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Automatic emotional expression of a face robot by using a reactive behavior decision model †

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Abstract

This paper introduces a face robot named ‘Buddy’ which can perform facial expressions, such as eye-tracking and lip synchronization, via movements of its facial elements (i.e., eyeballs, eyebrows, eyelids, and lips). Buddy has 14 degrees of freedom. To produce the realistic motion of Buddy, we built a ‘Reactive Behavior Decision Model’ which decides not only how to control the rotation angles and speed of facial elements, but to exhibit as well particular emotions that could express the robot’s personality. Buddy’s personality is formed in the model by the accumulated external stimuli and internal status. The process to automatically achieve reactive behavior in the model is classified into three steps: (1) to analyze the external stimuli and identify variations in Buddy’s internal status; (2) to decide the type and degree of emotion based on the robot’s personality; and (3) to generate specific facial expressions and gestures by combining the appropriate primitive behaviors chosen from emotion databases. By using this model, we have proven that Buddy can display various facial expressions and behaviors, at times very reasonable but quite unexpected.

Keywords: Face robot; Emotional expression; Human-robot interaction (HRI); Intelligent robot

1. Introduction

In the near future, when robots will work around (or live with) human beings at home, the need for robots that can express their feelings and provide emotional support for us will rapidly increase. The best way to express emotion is undoubtedly through verbal language, a capacity too complex to be programmed for robots. The second best option may be through facial expressions or gestures. The human face plays a vital role in the exchange of emotions. Irrespective of nationality and ethnic background, people use facial expressions not only to aid their communication, but also to tacitly express their feelings and thoughts.

To date, many studies on the facial expression of robots have been reported. Robots commonly express at least six basic emotions (i.e., pleasure, sadness, anger, surprise, fear, and disgust) by moving some action units of robot face with or without a human-like skin [1-3]. Most of the studies, however, mainly focus on the accurate recognition and judgment of human’s emotional status and the change of circumstances rather than the expression itself. Since the purpose of a robot’s facial expression is to establish people’s affinity for robots, expression is very important so that people do not get tired of the latter. For this purpose, a robot’s facial expression should be continuously vary, and not stop even for a few seconds, for one type of emotion.

In this paper, we introduce a mascot-type face robot named ‘Buddy’ which consists of two eye parts with seven degrees of freedom (DOFs) (i.e., eyebrows 1×2, Eyelids 1×2, Eyeballs 1×2+1), wherein pitch motion of eyeballs is coupled, the lip part has five DOF, and the neck part with two DOFs, as shown in Fig. 1. Buddy does not only express various facial expressions, but also looks at a person and makes eye contact with him (or her). To make Buddy emanate a feeling of intimacy, as if a living being, we developed an algorithm in which reactive expressions are generated from external inputs, including interaction data with users, which are based on the robot’s personality. The personality of robot is also formed based on the accumulated data on user interaction. The algorithm is named as ‘Reactive Behavior Decision Model’. Using the algorithm, Buddy can deliver various dynamic expressions continuously, even for the same emotion or an external input. In this paper, the effectiveness of the algorithm has been experimentally verified.

2. System layout of buddy

As shown in Fig. 1, Buddy is a mascot-type face robot.

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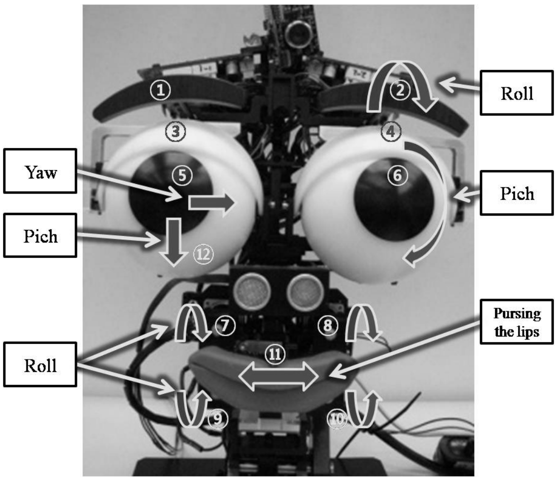


Fig. 1. Degrees of freedom in buddy.

