A Model-based Framework to Automatically Generate Semi-real Data for Evaluating Data Analysis Techniques

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Abstract: As data analysis techniques progress, the focus shifts from simple tabular data to more complex data at the level of business objects. Therefore, the evaluation of such data analysis techniques is far from trivial. However, due to confidentiality, most researchers are facing problems collecting available real data to evaluate their techniques. One alternative approach is to use synthetic data instead of real data, which leads to unconvincing results. In this paper, we propose a framework to automatically operate information systems (supporting operational processes) to generate semi-real data (i.e., "operations related data" exclusive of images, sound, video, etc.). This data have the same structure as the real data and are more realistic than traditional simulated data. A plugin is implemented to realize the framework for automatic data generation.

1 INTRODUCTION

Most enterprises are employing information systems, such as enterprise resource planning (ERP), e.g., SAP, customer relationship management (CRM), e.g., salesforce, to handle their business transactions. The amount of data being stored about the transactions is rapidly growing. In order to discover insights from the data, various data analysis techniques (such as data mining and process mining) have been proposed. Accordingly, the evaluation of these techniques becomes a significant task.

Data exist everywhere but it does not mean that we can get appropriate data easily for the evaluation of data analysis techniques. Most of the time, data of enterprises are confidential due to data privacy regulation, e.g., the EU General Data Protection Regulation ("GDPR"). The owners cannot provide the data or can only provide incomplete data (after deleting sensitive information to preserve privacy). Besides, original raw data from information systems usually contain a lot of irrelevant data elements such that data pre-processing is time-consuming.

For this reason, most researchers use synthetic data to evaluate data analysis techniques. However, synthetic data are often generated by simulation (according to the rules defined by users) rather than being derived from operating any real information system (Gray et al., 1994; Hoag and Thompson, 2009). As a result, the evaluation based on such data is not convincing since synthetic data may be quite different from the data generated by real information systems.

In order to solve these problems, this paper proposes a framework to generate "semi-real" data, which is easier to collect than real-life data and is more "realistic" than synthetic data. The basic idea is to (i) derive a log of click events by simulating a designed model and (ii) transform click events into real operations on information systems which support operational process, e.g., BPM, ERP, etc. Note that, the generated data are "operations related data" consisting of the business process transactions, which do not include images, sound, video, etc.

Figure 1 presents the framework of our approach and the context of evaluating data analysis techniques (Mans et al., 2010). First, a model is designed in *CPN Tools* (cf. Section 2) to indicate how an information system should be operated, which implicitly decides the profile of generated data.[1] By simulating the model, a simulation log consisting of click events is generated. The click events control the information system execution by transforming each click event

[1]http://www.cpntools.org.

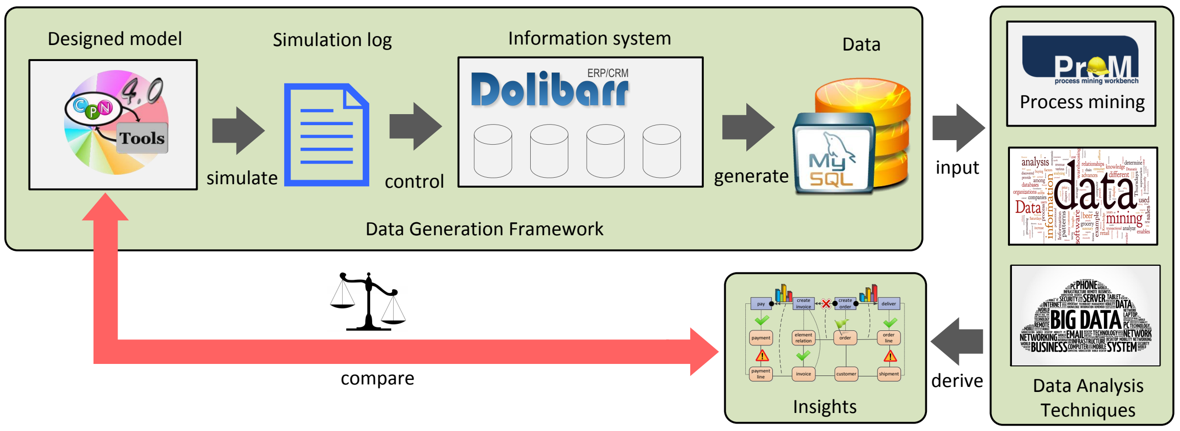


Figure 1: The framework for automatically generating data in the context of evaluation of data analysis techniques.

into a real click on the interfaces of the information system. In this way, the designed model is automatically executed in the information system, which results in a large set of data in the corresponding data repository, e.g., databases. Considering a Data Science context, various techniques can be employed to derive insights using the generated data as input (Li et al., 2018b; van der Aalst et al., 2017). By comparing the derived insights with the knowledge from the designed model, the techniques can be evaluated.

