TROMPA

TROMPA: Towards Richer Online Music Public-domain Archives

Deliverable 3.5

Multimodal Music Information Alignment

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Executive Summary

The alignment of multimodal musical resources, for unified exploration, discovery, and retrieval, represents an important priority in enriching digital music archives. In this document, we provide a description of various types of information resource subject to potential alignment within TROMPA; detail a number of candidate algorithms to perform alignment activities; and present a data model that provides a framework for the application of alignment outcomes in TROMPA use cases. We also present a set of initial resources subject to proposed alignment in future development of this deliverable, comprising Beethoven piano compositions, and early Spanish choral works.

Information resources subject to alignment include:

- ❖ Resources exposing events on a timeline (e.g., audio/video recordings; performance metadata streams; derived audio features)
- ❖ Resources exposing spatial coordinates (e.g., composer, performer, or stage images; video recordings; digitised score images)
- ❖ Resources exposing named (identified) structural elements (e.g., symbolic music encodings; encodings of textual resources such as librettos, concert programmes)

Section 2 of this deliverable discusses these resources in greater detail, and also introduces initial musical repertory resources proposed as initial alignment targets in immediate upcoming technical development of this task: a set of MEI encodings of Beethoven's piano compositions (Sonatas and other works); and, a corpus of 16th century Spanish choral music.

Notable *Candidate alignment algorithms* (available for inclusion within TROMPA workflows) include:

- ❖ **MAPS** (Matcher for Alignment of Performance and Score), a MIDI-to-Score HMM matcher with native MEI support developed with in-house involvement from mdw
- ❖ **MATCH** (Music Alignment Tool Chest), a tool based on Dynamic Time Warping
- ❖ **Peachnote** performance alignment tool, applying LCS and HMM approaches

Section 3 discusses these algorithms, alongside a number of other alternatives with less straightforward applicability within the TROMPA project, in greater detail.

Section 4 presents a discussion of alignment formats and representations, first outlining the typical tabular formats used by tools such as MATCH; then introducing the more flexible, reusable, and web-addressable graph-based, semantic representations implemented by the Music Alignment and Linked Data (MELD) framework, building on the Segment Ontology, a convenient means of bridging music-generic structural representation with music-domain-specific multimodal resources. MEI is described as a particularly suitable encoding schema for musical scores in this context, in terms of the comprehensive, addressable MEI hierarchy which interacts synergistically with the multi-level structural representations ("segment lines") offered by the Segment Ontology.

Section 5 presents an alignment data model proposed for the TROMPA project, which both: builds on the Music Encoding and Linked Data semantic framework, combining and extending widely used Semantic Web models including the Music, Segment, PROV, and Audio Feature ontologies, and the Web Annotation Data Model; and, which serves as a specialisation of the Schema.org based data model of the TROMPA Contributor Environment (see deliverable D5.1, Data Infrastructure). Using the proposed alignment model, alignments can be performed at different layers of abstraction - e.g. sections, measures, beats, or individual notes - as the individual use case necessitates.

Section 6 concludes this deliverable, summarising core concepts, and outlining the iterative nature of research description at this stage of the project (M10); we will outline our experience in applying the proposed technologies to the identified targets resources for alignment in a future iteration of this deliverable.

Version Log		
#	Date	Description
v0.1	16 January 2019	Initial version submitted for internal review
v0.2	26 February 2019	Revised version after internal review
v1.0	28 February 2019	Final version submitted to EC

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1. Introduction

From the proposal document: "The goal of this task is to adapt existing alignment technology to connect score information of selected standard repertoire to performance properties (timing, dynamics) of multiple available performances into unified data representations. Score information is integrated from T3.1 and T3.4 and WP4 and sources of performance metadata include audio recordings of renowned artists, high-quality symbolic data resources available online or through data collected within TROMPA (user pilots, WP6 and WP7). Methods established with this task are able to deal with incomplete or partial resources such as partially transcribed scores or excerpts of performances."

In this document we consider the variety of types of musical resources subject to alignment within TROMPA (section 2); catalogue available technologies to accomplish the alignment process (section 3); briefly discuss representation issues relating to the outcomes of these processes (section 4) before introducing a data model building on a graph representation consisting of a specialisation of the TROMPA Contributor Environment knowledge graph (section 5).

2. Musical resources subject to alignment

Resource types

We aim to support alignments between various types of multimodal musical resources. These include resources adhering to a timeline (e.g. audiovisual recordings; performance- and audio-derived feature data); resources adhering to a symbolic structure (e.g., musical scores encoded as MEI); and resources adhering to a spatial representation (e.g., digitised score images).

