Providing Explanations for the Intelligent Monitoring of Business Workflows Using Case-Based Reasoning

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Abstract. This paper presents an approach for providing explanation to the intelligent diagnosis and monitoring of business workflows based on operation data in the form of temporal log data. The representation of workflow related case knowledge in this research using graphs is explained. Workflow cases are represented in terms of events and their corresponding temporal relationships. The matching and CBR retrieval mechanisms used in this research are explained and the architecture of an integrated intelligent monitoring system is shown. The paper contains an illustration and evaluation of the approach based on experiments on real data from a university quality assurance exam moderation system. It is shown that a graph matching based similarity measure is capable to diagnose problems within business workflows and the results of this reasoning process can be explained to workflow managers and users with the use of graph visualisation techniques.

Keywords: Case-Based Reasoning, Explanation, Business Workflows, Temporal Reasoning, Graph Similarity.

1 Introduction

In modern organisations most activities are organised in terms of business workflows that allow for the timely and efficient coordination of people and systems to achieve organisational objectives. Increasingly, business workflows are defined, orchestrated, facilitated and monitored electronically by computer systems. This provides organisations with an opportunity to monitor and manage business workflows more efficiently and a challenge to do so in an auditable and trustworthy way that allows managers to take operational corrective actions and make useful business process improvements.

The Business Process Modelling Notation (BPMN) developed by the Business Process Management Initiative (BPMI) and Object Management Group (OMG) provides a standard for the graphical representation of workflow based business processes[1]. Workflow based business process representation is possible with standards covering the definition, orchestration and choreography of business processes.

Over the last few years, a number of standards have emerged and are widely accepted and supported by mainly Service Oriented Architecture (SOA) based enterprise technologies and systems. The OASIS Business Process Execution Language (BPEL), short for Web Services BPEL (WS-BPEL) is a key orchestration technology [2]. The Workflow Management Coalition (WfMC) backed XML Process Definition Language (XPDL) is a format standardised to interchange Business Process definitions between different workflow products and systems [3].

Using a graphical representation of business processes such as UML or BPMN allows business process designers, managers and participants in business workflows to understand the definitions and context of business workflows as these are designed to be viewed by humans. However, in monitoring business workflows, systems produce a large number of monitoring data, usually in terms of a number of temporally ordered logs of events that cannot be easily monitored, understood and acted upon easily by human operators.

Humans faced with the task of monitoring business workflows have to deal with the challenge of sifting through a large number of events appearing in a typical workflow event log and the complexity of reasoning with temporal relationships between events. Furthermore, effective monitoring may need the combination of more than one logs and/or correlation of workflow events to other events that may not be captured by the systems. Finally, contextual knowledge about the workflow execution may be incomplete or uncertain. This is due to the fact that workflows are very often adapted or manually overridden by managers in order to deal with unanticipated problems and changes in the operating environment, especially in the aspects of workflows that interact with human roles. Workflows are liable to change as the business requirements change and may involve business processes from different parts of an organisation, or between collaborating organisations which may cause conflicts.

It has become increasingly difficult for humans to monitor business workflows bringing the need for the intelligent monitoring, diagnosis and intervention into business workflows by software systems.

A software system attempting the automatic interpretation and monitoring of workflows requires the ability to provide explanations that can allow managers and stakeholders in business workflows to identify, understand and act on problems identified on the workflow data. In order for this to be efficient, the system should be able to provide adequate explanation on why a particular workflow has been tagged as requiring addition and on what the identified problem may be, as well as providing some explanation on a remedial action it may require.

This paper presents an approach to providing explanations for the monitoring of business workflows using the Case-Based Reasoning (CBR) approach[4]. A specific issue with this approach is the fact that a workflow monitoring CBR system does not attempt to build an explicit model of the knowledge associated with workflows, but reasons on the fundamental assumption that similar problems have similar solutions. A similarity measure is defined and used to identify possible solutions for a particular target case workflow case problem by finding similar neighbouring workflow cases from within a case base and reusing the solutions of these cases to provide a solution to the target workflow case problem. The explanation required for such a system is one that shows the system user why the system retrieved particular workflow cases as most similar and how the retrieved similar cases can be used to provide a solution to the problem in hand.

