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PERSONALIZATION OF BUSINESS PROCESS EXECUTION IN ENTERPRISE APPLICATIONS

Summary of Doctoral Thesis

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The defense of the thesis submitted for the doctoral degree in engineering science (Information Technology) will take place at an open session at the Faculty of Computer Science and Information Technology of Riga Technical University, in 1/3 Meza Street, auditorium 202, at 14^{30}, on October 6, 2014.

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DECLARATION

I hereby confirm that I have developed this thesis submitted for the doctoral degree at Riga Technical University. This thesis has not been submitted for the doctoral degree at any other university.

Inese Šūpulniece ……. (*Signature*)

Date: ……

The doctoral thesis is written in Latvian. It consists of introduction, 5 sections, conclusions, bibliography and 8 appendixes. It includes 47 figures and 18 tables. The thesis is printed on 132 pages. The full bibliography comprises 189 entries.

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GENERAL DESCRIPTION OF THE THESIS

Introduction

Business process is a structured set of activities ordered across time and space to produce a specific result for a particular customer or market [39]. Each activity can be executed by the particular role. Enterprise applications are used to perform enterprise's daily activities, which are realized in the form of business process. Enterprise resource planning system (ERP system) is a central enterprise application. It integrates information and information-based processes within and across functional areas in an organization. While a lot of money has been spent on implementing ERP systems, previous research indicates that potential users underuse them [30]. The ERP systems are monolithic and usually are not user-friendly [76, 99, 132, 156, 172].

Usability is a set of attributes bearing on the effort needed to learn the application, to prepare input data and to understand output data [6]. Usability of an application is characterized by efficiency and user attitude. It encompasses user-friendliness.

Poor usability of an enterprise application decreases business process execution efficiency, because 1) it is difficult to learn the application for a new employee; 2) it is difficult to execute an ad-hoc process without a special help; 3) amount of errors is increased. The main research problem is to improve business process execution efficiency in enterprise application from the usability perspective. Several approaches exist to improve the business process execution efficiency [60], and adaptation is one of those.

Adaptation definitions imply the notion of changing an object to meet some specific requirements or purpose [54]. The user adaptive application is an application, which adapts its behavior to the individual user on the basis of nontrivial inferences from information about the user [82]. Research on the user adaptive applications is fragmented focusing on individual aspects of these applications, and users often are not satisfied with the result of adaptation. Partially this is caused by the lack of generic theoretical analysis about essence of adaptation and causes of adaptation success or failure. Thus one of the tasks for the thesis is to develop a conceptual model of user adaptive application.

The adaptation process of user adaptive application includes personalization if personally identifying user information is utilized. Business process execution personalization is acquisition, processing and utilization of the information about the link between business process activities and users. The process consists of several activities and there are many alternatives how to execute the same or similar processes. Business process execution patterns are frequently observed sequences of business process activities. Personalized business

process execution patterns are executed by a particular user. There are few investigations of business process execution personalization in the context of enterprise applications, and empirical evidence concerning existence and effectiveness of the business process execution patterns and evaluation is patchy.

User Adaptive Enterprise Application (UAEA) is an enterprise application, what adapts to the user and business process. Its goal is to improve usability of enterprise applications supporting partially structured and ad-hoc processes, which allow for variability in activity execution sequence subject to the constraints imposed by business rules.

Research motivation

Poor usability of enterprise applications is documented in industry reports [64, 70, 75, 132] and academic investigations [36, 172]. Existing literature emphasizes the need for enterprise application's user interface usability improvements (e.g., [156]), personalization [118], and automated navigation support.

Today, user interfaces of large commercial enterprise applications are obsolete and do not use the latest technologies. Some researchers (e.g., [98]) argue for replacing them with modern user interface elements, e.g., touchscreens. This solution would be the most effective, however large enterprise applications are complex and implemented in medium and large international enterprises with a complex structure. Thus, transition to a new application version with completely a new graphical interface would require at least 10 years. These enterprises have invested a lot of resources in implementation of the current enterprise application. New investments would prolong the return of investments period. Employees also have already faced the changes in their processes after enterprise application implementation and will resist to additional changes.

In this thesis a solution for the transition period to new modern enterprise applications is proposed. The proposed solution can be attached to existing enterprise application without changing them. It can be employed during development of innovative enterprise application graphical interfaces, too.

Goal and the tasks of the thesis

The goal of the thesis is to improving usability of enterprise application using process orientation, adaptation and personalization.

To achieve this goal, the following tasks are specified:

1) To review state of the art of enterprise application usability issues and available solutions;

2) To analyze the conceptual aspects of adaptation and user adaptive applications;
3) To elaborate a user adaptive application modeling approach;
4) To apply the modeling approach developed for defining and describing the concept of user adaptive enterprise application;
5) To evaluate potential of business process personalization;
6) To develop the adaptation algorithm for one component of the user adaptive enterprise application – Adaptive Navigation Support (ANS);
7) To evaluate ANS impact on enterprise application usability.

Theses to be defended

The main hypothesis:

H - Business process personalization improves enterprise application usability.

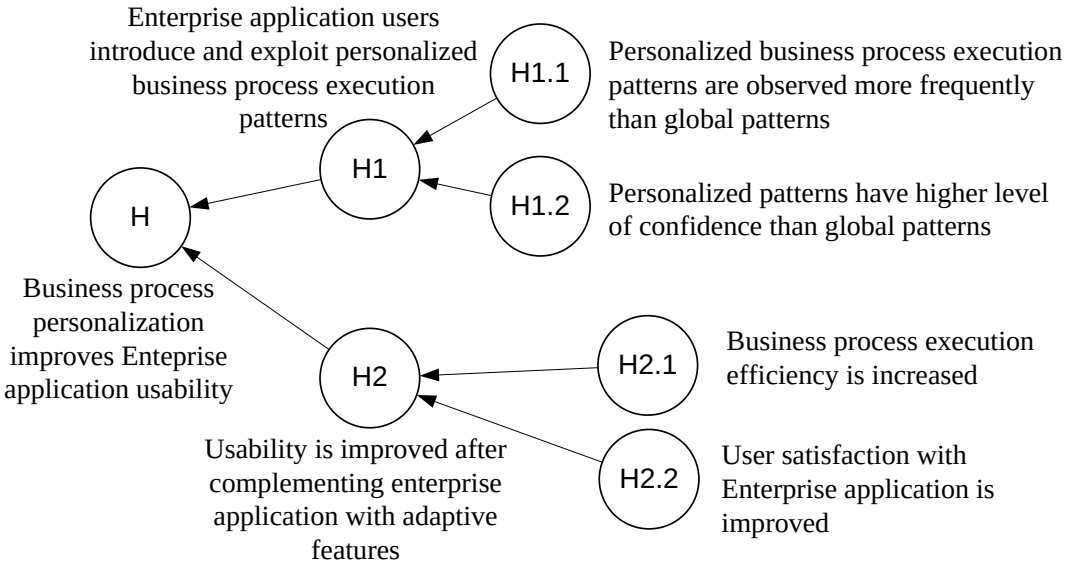

Fig. 1. Theses to be defended

Sub-hypotheses (Fig. 1):

H1 – Enterprise application users introduce and exploit personalized business process execution patterns.

H1.1 – Personalized business process execution patterns are observed more frequently than global patterns.

H1.2 – Personalized patterns have higher level of confidence than global patterns.

H2 – Usability is improved after complementing enterprise application with adaptive features.

H2.1 – Business process execution efficiency is increased.

H2.2 – User satisfaction with enterprise application is improved.

Research object and subject

Research object is the usability of large enterprise applications, e.g., ERP systems. Research subject is a user adaptive application utilizing business process personalization.

Research methods

A seven step approach is applied for the described research (Fig. 2): 1) Literature review; 2) Conceptual development of user adaptive application; 3) Description of adaptive enterprise application; 4) Empirical evidence of business process personalization; 5) Development of adaptation algorithm; 6) Adaptation algorithm evaluation; 7) Suggestions for enterprise application improvements.

