and the Semantic Web. The project defined Digital Music Objects (DMOs), flexible constructs consisting of recorded music essence coupled with rich, semantic, linked metadata with applications throughout the music value chain, from production through to distribution and consumption.[11] DMOs retain provenance traces of their activities throughout this chain, with implications for music digital libraries.[12]

Though not sharing TROMPA's focus on public-domain classical music, the notion of the DMO is particularly informative in an environment focusing on the interlinking of music metadata, provenance-tracked contributions by human and machine agents, and reuse and reinterpretation within different usage contexts.

Music Collections on the Web

A wealth of music resources is available digitally on the Web, composed of various types of music information, including scans of music score sheets, music encodings, audiovisual performance recordings, and metadata describing each of these resources and documenting extra-musical facets such as bib-

8 Nurmikko-Fuller, "A Linked Research Network that is Transforming Musicology."

9 Weigl and Lewis, "On Providing Semantic Alignment and Unified Access to Music Library Metadata."

10 Lewis, "Publishing Musicology Using Multimedia Digital Libraries;" Page, "MELD: A Linked Data Framework."

11 Sandler, "Semantic Web Technology for New Experiences."

12 De Roure, "Music and Science."

liographical information—works, composers, performers; composition, arrangement, publication, and performance events; and so on.

Though such resources and descriptions are publicly available in numerous Web-accessible repositories, each repository typically presents only subsets of both repertoire and information modality. The prospect of combining and inter-referencing, for instance, various editions of a musical score, performance recordings by various interpreters, alongside musicological commentary by various scholars, offers exciting possibilities for unified music exploration and analysis; but this prospect is hindered by the typically disparate nature of music repositories on the Web.

One of the largest and most notable collections, the International Music Score Library Project (IMSLP), also known as the Petrucci Music Library,[13] contains over 475,000 scores by more than 17,500 composers. All scores included in IMSLP belong to the public domain in either Canada or the US. The IMSLP is an important source for musicians and scholars seeking printed editions of classical music pieces, often offering multiple versions of the same composition. IMSLP also contains Creative Commons-licensed recordings uploaded by users, and links to commercial recordings provided by music labels, which paid subscribers can listen to.

Another important public-domain classical music score repository is the Choral Public Domain Library (CPDL),[14] which holds over 32,000 choral and vocal works by at least 3,200 composers. Both IMSLP and CPDL are important repositories as sources for different technologies and use cases in the TROMPA project.

The main resource for public-domain structured (and machine-readable) music metadata is MusicBrainz,[15] an 'open music encyclopedia' maintained by a global community of users. Although aimed broadly at music of all genres, MusicBrainz contains an impressive number of classical works, composers and performers. The MusicBrainz data model includes many features that uniquely suit classical music, including distinctly identifying compositions and movements, annotating compositions with catalogue numbers, and relating recordings to people who participated in them—e.g., performing orchestra, any soloists, the conductor—as well as specific information about composers and works performed. Data quality and quantity vary on initial

13 *IMSLP Petrucci Music Library*. https://imslp.org
14 *Choral Public Domain Library*. https://www.cpdl.org/wiki
15 *MusicBrainz*. https://musicbrainz.org

contribution, but community members can correct, adjust or complement the data. MusicBrainz' structured data model and use of unique identifiers have made it an authority for music identification.

The biggest non-commercial collections of audio recordings can be found in specialized music archives and libraries. They are often part of national libraries, like the British Library Sound Archive[16] or the Deutsches Musikarchiv.[17] Such collections are generally not publicly accessible outside of their source institution, remaining effectively 'invisible' (no audio playback; no display of artwork or record covers) and not searchable without specialist access.

Muziekweb,[18] based in Rotterdam, does provide publicly accessible collection of music data. It offers access to over 600,000 CDs and 300,000 LPs, described using international library standards, which it is matching to domain-relevant repositories, including MusicBrainz, Wikidata, sheet music archives, and streaming services. The archive, including digitized audio data that can be used for audio analysis and high-quality metadata, makes Muziekweb a relevant authority for classical music in the TROMPA project.