In many typical CBR systems, the similarity and relevance of the contribution of neighbouring cases can be simple to understand. However, due to the structural and temporal complexity of workflow related knowledge providing a suitable and trustworthy explanation is a challenge.

This paper presents an approach and a system that attempts to provide explanations to support the CBR monitoring of business workflows. Section 2 presents the CBR approach and its application to a real workflow monitoring problem. Section 3 discusses the workflow similarity measures used in this work that support the visualisation of workflow logs and the similarity between workflows used for explanation. Section 4 presents the architecture of a system used for the monitoring of business processes that incorporates an explanation module. Section 5 provides a simple evaluation of the proposed approach based on the example workflow monitoring case study.

2 The Case-Based Reasoning Approach for Monitoring Business workflows

Case-Based Reasoning (CBR) has been proposed as a natural approach to the recall, reuse and adaptation of workflows and knowledge associated with their structure. Minor et al [5] proposed a CBR approach to the reuse and adaptation of agile workflows based on a graph representation of workflows and structural similarity measures. Dijkman et al[6] have investigated algorithms for defining similarities between business processes focused on tasks and control flow relationships between tasks. Van der Aalst et al [7] compare process models based on observed behaviour in the context of Petri nets. Weber et al[21] demonstrates a tool for adaptive workflow management through conversational CBR. The definition of similarity measures for structured representations of cases in CBR has been proposed [8] and applied to many real life applications requiring reuse of domain knowledge associated with rich structure based cases [9],[10].

A new approach for the intelligent monitoring of business workflows using CBR has been proposed and has been shown to be able to monitor effectively real business workflows when compared to human domain experts[11],[12]. This approach can deal with the uncertainty aspect of the workflow monitoring problem. It is requires the definition of similarity measures informed from knowledge discovery of norms and known problems from past operation. It uses a simple graph based representation of cases based on events, actions, intervals and their temporal relationships. An architecture capable to deal with the definition and orchestration of business processes as well as capable of providing monitoring and control services over workflows is key to allowing for the intelligent management of business processes within an organisation.

2.1 The Exam Moderation Business Process Workflows

In order to evaluate the approach proposed in this research, it was decided to use a typical formal business process comprising of defined workflows and involving a number of actors interacting and communicating securely with a workflow monitoring system and involving artefacts tracked and changed by the workflow. The University of Greenwich, School of Computing and Mathematical Science exam moderation system is such a business process for which anonymised operational logs were made available to this research project. The exam moderation system is an automated web enabled secure system that allows course (module) coordinators, course moderators, exam drafters (typically senior managers), admin staff and external examiners to upload, modify, approve and lock student exam papers and orchestrates and captures the associated actions and communications. The system automates the whole process and provides an audit trail of events generated by workflow stakeholders and the system. The system orchestrates a formal process made up of workflows. The process can be defined and displayed formally in terms of a BPMN diagram. The system tracks most workflow actions as timed log events(fig. 1). Most of these actions generate targeted email communications to workflow stakeholders, some for information and others requiring specific further actions from these stakeholders.

For example, the action of a new exam version upload from a course coordinator is notified to the moderator, drafter and admin staff. This can prompt the moderator to approve the uploaded version or upload a new version. However, the coordinator can also upload a new version and admin staff may also decide to format the uploaded version and upload it as a newer version. The system captures all versions, workflow actions, emails sent. There is also a facility to initiate and record free form comments associated to particular document versions and/or workflow actions.

