An investigation of discovering business processes from operational databases

Abstract

Process discovery techniques aim to discover process models from event-logs. An event-log records process activities carried out on related data items and the timestamp where the event occurred. While the event-log is explicitly recorded in the process-awareness information systems such as modern ERP and CRM systems, other in-house information systems may not record event-log, but an operational database. This raises the need to develop process discovery solutions from operational databases. Meanwhile, process models can be represented from various perspectives, e.g. functional, behavioural, organisational, informational and business context perspectives. However, none of the existing techniques supports to discover process models from different perspectives using operational databases. This paper aims to deal with these gaps by proposing process expressive artefacts based on process perspectives adopted in the literature, as well as discussing how these artefacts can be extracted from data components of a typical operational database.

Keywords: Process Mining, Process Perspectives, Expressive Artefacts, Business Process Management.

1. Introduction

Process mining has been emerged and become a well-established discipline in the last two decades. Process mining aims to discover, monitor and enhance business processes. Three main applications of process mining are process discovery, conformance checking and process enhancement (W. van der Aalst 2016). The idea of process discovery is to construct process models with information learned from the event log. Then, the discovered process can be represented by popular notations for process modelling such as Petri-net, Business Process Modelling Notation (BPMN), Causal net, among the others. Conformance checking techniques screen an event log to detect deviations between the log and a given process model. The output of this analysis can be used to enhance the "as-is" to "to-be" business process.

Process models play an important role in process mining as they are the target of process discovery. Process models are represented by process modelling languages such as Petri Net (Van Der Aalst 1998) and BPMN (OMG 2011). Also, process models can be described from different perspectives (Curtis, Kellner, and Over 1992). Each perspective illustrates a specific view of the business process. For instance, a functional perspective shows what activities performed in the process. Behavioural perspective indicates the sequence of these activities. Organisational perspective considers participants involving in each activity, and informational perspective describes data objects manipulated by each activity. A process model may contain one or more perspectives depends on user interests and the levels of complexity of the model. The detail on process perspective is described in Section 2.1.

Many process mining techniques have been proposed to provide insights from different angles of business activities in organisations (W. van der Aalst 2016). Most of these techniques require "flat" event log as input. Event log, which is the heart of process mining, should be treated as "the first citizen" (W. van der Aalst et al. 2012). An event-log captures all data relevant to a business process, i.e. contains a set of traces corresponding to instances of a process. Each of the traces includes a set of events representing actions or operations performed in the system. Relevant attributes are also logged to provide semantic meaning to events, traces and the whole process. Example of the event log is shown in Figure 1. Normally, event logs can be easily extracted from process-awareness information systems which are "*a software system that manages and executes operational processes involving people, applications, and/or information sources on the basis of process models*" (Dumas, van der Aalst, and ter Hofstede 2005). Logging process activity execution is a critical part of such systems and the log is perfectly fit with the requirements of an event-log for process mining techniques. However, traditional systems, i.e. non-process-oriented software such as in-house developed or functional-based software, does not provide event log. Traditional systems typically record transactions into relational databases, forming operational databases. Operational data is stored by category, i.e. data of the same category (e.g. Order, Payment, Customer) is recorded in the same table and tables are linked through the primary key-foreign key mechanism. Hence, there is no explicit event log or even the logging data which can be easily transformed to the event log in such information systems. Consequently, it is not trivial to discover and monitor the business process in such traditional information systems.

Case Id	Activity Id	Activity Name	Timestamp
1	1	Place Order	2018-10-11 13:00:04
1	2	Payment	2018-10-12 13:00:04
1	3	Shipping	2018-10-11 13:00:04
2	4	Place Order	2018-10-15 09:23:06
2	5	Payment	2018-10-15 09:23:06
...			

Table 1. Example of an event log for process mining

Several techniques have been developed to apply process mining based on relational databases. For example, Wil M. P. van der Aalst (2015) proposed a notion of event model built on top of data schema to generate event log data. The data schema is also used to correlate event and build event log (Li, Medeiros de Carvalho, and van der Aalst 2018). In addition, Nooijen, van Dongen, and Fahland (2013) developed an automatic approach to discover business processes from a relational database based on data summarisation and clustering techniques. Other solution to utilise operational database for process mining is using redo log (Murillas, Aalst, and Reijers 2015). While these works proof the possibility to apply process mining based on operational databases, none of them supports to discover business process from different perspectives. It is a missing gap needed to be filled, which would give organisations better insight into their operations from various points of view based on process mining.

