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# The Past Through the Future: A Hypermedia Model for Handling the Information Stored in the Audio Documents

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## Abstract

The use of hypertextual structures has become very popular in humanities electronic critical editions. It provides a way of making connections between pieces of information, thus modelling what many humanities scholars actually do. Because hypertext has been popularized by the World Wide Web more than anything else, the linking mechanisms are fairly weak. Actually, there are two main open issues: the encoding models used lack separation between structure and content; and in recent years a strong request to handle various media (text, images, audio and video) has emerged. Thus, it is now time to take one step further: in this paper, we describe PSYCHO-MAD, a Powerful SYstem with Charming Hypermedia Objects for Music Audio Documents, a not-hierarchical hypermedia model for handling the information stored in the audio memories based on an extension of zz-structures. The cooperation activities of different classes of actors allow the user to create new virtual hyperdocuments and dynamic views (useful, for example, in performance of electro-acoustic music open work or in ethno music events). By adopting Vannevar Bush's point of view, the model herein elaborated connects, without preconceived limitations, documents stored in different media: annotations made by the author, scores, room programs, critical reviews, setting photos, sound recordings and video shootings.

> The Encyclopedia Britannica could be reduced to the volume of a matchbox. A library of a million volumes could be compressed into one end of a desk. [...] Mere compression, of course, is not enough; one needs not only to make and store a record but also to be able to consult it. [...] Our ineptitude in getting at the record is largely caused by the artificiality of systems of indexing. [...] One has to have rules as to which path will locate it, and the rules are cumbersome. Having found one item, moreover, one has to emerge from the system and re-enter on a new path. The human mind does not work that way. It operates by association. With one item in its grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain. Man cannot hope fully to duplicate this mental process artificially, but he certainly ought to be able to learn from it. Selection by association, rather than by indexing, may yet be mechanized.
>
> (Vannevar Bush, 1945, p.3)

## 1. Introduction

The musicologists, the scholars, the audio archives personnel usually need to use a large—hardly manageable—number of sources stored in different media: outlines and annotations, scores, room programs and critical reviews, setting photos, audio signal and video footages.

Although over the past few years, the European community has provided funding for many projects centred on text codification and the creation of editions in electronic format, in the majority of cases these studies, modelling the traditional ecdotica methods, apply technology without a real sharing of models and methodologies already in use by the information science. So, actually experimentation with integrated multimedia systems and improvement in the audio technology (in particular, in the field of the A/D converters, optical

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carriers and magnetic tape data storage) offer new possibilities for the treatment of audio/video documents.

From a technical point of view, now users can access and compare several sound sources at different representation levels, considering different classes of multimedia content description, like customized data for the performance (e.g. scores and oral instructions), or the video recordings of the artistic event and the metadata (e.g. attachment of the documents and signs on the carrier). On this basis, from a conceptual point of view, it becomes necessary to structure several levels and to use navigation models, capable of returning the sound documents in their entirety.

In the last few years, the great success of the Web has made the idea of using the hypertextual philosophy, on which it is based, attractive; so, many people have adopted, uncritically at times, ill-organized hypertextual structures with intrinsic problems of confusion and cognitive overload: the models, which have been used up to now by human science, do not allow the user to separate structure from contents, or to compare different media at various abstraction levels, or to use the system in a personalized and adaptive way, or to aggregate the data for generating new knowledge.

### 1.1 Our contribution

The aim of this work is to answer to the challenge imposed by the material itself; we describe a new conceptual approach for *organizing*, *preserving*, *accessing* correlated *multidimensional* (e.g. musical, visual, sound or textual) documents.

Our model, called PSYCHO-MAD (Powerful SYstem with Charming Hypermedia Objects for Music Audio Documents), organizes and manages data and knowledge using a distributed, agent-based extension of innovative data structures, the zz-structures (Nelson, 2004; Dattolo & Luccio, 2009a,b) and it is conceptually based on:

- the idea of the musical work as an *open system*, that is, a multidimensional object made up of the text, event, tradition, interpretation, fruition and reception;
- the hypertextual perspective: the used hypermedia model connects, without any previously formed restrictions, the contextual information recreated in the musical work from an historic-musicological, biographical and philological points of view and allows the user to listen different texts and interpretations of the same musical work and to compare them to scores (and other direct or indirect sources), musicological analyses and audiovisual recordings.

PSYCHO-MAD enriches the access to sound documents by connecting and synchronizing different versions of the same piece, or performing in different media (text, images and videos) and/or in different domains (temporal, frequency, symbolic, etc.), without interrupting their fruition; it makes possible to compare parallel documents, visualize dynamic and personalized views on the data and generating new documents, according to users' preferences or interests.

### 1.2 Case study

PSYCHO-MAD is focused on two types of music: electro-acoustic and ethno music. There are many reasons to believe that the audio documents of electro-acoustic music and ethno-music are the most complex in terms of authenticity. By studying examples from these fields, a broad range of open issues have been encountered.

- *Electro-acoustic music* refers to the tape music of the 1950–1980s, before the advent of the digital audio revolution, and the problem of lack of scores, different versions of recording, different performances etc. In electro-acoustic music, the tape medium is the score, the compositional/instrumental tool and the reproduction agent all at the same time, thus combining all preservation problems which are usually individually found in other musical genres (such as *commercial* music: from English and German art/progressive rock in the 1970s to electronic pop music in the 1980s; from soundtrack to advertising music used in television) together. Thus, while the current trend of digital sound preservation is going toward large-scale automation in order to tackle the magnitude required by large archives of recorded sounds, electro-acoustic music presents a number of serious musicological and technical problems which seriously challenge automation. In addition, all the tape alterations (splice, signs, corruptions) are important information from a philological point of view.
- *Ethno music* refers to the music recordings of non-western cultures since the beginning of the 20th century (e.g. in Africa) and the problem of multiple carriers (e.g. wax cylinders, sonofil, tape), formats, ethnic groups, regions, researchers etc. involved with the preservation of this music. The analysis of western music has been developed almost exclusively on the basis of analysis of written scores, which represent musical performance models, rather than the performance itself. Conversely, in the ethno-musicological field, one must consider that music is part of culture and social life, so that the authenticity issue must contain information on the whole system which produced the audio document. Ethnic music cannot be studied as music *an sich*, but must be regarded in its total context. In this sense, an essential assumption is to preserve, besides the audio signal,

the video of the social events, still images of the traditional costumes used by the musicians/dancers, the text included in the technical bulletin of the recording equipments, etc.

This paper is so organized: Section 2 presents a short review on the state of the art about electronic editions; Section 3 introduces the basics related to the structures used for representing information and knowledge in our architecture. Section 4 describes the PSYCHO-MAD architecture, while Section 5 shows different (and complex) case studies (in the fields of ethno music and electro-acoustic music), focusing the attention on the visualization aspects and on the creation of new performances.

## 2. State of the art

Before introducing PSYCHO-MAD, in this subsection we propose to the readers: because the audio documents are the result of a transmission process, whose phenomenology, although it has its own specificity, shows, however, interesting similarities to the textual tradition, in Subsection 2.1 a brief description is given of the electronic edition of text (a quite consolidated field). In Subsection 2.2 some open issues in the field of electronic edition of audio documents are given.

### 2.1 Existing models

The philological approach to text documentary tradition has been redefined according to the hermeneutic contribution from computer science. In the field of technological applications to ecdotic surveying, remarkable progress has been made in recent years, but the distrust from philologists and the naïve use of computer science (that is, the employment of tools instead of sharing formal models) has not permitted the carrying out of real progress in this field.