AUDIT TRAIL
Examination document Exam_COMPXX70_ver1_May_2009.DOC has been uploaded by Michael Peterson at 03/04/2009 12:21:43. Email sent to Moderator: mcXX Office: cms-exams
Examination document Exam_MS_COMPXX70_ver1_May_2009.DOCX has been uploaded by Michael Peterson at 04/04/2009 00:06:03. Email sent to Moderator: mcXX Office: cms-exams
Examination document Exam_COMPXX70_ver4_May_2009.DOCX has been uploaded by Ch&&&&g XX at 07/04/2009 13:15:22. Email sent to Coordinator: pmXX Office: cms-exams Head of Department: pmXX
Examination comment has been added by Ch&&&&g Ma at 07/04/2009 13:18:32. Email sent to Coordinator: pmXX Office: cms-exams Head of Department: pmXX
Moderator C&&&&g XX has signed off the Exam and Marking Scheme at 08/04/2009 00:07:17. No Emails sent
Drafter SXtX McKXXXie has removed the Moderator Sign Off for the Exam and Marking Scheme at 08/04/2009 11:40:49. Email sent to Moderator: mcXX Coordinator: pmXX Office: cms-exams Head of Department: pmXX

Fig. 1. An example excerpt of an event log for the exam moderation process (partially obfuscated)

Discussions with workflow monitoring managers showed that patterns of events indicated, but not defined uniquely the current context and state of a workflow. Managers were generally able to guess from looking at the workflow events and communications audit what the context and current state of a workflow was and point to possible problems. However, this is a very time consuming and error-prone process. The number of workflows monitored by a manager is more than one hundred and it is practically impossible to keep monitoring these continuously for problems. Most problems occur due to human misunderstanding of the current state and confusion with roles and responsibilities and usually result to the stalling of a workflow. Managers will then try to restart the process by adding comments to the system, or initiate new actions and communications. However, this depends on managers realizing that such a problem has occurred in the first place and on understanding the nature of the problem.

The CBR Workflow Intelligent Monitoring System (CBR-WIMS) is a system that was built to provide an automatic monitoring system that will notify managers and stakeholders of potential problems with the workflow and provide advice on actions that can remedy a perceived problem. The monitoring system works based on experience of past event/action temporal sequences and the associated contextual knowledge and classification in a Case-Based Reasoning system. Similarity measures allow the retrieval of close matches and their associated workflow knowledge. This allows the classification of a sequence as a particular type of problem that needs to be reported to the monitoring system. Additionally, it is intended that any associated knowledge or plan of action can be retrieved, adapted and reused in terms of a recommendation for remedial action on the workflow.

3 Workflow and Event Log Representation and Similarity Measures

In CBR-WIMS similarity measures between workflow representations can be defined using a graph representation of workflow processes using an exhaustive graph similarity search algorithm based on the Maximum Common Subgraph [10].

3.1 Representation of events in business workflows

The representation of events in the workflow event log uses a general time theory, based on intervals [13]. In the theory used here, the temporal relationships have been reduced from the ones proposed by Allen [14] to just one, the “meets” relationship.

The general time theory takes both points and intervals as primitive. It consists of a triad (***T*****, Meets, Dur**), where:

- ***T*** is a non-empty set of time elements;
- **Meets** is a binary order relation over T;
- **Dur** is a function from T to R_0^+, the set of non-negative real numbers.

A time element t is called an interval if Dur(t) > 0; otherwise, t is called a point.

This approach has been shown to be suitable for defining temporal similarity measures in the context of a CBR system based on the graph representation of events and intervals and their temporal relationships and similarity measures. This can be achieved using graph matching techniques such as the Maximum Common Subgraph (MCSG [10]. Additionally, such a graph can be checked for consistency of temporal references using linear programming techniques [15] and it has been show that it can provide the basis of a system that can derive explanations from partial temporal information[16].