The first step is to investigate if it is possible to discover business processes from different perspectives using operational databases. To solve this problem, we develop a set of expressive artefacts based on the concepts of process perspectives extracted from the literature. These are functional, behavioural, organisational, informational and business context perspective. They are the most critical information that a business process model needs to cover. Then, we review data components in a typical relational database and assess if they can partly or entirely provide information about expressive artefacts.

This paper includes five sections. Section 1 introduces the context and raises research problems. Section 2 introduces the basic concepts used in the paper including process perspectives and operational database. Section 3 proposes expressive artefacts in process models based on the concept of process perspectives. The assessment of the possibility that data components of object-centric databases can be used to discovered process expressive artefacts is given in Section 4, followed by the conclusion and future works in Section 5.

2. Preliminaries

2.1. Process perspectives

Organisations are running through business processes. Their business importance is already shared among many executives. Weske (2012) defined a business process as of a set of activities that are performed in coordination in an organisational and technical environment. These activities aim to achieve a business goal. A business process may interact with other business processes performed by other organisations. Process mining is becoming popular to help organisations to discover and monitor business processes.

The outputs of process mining techniques are typically process models represented by business process modelling languages (BPM), e.g. Petri Net and BPMN. To accommodate the goal of reflecting a business process, a model must have the capability of providing various informational elements to its users. Such elements include, for instance, what activities/tasks needed to be performed in the process, who conducts these activities, when and where the activities are completed, how and why they are executed, and what informational entities they manipulate. BPM languages vary in the extent to which their constructs express the information that answers these questions. A modelling technique can represent one or more of the following "process perspectives" consisting of "functional", "behavioural", "organisational" and "informational" (Curtis, Kellner, and Over 1992). These terms are mentioned in (Giaglis 2001) and (Mili et al. 2010) as purposes of designers when they construct a business process model. Also, these concepts of perspective have been widely adopted in the literature (Daoudi and Nurcan 2007; Ben Hassen, Gargouri, and Turki 2016; List and Korherr 2006; Letsholo et al. 2014; Hommes and van Reijswoud 2000).

While these perspectives adequately cover information in a single process model, they do not consider the factors of business goals as well as the relationships among processes. Therefore, we need to extend to additional aspects. List and Korherr (2006) extends to business context perspective which refers to overall information of a business process. This perspective is similar to the intentional perspective mentioned in (Ben Hassen, Gargouri, and Turki 2016). In general, they cover the alignment of a business process to its business context such as the overall goals of the process, roles in a broader context and collaboration with other processes. In this article, we use five process perspectives consisting of functional, behavioural, organisational, informational and business context.

- The functional perspective covers the information of what process elements (activities) are being performed.

- The behavioural perspective covers the information of when activities are performed (for example, sequencing) as well as aspects of how they are performed through feedback loops, iteration, decision-making conditions, entry and exit criteria, and so on.
- The organisational perspective covers the information of where and by whom activities are performed.
- The informational perspective covers the information of the informational entities (data) produced or manipulated by a process and their interrelationships.
- The business process context perspective captures critical business process information such as process goals and objectives, input and output of the process as well as the relationship between a business process with other processes in the organisation.

2.2. Operational database

Enterprise information systems typically provide interfaces for interaction with users, i.e. users operate transactions related to one or a set of business objects, e.g. order, customer, payment, on each interface. For example, an e-commerce information system may have different interfaces for Order Management, Customer Relationship Management, Payment, Shipment Arrangement. These transactions then are stored in a relational database, forming an operational database. Transactions of the same category or business object (e.g. Customer) are recorded in the same table (e.g. Customer table) in the database. Also, a table in the database may have relationships with other tables through a primary key-foreign key (PK-FK) mechanism.

Figure 1 shows an example of an object-centric relational database extracted from Odoo, an open source ERP (Enterprise Resource Planning) system. Nine tables are corresponding to different business objects such as Order, Delivery, Customer and Invoice. Each table has a primary key (a field name in bold), one or many foreign keys (a field name in italic-bold) to indicate its relationships with other tables, and other columns (fields), along with data rows.

