MLPM: A Multi-Layered Process Model Toward Complete Descriptions of People's Behaviors

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***Abstract*—Despite the rapid progress in the development of sensor technologies, as well as of information management, no technology exists for recording all the activities of people in the many varieties of human societies. In this paper, we propose a novel process meta model for describing people's activities that uses a Multi-Layered Process description Model, MLPM. The meta model allows models for various kinds of human social activities, such as sport plays, medical treatment, and agent communications, to be easily described. The significance of this model is that it can be used not only for searching a subpart of people's activities given a process query, but also for fostering a young novice by presenting to him/her behavior patterns, differentiating between those of the expert and the novice. The meta model can also be used for detecting outliers in process databases. In this paper, we describe the components and structures of the MLPM. It is mentioned that the MLPM is a model suitable toward complete descriptions of people's behaviors by comparing it with other methods.**

Keywords*—*process; behavior; action, meta model; searching.

I. INTRODUCTION

Recently, the use of various kinds of sensor devices, such as motion and location sensors, has become widespread. As a result of this rapid popularization, huge amounts of their monitored data have been obtained and analyzed for application-oriented purposes. For example, human motions can be easily detected by using motion sensor devices such as Microsoft Kinect [1] and Leap Motion [2]. Human trajectories can be traced by using position sensing devices, such as GPS and OptiTrack [3]. These advanced sensor devices are currently used primary for analyzing object movements, as well as for visualizing them.

Despite the fact that many data related to human activities, recorded by the sensors, the data exist, they cannot be managed for the purpose of processing in a unified way. In particular, motion data are stored in a proprietary format and no common formats have yet been proposed. The raw location data for human activities basically comprises a combination of human motions and positions. There are some common formats for representing human motions and positions, such as H-Anim [4] and BVH (BioVision Hierarchical data) [5]. However, these formats are used only for storage and exchange of the data, not for representations of all human activities.

In the area of business process management, some process description models exist, such as BPMN (Business Process Modeling Notation) [6], XPDL (XML Process Definition Language) [7], and BPDM (Business Process Definition Meta-model) [8]. Although these models are used for business management representation and business system development, their main purpose is not to represent people's behaviors, and thus, representations of human motions and positions are outside their scope.

In this paper, we propose a new and novel process meta model for describing a model for people's behaviors that uses a Multi-Layered Process description Model, MLPM. The model allows various kinds of human social activities, such as sport game plays, medical treatment, and agent communications, to be easily described.

For example, suppose that a skilled doctor is fostering junior doctors in order to impart to them better skills for the task of giving intravenous or subcutaneous injections. It is difficult for them to understand and to perform the task without any practical experience of it. Even if they have some experience of giving the injections, appropriate real-time comments from experienced doctors are very necessary and helpful. However, when they use a subcutaneous-injection simulator, such useful comments are not available to them. There is thus no opportunity to improve their skills in such situations. When our model can be applied to provide this medical treatment education, a system based on our process model will be able to support young doctors by presenting to them the differences between the activity as executed by a skilled doctor and by a junior doctor, with specific details. This is because all the activities in the injection process can completely be represented by our proposed model, and the difference can be detected by real-time checking of the distance between two processes.

Our proposed model is composed of seven fundamental components: Process, Task, Entity, Activity, Action, Motion, and Expression. These components are linked to many types of associations. The main characteristics of MLPM are:

- All processes related to people's behaviors can be modeled by using our MLPM. A process can be represented by a hierarchical structure, as well as by linked data among components.
- MLPM can give researchers in many fields a way of describing behaviors in a common representation format.
- Many functions and tools can be incorporated in the basic structure of MLPM. Some examples of such functions are process similarity searching, process outliers

detection, and process classification.

The contribution of this paper is that the proposed MLPM is the first representation meta model for describing overall people's behaviors comprehensively. Throughout this paper, it is assumed that the representation model is a model for describing people's behaviors that occurred in the past. The prediction of a future behavior from past behaviors is beyond the scope of this paper. The term "behavior" is used to define all the aspects of people's activities, including tasks, motions, positions, and interactions, because the term is defined in [10] as "behaviors refer to those activities that represent actions, operations or events as well as activity sequences conducted by human beings under a certain context and environment."

The remainder of this paper is structured as follows. Some previous works related to our paper are described in Section II. Next, in Section III, a detailed description of our model, MLPM, including examples and formal specifications, is presented. Some expected applications and discussions are then given in Section IV, followed by some concluding remarks in Section V.

