Cloud-based Non-invasive Tele-rehabilitation Exercise Monitoring

Saiyi Li, Pubudu N. Pathirana, *Senior Member, IEEE*

Abstract— **Exercise based rehabilitation plays a vital role in the recovery of various conditions, such as stroke, Parkinson's disease (PD), chronic pain, and so on. Recently, tele-rehabilitation has become increasingly popular quantitative nature in assessments particularly for systematic monitoring of progress as well as cost saving for the patients as well as for the health care sector at large. However, challenges do exist in implementing a distributed bio-feedback in a cost-effective and efficient way. In this paper, we present the associated conceptual framework of cloud-based tele-rehabilitation system employing affordable non-invasive Microsoft Kinect® allowing patients to perform rehabilitation exercises in non-clinical setting such as home environments without loosing the quality of patients care. More importantly, different from existing tele-rehabilitation systems, our system not only measures whether patients can perform rehabilitation tasks, but also how well they can finish the tasks. Preliminary experiments validate its potential in training healthy subject to perform exercise motions emulating the physical rehabilitation process.**

I. INTRODUCTION

Defined as an approach to maintain or recover physiological functionality [1], rehabilitation exercises have been widely used for patients suffering from physical impairments and disability for people with disabilities or even for the aged care sector [2] providing range of benefits in improving quality of life. [3]. However, despite the advantages, conventional therapeutic approaches suffer from certain drawbacks, such as time and financial cost in transportation, especially, for patients in rural areas [4], as well as limited intensity and length of treatment in clinics [5].

With the development of information and communication technology (ICT), tele-rehabilitation, defined as a medical service delivered remotely by using telecommunication technologies to provide rehabilitation treatment [6], has been continually improved in recent decades to overcome the potential issues in conventional physical therapeutic measures by allowing patients to practice exercises out of clinics, such as at home, while enabling physiotherapists to monitor and evaluate patient improvements progressively and remotely. According to [7], apart from alleviating various issues resulting from time and financial cost, tele-rehabilitation has numerous other benefits, such as providing an opportunity to mentor and develop experiences for the therapist training the transfer of knowledge. In addition, during the development of tele-rehabilitation, large number of devices, such as telephone, web camera, EMG and IMU, have been explored.

Saiyi Li is with the Department of Electrical Engineering, Deakin University saiyi@deakin.edu.au

Pubudu N. Pathirana is with the Department of Electrical Engineering, Deakin University pubudu.pathirana@deakin.edu.au

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In recent years, Microsoft Kinect® is also being increasingly popular in this field for its affordability and no-invasive form of human motion capture.

In the recent decade, cloud computing has captivated the developers world wide in ICT field, which is gradually changing the implementation and deployment of applications. A number of tech companies are offering cloud computing services, like Amazon EC2, Google cloud platform and Microsoft Azure, for the public. These services not only provide powerful computational capabilities by using a number of computer clusters, but also reduce the cost in terms of dynamically allocating resources with required performance capabilities to provide services [8]. Therefore, cloud service users no longer have to plan their system in terms of the hardware investigation far before the deployment of their software since the computational resources provided by cloud services can be expanded or shrunk easily according to the demand, thereby reducing the expenditure to a large degree [9].

Given the characteristics of tele-rehabilitation systems, many issues in implementing and deploying a tele-rehabilitation system can very well be served by the cloud computing service. More specifically, one of the most basic characteristics of a tele-rehabilitation systems is that it is a distributed system including at least two components, namely the therapist system and the patient system. The former usually plays the role as a passive data receiver so that therapists are able to receive critical information of the rehabilitation exercises for evaluation, while the later usually is associated with some sensors to capture patients' rehabilitation exercises data, such as motion data, breath and heart beat information. Secondly, a better tele-rehabilitation system may also includes data storage system so that patients' exercise data can be recorded and stored for further analysis. Thirdly, tele-rehabilitation system has to capture and process data collected from patients, which may require a large allocation of computing resources when the number of user increase. Lastly, due to the increasing number of individuals requiring physical rehabilitation, the number of tele-rehabilitation system users is highly likely to expand significantly. However, when and how fast the number will expand is unpredictable. Fortunately, cloud services can be used to address all these known problems.

