# AMBIENCE FOR AUDITORY DISPLAYS: EMBEDDED MUSICAL INSTRUMENTS AS PERIPHERAL AUDIO CUES

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**ABSTRACT**

From alarm signals and data sonification to multimodal interfaces, auditory displays are omnipresent in our everyday life and they become more and more popular. But there are some challenges we have to meet because of the differentness of the auditory sense compared to the visual sense.

Usually, audio notification signals are limited to simple warning cues and system feedback that are in most cases intrusive because they differ from the environmental noise [1]. That has the effect that people present in the room could be distracted from their current tasks because they cannot "close their ears." To prevent the disturbing effect of traditional notification signals we developed the novel concept of non-speech audio notification embedded in ambient soundscapes to provide multi-user notification in a more discreet and non-disturbing way.

Instead of using well-known non-speech cues like auditory icons and earcons [2], we decided to compose and record peripheral soundscapes and notification instruments by ourselves towards a more aesthetic approach.

In this paper, we give an overview of our location-aware system with two applications (PAAN, AeMN) and sketch a real life scenario in a wine department of a supermarket.

We will also present findings from a user study and provide a small collection of notification instruments and soundscapes as audio samples.

## 1. INTRODUCTION TO AMBIENCE AND PERIPHERAL AUDIO NOTIFICATION

In 1978, English musician Brian Eno coined the term ambience in combination with music in the notes to his longplayer *Ambient 1: Music For Airports*. This type of music has a calming effect and can be listened to either actively, which means the focus of attention lies on the music, or peripherally without paying attention to the music. This effect is also known as the auditive figure-ground phenomenon which decribes human's ability to pay attention to an auditory stream (figure) while at the same time any other sound is listened to peripherally (ground) [3].

In 1953, Colin Cherry described this effect in his famous cocktail party experiment when he found out that auditory perception is associated with the attention of a person [4]. The allocation of the limited resource of attention depends on a variety of factors like the stimuli that act on the person and his current mental and social conditions [5].

From cognitive science, we know that perception of auditory signals can be divided into the physiological phenomenon of hearing and semantic sound processing, which leads to the personal interpretation of the signal, influenced by the experiences of each individual listener. The intensity and complexity of environmental noises influence whether we perceive a single sound or whether it is masked which depends on multiple factors like loudness and the frequency of the noises. Traditional audio notification signals are mostly stand-alone cues that attract the attention of everybody in a room because they are not integrated in the natural sound environment [6]. That works fine for high-priority notifications (e.g. fire alarm), but often a more personal and discreet notification is desirable.

We had two main goals for the design of our notification signals. On the one hand we want to seamlessly integrate the notification signal into aesthetic music without arousing the attention of other people, but on the other hand the target person must become aware of the signal.

Auditory experiences can be learned and used [7]. We use this fact to make the listener more sensible for his specific auditory signals that we use for attracting his attention. The sound of the audio cues can be used to provide the listener with information that he links with the specific auditory signal. The user can choose which sound he wants to link with which information, so we get an individual and personalized notification that respects the user's preferences.

Since only the user knows which sound he selected for which information, this type of notification also slightly fulfills the privacy aspect.

## 2. RELATED WORK

Hudson and Smith designed a non-speech audio system that provides a preview of incoming emails by combining sound samples [8]. The "audio glance" gives an overview of four important properties of a received message by coding information into the notification sound. First, the optional preamble sound is used for announcing messages that are classified as important. The sound of the main audio icon gives information about the message category, e.g. sender information in which the sample length represents the size of the mail body. For whom the mail is appointed to (single or group of users) is coded in the recipients icon and the finishing optional content flags announced mails where a keyword matching test for header or body is positive. The playback of the resulting sound could distract other people that are in the same room in which the notification takes place. Users can also receive their audio glance while they are away from their desk by holding up a color coded card in front of a camera that are mounted in other rooms. For multi-user environments, concurrently played samples could produce a confusing sound.

Bruce N. Walker and his researchers at Georgia Tech introduced a peripheral soundscape system that provides information about stock market changes via sonification [9]. Changes can be extracted by live data or file data, mapped to animal or nature noises with respect to thresholds and finally mix them into a soundscape with a forest noise theme. The stock market soundscape system was tested in a user study [10] with stock traders. The lack of a graphical user interface as well as the possibility to sonify exact data values led to the implementation of the Audio Abacus and the Sonification Sandbox. The latter allows the user to have a look on the auditory graph and to customize the settings, for example selecting the sound of the notification which is made possible through the use of MIDI instruments.