II. Related Work

We describe the related work from three viewpoints: business process models, process mining, and multi-agent models.

Many studies on the business process model have been reported [7], [8], [9], [11], [12], [13], [14]. Three innovative business process models were proposed and standardized: Business Process Definition MetaModel (BPDM) [8], Business Process Modeling Notation (BPMN) [6], and XML Process Definition Language (XPDL) [7]. These proposed models were intended to represent all the processes performed in an enterprise. For example, the BPDM model is composed primary of Common behavior model, Activity model, and Interaction protocol model. The common behavior model is composed of two detailed models: Behavior model and Interactive behavior model. These models allow many types of processes used in a specific enterprise application field to be defined. In addition to these models, many similar models have been proposed. Typical examples of such models are explained in survey papers [9], [12]. Two examples are Object-Oriented Business Process Model [11] and ADONIS BPMS model [15]. Although all the business process models can be used for process representations in an enterprise, they can never be employed for representing people's behaviors including their motions and moving trajectories. The mining of business processes also has been studied recently [13], [14].

Process mining is a new area in the data mining research field. Many mining methods for acquiring useful and effective rules in terms of processes have been proposed [16], [17], [18], [19], [20]. The definition of the objective of the process mining is to discover, monitor, and improve real processes by extracting knowledge from the event logs readily available in today's (information) systems [16]. However, this definition is not appropriate in the case of descriptions of all aspects of people's behaviors. It is also difficult to perform mining from a large collections of logs of people's motions, trajectories, and actions, because of issues related to similarity definition, dimensionality reduction, and data cleansing.

Lastly, the multi-agent model is a model for simulating human behaviors by using virtual agents or humanized robots. Many studies on the multi-agent model have been proposed [21], [22], [23], [24]. The model usually includes the agents' motions as well as interactions with other agents or with humans. Examples of multi-agent models are AALAADIN [21], Swarms [23], and IPC/Q [24]. The common concepts applied in the models are based on the object-orientation concept and the procedural process description. This category of the behavior model has disadvantages in that in general it is difficult to archive all the process data, although a process can be described using the procedures provided by the model. Therefore, it cannot be used for representing people's behaviors comprehensively for the purpose of archiving.

In addition to the above related work, it should be noted that a behavior model has recently been proposed [10], [25]. The proposed behavior model is very general and can be implemented for many applications that require behavior mining. However, it cannot be used for archiving an overall process, to the best of our knowledge.

Recently, Neumuth et al. proposed a process model for surgery [26]. Although the basic idea seems similar to that of our proposed model, their model is basically a hierarchical structure built from the descriptive format viewpoint, using natural language sentences, ontological description, formal mathematical description, and actual description. In contrast, our model is a layered structure that uses the abstract-to-concrete viewpoint.

III. MLPM (Multi-Layered Process description Model)

A. Requirements

Before describing the MLPM proposed in this paper, we describe some requirements for process representation that we need to specify. The process model should meet the following requirements to specify the overall process of people's behaviors.

- People's behaviors should be described in various aspects, because they are recognized from an abstract view as well as from a concrete view.
- Usually, a business is run or a task is performed by a team of people who uses various tools. Therefore, their interactions should be represented by the process model.
- In terms of the actual people's behavior, the motions of each person can be captured using various kinds of equipment, such as cameras and GPS sensors. Therefore, the model should be able to use the data generated by these devices.

B. Basic concepts

We describe the basic concepts of our MLPM for process representation. We introduce the multi-layered structure to represent the overall process, which contains various kinds of descriptive aspects. Our proposed model is composed of three layers to meet the requirements mentioned above: the process/task layer, activity layer, and motion layer.

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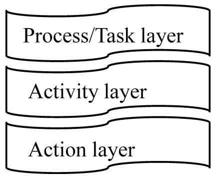

Figure 1. The layered structure.

- In the process/task layer, a sequence of tasks conducted in a process and their properties can be described. The business process model [8] or the work flow process model [7] can be introduced in this layer to describe the sequences and task properties.
- In the activity layer, activities representing each task can be described. In this layer, a task is decomposed into activities and represented by relationships with entities, such as individuals and instruments. The properties of the activity and the entity are also described here.
- In the action layer, an activity is decomposed into a sequence of actions. An action is further decomposed into a set of motions, which constitute the basic component corresponding to a human being's actual movement. Actual motions can also be described using various forms of expression, such as video and trajectories. Concurrent motions can be represented by multiple actions to which several such expressions are attached. Clearly, actions, motions, and expressions all have properties that describe them.