Each of these repositories provides useful information, but their interconnection is limited. Users of these platforms (and many others available on the Web) are often unaware that the other platforms exist. Most repositories use their own vocabulary and description standards, and typically do not integrate complementary information available across collections. Breaking through these 'silos' of music information by interconnecting music resources across repositories is a key motivation for the TROMPA project.

A Data Infrastructure for Interconnecting and Enriching Music Collections

Integrating and ingesting different datasets into a single combined repository ('data warehousing') is a complex problem, involving the alignment and translation of potentially different representations and data schemas.[19] However, the motivation of TROMPA is not to supplant established Web music repositories by copying entity descriptions and media representations into

16 "Sounds." https://sounds.bl.uk
17 "German Music Archive." https://www.dnb.de/EN/Ueber-uns/DMA/dma_node.html
18 *Muziekweb*. https://www.muziekweb.eu
19 Weigl and Kudeki, "Combine or Connect."

a centralized database and unified schema, but rather to describe them by reference, using URIs to address, interlink, and contribute layers of enriched descriptors and content to resources hosted in situ at their native (TROMPA-external) Web locations.

Schema.org,[20] a formalized vocabulary for describing Web resources, provides a core data model for this purpose of virtual integration across music repositories. This is augmented by other widely used, standardized vocabularies, including the Dublin Core Metadata Initiative's[21] vocabulary for encoding bibliographic relationships, the Simple Knowledge Organisation System's (SKOS)[22] vocabulary for mapping relations (providing the 'glue' for interconnecting entities across repositories), and the Web Annotation vocabulary[23] and PROV ontology[24] for capturing and tracking the provenance of contributions to enrich these resources by TROMPA users (Section 5) and by automated music information retrieval processes. Further established vocabularies are adapted for specialized applications, such as for the alignment of musical scores and performance recordings (Section 7).

Graph databases are ideally suited to support such flexible, mutably specified interconnection of Web-based resources. TROMPA has opted to adopt a Neo4j property graph database for this purpose. This database, exposed for query via a GraphQL endpoint, forms the core of the TROMPA Contributor Environment (CE), a data infrastructure that also comprises a number of component APIs for multimodal query, display and annotation of music resources, and automated assessment of scores and performances. Querying via the standard SPARQL[25] query language for Linked Data is not supported; while this would allow maximally flexible semantic queries over the CE graph, it is prone to performance issues at scale[26] and does not trivially support the automated processing of newly arriving data driving TROMPA's enrichment processes. However, each node in the graph can be accessed via a persistent URI through an HTTP wrapper interface, providing a JSON-LD[27] represen-

20 *Schema.org*. https://schema.org

21 *Dublin CoreTM Meta Data Initiative*. https://dublincore.org/specifications/dublin-core/dcmi-terms/

22 *SKOS Simple Knowledge Organization System*. http://www.w3.org/2004/02/skos/core.html

23 *Web Annotation Vocabulary*. https://www.w3.org/TR/annotation-vocab/

24 *PROV-O: The PROV Ontology*. http://www.w3.org/TR/prov-o/

25 *SPARQL 1.1 Query Language*. https://www.w3.org/TR/sparql11-query/

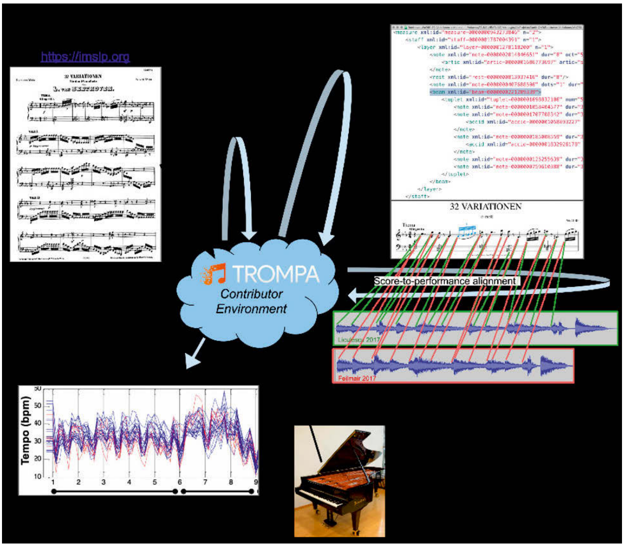
26 Fields, "A Case Study in Pragmatism."