Areni and Kim observed how customers in a wine store can be influenced by background music. They compared the influence of two music genres (classical music and Top-forty music) on the buying behavior [11]. One of the findings was that customers stayed longer in the store with background music than without and the people were more interested in expensive wine when classical music was played.

Brewster's gives an good overview of the research in the area of non-speech audio in human-computer interfaces. In several experiments he investigated the effectiveness of earcons as navigation cues [12]. Among other things, he found out that earcons can be used to represent hierarchical structures after a short training phase. The results could even be improved by using compound earcons. A detailed introduction to non-speech audio cues for human-computer interfaces and the mentioned earcon experiments can be found in Brewster‘s PhD thesis [13].

## 3. AMBIENT SOUNDSCAPES MEET NON-SPEECH AUDIO CUES

One of the major disadvantages of traditional stand-alone notification signals is the distraction of other persons present, especially in multi-user environments. Indeed, popular non-speech audio cues like earcons [14] and auditory icons [12, 15] can provide a perceptible type of notification but they are also separated from environmental noise.


Figure 1: *Score snippet of a soundscape with two optional notification instruments.*

To introduce more privacy and confidentiality, we decided to integrate notification instruments with respect to musical compositions seamlessly into background music, the *ambient soundscape*, which serves as the musical envelope. Instead of attracting the listener's attention, the soundscape should have a calming, mood influencing effect (see also [16, 17]) and should fade into the background of consciousness after a while.

To reach this goal we composed and recorded three ambient soundscapes and suitable notification instruments. Instead of using MIDI instruments we decided to record the WAV files ourselves to maximize aesthetics and sound. Figure 1 shows a score snippet of a soundscape with cello, keyboard, violin and drums and the melody of two appropriate notification instruments (piano and artificial effects). We took some perceptional constraints such as the auditive Gestalt laws and several studies dealing with musical perception into consideration as described in: [18, 19, 20, 21, 22].

Additionally, we add *notification instruments* to the ambient basic soundscape when an event that is assigned to an instrument occurs. Events are handled by an EventHeap that was developed at Stanford University ([23, 24]).

The notification instrument is played with slightly increased volume at the current location of the person being notified by using an indoor localization system [25] and a spatial audio framework [26]. The *Always Best Positioned* (ABP) mobile localization system called *LORIOT* uses RFID technology in combination with infrared beacons to find out what the user's current position is. The calculation is done on a PDA by using Dynamic Bayesian Networks (DBN's) [27]. Finally, *SAFIR* (Spatial Audio Framework for Instrumented Rooms) [26] is used to play the audio cues at the loudspeaker which is the nearest to the target person's postition at this moment.

Since the notification instruments will be seamlessly integrated in the ambient soundscape this could have the disadvantageous effect that a peripheral notification might not be noticed immediately or could even be missed. We have to strike a balance between peripheral notification and the importance that some notifications have to be perceived immediately. To prevent the effect of ignoring a notification, we also provide a hierarchy of notification signals that are grouped by their *level of intrusiveness*, depending on the importance of the occurring event. Users have to select their personal notification cues, minimum one from each group, to guarantee a proper user-cue mapping in all three notification classes. Increasing the priority involves a decreasing of the privacy effect because of the different intrusiveness properties.

Low-priority signals are melodies played by natural *instruments* (e.g. piano, drums, guitar, violin etc.). Their main feature is seamless and fluent integration of melody patterns (themes) into the ambient soundscape with respect to the structure of the composition. The dimensions of provided information could be expanded by using different themes played by different instruments. Usually, an instrument can only be selected by one person. But sometimes it makes sense to inform a group of people, e.g. in a conference. For this purpose, a group notification can be activated, which allows the mapping of multiple persons to an audio cue.

Signals with medium-priority include *ambient noises* (e.g. birds, rain, water- and wind noises). They are independent of the current compositional context, but still ambient.

The *arousing noises* (e.g. beep, siren and bell etc.) are a group of intrusive and highly alerting signals. Because of their missing ambience, these signals should only be used for events with highest-priority.