Figure 1 shows an outline of the layered structure of our MLPM.

C. Fundamental components

In our MLPM, seven fundamental components are used for describing an overall process. A brief explanation of these components follows.

1) The process/task layer
    a) Process: A process is an abstract unit of functions in the specific application field. People's behavior are first defined as a set of processes. Examples of a process are ordering-by-customer, injecting-drug, and ballroom-tango-dancing. The process definition in BPDM [8] or XPDL [7] can be used to describe the process.
    b) Task: A task is also an abstract unit of the sub-functions that compose a process. Each process is represented by a sequence of tasks as in BPDM or XPDL, although the name of the task is either the sub-process or the activity, representatively. The task can be defined using such a standard specification.
2) The activity layer
    a) Entity: An entity is an abstract class of objects, which can be modeled using MLPM. Entities are used to perform a process/task. They are divided into either user or instrument classes. Other classes can be introduced according to the specific application. The user classes are related to human groups, such as doctors and patients. The instrument classes are related to the machines, goods, or tools that support users' activities.
    b) Activity: An activity is a relationship between an entity and a task that is used to represent a task execution. It is possible to represent multiple activities for an entity executing one specific task. Moreover, there are multiple entities for one specific activity. One example is that a nurse inserts a syringe into a patient's vein in a blood collection task. In this example, Nurse, Injector, and Patient are described as entities, and the injection activity is an activity, which is followed by the activity of removing the inserted syringe.
3) The action layer
    a) Action: An action is an abstract movement related to one entity. One entity is related to a sequence of actions used to perform an activity associated with other entities.
    b) Motion: A motion is an actual entity's movement used to represent a specific action. The motion data are aggregated and integrated from various kinds of motion expressions.
    c) Expression: An expression is a view of one motion. The motion data can be extracted from various devices. Examples of these expressions include pictures, videos, voices, trajectories, and textual annotations.

In addition to these fundamental components, the following types of associations are introduced for each layer in our MLPM.

1) Temporal associations: A sequence is a kind of temporal association. In addition, there are other types of temporal associations between components such as those between activities and between motions. Other temporal associations can be introduced from concepts of temporal relations [27]. Examples include "done at the time" "after" "before" and "during."
2) Spatial associations: A spatial association is an association between components in terms of their locations. When two entities are located in certain region together, there is a type of spatial associations between them called "located together." Other types of spatial association can be defined and to be used to describe the overall process.
3) Link associations: There are other types of association in addition to spatial or temporal associations between components. These types of association are called link associations in our MLPM. For example, a nurse attaches a patient name label to a blood collection vessel after taking blood. There is a type of link association called "attaching" between the "Nurse," "Blood collection vessel," and "Patient name label" entities.

An example of MLPM representation for medical treatment process modeling is shown in Figure 2. In this Figure 2,

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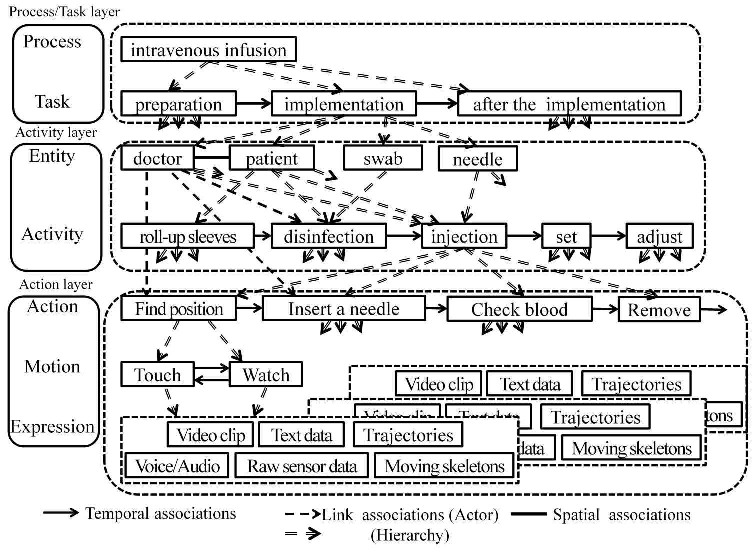

Figure 2. MLPM structure example.

not all the nodes are illustrated because of space limitations. Therefore, some associations with no destination nodes appear.