Our approach has the following contributions compared with existing approaches: (i) Simulation logs rather than humans are used to control the execution of information systems. As a result arbitrary amounts of data can be generated. This is not possible when the system is operated manually. (ii) Data are generated by real information systems and they can capture the complex structures of the real systems as the real-life data. Using existing approaches, it is impossible to recreate such rich data without coding the information systems in the simulation model, since the data inside such systems are collections of interrelated tables rather than simple tabular data.

The remainder is organized as follows. Section 2 briefly introduces how to design and simulate a model in *CPN Tools*. Using the simulation log derived by simulating the model, Section 3 illustrates how to automatically operate information systems and generate semi-real data. The framework is implemented as a ProM plugin, which is introduced through a case study in Section 4. Section 5 discusses the related work and Section 6 concludes the paper.

2 MODEL SIMULATION

As shown in Figure 1, in order to automatically operate the information systems in a customized manner, one first needs to design a model and derive a simulation log by simulating the model. In this section, we explain how to accomplish these two tasks using the *CPN Tools*.

2.1 CPN Tools

Petri nets are probably among the best studied process modeling languages and allow for describing systems involving communication, concurrency, synchronization and resource sharing (Murata, 1989). They are more expressive than other modeling languages such as FSMs, and have been successfully used for specification of workflow processes (van der Aalst, 1998). A Petri net is a directed bipartite graph which uses a very simple notation of circles representing places and squares representing transitions with arrows connecting them. Although the graphical notation is intuitive and simple, Petri nets are executable and many analysis techniques can be used to analyze them.

Colored Petri nets (CPNs or CP-nets) extend Petri nets with data. Tokens may have data values, often referred to as "color", which describes the properties of the object modeled by a token (Jensen, 2013; Jensen and Kristensen, 2009; Zervos, 1977). Besides, each token has a timestamp, which indicates the earliest time at which the token may be consumed. Transitions can assign a delay to produced tokens, and waiting and service times can be modeled in this way. Due to the extension, CPNs can deal with data-related and time-related aspects.

CPN Tools is a toolset providing support for editing, simulating, and analyzing CPNs. It basically comprises two main components, a graphical editor and a backend simulator component. Next, we illustrate how to edit and simulate a CPN using these two components, respectively.

2.2 Designing Models

In this section, we describe how to design the model in terms of a CPN using CPN Tools. The model specifies the scenario in which the information system is operated and decides what kinds of data are generated. For instance, if one wants to generate data including transactions such as “create order”, “create invoice” and “create payment”, a model to specify an *Order-to-Cash* (OTC) scenario can be designed.

Figure 2 presents a CPN to describe the OTC scenario of an open source ERP system Dolibarr.[2] A CPN can have a hierarchal multiple-level structure (i.e., transitions depicted by doubled squares). For instance, Figure 2 shows the business process on the top level and Figure 3 shows a sub-process for the “create order” transition in Figure 2. In order to control the CPN in Figure 2, we first assign an initial token with an attribute $id = 1$ to the “start” place. This token enables the “generator” transition to generate scheduled orders if its condition is satisfied, i.e., $id < 50$. In other words, this condition can be used to control the number of scheduled orders. Besides, we assign proper time delay between each two scheduled orders. The function *delay* attached to the “generator” transition controls the frequency of scheduled orders. For instance, $delay(week/100.0)$ means that 100 orders are scheduled in one week.

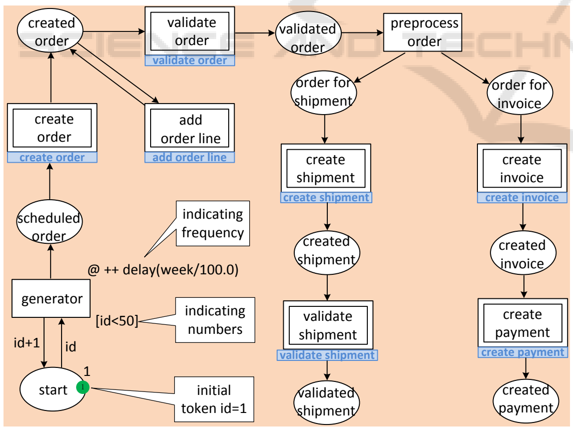


Figure 2: A CPN describing the OTC scenario.

