An HCI Model for Usability of Sonification Applications

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Abstract. Sonification is a representation of data using sounds with the intention of communication and interpretation. The process and technique of converting the data into sound is called the sonification *technique*. One or more techniques might be required by a sonification *application*. However, sonification techniques are not always suitable for all kinds of data, and often custom techniques are used - where the design is tailored to the domain and nature of the data as well as the users' required tasks within the application. Therefore, it is important to assure the usability of the technique for the specific domain application being developed. This paper describes a new HCI Model for usability of sonification applications. It consists of two other models, namely the Sonification Application (SA) Model and User Interpretation Construction (UIC) Model. The SA model will be used to explain the application from the designer's point of view. The UIC Model will be used to explain what the user might perceive and understand.

Keywords: Usability, Sonification, Usability Inspection, Human Computer Interaction (HCI), Usability Inspection Material, Perception.

1 Introduction

Sonification is the representation of data using non-speech sound for the purpose of communication and interpretation. The specific conversion process and technique involved in transforming the data into sound representation is called the *sonification technique*. There are many techniques currently available in data sonification such as parameter-mapping [5], model-based sonification [6], audification [25] and so forth. These techniques are normally guided by the type of data to be presented and the required user tasks that the sonification can support such as program debugging [10], multi channel data display [5], stock market prediction [22], computer network auralisation [27] etc. Sometimes the type of 'tasks' is not clear especially for sonification applications that involve data exploration. This makes the usability aspects quite difficult to implement and evaluate in such applications.

However, the issue of usability is no longer an option, but rather a requirement for sonification applications. We believe that, the usability of applications is very much influenced by the specific sonification technique employed. One or more techniques might be required by a sonification application. However, a technique is not always

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suitable for all kinds of data or domain; and often we use custom techniques, where the design is tailored to the nature of the data and the user's required tasks within the application. Therefore, it is important to assure the usability of the techniques for the specific domain application being developed. To produce a usable sonification application, it is important to understand the technique as well as how the users will interact with the application. Since the output will be in the form of sound, it is also important to understand how the sound will manipulate the capability of human auditory system.

In this paper, we propose a new HCI model for usability in sonification applications. It is used to explain and understand sonification applications (at the design stage) and how they might be interpreted by the users. This is done through two different models namely the Sonification Application Model (SA Model) and the User Interpretation Construction Model (UIC Model).

Our starting point is *Norman's Model of HCI* (as shown in Fig. 1) which is expanded using *three elements of sonification* (as shown in Fig. 2.a)). This gives rise to our *HCI model for usability of sonification applications* (which is shown in Figure 2.b)). Norman's model consists of two gulfs - namely execution and evaluation. The *execution* gulf is the gap between the effects that the user intends to achieve and the actions provided by the system. The *evaluation* gulf is the gap between what the users want to do and what they actually manage to achieve; thus it provides a way for users to determine whether or not they achieve their goal.

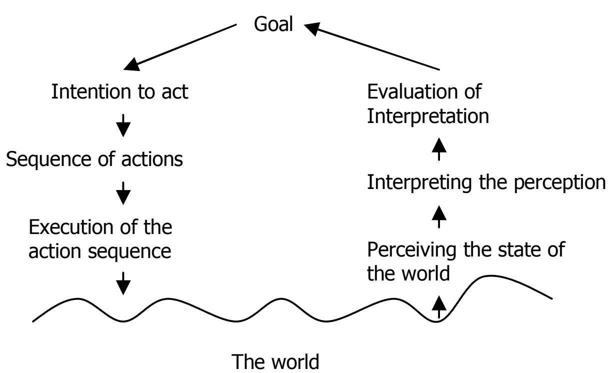

Fig. 1. Norman's Seven Stage Model of Human Computer Interaction [28]

In our model, the effects that the user intends to achieve (user requirements) and the actions provided by the system are dealt with separately. The user requirements are described as *goals* and *abstract tasks*. An example of an existing analysis of user requirements for sonification applications is *TaDa* (Barrass, 1997). '*The world'* in Norman's model relates to our system (in this case is a sonification application) which provides interactivity with the users and produces sounds as the output. This sonification application is described using our SA Model. The output of sonification applications is normally sound, representing the data that the user perceives. Norman's model mentions this in the evaluation gulf that involves perception, interpretation and evaluation. We explain this through our UIC Model.