Although tele-rehabilitation has been extensively studied, the majority of implementations in this arena have various limitations (refer to Section II). Therefore, in this paper, we not only investigate a new tele-rehabilitation system with affordable and non-invasive Microsoft Kinect, but also take the cloud-based system infrastructure into consideration.

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There are three novelties in this paper.

- Unlike existing tele-rehabilitation systems, we not only consider whether patients can finish tasks, but also evaluate how well they can finish the tasks by comparing their motion trajectories with model ones recorded by therapists;
- The proposed system provides therapists a tool to record model motions for patients according to the patients' conditions so that therapists' professional knowledge can be integrated into the system;
- Lastly, we offer an architecture to construct a tele-rehabilitation system with Microsoft Kinect with cloud services to make the whole system more reliable and flexible.

The rest part of the paper is organised as follow. Section II discusses the related work, followed by the introduction of the hardware requirement and software implementation of the proposed system. In Section V, the detailed implementation of data processing, storage and communication system is introduced since it is the core of the system and deployed in cloud. Preliminary experiments and the result is shown in Section VI to illustrate the promising application in tele-rehabilitation field. Eventually, the paper is discussed and concluded in Section VII.

II. Related Work

To develop more efficient tele-rehabilitation systems, a number of studies have been conducted in the past few decades. In the early stage, tele-rehabilitation was usually performed through plain old telephone system (POTS). Pamela *et al.* [10] proposed in 2002 to utilise interactive video to provide tele-therapy for stroke patients. Two videophones were set up in both therapist's office and patient's home so that they could communicate with and see each other for physical rehabilitation. In terms of the outcome, Mrs. M was able to walk and take care of herself at home independently. Liu *et al.* [7] deployed a videoconference device based tele-rehabilitation system between staff in University of Albert and clinicians and students in rural areas. Instead of applying this system in patient treatment, it was utilised in education field for supervising students and clinicians. According to the result, 96% of tele-health sessions were successful. Russell *et al.* [11] developed tele-rehabilitation software to record video from videoconferencing link so that patients with gait conditions could be remotely assessed. In the paper, they evaluated the accuracy and reliability of this approach and made the conclusion that the result of gait assessment through the Internet was very close to traditional method with less than 1 point on Gait Assessment Rating Scale (GARS). More examples can be found in [6].

Recently, with the development of virtual reality technology, it is being increasingly applied in tele-rehabilitation area. Viorel *et al.* [12] integrated a PC, a Polhemus tracker and a haptic control interface together to provide tele-rehabilitation service with force feedback for patients and remote monitoring for therapists. David et al. [13] developed a web-based tele-rehabilitation system enabling post-stroke patients to perform and monitor rehabilitation exercises by playing therapy games. A force-feedback joystick was involved to provide resistance. In addition, Holden *et al.* [14] designed a virtual environment with a motion capture device (approximately $8500) to offer tele-rehabilitation for patients at home. Meanwhile, therapist was able to monitor patients' performance and hold videoconference remotely. The improvement of assessment scores during clinical trials illustrated the effectiveness of this system.

More related to our study, Kinect has been utilised for tele-rehabilitation in recent years. Simonsen *et al.* [15], [16] utilised a Kinect sensor to build a closed-loop tele-rehabilitation system to recover hand function of post-stroke patients. Obdrlek *et al.* [17] developed a Kinect-based system for tele-rehabilitation. In addition, Weiss *et al.* [18] developed and validated a Kinect-based tele-healthy system for stroke rehabilitation. In their system, apart from therapist and patient system, a clinical database was also utilised for offline monitoring.Kurillo *et al.* [19] also proposed a tele-medicine tool named as Tele-MFAsT for motion and function evaluation. In the past one and a half years, a number of cloud-based tele-rehabilitation systems with Kinect are emerging [20], [21].

However, the majority of these existing approaches to design and implement tele-rehabilitation systems with Kinect have certain limitations. For instance, game (task)-based approach were utilised to deliver rehabilitation exercises, which means that, although the systems were attractive, they merely focused on the result, while paid less attention on how the patients finish the task, such as motion trajectories. In addition, the interactive between the therapists and the systems were limited. In the majority of the systems, therapists can only assign pre-designed games to patients, while could not create games, which could not fully utilise the knowledge of these professionals. In this paper, these two problems are going to be addressed.