In a CPN, each token has a corresponding class, which indicates the colors (i.e., attributes) added on the token. Therefore, some classes are created for the involved entities in the business process, such as “order”, “invoice”, etc. Note that, the attributes of each class conform to the attributes of its corresponding

[2]Dolibarr ERP/CRM is an open source (webpage-based) software package for small and medium companies (www.dolibarr.org).

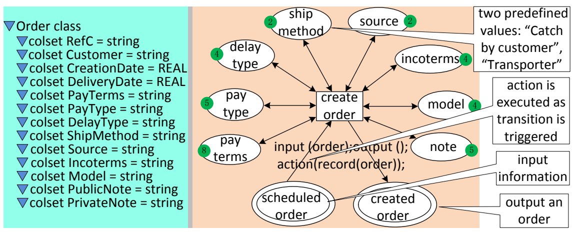

```
▼Order class
  ▼colset RefC = string
  ▼colset Customer = string
  ▼colset CreationDate = REAL
  ▼colset DeliveryDate = REAL
  ▼colset PayTerms = string
  ▼colset PayType = string
  ▼colset DelayType = string
  ▼colset ShipMethod = string
  ▼colset Source = string
  ▼colset Incoterms = string
  ▼colset Model = string
  ▼colset PublicNote = string
  ▼colset PrivateNote = string
```

Figure 3: The order class and its attributes in the sub-process for the “create order” transition in Figure 2.

entity in the interface. Consider for example the interface for creating an order in Figure 5. An order has attributes such as “Ref.customer”, “Customer”, etc. Accordingly, we build an “order” class with the same attributes as shown in Figure 3.

In order to make the generated data as realistic as possible, we predefined possible values for some attributes. For instance, the “ship method” attribute has two predefined values: “Catch by customer” and “Transporter” (referring to the values in Dolibarr). During the simulation, one value is randomly selected as the attribute value. Differently, the time attributes (e.g., “CreationDate”) derive their values based on the timestamps of tokens. For instance, when the “create order” transition is triggered, the current timestamp is assigned to the “CreationDate” attribute.

2.3 Simulating Models

In order to generate data on a large scale, we need a “robot” to automatically operate the information system (e.g., fill in attributes and click buttons) like a human. Our approach (as shown in Figure 1) supports to control the operation of the “robot” in a customized manner. More precisely, by simulating the designed CPN in Section 2.2, a simulation log consisting of a list of click events (with attributes) is derived, which tells the robot how to operate the system.

The simulation process is reflected by the flow of tokens through a CPN, governed by the firing rules illustrated next. A transition can represent a task and when triggered it consumes one token from each of its input places and produces a token in each of its output places. In this way, tokens are moved between places to trigger transitions. Note that, each transition may have a corresponding function. When the transition is triggered, the function is executed which can output some information in a simulation log. Consider for example the “create order” transition in Figure 3. When it is triggered, the “record” function is executed, which writes a click event in the simulation log, as shown in Figure 4.

Based on the rules explained above, the simulation process is described next. The initial token en-

```
<log>
    <event>
        <activity>create_order</activity>
        <refCustomer>customer_1</refCustomer>
        <customer>Sander</customer>
        <orderDate>12/03/2018</orderDate>
        <deliveryDate>12/07/2018</deliveryDate>
        <payTerms>60 days</payTerms>
        <payType>Check</payType>
        <availabilityDelay>3 weeks</availabilityDelay>
        <shipMethod>Transporter</shipMethod>
        <source>Sponsorship</source>
        <incoterms>CIF</incoterms>
        <model>einstein</model>
        <publicN>customer order</publicN>
        <privateN>VIP membership</privateN>
    </event>
    ...
</log>
```

Figure 4: A segment of a simulation log.

ables the "generator" transition. When it is triggered, it produces a scheduled order. Then an order is created by the "create order" transition, and one or more order lines are added into the order by the "add order line" transition. After validating the order by the "validate order" transition, the "create shipment" transition packs the orders and "create invoice" transition creates invoices for the orders in parallel. Note that, there exists a one-to-many relation between orders and shipments (Dolibarr does not support creating a shipment for multiple orders), and a many-to-many relation between orders and invoices. At last, the shipments are validated and invoices are paid. By repeating the above process, a simulation log is derived as shown in Figure 4.