Since it has no exterior skin, its components on the sensors, motors, links, and motor driver circuits, which are fixed on the main frame, form the appearance of the robot. Buddy weighs about 2.0 kg and its dimension is 195×320×200 mm^3.

The structure of Buddy consists of three parts: eye, mouth, and neck. In the eye part, there are the eyeballs, eyebrows, and eyelids, which are exaggeratedly designed so as to draw human attention and to make its expression more effective. It has been noted that the eyes are most important part in generating realistic feelings, such as with
living beings.

The mouth part is also important in expressing emotion, playing a critical role in lip synchronization. In order to achieve spontaneous and dynamic expressions, four motors for rotation at both ends of the upper and lower lips, and a motor to pull the ends of the lips to the center, were employed. This pursing motion can make the mouth take on more natural shapes for the phonemes '[o]' or '[u]', and assist other motors in delivering the shapes for '[a]' or '[e]'.

For the eye and mouth parts, hybrid stepping motors were used to reduce noise and control effort. The stepping motors are driven by the custom-built driver circuit (TMS320LF2406 PZACA core), and each circuit board can control two motors. The degrees of freedom and moving ranges of each driving part are listed in Table 1.

The human neck is comprised of seven disk-shaped bones and has considerable DOFs. With Buddy, due to restricted space, we designed a 2-DOF neck structure to allow panning and tilting motions. Although the rolling motion of the neck is also essential for expressing emotions, such as doubt, pleasure, and many others, considering its relative importance, we chose the panning and tilting motions instead. These two motions are crucial for face robots because they are indispensible for expressing emotions and tracking user's face. In order to acquire sufficient torque to sustain the inertia of the whole face, the neck uses two RC-servo motors.

For operation, a laptop PC with a CPU of Intel Pentium 4M 1.80GHz and a RAM of 787MHz 1GB was used. All control

Table 1. DOFs and moving range of each part.

Driving Part		DOF	Direction	Moving Range
Eye	Eyebrows	1x2	Roll	±30°
	Eyelids	1x2	Pitch	±30°
	Eyeballs	1	Coupled Pitch	±30°
		1x2	Yaw	±15°
Mouth		4	Roll	±30°
		1	Pursing	20mm
Neck		1	Yaw (Pan)	±30°
		1	Pitch (Tilt)	±30°

commands were generated via a user interface program (UIP) on the PC and transferred to the robot by serial communication.

The varying status of the robot is also monitored on the UIP, including the Reactive Behavior Decision Model, which enables the robot to perform long-term spontaneous interactions by automatically creating its own emotions, motives, and personality. Between the robot and the control PC, an interface circuit is employed to supply power to the robot and deliver sensor data packets.

3. Reactive behavior decision model

Reactive behavior decision model consists of three parts: stimuli definition and appraisal, emotion decision, and facial expression generation. Stimuli definitions and appraisal procedure extracts recognizable stimuli based on physical changes in the external environment. Then, these stimuli are used to generate emotions based on the personality of the robot. Finally, after the emotional states are decided, facial expression procedure generates behaviors of robot by building probable and dynamic mixed motion. This includes not only basic facial expressions, but also lip synchronization and neck gesture.

3.1 Stimuli definition & appraisal

Buddy can recognize external stimuli via built-in sensors, including a web cam, an ultrasonic sensor, a microphone, and an illumination sensor. The specifications of the sensors are listed in Table 2.

The web cam is used to recognize a human face and for eye tracking. It can recognize several faces at the same time. The ultrasonic sensor measures distance to an object in real time. This signal helps the robot detect objects in front of him, and additionally, to judge whether the object is approaching or moving away, including the speed of its movement even if the direction cannot be sensed. The microphone and the illumination sensor measure environmental sound level and brightness, respectively. This includes not only the intensity of the level of sound or brightness, but also the frequency of the stimulus outcomes, which can then be used as useful information to make a reasonable reactive behavior.

Table 2. Specification of sensors.