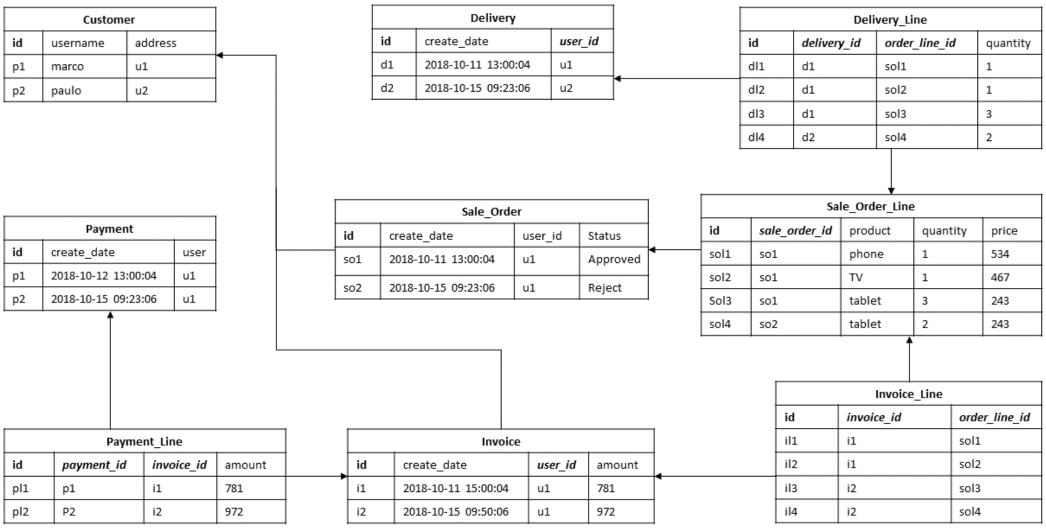

Figure 1. An object-centric relational database in an ERP system

A typical relational database constitutes data components described as follow:

- **Table and Table name:** Tables are the key components of the relational database. A table is used to store information of the same category. A table consists of records. Every record is divided into a field that has a specific data type (e.g. integer text, DateTime.). The table name should refer to the business object whose data is stored in that table.
- **Primary key:** Each table should have a primary key. The primary key is the field that contains unique values. In other words, a primary key is the identifier of a table record.
- **Foreign key:** Foreign keys are particular fields used to connect tables in a database. A foreign key of a table is typically a copy of a primary key of another table, indicating the relationship between them.
- **Field:** Fields are columns of a table. Each field has a particular datatype. The field name may semantically indicate information type in the table (e.g. Username, product name).
- **Data integrity constraint:** Data integrity is applied in a relational database by a set of rules or restrictions. Three types of data integrity can be considered including entity integrity, referential integrity and domain integrity.
- **Redo logs:** Most modern relational database management systems (RDBMSs) provide many mechanisms to ensure data consistency. One of these

mechanisms is redo log, which consists of a set of files in which database operations are recorded before being applied to the actual data. This allows to roll back the state of the database to previous points in time, undoing the last operations affected the database based on redo log files. Example of a redo log can be seen in Table 2 below:

#	Timestamp	Operation
1	2018-10-11 13:00:04	INSERT INTO "ORDER" (id, create_time, user_id) values ("so1", "2018-10-11 13:00:04", u1)
2	2018-10-11 11:34:23	INSERT INTO "SALE_ORDER_LINE" (id, sale_order_id, product, quantity, price) values (sol1, so1, phone, 1, 534)
3	2018-10-11 11:37:23	INSERT INTO "SALE_ORDER_LINE" (id, sale_order_id, product, quantity, price) values (sol2, so1, TV, 1, 467)

Table 2. Redo log example

3. Expressive artefacts in process models

We use five process perspectives adopted from the literature, including functional, behavioural, organisational, informational and business context. In each perspective, we propose a set of expressive artefacts constituting a business process. Each artefact refers to an informative element about an aspect of a business process model. While some artefacts are mandatory to construct a business process, others may be optional. Table 3 below lists expressive artefacts with their explanations.