In textual philology, already for some decades, computer science has been used to conserve sources, to organize data and to present a critical edition.

Actually, standards for text structuring are lacking: usually, mark-up languages are used to structure the text and for information retrieval. This lack of separation between structure and content makes it impossible to consider complex models (often HTML is used), and the use of general tools to access contents.

Textual philology often uses HTML as an encoding model: this choice is justified not by the virtues of the encoding scheme itself but by the fact that HTML is directly interpreted by a Web browser. Thus an electronic critical edition can be disseminated very quickly, and it can easily incorporate links to images, notes, audio, video, and other apparatus.

Unfortunately the real problem with HTML is in actual tags, and in what they indicate. HTML uses a rather curious mixture of simple structural tags (for example, <p> to indicate a paragraph, <ul> to indicate an unordered list, etc.) and some typographical tags (<i> to indicate italic, etc.). Very few of these tags are of much use for any complex searching of the text (to search only within titles, quotations, within a list of sources).

SGML (HTML is a simplified version of a subset of SGML) and XML are frameworks for defining markup languages; these markup tags, and the relationship between them, must be defined in a document type definition (DTD), which gives a formal specification of the document structure. The designer of a DTD—to determine what is important and what should be encoded—is a process known as document analysis. Fortunately for editors of electronic editions in our field, a good deal of SGML (and, more recently, XML) work has already been done in the humanities. The Text Encoding Initiative (TEI) Guidelines are an international and interdisciplinary standard that enables libraries, museums, publishers, and individual scholars to represent a variety of literary and linguistic texts for online research, teaching, and preservation. TEI defined 400 features that might be of interest in electronic text and specified SGML/XML tags for them (McGann, 2002; Sperberg-McQueen & Burnard, 2002).

Unfortunately, SGML and XML does present one problem for the representation of humanities material: it assumes that the text consists of a single hierarchic structure: a problem can arise in overlapping structures, that involve pages and folios, a phenomenon which occurs frequently in humanities material (Hockey, 2004).

Some other markup schemes are capable of handling overlapping structures. Perhaps the best-known of these is COCOA (word Count and Concordance on Atlas) used by the Oxford concordance Program (OCP) and by the Text-Analysis Computing Tools (TACT) suite. Because it has no end-tag syntax, it offers some flexibility for handling overlapping structures, but it also means that the markup cannot be validated (since the structure of the text is not predictable). The Wittgenstein Archives Project at the University of Bergen has defined an encoding scheme called Multi-Element Code System (MECS) that can handle overlapping structures. It contains some of the properties of SGML, but it also contains additional mechanisms for representing structures that are cumbersome in SGML, permitting overlapping structures. Unfortunately, MECS can be processed only by way of software written at Bergen.

### 2.2 Open issues

In the field of *recorded* music, according to the definition given by Byrum and Madison (2000), we consider a musical work as: 'The work is the distinct intellectual or artistic creation. This is an abstract entity with no material object. The work is recognized through individual realizations or expressions of the work, but the work itself exists only in the commonality of content between and among the various expressions of the work. The work enables us to give a name and draw relationships to the abstract intellectual or artistic creation'.

These *individual realizations* are storage in various media (text, images, audio and video) and they have to be handled: in a critical edition, for example, it is necessary to compare various documents on different abstraction levels (MPEG7-like). The ancillary information (meta-data and contextual information) is moved by different media: texts (e.g. annotations by author or technicians, description of the processes of synthesis and sound processing, information programs for live-electronics, etc.), still images (e.g. electronic equipment schemes, photos), and videos (e.g. footages of the carrier, of the author's or the technician's gestures during the recording phase). In general, audio documents are composed of several data sets. In the authors' experience, it is necessary to consider three different levels of information:

(i) primary information (master recordings and *n*th generation duplications);
(ii) meta-data (intentional and unintentional alterations, carrier degradations—see Figure 1(b));
(iii) contextual information (video recordings of the performance, cover annotations, annexes, labels—Figure 1(a));

All these data have to be preserved and compared among themselves in an electronic edition. It must be noted that the lack of musicological rigour and attention to source consistency has already produced in the past several gross mistakes in the A/D transfer of musical audio archives, producing yet more sources which often feature disfiguring transmission errors. Interesting examples can be retrieved in:

- *Stria* (John Chowning, 1977): in the CCRMA version (four-channels), there was a 'discontinuity' in the D/A conversion of the data at 6′29″ (389″) from the original computation that was unintended This caused a sudden change of timbre and a consequent click: '[T]he PDP-10 burped!' (Zattra, 2007). This imperfection in the computation emerges slightly, but very clearly indeed, in the audio source. Mr Chowning did not re-compute the section to eliminate this problem. He rather learned to accept it 'as one does a birth mark or beauty mark on one's skin ... noticeable but of no substantive consequence' (Zattra, 2007). The *faulty*, imperfect, and therefore fascinating four-channel version is the version Mr Chowning now uses to play during the concerts. Conversely, in the commercial version (CD Wergo, WER 2012-50) this burp is missing. The audio is


Fig. 1. Meta-data examples in audio documents: (a) front and back of an Italian 78 rpm phone postcard (Happy new year); (b) phonographic disc degradations (spore of moulds, fungi and microorganism; flaking).

truncated exactly at that point (6′29″) with a fade out to the following section. For a detailed description of this transmission error see Zattra (2007).

- *Y entonces comprendió* (Luigi Nono, 1970): it is a four-channel music work. Luigi Nono performed also a stereophonic version in a four-channel tape (A, B, C, D), mixing the original four-channel tape (1, 2, 3, 4): $A = 1+3$; $B = 1+3$; $C = 2+4$; $D = 2+4$. The Stereo Long Playing Deutsche Grammophon DGG 2530436 (stereo: X, Y) was mixed: $X = A + C$; $Y = B + D$. In this way, a stereo version is reduced to a monophonic version, because of a transmission error.

The music work (IFLA, 1998; Byrum & Madison, 2000) is not limited to the carrier recorded by the author; different performances need to be considered, too (e.g. radio broadcastings, concerts, etc.: output of specific writing systems) and the possible editions of the work (i.e. specific media systems, enable to produce audio-cassettes, discs, CD-A, DVD-V, SA-CD, etc.). Each of these works has been tested by audio signals as well as by many documents on different media (ancillary information): video recordings and concert photos, room programs, newspaper criticism, descriptive schemes of the system for sound direction, playbills and posters.

In addition, in the specific case of the *open works*, which involve the user's interventions, the composer's interpretation rules—more or less strictly fixed—need to be considered by the user as a control instrument of randomness at an interpretative level and through which it is possible to produce different versions of the work. The figure of the audience is replaced by the *prosumer*, the definition given by Alvin Toffler ten years ago: the consumer becomes a producer.

The phenomenological study of the transmission of audio documents outlines the non-trivial evidence that the *recorded* music on a reproduction medium is not a stable object indefinitely duplicable over other media. Rather, it shows a complexity comparable with other documents traditions (e.g. text). For example, a set of duplications could show the presence of tape splices over the same musical passage, indicating that the composer or the technician worked in parallel on two different copies. In such cases, it is necessary to ascertain the order of generations to pick up the original source in order to proceed to a further restoration process. Automation of such evaluation can hardly be attained, but a great deal of computer assistance can be reached with novel techniques developed in other fields (such as Music Information Retrieval).

Other information can be gathered by textual elements written on media containers such as reel covers, reel flanges, tape marks, etc. Although this information cannot be completely trusted (reels are often re-used/misplaced/etc.), it may provide essential insight into production schemes and copy generations.