Both models are created based on (a) the definition of sonification, (b) our assumptions about the usability of sonification applications, (c) a data state model, (d) issues in designing sonification applications; and (e) seven stages of Norman's Human Computer Interaction. All of these will be explained in this paper.

In summary, both the SA Model and the UIC Model can be used to explain what the application offers and what will be interpreted by the users. The application is considered usable if what it offers (SA) is interpreted (UIC) correctly as what was intended by the users as stated as their goal and abstract tasks.

2 Definitions

2.1 Sonification

Sonification is defined as the representation and transformation of data/information using non-speech sound for the purposes of facilitating, communication, comprehension or interpretation by listening [1] [2] [3].

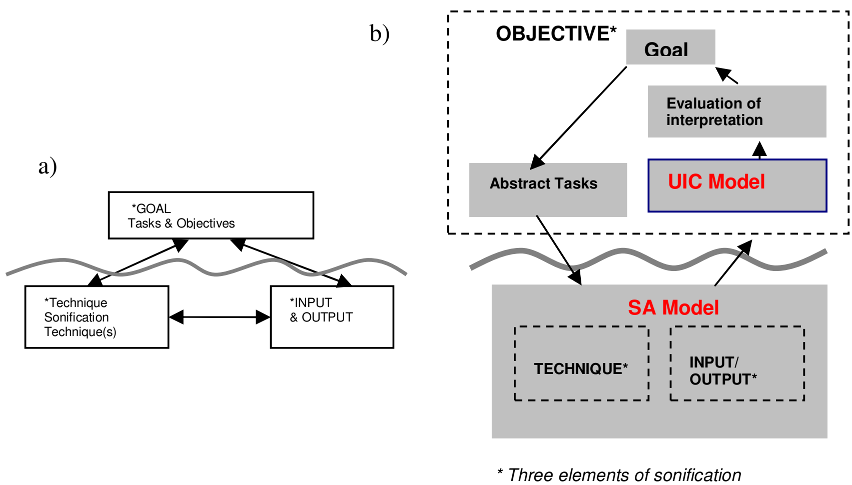

Fig. 2. a) Three important elements from the definition of Sonification. b) General framework of our HCI model for the Usability of Sonification Applications, based on Norman's Model and three important elements of sonification.

From the definition, we clarify the term sonification from three distinctive elements specifically (a) *Technique*, *(*b) *Input/output* and (c) *Goals* as presented in Fig. 2 a). The 'technique' refers to how the data is transformed into sounds. The 'input/output refers to the data/information as the input and the sounds as the output of the transformation (technique). And the 'goals' concern what the application (including the 'technique' and 'input/output') wants *to achieve.*

These three elements of sonification (Technique, Input/Output and Goals) as illustrated in Figure 2 a) are important to our HCI model. By comparing Norman's model (Figure 1) and the three elements of sonification; and imagining that the curly line is the interface and interaction between the users and the application, the 'Technique and Input/output' (used in the SA Model) can be considered as part of the application (the 'world' in Norman's model). The 'Goals' element in sonification is divided into the 'user requirements' and 'sound interpretation' of the application. The interpretation will be explained through our UIC Model, which involves the perceiving, interpreting and evaluating stages in Norman's model. This is illustrated in 2 b).

The definition of usability for sonification will be based on the existing definitions of *usability*, *sensation*, *perception* as well as *our usability assumption* as explained below:

2.2 Usability

Below are several definitions of usability for sonification applications as well as an assumption which we will find useful.

Usability
Usability is defined as: The capability of applications to enable specified users to achieve specified goals with effectiveness, efficiency, learnability, memorability, low errors and satisfaction in the specified context of use [24] [30] [31] [32] [33].

Our Assumption of usability for sonification applications
The effectiveness of sonification applications is dependent on the effective use of the human auditory system's capability to perceive auditory structure.

Sensation
Sensation is concerned with the first contact between the sense organs and the external world. It deals with basic aspects of experience such as "how loud does the sound appear to be?" [4].

Perception
Perception is the attempt to identify objects and relationships in the external world [4]. The focus is on how we form a conscious representation of the objects and object relationships. The processes involve *selecting, organizing* and *interpreting* the sensory data into a useful mental representation of the world. The perception question is related to the question "Can you identify the sound?"