By an occuring event that has to be notified, the service selects the notification with the lowest-priority (instument) which is the most ambient cue with the highest ambient effect. As mentioned above, this type of seamless notification could be missed by the user. Since the instrument appearance is linked to parts of the soundscape (e.g. chorus), the embedded notification will be repeated as often as the part reappears (see also Figure 3). We also provide the opportunity that the user preselect how often each cue is played before the next higher cue will be triggered. The ambient- and arousing noises are independent of the current compositional context, so they start immediatley after triggering. To prevent an overloading effect causes by different concurrently played cues, we integrated a smooth transition between different cues by using a selectable fade-in/out effect (linear, log, exp).

Figure 2 shows the structure of our implemented prototype system. Compositions are stored in a sound repository as multi channel audio files. They contain a track with the core part and one track for each optional part. In our test scenario the user chooses which songs are played and which optional part is used as her personal notification part. The sound files each create an audio object in the SAFIR framework, which mixes them together and plays the result over currently eight loudspeakers in our instrumented environment.

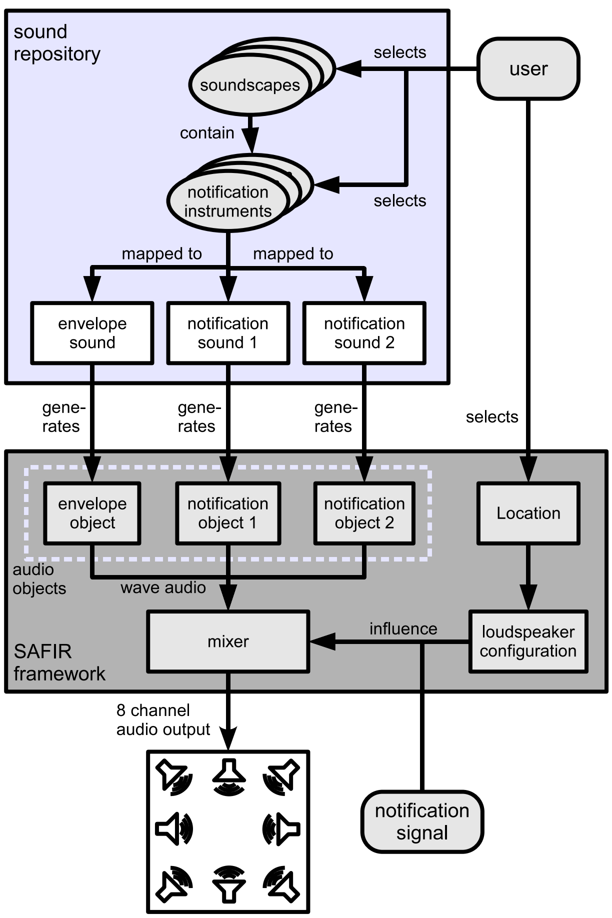


Figure 2: *Sound Repository and Spatial Audio Framework*.

When the system starts, the audio mix only contains the core background soundscape. If the external notification signal for a user is triggered, the user's particular notification sound is added to the mix at the next musically possible point in time. Pontential appearances (time code indices) of each instrumental pattern is stored in a database.

Depending on the user's location, a notification can also be given from a particular direction. Thereby, the user will not only notice the notification, but also where it came from. The environment can thereby make the notification appear as if it came from a particular object or device. Other users will remain undisturbed, since they have chosen different notification sounds and won't be able to distinguish the optional element from the core.

Since we have to keep in mind what the right time is for an instrument to enter a soundscape. But, we also have to pay attention what kind of melody the notification instrument plays at this time and whether it fits into the composition. Figure 3 sketches potential audio cues that are played by a notification instrument (guitar) depending on time. Each guitar pattern, recorded with acoustic- and electric guitars, is matched to an compositional element (intro, vers, chorus, interlude and outro) that turns out to be a potential notification slot.

In the near future, we will extend our music repository with non-vocal songs from the Real World Computing (RWC) music database which is a copyright-cleared music database developed by Masataka Goto at Japan's National Institute of Advanced Industrial Science and Technology (AIST). Further information about RWC can be found in: [28] and [29].