All this information—together with audio signal—must be collected and preserved in an organic fashion using a hypermedia structure in order to preserve the entire musical work and to carry out a musicological study.

It becomes necessary to link audio (musical recording) with video (video recording of: (i) the event—concert, social or religious event—that has produced the musical work, in the case of live recordings; (ii) the original analogue support, to maintain information of both the degradation—loss of magnetic paste, scratches—and the intentional alterations, in the case of re-recordings). Thus, it is now time to go one step further:

(1) proposing innovative philological solutions for electronic editions of music works;
(2) using navigation models able to handle complex, multidimensional documents (that is documents analysed in different domains: symbolic, time, frequency, etc.);
(3) generating authoring tools for the runtime creation of virtual sources and for analysis in different domains.

This formalization allows the definition of a data structure, appropriate to encode a connectionist model able to give back the complexity of the musical work. Our proposal is the actor-based extension of the ZigZag™ model. Conceiving a system as aggregation of populations of intelligent and autonomous agents, which cooperate to accomplish common goals, is one of the most exciting aspects of the challenging arena known as Multi-Agent System (MAS) and revolutionizes radically the perspective in which a model may be conceived and work (Dattolo & Loia, 2000).

## 3. The model for representing information

The compound and complex nature of *recorded* music (in particular electro-acoustic and ethno music, as defined in Section 1) produces, during the repositioning into the digital domain of the documents related to it, a particularly wide and varied set of sound recordings, metadata and contextual information. This set composes the musical work: it is possible to reconstruct its unity only through the knowledge of all the production systems, media, reading and archiving, which have been involved during the communication process.

The different *physical features* of the material objects make their preservation objectively difficult. Inevitably, the documents of the musical work are collocated into different physical places (audio archives, libraries, private archives and dramatic archives); the documents are not always easily available to the audience and the experts, and their spread often makes difficult even an ideal reconstruction of the musical work. Another intrinsically complex aspect of the documents of electro-acoustic music is their *typological variety*: audios, videos, textual documents, and still images. According to cataloguing standards the material has to be classified and matched by homogeneous typologies, and thus it has to be catalogued according to different standards aimed at each documentary typology: it follows that the catalogue information about different documents of the same work converges into different and heterogeneous information systems, which often do not communicate among themselves. So, not only the individual documents of music works are located in *different physical places*, but also in repositories that store data in non-interoperable formats.

Traditional methodologies and techniques for handling documents and catalogue information have proved to be ineffective not only for practical reasons, but also because they do not allow the system to create hypermedial connections between the preserved documents, neither to reposition the individual partial sources into the original places in which they were during the execution of the work. In order to overcome these open issues, it is necessary to innovate the information treatment, by designing a document preservation and an access system, which is capable of connecting what archiving has divided, allowing users to:

(1) connect different document sources within their entirety; for example, in the live-electronics works, the video shooting of the sound direction can be synchronized with the execution recording and executive indications;
(2) split the contents of a document into segments and connect them in a totally personalized way; for example, the comparison of the audio segments to the assembly operations, which can be recognized through the video shooting of the tape transfer.

### 3.1 Data structures and distributed models

Before introducing PSYCHO-MAD, in this subsection we propose to interested readers a brief introduction to the basics of zz-structures and the actor model, both used in our architecture.

#### *3.1.1 Zz-structures*

Zz-structures are innovative, hyper-orthogonal, non-hierarchical data structures, based on the non-Euclidean multidimensional ZigZag$^{\text{TM},1}$ model (Nelson, 2001). A reference description of them is provided in Nelson (2004), and Dattolo and Luccio (2009b), while a formal description, based on graph theory, is present in Dattolo and Luccio (2009a).

A *zz-structure* can be thought of as a space filled with a cell: formally, it is an edge-coloured multigraph (i.e. a graph where a pair of nodes may have multiple coloored edges connecting them), where each node *has at most one outcoming edge and one incoming edge* for each colour. Each node is called a zz-cell (or simply cell) and each edge a zz-link.

Each zz-cell may have content (such as integers, text, images, audio, etc.), and it is called *atomic* if it contains only one unit of data of one type, or it is called *referential* if it represents a package of different cells. There are also special cells, called *positional*, that do not have content and thus have a positional or topographical function. Cells are connected together with zz-links of the same colour into linear sequences, called *dimensions*.

An alternative way of viewing a zz-structure is a union of subgraphs, each of which contains edges of a unique colour (Dattolo & Luccio, 2009a).

A single series of cells connected in the same dimension is called a *rank*, i.e. a rank is in a particular dimension. Moreover, a dimension may contain many different ranks; in particular, each connected component present in a dimension is a rank. Explicit meaning, associable to dimensions and ranks, will be proposed in Section 5.

The starting and the ending cell of a rank are called, *headcell* and *tailcell*, respectively, and the direction from the starting (ending) to the ending (starting) cell is called posward (respectively, negward). A fundamental restriction is that *for any dimension, a cell can only have one connection in the posward direction, and one in the negward direction*. This ensures that all paths are non-branching, and thus embodies the simplest possible mechanism for traversing links. An example of zz-structure is shown in Figure 2.

This zz-structure is composed of 12 cells, the set {c1, . . . , c12} connected by three different dimensions, denoted respectively by thick, normal and dotted lines.

In Figure 3, the same zz-structure has been decomposed into its dimensions, which in turn contain some ranks. In particular, the thick dimension contains two parallel ranks {(c9, c2, c3, c4), (c6, c7, c8, c12)} and four isolated cells {c1, c5, c10, c11}, the normal dimension has two parallel ranks and four isolated cells, while the dotted dimension has one rank and seven isolated cells.

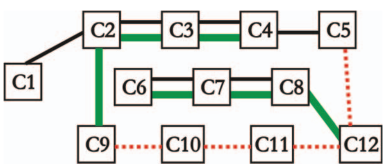


Fig. 2. An example of zz-structure.

[1]'ZigZag' is a registered trademark in the USA for zz-structured-based software of Project Xanadu.

A meaningful contribution of zz-structures is the fact that they enable users to enrich their interaction with information, presenting both pieces of information and connections among them; in this way, users have the opportunity to go beyond the current Web modality of accessing only the information itself, becoming instead able to access information from multiple perspectives and a variety of contexts.

The visualization of contexts and connections can be presented to the users using different methodologies and defining opportune views (Dattolo & Luccio, 2009c).

A *view* is a way of placing the cells on a screen. Generic views are designed to be used in a big variety of cases and usually show only few dimensions or few steps in each dimension. Among them the most common are the *rectangular views* on two dimensions: the cells are placed on a Cartesian plane where the dimensions increase going down and to the right. Obviously some cells will not fit in these two dimensions and will have to be omitted. A cell is chosen and placed at the centre of the visualization (cursor centric view); it assumes the role of *focus*. Moving the cursor horizontally and vertically enables the user to select a new cell as the focus.

The most common rectangular views are the column and the row views, called respectively *H-view* and *I-view*. The name *H-view* (respectively, *I-view*) comes from the fact that it resembles to the bars of the capital letter H (respectively I) with serifs. Vice versa, in an *I-view*, a rank is chosen and placed vertically. Then the ranks related to the cells in the vertical rank are placed horizontally.

A *H-view* of size $l = 2m + 1$ and focus a chosen cell, on a main vertical dimension and a secondary horizontal dimension, is a tree, whose embedding in the plane is a partially connected coloured $l \times l$ mesh in which

- the focus cell occupies the central position $((m+1), (m+1))$;
- the horizontal central path (of maximum size $l$) is centred on the focus and is composed of the cells present in the secondary dimension and connected to the focus in the posward and negward directions;
- each cell, present in the horizontal central path, represents the central cell for the vertical paths (of maximum size $l$) composed of the cells present in the main dimension and connected to it in the posward and negward directions.