D. MPLM specifications

Basically and intuitively, an actual model, described using MLPM, is represented as a directed graph, which is composed of nodes and links. Both a node and a link have a type, which is the special attribute for identifying its MLPM component. The formal specifications of the fundamental components in MLPM are described here.

First, the fundamental component FC is defined, which is the set of fundamental component classes FC_i, as $FC = \{FC_i\}$. When instances of the fundamental components FC are denoted by $\{FI\}$, the set of fundamental component instances are described as $FI = \{FI_j\}$. As the fundamental components FC are composed of seven actual fundamental components- Process $P = \{P_j\}$, Task $T = \{T_j\}$, Entity $E = \{E_j\}$, Activity $AV = \{AV_j\}$, Action $AT = \{AT_j\}$, Motion $M = \{M_j\}$ and Expression $E = \{E_j\}$, a fundamental component class FC_i is a class of one of these component classes. In addition, a fundamental component instance set FI_j is the set of instances of one of these classes: P, T, E, AV, AT, M, and E. Moreover, the entity class set E is decomposed into of Human Entity HE and Artificial Entity AE. That is, $E = HE \cup AE$ where $HE \cap AE \neq \emptyset$.

In order to formalize the relationship between a class and its instance, we define it as follows. For each class P_j in P, the instance set is

$$PI_j = \{PI_{j,k} | PI_{j,k} \in FI, PI_{j,k}\ is\_an\_instance\_of\ P_j\}$$

In the same way as PI_j, the instance set in the other components can be defined. For each class FC_i, in FC, the class has multiple attributes, represented by $\{AC_k\}$, where AC_k denotes the domain of an attribute of FC_i. By using these $\{AC_k\}$, we can define the set of the instances of FC_i as $FC_i \subset AC_1 \times \ldots \times AC_{p_i}$.

Second, because the structure of MLPM is basically hierarchical, it is necessary to introduce the definition of the hierarchical relationships between multiple fundamental component classes. The hierarchical relationship HR is defined as the set of the hierarchical relationship classes: $HR = \{HC_j\}$. A hierarchical relationship class HC_j has the relationship instances HI_j, where $HI_j \subset C_1 \times \ldots \times C_{ph_j} \times AH_1, \times \ldots \times AH_{qh_j}$. In this definition, C_k is a set of instances belonging to one of the classses of FC, and AH_k is the domain of an attribute of HC_j. An attribute is a property of the hierarchical relationship and its value changes depending on the HC_j instance. For example, if C_1 is a set of instances belonging to one process class P_k, then $C_1 = PI_k$, where PI_k is the set of P_k instances.

Finally, there are three types of associations: Temporal, Spatial, and Link. Therefore, we introduce the following definition of these associations. A link association LA_k is described as $LA_j \subset Label_{link} \times C_1 \times \ldots \times C_{pl_j} \times AL_1, \times \ldots \times AL_{ql_j}$, where $Label_{link}$ is the set of label names for identifying the type of link associations and AL_k is the domain of an attribute of LA_j. Similarly, a temporal association TA_k is described $TA_j \subset Label_t \times C_1 \times \ldots \times C_{pt_j} \times AT_1, \times \ldots \times AT_{qt_j}$, where $Label$ is the set of label names for identifying the type of link associations and AT_k is the domain of an attribute of TA_j. The formalization of the spatial associations is defined in a similar way.

The fundamental components described above are only a part of the components in MLPM. There are other components, necessary for describing the overall processes using MLPM: Event, Role, and Environment. These additional components are all related to other types of relationship. The event is used to represent a thing that occurs at a certain time hav-

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TABLE I. MODEL COMPARISON RESULTS.

	Main Components	Target Applications	Similarity. Definition
MLPM	- Process and Action Models - Motion model incl. movements & expressions - Temporal/Spatial assoc.	- Medical process - Sports	- (TBD)
BPDM [8]	- Business Process Model - Business Semantics - Rules and Policies	- Business	- None
Behavior model [10]	- Abstract Behavior Model - Actor/Operation/Coupling - Temporal/Inferential/Party - Behavior Aggregator - Risk and Impact	- Business - Data analysis	- Behavior Feature Matrix-based similarity
Process model [26]	- Natural Lang. level - Conceptual levels - Formal level - Implementation level	- Surgical . process	- Combination of five similarity definitions

ing relationships with other components, the role is defined as the set of relationships among component instances, and the environment can be represented as the space containing many component instances. These components contain their attributes, as do the fundamental components.