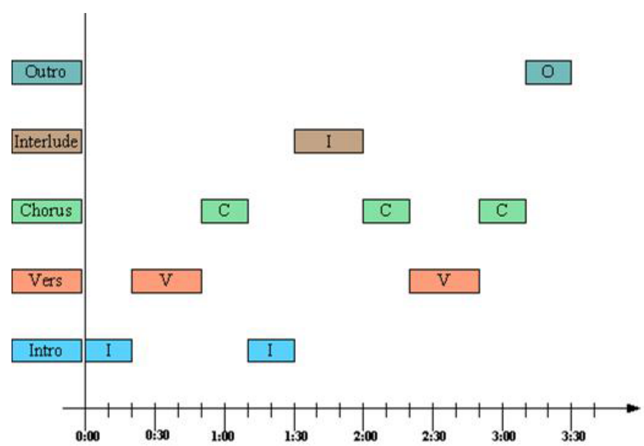


Figure 3: *Guitar notification patterns*.

Since we follow a human-centered approach, we want to increase the acceptance of our notification system by giving the users the possibility to change personal settings. The soundscape matching the personal preferred music style can be chosen by the user as well as an instrument or ambient noise that he can easily recognize. His personal preferences can be stored in his user profile of UbisWorld, a user model ontology [30]. The profile information can be accessed by the notification system via http request. By integrating the web-based user model ontology UbisWorld and the indoor positioning system LORIOT, notifications become nomadic and more flexible, which means it can adapt preferences for different locations and users.

## 4. EMPIRICAL STUDY

We conducted a user study to verify our approach of event notification with instrumental audio cues embedded in aesthetic background soundscapes. In our study, we focused on the effectiveness which means how often a notification is perceived and the reaction time which is the elapsed time starting with the appearance of the notification and ending with the confirmation of recognition through the user. We compared the performance data with the results of a control signal, a traditional auditory cue.

The study was divided into a computer-based test and a questionnaire to get the subjective and personal feedback of the participants' opinion about the soundscapes and this new concept of notification. In the first part, the participants were asked to solve a primary task, namely dissolving mathematical equations under time pressure. At the same time, a soundscape was played in the test environment and selected audio notification cues, instruments (piano and drums) and a traditional warning cue (knocking), were mixed into the background soundscape. The participants were asked to press the appropiate button in a GUI when they recognize a notification. The questionnaire was useful to get a personal feedback and the participants' opinion about the soundscapes and this new concept of notification.

### 4.1. Participants

Twenty persons (five women and fifteen men) with academical background (undergraduated- and PhD students) participated. All subjects reported normal hearing and no extraordinary musical abilities, like professional musician.

### 4.2. Procedure

The experiment has been carried out in an instrumented room equipped with a desktop PC, spatial audio hardware, a multichannel soundcard, two 5.1 surround amplifiers and eight speakers that are located on the ceiling. The sound positioning in the room has been done with a spatial audio framework [26].
The study consisted of three parts with a overall duration of 30 minutes.

Introduction and sound presentation (15 minutes).
In a preliminary talk, the participant was first introduced in the test procedure. The subject learned his two personal notification instruments with the corresponding basic soundscapes and the control signal by repeated listening to the audio sounds.

Computer-based test (10 minutes).
The test environment was implemented in Java Script and included a question window, a signal button area and a radio button area for possible answers. The challenge for the subject was to press the corresponding signal button after recognition of a notification signal as soon as possible. To prevent focusing the background soundscape, the subject has to answer some time limited questions to distract him from the auditive stimulus. As a result of the limitation of his cognitive resources the subject perceive the audio signals in a more peripheral way. We prepared two recorded and prearranged soundscapes in which the introduced notification instrument of the test person appeared randomly with respect to the context sensitive approach. In ambient soundscape *AS01:Sphere* the piano was appointed as the relevant notification instrument. In the second soundscape *AS02:Ballad* we chose the drums for the audio cues. In contrast to the melodic dominated piano, the drums