An example of H-view related to the zz-structure of Figures 2 and 3 is shown in Figure 4. This view has size $5 \times 5$, the cell c3 as the focus, the thick dimension as the main dimension and the normal as the secondary (dimensions are explicitly indicated in the bottom-left corner of Figure 4). Note that the same cells may appear in different positions as they may represent the intersection of different dimensions.

'Many more views are possible. Lukka's group has programmed more than a dozen, some of which—such as the ''MindSunDew'' view—are wonderfully expressive' (Nelson, 2004), and many of them visualize the zz-structures on more than two dimensions: two examples are shown in Figure 5.

The view on the left of Figure 5 is a five-dimensions *H-view* (5 is the number of visualized dimensions), while the view on the right is a *4-extended star view* (4 is the number of cells, if existing, visualized in a given dimension, besides the first cell). In the example of Figure 5 (right) the star view, constituted by the focus cell c3, is displayed on six different dimensions. For each of them, are visualized the first cell and the extension constituted by at most four cells. So, in the dotted dimension are visualized the cell c10 and another four cells, while in the normal dimension are visualized the cell c3 and only two other cells, with respect to the zz-structure shown in Figures 2 to 4. Formal definitions of these and other views may been found in Dattolo and Luccio (2009c).

The zz-structures result, particularly indicated in our specific application field, support the multiplicity and variety of relations among the data and simplify the access to them.

Other data structures are used in the literature for organizing and navigating information in the hypermedia applications. An interesting survey and comparison of the

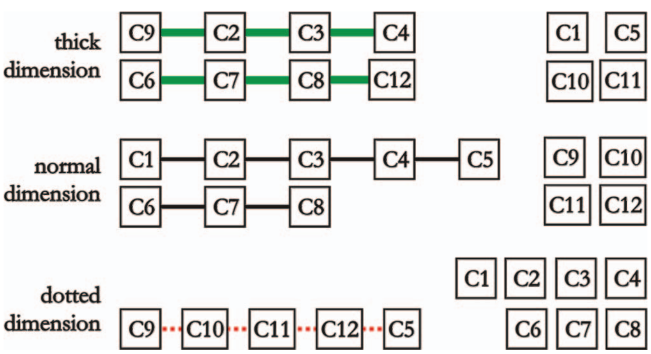


Fig. 3. Dimensions and ranks related to zz-structure of Figure 2.

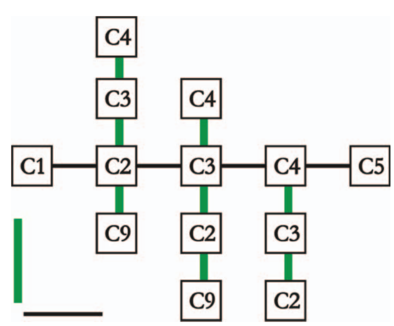


Fig. 4. An example of H-view.

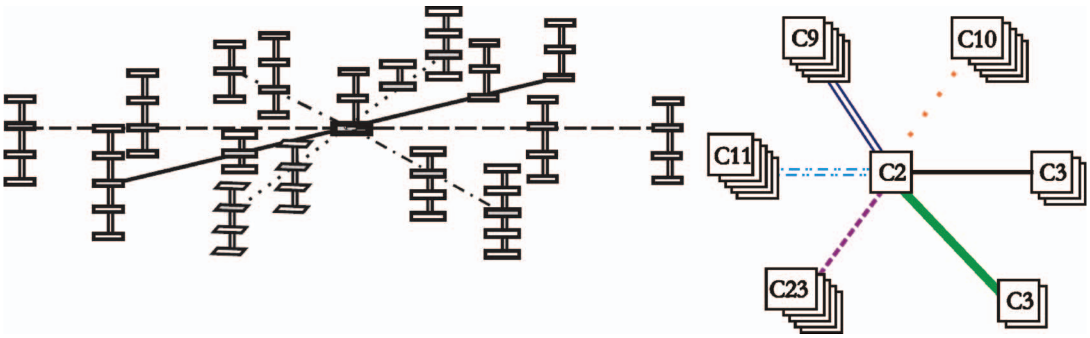


Fig. 5. Two views in more than two dimensions: a five-dimensions H-view (left) and a four-extended star view (right).

best-known data structures are presented in McGuffin and schraefel (2004): traditional lists (one-dimensional arrays), tables (two-dimensional arrays), trees, graphs and relational databases are presented with their advantages and limitations and discussed in relation to innovative and newer classes of structures, such as mSpaces (schraefel, Karam, & Zhao, 2003), polyarchies (Robertson, Cameron, Czerwinski, & Robbins, 2002) and zz-structures (Nelson, 2004). McGuffin and schraefel (2004) propose a taxonomy, based on a graph-theoretic perspective, in which zz-structures subsume the other structures' classes, being more general and capturing the others as special cases; in fact, zz-structures generalize lists, two-dimensional arrays and trees, and, encoding multiple alternative sub-structures, they also subsume polyarchies and mSpaces. Finally, if compared to relational databases, zz-structures are more general than them; in fact, as deeply discussed in Nelson (2004), 'relational databases are rectangular tables which map particular relations into rows and columns'. They 'do much of what a relation database does more simply than the existing methods': so, the equivalent of some complex programs in a conventional database become simple input using zz-structures, while some complex database queries become simple views.

### *3.1.2 Actor model*

The actor model is a mathematical model of concurrent and distributed computation; it is based on autonomous computational entities, called *actors*, which interact with each other by sending asynchronous messages. Actors are computational agents, defined by

(a) a set of local variables, called *acquaintances*, which constitutes its passive part and defines its internal state, not available to other actors;
(b) an active part, identified by a set of executing procedures, named *scripts*, used by the actor for reacting to the external environment: scripts define the behaviour of the actor;
(c) a *mail queue*, which stores the incoming communications, received from the other actors.

Each actor has a unique name (*uniqueness property*); it communicates to other actors via asynchronous messages; it has a *behaviour* and its nature is *reactive*, i.e. it executes the scripts only in response to the messages it receives. An actor can execute three different actions in response to a message: *creating* a finite number of new actors, *sending* a finite number of messages to other actors, *designating* the behaviour to be used for the next message it receives. The behaviour of an actor is deterministic, because its response to a message is uniquely determined by the content of the message and by its own internal state. All the actions, performed in response to a message, are concurrent. The actors can be totally described by adopting the formalism used in Dattolo and Loia (2000) specifying their name, data and the scripts, and graphically visualizing them using an extension of UML (Unified Modelling Language) for agents (Odell, Van Dyke Parunak, & Bauer, 2000).

## 4. The PSYCHO-MAD architecture

The architecture of PSYCHO-MAD is organized in two layers: the *component layer* contains the zz-cells, that are actors specifically designed to model the different typologies of multimedia documents, while the *meta layer* contains the actor classes specialized to manage, for example, the connections among zz-cells or to generate specific views on them.

### 4.1 Component layer

The component layer contains and models audio documents, including in them primary information, meta-data and contextual information (see Section 2.2). Here we present in detail the part of this layer dedicated to magnetic tape recording: it is shown in Figure 6.

Each open reel is usually composed of several physical segments (see Figure 7), i.e. pieces of magnetic tape connected by means of adhesive tape (called junction). In each segment, the audio signal is recorded in one, two or more tracks. Following this structure we defined the actors *Source*, *PhysicalSegment*, and *DigitalSignal*. Moreover, the actor *LogicalSegment* is introduced, with the aim to compare the sources on the basis of a segmentation that is different from the physical one.