Media type	**Example**	**Typical source**	**Anchor types**
Image-based	Digitised score images Photographs Diagrams	TROMPA-contributed External	Page Fragment coords IIIF
Structured music encodings	Sparse scores Part scores Orchestra scores Piano reductions	TROMPA-contributed External	Named elements XPath selector CSS selector
Structured textual encodings	Libretto Concert programme	TROMPA-contributed External	Named elements XPath selector CSS selector
Audio	Rehearsal recording Performance recording Studio recording	TROMPA-contributed External	Timed offset
Video	Performance recording	TROMPA-contributed	Timed offset

		External	Fragment coords
Performance metrics stream (e.g. CEUS key positions)	Rehearsal recording Performance recording	TROMPA-contributed	Timed offset
MIDI/OSC stream	Rehearsal recording Performance recording	TROMPA-contributed	Timed offset
Content-derived feature data	Audio descriptors Performance descriptors	TROMPA-contributed	Timed offset Feature entity URI

Corpora targeted for initial alignment

While we aim to establish and implement a set of workflows and data models to enable alignment of arbitrary classical music resources in line with long-term project aims, we now briefly propose two corpora to act as initial alignment targets in immediate upcoming development of the project.

1. Beethoven piano works - we have access to a collection of high-quality MEI encodings of Beethoven piano works: all Sonatas (converted from Humdrum encodings by Craig Sapp [c]), and an encoding of the 32 Variations in C minor (WoO 80) hand-encoded by Werner Goebl at mdw. For many of these works, we have access to permissively licensed audiovisual recordings and performance metadata (multiple recordings per work) obtained from the International Beethoven Piano Competition held at mdw in 2017. This corpus is chosen to bootstrap development of the piano performance companion use case.
2. 16th century Spanish choral music - available as digitised score images (PDFs), Lilypond encodings and as MIDI with individual voice-parts [d], featuring works by Tomás Luis de Victoria, Morales, Guerrero, Vasquez, and their contemporaries. This corpus is chosen in the hope that it will prove useful to development of the choral singing use case. (N.b.: subject to obtaining permission from the maintainer of this resource).

3. Alignment technologies

Given the varied kinds of multimedia resources subject to alignment, it is convenient to identify a particular reference structure into which these resources can be interwoven according to their relevant anchor types. The structure offered by musical score encodings is well suited for this purpose, providing a performance-independent canonical reference (unlike individual performance recordings) with fine-grained musical semantics (unlike digitised score images).

The challenge, then, is to anchor the various multimodal resources into a musical score structure. This requires algorithmic processes to map between anchors expressed in the source modalities, and identified score elements. Largely, this involves mapping from

I. timed information streams (audio/visual media, MIDI, performance- and audio-derived metadata), and
II. spatial information (page coordinates).

These tasks are accomplished through (I.) audio-score (or MIDI-score) alignment, where the audio (or MIDI) timeline corresponds to a performance recording, and serves as a clock-provider for performance- and audio-feature metadata; and (II.) Optical Music Recognition (OMR), where salient image regions are identified within images of musical score and mapped to matching granular representations within the symbolic score. As OMR techniques are subject to the "visual analysis of scores" task, with their own deliverable document D3.4, we focus on technologies concerned with aligning timed information streams and musical scores in this section.

Audio-/MIDI-Score alignment

While approaches to audio alignment, score following, and related tasks have received considerable attention in the MIR literature, the availability of "off-the-shelf" solutions is limited. Here we briefly detail several algorithms performing audio- or MIDI-score alignment that are (or could potentially be made) available. At this stage of the project, we refrain from making concrete recommendations, but instead set out the several available options for incorporation into TROMPA workflows.

MAPS (Matcher for Alignment of Performance and Score)

- Authors: Martin Bonev, Carlos Cancino-Chacón
- Modality: MIDI-score (Audio-score under development at JKU Linz University and likely to become available within the course of the TROMPA project)
- Module of the *ACCompanion* piano accompaniment system [1], implementing score following with skips using a specialised variation of a Hidden Markov Model (HMM) inspired by Nakamura [2].
- Supports alignment of partial performances and partial scores; real-time and offline (batch-mode) alignment.
- Natively supports direct alignment from MEI, MusicXML, and MATCH format encodings.
- Accommodates note insertions / deletions, arbitrary repetition, large skips.
- Under active developed with in-house involvement from mdw (in collaboration with OFAI, the Austrian Research Institute for Artificial Intelligence)
- License status tbc - software likely open-licensed - definitely can be incorporated into TROMPA workflows.