3 AUTOMATIC DATA GENERATION

In general, it is impossible or at least time-consuming to create a large enough data by manually clicking buttons in information systems. Therefore, Section 2 presented a method to derive a simulation log (by designing and simulating a CPN) for controlling automatic execution of information systems. In this section, we illustrate how to transform click events from the simulation log into real clicks in information systems to generate data. Note that, we call this kind of data "semi-real" because it has the same structure as real data generated by the same information system, but with different attribute values.

3.1 Identifying Interface Elements in Information Systems

A large variety of information systems one encounters in companies nowadays are webpage-based (or browser-based) systems. A webpage-based application is any program that runs inside a web browser.[3] A web browser can have a graphical user interface, like Internet Explorer / Microsoft Edge, Mozilla Firefox, Google Chrome, Safari. The webpage usually is written in HTML or a comparable markup language. Web browsers coordinate various web resource elements, such as style sheets and images, to present webpages.

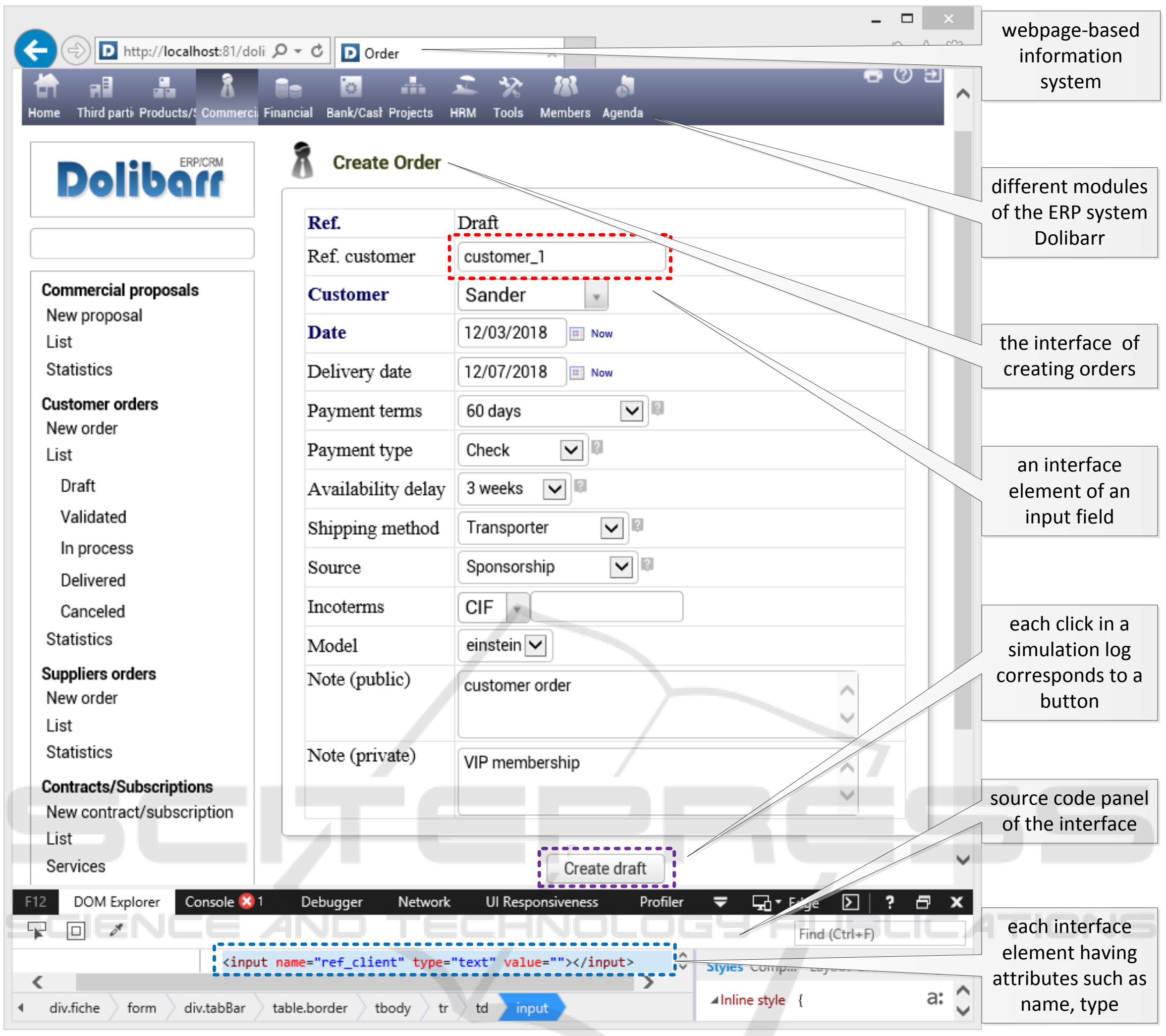
Dolibarr is a webpage-based information system and Figure 5 shows its interface for creating orders. As one can see on the menu bar, Dolibarr has moduels such as "Products", "Commercial" and "Financial" to support functionalities such as sales, finance & billing, product & stock, etc. The "Create Order" interface has different interface elements, such as labels, input fields, drop-down menu and buttons. One can manually fill in the required attributes and create an order by clicking the "Create draft" button. However, it is impossible to generate large-scale data in a short time by manually interacting with the system. A method to solve this problem is to fill in attributes and click buttons automatically by searching interface elements, as explained as follows.