Sensor	Type	Range	Sensitivity
Webcam	USB2.0	640×480 Pixel	30 fps
Ultrasonic Sensor	Sender-Receiver Separate	3 cm~3 m	1 V/μbar
Microphone	Omni directional	110dB (THD3%)	461 V/μbar
Illumination sensor	Silicon PDA	1130 μW/cm2	532 Hz

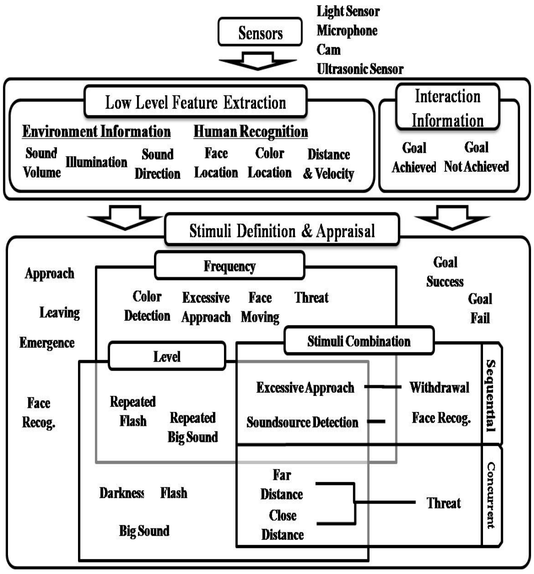


Fig. 2. Stimuli definition & appraisal.

In the step of 'Stimuli Definition and Appraisal', which is the first step of the Reactive Behavior Decision Model, the raw data measured by the sensors are analyzed to interpret the meanings, as shown in Fig. 2. That is, even with the same data, the meaning of the stimuli may be different depending on the previous stimulus. For example, stimuli on a sudden loud sound, intensive light, and excessively fast approaching movement (threat) makes Buddy deliver negative emotions. Meanwhile, the constant appearance of a human face (concern) can make Buddy deliver positive emotions. On the other hand, several stimuli that have physically neutral meaning (neither negative nor positive), such as a new human face and approach/retreat of users, cannot act as independent emotion inductors. Their effects on emotions are decided by history of series of stimuli. In other words, stimuli appraisal depends on previous stimuli. For example, a new human face, by itself, has no meaning to the robot. With series of positive stimuli, it is later positively appraised by Buddy. However, it is interpreted as a negative stimulus when the face recognition is constantly followed by negative stimuli. Other examples are listed in Table 3.

3.2 Generation of emotion and personality

In this paper, pleasure, anger, sadness, fear, disgust, and surprise are chosen as the robot's basic emotions, referred to as 'Emotions Revealed' [4]. In the Emotion Decision Model, which is the second step of the Reactive Behavior Decision Model, as shown in Fig. 3, the robot's emotions are decided from the stimuli interpreted in the previous step, based on robot's internal state and personality. Here, the internal state is influenced by success or failure in recognizing a person, the degree of intimacy with the person, and the degree of fatigue [4, 5]. The robot's personality consists of openness, neuroticism, agreeableness, and extroversion [5, 6]. Openness is mainly influenced by the consistency of stimuli. High openness makes the robot to briskly express its emotion and be in amity even with strangers. Neuroticism is closely connected to long sadness. If sadness is continued, neuroticism increases, and conversely, high neuroticism causes relatively large sadness. Agreeableness is concerned with the response of people. If the response of people to a certain robot's behavior is positive, the agreeableness is increased, and vice versa. Agree-

Table 3. Stimuli appraisal.

Single stimulus appraisal		
Stimuli	Meaning	Appraisal
Sudden big sound	Surprising /bothering	Negative (surprise, fear, anger, disgust)
Sudden intense light	Surprising bothering	Negative (surprise, fear, anger, disgust)
Abrupt approach /retreat	Surprising /threatening	Negative (surprise, fear, anger, disgust, sadness)
Constant existence of human face	Attention	Positive
Combined stimulus appraisal		
Previous stimuli (1st step)	Neutral stimuli (2nd step)	Appraisal
Negative	Advent of human face	Negative
Positive		Positive
Negative	Approach	Negative
Positive		Positive
Negative	Retreat	Negative
Positive		Positive

