BEAN: A DIGITAL MUSICAL INSTRUMENT FOR USE IN MUSIC THERAPY

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ABSTRACT

The use of interactive technology in music therapy is rapidly growing. The flexibility afforded by the use of these technologies in music therapy is substantial. We present steps in development of Bean, a Digital Musical Instrument wrapped around a commercial game console controller and designed for use in a music therapy setting. Bean is controlled by gestures, and has both physical and virtual segments. The physical user interaction is minimalistic, consisting of the spatial movement of the instrument, along with two push buttons. Also, some visual aspects have been integrated in Bean. Sound synthesis currently consists of amplitude and frequency modulation and effects, with a clear separation of melody and harmony. Bean is being co-developed with clients and therapists, in order to assess the current state of development, and provide clues for optimal improvement going forward.

1. INTRODUCTION

A basic working definition of music therapy is the use of music as a tool, in a therapeutic setting. Tailored to the individual needs of the client, this tool can be used to achieve therapeutic goals such as enabling communication or improving motor skills [1]. The flexible nature of a Digital Musical Instrument's (DMI) sonic output and control possibilities could be a powerful tool to add to the arsenal of a music therapist. Indeed it has been shown that the use of electronic musical technologies has an impact on outcomes relating to communication and expression [2], while also enabling a sense of achievement and empowerment [3]. As mentioned, communication is a common goal in this form of therapy. Facilitating performance and ancillary gestures through tangible interaction, could therefore lead to expressive communication when combined with music [4].

For some clients the "up to date technology" itself can be a positive and engaging factor in music therapy, in addition to the possibility for new and interesting sounds or "new sound worlds" [5]. The use of novel technologies in music therapy can however pose some practical, as well as design problems. For instance, can clients easily understand the musical contribution is of their making? Is the control of these contributions intuitive and understandable? Is the experience of using these technologies engaging, with enough variance to hold interest? These issues are not directly related to music therapy, but are in fact universal factors associated with DMI design, for example the "ubiquitous mapping problem" [6]. While the term music therapy is too general, and may cover physical, cognitive, learning, and rehabilitation goals, as well as different target groups, effective utilization of these factors could possibly be tried out in participatory design settings. Participation in design is of greater importance when the user has complex needs.

In this paper, we present the iterative development of Bean, a novel *visual, aural, and tangible* DMI. Bean was created to investigate problems like the above-mentioned, and to help provide some answers. After outlining the background research relevant to the design, the design and construction process of Bean is elaborated on. Next an initial participatory design session is described, followed by a discussion. We conclude with the future plans for the development of Bean.

2. BACKGROUND & RELATED WORK

The use of technology in music therapy has the potential for many positive applications, but the therapist must have the required knowledge to effectively use these technologies in a therapeutic setting [7]. Previous research has investigated technology use in music therapy [7][8]. While these studies cannot be directly used as design requirements for new musical instruments, they provide some starting points. For example, they make clear that distance sensing is the most frequently used sensing mode.

Tangible interface use is not as widespread in music therapy; a percentage of clients would have physical disabilities that could hinder such interaction. Despite a lack of total inclusivity, there is still a need for the option of tangible interaction for those clients with this ability, to ideally enable an embodied musical experience. Tangible DMIs could reveal the conceptual metaphors of the clients, address their tactile/kinesthetic hyposensitivity, and act as diagnostic and performance tools to gauge their capabilities.

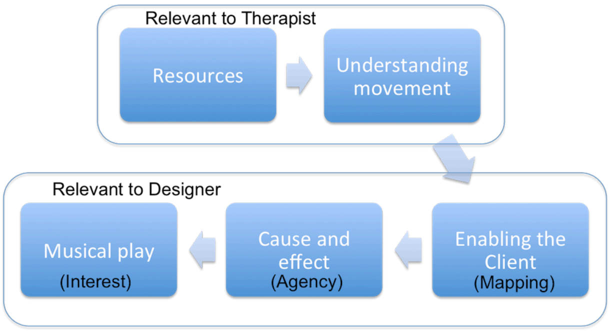

Figure 1. Framework for technology use in music therapy, adapted from [2]**.**

A framework has been previously suggested through an investigation of music therapists' experience with technology use [2] (see Figure 1). The data gathered here can in part, be used to effectively design technologies that suit this setting. The first two points are aimed more at informing the therapist, and have little relevance to the design of instruments. The three last points can be intrinsically linked to the functionality and design of DMIs such as Bean. These elements in the context of DMI design would however be more intuitive in the following order: Cause/effect and a sense of agency is a primary element. After this, comes enabling the client through effective mapping, which should lead to musical play that holds the interest of the user.