27 *JSON-LD 1.1*. https://www.w3.org/TR/json-ld/

tation of the respective entity and its associated properties and values, thus interweaving the CE graph with the wider Web of Linked Open Data.

Figure 1 illustrates several enrichment processes coordinated by the CE upon resources in TROMPA-external music repositories. A PDF score is ingested into the CE by reference to its URI. Automated processes validated and improved by human insight through crowd-based activities are triggered in order to arrive at a machine-readable digital music encoding, which is aligned with recordings of performances of the work enabling rich interactions and analyses serving TROMPA users.

Figure 1: The TROMPA Contributor Environment (CE) interlinks and coordinates enrichment activities upon repositories of publicly licensed music resources on the Web.

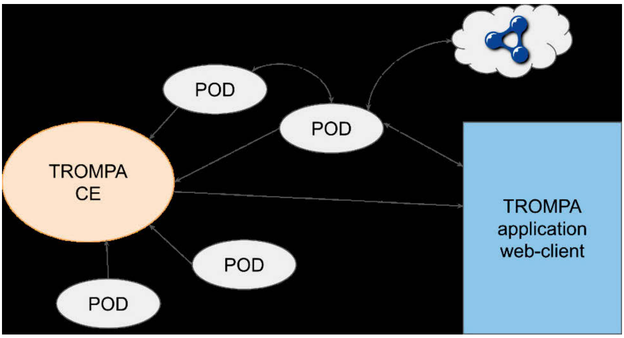


Five Types of User Contributing to One Web of Data

TROMPA explicitly targets five user types—music scholars, instrumental players, choir singers, orchestras, music enthusiasts—through Web applications providing specialized views of the graph described above, designed to fulfill information needs and usage requirements identified in user studies conducted throughout the project. Beyond consuming music content, each user produces information associated with resources described by the CE through their interactions with these applications, such as: scholarly annotations, rehearsal marks, score encodings, recordings of rehearsal renditions or the subjective ratings of such recordings.

Users may wish to retain private access to the resulting data; to share only selectively with specified other users; or, to maintain private drafts until a contribution is ready for publication. To support such behaviors, and to yield greater control to users over their data in a principled manner, TROMPA's Contributor Environment is affiliated with a secondary, decentralized layer of Personal Online Datastores (PODs; Figure 2) that also act as identity providers for TROMPA applications.[28]

Figure 2: Data generated by users in their interactions with TROMPA applications is stored in personal online datastores (PODs). Each user retains fine control of access to their data, allowing them to retain private drafts, share with selected other users or the public, or publish their contributions to the TROMPA Contributor Environment (CE) under an open license.



Contributions generated by a user's interactions with such applications are stored in the user's POD, referenced by a URI which can be requested

28 Mansour, "A Demonstration of the Solid Platform for Social Web Applications."

through an HTTP interface. An access control layer allows the user to selectively share or retain private access to each generated data item, or to open it to the public. PODs may be hosted with any POD provider on the Web, including options for self-hosting by users with the required technological expertise; as such, user-generated contributions hosted in this way are not tied into the TROMPA infrastructure, and remain open for reuse in other contexts and within other applications.

Users may further choose to publish their contributions under an open license, at which point the relevant data is ingested into the CE's graph, and thus made discoverable by other TROMPA users. Each type of user stands to benefit from improvements to this graph: contributions published to the CE by one type of user stand to provide holistic benefits to other users across all use cases—e.g., scholars and enthusiasts stand to benefit from access to recorded renditions by instrumental players and choral singers, who in turn stand to benefit from access to scholarly insight and subjective listener ratings of their performances.

Music Encodings as a Basis for Dynamic Semantic Music Notation

Digital music scores form a core information modality around which many of TROMPA's applications are built. Beyond providing graphical music notation for the benefit of performers and scholars (as PDFs of scans of printed musical scores might also provide), the musical meaning conveyed by the notation must also be machine-readable to support the rich interactivity offered by TROMPA's user-facing applications.

