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# Music-Related Media-Contents Synchronization over the Web: the IEEE 1599 Initiative

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## ABSTRACT

IEEE 1599 is an international standard originally conceived for music, which aims at providing a comprehensive description of the media contents related to a music piece within a multi-layer and synchronized environment. A number of off-line and stand-alone software prototypes has been realized after its standardization, occurred in 2008. Recently, thanks to some technological advances (e.g. the release of HTML5), the engine of the IEEE 1599 parser has been ported on the Web. Some non-trivial problems have been solved, e.g. the management of multiple simultaneous media streams in a client-server architecture. After providing an overview of the IEEE 1599 standard, this article presents a survey of the recent initiatives regarding audio-driven synchronization over the Web.

## Categories and Subject Descriptors

H.5.5 [**Sound and Music Computing**]: Systems; H.5.3 [**Group and Organization Interfaces**]: Web-based interaction

## Keywords

IEEE 1599, XML, Web applications, Synchronization

## 1. INTRODUCTION

The goal of this paper is providing some details about the recent evolutions of the IEEE 1599 standard, originally conceived for the description of music contents. This format adopts an XML-based encoding and is fully compliant with the World Wide Web Consortium (W3C) specifications. In order to comprehensively describe a music piece, IEEE 1599 presents a multi-layer structure where many instances of textual, graphical, audio, and video contents can be grouped and mutually synchronized.

IEEE 1599 in its early development phases had to face a number of design issues, mainly related to multimedia linking and synchronization. After the standardization, the focus of the working group moved to the design and implementation of off-line and on-line applications. As regards the latter category, the main issue was providing a Web client with ad hoc data structures and media streams, as explained in Section 2.

In Section 3 we will present a brief survey of Web applications developed through such a standard. Most case studies have been published on line and are still publicly available.

Describing the key features of the IEEE 1599 standard goes beyond the purposes of this work. After the conclusion of the balloting phase in 2008, the IEEE official documentation was released. In order to get further details about IEEE 1599 theoretical approach and syntax, please refer to [2]; some commented examples are available in [3].

## 2. ENABLING WEB-AUDIO TECHNOLOGIES FOR INTELLIGENT STREAMING AND INTERACTION

The problem of managing digital multimedia documents including audio and video in a Web environment is still a challenging matter. In the past this problem was often solved by requiring the installation of extensions and third-party plug-ins into Web browsers. On the contrary HTML5 can solve the problem by adopting a multimedia-oriented architecture based on *ad hoc* tags and APIs. For more details about the HTML5 implementations please refer to [4].

### 2.1 IEEE 1599 Web Player: Infrastructure and Application Design

An aspect of interest not yet deeply explored is the simultaneous transmission over the Web of a number of high-quality media streams presenting mutual synchronization.

There are two main alternatives: either using a common Web server and adopting the progressive download ap-

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proach, like almost every "streaming" player for the Web, or setting up a full-fledged streaming server. While the latter option permits the use of protocols specifically designed for streaming (like RTP and RTSP) and may therefore be more flexible, our choice has fallen on the former one because it is effective for our purposes, easier to implement and widely used in similar application domains. Moreover, HTTP/TCP traffic is usually better accepted by the most common firewall configurations, and less subject to NAT traversal problems. Finally, Web users seem to be less annoyed by some little pauses during the playback rather than by quality degradation or loss of information.

On the client side, the fundamental choice is what media streams to request, when to request them, and how to manage them without clogging the wire or the buffer. Three possible cases have been studied:

- *One stream at a time:* Among all the available contents, just the stream currently chosen by the user for watching or listening is requested and buffered. When another stream is selected, the audio (or video) buffer is emptied and the new stream is loaded. The main advantage of this solution is that only useful data are sent on the wire: at every time, the user receives just the stream he/she requested. The principal drawback, on the other side, is that every time the user decides to watch or listen to other media streams, he/she has to wait a considerable amount of time for the new contents.