The *Source* actor (shown in Figure 8) contains the list of the *PhysicalSegments*, which compound the reel-to-reel tape, a set of *texts* representing cataloguing fields (like the tape width—typical values are 1/4, 1/2, 1, and 2 inch), the original archive, the shelf mark, the inventory and condition of preservation) and *static images* (related, for example, to covers, annexes, flanges). This actor is able to perform several actions, e.g. the script *calculate-Duration* asks each *PhysicalSegment* for its length and rate and calculates the total duration of the tape. The *LogicalSegment* actor (shown in Figure 9) carries out a virtual partition of the *Source*.

Its acquaintances are the *start* time and the *length* of the segment, a pointer to the corresponding *source*, the recording *rate* (typical values are 7.5 or 15 inch $s^{-1}$), the *equalization* (e.g. IEC1/CCIR), the *noise-reduction system* (e.g. Dolby or dbx), the *tracks layout* (i.e. the tracks number and width), a pointer to the *digitalSignal* representing the audio recorded on each track, and an *audioQuality* index, that can be subjectively specified by the user. If the *audioQuality* field is left blank, the script *getQuality* asks the *digitalSignal* to estimate the signal-to-noise ratio of each track and returns an index of quality. The script *getSignalProperties* asks the *digitalSignal* for the digital audio of each track and estimates if the audio signal is monophonic, stereophonic, or polyphonic. This information doesn't always correspond to the number of tracks, because, following the practice of magnetic recording, a monophonic signal can be recorded on a multi-track format, writing the same signal in all the tracks.

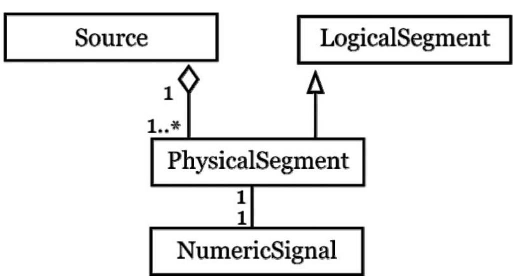


Fig. 6. Modelling magnetic recording in the component layer.

A specialization of this actor class is the *PhysicalSegment* actor (shown in Figure 10) that specifies geometrical features of the segment, such as the angle of its splice.

The script *getFadeDuration*, starting from the geometrical properties of the junction, calculates the duration of the fade-in and fade-out of the audio at the segment edges. Finally, the *digitalSignal* actor (shown in Figure 11) represents the audio signal recorded on the tracks. Its acquaintances are related to the numeric format: *number of samples, sampling rate, resolution, data*. $[i, j]$ is a matrix, with a row for each track and a column for each sample. This actor can perform several actions, which, using signal processing techniques, calculate signal-to-noise ratio, short-time Fourier transform, amplitude envelope or other kinds of representations.

## 4.2 Meta layer

Meta-actors are added to the model, in order to manage the information in a zz-structure context. Next Figure 12 proposes a look at the meta layer, visualizing only some actor classes that will be used in Section 5 for presenting our case study.

Actors present in this layer are devoted to organize, manage and follow the dynamic evolution mainly in relation to three typologies of operations: access,

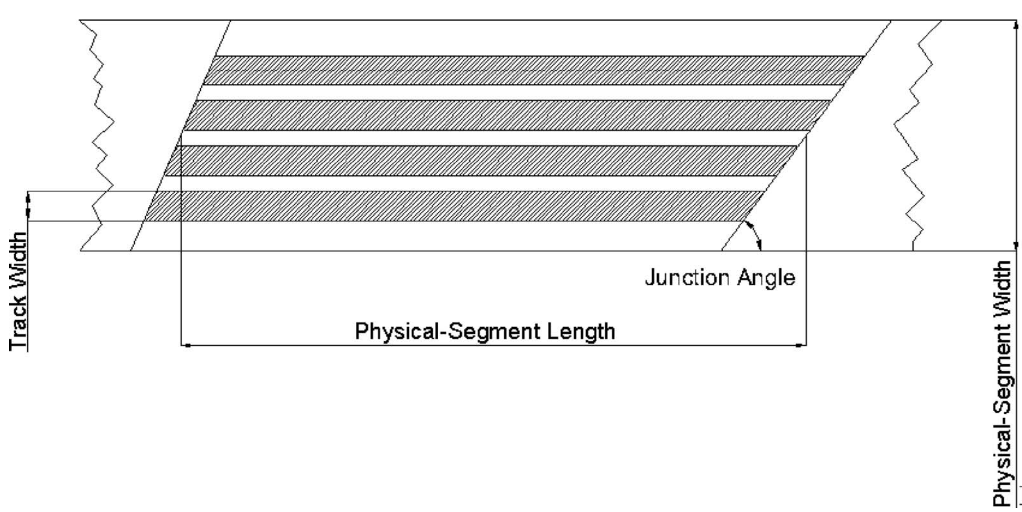


Fig. 7. The magnetic tape structure.

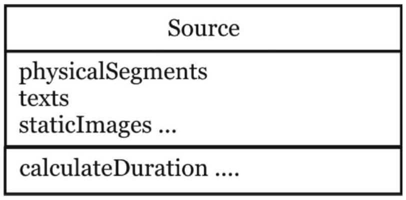


Fig. 8. The Source actor.

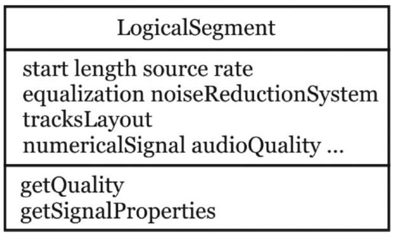


Fig. 9. The LogicalSegment actor.

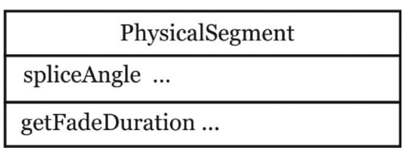


Fig. 10. The PhysicalSegment actor.

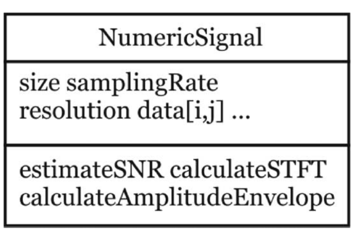


Fig. 11. The DigitalSignal actor.

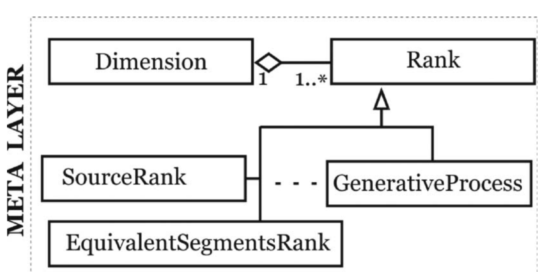


Fig. 12. The meta layer.

navigation and authoring. In particular in Figure 12, the actor *Rank* can be described as an ordered list of actors, belonging to the same dimension.

Each specific dimension contains one or more ranks. Examples of dimensions are:

- *source* dimension: it composes given sources as an ordered sequence of segments;
- *equivalent segments* dimension: it links segments with a common music content present in different sources.

For each dimension, we define specialized classes of Rank actor; in particular, *SourceRank* represents the rank containing a source decomposed into separate components (for example, in physical or logical segments), while *EquivalentSegmentsRank* contains sets of equivalent segments. Finally, the *GenerativeProcess* is a meta actor devoted to the authoring process, and in more detail to the generation of dynamic views and new virtual hyperdocuments.