Each element on webpages has some properties (on the source code perspective) such as "name", "type" and "value", which can be used to identify the element.[4] Consider for example the input field highlighted in the red square in Figure 5. The bottom panel, in the blue square, presents the source code of the input field. More precisely, it has three attributes "name", "type" and "value", whose values are "ref_client", "text" and "", respectively. These attribute names and values can be used to identify interface elements through some functions. For instance, the PHP language is widely used to encode webpage interfaces and it provides functions such as "getElementsByTagName" to return an element by inputting the tag name.

Our plugin (cf. Section 4.1) employs the above functions to identify elements based on tag names configured by users. If information systems are not webpage-based, robotic process automation (RPA) techniques (van der Aalst et al., 2018) can be employed to identify interface elements. For instance, the company "UiPath" develops a platform "UiPath Robot" to automatically execute business processes

[3]http://www.businessdictionary.com/definition/browser-based-applications.html.

[4]https://www.w3schools.com/html/html_elements.asp.



http://localhost:81/doli

Order

Home Third parti Products/S Commerci Financial Bank/Cast Projects HRM Tools Members Agenda

Dolibarr ERP/CRM

Commercial proposals
New proposal
List
Statistics

Customer orders
New order
List
Draft
Validated
In process
Delivered
Canceled
Statistics

Suppliers orders
New order
List
Statistics

Contracts/Subscriptions
New contract/subscription
List
Services

Create Order

Ref.	Draft
Ref. customer	customer_1
Customer	Sander
Date	12/03/2018 Now
Delivery date	12/07/2018 Now
Payment terms	60 days
Payment type	Check
Availability delay	3 weeks
Shipping method	Transporter
Source	Sponsorship
Incoterms	CIF
Model	einstein
Note (public)	customer order
Note (private)	VIP membership

Create draft

F12 DOM Explorer Console 1 Debugger Network UI Responsiveness Profiler Edge

```
<input name="ref_client" type="text" value=""></input>
```

div.fiche form div.tabBar table.border tbody tr td input

Find (Ctrl+F) Styles Comp... Inline style {

webpage-based information system
different modules of the ERP system Dolibarr
the interface of creating orders
an interface element of an input field
each click in a simulation log corresponds to a button
source code panel of the interface
each interface element having attributes such as name, type

Figure 5: The interface for creating a customer order in Dolibarr.

on common information systems (including non-webpage-based systems).[5] These techniques can be referred to apply our approach to more general information systems.

3.2 Replaying Simulation Logs onto Interfaces

Section 3.1 proposed a method to identify the interface elements based on the source code and functions. It builds a mapping between click events (and their attributes) in the simulation log and buttons (and their attributes) on the interfaces. In this part, we illustrate how to replay a simulation log onto the interfaces of information systems, i.e., filling in attribute values and triggering buttons.

[5]https://www.uipath.com.

Consider for example the click event in Figure 4 and the interface in Figure 5 to understand the replaying process. The click event has a special attribute "activity" with a value of "create_order", which indicates that this event is replayed onto the "Create Order" interface. After entering the corresponding interface, the attribute values of the click event are filled into the corresponding interface elements. This can be automatically done by the implemented plugin (cf. Section 4.1) because PHP provides a function *setAttribute* to fill a value into an interface element, e.g., *RefC.setAttribute("Value", "customer_1")* fills the value "customer_1" into the input field "RefC" in the red square in Figure 5.