- *All the streams at the same time:* All the available contents are requested by the client and sent over the net. This approach drastically reduces delays when jumping from one media stream to another, at the cost of a huge waste of bandwidth caused by the dispatch of unwanted streams. In order to reduce network traffic, contents which are not currently selected by the user may be sent in a low-quality version, and upgraded to full quality only when selected. With this approach, a smooth transition occurs: when the user selects a new media stream, the client instantly plays the degraded version, and switches to full quality as soon as possible, namely when the buffer is sufficiently full.

- *Custom packetized streams:* Borrowing some principles from the piggyback forward error correction technique [12], streams can be served all together inside a single packet, containing the active streams in full quality and the inactive ones in low quality. This implies the existence of a "smart" server, which does all the synchronization and packing work, and a "dumb" client which does not even need to know anything about IEEE 1599 and its structure.

The current implementation of the streaming framework is based on the multiple streams scenario, with a quality switching mechanism to avoid an excessive waste of bandwidth.

## 2.2 Preparing IEEE 1599 documents for Web streaming

A preprocessing step of IEEE 1599 documents is required for both bandwidth optimization and to avoid compatibility issues across different HTML5 implementations. When a document is loaded on the server, a python script is used to convert audio, video and pictures to uniform encodings and to reflect those changes on the associated XML.

The formats chosen to represent audiovisual information are:

Audio:

- Vorbis in OGG container
- MP3

Video:

- Vorbis + Theora in OGG container
- Vorbis + VP8 in WebM container
- H.264 (baseline profile) + MP3 in MPEG4 container

Vorbis and Theora provide compatibility with Mozilla Firefox, Google Chrome, Opera and all the other browser relying on the Mozilla and Webkit rendering engines. MP3 and H.264, on the other side, are consumable by the HTML5 implementation of Microsoft Internet Explorer 9 and above. The VP8 encoding is included because it provides better compression performances than Theora and because of its popularity among other state of the art HTML5-based Web streaming services. For each of the listed format a standard version and a low quality version have been produced, to be used inside the quality switching system.

Contents represented as static images, like digitized sheet music or lyrics, are converted to high quality JPEG files and rescaled to be easily consumed in a Web context. Information in the notational layer of the XML document, representing the position of the graphical symbols across the page, is then consistently updated to reflect changes in the resolution of the image.

The extreme verbosity of the XML markup can be significantly reduced through the use of appropriate compression techniques. The current implementation exploits HTTP compression to achieve this goal, being a standard feature of HTTP/1.1 and natively implemented in all modern Web browsers. XML files are processed by the popular GZIP compression algorithm and saved in the HTTP server with a *.xgz* custom file extension. The server is then configured to associate the correct MIME-type (text/html) and encoding (x-gzip) to that file extension. Whenever a IEEE 1599 document is requested, the server response tells the browser to activate its HTTP compression features and sends the compressed version of the document, which is then extracted client-side and loaded in a DOM.

## 2.3 Audio and Video Synchronization

One of the key features of the IEEE 1599 format is the description of information which can be used to synchronize otherwise asynchronous and heterogeneous media. Every musical event of a certain interest (notes, time/clef/key signature changes etc.) should have its own unique id inside the *spine*. Those identifiers can be used to reference the occurrence of a particular event inside the various resources available for the piece: the area corresponding to a note inside an image of the music sheet, a word in a text file representing the lyrics, a particular frame in the video shot of the performance, a given instant in an audio file, and so on.

For the IEEE 1599 streaming Web player, the *Audio* layer is the most interesting. Each related audio or video stream is represented by the `<track>` tag, whose attributes give information about its URI and encoding format. Inside each `<track>` there are many `<track_event>` tags, which are the actual references to the events in the *spine*. Every `<track_event>` has two main attributes: the unique id of the related event in the spine, and the time (usually expressed in seconds) at which that event occurs inside the audio or video stream.

The HTML5 audio and video API already offers all the features needed to implement a synchronized system: media files can be play/paused and sought. On certain implementations (later versions of Google Chrome, for example) there is even the possibility to modify the playback rate, thus slowing down or speeding up the track performance. It is sufficient to use the information stored inside the IEEE 1599 file to drive via JavaScript the audio and video objects inside the Web page.