Based on the definitions and our assumption above, we can summarize that the purpose of usability study for sonification applications is as follows:

*To understand and investigate how the main usability factors (efficiency, learnability, memorability, satisfaction and error handling) will support the effectiveness of sonification applications in manipulating the human auditory system's capability in the process of selecting, organizing and interpreting the sound (*sonified data*) and its structure into useful mental representations or information.*

Therefore, the application is said to be effective if the user's intended tasks can be accomplished with high accuracy and completeness. This will have happened if the user gets a useful mental representation from the sound as what it "*should and could be*". This can be achieved if the intended structure of the data and the perceptual structure of the sound coincide.

In summary, it is important to give detailed attention to each element of sonification (*Technique, I/O and Objective*) and explain them as the interaction between the user and the application. Therefore, our models give more attention to the questions below:

1. How is the data or information [*as the Signified or Input*] transformed [*by the Technique*] into sound representation [*as the Signifier or Output*]? – **Sonification Application Model (SA Model)**
2. How can the application help the user to perceive the sound as a useful mental representation of the original data [*as the goal*]? – **User's Interpretation Construction Model (UIC Model)**

3 Sonification Application Model

This section explains the **Sonification Application (SA) Model**. This model is used to explain a sonification application from the designer's point of view, including what would the user would like to do and to know. Besides describing the data transformation processes, it is also important to consider any interactivity of the system with the user.

To relate our model to 'usability', we need to look at existing issues in sonification application design. These issues are based on previous research and user testing of various sonification applications. Due to space limitations, we list here a few of the most important issues as examples. We have split them into two categories; (1) *Signified issues* [*data, data attributes, information etc.*] and (2) *Signifier issues* [*physical sound parameters, sound perception parameters, sound etc.*]. Examples of issues in the signified category are data scaling [5] such as increasing or decreasing the data values; data set reduction [6] such as reducing the data dimension; and mental image of the data [7] which involves an investigation of the user's imagination about the data. Examples of issues in the signifier category are musical knowledge requirements [8] [9] [10] [11] such as whether or not the user must have knowledge of musical theory for a better understanding; sound type (musical and non-musical) [12] [13] to avoid fatigue; number and type of acoustic parameters [12] [14]; Perceptual Issues [10] [12] [15] [16] [17]; sound aesthetics [18]; the number of signals that can be played at the same time [19] [20]; sound density [18]; sound structure[12] and so forth.

We use a data state model to describe the conversions processes as well as the input and output of sonification applications. The data state model is inspired by [21] as it involves data transformation processes. The transformation processes explain how the data is transformed from its original form into the final sounds. These transformation processes are used to explain the *technique* in Sonification applications. The data and sound parameters involved in all the transformation processes are considered as the *I/O* (input/output).

To ensure that detailed attention is given to the transformation processes, Input/Output and users' interactivity, the sonification application model should consist of the elements below (which appear as the rows in the table in Figure 3):

1. Technique – *[transformation processes]*
2. *I/O – [data/information and sounds]*
3. Interaction – *[interaction between the users and the application in all the transformation processes]*
4. Users – *[Users involvement in all the transformation processes]*