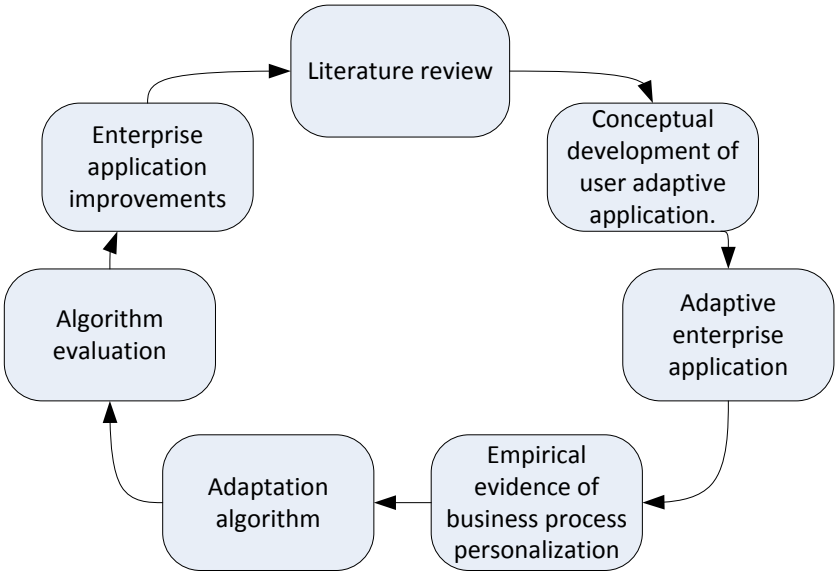

Fig. 2. High level approach

The usability problem is described using a qualitative research method – literature review. The literature review is done according to a descriptive/interpretive research approach.

A conceptual development allows identifying and analyzing conceptual artefacts. An input/output model is used during a conceptual development. The user adaptive application meta-model is applied during defining a user adaptive enterprise application.

An experiment is executed to gather the empirical evidence of the business process personalization. Two hypotheses are defined and approved using the five step methodology: (1) data preparation; (2) finding global patterns; (3) finding personalized patterns; (4) filtering of the results; (5) evaluation of global and personalized patterns. Temporal data and process mining techniques are applied in the pattern finding steps. Pattern efficiency is measured using cross-tabulation. The hypotheses are verified using the non-parametric Mann-Whitney test.

The adaptation algorithm is developed with the following framework: (1) a literature review; (2) conceptual modeling of the ANS component and creating the architecture; (3) algorithm description using an input/output data model and a block diagram; (4) algorithm initial testing using a cognitive walkthrough; (5) prototyping using software engineering methods.

The ANS algorithm is evaluated during a controlled experiment. Data are gathered with direct observation, which is an ethnography method; user actions logging and the questionnaire. Results are analyzed using the quantitative positivist perspective [160]. Quantitative data are analyzed using the ANOVA method [95]. The results of direct observation are analyzed using an interpretative approach.

Scientific novelty

The main scientific contribution of the thesis is formulation of the user adaptive enterprise application and development of the adaptive navigation support algorithm.

The scientific novelty of the results obtained is:

1) Identification of the user adaptive application specific objects as stakeholder, goals, end-user and expectations. Understanding these objects is crucial to improve the adaptation efficiency.
2) Defining the concept of the user adaptive enterprise application.
3) Development of the user adaptive application modeling meta-model. The proposed meta-model supplements traditional software modeling approaches as complementary modeling dimensions. These complementary dimensions are aimed to explore and extend adaptive characteristics of the system – to understand the goal and interested parties, system architecture and components, interaction between these concepts, and main mechanisms behind the adaptation. It emphasizes adaptive dimensions of application and processes.
4) Design and implementation of the adaptive navigation support adaptation algorithm.
5) Empirically confirmed business process execution patterns in enterprise application.

Practical contribution

The following practical results are expected in this research:

1) Implementation of the adaptive navigation support prototype.
2) Comparison between enterprise application with an adaptive navigation support and enterprise application without the adaptive navigation support. The process execution

results have fewer errors, a shorter process execution time and an improved user satisfaction if the adaptive navigation support is applied.

3) ANS integration with existing enterprise applications.

Approbation

The results have been published in 9 scientific papers:

1) Lambeck, C., Supulniece, I., Fohrholz, C., Leyh, C., Muller, R., Commonalities and Contrasts: an Investigation of ERP Usability in a Comparative User Study // Proceedings of the 22nd European Conference on Information Systems (ECIS 2014), Israel, Tel Aviv, June 9-11, 2014.
2) Šūpulniece, I., Grabis, J., Boguševica, A., Petrakova, A., Monitoring perceived usability of ERP systems in Latvian medium, small and micro enterprises, "Computer Science", volume "Information Technology and Management Science", 2013, pp. 73-78. (EBSCO)
3) Šūpulniece I., Adaptation Algorithm for Navigation Support in User Adaptive Enterprise Application // Proc. of the 4th International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2012), 2012, pp. 19-23.
4) Šūpulniece I., Grabis J., Modeling of User Adaptive Enterprise Applications // Proc. of 14th International Conference on Enterprise Information Systems (ICEIS 2012), 2012, pp. 108-111. (Scopus)
5) Šūpulniece I., Conceptual Aspects of User-Oriented Adaptive Systems // Proc. of IADIS Information Systems Conference (IS 2012), 2012, pp. 116-124.
6) Grabis J., Šūpulniece I., Simulation Based Evaluation of Adaptive Applications models // Proc. of 20th International Conference on Information Systems Development (ISD2011), 2011.(SpringerLink)
7) Šūpulniece I., Grabis J., User Oriented Process Adaptation in Enterprise Applications // Proc. of 1st International Workshop on User Oriented Information Integration (UOII 2011), 2011, pp. 355-363.
8) Šūpulniece I., Grabis J., Discovery of personalized information systems usage patterns // Proc. of Information Technologies' 2010, 2010, pp. 25-32. (Web of Science)
9) Šūpulniece, I., Grabis, J., User Modelling Driven Adaptive Enterprise Applications // Proc. of ICESAL 2008, 2008, pp. 131-142.

Other scientific papers published by the author:

10) Businska L., Supulniece I., Kirikova M., On data, information, and knowledge representation in business process models // Proc. of 20th International Conference on Information Systems Development (ISD2011), 2011. (SpringerLink)
11) Bušinska L., Šūpulniece I., Towards Systematic Reflection of Data, Information, and Knowledge, "Computer Science", volume 5 (46), 2011, pp. 12-18. (EBSCO)
12) Šūpulniece I., Bušinska L., Kirikova M., Towards Extending BPMN with the Knowledge Dimension // Enterprise, Business-Process and Information Systems Modeling, Proc. of 11th International Workshop, BPMDS 2010, Springer-Verlag Berlin Heidelberg, 2010, pp. 69-81.(Web of Science, Scopus, SpringerLink)

The results of the thesis have been presented at 8 international scientific conferences:

1) Riga Technical University 54th International Scientific Conference, Riga, Latvia, October 14-16, 2013.
2) 4th International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE 2012), France, Nice, July 22-27, 2012.
3) The International Conference: Information Systems (IADIS) 2012, Germany, Berlin, March 10-12, 2012.
4) 14th International Conference on Enterprise Information Systems (ICEIS 2012), Poland, Wroclaw, June 28- July 1, 2012.
5) The International Conference Perspectives in Business Informatics Research, Latvia, Riga, October 6, 2011.
6) 11th International Workshop BPMDS, Tunis, Hammamet, Jun 7-8, 2010.
7) The International Conference: Information Technologies' 2010, Lithuania, Kaunas, April 22-23, 2010.
8) 5th International Conference on Enterprise Systems, Accounting and Logistics, Greece, Crete, July 7-8, 2008.

Structure of the thesis

The doctoral thesis consists of introduction, 5 chapters, conclusions, bibliography and 8 appendixes. The thesis contains 139 pages, 47 figures and 18 tables. The bibliography contains 189 entries. The thesis is structured as follows:

Introduction provides a motivation of the research, formulates the goal and tasks of the thesis, defines the research object and subject, lists research methods used in the thesis, and

describes the scientific novelty of the thesis, its practical value and approbation of the results obtained in the thesis.

Chapter 1 "Literature Review and Problem Statement" reviews the related work on enterprise application, their usability problems and possible solutions, adaptation and adaptive applications, and user adaptive applications.

Chapter 2 "Conceptual Model Development for User Adaptive Application" characterizes a role of user in the context of the user adaptive enterprise. An user adaptive application modeling approach is proposed and it is applied for describing the user adaptive enterprise application.

Chapter 3 "Evaluation of Business Process Personalization" describes empirical evaluation of personalized business process execution patterns.

Chapter 4 "Adaptive Navigation Support" presents one of the user adaptive enterprise application components – the Adaptive Navigation Support.