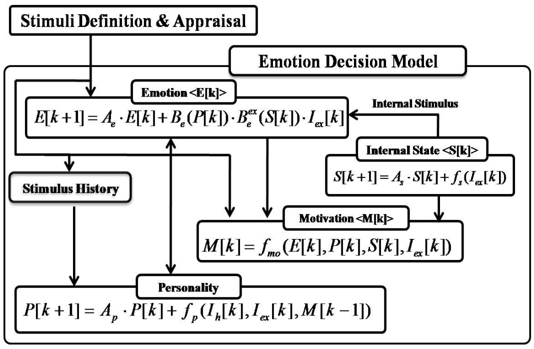


Fig. 3. Emotion decision model.

ableness affects the robot's selection of motivation. Lastly, high extroversion induces a robot to become outgoing and frequently express its emotions. Meanwhile, the robot with low extroversion expresses its internal states such as fatigue, uneasiness, and drowsiness, unrelated to external stimuli, rather than active emotional interaction with people.

As a result, to generate an emotion and its degree in the Reactive Behavior Decision Model, the information related to the type of external stimuli and robot's personality and internal state should be considered. For this, we used four kinds of dynamic equation models to generate and update internal state, personality, motive, and emotion, although we do not introduce the equations here in detail because they are complicated and beyond the scope of this paper.

3.3 Generation of facial expression

In the last step of Reactive Behavior Decision Model, as shown in Fig. 4, the motions of face elements (or action units; AUs) for facial expressions, gestures, and lip synchronization are generated and combined according to the type and strength of the emotion given in the previous step. Here, note that the generation and combination of the motions are nondeterministic and are based on a database. The ID number of an AU to move, the position (or angle) and velocity of the AU, and driving time are sequentially listed.

This step again consists of two stages: in the first stage, dynamic facial expression is made based on the type and strength of stimulus and robot's personality, while in the second stage, gestures such as movements of the neck or eyeballs consistent with the proper dynamic facial expression are produced. The facial expressions and gestures are combined to make a rich and realistic expression. If the robot is in talk mode, the motion of lips for lip synchronization should also be congruent.

In the first stage, a static facial expression consistent with the proper emotion is extracted from the primitive expression database. Fig. 5 shows examples of the static facial expressions for the six basic emotions. Then, the moving angles and velocities of the AUs are selected according to the intensity of stimuli and robot's personality. For example, when the stimulus is strong and the personality is extrovert, the expression gets quicker and larger in action, and vice versa. This facial expression remains for about 5-20 seconds.

In the second stage, to fertilize the dynamic expression, proper gestures should be added along with the expression. For example, when the robot's emotion is a surprise, it is but normal for its neck to quickly move backwards, as its eyelids go up and eyes open wider. As much as the gestures directly concern with the basic emotions, there may be other gestures that express various situations such as 'looking around' or 'dozing'. For this, our Reactive Behavior Decision Model has a gesture database in which some motion patterns of the neck or eyeballs are classified according to situation as well as emotion. The gestures appropriate to the given emotion are selected from the database based on personality. If it tends to be extrovert, the gestures get more varied and rapid. Reaction to stimuli also gets faster. On the contrary, in the case of 'introvert', small and slow gestures are chosen. On the other hand, there is a lip-synch database in which lip motions for all Korean vowels are listed. After a word of the robot is given, a text-to-speech (TTS) system converts the word to a list of phonemes and their durations. From the list, we extract the information on vowels needed to make lip motions. Finally, this lip motions for lip-synch is combined with the dynamic facial expression like other gestures. Here, note that the lip-synch motions take precedence over other lip motions for emotion expression, and that the combination order is also dependent on the emotion, personality, and environmental situation. For example, when the personality of robot is extrovert, fast gestures with lip-synch motions will appear preliminary to any other facial expressions.

The automatic selection and combination of facial expressions, as described above, enable the robot to give different expression to even the same emotion or the same stimuli.