The Music Encoding Initiative's (MEI) XML schema offers a suitable encoding format.[29] Music encodings adhering to the MEI schema are versatile music information Web resources comprehensively capturing musical meaning within a finely addressable XML structure. Paired with the Verovio[30] engraver, which reflects the hierarchy and identifiers of the source MEI document into its generated SVG output, this supports the creation of richly interactive Web applications around digital score encodings.[31]

---

29 Crawford, "Review: Music Encoding Initiative."

30 *Verovio*. https://www.verovio.org

31 Pugin, "Interaction Perspectives for Music Notation Applications."

Typical MEI workflows involve initial scholarly or editorial activities to generate an encoding, followed by its subsequent publication and use. Further iterations may derive new encodings from precedents; but the suitability of MEI to interactive applications also offers more dynamic alternatives in which the encoding provides a framework connecting data that is generated and consumed simultaneously in real time. Exemplars include compositions which self-modify according to external contextual parameters such as the weather at the time of performance,[32] or compositions assembled by user-imposed external semantics, such as a performer's explicit choices and implicit performative success at playing musical triggers within a composition.[33]

When captured, these external semantic signals (interlinked with the MEI structure) themselves encode the evolution of a dynamic score during a particular performance. They have value beyond the immediate performance context; when archived, they allow different performances to be revisited and compared.[34]

MELD (Music Encoding and Linked Data),[35] a semantic framework and set of open-source client libraries for the creation of dynamic digital scores, offers a route to the implementation of such ideas. MELD was developed during the FAST project as a means of instantiating Digital Music Objects,[36] and applied toward multimedia publication of music scholarship in work related to the Transforming Musicology project.[37] In TROMPA, we are extending MELD with facilities for general-purpose and user-customizable score annotation, automated and highly granular (note-level) score-to-performance alignment, and with new capabilities for performance feature visualization.

TROMPA applies this tooling to provide musicians with applications that capitalize on the affordance for dynamic interactions with digital scores, providing fruitful ground to incorporate reflection and introspection into the music rehearsal process.

32 Arkfeld, "'Fortitude Flanked with Melody.'"
33 Kallionpää, "Composing and Realising a Game-Like Performance."
34 Benford, "Designing the Audience Journey through Repeated Experiences."
35 Weigl and Page, "A Framework for Distributed Semantic Annotation."
36 Sandler, "Semantic Web Technology for New Experiences."
37 Lewis, "Publishing Musicology Using Multimedia Digital Libraries;" Page, "MELD: A Linked Data Framework."

A Performance Companion for Instrumental Players

Performance companions target instrumental players and ensembles with applications to support them in their daily rehearsal regime, enriching rehearsal and teaching situations through immediate feedback on one's own and others' performances.[38]

TROMPA's CLARA (Companion for Long-term Analyses of Rehearsal Attempts)[39] is a MELD application that provides performers with a digital score that tracks their performance, aligning a performed MIDI stream with the score encoding such that temporal positions along the performance timeline are associated with corresponding notes according to their digital identifiers within the score. This alignment is accomplished in two modes, both using variations of hidden Markov model (HMM)-based score following systems for symbolic (MIDI) instrumental performances:[40] a real-time mode enabling interactions such as automated page turning and highlighting of notes in the score as they are played; and offline alignment performed within a few seconds immediately after each rehearsal attempt is completed, capable of more robust alignment by virtue of post-hoc access to the entire performance, and providing for more complex interaction mechanisms allowing the performer to revisit and review their rehearsal rendition by simultaneously navigating the score, and, via the aligned performance timeline, the corresponding MIDI stream.