Process Perspective	Expressive Artefact	Explanation
Functional	Activities	Activities are a set of tasks need to be performed in a business process. An activity can be at a high level, i.e. it contains a set of low-level activity (atom activity). For example, an activity of "Contact Customer" may contain other activities such as "Query a customer" and "Update customer profile". Activities are mandatory artefacts to construct a process model.
	Decision points	The points indicate the route of the workflow, based on specific conditions. For example, if the order value is higher than 2000, it will be sent to the Director for review. Otherwise, it will be sent to the

		inventory department. Here the routing point is after the order is placed, and the routing condition is "higher than 2000". Decision points are optional artefacts as some processes may be linear, i.e. all activities are sequentially performed.
	Activity types	This artefact refers to a type of activities in the business processes. For instance, an activity can be manual or automatic and start or complete. This artefact is optional.
Behavioural	Activity-performed conditions	This artefact defines sequential conditions make activities performed in the business processes. For example, step B is performed after step A. This artefact is mandatory as it is essential to see the order of the activities in the business processes.
	Routing condition	Decision points require specific conditions to route the workflow to a certain way. This artefact is optional; however, it becomes mandatory if the business process contain decision points.
Organisational	Activity Role/Actors	Role/Actors are responsible for performing activities in the business process. Typically, an activity is assigned to a human agent. In some case, an activity can be automatically implemented by the system. Although it is not necessary to indicate activity role in a process model, this artefact will give useful information about the responsibilities of process participants.
	Role relationships	Role relationship refers to the communication between actors involving in a business process. This artefact is optional.
Informational	Activity data objects	This artefact refers to data objects manipulated by activities in the business processes. For example, in the activity of "Place Order", a new order is created in the table "Order", and information of ordered items are added in the table "Order Line". This artefact is optional in a process model.
	Decisive data objects	This artefact describes data objects and values needed for deciding decision points in business processes. This artefact is optional.
	Data value transformations	Values of data objects in the database can be modified after every action is performed in the process. This artefact refers to the ability to record and monitor value changes in relevant data objects across the business process.
Business Context	Goals	This artefact describes information about the purposes of a business process within organisational view. This artefact is optional.
	Process collaboration	This artefact indicates the collaboration of the process with other processes in the organisation.

Table 3. The expressive artefact in process models

4. Discuss the possibility to discover expressive artefacts from operational databases

In this section, we investigate the possibility to extract expressive artefacts (in section 2) from the object-centric database. We discuss if data components in operational databases can be used to retrieve expressive artefacts at two coverage level including (+): fully coverage and (+/-): partly coverage. Fully coverage means the value of the data component can explicitly refer to an artefact while components with partly supporting level may need additional information to construct corresponding expressive artefacts. Along with the analysis, relevant articles are provided as references if they use the data component to extract the corresponding artefacts. The evaluation is summarised in Table 4. All the examples we use in the discussion refer to the object-centric relational database in Figure 1.

Data component	Potential discovered expressive artefacts	Coverage level
Table name	Activities	+/-
	Activity data objects, Decisive data objects	+
Primary key	Activity-performed conditions	+/-
Foreign key	Activities	+
	Activity-performed conditions, Routing conditions	+/-
Field		
Decision tracking field	Decision points	+
Timestamp related tracking fields	Activities	+/-
Timestamp-related fields	Activity-performed conditions	+
User tracking related fields	Activity Role/Actors	+
User tracking related fields	Role relationship	+/-
Integrity constraints	Activity-performed conditions, Routing	+/-

	conditions	
Redo logs	Activities, Activity-performed conditions, Activity Role/Actors, Data value transformations.	+

Table 4. Evaluation of the possibility to extract expressive artefacts based on data components in operational databases

We illustrate the extracting process from the database of the schema in Figure 1 based on the guidelines in table 4 as follows:

4.1. Functional perspectives

Table names can also be used to extract process activities. In some case, one may need information from other sources (e.g. domain knowledge) to identify activities, especially to discover high-level activities in a business process. For example, in the database in Figure 1, one may need to be familiar with the process to identify "Place Order", "Approve order", "Shipping item" activities based on Order, Order Line, Delivery and Delivery Line tables (see in Figure 2). Furthermore, we can combine two or more activities from tables (e.g. Create Sale Order and Create Sale Order Line) to build a higher-level activity (e.g. Place Order).

Timestamp-related fields are also helpful to define process activities. For instance, if the "Order" table contains the field for tracking updating records, e.g. modified date, one can identify that the order can be modified in the processes and that the process contains an "Update order" activity. However, as the timestamp-related fields merely record the current status (e.g. "last update date" field) of the database, the previous status can be missing from the discovery (e.g. an order can be modified three times, but only the last time is recorded). In this case, additional data sources are needed (e.g. redo log) to avoid missing process activity when discovering the process.