## 5. Case studies

In order to emphasize the effectiveness of our model, we present three case studies related to different music genres, focusing our attention in Section 5.1 on visualization aspects and in Section 5.2 on the creation of new performances.

### 5.1 Visualization of dynamic views

The multilevel organization and the use of computational agents provide new possibilities for accessing sound documents. The users may choose the dimensions, in which they can make comparisons among the sources, using simple controls (gesture, pressing bottoms or vocal devices) carried out on the selected input device. In this way, they can compare the audio signals (in time and/or frequency domain) of different sources with corresponding metadata, without interrupting the sound performance. The use of actors permits the virtual decomposition of the sources in their physical segments, the visualization of different versions, a partially automated analysis and the comparison, with the advantages of having a layout of the work both on the synchronic axis and on the diachronic one and also a free deconstruction of the work.

In this section, we propose two examples of views in two different application domains: the electronic music and the ethnic music.

**Electronic music works**. As the first case study we have chosen Maderna's electronic work *Invenzione su una voce*; for this work, there are about 20 different audio documents, stored in different European archives. The sources have different signal properties (monophonic and stereophonic), different audio qualities, partially different musical content, and a duration ranging from 10′50″ to

18′51 , and they can be compared on the basis of their musical content, in order to find commonalities and differences. An example is shown in Figure 13, in which two sources (identified in the archives by tr530 and fon21) are segmented in their initial parts, identifying the segments equivalent for amplitude envelope: logical segment $tr530_1$ is equivalent to $fon21_1$, $tr530_3$ to $fon21_2$, and $tr530_5$ to $fon21_3$, whereas $tr530_2$ and $530_4$ don't have an equivalent segment in source fon21 (Canazza & Dattolo, 2007).

The set constituted by ranks, containing logical segments that are equivalent for amplitude envelope, composes the dimension *equivalent segments*, while the set constituted by ranks, containing the sequence of logical segments related to a given source, composes the dimension *source*; in our example, dimension *source* contains parallel ranks, one for each existing source. A view related to these two dimensions is shown in Figure 14.

This view of size 3 × 5 visualizes part of three different sources (fon21, tr530 and tr532) and may be used to describe (and activate the listening of) all the segments of a variant or to create new virtual versions. The system makes it possible to analyse and to listen to the variants between two or more different versions of the same music work.

**Ethnic music documents**. The aim of the ethnomusicology is the study of social and cultural aspects of music in local and global contexts. In this sense, it is essential to preserve the information of the whole system which has produced the audio document, taking trace and managing a wide set of information, such as: the social event in which the music was performed, the dancers, the audio signal, the dancing, the musical instruments, the traditional costumes used by the musicians/dancers, the recording equipment and the score. PSYCHO-MAD is

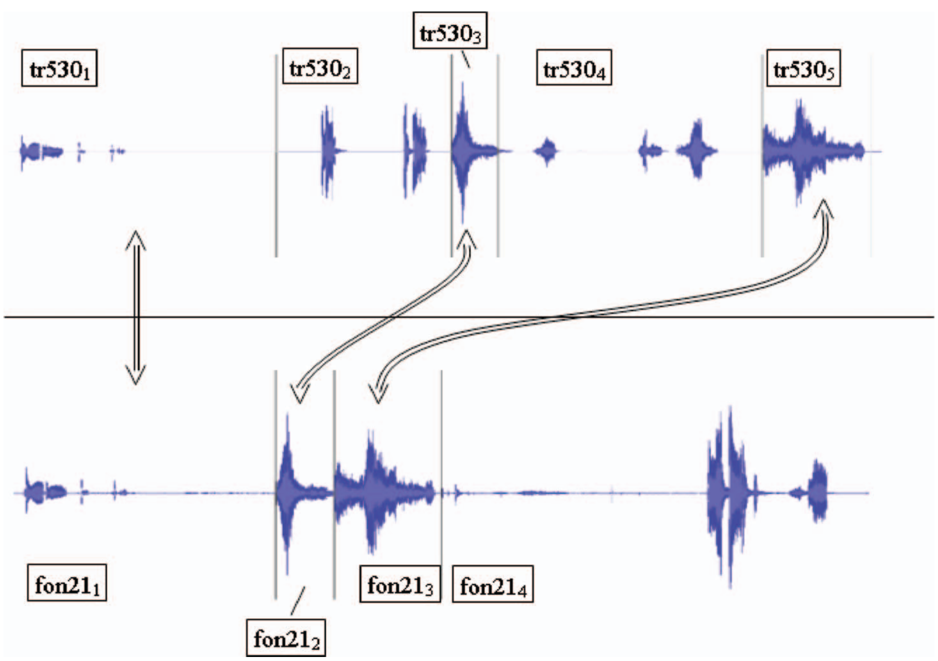


Fig. 13. Amplitude envelope of tr530 and fon21 with equivalent segments.

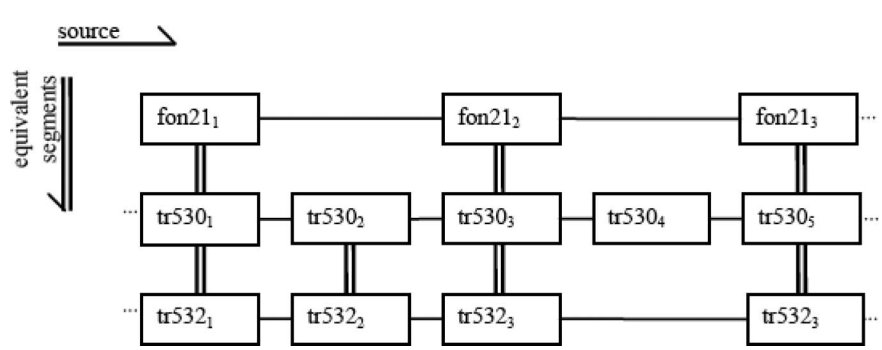


Fig. 14. The zz-view showing *source* and *equivalent segments* dimensions.

capable of mutually connecting all the elements stored in different media (text, static images, audio signals and videos), thereby allowing the user to explore the different views of this multi-dimensional structure.

As a case study, we present a typical rite of Sicilian folk culture, *The 'cries' of the Jews of San Fratello*, during the Holy Week (Fugazzotto, 2004): the leading actors are menfolk, who freely roam the streets playing loudly and menacingly as they swing a thick chain known as the *discipline*.

By progressively amplifying the spectacular but also the liberating force of that rite, the popular tradition took possession. This new ritual, called in the different local dialects also *Terremoto* (Earthquake) or *Tremmete* (Tremor) or *Bbatte porte* (Bang the doors), is widespread throughout Italy, from the North to the southern islands, and is variously interpreted by the scholars (Perrotta, 1986). A view on this event is shown in Figure 15.

The view proposes, horizontally, the dimension *event*, constituted by parallel ranks containing heterogeneous information related to each event and including, following Figure 15 from left to right, musical instruments, dancers, video, audio represented in time and frequency domains, but also year, textual descriptions, musicians, photos, and so on. Vertical connections represent the related dimensions. The cell, focus of attention, occupies the central position in the view.

The selection of a cell, different from the current focus, entails the visualization of a new view (of same size and style but on different dimensions) in which the selected cell will occupy the central position of focus. Finally, clicking on one of the hidden cells (Figure 15 shows only the borders of them) involves the shift of view in the selected direction.

The user can choose to change the view, selecting, for example, the two-extended star view, shown in Figure 16. The focus cell is still the same as Figure 15, but in this new view are present six dimensions and the user can access each of them.