Chapter 5 "Evaluation" summarizes evaluation results of Adaptive Navigation Support efficiency.

The thesis concludes with results and further research directions.

1. LITERATURE REVIEW AND PROBLEM STATEMENT

Every employee executes some business processes or their parts. The process consists of several activities, and some of these activities are realized in the enterprise application. Usually business process is documented and their execution instructions are provided at a relatively high level. The employees are left to choose the proper execution sequence of specific tasks or activities (e.g., input contact address, select address), because there are many alternative ways to accomplish the business process. Business process execution habits are formed for every employee in the course of time and they can be utilized in the business process execution personalization.

Business process execution personalization

Business process is a set of activities, restrictions and roles:

$$B = \{O, D, L, \sigma\}, \tag{1.1}$$

where B is a business process, $O = \{a_1, a_2, ..., a_{an}\}$ is a set of activities, $D = \{i_1, i_2, ..., i_m\}$ is a set of restrictions, $L = \{l_1, l_2, ..., l_b\}$ is a set of roles and σ relates the activities to their executory roles. The restrictions define process flow, allowed and prohibited actions.

Business process personalization is the role replacement with a particular individual users and association between activities and the individual users or

$$B^* = \{O, D, L^i, \varphi\}, \tag{1.2}$$

where B^* is a personalized business process, $L^i = \{u_1, u_2, ..., u_{uk}\}$ is a set of individual users and φ associates the activities with the users prefoming these activities.

Business process execution patterns are the most frequently used business process execution sequences. A personalized business process execution pattern is a set of activities, which are performed by a particular user

$$P_{pk}(u_{ui}) = \{a_1, a_2, ..., a_{ax}\}, \tag{1.3}$$

where $P_{pk}(u_{ui})$ is a personalized business process execution pattern. A global business process execution pattern is a set of activities, which are performed by any user.

Enterprise applications and their usability issues

Enterprise applications are used to execute daily enterprise transactions, which are realized as business processes. Typically, they are designed to integrate with other applications used within the organization, and to be deployed across a variety of networks while meeting strict requirements for a security and an administration management. The common characteristics of enterprise applications are:

1) integration of business processes across business areas [96];
2) data availability in real time;
3) a centralized data base;
4) modification and customization capabilities;
5) integration of transactions and planning activities and
6) a uniform presentation layer.

The disadvantages associated with an enterprise application are:

1) very expensive to purchase and even more so to customize [141];
2) many of the integrated links need a high data accuracy in other applications to work effectively [47];
3) high switching costs. [139];
4) a customization is limited [86] and expensive, so most companies installing enterprise application need to adapt or even completely rework their processes to fit the requirements of the enterprise application [40];
5) relatively low user acceptance [30].

Enterprise application user interface complexity, inaccurate data and employees disinclination to use the application partially is caused by poor usability. User satisfaction is one of the main factors for a successful application acceptance [7, 135, 164].

Despite popularity of the term „usability", there is, as yet, no generally agreed definition of the usability and its measurement [62, 153]. Research on usability of is limited. Topi [172] described a case study about enterprise application usability problems in one American company. Lambeck [98] conducted a users' survey to understand the actual usability issues in the market. The research results state user requirements towards the user interface. The IFS North America industry report surveyed medium and large manufacturers to identify usability issues of available commercial enterprise applications [76].

Summary of literature review and problem statement

Enterprise applications are complex and traditional usability evaluation and improvement methods are not efficient for them. Consequently, automated usability evaluation methods and adaptation should be applied.

There are several explanations related to the concept of adaptation. The definitions usually involve the notion of changing something to meet some specific requirements or purposes [54]. In the literature, there is a mix of the terms "adaptation", "adaptability" and "customization" despite each of them having a different definition. Only adaptation mechanisms are analyzed and applied in this thesis.

The largest research body about enterprise application adaptation is in the area area of adaptive workflow management systems. In the adaptive workflow management systems, adaption occurs at different layers – domain, process, resources and infrastructure. A workflow model is built in the data oriented enterprise application; a configuration is changed during the implementation to customize the process model [32]. An adaptive workflow management system might exist apart or inside the enterprise application.

The adaptation process in the adaptive workflow management system is similar to the user adaptive enterprise application proposed in the thesis. The difference lies in the cause of adaptation. The process is changing in the adaptive workflow and the application is adapted to it. Meanwhile the process and also the user is changing in the user adaptive enterprise application and the application is adapted to both of them. The personalized patterns are not accumulated in the adaptive workflow systems.

The user adaptive application is an application, which adapts its behavior to the individual user. Users often are not satisfied with the result of adaptation.

A user adaptive enterprise application needs to be designed before development of its prototype. There is a wide spectrum of modeling languages, techniques and approaches for system modeling, however adjustments are needed for modeling specific aspects of adaptive applications, because adaptive applications are perceived differently than non-adaptive applications [187]. Modeling of adaptive applications is researched in several domains, from various perspectives and for different purposes. Majority of these investiagtions focus on specific methods rather than on capturing common features of user adaptive applications. The common high level representation is useful because adaptive mechanisms can change quickly. It is necessary to develop a user adaptive application modeling approach, which is based on a conceptual model of the user adaptive application. Modeling dimensions, which are proposed by Andersson [10] are applicable for describing the adaptation process, however relations between business and adaptation goals are missing. Modeling of the business goals is important part of an enterprise modeling and these models must be considered during the enterprise application development and implementation.

2. CONCEPTUAL MODEL OF USER ADAPTIVE APPLICATION

In order to conceptualize, the user adaptive application, nature of adaptive aplications is analysed, the meta-model defining the key concepts relevant to these applications is developed and the user adaptive enterprise application and its components are defined in terms of the meta-model.

In the adaptation process, there are changing [54] and adapted objects. A simplified input/output view of the core concepts of the adaptive application is presented in Figure 3.

The adaptive application state after the adaptation (Q_a) depends on the state before the adaptation (Q), changes (C) and the adaptation algorithm (F) or

$$Q_a = F(C, Q). \tag{2.1}$$

Consequently the main core concepts of the adaptive applications are: Changing object (Co), Adapted object (Qo) and Adaptation algorithm (F).

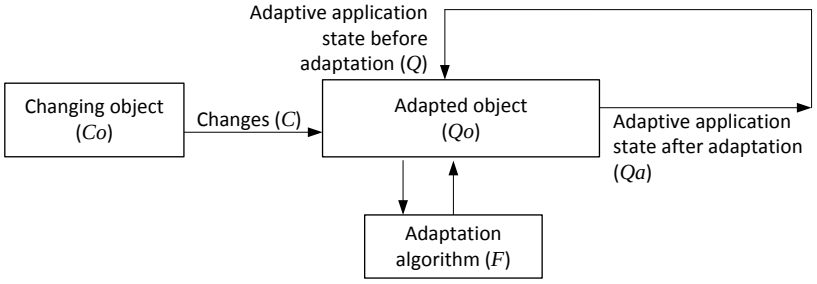

Fig. 3. A simplified input/output view for the core concepts of the adaptive application

User perspective of adaptive Application

The adaptation is a purposeful process, so a stakeholder (H) defines the goals, which are realized by the adaptation process [140] (Fig. 4.). Another important actor is an end-user (U), who has expectations in her mind, what should be the state of the application after the adaptation process. The stakeholder and the end-user view the adaptation result on a different generalization level (as goals and expectations). The stakeholder and the end-user are a role, and one person might take both roles at the same time.

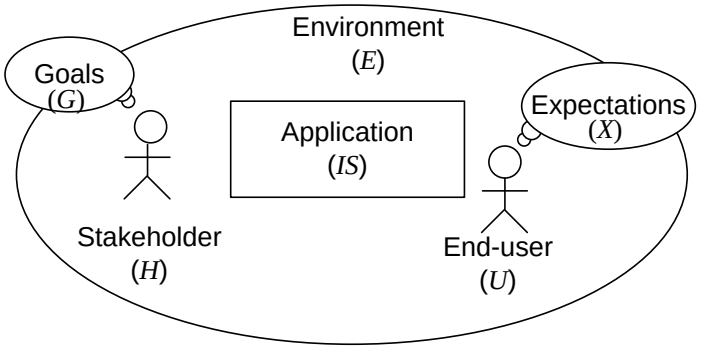

Fig. 4. Stakeholder and End-user concepts in an adaptive application

The stakeholder benefits from the adaptive application, so she formulates the set of goals $(G_{H_{ih}})$ for the adapted object. The set of goals for the adaptive application is a union of all stakeholders' goals or

$$G = G_{H_1} \cup G_{H_2} \cup \ldots \cup G_{H_h}, \tag{2.2}$$

where $G_{H_{ih}} = \{G_{H1}, G_{H2}, ..., G_{Hvg}\}$ is a set of goals defined by the ih th stakeholder and G is a set of all goals defined by the all stakeholders. The goals do not change in time.