2.1 Cause and effect: agency

Cause and effect are interlinked with agency. Paine & Drummond [9] categorize agency into two approaches in relation to DMI design: 1) the control of predetermined sequences of sounds such as triggering sounds in sample based software, and 2) the *creation* of sound through real-time manipulation of software synthesis variables. Furthermore, when the *creation* paradigm is designed for, it is suggested immediate agency should be facilitated accounting for primary causality in the use of the DMI. Immediate agency and corresponding feedback could be seen as modeling the cause and effect cycle.

2.2 Enabling the client: mapping

Magee & Burlan [2] take a practical view to enabling the client, with mention of switch or sensor placement in relation to the client's difficulties that is very similar to the aforementioned understanding movement element of the process. The focus is mostly on physical impairments. Mapping is nonetheless also rudimentarily mentioned.

The importance of mapping has been investigated [10]. It largely defines the user interaction and experience [6]. An effective mapping strategy would enable the client to effectively interact with the musical content. A client with complex needs might benefit also from a *transparent mapping* strategy, which could be complemented by cross-modal feedback such as visual cues similar to those discussed in [11, p52]. The use of transparency in this context can be defined as an easily understandable connection from action to audible change.

2.3 Musical Play: sustained interest

Playing music is inherent in music therapy, but the quality aesthetically, is secondary to the effectiveness of the use of music as a tool to achieve a goal. Sound design and the aural feedback framework are, along with mapping, central to this topic. The effectiveness of the sound design and amount of control over these sounds can have an influence on the amount of time a client is willing to spend playing the instrument. Effective integration between these aspects could lead to sustained play. It is not necessarily the quality of musical content, but rather the sustained interest in the content, which in turn provides a tool to possibly facilitate communication and expression in a therapeutic setting.

2.4 Related Commercial Applications

According to a survey investigating current technology use in music therapy, including over 600 therapists [8], Soundbeam[1] is the most popular system of interactive technology in use in music therapy, followed by MIDIcreator.[2] Both of these systems are directed more towards physical impairments, and the first one lacks an option for tangible, embodied interaction. As regards tangible interfaces for musical novices, notable commercial examples include the Skoog[3], which was produced with an aim towards inclusion of those with special needs, and the open-source, Teensy-based Kyub[4].

3. BEAN

Bean is a gesturally controlled digital musical instrument. It is ellipsoidal in shape, which innately fits well between two hands. The user interaction is minimalistic, consisting of the rotational movement of the instrument, along with two push buttons. The instrument is played by a combination of these two modes of interaction. Some combinations happen naturally through gestures. This could be described as an extra mapping layer [10]. The block diagram and various stages of the Bean's design are illustrated on Fig 2 top and bottom, respectively.

3.1 Musical Interaction Design

The simplicity of Bean is an intentional design feature, to provide a safe and durable entry point for two-handed interaction and transfer back and forth to other clients or therapists. Although primarily a musical instrument, there are also some visual aspects integrated in Bean. All aspects can be easily extended, augmented, or redesigned within or after participatory sessions.

[1] http://soundbeam.co.uk
[2] http://www.midicreator-resources.co.uk/
[3] http://www.skoogmusic.com
[4] http://kyubmusic.com/