III. Hardware And Infrastructure Overview

The simplest structure of this tele-rehabilitation system involves two computers, two Microsoft Kinects, as well as the cloud computing service. As an option, a large screen TV and a speaker are preferred for patients so that they are able to view their exercises without much effort and listen to auditory feedback. The multiple PAMS and PES hardware architecture of the system with various types of hardware is shown in Fig. 1 and PAMS, DPSCS and PES are for patient assessment and management system, data processing, storage and communication system and patient exercise system.

- Computers
  A computer is required in each PES, while is not necessary in PAMS if a therapist does not have to create model motions for patients since a mobile phone or tablet can review or monitor patients' rehabilitation exercises as well. To smoothly run the proposed tele-rehabilitation system, 64 bits Microsoft Windows® 7 operating system with .Net framework 4.0 should be installed if a Kinect is used. In addition, Microsoft Kinect

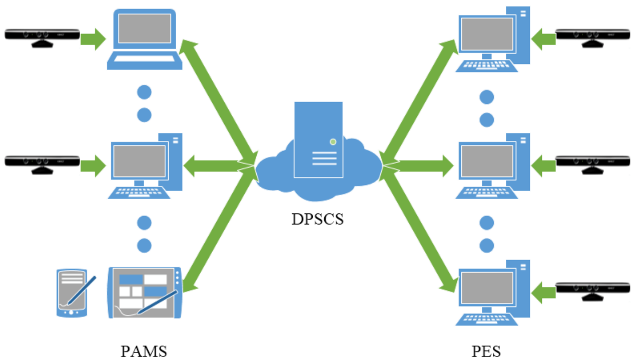


Fig. 1: Hardware architecture

SDK 1.8 should be installed for receiving Kinect data. At the same time, the computer in PES is recommended to be associated with a speaker for delivering auditory feedbacks and instructions, as well as a large screen TV for visual feedback.

- Kinects
  Apart from a computer, a Kinect is required in PES while optional in PAMS. Being a motion capture device, a Kinect is able to project an infrared mesh with a infrared projector on the body of the subject and pick up the infrared dots on the subject by a infrared camera to form a point cloud (depth image with resolution of 640 $\times$ 480 pixels and frequency of 30 Hz), from where the 3D skeleton of the subject could be derived [22], which involves 20 joints throughout the body of the subject. The 3D positions of each joint are given by the Kinect with accuracy of approximately 10 cm [23]. In addition, the field of view of a Kinect is 57° in horizontal, 43° in vertical and 0.8 to 3.5 meter in distance [23]. For general movements in rehabilitation exercises, one Kinect is sufficient, while multiple Kinects are supported as well for increasing accuracy.
- Mobile phones and tablets
  The coupling between different subsystem in the proposed system is very loose, which means that the system, especially PAMS is platform independent. Therapists can use smart phones and tablets to connect to the cloud to receive online or offline data for reviewing and monitoring.
- The cloud computing service
  This component is critical to the whole system since it provides the data processing, storage and communication between PAMS and PES. In our case, Amazon EC2® is selected to deploy the data processing component since it is one of the oldest cloud service provider with high reliability. As is known that cloud computing services usually have three levels of architectures, including Infrastructure as a Service (IaaS), Platform as a Service(PaaS) and Software as a Service (SaaS). We deployed our system in EC2 as SaaS to provide tele-rehabilitation services.

IV. Software Systems Overview

To reduce the coupling between each module in the whole system, it is decomposed into three major subsystems corresponding to the hardware deployment (refer to 1). The brief roles of these subsystems are shown as follow.

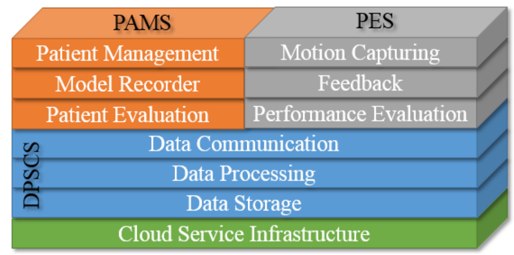


Fig. 2: System framework

A. PAMS

This subsystem is for therapists to remotely manage and evaluate patients' rehabilitation exercises, including three components.