All of the described operations are carried out from the actors present in the meta layer, in collaboration with the actors of the component layer.

### 5.2 Creating new perspectives for old musical open works

A classical musical composition (a Beethoven's symphony, a Mozart's sonata, or Stravinsky's *Rite of Spring*) posits an assemblage of sound units that the composer arranged in a closed, well-defined manner before presenting it to the listener. He converted his idea into conventional symbols, obliging (more or less) the (eventual) performer to reproduce the format devised by the composer himself. Conversely, a number of music pieces (or, more general, of multimedia works) are linked by a common feature: the considerable autonomy left to the individual performer in the way he chooses to play the work. Thus he is not merely free to interpret the composer's instructions following his own discretion (as happens in traditional music), but he must impose his judgment on the form of the piece, as when he decides in what order to group the sounds: a real act of improvised creation. In *Klavierstück XI*, Karlheinz Stockhausen presents to the performer a single large sheet of music paper with a series of note groupings; he then has to choose among these groupings, first for the starting unit and, next, for the successive ones in the order in which he elects to weld them together: in this way, he can *mount* the sequence of musical units in the order he chooses, changing the *combinative* structure of the piece. In Pierre Boulez' *Third Sonata for Piano*, the first section (*Antiphonie*, *Formant 1*) is made up of ten different pieces


Fig. 15. A view on three events.
*Note*: All photographs in Figures 15 and 16 were taken by the authors and Giuliana Fugazzotto.

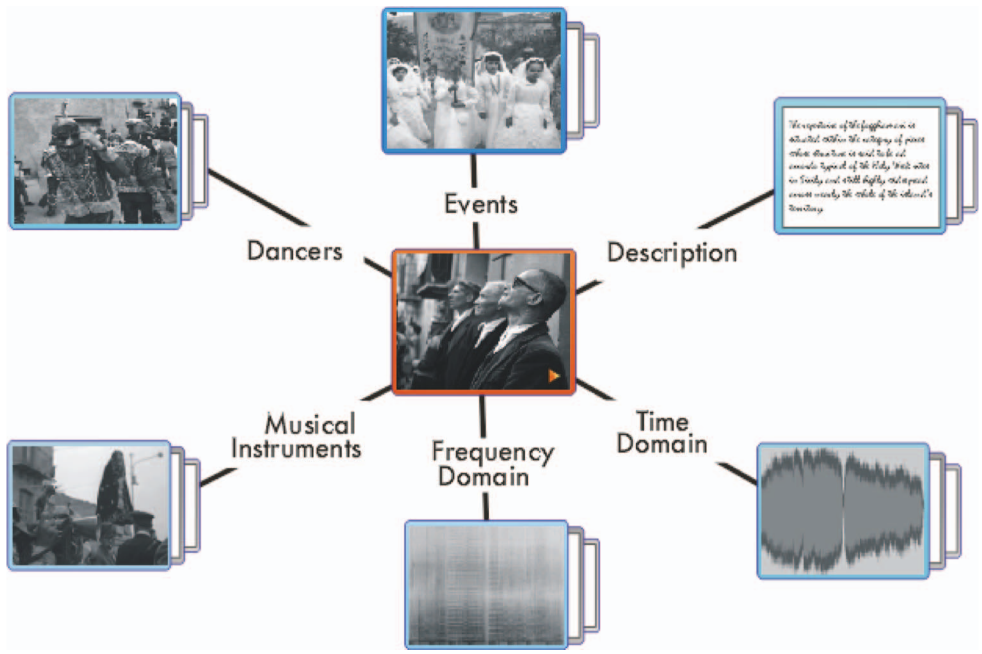


Fig. 16. A two-extended star view. In this view six dimensions are present and the user can access each of them.

on ten corresponding sheets of music paper. These can be arranged in different sequences like a stack of filing cards, though not all possible permutations are permissible. A particularly representative example of open musical work is *Scambi*, an analogue tape work created in 1957 by the Belgian composer Henri Pousseur at the Studio di Fonologia in Milan. By means of a specific process, called dynamic filtering (realized by using special equipment, designed by Alfredo Lietti, the engineer of the studio), the composer is able to extract from noise animated time structures, then to process them further in different parameters, and thus to produce 32 sequences. These sequences can be arranged by anyone who accessed them and who wished to realize the work, according to certain rules regarding their order and possible overlapping (Canazza & Dattolo, 2008).

Writing about his work in 1959, Pousseur ended by envisaging the day when technology would allow listeners to make their own realizations of the work (either following his *connecting rules* or not) and to give the, now active, listener the experience of a temporal event, open to his intervention and which could therefore be elevated in type, as vital, creative freedom. The active listener becomes, in effect, a composer; reception and interpretation are expressed as (musical) production.

In PSYCHO-MAD, Pousseur's invitation to interpret his work creatively as re-composition has been extended to remix and other types of appropriation that were not only permitted but welcomed by the composer (a position that associates him with popular-music culture in which such freedom is assumed).

In our case study, we have collected the original 32 audio sequences realized by Pousseur, thanks to the *Scambi Project*, Lansdown Centre for Electronic Arts, School of Arts, Middlesex University, UK (http://www.scambi.mdx.ac.uk).

Thanks to the cooperation among different classes of actors, PSYCHO-MAD allows user-author to surf among the existing performances of *Scambi* (by the composer, Luciano Berio and others) and to create a new virtual source, automatically picking up the audio sections following the *connecting rules* proposed by the composer (Canazza & Dattolo, 2007). The four acoustic parameters taken into account by Pousseur are:

(1) statistical tempo (from slow to fast);
(2) relative pitch (from low to high);
(3) homogeneity of the sound pattern (from dry to strong reverb);
(4) continuity (from long breaks to continuous sound).

Moreover, in PSYCHO-MAD the user-author can establish himself stochastic rules.

We assume that a user is interested in creating a new performance, starting from a given sequence seq_$k$ ($k = 1, \ldots, 32$), chosen among the 32 possible ones belonging to {seq_1, ... , seq_32}. The user selects the starting sequence, and the system shows the sequences that respect the rule of Pousseur's *complete continuity*. Anyway, the user can disregard the connecting rules according to the composer himself (Pousseur, 1959). The user can realize a polyphonic structure and modify