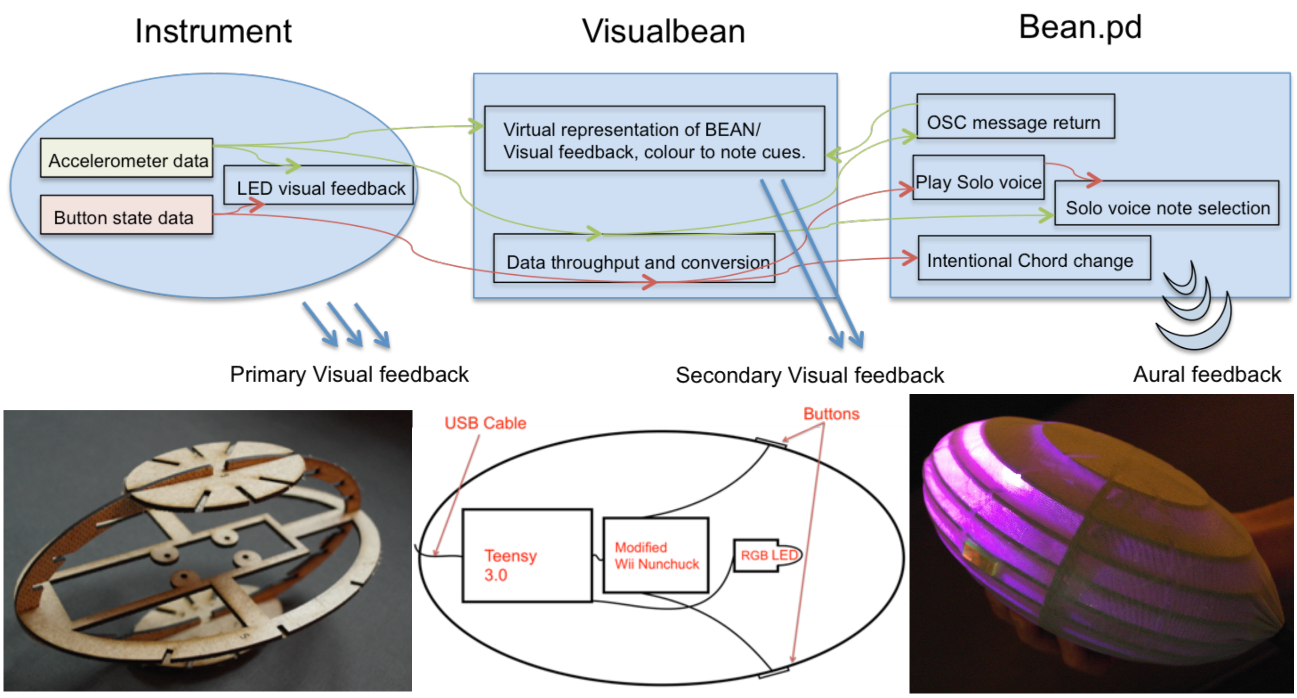

Figure 2. (Top) A data flow diagram showing the sensor data and control paths. (Bottom) Various stages of design.

3.1.1 Sonic feedback

The concept behind the current implementation of aural feedback is that of harmonic backing chords, which shift autonomously. This harmony provides a musical setting, a starting point. Over this the client has the opportunity to improvise using a solo voice, which is governed by certain rules to enable the client to easily find notes that fit with these chords

The harmonic content of the chords is noncomplex in nature. The four chords are Cmaj9, Dmin9, Emin7 and Fmaj9: all the elements of the C major pentatonic scale fit with these chords. For this reason, the notes of the C pentatonic scale in two octaves are used for the solo voice element of the aural feedback. There is also another group of tones made available to the user when the instrument is shaken briefly. These notes constitute an A blues scale. This new state lasts for 30 seconds, providing and option for tonal variance and possible dissonance in the solo, before the pentatonic tone mode is re-engaged.

Aural feedback was implemented using Pure Data. Bean.pd is the main hub where the sensor data is received and formatted. Open Sound Protocol (OSC) is used to transmit the sensor data into this patch. Formatting, in this context, can be understood in this way; the accelerometer data and the current state of both buttons are transformed into data usable by the synthesizers and control elements, e.g. accelerometer roll data is received as numbers between 70-170 then scaled to a number between 0-1. There are also OSC control messages broadcast from Bean.pd. These messages are composed using the sub-patch OSCreturn.pd, and have the purpose of controlling certain aspects of the visual feedback.

The method of sound creation is a combination of additive synthesis and frequency modulation synthesis. The additive synthesis comprises of a fundamental and three partials. These partials are individually adjusted in amplitude to provide an element of timbre change. Frequency modulation is used to add complexity to the aural content of the users' solo. An ADSR envelope and a phaser complements the solo instrument.