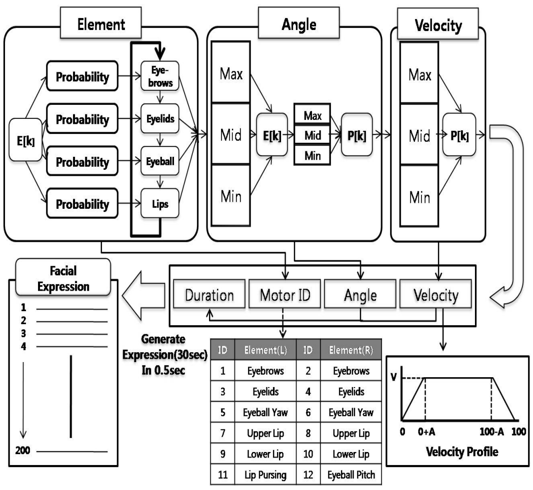
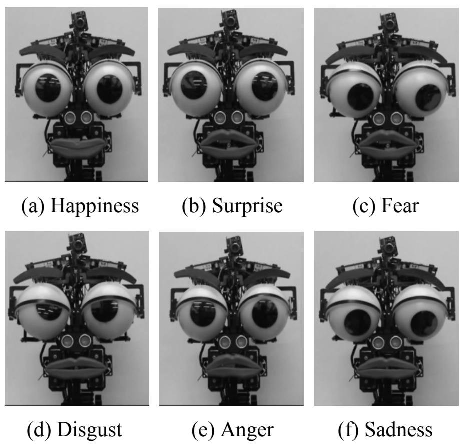


Fig. 4. Generation of facial expressions.



(a) Happiness (b) Surprise (c) Fear

(d) Disgust (e) Anger (f) Sadness

Fig. 5. Static facial expression for 6 basic emotions.

4. Experiment results

4.1 Emotion and personality

Fig. 6 shows an example of emotion generation results, which is an output Fig. of the developed 'Reactive Behavior Decision Model' software. In the figure, the horizontal axis is time and the vertical axis is the strength of emotion. There are six strips with their own color which means the six basic emotions, respectively. They move up and down, depending on the type of stimulus. Among the six, the emotion to be expressed at every moment is the emotion with the highest strength. Here, note that the strengths of emotions decline with time and the decline ratio depends on the personality of the robot. When the robot is neurotic, the decline speed of sadness is very low. And when the robot personality is the extrovert, the emotion of pleasure is sustained for a long time. Table 4 shows a set of sequential stimuli causing the variation of emotions in Fig. 6.

According to External Stimuli at Time Domain First, the appearance of someone (or something) unrecognized by the robot and his (or her or its) approach to the robot may be enough to make the robot feel fear and disgust. But, the repeated positive input such as a smile, caressing, or greeting can convert the robot's emotion to pleasure. On the other hand, negative stimuli such as beating, loud sound, or close approach increase fear, disgust, and sadness, while pleasure is decreased. In Table 4, the withdrawal of the object from the robot's presence causes pleasure, since the previous stimulus is negative. If an object which gives pleasure to the robot withdraws, the robot will feel a sad emotion.

Table 4. Stimuli causing the emotion variation of Fig. 6.

Order	Stimulus	Emotion Variation	
		Increase	Decrease
1	Appearance	Fear, Disgust	•
2	Approach	Fear, Disgust	•
3	Positive Stimulus*2	Pleasure	Fear, Disgust
4	Negative Stimulus	Fear, Disgust, Sadness	Pleasure
5	Withdrawal	Pleasure	Fear, Anger, Disgust
6	Positive Stimulus*2	Pleasure, Surprise	Fear, Anger, Sadness
7	Negative Stimulus*2	Fear, Anger, Sadness, Disgust	Pleasure, Surprise

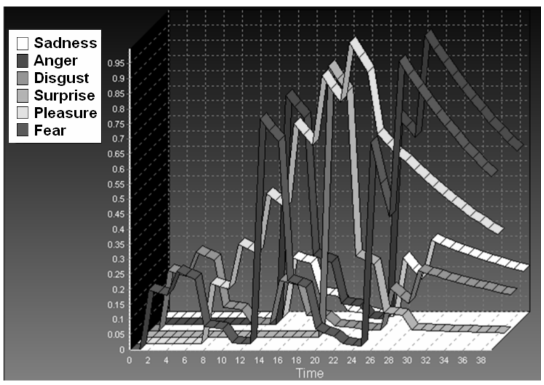


Fig. 6. Example of the emotion variation.

4.2 Emotional expression

Fig. 7 shows an example about the smooth change of facial expression automatically generated according to the emotion change, when the robot personality is introvert. In this case, neck gesture is minimally combined. Here, the emotions were generated by sequential stimuli as described in the previous section, while 'absence' in the Fig. means the absence of emotion.