However, the set of expectations (X_{u_w}) towards the adaptation result is defined by the end-user U. All end-users' expectations form the set of expectations for the adaptive application or

$$X = X_{u_1} \cup X_{u_2} \cup \ldots \cup X_{u_{uk}}, \tag{2.3}$$

where $X_{u_w} = \{X_{y_1}, X_{y_2}, ..., X_{y_{vx}}\}$ is a set of expectations towards the parameters characterizing the application state after the adaptation.

The expectations (X_{u_w}) differ per each individual end-user (U). These expectations also are time dependent (e.g. depend on the user's mood or the particular situation) even if a subject is the same.

According to the Figure 5, the adapted object state after the adaptation is as follows:

$$Q_a = F(C, Q, G, W), \tag{2.4}$$

where W is a set of the calculated expectations (see for the explanation at the end of this section).

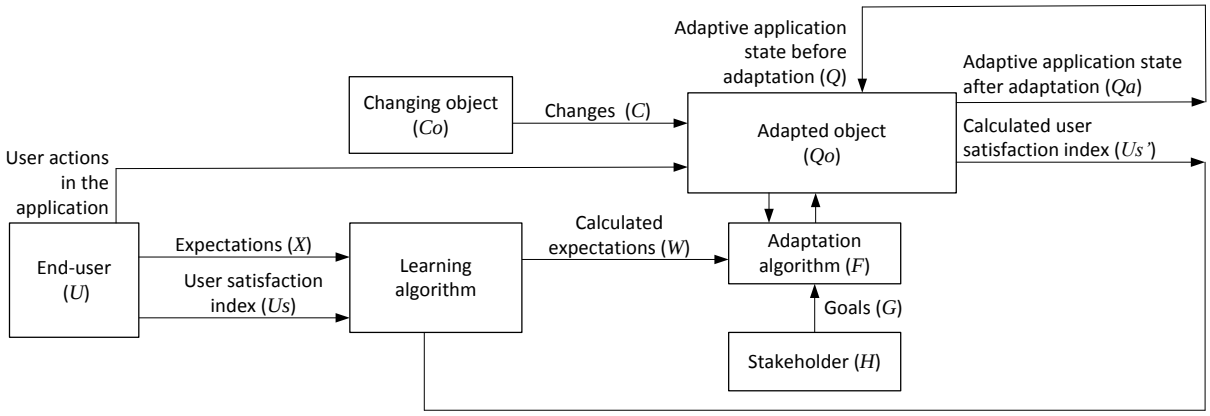

Fig. 5. An extended input/output view for the core concepts of the adaptive application

The identified core concepts of the adaptation are used during the modeling and development of the user oriented adaptive application. They can be used to illustrate the differences between similar adaptive applications, too.

The expected result or the adaptive application state after the adaptation should be equal to the expectations set by the end-user or

$$Q_a = X_{u_w}, \tag{2.5}$$

where $Q_a = \{Q_{a_1}, Q_{a_2}, ..., Q_{a_{vx}}\}$ is a set of the real adaptive application parameters after the adaptation. Practically, that is hardly achievable. The user satisfaction index (Us) shows the proportion of the user expectations fulfilled as result of the adaptation:

$$Us = \frac{\sum_{vix=1}^{vx} IX_{vix}}{vx}, \tag{2.6}$$

where $IX_{vix} = \begin{cases} 1, if\ X_{y_{vix}} = Q_{a_{vix}} \\ 0, if\ X_{y_{vix}} \neq Q_{a_{vix}} \end{cases}$.

If $Us = 1$, then user expectations are equal to the application state after the adaptation (this is an ideal adaptation), where the user is completely satisfied with the adaptation result. If $Us < 1$, then all user expectations are not met and the user is not satisfied.

Thus, the main goal of the adaptation would be to minimize the difference between the adaptation result and the user expectations:

$$|QX| \to \max, \tag{2.7}$$

where $QX = Q_a \cap X_{u_w}$.

Even if it is unrealistic to fully capture all individual expectations, the application might know or predict some user expectations towards the adaptation, e.g. user preferences available in the application. These are reffered as to calculated user expectations (W).

Substituting X_{u_w} with W_{u_w} yields that the goal of the adaptive application is to minimize the difference between the application state after the adaptation and the calculated user expectations or

$$|QW| \to \max, \tag{2.8}$$

where $QW = Q_a \cap W_{u_w}$.

Modeling of User Adaptive Enterprise Applications

A general meta-model for modeling the UAEA is developed in the thesis. It provides a common general representation of this kind of applications, and the specific adaptive method can be detailed using this model as a basis.

The UAEA meta-model consists of a number of sub-models corresponding to the main concepts identified in the previous section (Fig. 6):

1) Stakeholder and End-user Model (SEM) presents the structure of actors (human roles), which are related to the adaptive application.
2) Goals and Expectations Model (GEM) illustrates the structure of goals towards the adaptation and individual user's expectations behind them.
3) Model of Changing Object (COM) is the structure of the application or the environment part, which is changing (triggers the adaptation).
4) Model of Adapted Object (AOM) is the structure of the application's adaptive part (which reacts to the changes).
5) Adaptation Algorithm Model (AAM) describes the rules and the behavior of the particular adaptation algorithm.
6) System's Model (SM) presents the structure of the application (e.g., the architecture).

SEM, GEM, COM, AOM and SM are structural diagrams, which present the main elements of the adaptive application and relationships between them. AAM is a behavioral diagram.

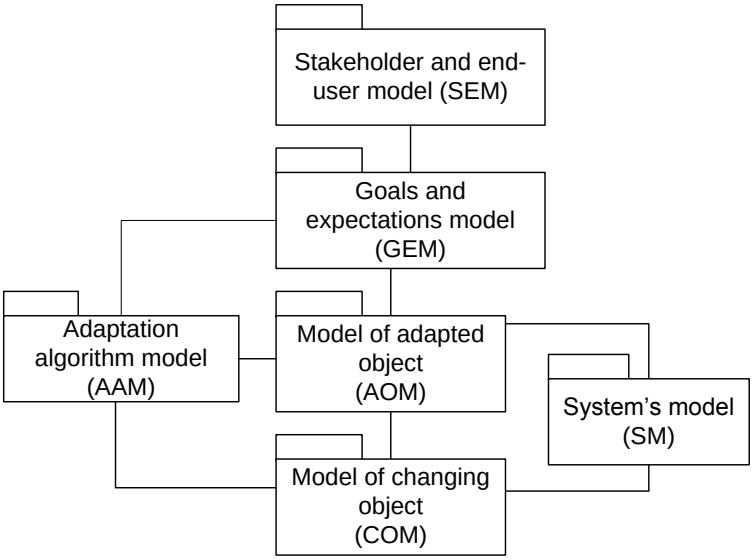

Fig. 6. The model of the user adaptive enterprise application – a high level abstraction

Figure 7 shows goals and expectations in the meta-model. There are three types of goals: business goals, operational goals and technical goals. The technical goals are associated with expectations and adapted object. All types of goals are associated with stakeholders and expectations are associated with end users.

The developed meta-model is applied for describing the user adaptive enterprise application.