Another sub-patch creates the accompanying harmonies with a bank of five additive synthesizers, one for each note in the harmony. Each of these synthesizers in turn composes a tone, constructed of a fundamental and three partials. The four chords change randomly over time with equally weighted probability for each. In the current implementation there is also an additional option for the user to intentionally change the accompanying chord.

3.1.2 Mapping

The mapping strategy for Bean is generally one-to-one mapping. The selection of note in the solo voice is the most discernable change aurally. This change is mapped to the pitch angle of the instrument (Fig. 3). When the instrument is swiveled downwards on the X-axis, the pitches fall, and conversely when the instrument is swiveled upwards on this axis, the pitches rise. Measurable movement range is divided into ten to facilitate the available notes.

Change in roll is mapped to the aforementioned tonal variation. Rotational movement on the Y-axis to the left effectively gives a more bass rich sound. This movement is mapped to a reduction in amplitude of the upper partials of the additive synthesis component in the solo voice. The opposite gesture, rotation to the right, produces the effect of a strong higher frequency element to the sound. This is achieved by increasing the amplitude of the three upper partials. This increase is staggered from low to high in order to give a smooth timbral alteration. It is envisaged that these movements, swivel up/down and rotate left/right, will become elements of dynamic gestures by the user. The *jolt* gesture in the Z-axis is currently functioning as a trigger, which when activated, switches the scale from C pentatonic to the A blues scale. This change of scale automatically resets after 30 seconds if not re-triggered.

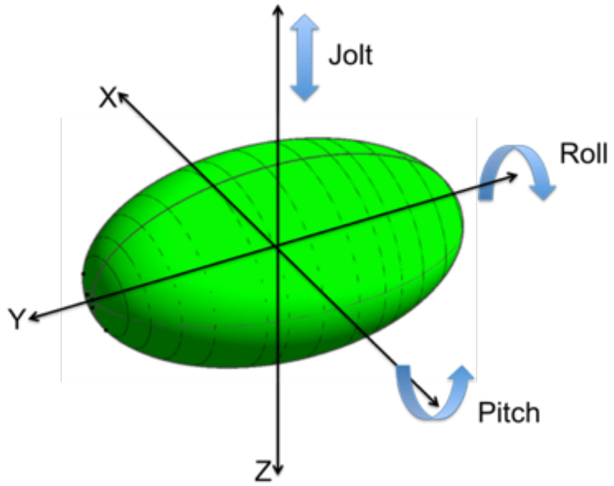

Figure 3. The accelerometer data used in mapping.

The two buttons also have the possibility to have a major effect on the aural feedback. The button situated on the right of the instrument, is assigned as a *play* button. When this button is pressed, the attack, decay and sustain part of the envelope is engaged and the solo voice plays. When the button is released the release part of the envelope engages to taper off the amplitude. This is an intrinsic element in every instrument, the initiation of sound. Rather than a higher level continuous *control* model where the user would interact with a pre existing sound framework, Bean is designed with the *creative* model, as discussed in [9].

3.2 Physical Design and Implementation

Bean's ellipsoidal has been modeled in 3D, segmented and laser cut from a press-fit format. The internal hardware was securely attached of. Several iterations where cut, during a fine-tuning process for both fit and size. The material used to manufacture the press-fit skeleton was 3mm hardboard. Corel Draw and the laser cutter were also used to cut the button tops from 3mm acrylic sheet material. These additions were needed to increase the surface of the pressable area on each of the buttons. Finally, the outer surface covering consists of layers of PVC foil, covered by a double layer of nylon from a pair of stockings. This covering has a dual purpose. The first restricts access to the internal hardware by enclosing the skeletal frame. The second is partly cosmetic, to diffuse the internal light source and make Bean pleasing to the eye.

3.2.1 Hardware

Embedded computing is at the heart of Bean (Fig. 2). Teensy 3.0[5], a compact Arduino[6] compatible USB microcontroller, is the "brain" of the physical segment of the instrument i.e. the ellipsoid. The Teensy board powers up and initiates communication with the Wii Nunchuck[7] board. It then receives all the sensor data, turns the relevant data into direct visual feedback, and also transmits all the data further over serial communication to the computer. For ease of connection the Teensy was mounted on a custom made circuit board, which allowed for effective connection and disconnection with both the Nunchuck board and the LED.