MATCH (Music Alignment Tool Chest) [3]

- Authors: Simon Dixon, Gerhard Widmer.
- Modality: Audio-Audio
- Employs Dynamic Time Warping (DTW) to calculate minimal-cost alignments between two audio signals. Thus, this is an audio-audio alignment; audio-score is performed by first synthesising the score to audio (e.g. via MIDI). Similarly, MIDI-MIDI or MIDI-score alignment is accomplished through synthesis.
- Batch alignment, i.e. cannot align in real-time.
- Accommodates note insertions / deletions, but may get confused by larger structural deviations (i.e. arbitrary repetitions, large skips) that are likely in rehearsal practice.
- Available as open-source code [a], although no license specified.
- Also available as a VAMP plugin [b] for Sonic Visualiser [4] - potentially be used for crowd-sourced / crowd-corrected alignments?

(PHENICX) Piano Music Companion [5]

- Authors: Andreas Arzt et al.
- Modality: Audio-Audio
- Employs DTW, building on and improving the MATCH approach by Dixon et al.
- Capable of real-time alignment, supports partial performance
- Accommodates structural deviations (repetitions, skips)
- Code appears to be not publicly available, although we could approach the authors. Unclear whether we could incorporate into TROMPA workflows.

Niedermayer/Widmer tool [6]

- Author: Bernhard Niedermayer and Gerhard Widmer
- Modality: Audio-Audio
- Another DTW-based approach employing a multiple-pass method for improved alignment accuracy.
- Batch alignment, i.e. cannot align in real-time.
- Code appears to be not publicly available, although we could approach the authors. Unclear whether we could incorporate into TROMPA workflows.

Peachnote performance alignment tool

- Authors: Vladimir Viro and Julian Schmidt
- Modality: MIDI-MIDI
- Two approaches, based on LCS alignment (faster) and on HMMs (more flexible)
- Accommodates structural deviations (repetitions, skips)
- Can do batch and real-time
- Code not publicly available, but can be incorporated in TROMPA workflows

4. Alignment formats and representations

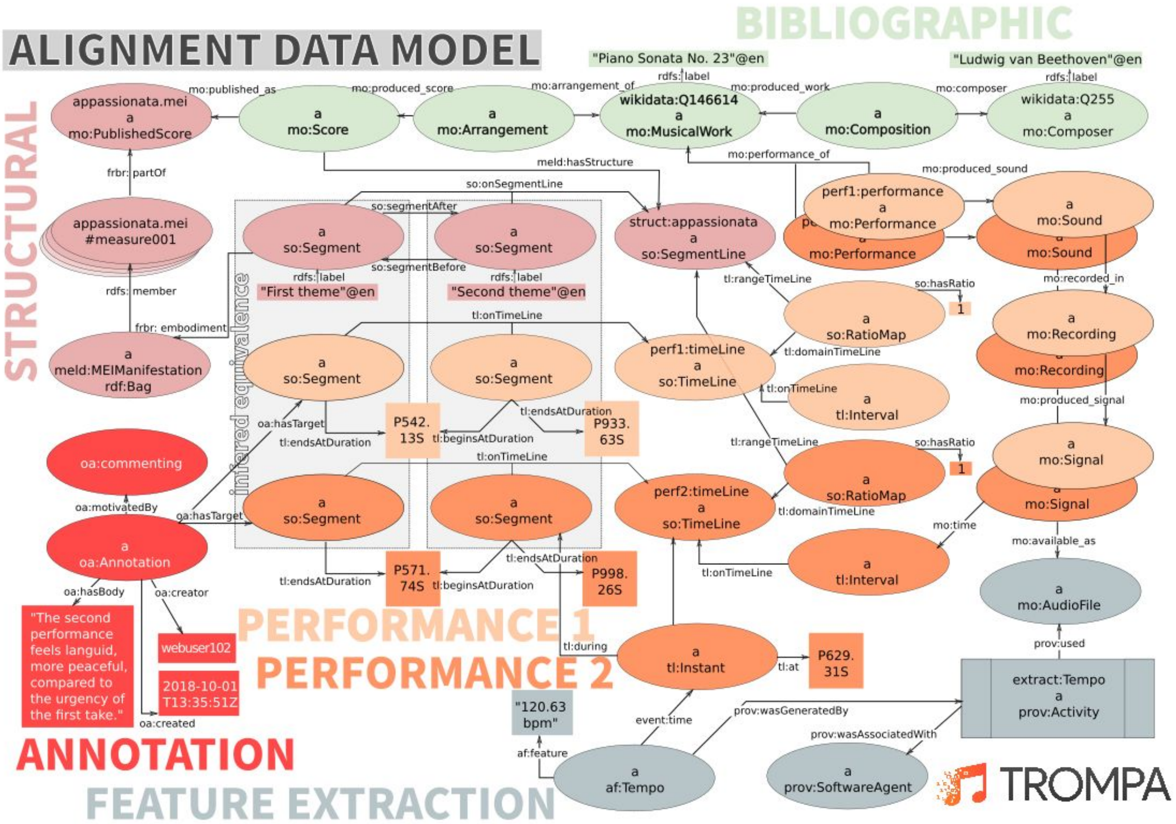
Fundamentally, the alignment technologies discussed in the previous section produce a collection of tuples that each express the connection of anchor points (e.g., timed offsets, MIDI ticks, note identifiers) on either of the two information resources subject to alignment. These connections are typically expressed in a tabular form that is simple to parse but becomes unwieldy when alignments between newly contributed resources are expected to be accommodated over time, in a reusable, web-addressable way.