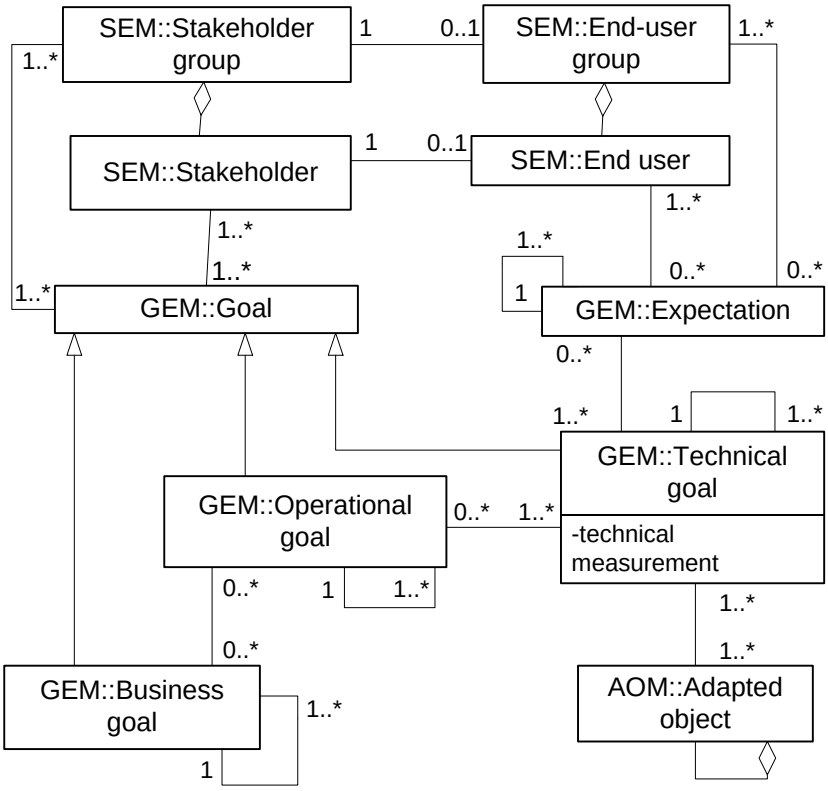

Fig. 7. Goals and expectations in the meta-model

User Adaptive Enterprise Application

The overall goal of the User Adaptive Enterprise Application is to identify the improvement possibilities of the existing EA to raise the performance efficiency. This is a business goal. However, technically this can be completed by improving the application usability – decreasing time for routine activities, avoiding mistakes and helping users in ad-hoc situations.

The UAEA is developed to solve usability issues in the currently available commercial enterprise applications while taking into account the spatial visualization ability of their users.

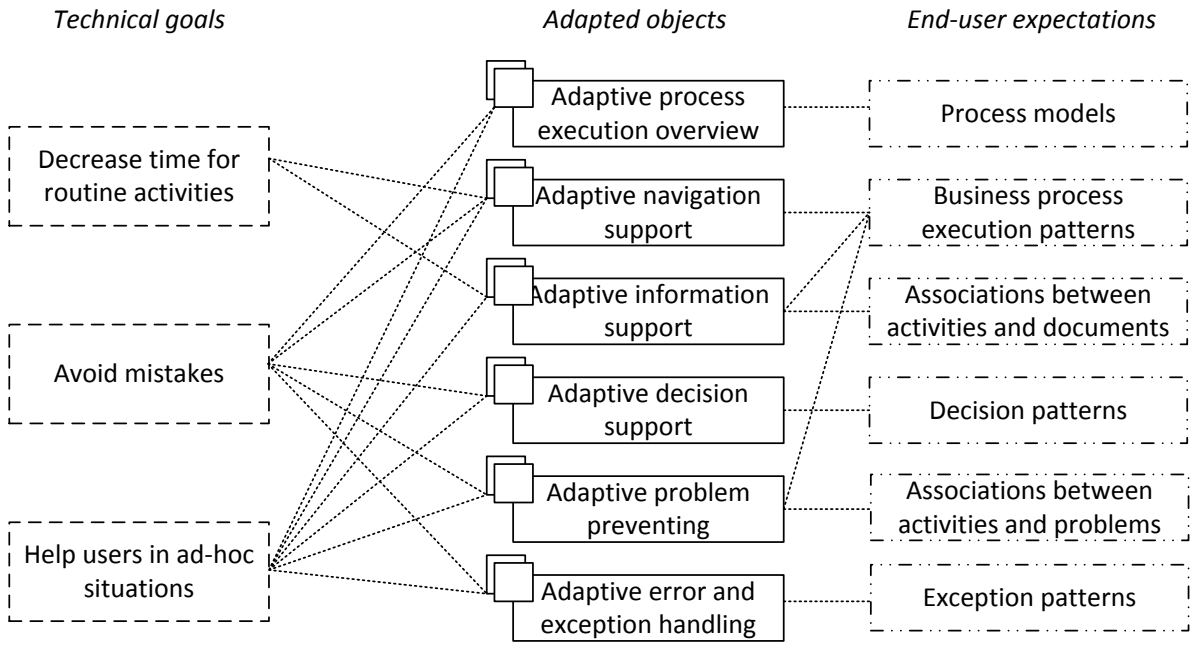

Fig. 8. UAEA components (adapted objects)

Thus the UAEA complements the existing (non-adaptive) enterprise application, but does not change it. The UAEA consists of six independent components (Fig. 8):

1) Adaptive process execution overview shows a full process or the part of the process, the current activity and possible paths to finish the process.
2) Adaptive navigation support presents a quick link of next recommended activity, mandatory activities, prohibited activities and already executed activities.
3) Adaptive information support recommends related documents, systems or data based on a personal or a global user experience.
4) Adaptive decision support recommends possible decisions based on a personal or a global user experience.
5) Adaptive problem preventing presents most common problems and solutions related to the current activity. It prevents possible mistakes for non-routine activities or new users.

6) Adaptive error and exception handling notifies user about an incompleteness in process execution, e.g., a missed activity or unfinished process.

Users use an enterprise application to accomplish their tasks usually consisting of multiple steps; each user or user group has a preferred sequence of the activities (business process execution patterns). UAEA attempts to exploit such business process execution patterns to improve business process execution efficiency.

3. EVALUATION OF BUSINESS PROCESS PERSONALIZATION

The objective of this section is to analyze empirical application usage data in order to confirm the existence of personalized business process execution patterns and to evaluate their efficiency comparing to global patterns. Two main hypotheses tested are that: 1) personalized business process execution patterns are observed more frequently than global patterns; and 2) personalized patterns have higher level of confidence than global patterns.

Two empirical application usage data sets are used in this evaluation. These data sets are derived from the log files of customer service website of telecommunication company (CS data) and of university's e-learning application (ES data).

The Longest Common Subsequence algorithm [37] is used to discover patterns in the business process execution. The patterns discovered are evaluated using two measures commonly used in data mining, namely, support and confidence [100]. The support measure indicates the frequency of the pattern observation, and the confidence measure is a proxy for pattern precision measurement.

A pattern efficiency chart is used to visualize the pattern efficiency (Fig. 9). AB_{pk} is pattern support value. TC_{pk} is pattern confidence value. It is obvious that the best patterns are within Quadrant 1 and non-efficient patterns are within Quadrant 3. Therefore, patterns in each quadrant are counted separately for global and personalized patterns, and association between counts is used to check the overall hypothesis that the personalized patterns are more efficient than the global patterns.

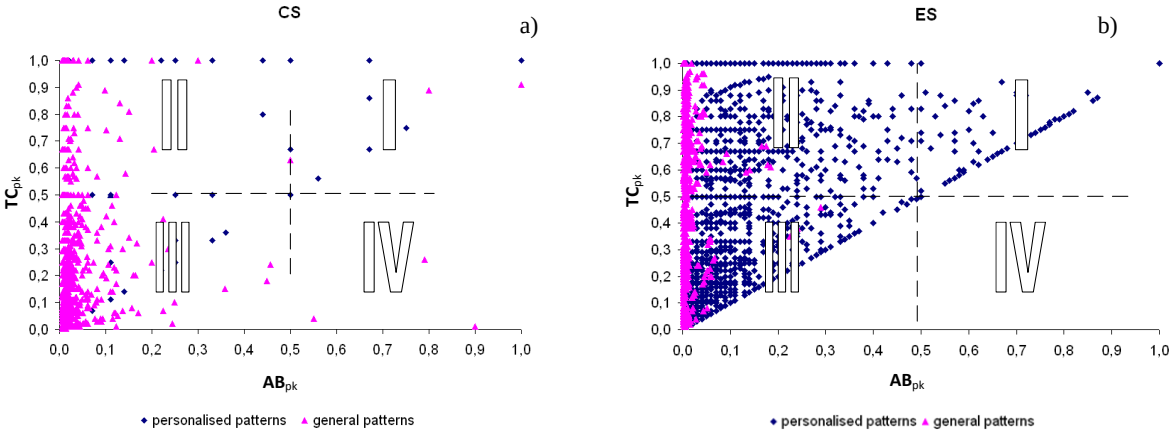

Fig. 9. Pattern efficiency chart for (a) CS data and (b) ES data

One point in the chart can represent multiple patterns if their values of support and confidence numbers are the same, therefore a numerical evaluation of the pattern efficiency is obtained by a cross-tabulation (Table 1) showing the percentage of patterns falling in each quadrant for global patterns and for personalized patterns. Data from the CS log files confirm our assumption that the personalized patterns are more effective. Additionally, the personalized patterns have very high efficiency and almost all patterns are very precise and popular. That means that if users return to the webpage, their activities are the same almost in all sessions. The personalized patterns discovered in the ES data are slightly more efficient than the global patterns. The Chi-square test of cross-tabulation data confirms that the position of patterns in the pattern efficiency chart depends upon the pattern personalization.