The sensor unit is in fact a modified Wii Nunchuck, to enable the original buttons to be extended away from the body of the Nunchuck, and to be placed on the outer shell of the instrument. The main sensor is an on-board accelerometer from the Nunchuck. This sensor enables movement tracking in both the pitch (X-axis) and roll (Y-axis), and *jolt* detection vertically (Z-axis). The two buttons allow extra access to control parameters.

3.2.2 Sensor input

The first step was to program the Teensy microcontroller. An Arduino sketch was created that enables the Teensy to initialize the Wii Nunchuck, by using the I2C[8] communication protocol, and begin receiving the sensor data. The LED is also initialized with this sketch, and is communicated with, by the use of the SPI- communication protocol. The sketch also directly maps certain sensor data to different colours produced by the LED. The final step is the formatting and transmission of the sensor data over the serial bus to the laptop.

3.2.3 Visual feedback

The LED installed inside the physical element of the instrument provides primary visual feedback. This feedback is mirrored in a secondary visual feedback, which is a 3D virtual representation of Bean. Colour to musical note mapping was implemented to provide a form of visual cueing. To facilitate this virtual representation, the application *VisualBean* was created on Processing[10], but will be not discussed here. However, the colour to tone mapping will be discussed only on the physical part of the instrument here. The equal temperament frequencies of the selected notes were transposed and superimposed from the audible range to the visual frequency range; chromesthesia [13] could have been an alternative way.

4. PARTICIPATORY DESIGN AND EVALUATION

Participatory design and evaluation has been done in two sessions over two days.

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[5] https://www.pjrc.com/teensy/index.html

[6] http://arduino.cc/

[7] The Wii Nunchuck is a controller for the Wii game console.

[8] http://www.i2c-bus.org/

[10] http://www.processing.org

4.1 Session 1: Clients

Two service users (Participant A and B) of an adult training center, along with a member of staff, agreed to participate in an informal evaluation and participatory design session. Both clients are male, were in their early twenties and have mild/borderline intellectual disabilities. They both had no formal music training, but both have had music therapy sessions in the past. The setting was informal, not therapeutic in nature. Nevertheless, this was a valuable opportunity to initially assess the instrument with a prospective target group, with a view to gathering information for further development.

The session took between 30-35 minutes. Both participants were in the room simultaneously. The format of the meeting took the following form: The first 20 minutes were spent with the two participants taking turns in free play with the instrument, without any instruction. After this, there was a short discussion about the device, to gauge the participants' impressions, and level of understanding. The session then continued, with the participants and the staff member engaged in more free play turn taking. The prototype used in the session was an earlier, less developed iteration. There was no outer covering on the prototype and there was also no internal LED.

4.1.1 Free play

Participant A was initially hesitant in using Bean. His interaction was exploratory, starting with just moving the instrument in space, registering that the representation on screen was mirroring the physical movements. Shortly after, the buttons were pressed, with resulting surprise when the solo voice engaged.

Participant B was more direct in use, engaging the play button immediately. This was to be expected, as he could see the first participant's use of the device. His gestures were slow and deliberate at the start, but quickly changed to moving the device more aggressively.

4.1.2 User impressions

An open discussion followed the free play. Semi-structured questions included: What are your first impressions? Did you understand the control functionality? Was it interesting to use? How would you change/improve it? First impressions of Bean were that it was different, but fun. Whether this fun factor was because the technology is new, or the fact that making music was facilitated in a new way, was unclear. They were both nevertheless eager to try the interface again.

Both participants understood that movement affected the sound, and that the *play* button had to be pressed to solo. The *change chord* button however was a mystery. Participant B triggered the *jolt* that controlled A blues scale; the participants did not realize the change in scale.

Both participants found Bean interesting to use. When they were asked in connection to interest, if they could see themselves using the instrument for a sustained time, they both answered yes. As with the first question it is unclear if the opportunity to play music, or the opportunity to play with new technology was the deciding factor. As for the improvement, both participants agreed that a cover for the surface of the device would be a good idea. Participant A also felt that the device could be used for other purposes, relating to computer control. The member of staff was also of the opinion that the device was very flexible and could be used for other purposes.