Firstly, patient management component enables therapists to add, delete, update and search patients participating rehabilitation programs. This is a basic function of the system so that patients' information and progress can be well managed by therapists. In addition, therapists are able to assign an existing rehabilitation exercise model for patients so that they can have a specific task to speed up the recovery.

Secondly, if there is no suitable exercise model in the database, model recording component should be utilised, which is one of the major contribution of this paper. As is known, patients with different conditions requires various types of exercises, which needs experience and professional knowledge of therapists. By setting such exercise tasks, patients are able to improve their ability to control their motion, as well as keep being stimulated. The majority of existing game(task)-based tele-rehabilitation systems are lack of such flexibility in terms of fully utilising professional knowledge of therapists to create exercises for patients case by case. Therefore, in our system, we provide such chances for therapists to easily record model motions according to patients' conditions. At the same time, another useful function included in this component is that therapists are able to select interest joints. These joints will be the most important ones during patients' rehabilitation exercises and data related to these joints, such as speed, angle and positions, will be shown to therapists during or after exercise sessions for evaluation. After recording model trajectories, therapists are able to tailor them to meet the requirement of some specific patients.

Thirdly, patients' rehabilitation exercise monitoring and review component provides therapists a tool to review patients' rehabilitation exercise sessions online or offline. In this component, therapists are able to see almost whatever patients can see in PES, including model motions and patients' motions. In addition, exercises related data, such as number of sessions in the past few days, as well as quantitative values of interest joints, like angle, speed and positions, can also be reviewed for further assessment.

B. PES

PES is the subsystem used by patients in their daily rehabilitation exercises out of clinics. Given limitation of movement of patients, PES is designed as simple as possible. For example, virtual panel is created with large buttons so that patients do not have to use mouse, which may be hard for them to operate. Therefore, patients can use this system by moving one of their arms to touch buttons in screen with certain joints (such as right wrist in our implementation) to start exercises.

Furthermore, one of the main functions of PES provides patients model motions created by their therapists. The model motions will be shown as trajectories of interesting joints selected when the model motions were recorded. To perform rehabilitation exercises, what patients should do is to use interest joints on their body to follow the model trajectories as accurate as possible with reasonable speeds.

Moreover, during rehabilitation exercises, patients will receive various types of feedbacks. For instance, descriptive feedbacks are more frequently used to show the directions that their body parts should more, such as ”Move right wrist to left”. At the same time, auditory feedback will be given to indicate the total distance between patients' interesting joints and that of model motions. Higher and lower volumes are for longer and shorter distance. Last but not least, visual feedback also is given for patients to acquire visual awareness of the difference between their motions and therapists' ones. One of the reasons why descriptive and auditory feedbacks are important is that visual one can only provide 2D images. Since rehabilitation exercises involve 3D motions, the feedback for the third dimensions should be given non-visually.

After each session, an overall score will be given to illustrate the performance of patients during this rehabilitation session. To compute this score, various elements are taken into consideration. For task related criteria, whether the exercise is finished and how long it is finished are two important factor. In addition, how well the patients can follow the model trajectories is used to evaluate the motor control ability, which is missing in the majority of the existing tele-rehabilitation systems.

C. DPSCS

Being the bridge between PAMS and PES, DPSCS is deployed in cloud side to take the advantage of powerful computational ability in the cloud service. There are three functions implemented in this system, including data communication, processing and storage. The details of the implementation of DPSCS is discussed in Section V.

V. Implementation of DPSCS

This subsystem is implemented as an infrastructure to deal with data transferred from and to PAMS and PES. In the proposed system, there are three types of data, including information data, instruction data and 3D motion data. The first type includes information to describe entities, such as patients, therapists and model motions, which mainly come from PAMS. The second type usually contains selection criteria. For instance, in patient performance evaluation phase in PAMS, therapist should select what data they are interested in, while in PES, patients should select which model motion they would like to follow. As for the last type, which also is the most important type, includes positions data of joints on human bodies to represent the movements for comparison and analysis.

A. Data Communication

Data communication process involves two stages, including data acquisition and return (refer to Fig. 3). In our system, two stages have different implementation techniques. To simplify the description, the clients mean PAMS and PES.