Table 1

Cross-tabulation results

	CS data		**ES data**	
	Global patterns	Personalized patterns	Global patterns	Personalized patterns
Quadrant I	0.2	91.3	0.0	0.9
Quadrant II	22.0	7.4	65.5	79.2
Quadrant III	75.2	1.3	34.5	20.0
Quadrant IV	2.7	0.0	0	0.0
	Pearson Chi-Square = 11853, DF = 3, P-Value = 0.000		Pearson Chi-Square = 667, DF = 3, P-Value = 0.000	

4. ADAPTIVE NAVIGATION SUPPORT

The Adaptive Navigation Support (ANS) component is a UAEA component aimed in: 1) helping new users to navigate around the application and to learn the application faster; 2) decreasing amount of mistakes; and 3) helping users to complete routine processes faster. The changing object is a user and a process, so the adaptation result is different for every user.

In the case of ANS, the calculated expectations are personalized business process execution patterns, i.e., it is assumed that the users would like to follow their personalized business process execution patterns. Consequently, the ANS adaptation goal is to maximize intersection between the sequence of activities executed thus far and the personalized pattern or

$$|IP| \to \max, \tag{4.1}$$

where $IP = I(u_{ui}) \cap P_{pk}(u_{ui})$ and $I(u_{ui})$ is a sequence of executed activities; $P_{pk}(u_{ui})$ is the personalized pattern.

The ANS component utilizes: 1) business process execution restrictions to control business process execution rules; and 2) business process execution patterns to manage user oriented business process execution variations.

The main part of the ANS component is the adaptation algorithm with the following inputs: the executed activity, business process execution patterns (personalized and global) and business process execution restrictions (Fig. 10). The output is the next step recommendation, mandatory activities and prohibited activities.

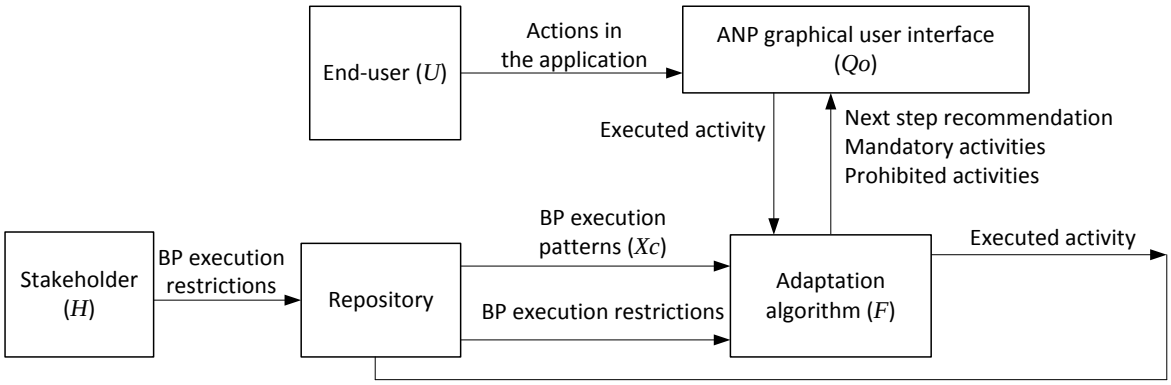

Fig. 10. The adaptation algorithm's inputs and outputs

The ANS shows a shortcut to the next activity, mandatory activities, prohibited activities and already executed activities. The enterprise application interface itself is not changed, only the recommendation part is adapted. Hence, the business process execution patterns help users to complete the process successfully and allow users to select a different activity than recommended.

The ANS adaptation algorithm can be used also for creating personalized data input forms or emphasizing recommended activities in the current user interface.

ANS adaptation algorithm

The following notations are used for the ANS adaptation algorithm (Fig. 11):

1) U - a user;

2) A - an activity executed by the user U or an element activated in the user interface (e.g., a button, a link).

3) F_o - a form or a group of user interface elements;

4) M – a set of mandatory activities $M_1, M_2, ..., M_r$;

5) V – a set of prohibited activities $V_1, V_2, ..., V_v$;

6) I – a set of executed activities $I_1, I_2, ...I_z$.

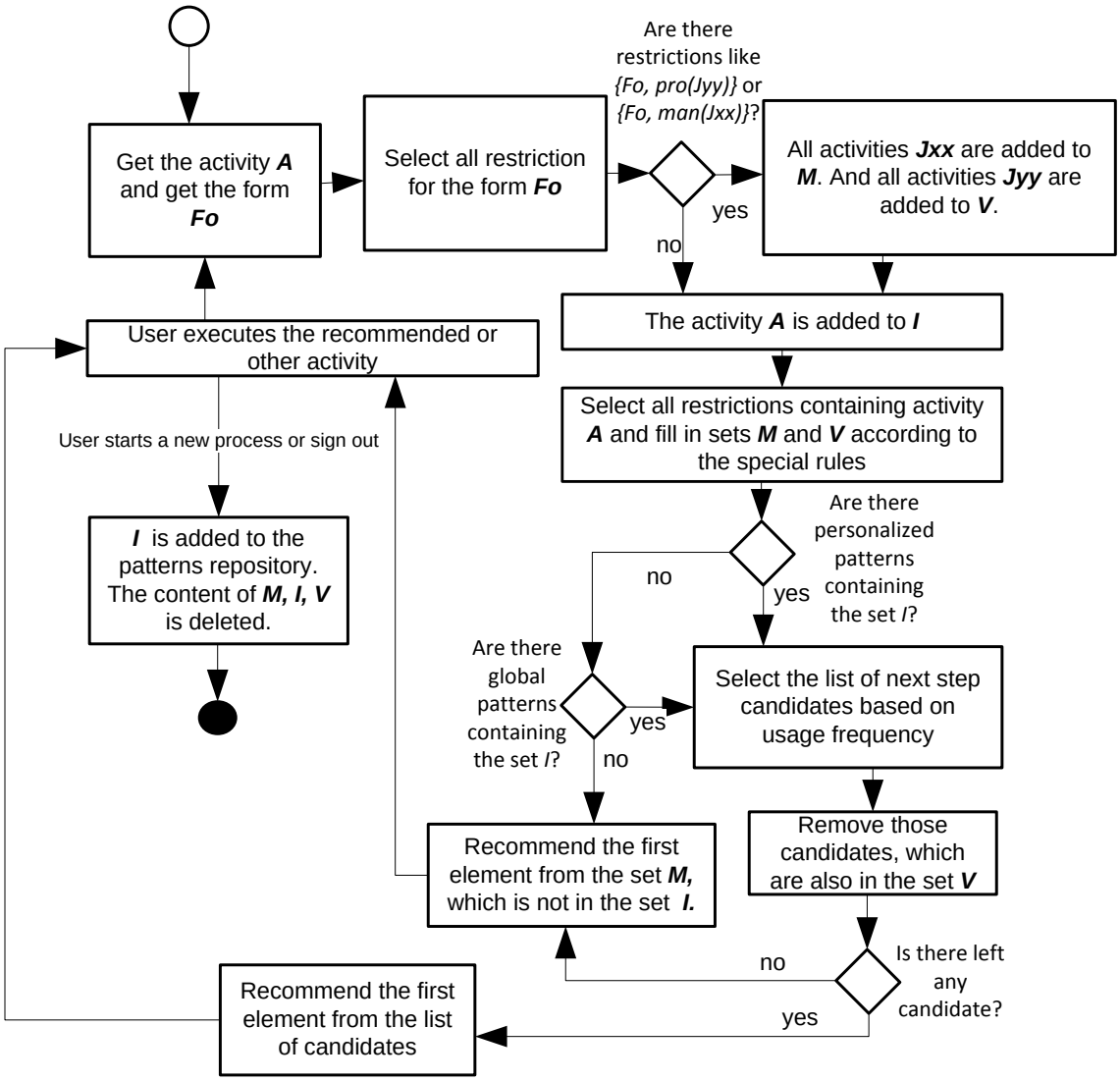

Fig. 11. A simplified ANS adaptation algorithm

The application reads activity A and the form F_o after each user click. Firstly, all restrictions are selected for this form. If there are mandatory or prohibited activities, then they are added to the sets M and V. Afterwards activity A is added to the set I and special rules are applied. If there is at least one personalized pattern, then the next activity is recommended based on personalized pattern usage frequency. If personalized patterns are not found, then

global patterns are searched and the next activity is recommended based on the global pattern usage frequency. If the global patterns are not found, then the first element of mandatory activities is recommended.