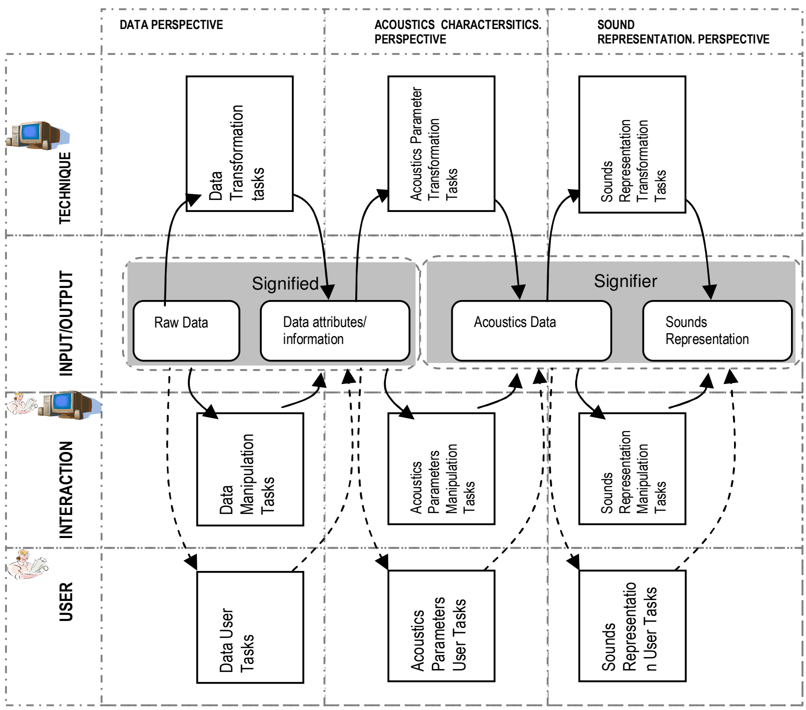

Fig. 3. Sonification Application (SA) Model

Interaction is important in the model because some of the applications allow the users to manipulate and interact with the final sound representation [23], acoustics parameters [5] or even the data [5][6][22]. This is illustrated as the '*interaction*' row in Figure 3. The user aspect is also important as most sonification applications are domain dependent. Therefore, explanation of user's knowledge and what they should know are important as these influence how they use and interpret the system and its sound outputs.

In the SA model, both *interaction* and *user* layers focus on the designer's point of view, including what the user needs to do and to know. What the user might perceive and understand will be explained later in the UIC Model. These two different points of view towards the users are important to know whether or not what was designed will be well interpreted by the users.

Wittgenstein ((1953) cited from Barrass, 1997[26]) said that the meaning of a sign is not the object it signifies but rather the way it is used. Therefore, the signifier does not necessary carry a direct representation or meaning of signified but rather the tasks or the function of the signified. This is where the *interaction* and *user* parts (*in the diagram*) will play important roles to elaborate a more meaningful of signifier towards the signified that it represents. Both parts can be used to explain how to use the sound.

Basically, the 'technique', 'interaction' and 'users' layers are used to explained the data transformation processes starting from its original form via an intermediate "ready to play" form and then into the final sound. We call the transformation processes *data transformation, acoustics parameters transformation and sounds transformation*. These produce three different perspectives – namely data, acoustic characteristics and sound representation perspectives as shown in Figure 3 above. In terms of tasks analysis (excluding the Input/Output level), there are at least nine different tasks categories which can be used to explain the processes involved in creating sounds from data (*as shown in Figure 3*).

In general, the tasks at the '*technique'* level are those performed by a system to process, manipulate and transform data into sound representations without user interruption. Tasks at the '*interaction'* level are those performed by the user through interactions with a system. And the tasks at the *'user'* level are those entirely performed by the user independent of the system.

These three types of tasks can be further divided into three different perspectives. For instance, *'acoustics user tasks'* are those performed by users without interacting with a system which relate to acoustics parameters such as judging the loudness level of sound from two different instruments. '*Data manipulation tasks'* are those performed by users through interactions with a system which relate to data changes, such as selecting either to sort the data in ascending or descending order; or choosing which data dimension of multidimensional data is to be sonified.

In summary, in this section, we have described briefly the Sonification Application Model, existing design issues categories and the first questions of how the data or information (*Signified or input*) is transformed (*Technique*) into sound (*Signifier or output*), which is illustrated in Figure 3 above.

4 User Interpretation Construction Model

This section describes the second question about how sonification applications can help users to perceive the output sound as useful mental representations. To answer this question, we model the possible user activities and interactions with sonification applications and relate them with what the users might interpret. The model is also based on the definitions of *sensation* and *perception* as defined earlier.

Since the users will be listening to sound representations, this will directly involve '*sensation'*, which is concerned with the first contact with the sound. It is then followed by '*perception'*, which is our attempt at identification and interpretation. It involves processing '*perceived sound* into '*useful mental representations*' of the world.

In our previous assumption of usability, effectiveness depends on the capability of users to '*perceive'* auditory structure as what it should be. Therefore, our model is based on the definition of '*perception'*, which involves *selecting, organizing* and *interpreting* activities.