For example, consider a scenario with a temporal reference (T, M, D), where:

$T = \{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9\}$;

M = {Meets(t_1, t_2), Meets(t_1, t_3), Meets(t_2, t_5), Meets(t_2, t_6), Meets(t_3, t_4), Meets(t_4, t_7), Meets(t_5, t_8), Meets(t_6, t_7), Meets(t_7, t_8);

D = {Dur(t_2) = 1, Dur(t_4) = 0.5, Dur(t_6) = 0, Dur(t_8) = 0.3}

The graphical representation of temporal reference (T, M, D) is shown in Fig. 2:

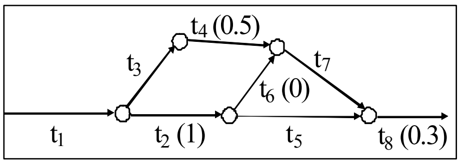

Fig. 2. Graph representation of temporal relationships

3.2 Similarity between graph representation of workflows

To determine the similarity between workflows the WIMS-CBR system uses a number of measures. The main one is based on the Maximum Common Subgraph (MCSG) between two graphs representing workflows.

The Maximum Common Subgraph similarity between two such graphs can be defined as:

$$S(G,G') = \frac{\left(\sum_{\substack{matches\\ C,C'\\ in\\ MCSG}} \sigma(C,C')\right)^2}{count(G).count(G')} \tag{1}$$

where count(G) represents the number of edges in graph G and σ(C,C') is the similarity measure, $0 \leq \sigma(C,C') \leq 1$, between two individual edges (intervals or events) C and C'.

In the case of time stamped events produced by the workflow event log, the duration of each interval can be calculated, so the graphs are collapsed into a single timeline. In this case, the similarity measure is easier to calculate as the MCSG is a common segment made up of events and intervals in a given order in each of the compared workflow logs. In this common graph segment each edge (event or interval) has a similarity measure to its counterpart in the other log that exceeds a given threshold value **ε**. Eq. 1 above can be used to provide the overall similarity between the two workflows. Other branches of the graph can represent contextual temporal information necessary for the interpretation of a sequence of events. This other temporal information could be, for example, the proximity to a deadline, or reminder communications broadcast to staff by managers outside the system (i.e. using normal direct email).

3.3 Providing explanation on temporal similarity between workflows

Tools specialized on log visualisation are common in the computer Systems and networking area. Snort View [17] works in a similar way analysing data from network attack logs. LogView [18] conducts application log analysis after searching within the various web traffic data that were produced from log clusters. Tools use different visualization techniques to present log data. SnortView uses 2-D plots to represent the log events whereas LogView uses Treemaps. Treemaps [19] can visualise hierarchical data in a concentrated, effective way regardless of their size. More specifically, in the workflow explanation area Michaelis et al have proposed a provenance focused approach using RITE networks to represent workflows[20].

The key advantage of the representation and similarity measures for workflow cases in the CBR system represented as graphs containing temporal information about the workflows allows the visualisation of workflows that provides the basis for providing explanation to support the monitoring of workflows.

A workflow event log audit trace is represented in its simplest form (no other contextual temporal relationships) as a simple graph segment:

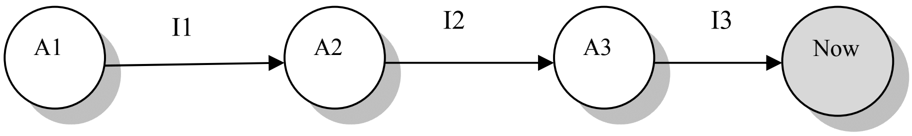

Fig. 3. A Simple workflow Event log segment

which can then be represented as:

(Action1, Actor1, Interval1, Action2, Actor2, Interval2, Action3, Actor3,Interval3)

An example of this would be (intervals are in days):

(CoordUpload,John,3, ModUpload, Phil, 0,CoordUpload, John, 5)

In the first instance the name of the person involved was ignored, focusing solely on the role involved in the action. The similarity measure between two actions A_1 and A_2 is defined as:

$\sigma(A_1,A_2) = 1$ if $A_1 = A_2$ and $\sigma(A_1, A_2) = 0$ if $A_1 \neq A_2$

The similarity measure between two intervals I_1 and I_2 is defined as:

$\sigma(I_1, I_2) = 1 - |I_1-I_2|/(|I_1|+|I_2|)$, $\max(|I_1|,|I_2|)>0$, $\sigma(0, 0)=1$