The alignment of score and rehearsal encodings further enables visualizations to be created of visualizations of particular performance features—such as tempo curves—connected to score positions, providing the performer with immediate feedback regarding corresponding stylistic and technical aspects of their rehearsal rendition (Figure 3). To make this feedback as intuitive as possible, in this analytical viewing mode the score is rendered as a single, fully expanded system, with feature visualizations displayed above such that each unit of score-time, and the corresponding part of the visualization share a position on the X-axis. This achieves a continuous correspondence of graphical progression across the screen (corresponding to score-time), and temporal

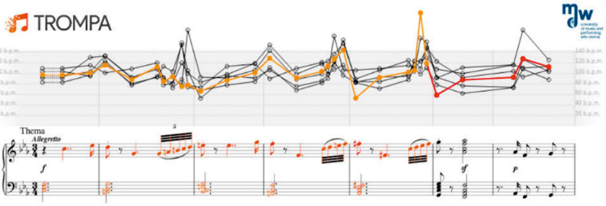
38 Arzt, "Towards a Complete Classical Music Companion;" Goebl, "Unobtrusive Practice Tools for Pianists."

39 "Clara Schumann 200." https://iwk.mdw.ac.at/trompa-clara

40 Cancino-Chacón, "The ACCompanion v0.1;" Nakamura, "Performance Error Detection and Post-Processing."

progression through a rehearsal rendition (corresponding to the timeline of a recorded performance).

Figure 3: CLARA interface visualizing tempo curves for six renditions of Beethoven's 32 Variations in C minor (WoO 80). The colored tempo curve corresponds to the currently selected rendition; coloration of tempo curve and notes indicates current playback position; note hue corresponds to performance dynamics (MIDI velocity).



The notion of score position in this case is operationalized using the X-position of all note elements associated with a particular performance timeline instant during the alignment process. The corresponding score time is calculated by averaging the qstamps (score-based timestamps in terms of the number of quarter notes from the beginning of the encoding) obtained from the Verovio toolkit for the note elements aligned to the timeline instant. The tempo curve visualizes the change in score time per change in performed time, with Y-positions reflecting the difference in average qstamp associated with each timeline instant and its immediately preceding neighbor (q) divided by the difference in seconds between the performed instant's timeline position and that of its immediately preceding neighbor (t), multiplied by 60 to arrive at an approximate measure of beats (in fact, quarter notes) per minute for a given timeline instant. Visualizations of other feature types (e.g., dynamics, performance errors determined during the alignment stage) are currently under development.

Like Verovio's score engraving, CLARA feature visualizations are also generated as semantically structured SVGs, supporting in-browser interactions such as highlighting corresponding regions of the visualization during playback, and tapping on regions of the visualization to spool to the appropriate playback position. Beyond interactive review of a single rehearsal rendition, this enables systematic comparison of multiple renditions, allowing users to tap on the different tempo curves to listen in to the corresponding section played in different rehearsal attempts.

Rendition timelines are gathered for a particular comparison view according to their URI's inclusion within a Linked Data Platform (LDP)[41] container, itself a simple Linked Data structure stored in the user's POD (Personal Online Datastore; Section 5). A selected rendition can be shared with another user by adding a reference to the rendition's URI into a corresponding LDP container on the other user's POD; the same rendition can be included in many containers (potentially owned by many different users), and one user may manage a number of different containers, each potentially including renditions by different users. Further, CLARA supports the creation of Web Annotations targeting specified score regions and selected corresponding renditions. These annotations are themselves Linked Data structures with their own URIs, meaning they too can be shared between different users.

Through these mechanisms, we foresee performers tracking their own rehearsal progress; comparing their playing with selected peers; communicating with their teachers through annotations and by comparison with reference renditions; and incorporating notable pianists' renditions into their comparisons.

The rehearsal companion provides a powerful tool for reviewing one's rehearsal progress by allowing rehearsal attempts to be captured, gathered, and compared with fine granularity, providing insights into the evolution of the stylistic and performative aspects of one's renditions of a piece over time. Consider, for instance, the case of a pianist practicing a new piece (say, Beethoven's *Appassionata*). She selects a score on her tablet computer. As she practices, her performance is streamed to an alignment process coordinated by the CE, which generates metadata to synchronize her performance timeline with the digital score. After she has finished playing her rehearsal rendition, a note-level tempo curve visualization is immediately available for her inspection. She can now compare her tempo curves with those extracted from her favorite recording of the piece on YouTube or Spotify, performed by, for instance, Claudio Arrau. While listening to Arrau's performance, she jots down a personal note about a particular section of the *Appassionata*. She publishes her comment to TROMPA's CE as a Web Annotation that targets both the relevant section of the digital score and the corresponding timespan of Arrau's performance.