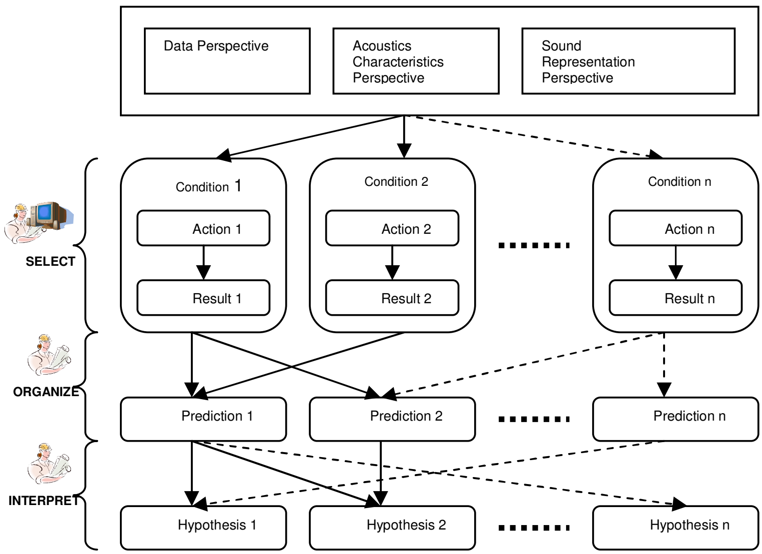

Fig. 4. User's Interpretation Construction (UIC) Model for Sonification Applications

In sonification applications, variations in sounds are heard due to changes or differences which occur in the data set. Such variations might also occur due to different approaches on how users interact and manipulate the same data.

The differences in sounds might attract the user's attention, which will produce different *conditions* during the first contact with the sound (*sensation*). This will produce questions from the users that are at a relatively low level, such as '*Can I hear the high pitch?*', or '*Can I identify the object?*' [4]. Conditions are the possible *answers* or *results* of these questions; or the possible useful sounds. This is illustrated as selection level in our model as shown in Figure 4 above. Selection is a discriminating process where the user selects potential useful sound representations. Among all the outputs, probably only a few of them are significant and will attract the user's attention, which eventually become the final conditions. Therefore, this level it is more concerned with filtering and attending only to significant conditions that might contain the required information.

The 'filtered conditions' are organized in the following level called 'Organizing'. This is the activity where the user constructs, arranges or puts together several conditions into a statement or structure. These 'organized conditions' or statements are called 'prediction'. Prediction is a statement about future conditions. In this level, the user will try to predict from all the available filtered conditions. The prediction is based on one or more conditions and focuses on predicting ‘what will happen' or ‘what does that mean?’

In the ‘interpret' level, the user tries to make sense, conceptualize or conceive the significance of the prediction. This is performed based on at least one or more predictions from the previous level. The combinations of several predictions form a statement called a *hypothesis*. A hypothesis is a proposed explanation of a phenomenon based on several predictions (*which are also based on the sound with or without interaction*) of the application.

We will explain briefly the model through a simple physical analogy – ‘*exploring the number and type of different materials used on a surface*’. Let us assume that there are two types of interactions involved; *knocking* and *scratching*. Every action will produce different sounds, which will create several different *conditions*. Among all the conditions, probably only a few of them are important and will attract to the user, which will eventually become the ‘*final conditions’* for the users. That is why it is called the ‘*selection’* level. This level involves filtering and attending only to important conditions that might contain the important and required information.

Let us assume that the possible conditions are represented by the sets below:

1. *‘knocking’ conditions = {knock1-soundA, knock2-soundB, knock3-soundC}*
2. *‘scratching’ conditions = {scratch1-soundA, scratch2-soundB, scratch3-soundC, scratch4-soundD}.*

The ‘knocking’ action (interaction) has three conditions (*possible information*) while ‘*scratching’* action has four conditions that might attract the user. In the ‘*organize’* level, the user tries to organize the available conditions and make predictions about the surface. Such prediction is based on one or more conditions and focuses on drawing up a set of rules in the user’s head which helps them to understand the role of their interaction with the surface’. From the conditions above, some examples of prediction are;