Evaluations of the specifications of MLPM are necessary and are currently in progress in a medical treatment application field. We are also developing a detailed design of all the MLPM specifications, for which we are considering the related standards.

IV. DISCUSSIONS

A. Comparison with other models

Although it is difficult to compare our MLPM with other related models, the preliminary comparison results are shown in Table I. In Table I, three features for each model are described: the main components, target applications, and similarity definition. The last feature is important for extracting processes, activities, or motions that are similar to given process data from a large collection of process data. In this table, it can be seen that the point of the MLPM is an integration of the existing process and motion models. However, it is important to define the similarity function, which will be done in future studies.

B. Functions to be realized based on MLPM

There are many functions that can be realized based on MLPM. In particular, the followings are important and basic functions, which we are developing.

- Process database: In order to realize the proposed MLPM, we need to develop a method to manage the detailed specifications of our process model, in order to realize an automatic process construction method by developing data aggregation and abstraction methods.
- Process classification: When the process database has been generated, we need to develop a method for comparing two processes and then a method for classifying processes for process management.
- Process matching and similarity search: It is important to develop a matching or search function of similar processes for improving the current process management or for supporting a user's process management.
- Process mining: Process association rules or process correlations need to be extracted from an MLPM-based process database.

C. MPLM limitations

Currently, the following types of process data cannot be represented using MLPM: 1) continuous motions and trajectories, and 2) ontological relationships among component instances. After specifying MLPM in detail and developing several applications, the model will be extended to nullify these limitations.

D. Applications

As mentioned in the previous section, suppose that an junior doctor has to learn how to do an intravenous injection. Although the doctor possesses useful how-to books for self-study of the intravenous injection process, it is impossible to practice the injection on a medical volunteer without a skilled doctor being present. The most difficult problem is how to impart the doctor the know-how and the difference between his/her execution of the injection process and that of skilled doctor, by dynamically checking the injection process. If it were possible to realize such support for a junior doctor, this would draw a better and more natural way to practice a process than looking at a how-to-book.

Moreover, it is also impossible in general to impart the know-how of skilled doctors to junior doctors, because it tends to be difficult to describe the know-how precisely. If the know-how can be extracted by comparing the junior doctor's and skilled doctor's processes and by generating a process rule from many skilled doctors' processes, the know-how can be expressed and thus transferred to junior doctors.

Finally, if the know-how can be extracted, described, and visualized based on a process model and its database, skilled doctors can identify their own skills and know-hows and offer them to aid the development of the best process. Currently, such doctors watch their past videos many times in order to develop the best process, to improve the current process or to solve a problem related to the current process. A process model-based technique, such as our MLPM, can help them to do this more effectively.

Another application of our MLPM, in addition to that for the medical field, is a process model for team sports. A team sport is one that involves people playing together to accomplish a specified goal. Although there are many team sports in the world, we consider ballroom dancing, a sport that involves pairs, as an example. In a ballroom dancing competition, the competitors are judged according to several factors using posture, timing, togetherness, and musicality. After archiving and describing the entire process of a ballroom dance using our MLPM, the dancers can check their process from the abstract to the concrete level by examining the results of the differentiating function of a MLPM-based system or mining the processes using a method based on the MLPM.

The model can also be applied to improve worker's skills. After skilled worker's movements have been captured and the captured data have been annotated and aggregated, the worker's skill processes can be archived using our model. Then, when a novice worker is learning how to do a job, the archived processes can be used effectively by using functions based on the model. That is, the model enables the workers to improve their skills by checking the differences between a skilled worker's process and their own process. The model can also produce a set of rules to a worker learn the skills more easily. Clearly, many studies on the model refinement, model application experience, and MLPM-based mining method development are still necessary.

V. Conclusion and Future Work

In this paper, we proposed a meta model for representing the overall processes from the higher abstract level to the lower actual motion level. The point of the meta model is to introduce a multi-layered process meta model to represent various kinds of representations of processes in an integrated way. We described the basic concept and fundamental components for developing the process meta model.

The proposed MLPM requires further work. In particular, it is necessary to develop 1) detailed specifications of MLPM, 2) methods for matching, searching, and classifying processes using our MLPM, and 3) a new method of process mining from MLPM-based process databases. We also plan to develop a system based on the proposed MLPM after the design of the architecture has been completed.

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