The primary key can be used to identify when activities are performed, along with relevant information such as identifiers for activities and process instances. Likewise, a foreign key can be used to extract process activities.

Decision tracking fields can be a good source of detecting decision points in a business process. For example, one can rely on the "Status" field in "Order" table to determine that there should be a decision point after an order is placed. Depending on a specific condition, an order can be "approved" or "rejected". This approach is potential and needs more attention to develop a complete solution.

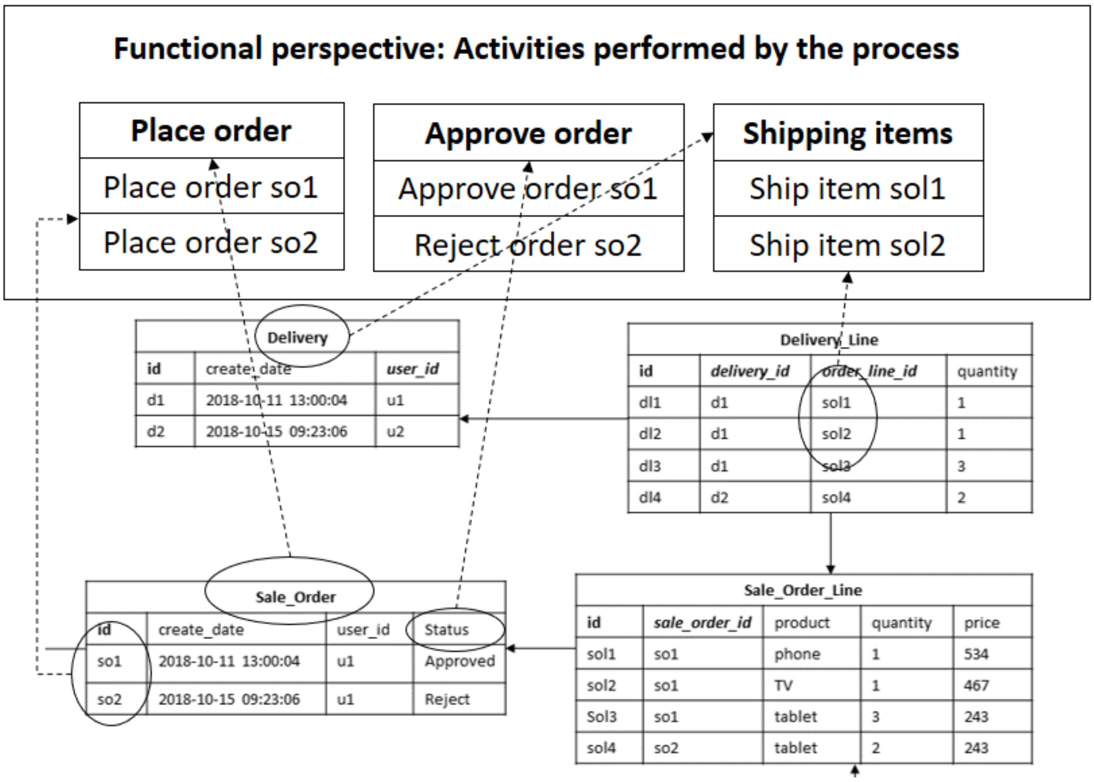

Figure 2. Example of extracting functional perspective process from the operational database

4.2. Behavioural perspectives

Timestamp-related fields are the most appropriate data components to discover the sequence of process activities. For instance, in Figure 3, with the create_date field, one can determine the "Place order (so1)" activity was performed before its payment, followed by the corresponding shipment.

In some case, the primary key may reveal the order of activities if the database uses auto-increment keys (e.g. auto-increment integer number) that we know the row with higher value key is created after the one with lower value key. Furthermore, foreign key, in combination with referential integrity constraint, reveals a part of information about the order of activities in the business process. For example, "Delivery_Line" table contains foreign keys which are "delivery_id" and "order_line_id" linking to the "Delivery" and "Sale_Order_Line" tables respectively. It means that the records (e.g. dl1) in "Delivery_Line" table should be created after the corresponding records in "Delivery" table (e.g. d1) and "Sale_Order_Line" table (e.g. sol1), indicating that the activity of delivery an item should be performed after the item is ordered. This information would be helpful when these tables contain issues such as missing timestamp in individual records. However, there has been no effort implementing this idea in the context of process mining from the literature.