41 *Linked Data Platform 1.0.* https://www.w3.org/TR/ldp/

Apart from instrumental players, this data, expressed in interoperable fashion using Web standards, becomes available for reuse by others—providing scholars with empirical data on performance practice (e.g., to determine a typical tempo profile of the *Appassionata* as rehearsed in the 'wild'), or music enthusiasts with a landscape of renditions to listen into and explore.

Conclusion

In this paper, we have presented an overview of TROMPA, an international project aiming to interconnect and enrich public-domain music repositories on the Web, rooting the project's ambitions in its predecessor projects around music semantic technologies, enriched concert experiences, and digital musicology scholarship; describing exemplar collections of publicly licensed music content to convey the richly varied resources available in openly accessible, but disparate, repositories on the web; then outlining the data infrastructure we are assembling to interconnect these repositories within a knowledge graph, ever-expanding through publicly licensed user contributions.

We have detailed CLARA, the Companion for Long-term Analyses of Rehearsal Attempts, a TROMPA application enabling musicians to track, analyze, and share insights on the evolution of rehearsal renditions. We have presented this as an exemplar application available to instrumental performers, as one of five user types (alongside music scholars, choir singers, orchestras, and music enthusiasts) explicitly targeted by applications making use of and adding to the knowledge graph managed within TROMPA's Contributor Environment. Beyond these use cases, we provide for future project-external reinterpretation, recontextualization, and reuse beyond any application currently anticipated by the project through its emphasis on publicly licensed content, standardized Web technologies, and FAIR data practices.

Together, we envision these technologies and their user base to function as a social machine[42] continuously playing with and expanding an interconnected Web of music information, a process in which "the people do the creative work and the machine does the administration"[43]—and, in our case, the music information processing. We are faced, however, with a cold-start problem; in order to be attractive to new users, we require MEI encodings for mu-

42 Hendler, "From the Semantic Web to Social Machines."
43 Berners-Lee, *Weaving the Web* 172.

sicians to rehearse, and recorded rehearsal renditions to seed comparisons. Within TROMPA we are addressing this issue through crowd-sourcing techniques and by recruiting participants at partner institutions.[44] We will require coordination with the wider community of digital musicology scholars, music encoding specialists, music information researchers and practitioners, and performers with an affinity for the digital in order to fully achieve our vision of a shared, dynamic, and richly interactive repertoire of publicly licensed scores, performance recordings, and other associated music information resources.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation program H2020-EU.3.6.3.1., supporting the study of European heritage, memory, identity, integration, and cultural interaction and translation, including its representations in cultural and scientific collections, archives and museums, to better inform and understand the present by richer interpretations of the past under grant agreement No. 770376. We gratefully acknowledge the collaboration of all our colleagues in the TROMPA consortium.

Bibliography (last accessed 16 April 2020)

Arkfeld, Joseph, and Raffaele Viglianti. "'Fortitude Flanked with Melody:' Setting Emily Dickinson's Poetic Fragments to Music via a Digital Dynamic Score." *Proceedings of the Music Encoding Conference*, Maryland, USA (May 2018).

Arzt, Andreas, et al. "Towards a Complete Classical Music Companion." *Proceedings of the 20th European Conference on Artificial Intelligence – ECAI 2012*, Montpellier, France (August 2012). DOI: 10.3233/978-1-61499-098-7-67

Arzt, Andreas, et al. "Artificial Intelligence in the Concertgebouw." *Twenty-Fourth International Joint Conference on Artificial Intelligence*, Buenos Aires, Argentina (July 2015): 2424–30.

44 MEI encodings generated by TROMPA project activities are available at https://github.com/trompamusic-encodings

Benford, Steve, et al. "Designing the Audience Journey through Repeated Experiences." *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, Montréal, Canada (April 2018): 1–12. DOI: 10.1145/3173574.3174142

Berners-Lee, T., and Mark Fischetti. *Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web*. New York: Harper Collins, 1999.