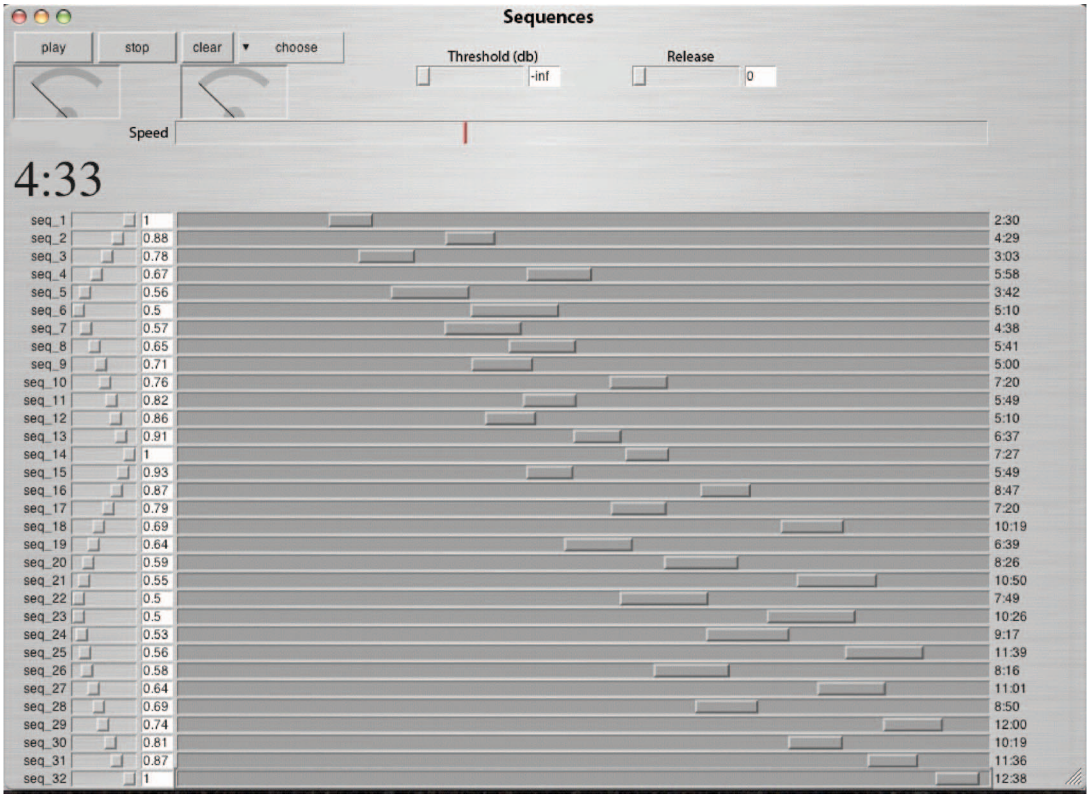


Fig. 17. A new user-created performance.

the duration and the amplitude of each sequence. In addition, the user can listen to several existing performances of *Scambi* (by the composer, Luciano Berio and others) and virtually change the parameters of the equipment (selettore d'ampiezza) used by Pousseur in Studio di Fonologia Musicale in Milan (Italy) during the realization of the work.

The process that enables the system to suggest new sequences and to create a new performance is managed by the meta-actor *GenerativeProcess*, which coordinates each operation and the sequence actors. Each time that a user adds a sequence to his performance, *GenerativeProcess* asks it to *applyRule* in order to obtain suggestions about the next possible sequences. The process is iteratively applied on the remaining sequences. Next Figure 17 contains a new created performance.

There are two important provisos:

(1) The general dynamic level of each sequence should be considered carefully by the performer. Henri Pousseur (1959, p. 54) states: 'the free dimension of dynamics had been left quite undefined, giving rise to the following possibilities: dynamic changes could be worked out in advance, and recorded before montage; it could be left until the performance to start interpreting, either to a plan or just improvising; in fact each polyphonic layer could here be controlled separately, if desired, by a group of interpreting artists.' Thus, there is great potential for the creative use of dynamic levels: for this reason, our system allows one to define the dynamic of each sequence (see the cursors just at the right of the sequence number in Figure 17).

(2) The different durations of the sequences. Henri Pousseur (1959, p. 54) wrote that there are no objections to the use of other tape speeds: 'the structures can easily take a transposition an octave down without loss of interest—on the contrary, some details which tend to become lost in the homogeneous surfaces are suddenly brought out by the loss of speed, which is thus balanced by an increase of inner movement.' The system consents to change the duration, by means of the cursor *Speed*, of each sequence.

## 6. Conclusion

In this paper, we describe a non-hierarchical hypermedia model for handling the information stored in the audio memories based on an extension of zz-structures. The given model, thanks to the use of actors, is capable of exhaustively showing the interaction among different elements of the basic system (author, technicians, instruments for generating and storing the sound) and media (technicians, equipment for transferring data—audio signal, metadata, contextual information—and for encoding them digitally). This extends the state of the art (composed of relational database, CD-ROMs and web sites devoted to music works) from different points of view.

(a) *Interaction*: in case of work, that is *on the move* and *open* to the interpretative interventions, the author delegates to the user the sound material assembly (stored originally on different carriers) as well as the calibration of some acoustic parameters (from the simple regulation of intensity to the balance of the channels). The given model allows the user to interact creatively with a simulation of the work production system: the users, having at their disposal, original sound material and assembly instruments, will be able to create new versions of the work. Pousseur's point of view will be made finally concrete. He was the first to suggest, with *Scambi*, an example of an *open* music work, according to which: all the material should have been offered the 'lovers' within the new 'music labs' (Pousseur, 1959). The most interesting perspective in this experience is, indeed, the interactive dynamic.

(b) *Hypertext and hypotext*: like the original palimpsests—a written parchment which was scratched out to be used again—in which the crossing out left traces of the primitive text, that can be read in transparency, a text can hide another one partially, albeit never totally. When the *hypertext* lays over its *hypotext* (Genette, 1982), both texts admit of a double reading, creating what Genette called 'literature in the second degree'. In the field of electro-acoustic music, the composer often uses some sound materials in different works and contexts, producing what can be defined as 'listening in the second degree': this model can be used to connect—interactively—the sound equivalents of the *hypertext* and *hypotext*.

(c) *Philological*: the model makes the collation of variants easy; in case of works with a wealth of sources (see part 4); in the case of an original source that is now unavailable (because it is impossible to find, or because its segments have been used for composing new versions). At the basis of certain pieces of information about the composition of the source sound tissue, the system may provide a digital version of the original assembly, via elaborations—executed by opportune actors of the sources.

(d) *Cataloguing*: there is no reason why a search on attributes could not be combined with a data structure, without using the entity-relation model; since each zz-cell can be assigned a set of attributes, which can be sought, this model can be also used as a cataloguing instrument. In this way, many disadvantages of database navigation can be overcome (Chen & Czerwinski, 1998).

(e) *Theatre music and music for movies*: using the possibilities of creating *views* in audio/video domains and mutually synchronizing the scores, audios, texts and videos, the model admits new methods for the preservation and access to documents within the fields of theatre music and the music for movie.

(f) *Commercial*: nowadays *Deluxe editions*, *Deluxe boxes*, *n*th *Anniversary editions* (with $n = 20$, 30, 40, ...) and *Legacy editions* are often the last chance for the discographic labels survival. They contain the same (very) old pop/rock hits (originally in Long Playing microgrooves vinyl disc) with some outtakes: sometime they are interesting from a musicology point of view, sometime they are (only) collectors material. At the same time the games like Guitar-Hero have a great success: 'despite how easy they may make it look to the adoring eyes of their fans, your typical rock god spent years practicing. Every day, until their fingers bled. It's not something everyone can do, but it's something that everyone (guys in particular) wishes they could. Hence the phenomenal success of Guitar Hero, a game that taps into this primal urge to jump around like an idiot, trash your immediate surroundings, tear down the very fabric of society via blues riffs and power chords ... on a plastic toy guitar' (http://www.amazon.com). It could be interesting to use our model in order to give to the user a trade-off among musicology needs, the collector demands and the edutainment request. Different tracks (voice solo, guitar solo, drum solo, bass solo, keyboard solo, etc.) of some pop/rock hits could be recorded in a optic carrier (e.g. Blu-ray Disc). The user could perform different versions of his favourite song. The actors help to respect the musical rules or they suggest new forms.

We are maybe on the verge of a great revolution, where the reconstruction—through necessary information models—of the music work will be recognized and connected by all its components.

The cooperation activities of different classes of actors allow the user to create new virtual hyperdocuments and dynamic views (useful, for example, in performance of electro-acoustic music open work or in ethno music events). This paper provides the description of both the model architecture and three different (and complex) case studies (in the fields of ethno music and electro-acoustic music), focusing the attention on the visualization aspects and on the creation of new performances.

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