Data integrity constraints can be used to extract many expressive artefacts. We focus more on the possibilities to extract behavioural perspective artefacts. Along with the idea of referential integrity constraints mentioned above, domain integrity constraints may reveal sequential order of activities. For example, with a domain constraint such as "no payment can be made for a rejected order", one may determine that the payment activity should be implemented after the corresponding order is placed and approved. Although this idea is potential, developing a general approach based on data integrity constraints is not trivial because the constraints vary and are set up for specific business contexts.

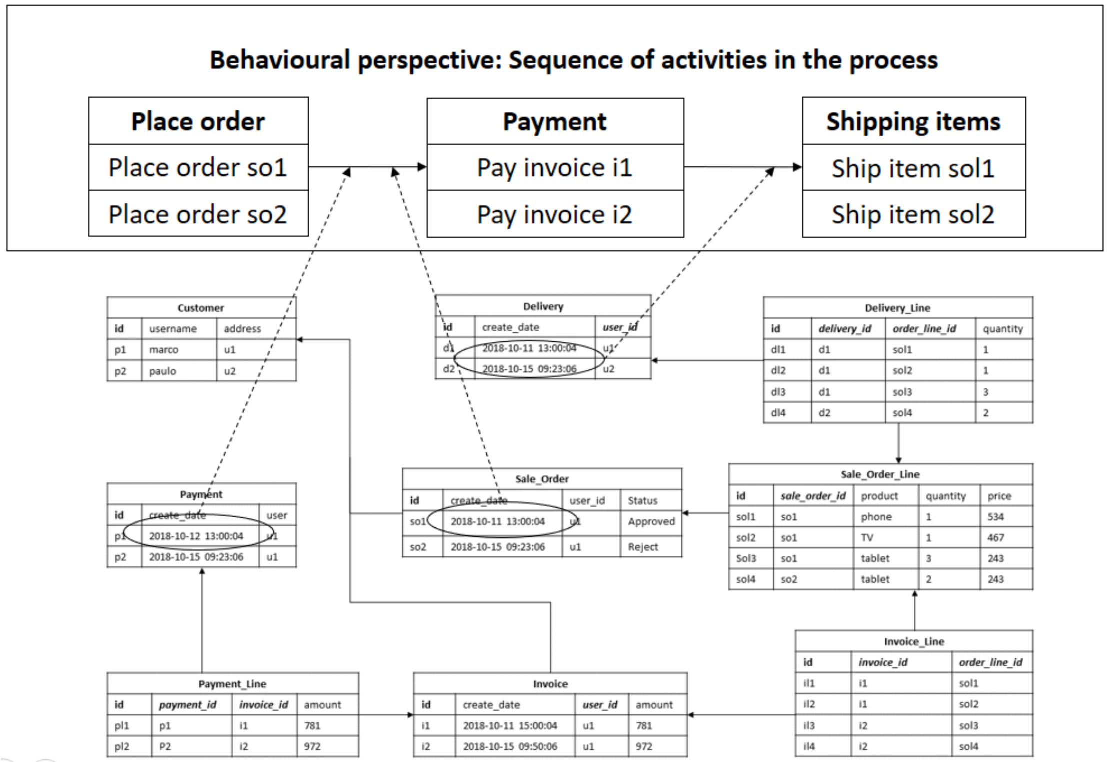

Figure 3. Example of extracting behavioural process perspective using timestamp fields

4.3. Organisational perspectives

User tracking fields (e.g. "create_user" or "modified_by") appears to be the only way to know participants taking part in certain activities in the business process. For example, if the record "d1" is created by "user1", "user1" should be the one assigned to deliver items. Meanwhile, the "Role relationship" artefacts cannot be explicitly extract merely based on the operational database. It may need more support from social network process mining techniques (Wil M. P. van der Aalst and Song 2004) and tools (W. M. P. van der Aalst et al. 2007).