ANS implementation and prototype

The adaptation algorithm is implemented as a part of the ANS component The architecture of the ANS component (Fig. 12) also consists of event logs, user repository, business rules or restrictions respository, activities repository and process models repository; the adaptation algorithm and the ANS graphical user interface. The component can be implemented as add-on to existing enterprise application.

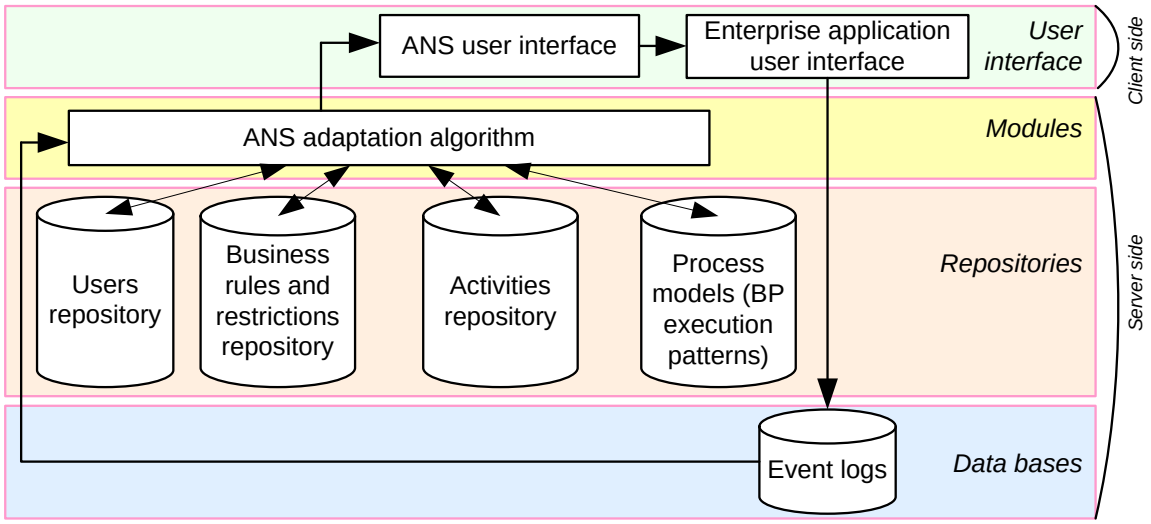

Fig. 12. ANS architecture

For the experimental purposes, the enterprise application prototype is developed with the add-on ANS component (Fig. 13.). The prototype is created using PHP software development language and MySQL data base and designed to resemble an actual ERP systems. The recommendations generated by ANS are shown in the window with the yellow bar.

5. EVALUATION

Participants of the ANS evaluation experiment are selected based on a quota convenience nonprobability sampling. In total there are 16 participants, who are randomly divided into two groups. Each group has 8 participants. The first group has the enterprise application with the ANS component. The second group has the same enterprise application, but without the ANS component. All participants are asked to complete three instances of the same process in the sales module.

The participants and their actions in the enterprise application are observed and participants are asked to think aloud during the process completion. The most interesting thoughts and observations are fixed by the observer. The observer also records whether the participants follow the same process flow for all three process instances. The participants are asked to fill in the questionnaire, when all three process instances are completed.

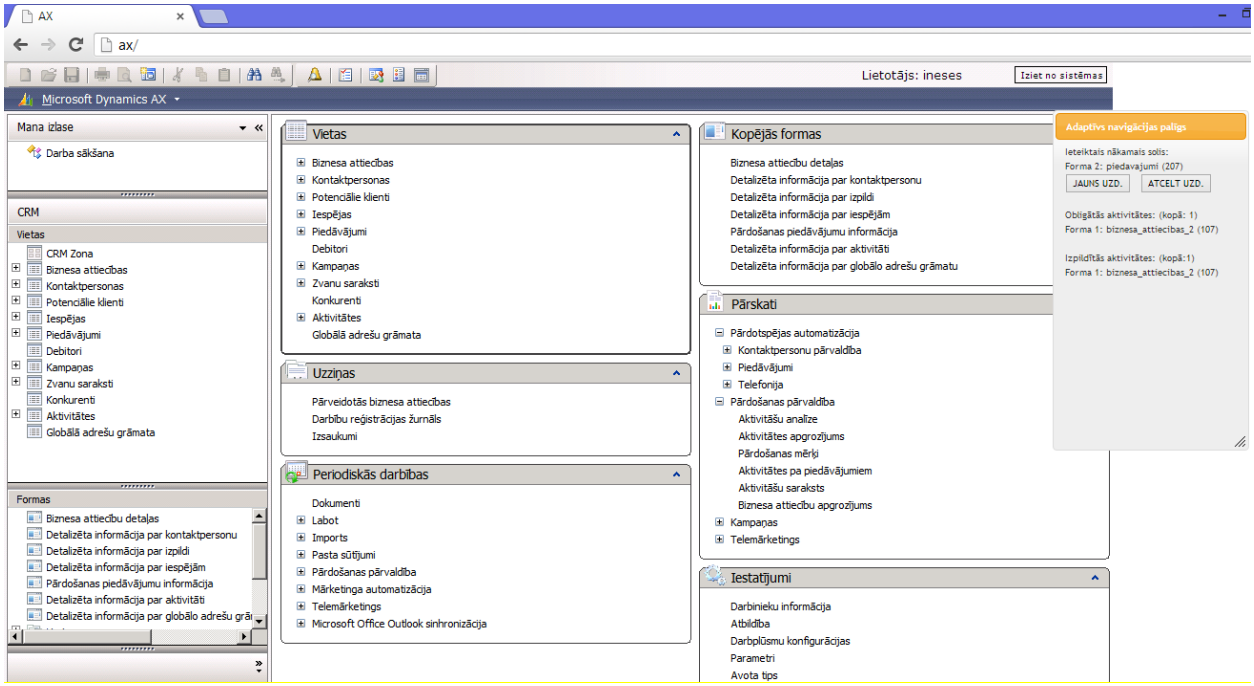

Fig. 13. A prototype screenshot

Direct observation results

The direct observation results confirm that all participants (from both groups) follow the same process flow in the second and the third process instance after successfully completing the first process instance. They use the same menus and buttons that are discovered during the first process instance execution.

The main befits of the direct observation is an opportunity to discover the factors, behavior or opinion not considered in the primary goal and the hypothesis. The following phenomena are recorded during this experiment:

1) Users expect the same or similar interaction with enterprise application as with other popular applications.
2) Users judge their actions in comparison to achievements of other users.
3) Many users faced problems with terminology.

Quantitative data analysis

The average process execution time for all process instances together and average time for each single process instance completion is shorter for the first group (Fig. 14). Statistical analysis using ANOVA is reported in Table 2, where the process execution time is dependent variable and the participants group and process are the independent variables. The data have been transformed to satisfy assumptions underlying the ANOVA analysis.