The Maximum Common Subgraph (MCSG) between cases C and C' is assembled starting right (latest) to left (earliest) calculating similarity measures matching each interval and action in C to the corresponding one in C', stopping when the similarity between two edges falls under a threshold set at 0.5.For example, given the following two cases:

C= (CoordUpload,John,3, ModUpload, Phil, 0,CoordUpload, John, 5) and
C'=(ModUpload,Phil,4, ModUpload, Phil, 0,CoordUpload, Mary, 3)

Assembling the MCSG:

1. σ(5, 3)=1-2/8=0.75
2. σ(CoordUpload, CoordUpload) = 1
3. σ(0, 0)=1
4. σ(ModUpload, ModUpload) = 1
5. σ(4, 3)=1-1/7=0.857
6. σ(CoordUpload, ModUpload) = 0 .. MCSG Matching stops

So, the overall similarity between C and C’ from eq. 1 is:

$$S(C,C') = (0.75+1+1+1+0.857)^2/6^2=0.59$$

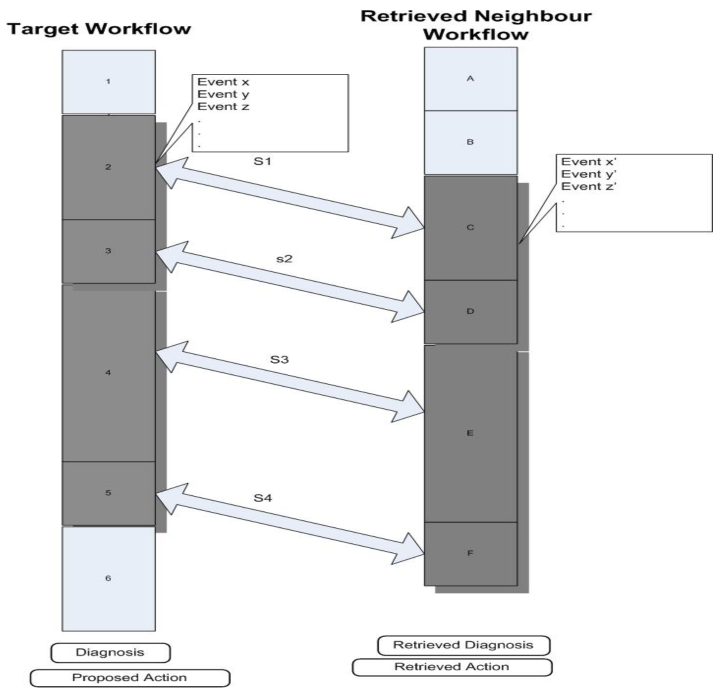

Fig. 4. Visualising the similarity between workflows

When comparing two workflows, the similarity is measured as the normalised sum of similarities between a number of non overlapping MCSG segments in the two workflows. The identification of these workflow segments and their visual communication to the user provides the visual explanation of the CBR monitoring process:

- It explains visually how similar two workflows are.
- It explains visually which parts of the workflow contribute most to this similarity. This allows the user to focus to specific patterns in parts of the workflow that may flag a workflow as problematic.
- It shows visually past remedial actions taken and the results of such actions. This allows a user to understand why the system has made a particular diagnosis and provides an insight into possible remedial options to the current target workflow case problem.

Fig 4 shows the visualisation of the similarity between simple linear workflow event logs. The MCSG is highlighted and there is an ability to drill down to the events and intervals in individual workflow segments. The similarity measures and diagnosis and proposed actions are also shown to provide the user with a deeper understanding of the workflow monitoring process.