The currently active media stream is used as the master timing source: while it is playing, the client constantly keeps trace of the last event occurred inside the track. When another stream is selected the client loads it, looks for the event of the new track with the same identifier as the last one occurred, then uses the time encoded for this event to seek the new stream. Consequently, the execution resumes exactly from the same logical point where we left it, and media synchronization is achieved. Since event identifiers are used as a reference to jump to the exact instant inside the new stream, all the events related to the whole piece should hopefully be present inside each track. In other case, we could fall back to the previous (or next) event in common to both tracks, potentially very distant from the exact synchronization point. Please note that such a common event could not exist.

The synchronization of static images is realised in a similar way. In this case the desired information is encoded in the *notational* layer: `graphic_instance_group` tags represent groups of pages belonging to the same graphical object, `graphic_instance` tags represent single pages, while `graphic_event` tags are used to encode pixel areas occupied by a given graphical symbol. An HTML5 canvas is used to display graphical instances one at a time, and to highlight the symbols related to the music event currently played. The synchronisation is bi-directional: audio/video playback triggers highlighting and page turning, while clicks on the symbols in the page can be used to seek the audiovisual material.

## 2.4 Navigating the document

As stated before the event list could be large, so we have to use efficient algorithms to navigate it and find the events we need in a small time amount. Depending on the situation, certain techniques may be more convenient than others:

- During continuous playback of a single stream, a linear search over the event list is maybe the most appropriate for keeping trace of occurring events. Of course, the list has to be sorted by the occurring instant of each event;
- When the user seeks, movements inside the stream become non-linear, thus making linear search inefficient. In this case, a binary search is preferable. It is rare to find an event exactly at the seeking position, so event search must be approximated to the event immediately before (or immediately after) the current instant;
- When changing media streams, events are searched by their unique identifier. Therefore, a dictionary using it as its key becomes really useful.
- When the user clicks on the page, an R-tree structure is used to efficiently search the desired event inside the bi-dimensional space of the page.

After the IEEE 1599 file has been downloaded and stored as a DOM by the player, an event list is populated for each track and quick-sorted by occurrence time. Then, for every list, an associative array is used to bind the index of each event to its unique identifier. Finally, the R-tree representation is populated using layout information in the notational layer. These data structures enable the use of all the four search techniques mentioned above, thus making the retrieval of events efficient in every possible case.

## 2.5 Quality switching

To improve user experience and to find a compromise between playback quality and bandwidth allocation, a quality switching mechanism has been implemented for audio and video content. The application loads a low quality preview of all the available streams at the same time, plus a standard quality version just for the currently selected stream. When the user selects another stream, the application plays back the low quality preview as soon as possible and upgrades to the standard version when the corresponding buffer is sufficiently full.

To decide when this transition can occur there are two possible methods:

- Listening to buffer state events,
- Periodic inspection of the `buffered` attribute in audio/video tags.

As the various HTML5 implementations have very different behaviours when sending and handling buffer state events, the proposed implementation is based on the second approach. The `buffered` attribute contains a list of pairs, representing the beginning and the end of the file portions loaded in the buffer. Quality upgrading occurs whenever the playback cursor of the low quality buffer lies in an area which is also present in the high quality buffer. On the contrary, degradation occurs when the playback cursor in the high quality buffer gets close to an area which is not yet loaded.

To improve bandwidth availability for the high quality audio/video stream, the common policy of fair bandwidth distribution typical of the TCP connections handled by a Web server must be overridden. Our streaming framework uses the module *mod_bandwith*, available in Apache 2 and above, to implement this behaviour. Low quality multimedia files are named following a common pattern, so that regular expressions can be used to identify them and cap their download rate at twice their encoding rate.

# 3. A SURVEY OF IEEE 1599 APPLICATIONS

Within the context of the IEEE 1599 initiative, developed by the *IEEE CS Technical Committee on Computer*

*Generated Music* [1],[1] a number of applications have been developed over the years. Such outcomes mainly fall into three categories:

- *Multimedia Fruition* - This category embraces all the applications that can benefit from an enriched content-fruition model, where the synchronization of different materials can improve the immersiveness of the performance;
- *Music Education* - The focus is fostering the learning process of music or music-related disciplines through suitable technological supports;
- *Cultural Heritage* - The revivification of materials can shade new light on the heritage that is normally available only to "local" users.