Based on the method introduced above, all the attribute values of the event click are filled into corresponding interface elements, resulting in the filled interface in Figure 5. Then the "Create draft" button can be triggered using the function *click* provided by PHP, just like a real person clicking the button. Afterwards, another interface pops up, on which the next click event is replayed. Note that, the order of click events in the simulation log should totally match the order of interfaces in the information system.

Information systems have data sources to store the executed business processes in the interfaces, e.g., Dolibarr has a corresponding database which stores information of all created objects. When the interfaces of the information system are operated automatically, the corresponding tables in the database are populated. For instance, when the "Create draft" button is triggered in the interface (i.e., an order is created), a new row is immediately added into the "llx_commande" table to record the information filled in the interface. By replaying the simulation log, an arbitrarily large amount of records can be added into different tables in the database.

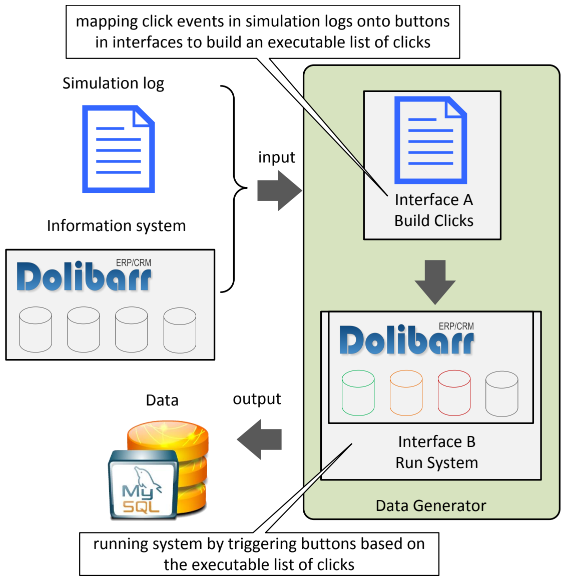

mapping click events in simulation logs onto buttons in interfaces to build an executable list of clicks
Simulation log
input
Interface A
Build Clicks
Information system
Dolibarr ERP/CRM
Data
output
Interface B
Run System
Data Generator
running system by triggering buttons based on the executable list of clicks

Figure 6: The architecture of the data generator.

4 IMPLEMENTATION AND CASE STUDY

We have now introduced all the involved ingredients in the data generation framework shown in Figure 1. In this section, we show how to generate semi-real data using a case study based on Dolibarr.

4.1 Data Generator

The part of the framework in Figure 1 which controls the automatic execution of information systems based on the simulation log, has been realized as a plugin named *Data Generator* in ProM.

Basically, the generator takes a simulation log and a webpage-based information system as input and generates data in the database connected to the system as shown in Figure 6. It consists of two interfaces: "Build Clicks" (denoted as Ⓐ) and "Run System" (denoted as Ⓑ) as shown in Figure 7. More precisely, interface Ⓐ builds an executable list of clicks by mapping click events in simulation logs onto buttons in interfaces, while interface Ⓑ runs the system by triggering buttons based on the executable list.

Figure 7 shows the details of interface Ⓑ, which is the main component to control the execution of the information system. The basic idea is to embed the system into the interface, and control the execution of the system based on the click list. More precisely, panel ② presents the click list while panel ③ shows the related attribute for the focused click. Panel ④ is used to fill in the website address and login. After providing the home page of the system, one can press "run" button in panel ① to start running Dolibarr system. Panel ⑤ displays the state of Dolibarr system after each click, which is the same as operating Dolibarr in a browser. It is possible to suspend the execution using the "stop" button in panel ① and resuming the execution using the "run" button. In order to investigate the details, one can press the "execute one" button to execute the click one by one.