4 The Architecture of the Workflow Intelligent Monitoring System

CBR-WIMS is an Intelligent Workflow Monitoring System incorporating a CBR component and an explanation module. The role of the system is to assist the transparent management of workflows in a business process and to orchestrate, choreograph, operate, monitor and adapt the workflows to meet changing business processes and unanticipated operational problems and inconsistencies. Fig. 5 above shows the overall architecture and components of CBR-WIMS. The system allows process managers to create, modify and adapt workflows to suit the changing business needs, and/or to allow for variations related to special business requirements. Furthermore, managers can monitor workflow operation and get diagnostic warnings and context sensitive advice. If a fault or possible problem pattern is detected, this is reported to the workflow operations manager together with the retrieved similar cases and associated recorded experience of any known remedy/course of action. The system provides explanation to users based on the graphical representation of the target workflows and the comparison to the retrieved nearest neighbours.

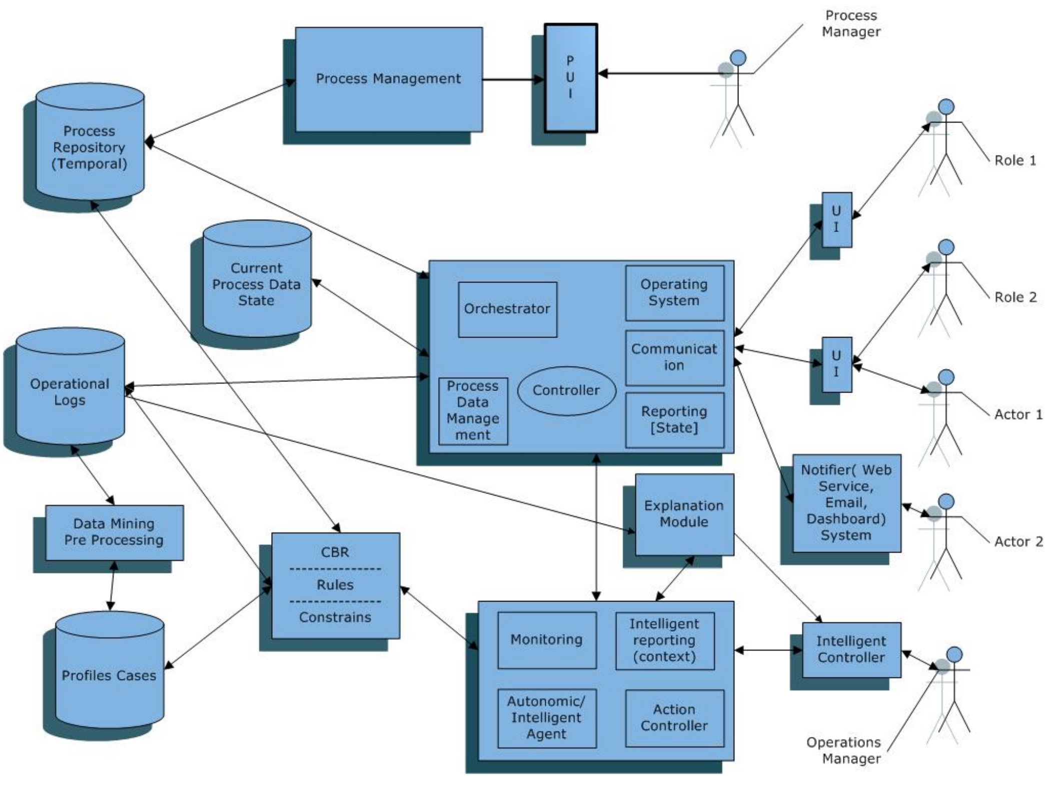

Fig. 5. The Intelligent Workflow Monitoring System Architecture

5 Providing Workflow Monitoring Experiments and Evaluation

In order to evaluate the suitability of the approach proposed in this paper, a number of simple experiments were conducted using the CBR-WIMS system. A small number (20) of exam moderation workflows were monitored and compared to a case base of 130 known workflows which contained expert monitoring classification and advice. The ability of the system to provide suitable monitoring advice on this data set has been evaluated in previous research [12]. The purpose of this experiment was to establish the ability of the system to explain the decisions of the CBR workflow monitoring system.

Workflow managers used WIMS-CBR to establish whether the system provides useful explanation on:

1. The classification of a workflow as “stalled”/”not stalled”
2. The reasons for a “stalled” diagnosis
3. Proposed remedial actions.