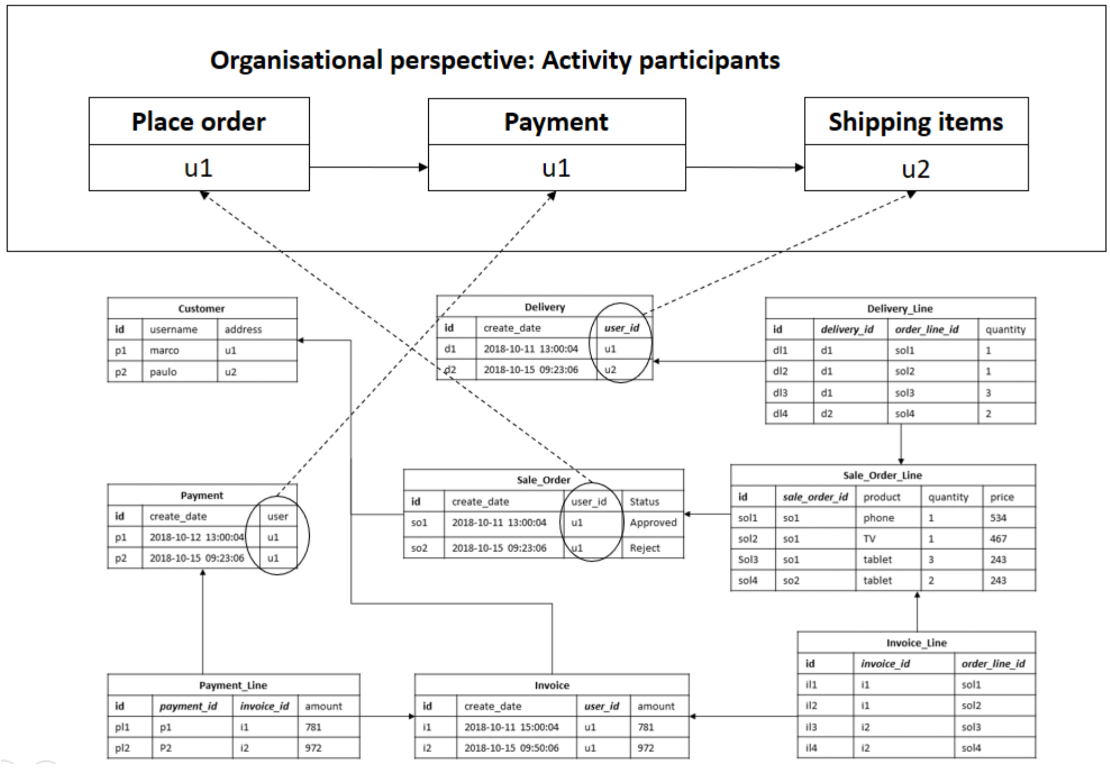

Figure 4. Extracting organisational perspective process from the operational database

4.4. Informational perspectives

Table names are a sufficient source of informational perspective artefacts, as they provide data object manipulated by business processes. For example, if one use “Order” and “Order_Line” tables to identify “Place Order” activity, apparently the activity manipulates two data objects including Order and Order_Line.

Redo log is a convenient source for expressive artefact extraction. As redo logs record all data queries sent by users and the system during the process, this data components can provide information about most of the expressive artefacts across process perspectives, especially for data value transformation which needs to track the change of the database states after conducting each process activity. However, the limitation of this approach is that the redo log is not an essential part of an operational database. They are typically integrated into database management systems with various logging and storage structure. Moreover, data administrators may remove a part of the log (e.g. cleaning the last year log) to ensure the storage ability of the system server, resulting missing information to extract expressive artefacts. Other problem is that when one uses an event in redo log to roll back the corresponding transactions, the relevant event is no longer valid to be included in the process. Hence, this data component requires more attention to ensure the data validity and consistency of the discovered process.

4.5. Business context perspectives

With the relationship between tables in the operational database schema, one may identify the collaboration between discovered business processes. For example, in Figure 4, one may discover two processes consisting of “Order” and “Payment” from the operational database. The Order process includes “Place order”, “Make an invoice” and “Shipping” activities while the Payment process includes “Select invoice” and “Make a payment” activities. As both processes share the invoice data and there is a relationship between Payment, Payment_Line and Invoice tables, the collaboration between “Order” and “Payment” processes can be defined, indicating that both processes are related to each other. More advanced modelling techniques are necessary to represent this perspective, such as Proclet (Van Der Aalst et al. 2001) and Relational business process (Steinau, Andrews, and Reichert 2018).