Graph-based representations offer an alternative that overcomes these limitations. Here, a structural representation of a canonical resource - ideally, a score encoding, or perhaps an audio recording deemed as representative of a work - offers a semantic spine through which all information resources subject to alignment can be interwoven. Newly contributed resources are simply incorporated into this structural representation as they arrive, becoming immediately available for retrieval. The Segment Ontology [7] (SO) provides a convenient means of expressing such a music-generic structural representation in order to bridge domain-specific multimodal resources. MEI is particularly well suited as an encoding schema for musical scores in this context, as the comprehensive, addressable MEI hierarchy interacts synergistically with the ability to specify structural representations (“segment lines”) at multiple levels of abstraction within SO.

Music Encoding and Linked Data (MELD) [8] provides a semantic framework and JavaScript client library that implements these ideas. It has been applied to a number of use cases, including music performance, composition, real-time score annotation, and musicological scholarly communication in previous work (e.g. [9-11]). It has been developed with involvement of TROMPA consortium members at mdw and GOLD, and forms the basis for our proposed alignment data model here.

5. Alignment data model

The alignment data model serves as an extension and specialisation of the TROMPA Contributor Environment (CE) data model detailed in D5.1 (Data Infrastructure), mapped using the additionalType property available for each entity within the CE model.



The proposed model builds on the Music Encoding and Linked Data framework, combining several pre-existing ontologies in order to express multimodal alignments between performance recordings (Timeline and Event ontologies) and musical score (Segment ontology with MEI anchoring), while interlinking with bibliographic information (Music ontology) and performance feature data (Audio Feature ontology). The Linked Data representation affords the creation of Web Annotations addressing (fragments of) individual media representations, or indeed their combination in the form of structural segments.

Alignments can be performed at different layers of abstraction - e.g. sections, measures, beats, or individual notes - as the individual use case necessitates. The section-level alignment illustrated above is sufficient to serve as a navigational model e.g. for the piano rehearsal (performance companion) use case by associating performance audio, score information, and aggregated feature data (e.g. average tempo) for salient large-scale musical sections (e.g. allowing users to jump to a particular theme across multimodal representations). Finer-grained alignments can be expressed by specifying additional segment lines, which can coexist hierarchically with other segment lines (via the use of segmentLineMaps, and the "contains" relationship between segments, in order to capture information in fine detail (e.g. for the scholarly analysis of onset timings of individual notes).

6. Conclusion

In a project relating to digital music libraries and archives of the scope we are targeting in TROMPA, alignment tasks are necessarily multimodal as many different kinds of information resources - timed (e.g., performance audio), spacial (e.g., digital score images), and structural (e.g., score encodings) - need to be interconnected. In this document, we have provided an enumeration of the different resource types likely to be relevant within TROMPA; we have catalogued a number of different algorithmic solutions to problems of audio-audio (MIDI-MIDI) and audio-score (MIDI-score) alignment, of which we anticipate several to be applicable in future development; and we have presented an alignment data model, extending the Contributor Environment's model and building on previous work around Music Encoding and Linked Data, to provide a framework for unified exploration, discovery, and retrieval of aligned musical resources.

We have also identified some initial musical corpora for alignment - including Beethoven's piano compositions, and early Spanish choral works - upon which our immediate future development efforts will be focused. We will report on our experiences in aligning the different media types available for these resources in future iterations of this deliverable.

7. References

7.1 Written references

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[11] De Roure, D., Klyne, G., Pybus, J., Weigl, D. M., & Page, K. (2018). Music SOFA: An architecture for semantically informed recomposition of digital music objects. In Proc. *1st International Workshop on Semantic Applications for Audio and Music*, pp. 33-41, California, USA.

7.2 Web references

[a] Source code available at https://code.soundsoftware.ac.uk/projects/match

[b] Source code available at https://code.soundsoftware.ac.uk/projects/match-vamp

[c] Humdrum encodings available at https://github.com/craigsapp/beethoven-piano-sonatas and converted to MEI using Verovio

[d] Available from https://www.uma.es/victoria/index.html

7.3 List of abbreviations

Abbreviation	Description
DTW	Dynamic Time Warping
HMM	Hidden Markov Model
MAPS	Matcher for Alignment of Performance and Score
MDW	University of Music and Performing Arts Vienna

MEI	Music Encoding Initiative
MIR	Music Information Retrieval
SO	Segment Ontology