4.1.3 Free play continued

After the discussion, the participants got more play time. During both of these free play sessions contrasting styles of use could be observed. Participant A continued with a more methodical style, actively searching certain notes and evaluating the sound changes. In contrast participant B was more interested in moving the device as fast as possible, not as selective with which notes he played, but rather getting fast runs up and down the scales. The movement of the virtual representation was possibly of more interest than the sound of the instrument for this participant. The member of staff helping in the evaluation also played the instrument at this time. He put forward the opinion that the device could be very beneficial in a group music therapy setting.

4.2 Session 2: Therapists

There was also an opportunity to talk to a practicing music therapist and an art therapist. The music therapist is an experienced musician and uses an improvisational approach to music therapy. He has some experience with the use of Soundbeam, but aside from that limited experience of technology use in therapy. The art therapist also had limited experience with tangible technologies in therapy.

Both of the therapists played the Bean. The music therapist was the first to use the interface, and immediately wanted more methods of control. On the top of Bean where his thumbs naturally rested in use, could be an optional placement for more buttons, he suggested. Also he felt that the aural feedback lacked a rhythmic element or a "beat". After considering the device's current state, he felt that the prototype could be easily destroyed by some of his users. If they for instance became frustrated the gaps in the outer structure were finger sized, providing a grip to pull the device apart.

The art therapist was positive about the applications a device like Bean could have in an art therapeutic setting, if the visual feedback was more flexible, to perhaps enable drawing. In effect translating the visual cue based feedback currently implemented, into a more visually creative virtual canvas.

5. DISCUSSION

Valuable information was gathered in the sessions. Observations of the two participants' free play sessions suggested two potential paths of development: *refine the musical control* and *promote the kinetic aspects* of the instrument.

The implementation of extra control options, also mentioned by the music therapist, would have both positive and negative consequences: The balance of control options and usability must be carefully maintained. Users with complex needs could possibly have trouble conceptually managing more control options. With the minimalistic style of Bean comes the risk of a lack of control content to maintain interest. This was not evident in Session 1 (Sec. 4.1). Both participants seemed to be engaged while using the device. A larger scale, formal evaluation would be needed to give more conclusive results to this problem, the initial results are nonetheless promising.

During the sessions, the fact that Bean was a new device using up to date technologies, was clearly a positive influence. The participants were interested, and one could even say motivated by that fact alone, before interaction even took place. This adds weight to a claim that more technology use in music therapy could have positive effects, at least relating to a young male demographic, similar to our participants, and possibly not exclusively to this demographic.

The rhythmic element suggestion mentioned by the therapist is an interesting one. In some forms of contemporary music the "Beat" could be seen as being of more importance than harmonic content. This suggestion is certainly food for thought going forward, and outlines a possible deficiency in the current musical content of Bean. Visual interactivity changes as proposed by the art therapist, were interesting and undoubtedly an avenue of development for a broader base of therapy options.

6. CONCLUSIONS AND FUTURE WORK

This paper has outlined the design and development of a digital musical instrument, Bean, which is primarily being designed for use as a novel tool in the arsenal of the music therapist. Research pertaining to the fields of music therapy practice, DMI/NIME design and human computer interaction has guided the process. An initial informal evaluation of a functioning prototype by a possible target group and professionals in the field has proved to be informative for the further development of Bean.

Much work is still needed on some aspects of the system, but there is a firm foundation to work further from here. The developments carried out since this evaluation have improved the device structurally, and the hope is that the instrument now has better playability after visual cueing has been introduced. Some aspects of the mapping strategy will also be reviewed, such as the *change chord* option. This could possibly be changed to an option, which would allow extended range, similar to some small MIDI keyboard controllers offer.

To provide more flexibility in sound choice, and a familiar protocol the music therapists, MIDI messaging could be implemented. The proliferation of MIDI device use in music therapy would suggest that it would be preferable to have some MIDI functionality integrated in the system. The Bean.pd patch could be developed further to facilitate flexibility with regards MIDI communication.

There are plans to replicate the Bean system, in order to enable musically collaborative therapeutic group work. A larger scale, formal evaluation would however be a next step, to possibly get empirical data, informing on how Bean would perform in a therapeutic setting, We could, for instance, implement two different mappings (the current one plus a more percussive-like mapping - using the accelerometer to trigger notes with varying velocities similar to the Kyub), and use both empirical data and user experience feedback to compare and contrast the different modes/playing styles.

7. ACKNOWLEDGMENTS

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