These aspects will be discussed in depth in the following subsections.

## 3.1 IEEE 1599 and Multimedia Fruition

As regards advanced multimedia fruition, a comprehensive showcase of IEEE 1599 possibilities is provided by the *EMIPIU* project. *EMIPIU* is an acronym standing for *Enhanced Music Interactive Platform for Internet User*. The project aims at applying information technology to music, supporting applications that range from Web broadcasting to new media publishing.

The *EMIPIU* project is the result of an international cooperation between the *Laboratorio di Informatica Musicale (LIM)* - Università degli Studi di Milano[2] and the *Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier (LIRMM)* - Université Montpellier 2.[3] The project has been partially funded by the Lombardy Region, and the portal has been implemented by Didael KTS S.r.l.[4]

All the materials in the portal are available free of charge and are not covered by copyright, since either they adhere to *Creative Commons Public Licenses* (CCPL), or they are courtesy of the right owners. For instance, most scores have been imported from the *International Music Score Library Project (IMSLP)*,[5] also known as Petrucci Music Library [11], which constitutes a reference archive for free printed scores.

The music library of the *EMIPIU* initiative is constantly growing. Multifarious music genres are represented, ranging from Gregorian chant to pop/rock, from opera to folk songs, from jazz to ancient music. In fact, the project has intentionally covered heterogeneous music works, in order to show the features and the advantages introduced by the IEEE 1599 format.

The *EMIPIU* portal is publicly available at `http://emipiu.di.unimi.it`, and the interface of the Music Box area is shown in Figure 1.

The *EMIPIU* portal lets the user enjoy and interact with music in an environment enriched with a number of multimedia contents, supporting multiple graphical, audio and video materials. Now we will present a number of relevant examples in order to show the main features of the standard

[1] `http://www.computer.org/portal/web/mm/home`
[2] `http://www.lim.di.unimi.it`
[3] `http://www.lirmm.fr`
[4] `http://www.didaelkts.it`
[5] `http://www.imslp.org`

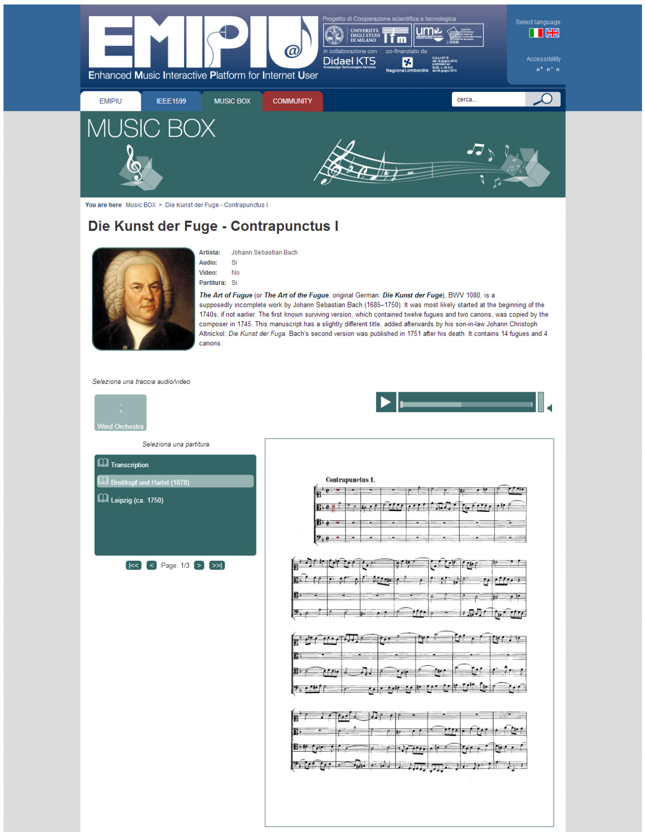


**Figure 1: The interface of the *EMIPIU* Music Box section.**

and the fruition modes supported by the Web interface. All the examples available in the Music Box area can provide further case studies.