For data acquisition, since the data transferring usually is point-to-point (P2P from one PAMS or PES to DPSCS), Windows Communication Foundation (WCF) is implemented as Web Service to provide the interface between the clients and DPSCS. By invoking methods offered in WCF with acquired data as parameters, the clients can transfer data to DPSCS for further analysis and storage. In this stage, data includes all types introduced previously.

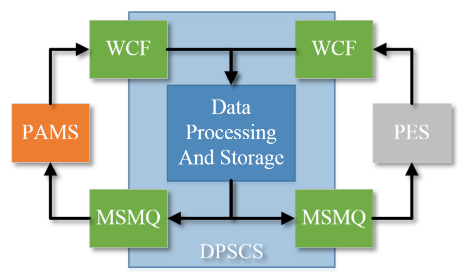


Fig. 3: Data Flow between systems

However, data return is slightly different from the previous stage. In this stage, only certain information data, such as the exercises related data for evaluation and 2D image data for drawing skeletons in clients, is transferred. According to the function of this tele-rehabilitation system, one or multiple therapists can monitor a patient's rehabilitation exercises for group consultations or education, the data transferring in this stage is point-to-multipoint (P2MP from DPSCS to multiple PAMS and PES). Therefore, we implemented Microsoft Message Queue (MSMQ) to fulfil the demand, which provides guaranteed data delivery service even when the clients are not online temporally. Secondly, since the data is pushed from DPSCS to clients, the frequency of returning data to clients can be synchronised with the data acquisition stage, thereby reducing the delay in the whole system.

B. Data Processing and Storage

Three types of data are processed and stored in different approaches. For the information data, it does not need to be processed while stored directly after being received by

DPSCS. Additionally, instruction data is only utilised as selection criteria and does not need to be processed as well. The only type of data requiring data processing and storage is motion data. In this subsection, it is discussed in detail.

Firstly, since the proposed system provides the model motion recording function to therapists, data in this process should be dealt with as follow.

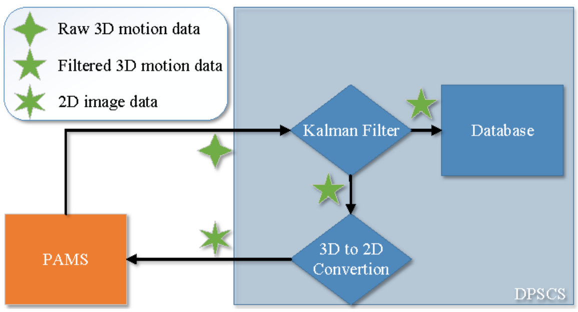


Fig. 4: Data flow and processing in building model motion

From Fig. 4, we can see that 3D motion data is denoised with Kalman filter [24] and then stored into database. Actually, if there are more than one Kinects connecting to the computer, the Kalman filter can be utilised to fuse data. On the other hand, the denoised 3D motion data is converted to 2D image data with functions provided by Kinect SDK 1.8, which is then returned to PAMS for presentation.

Secondly, the other path of processing motion data starts from PES as show in Fig. 5.

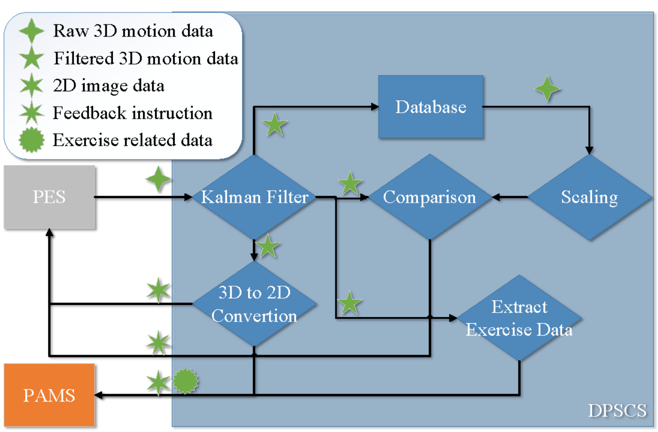
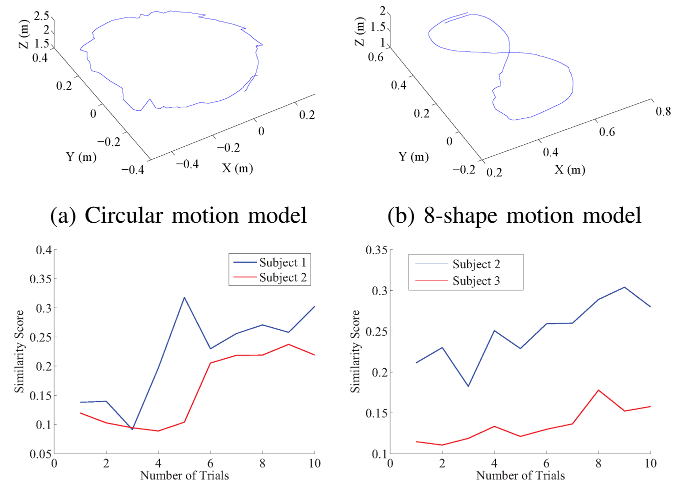