Table 5 shows an example of the combination of facial ex-

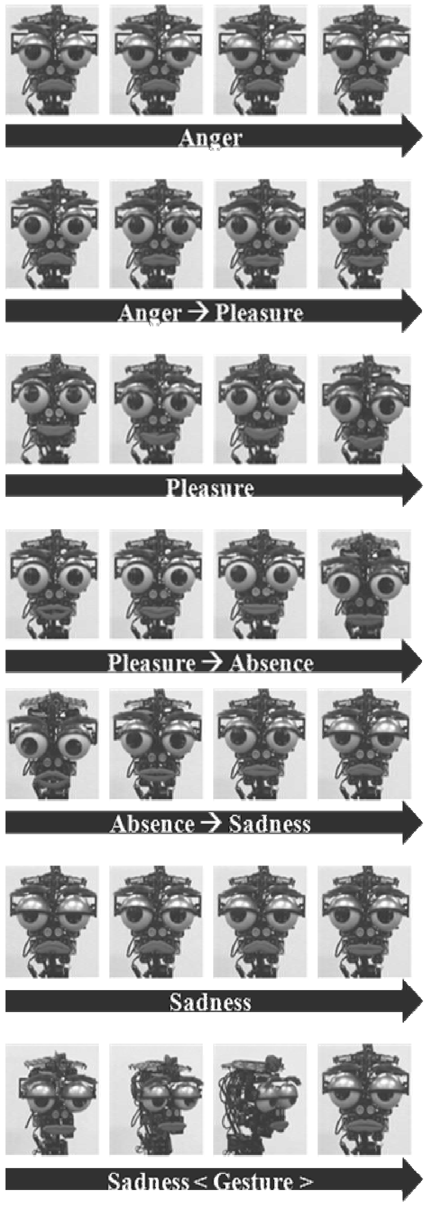


Fig. 7. Smooth change of facial expression.

Table 5. Example of combination of facial expressions.

Emotion (stimulus)	Selection (1:Facial expression)		Combination Order
	Gesture	Lip-Sync	
Pleasure (user's concern)	2:Wink 3:opening eyes wide 4:Nod	5:'Happy! Happy!' 6:'Ha-ha'	Extrovert: 6→1→3→4→1→2→5
			Introvert: 1→4→1→3→6→1
Sadness (withdrawal)	2:Blinking 3:Withering 4:Panning	5:'I am sad'	Extrovert: 1→5→2→1→4→1
			Introvert: 1→3→2→1→4→2→1

pression, gesture, and lip-synch for the given emotion and personality. The first depicts the case in which Buddy expresses the pleasure, saying 'Happy! Happy!' or 'Ha-ha'. There are three kinds of gesture in the gesture group concerning pleasure: wink, opening eyes wide, and nod. The second case is when Buddy feels sad. Gestures such as blinking, withering, and panning demonstrate sadness and the motion speed is slow, or it may say 'I am sad'. In the table, it is shown for both cases according to the robot's personality, the gestures and lip-synch motions are properly combined with the facial expression in a different order.

5. Conclusions

For an intimate emotional interaction between human and robot to flourish, it is important for robot to properly express the feeling of animate things as well as the corresponding gestures or actions to human. However, as long as the robot remains inanimate, such emotional bonding may stay a remote reality. Thus in this paper, we attempted to embed personality into the robot, and express its emotion automatically and in various ways. As such, we built a reactive behavior decision model and emotional behavior databases. Based on the personality that is also formed in the model, the strength and time length of facial expression are decided and the primitive motions for it are chosen in the database according to the emotion to be expressed. Next, the facial expressions are combined with some proper gestures and lip-synch motions which are also chosen in their databases categorized according to the emotion. At this point, the combination order varies depending on the robot's personality. We applied this scheme to our face robot, Buddy, to verify feasibility, and staged demonstration in the 2008 Robot World held in COEX, Seoul, Korea, where many visitors expressed great interests in Buddy.

Hereafter, we will make steady progress not only for the improvement of Buddy's hardware structure but also for the improvement of automatic generation algorithm of facial expression and for the enlargement of databases.

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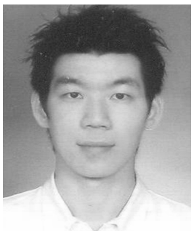

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