Cancino-Chacón, Carlos, et al. "The ACCompanion v0.1: An Expressive Accompaniment System." *Late Breaking/Demo Session, 18th International Society for Music Information Retrieval*, Paris, France (2018).

Crawford, Tim, and Richard Lewis. "Review: Music Encoding Initiative." *Journal of the American Musicological Society* 69, 1 (Spring 2016): 273–85. DOI: 10.1525/jams.2016.69.1.273

De Roure, David, et al. "Music and Science: Parallels in Production." *Proceedings of the 2nd International Workshop on Digital Libraries for Musicology*, Knoxville TN, USA (June 2015): 17–20. DOI: 10.1145/2785527.2785530

Fields, Ben, Penelope Phippen and Brad Cohen. "A Case Study in Pragmatism: Exploring the Practical Failure Modes of Linked Data as Applied to Classical Music Catalogues." *Proceedings of the 2nd International Workshop on Digital Libraries for Musicology*, Knoxville TN, USA (June 2015): 21–24. DOI: 10.1145/2785527.2785531

Gasser, Martin, et al. "Classical Music on the Web-User Interfaces and Data Representations." *Proceedings of the 16th International Society for Music Information Retrieval Conference,* Malaga, Spain (October 2015): 571–77.

Goebl, Werner, and Gerhard Widmer. "Unobtrusive Practice Tools for Pianists." *Proceedings of the 9th International Conference on Music Perception and Cognition – ICMPC9*, Bologna, Italy (August 2006): 1–5.

Gómez, Emilia, et al. "PHENICX: Performances as Highly Enriched aNd Interactive Concert eXperiences." *Proceedings of SMC Sound and Music Computing Conference*, Stockholm, Sweden (July–August 2013): 681–88.

Hendler, Jim, and Tim Berners-Lee. "From the Semantic Web to Social Machines: A Research Challenge for AI on the World Wide Web." *Artificial intelligence* 174, 2 (February 2010): 156–61. DOI: 10.1016/j.artint.2009.11.010

Kallionpää, Maria, et al. "Composing and Realising a Game-Like Performance for Disklavier and Electronics." *Proceedings of New Interfaces for Musical Expression – NIME'17*, Copenhagen, Denmark (May 2017): 464–69.

Lewis, David, et al. "Publishing Musicology Using Multimedia Digital Libraries: Creating Interactive Articles Through a Framework for Linked

Data and MEI." *Proceedings of the 5th International Conference on Digital Libraries for Musicology*, Paris, France (September 2018): 21–25. DOI: 10.1145/3273024.3273038

Liem, Cynthia C. S., et al. "Innovating the Classical Music Experience in the PHENICX Project: Use Cases and Initial User Feedback." *1st International Workshop on Interactive Content Consumption (WSICC) at EuroITV*, Como, Italy (June 2013).

Mansour, Essam, et al. "A Demonstration of the Solid Platform for Social Web Applications." *Proceedings of the 25th International Conference Companion on World Wide Web*, Montréal, Canada (April 2016): 223–226. DOI: 10.1145/2872518.2890529

Melenhorst, Mark S., et al. "A Tablet App to Enrich the Live and Post-Live Experience of Classical Concerts." *CEUR Workshop Proceedings, no. 1516, 2015. Third International Workshop on Interactive Content Consumption – ACM TVX'15*, Brussels, Belgium (June 2015).

Melenhorst, Mark S., and Cynthia C. S. Liem. "Put the Concert Attendee in the Spotlight: A User-Centered Design and Development Approach for Classical Concert Applications." *Proceedings of the 16th International Society for Music Information Retrieval Conference,* Malaga, Spain (October 2015): 800–06.

Nakamura, Eita, Kazuyoshi Yoshii and Haruhiro Katayose. "Performance Error Detection and Post-Processing for Fast and Accurate Symbolic Music Alignment." *Proceedings of the 18th International Society for Music Information Retrieval Conference*, Suzhou, China (October 2017): 347–53.