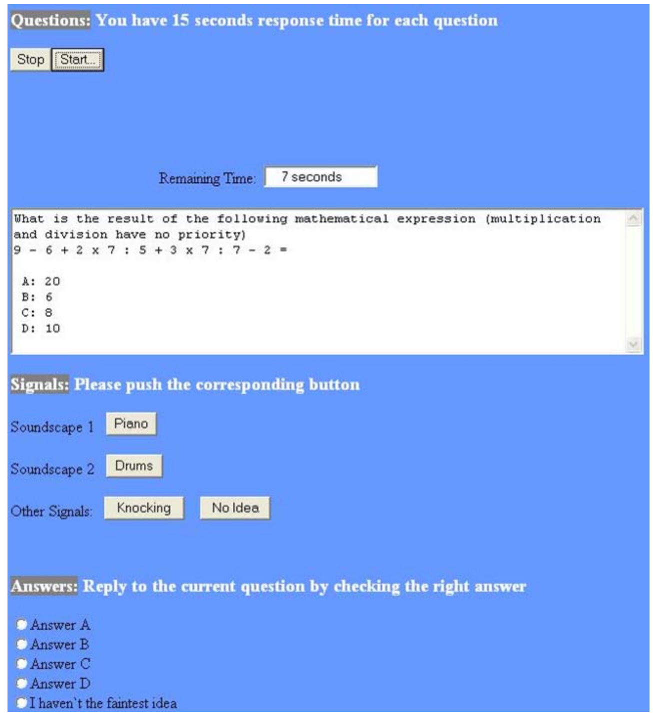


Figure 4: *Screenshot of computer-based test.*

in AS02 were more rhythmical oriented. As a representative traditional audio signal we mixed in both soundscapes a *knocking signal* randomly to compare the effectiveness of the instrument audio cues with a conventional signal. The two soundscapes were played in a row. The user‘s task was to push the corresponding signal button as soon as possible when he perceive an audio cue. The appearing of the audio cues, the pushed signal button and the reaction time were recorded and annotated with a timestamp.

Questionnaire (5 minutes).
The used questionnaire enfolded three pages with different styles of questions and was filled out by the subject after the computational test. In contrast to the computer-based test, the evaluation of a questionnaire is more subtle. The results are personal opinions and can be influenced by many psychological factors. Thus we used the questionnaire only for retrieving additional information.

### 4.3. Results

#### *4.3.1. Notification Efficiency*

Figure 5 shows the efficiency of the recognized and identified notification signals of all users. Looking at the calculated standard deviation shows that the deviation of the drum signal with a value of 0,162 is lower than the piano value (0.244) and clearly lower than the knocking deviation (0,286).

Especially the drums notification (86%) in AS02 overbid the knocking sound (79%) with a value of seven percent and reached the top rating in the efficiency test.

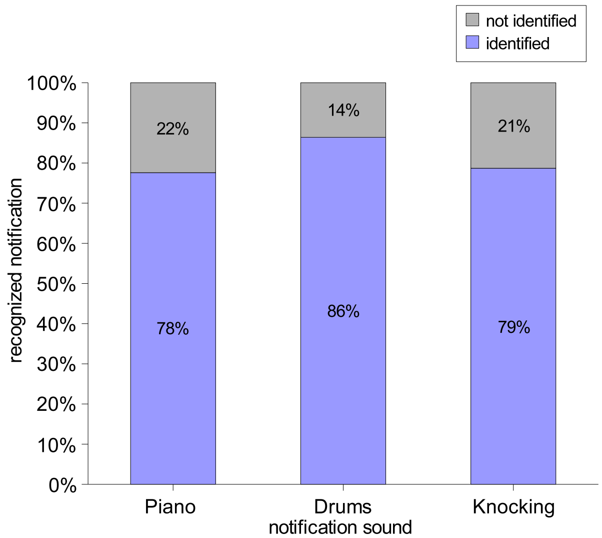


Figure 5: *Efficiency of notification*.

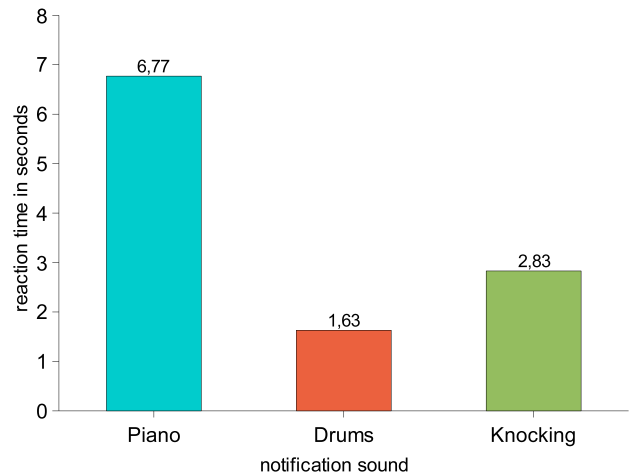


Figure 6: *Reaction time*.

### *4.3.2. Reaction Time*

The second interest laid on the delay between the notification appearance and the button press action. The subject had to perceive the audio signal, identify it and push the corresponding signal button on the screen.