As regards graphical description of scores, the operatic aria "Il mio ben quando verrà" from G. Paisiello's *Nina o sia La pazza per amore* presents many score versions mutually synchronized. Graphical materials include the original handwritten score by Paisiello, a historical transcription by a copyist, an early printed version of the libretto, and a piano reduction (see Figure 2).

Similarly, a single IEEE 1599 document can include and synchronize multiple audio and video tracks. In the *EMIPIU* digital archive, *Ave Maria* by Johann Sebastian Bach and Charles Gounod has been encoded including four different audio performances. Two performances can be considered "traditional": they are sung by Montserrat Caballé (soprano) and Andrea Bocelli (tenor) respectively. The other two performances are less conventional: Antonella Ruggiero is an Italian pop singer famous for her voice timbre and extension, with no operatic training; also the performance by Bobby McFerrin (solo voice, in place of accompaniment) and Yo-Yo Ma (cello, in place of lead voice) is a non-traditional one.

As regards the support to different genres and historical periods, "Lullaby of Birdland" by George Shearing demonstrates the applicability to jazz, "Maple Leaf Rag" by Scott Joplin to ragtime, "Por una Cabeza" by Carlos Gardel to tango, "Ul parisien" by Fernando Paggi to folk music. At the moment, mainly due to copyright issues no work by contemporary composers has been considered. For the same reason,

**Figure 2: Different versions of the same score.**

pop/rock music has not been encoded in *EMIPIU*. Nevertheless, we are convinced that the establishment of agreements with the right owners of huge music archives could re-live and emphasize their catalogue, leading the way to the release of advanced and innovative commercial products.

Finally, let us focus on a specific case study where different arts melt together. Many music pieces, such as the already mentioned "Por una Cabeza", "An der schönen blauen Donau" (By the Beautiful Blue Danube) by Johann Strauss, etc. have been employed as soundtracks or background music in movies. IEEE 1599 format allows to include video contents too, and to synchronize them on the base of music events. For example, special contents of DVDs and Blu-ray Discs could be enriched through a music-driven approach, namely enjoying the soundtrack of the movie together with its score and the related video takes.

The IEEE 1599 approach, based on comprehensive multimedia description and multi-layer structuring of data, can be applied to non-musical contexts as well. An example is *Prospettiva 2009*, an initiative to foster an integrated and interactive Web experience of live theatrical performances [5]. In this case, IEEE 1599 features have been exploited to synchronize in real time a theatrical script instead of a music score. Web audience could choose the set of materials shown in their client (e.g. the original text, its translation, the current camera to watch the stage, etc.) and take advantage of the global synchronization of contents.

## 3.2 IEEE 1599 and Music Education

One of the most intuitive ways to take full benefit of IEEE 1599 features is applying such standard to music education. Traditional tools to teach and learn music (e.g. frontal lessons, paper books, pre-recorded audio tracks, etc.) can be considered obsolete in the digital era. In this sense, IEEE 1599 can be used to release advanced learning tools, both in an off-line and in an on-line framework.


**Figure 3: Screenshot of the IEEE 1599 application for *That's Butterfly*, Castello Sforzesco di Milano, Milan, Italy, 09/08/2009 - 01/10/2010.**

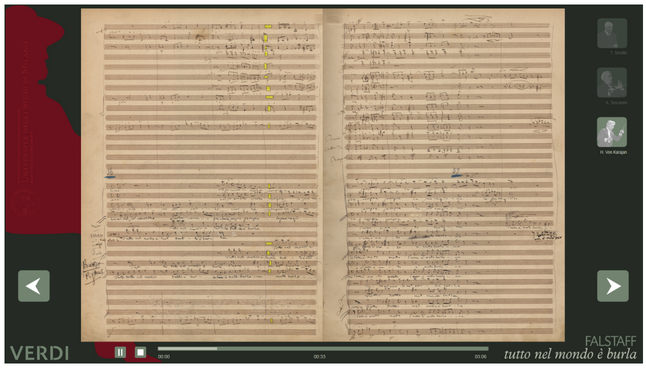


**Figure 4: Screenshot of the IEEE 1599 application for *The Enterprise of Opera: Verdi. Boito. Ricordi*, Bertelsmann Premises, Berlin, Germany, 08/30/2013 - 09/15/2013.**