Nurmikko-Fuller, Terhi, and Kevin R. Page. "A Linked Research Network that is Transforming Musicology." *WHiSe @ ESWC*, Anissaras, Greece (May 2016): 73–78.

Page, Kevin R., David Lewis and David M. Weigl. "MELD: A Linked Data Framework for Multimedia Access to Music Digital Libraries." *2019 ACM/IEEE Joint Conference on Digital Libraries – JCDL, IEEE*, Milan, Italy (June 2019): 434–35. DOI: 10.1109/JCDL.2019.00106

Pugin, Laurent. "Interaction Perspectives for Music Notation Applications." *Proceedings of the 1st International Workshop on Semantic Applications for Audio and Music*, Monterey CA, USA (October 2018): 54–58. DOI: 10.1145/3243907.3243911

Sandler, Mark, et al. "Semantic Web Technology for New Experiences Throughout the Music Production-Consumption Chain." *2019 International Workshop on Multilayer Music Representation and Processing – MMRP, IEEE*, Milan, Italy (January 2019). DOI: 10.1109/MMRP.2019.00017

Sarasúa Berodia, Álvaro, Julián Urbano and Emilia Gómez. “Mapping by Observation: Building a User-tailored Music Conducting System from Spontaneous Movements.” *Frontiers in Digital Humanities* 6 (February 2019). DOI: 10.3389/fdigh.2019.00003

Weigl, David M., and Kevin R. Page. “A Framework for Distributed Semantic Annotation of Musical Score: ‘Take it to the Bridge!’” *Proceedings of the 18th International Society for Music Information Retrieval Conference,* Suzhou, China (October 2017): 221–28.

Weigl, David M., David Lewis et al. “On Providing Semantic Alignment and Unified Access to Music Library Metadata.” *International Journal on Digital Libraries* 20, 1 (August 2019): 25–47. DOI: 10.1007/s00799-017-0223-9

Weigl, David M., Deren E. Kudeki et al. “Combine or Connect: Practical Experiences Querying Library Linked Data.” *Proceedings of the Association for Information Science and Technology* 56, 1 (October 2019): 296–305. DOI: 10.1002/pra2.24

Weigl, David M., Werner Goebl et al. “Interweaving and Enriching Digital Music Collections for Scholarship, Performance, and Enjoyment.” *Proceedings of the 6th International Conference on Digital Libraries for Musicology*, The Hague, Netherlands (November 2019): 84–88. DOI: 10.1145/3358664.3358666

Wilkinson, Mark D., et al. “The FAIR Guiding Principles for Scientific Data Management and Stewardship.” *Scientific data* 3 (March 2016). DOI: 10.1038/sdata.2016.18

Online Sources (last accessed 16 April 2020)

Choral Public Domain Library. https://www.cpdl.org/wiki

“Clara Schumann 200.” *MDW*. https://iwk.mdw.ac.at/trompa-clara

Dublin Core™ Meta Data Initiative. https://dublincore.org/specifications/dublin-core/dcmi-terms/

“German Music Archive.” *Deutsche Nationalbibliothek*. https://www.dnb.de/EN/Ueber-uns/DMA/dma_node.html

IMSLP Petrucci Music Library. https://imslp.org

JSON-LD 1.1. https://www.w3.org/TR/json-ld/

Linked Data Platform 1.0. https://www.w3.org/TR/ldp/

MusicBrainz. https://musicbrainz.org

Muziekweb de muziekbibliotheek van Nederland. https://www.muziekweb.eu
PROV-O: The PROV Ontology. http://www.w3.org/TR/prov-o/
Schema.org. https://schema.org
SKOS Simple Knowledge Organization System. http://www.w3.org/2004/02/skos/core.html
"Sounds." *British Library.* https://sounds.bl.uk
SPARQL 1.1 Query Language. https://www.w3.org/TR/sparql11-query/
Trompa. https://trompamusic.eu
Verovio: A Music Notation Engraving Library. https://www.verovio.org
Web Annotation Vocabulary. https://www.w3.org/TR/annotation-vocab/