We found out that the average reaction time of piano notifications is higher (6.77 seconds / SD=3.33) than the knocking sounds delay (2.83 seconds / SD=1.33). The second instrument, the drums, had an average reaction time of only 1.63 seconds (SD=0.75) and seems to be more effective than the traditional knocking sound (see Fig. 6). The performed paired T-test shows a significant difference ($p<.05$) between the knocking and the drums reaction time.

We assume that the more rhythmical nature of the drums and its different timbres (bass drum, snare, hi-hat, cymbals etc.) could be easier perceived as the more complex harmonical structure of the piano melody. We will conduct more studies towards this assumption in the near future.

## 5. APPLICATIONS AND SHOPPING SCENARIO

The implemented JAVA applications *PAAN* (Personal Ambient Audio Notification) and AeMN (Ambient E-Mail Notification) handle an audio server, the data exchange to the user model service *UbisWorld*, the indoor positioning system (*LORIOT*) and the spatial audio system (*SAFIR*).

UbisWorld includes a user model ontology (Gumo) [30] which is defined in the semantic web language OWL and provides an ubiquitous user modeling service for updating and retrieving user preferences via http requests. For a scenario where the user changes his position, we use the Always Best Positioned system LORIOT that uses PDA equipped with wireless LAN and an RFID reader card, active RFID tags that are mounted at the ceiling of the room and optionally infrared beacons mounted at shelves or walls.

In the following, we draw a possible shopping scenario in a wine department where we use the introduced concept of ambient audio notification including the Personal Ambient Audio Notification service PAAN and the Ambient E-Mail Notification service AEMN.

Employees of the store can change their personal audio notification instrument by updating their UbisWorld account. The IP adress of the user's PDA can also be specified and exported in an XML file which can be accessed by PAAN via http request to route an event notification to the appropriate task person.

Figure 7 shows an audio sequence of a possible shopping scenario with two selected Notification Instruments (NI 1, NI 2) assigned to two employees, an Ambient Noise (AmN) for group notification and an Arousing Noise (ArN) for high-priority notification. The notification service reacts to relevant events ($E_i$) by mixing the adequate notification at the right time in the playing soundscape.

The Ambient Soundscape (AS) starts automatically when a registered user, namely an employee, enters the instrumented area of the shop with his PDA ($E_0(t_1)$). The preselected notification signals that are assigned to authorized users are in stand-by mode (muted).

Assume a consumer who enters the wine departement of the supermarket with the intention of purchasing a French red wine while at the same time the employees are out of sight and don't notice the appearance of the potential consumer. The arrival of the customer ($E_1(t_2)$) can be detected for example by the instrumented shopping cart [31] or a location-aware PDA [25]. The notification system finds out the salesman's current position by checking the positioning coordinates of his PDA, matches them to the nearest loudspeaker and informs him about the presence of a person by starting to play his personal notification instrument (NI 1) with slightly increased volume at his position. The salesman notices that his instrument (e.g. piano) starts playing in the soundscape and that this is the appointed signal for a potential consumer in the wine department. Back in the wine area, it turns out that he can't satisfy the consumer's wish because he is looking for a specific red wine and needs the advice of a wine specialist focused on French red wines.