4.2 Generated Data

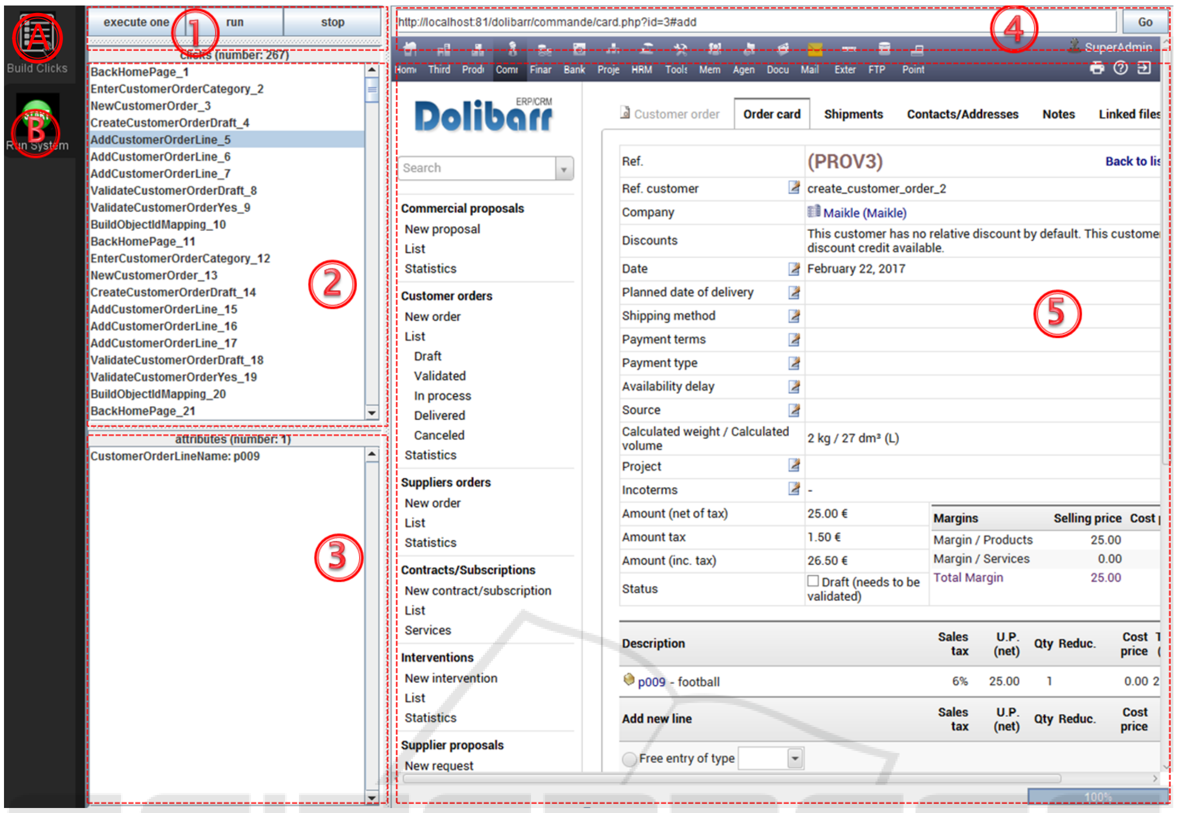
After running Dolbiarr system, the corresponding database is populated with the generated data. In the database, there are in total 148 tables involved in all business processes (e.g., OTC and PTP) supported by the Dolibarr system. All the table names have the same prefix "llx_".[6]

Table 1: A segment of the tables in the Dolibarr system.

Index	Table name	Alias	Description
1	llx_commande	order	record order information, such as customer, time, note
2	llx_commandedet	order line	record items information, such as product, quantity, price
3	llx_societe	customer	record customer information, such as name, phone, address
...	...	...	...

Table 1 presents some database tables involved in the OTC scenario. For instance, the "llx_commande"

[6]https://wiki.dolibarr.org/index.php/Category:Table_SQL.



Clicks (number: 267)

BackHomePage_1
EnterCustomerOrderCategory_2
NewCustomerOrder_3
CreateCustomerOrderDraft_4
AddCustomerOrderLine_5
AddCustomerOrderLine_6
AddCustomerOrderLine_7
ValidateCustomerOrderDraft_8
ValidateCustomerOrderYes_9
BuildObjectIdMapping_10
BackHomePage_11
EnterCustomerOrderCategory_12
NewCustomerOrder_13
CreateCustomerOrderDraft_14
AddCustomerOrderLine_15
AddCustomerOrderLine_16
AddCustomerOrderLine_17
ValidateCustomerOrderDraft_18
ValidateCustomerOrderYes_19
BuildObjectIdMapping_20
BackHomePage_21

attributes (number: 1)