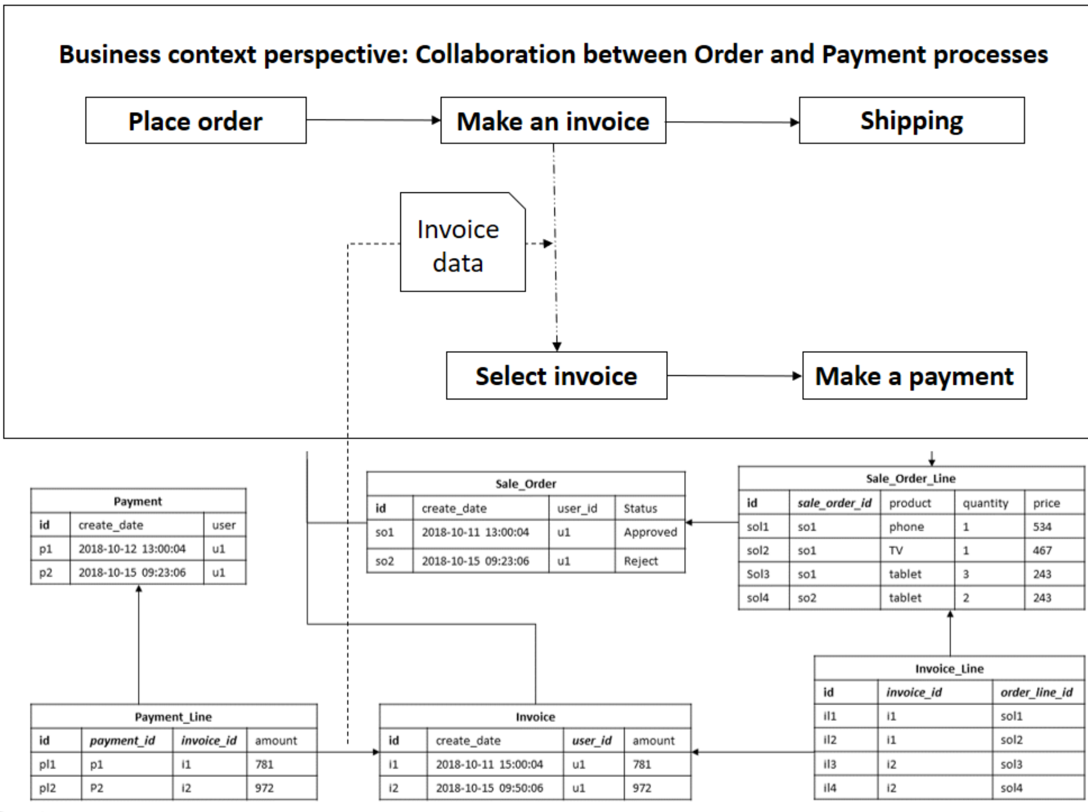

Figure 4. Discover process collaboration from the operational database

5. Conclusion and future work

In this paper, we propose expressive artefacts from five process perspectives (including functional, behavioural, organisational, informational and business context) which are essential to construct a business process model. Then we assess the possibility to discover these artefacts from data components in an operational database. Several ideas to extract expressive artefact based on the database are proposed with a demonstration from an example where possible.

According to our analysis, data components of an operational database can fully provide information about expressive artefacts of "Activities", "Activity data objects", "Decisive data objects", "Decision points", "Activity performed order", "Activity role/ actors", "Data value transformation". However, they merely contain a part of the expressive artefacts of "Activity types", "Routing condition" and "Role relationship". One may need extra information from different sources to fully extract these artefacts, and we need to develop more formal techniques to fill this gap. Meanwhile, all process goal in a business context perspective cannot be obtained based on the operational database. For this artefact, other sources need to be considered with a sufficient approach to combine with existing solutions. Note that when we assess each data component, we assume that the component is available in the database. Hence, if a database does not contain a specific component (e.g. user tracking field), it is impossible to extract process information from an organisational perspective. Existing researches merely develop techniques of extracting event log from operational databases, but they have not considered which perspectives and expressive artefacts covered by the operational database. In the future, we will deal with this problem. A set of measurement method will be developed, along with novel mining techniques to utilise all data components in the operational database.

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