1. *‘if the ‘knock’ action produces sound A, the scratch action* <u>*should also produce*</u> *a more or less equivalent sound for the same area’,*
2. *‘if the knocking produces sound C and the scratching also producing sound C, it* <u>*could be made*</u> *from the same materials’*
3. *‘knocking has produced three different sounds, therefore, three different materials* <u>*might exist’*</u>
4. *‘scratching has produced four different sounds, therefore, four different materials* <u>*might exist’*</u>*; and*
5. *‘Sound D does not appear in knocking actions, it* <u>*might not be*</u> *a new material”*
6. *Sounds from knocking and scratching* <u>*might not be*</u> *related, therefore, sound D* <u>*might be*</u> *a new material.*

In the ‘*interpretation*’ level, users try to make sense of and interpret the outputs through several predictions. The combination of several predictions is used to form a *hypothesis*. A hypothesis is a proposed explanation of a phenomenon based on several predictions (*which are also based on the sounds either with or without interaction*). Some examples of possible hypotheses from the predictions above are:

1. *Based on the prediction number 1, 2 and 5, it is hypothesized that: 'different materials exist if the knocking sounds are more or less the same with the scratching sounds'*
2. *Based on the prediction number 3, 4 and 6, it is hypothesized that: 'differences of sounds in knocking and scratching are because they are not related'*
3. *Based on the prediction number 1, 2, 3, 4 and 5, it is hypothesized that: 'if the sound does not appear in both type of interactions, it cannot be considered as different material, and therefore, the number of materials exist in the surface can be referred to the lowest number of sounds between the two types of interactions'*

By doing this, we are actually producing the possible user perceptions of the sound representation.

As explained earlier in the definition of usability for sonification applications - where '*the intended structure of the data'* and *'perceptual structure of the sound'* coincide, the user can get a useful mental representation. By comparing what we have explained in this section with the previous section – '*what the application or designer would like the users to do and to know'* with *'what the user might perceive and understand*', the sonification application is said to be effective if these two coincide. If this has happened, the task could be accomplished with high accuracy and completeness and therefore, the application is said to be effective. As a result, these two models are important and should be integrated in one '*HCI model of usability for sonification applications'* as illustrated earlier in 2 b).

5 HCI Model of Usability for Sonification Applications

The bigger picture of the HCI model is shown in Figure 5. The Goal is a description of something to be achieved by using the application. Tasks analysis involves determining the *abstract tasks* for the application. The abstract tasks explain the user requirements, regardless of what the application offers. The abstract tasks will then need to be explained from the designer's point of view, which includes what the application will do, and what the application expects the users to do and to know (*SA Model*). For the purpose of evaluation, we will then need to analyze the possible interpretation through the *UIC Model* which includes selecting, organizing and interpreting. Finally comes the '*evaluation of interpretation'* that will determine whether or not the goal has been achieved.

The *evaluation*, *interaction*, *perception, organizing* and *interpretation* can be repeated until the task is accomplished or the goal is achieved. If this happens, it will create an interaction loop between the users and the application itself (also illustrated in Figure 5). Outside the scope of this paper is a thorough analysis of how the existing research focuses could be fit into this model. For instance TADA [26] (Tasks Analysis-Data Analysis) focuses on Tasks and Signified or data; Model-based sonification technique [6] focuses on interaction and the signified; Parameter mapping focuses on signified and signifier [1] [5], semantic approach [29] focuses on signified; and Syntactic [8][12] and Pragmatic focus on signifier (refer to Figure 5 above). This shows that the previous 'design approach' and 'sonification technique' can be