Examples of the former approach are computer applications realized for international exhibitions and shown through touchscreen stations. In this sense, one of the most recent initiatives is *That's Opera* by Ricordi & C. and Archivio Storico Ricordi. This travelling exhibit contains an IEEE 1599 application whose contents are tailored on the base of the current theme (see Figures 3, 4 and 5). The goal of this multimedia installation is mainly dissemination for an audience not musically trained.

Some IEEE 1599 educational applications have been implemented via the Web, too. Let us recall that IEEE 1599 is fully compliant with W3C standards, and it perfectly interacts with HTML5. Thanks to the introduction of native audio and video player, and to a better support to graphics, any HTML5-compatible browser can be used as a teaching or learning tool, even on portable devices.

A hybrid off-line/on-line approach has been adopted in some recent projects, where Web technologies are coupled with digital book (e.g. PDF) and e-book standards (e.g. EPUB3). Currently, the Laboratorio di Informatica Musicale - Università degli Studi di Milano and Pearson Italia are designing and developing an active book to teach mu-

**Figure 5: The IEEE 1599 application integrated in the museum exhibition at Berlin.**

sic to young students. At the moment of writing, the first release is already available on the bookshelves.

Now we will briefly describe the main advantages of the IEEE 1599 approach to music teaching and learning. This issue has been already addressed in a number of scientific works. As regards IT scientific community please refer to [7], whereas the most recent advances in the field of pedagogical research have been discussed in [10].

First, let us focus the issue of computer-supported teaching of music notation. Virtually there are no limits to the possibilities of including heterogeneous kinds of notation. For instance, the *Prélude* from *Suite n. 3* by Silvius Leopold Weiss - available in the *EMIPIU* digital library - contains an example of ancient French lute tablature. Similarly, the study of Gregorian plainchant notation or ancient keys sight-reading can be improved thanks to the availability of a synchronized score version transcribed in modern notation.

Presenting ad hoc materials in an interactive and integrated environment can foster advanced learning activities. In this sense, it is worth citing the piece “Pas de six: Variation III” (also known as “Falling crumbs”) from *The Sleeping Beauty* by Pyotr Ilyich Tchaikovsky. This case study, available in the *EMIPIU* portal and discussed in [9], introduces another kind of non-standard notation, namely the system for recording and analysing human movement in dance known as Labanotation [8]. Thanks to the intrinsic characteristics of IEEE 1599, the activity of dance teachers and choreographers can take benefit from an integrated environment where videos of different dance and music performances are synchronized with standard music notation as well as Labanotation.

## 3.3 IEEE 1599 and Cultural Heritage

In the framework of the *TIVal* project (*Tecnologie Integrate per la documentazione e la Valorizzazione dei beni culturali lombardi*), supported by the Lombardy Region, a campaign held at the Certosa of Pavia (Italy) produced the digitization of 13 graduals dating back to the XVI century and containing masses in neumatic notation.

A Web portal containing selected masses has been released [6] and is available at `http://graduali.lim.di.unimi.it`. A screen capture is shown in Figure 6.