CustomerOrderLineName: p009

http://localhost:81/dolibarr/commande/card.php?id=3#add

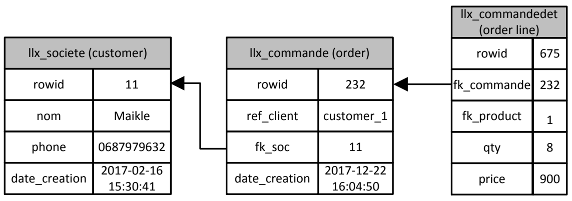
Ref.	(PROV3)
Ref. customer	create_customer_order_2
Company	Maikle (Maikle)
Discounts	This customer has no relative discount by default. This custome discount credit available.
Date	February 22, 2017
Planned date of delivery	
Shipping method	
Payment terms	
Payment type	
Availability delay	
Source	
Calculated weight / Calculated volume	2 kg / 27 dm³ (L)
Project	
Incoterms	-
Amount (net of tax)	25.00 €
Amount tax	1.50 €
Amount (inc. tax)	26.50 €
Status	Draft (needs to be validated)

Margins	Selling price	Cost p
Margin / Products	25.00	
Margin / Services	0.00	
Total Margin	25.00	

Description	Sales tax	U.P. (net)	Qty	Reduc.	Cost price
p009 - football	6%	25.00	1		0.00

Figure 7: The “Run System” interface of the *Data Generator*.

table records all information related to customer orders. Each table has some columns to store the input attribute values in interfaces, e.g., “llx_commande” has columns such as “rowid”, “ref_client”, “fk_soc” and “date_creation”, and the “ref_client” column stores the input values in the “Ref.customer” filed in Figure 5.



llx_societe (customer)	
rowid	11
nom	Maikle
phone	0687979632
date_creation	2017-02-16 15:30:41

llx_commande (order)	
rowid	232
ref_client	customer_1
fk_soc	11
date_creation	2017-12-22 16:04:50

llx_commandedet (order line)	
rowid	675
fk_commande	232
fk_product	1
qty	8
price	900

Figure 8: A segment of the data model of the generated data in Table 1.

Figure 8 presents a segment of the data model of the generated data, which specifies the table columns and reference relations between tables. For instance, the column “fk_soc” in the “llx_commande” table corresponds to a foreign key which references the primary key (i.e., “rowid”) of the “llx_societe” table. Each table in Figure 8 has an example record. The record in the “llx_commande” table references the record in the “llx_societe” table, as the value of the column “fk_soc” is equal to the value of the column “rowid” in “llx_societe”.

The generated data have the same structure as the real-life data and contain complex relations such as the many-to-many relation between orders and deliveries. Therefore, the data can support the evaluation of data analysis techniques (Li et al., 2017; Mans et al., 2010; Li et al., 2018a).

5 RELATED WORK

In this section, we review the existing approaches used to generate data in both commercial and academic fields.

Commercial synthetic data generation products (Centre, 2018; Global Software Applications, 2018; IRI, 2018) do a good job producing moderate amounts of simply defined data through polished and intuitive user interfaces. However, they have limited range of representation and are not easy to describe some types of functional dependencies, relations and intra- and inter-table constraints (Hoag, 2008).

Data generation tools have been developed in the academic world as well (Scott and Wilkins, 1999; Lin et al., 2006). These present new concepts in the form of graph- and language-oriented synthetic data description, providing greater flexibility in the description and generation of synthetic data. An approach was proposed in (Gray et al., 1994) to generate special-purpose data sets in parallel. It converts a simple sequential load into a parallel load, which turns a two-day task into a one-hour task. (Bruno and Chaudhuri, 2005) introduces a Data Generation Language (DGL), to generate databases with complex synthetic distributions and inter-table correlations. (Mans et al., 2010) proposed experimental frameworks to generate event data and specify, develop, test, and validate the operational performance of systems.

Our approach differs from previously published approaches in some aspects. First, the data are generated by real information systems, such that it always has the same structure as the real-life data. Existing approaches can also generate the "semi-real" data, but they require more efforts such as investigating the data schema and how operations in the information system change the database. Second, the user can design a business process to control the execution of information systems.

6 CONCLUSION

This paper proposes a framework to automatically generate semi-real data. Indicated by the name, the generated data are located between real-life data and purely synthetic data. More precisely, it is generated by automatically operating real information systems, e.g., an ERP system Dolibarr. Therefore, it has the same data structure as real-life data. The attribute values in the data are created based on domain knowledge and these may not be as precise as the values in real-life data.

The framework is implemented as a ProM plugin to support automatically operating on information systems based on a simulation log (derived by simulating a design model). Based on the generated data and the designed model, various analysis techniques can be verified.

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