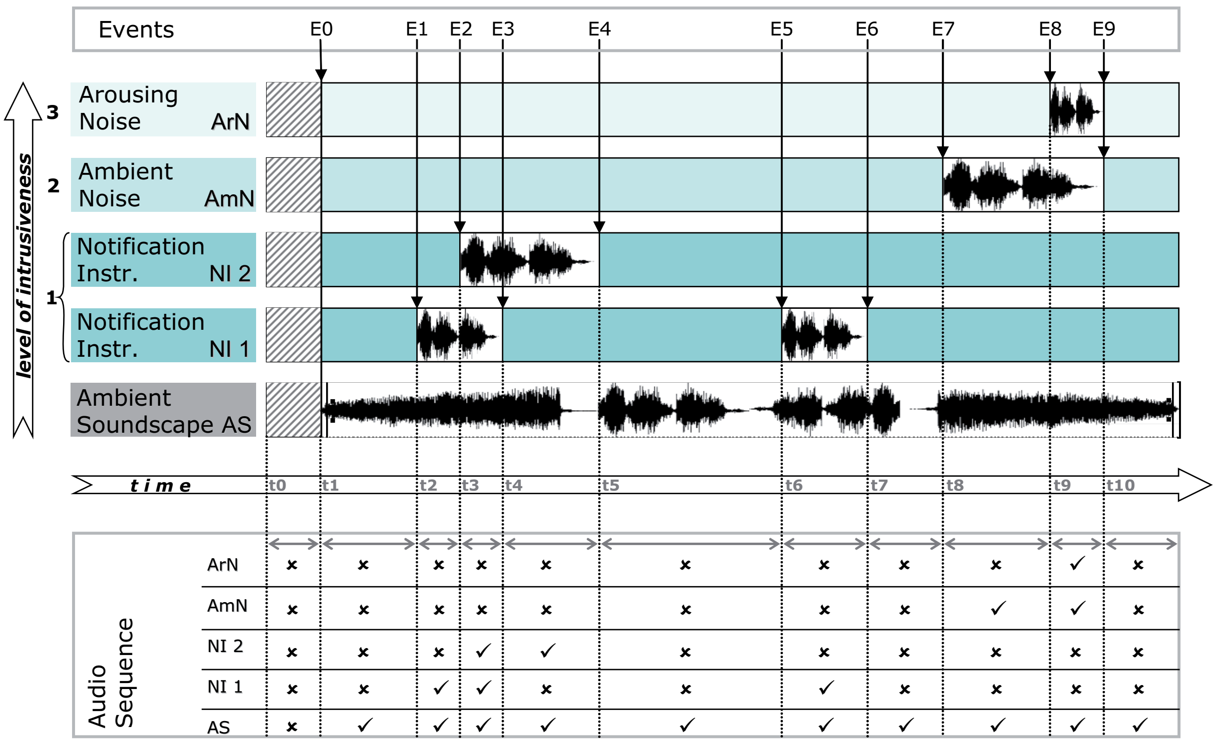


Figure 7: *Audio Sequence Example.*

Thereupon, the salesman calls the specialist by starting NI 2 (e.g. drums), which is the signal for the French wine specialist to come to the wine departement ($E_2(t_3)$). After whose arrival, the salesman and the specialist stop their notification instruments by pressing a GUI button on their PDAs ($E_3(t_4)$, $E_4(t_5)$). The instruments leave the music seamlessly and only the basic soundscape is still playing. Event $E_5(t_6)$ describes a similar scenario where the salesman receives a call to come to the department where he stops the notification after his work is done.

Event $E_7(t_8)$ is an example for group notification and could occur if the head of the wine department wants to call his colleagues for a meeting by sending an email to the department's mail account. The Ambient E-Mail Notification system (*AEMN*) periodically checks the mail server for incoming messages and filters them for predefined keywords. The important announcement email triggers an event with the corresponding group notification signal in the form of an ambient water noise (AmN) which immediately starts playing in the whole departement.

Unfortunately, not every staff member noticed the ambient notification after a while, so AEMN sets the level of intrusiveness to the highest level and starts playing an additional Arousing Noise (ArN), e.g. a beep sound ($E_8(t_9)$). After the arrival of the remaining employees, the two notification sounds were stopped on the PDA or on the departement's desktop PC at time $t_{10}$.

## 6. SOUNDSAMPLES

A few soundsamples of *Ambient Soundscape AS01:Sphere* with two of its notification instruments [click to activate sound].

- Background soundscape:
  *AS01Soundscape.mp3*
- Notification instrument patterns:
  *AS01Piano1.mp3*
  *AS01Piano2.mp3*
  *AS01HiHat.mp3*
- Soundscape including piano and hihat:
  *AS01SoundscapeP+H.mp3*

## 7. CONCLUSIONS

In this paper, we presented the concept of non-speech audio notification with natural instruments embedded in ambient soundscapes. We introduced musical compositions as an auditory display for increasing the mood of users and as a notification system with respect to some constraints arised from cognitive psychology and musicology that have an influence on human perception. Our non-intrusive approach provides users with information depending on their current location and under low-privacy aspects which could be useful in different ubiquitous scenarios where an ambient notification system makes sense. By providing auditory cues that are encoded in an ambient soundscape, we get the opportunity to send primitive information in a more peripheral and aesthetic way. In the near future, we will conduct a more detailed user study in a real life shopping scenario as described in Chapter 5.

## 8. ACKNOWLEDGMENTS

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