For this repertoire, score notation substantially differs from

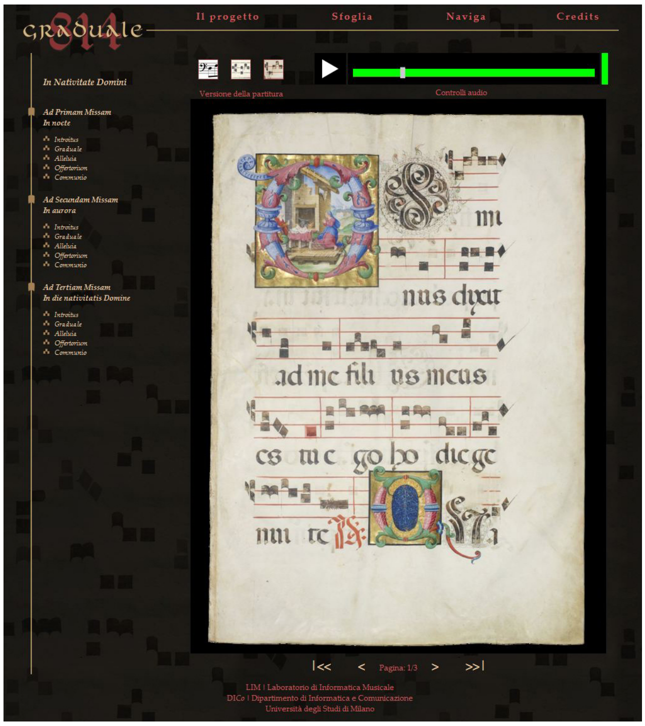


**Figure 6: Web portal of the *TIVal* project.**

Common Western Notation, namely standard score notation. There are commonly accepted transcription rules to convert neumes into modern notation, so that a standard symbolic encoding can be obtained. In the IEEE 1599 document, both plainchant neumes and their modern transcription can be described. A comprehensive encoding may include lyrics as well.

As regards notational aspects, the original score, a more recent printed version and a transcription in modern notation have been encoded. Audio contents include a vocal version, recorded in a *schola cantorum*, and a synthesized instrumental performance.

This kind of approach presents a number of advantages: first, contents are available via the Web, allowing a huge audience to watch relevant historical documents usually protected and reserved for scholars and researchers. Besides, even people with no knowledge about neumatic notation can experience interaction with music contents, ranging from a mere score following to the choice of in-use materials and comparisons among notations. Finally, experts have a powerful tool for their research. For instance, due to the extremely wide diffusion of this repertoire and to the handmade process of copying, often manuscripts presented small variants as regards note pitches or grouping into neumes. Thanks to this tool, comparisons can be easily performed in a fully synchronized environment.

Due to its features, IEEE 1599 has been recently adopted in many musicological projects presenting Web outcomes. A relevant example is the project *Thematic catalogue in music: features and perspectives in the digital era*, started in 2009 and financed by the Italian Ministry of Education, University and Research (MIUR). In this context, a thematic catalogue of selected Italian composers (Domenico Guaccero, Alessandro Rolla, etc.) was released. IEEE 1599 was employed to encode music incipits and to enable content-based score queries. The Web application can be found at: `http://www.prin2009.lim.di.unimi.it`.

Similarly, the Laboratorio di Informatica Musicale is currently cooperating with Leipzig Bach Archive, namely the most comprehensive Bach collection anywhere, whose library features original sources, manuscripts, rare books, and early printed editions. The goal is applying IEEE 1599 technologies to a set of multimedia contents related to Johann Sebastian Bach.

# 4. CONCLUSIONS AND FUTURE WORKS

We presented a number of case studies that benefit from the employment of commonly available Web technologies as well as customized solutions in order to solve the challenges that arise from the "webization" of multimedia applications.

The IEEE 1599 initiative will go along the way here described, constantly increasing the collection of encoded materials and exploiting the technological advancements in order to provide an advanced on-line fruition of contents.

Currently, the most promising researches address two aspects of the standard. First, a special interest group on education is exploring the possibilities to foster adaptive learning in music field through a rethinking of both traditional and technological didactic tools. The goal is designing and implementing an active music e-book, whose contents and learning paths are user-tailored and automatically adapt to the student, also in the context of special need education.

Another relevant research currently under development addresses Digital Right Management and Intellectual Property in IEEE 1599. In fact, since this format embeds a potentially high number of heterogeneous materials, issues about multiple right holders, different distribution licences, etc. can emerge. Besides, structuring multi-layer information in a single document introduces new kinds of rights, such as synchronization rights. Intellectual property in IEEE 1599 can be a challenging matter, but it can also suggest new strategies to deliver multimedia contents over the Web.

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