Fig. 5: Data flow and processing in performing rehabilitation exercises

In this process, 3D motion data captured from PES is filtered or fused with Kalman filter and stored in database. At the same time, the denoised data is converted to 2D image data like the previous process for visualisation. What should be noticed here is that 2D image data is delivered to PES and PAMS simultaneously, which is a P2MP process.

When 3D motion data is transferred from PES to DPSCS, another dataset of model motion recorded in the previous stage is retrieved from database according to the instruction data given by PES. Since it is highly likely that the height and length of body parts of therapists are different from that of patients, it is critical to scale model motion so that it fits patients' body size. To achieve this, firstly, both therapist's and patient's height should be measured with the length of arm from one hand tip to the other since in [25], Jarzem *et al.* shown that the length of parts in upper body is in proportional to the height. Secondly, a ratio is computed as $r = \frac{patient's\ height}{therapist's\ height}$, which is applied on model motion dataset for scaling. Lastly, we select the shoulder centre joint as the reference joint to scale the whole skeleton in model motion with this ratio. Eventually, the scaled model motion would be utilised to be compared with motion data collected from PES to generate the instruction to correct patient's rehabilitation exercises trajectories, which is sent to PES as feedback instructions.



(a) Circular motion model (b) 8-shape motion model

(c) Circular motion similarity scores (d) 8-shape motion similarity scores

Fig. 6: Models and exercise results

Lastly, certain information data, such as angles and speed of certain joints, is extracted from denoised 3D motion data, stored in database and transferred to PAMS for evaluation.

At the end of each exercise session, a score is computed to generally illustrate the performance of the patient in this session. Here, longest common subsequence (LCS) [26] is utilised for this purpose.

VI. Experiment and Result

An experiment with three healthy subjects was done to preliminarily validate the system in lab environment in terms of the function of drawing a specific trajectory to simulate the ability to acquire a new skill. The ethics has been approved for this experiment and there is no video or audio record that may disclose the subjects. One subject created two trajectories, including a circle and a 8-shape trajectory, with his right wrist shown in Fig. 6a and 6b. After that the other two subjects followed each models for ten times. Eventually, scores were computed by comparing the trajectories of subjects and the model.

From Fig. 6c and 6d, it can be observed that with the increase in the number of trials, the similarity scores for all subjects and motions increase with certain fluctuation. For instance, the score for two subjects increased from approximately 0.13 to 0.3 and 0.2 respectively for circular motion and that increased from 0.2 and 0.11 to 0.27 and 0.16 for 8-shape motion. Although the improvement is not very significant, the increasing trend still can be observed, which illustrates the promising application of this system in tele-rehabilitation field.

VII. Conclusion

This paper introduced a new cloud-based physical tele-rehabilitation system. Due to readily available features in cloud implementations, the systems are more reliable, flexible and accessible than conventional rehabilitation and tele-rehabilitation systems. More importantly, the proposed system enables therapists to create specific motion models with their knowledge about their patients, which undoubtedly contributes to the rehabilitation effectiveness. In addition, by following the model motion, patients are not only required to finish tasks, but also have to learn how to finish the tasks effectively, which, to a certain extent, helps patients to recover or maintain skills. The preliminary real-data experiment with healthy subjects illustrates the feasibility of using the proposed system to acquire (recover) skills.

As future work, more subjects, including healthy ones and patients, will be recruited for clinical trials with professional physiotherapists. Extra functionality will be added to the underlying system as per the recommendations and the requirements of the clinicians.

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