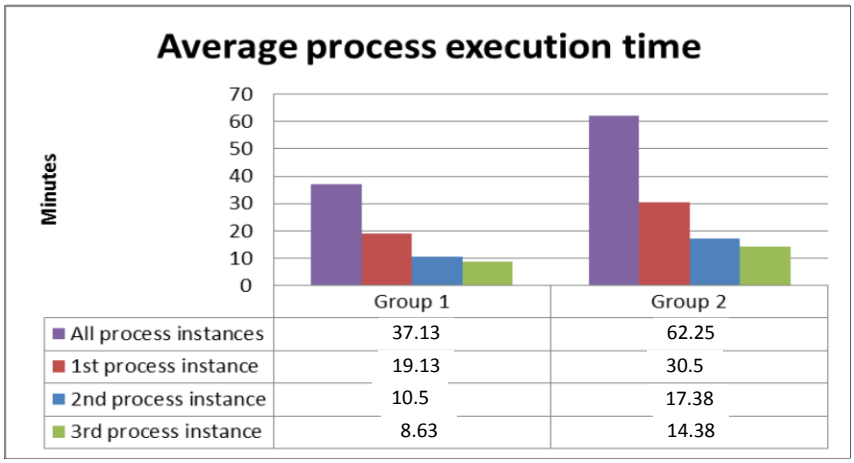

Fig. 14. Average process execution time

P values are less than 0,1 so the group and the process number is statistically significant for the process execution time at the 90% level of confidence. In the statistical sense, the hypothesis on improved efficiency is confirmed only the low level of statistical confidence. That is partially explained by the low power of the statistical tests because of the limited number of observations (empirical experimentation with enterprise applications is very costly). Additionally, the box diagram (Fig. 15) shows very wide distribution of the process execution time for the second group what is an undesirable characteristic for enterprise applications because of reduced predictability of the process efficiency.

Table 2

ANOVA results

Factor	**SS**	**Model degrees of freedom**	**Variance**	**F-statistics**	**P**
Group	0.81	1	0.81	2.25	0.1
Process number	6.87	2	3.43	9.64	0

The participant group and process number interaction does not influence the process execution time significantly.

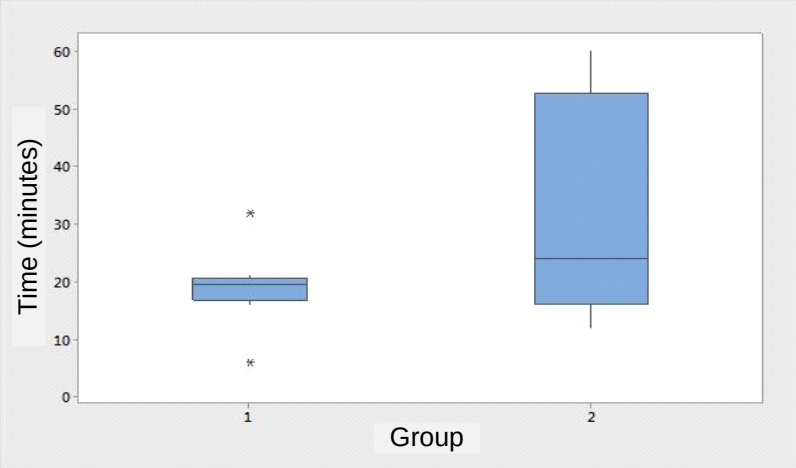

Fig. 15. Box plot chart

The processes execution errors considered in the thesis are activities omitted or incorrect sequence, (data errors are out of scope). The results show that the ANS component has decreased the number of errors. However, all mistakes are not prevented. That is cause by the ANS implementation as the recommendation block not forcing a user to execute the recommended activities. The adaptive problem preventing component of UAEA could solve this problem more effectively.

Business process execution time and amount of errors are the main measures for business process execution efficiency. Improvements of those criteria confirms the hypothesis H2.1 that the ANS component improves the business process execution efficiency.

Questionnaire data analysis

The user questionering results are presented in Table 3. The scale of 1 to 5 is used, where 1 indicates the most favourable evaluation and 5 is the least favourable evaluation

The questionnaire results show that the ANS component improves the user attitude towards the efficiency, flexibility and comfort. It does not change the user attitude towards errors and memorability. The user attitude towards the learnability, control, reliability and help has decreased. The positive feedback about the comfort could mean that users would use the ANS for their daily work. While the learnability, errors and memorability results suggest a necessity for visual improvements of the ANS component.

Table 3

Prototype evaluation results

No.	*Parameter*	*Meaning of value 1*	*Meaning of value 5*	*Group 1*		*Group 2*	
				ME	**SD**	**ME**	**SD**
1	Learnability	Application is suitable for all users regardless their knowledge	To work in application user requires a specific knowledge	3.14	0.98	2.57	1.33
2	Control	I can control the application	I cannot control the application (actions are automated and not understandable)	3.14	1.12	2.86	1.56
3	Reliability	I trust this application	I do not trust this application	3.29	1.21	3.00	1.46
4	Efficiency	I can complete all activities	Application prohibits completing all activities	2.57	1.21	3.57	1.22
5	Comfort	Application is easy to use.	Application is complex	3.00	1.25	3.57	1.53
6	Learnability	Application is easy to learn	Application is hard to learn	2.71	1.24	2.57	0.95
7	Flexibility	Application is flexible	Application is inflexible	3.00	1.36	4.00	1.20
8	Help	Help is provided to complete the process	Help is not available to complete the process	3.86	1.18	3.57	1.71
9	Error preventing	I am informed about mistakes	I am not information about my mistakes	4.71	1.29	4.86	1.22
10	Memorability	After a week I will remember how to compete the process	After a week I will not remember how to complete the process	2.43	1.59	2.57	1.33
11	Efficiency	Menu structure is understandable	Menu structure is not understandable	3.14	1.64	4.00	1.31
12	Efficiency	I can find all information/functions easily	I cannot find all information/functions	2.86	1.14	3.43	1.28

ME – mean response for all participants
SD – standard deviation of responses for all participants

RESULTS AND CONCLUSIONS OF THE THESIS

The aim of the doctoral thesis was to improve usability of the enterprise application using process orientation, adaptation and personalization.

The results of the thesis are as follows:

1) The summary of the main problems of enterprise applications and detailed overview of the usability problem and possible solutions (Chapter 1). It is concluded that complexity of enterprise applications renders inefficient traditional usability evaluation and improvement methods. Automated usability evaluation and improvement methods as well as adaptation should be used for such applications.

2) The analysis of conceptual aspects of adaptation and user adaptive applications (Chapter 1 and 2). The end-user and her expectations are identified as two concepts of major importance not sufficient explored in the existing research. Understanding these objects improves the adaptation result in the user adaptive application.
3) The approach for modeling user adaptive application (Chapter 2). User adaptive application modelling incorporates results of enterprise modelling (as goals and stakeholders); application modelling (as application components) and adaptive characteristics of the application (as changing and adapted object).
4) The formalized definition of the concept of User Adaptive Enterprise Application (Chapter 2). User Adaptive Enterprise Application helps to improve business process execution efficiency.
5) The empirical evauation of potential of business process execution personalization (Chapter 3). The formation of business proces`s execution patterns is empirically proved. The personalized business process execution patterns have higher support and confidence than the global business process execution patterns.
6) The Adaptive Navigation Support component and adaptation algorithm (Chapter 4). Adaptation algorithm incorporates business process execution restrictions and business process execution patterns.
7) The prototype of the ANS component of UAEA (Chapter 4). This prototype has the following benefits in comparion to related researche: a) it is based on a real enterprise application; b) the prototype presents relations between the business process and user interface elements while majority of the related works focus on the process level and the functional aspects leaving the user interface out of the scope. This dimension is important for large and complex applications as a single process activity might impact several user interface elements.
8) The assessement of the ANS component to solve the usability issues (Chapter 5). The results of direct observation confirm the formation of business process execution patterns. The results of quantiative analysis show that the process execution time is shorter and fewer errors are commited using the enterprise application with Adaptive Navigation Support. The questionnaire data shows an improved user satisfaction with the comfort, efficiency and flexibility parameters no changes in errors and memorability parameters and small decrease on the learnability, control, reliability and help parameters. A random participant selection should be applied in order to generelize the results.

The main conclusions of the thesis are as follows:

1) Human behavior in enterprise applications is similar to real life – it is affected by attitude towards the change, route and shortcut preferences, colors, information representation, etc. These factors should be considered to improve usability.
2) The large number of functions and differentiation among many user groups make traditional usability methods inneffective for enterprise applications. An adaptation should be aplied for these applications.
3) The adaptation result in the user adaptive application can be improved by identifying, modeling and utilizing user expectations, e.g., personalized business process patterns.
4) Several enterprise applications include workflows for a process realization. The traditional workflows are based on business process execution patterns for roles. The UAEA is based on the personalized business process execution patterns as they are more precize than global patterns.

Further research directions are as follows:

1) The visualization of the Adaptive Navigation Support. The current ANS design shows only the recommended next activity and a full form is opened after clicking on it. This approach has several limitations, which were discovered also during the questionnaire analysis.
2) Development of adaptation algorithms for other UAEA components.
3) Data quality improvements based on a personalization.

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