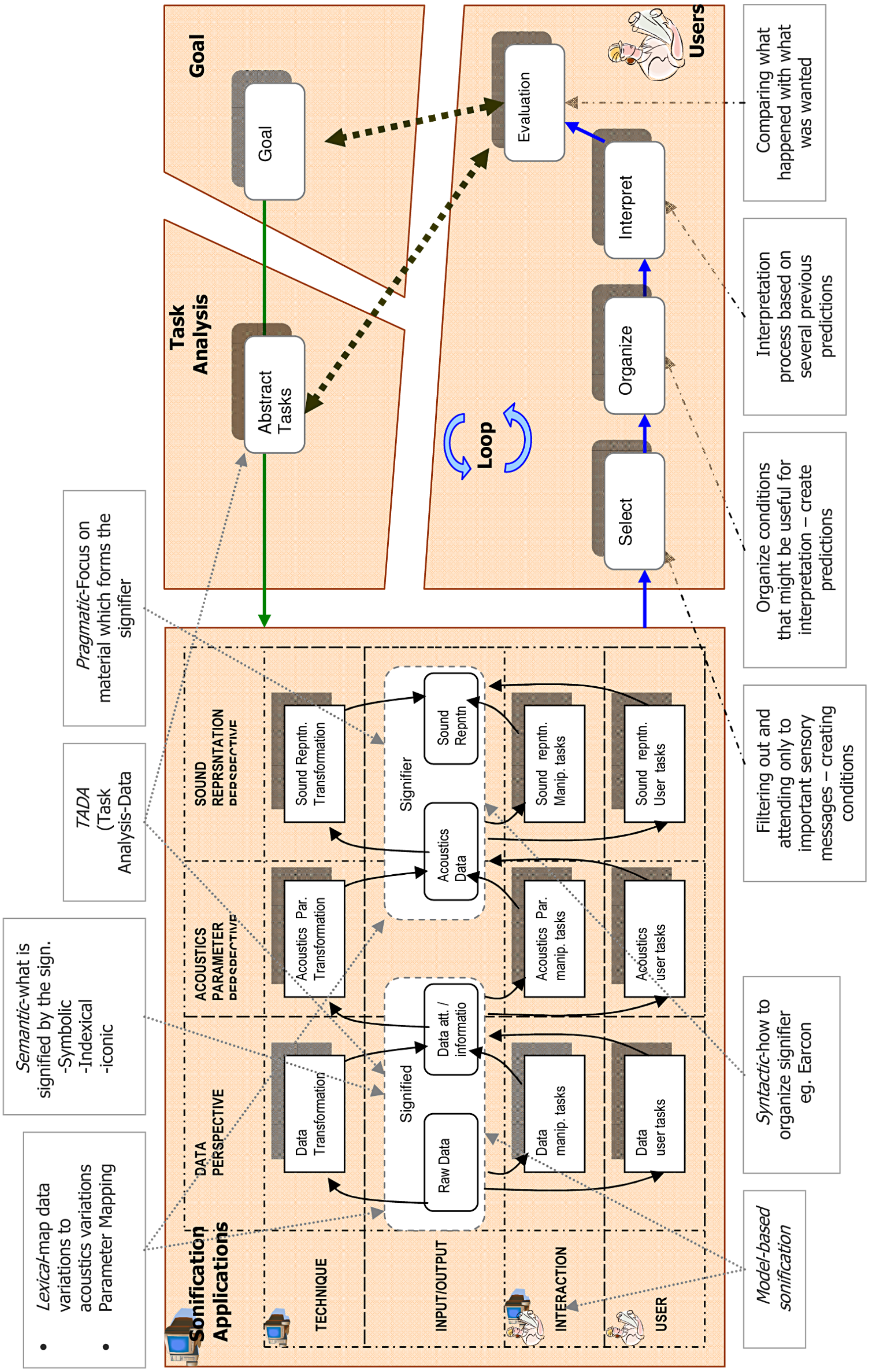

Fig. 5. HCI Model for Usability for Sonification Application

explained and described by using this HCI model. Therefore, in general, this model can be used as a framework to describe sonification applications as well as its possible interpretation that can be used in usability inspection or evaluation.

6 Conclusion and Future Works

As a conclusion, we have introduced our HCI model for usability of sonification applications. The model is derived and created based on the 1) *definition of sonification*, 2) *existing issues in sonification design*, *3) definition and our assumption of usability for sonification, 4) data state model and 5) Norman's HCI model*. We have also described two sub-models namely the Sonification Application Model [*what the application or designer would like the user to do and to know*] and the User Interpretation Construction Model [*what the user might perceive and understand*]. Both are important to form our HCI model for usability. We have also explained briefly how existing research could fit into our HCI model. For future work, we hope to use this model to help usability inspectors to analyze sonification applications from the perspective of the designers as well as the users. The model will be used as a basis to produce *inspection materials* to be using in a usability inspection for sonification application. Future sonification applications, using this design model, should have more of their problems ironed out at the design stage, and thus the cost of production will be reduced, due to more trouble-free programming and user-testing phases.

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