Figure 6 shows the typical view of the explanation screen of WIMS-CBR. The user can select any of the nearest neighbours of the target case and investigate the similarity and the retrieved advice. The colour coding of regions shows the degree of similarity. Clicking on particular matching workflow segments within the MCSG allows the user to visualise the areas of overlap which are automatically highlighted in the same colour and compared on the screen. The systems allows the users to “drill” down to particular areas of similarity between the workflows and investigate the monitoring advice retrieved by each of the most similar neighbours.

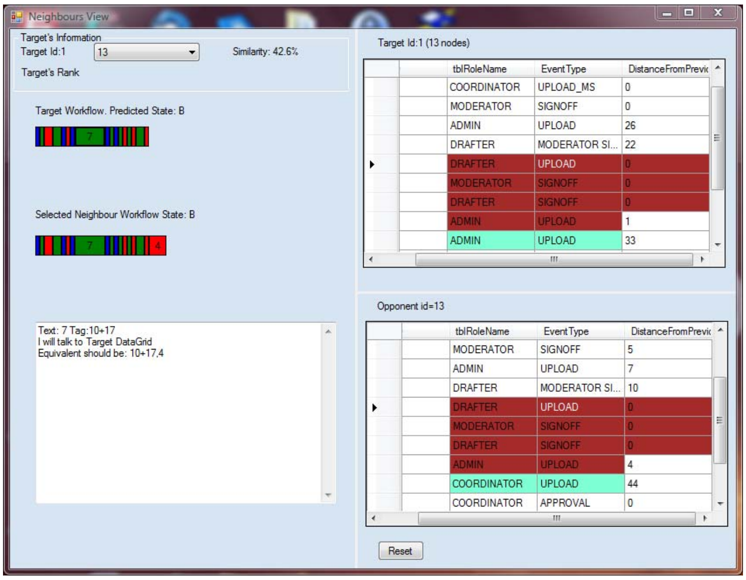

Fig. 6. The Similarity explanation screen in WIMS CBR

The table below (table 1) summarises the results of the simple evaluation of the explanation capabilities of WIMS-CBR. The experts replied to the questions using a scale of 1 (disagree) to 5 (agree strongly). The results were averaged over the 20 target cases.

	WIMS-CBR no explanation	WIMS-CBR with explanation
Correct classification is clear	3.2	4.2
Similarity is obvious to the 3NN	2.8	3.9
Advice clarity	3.3	4.5

Table 1. Evaluation of the explanation and advice

This preliminary evaluation has shown that the explanation module in WIMS-CBR can provide a significantly better insight to workflow managers to allow them to understand better the monitoring warnings and achieve an insight and confidence on the associated advice on remedial action. It is worth noting that even in cases that the CBR system retrieved low quality solution (mainly false positives), the experts reported that the explanation system in WIMS-CBR allowed them to discard the retrieved solution as drilling down to workflow event data showed that the retrieved advice was not relevant to the problem in hand.

6 Conclusions

This paper discussed an approach for the explanation of intelligent diagnosis and monitoring of workflows based on incomplete operation data in the form of temporal log data. This was based on a graph representation of workflows using temporal relationships. Within the CBR process, providing suitable explanations for similarity matching of cases is key to making the CBR approach effective. This is particularly relevant with a complex case representation. The workflow process is orchestrated by a software system using BPEL technologies in service oriented architecture in the CBR-WIMS system. The CBR-WIMS architecture was evaluated in the context of a system that monitors exam moderation workflows. The use of explanation of the matching and similarity measures presented here was showed through a preliminary evaluation using real data from a typical workflow process. The evaluation showed that the approach is capable of providing useful explanations to the CBR workflow monitoring process. Further work will concentrate on further evaluation of the approach, explaining using more complex case representation across multiple workflow logs and providing contextual temporal knowledge, also allowing the adaptation of solutions to retrieved similar workflows using local optimisation criteria.

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