Representing and Mining Association Rules from Multisource Heterogeneous Simulation Traces

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Résumé

Nous présentons dans cet article le framework PeTra conçu pour la représentation et le traitement de traces d'activités hétérogènes multi-sources enregistrées à partir d'environnements d'apprentissage intelligents. Nous avons testé les performances de PeTra sur des traces enregistrées sur un Système Tutoriel Intelligent (STI) dédié à la chirurgie orthopédique percutanée, TELEOS. Les expérimentations réalisées ont démontré que notre framework a permis de générer des séquences à partir desquelles il a été possible, (1) de produire des analyses didactiques sur les liens entre le comportement des apprenants et leurs performances ; (2), d'extraire des règles d'association pertinentes potentiellement réutilisables dans le STI.

Mots Clef

Systèmes Tutoriels Intelligents, Fouille de Données Educationnelles, Fouille de règles séquentielles, chirurgie orthopédique percutanée

Abstract

This paper presents PeTra, a framework proposed for representing and treating multi-source heterogeneous traces from intelligent learning environments. We tested the framework performance on traces from TELEOS, a simulation-based Intelligent Tutoring System (ITS) dedicated to percutaneous orthopedic surgery. This ITS captures learners' interactions from three different and independent sources. The conducted experiment demonstrated that the sequences generated by PeTra fostered efficiently: 1) the learning analytics task of evaluating the influence of visual perceptions on learners' errors; 2) the extraction of interesting association rules potentially reusable for the improvement of TELEOS tutoring services.

Keywords

Intelligent Tutoring Systems, Educational Data Mining, sequential rules mining, percutaneous orthopedic surgery.

1 Introduction

Perceptual-gestural knowledge is multimodal knowledge that involves a combination of actions and/or gestures along with perceptions used as controls for deciding on actions execution or validation [7]. However, in the literature, Intelligent Tutoring Systems (ITS) dedicated to domains involving this type of knowledge often discard the analysis of its perceptual part. This type of knowledge is often tacit and empirical and, thus, hard to capture and model. In fact, capturing perceptual-gestural knowledge in a learning environment requires the use of complementary sensing devices such as eye-trackers for visual perceptions, haptic devices for the touch or computer vision technology to detect postures, facial expressions, etc. The multiplicity of sources generate heterogeneous traces. To provide tutoring services based on these traces, one of the main challenges is to foster their transformation into sequences that reflect consistently the perceptual-gestural aspect of involved knowledge.

The framework PeTra (PErceptual-gestural TRAces treatment) that we present is a proposition to address this challenge. Our case study is TELEOS, a simulation-based ITS dedicated to percutaneous orthopedic surgery. Knowledge involved in this domain is perceptual-gestural [1, 7]. In fact, this surgery requires mastery of coordination of visual analyzes of X-rays, theoretical knowledge on the human anatomy and interpretation of resistance felt on the tools at different points of progression. The evaluations conducted on the validity of our proposition are twofold. We tested first the possibility to analyze learners' performance through their behavior related to perceptual analyses from the proposed representation of generated sequences. Secondly, we evaluated the possibility to extract from the set of generated sequences interesting perceptual-gestural association rules based on domain experts' belief. The rest of the paper is organized as follows. The 2nd section presents related works on analyzing perceptions in ITSs; the 3rd section, the methodology for recording traces in our case study; the 4th section details the traces processing with PeTra; the 5th section, the rules extraction process from the set of transformed sequences; the 6th section, our evaluation and findings and the 7th section, our conclusion and perspectives.

2 Related Works

The literature reports many prominent works on Intelligent Tutoring Systems dedicated to domains where perceptual-gestural knowledge is involved. We can mention ITSs that have been proposed for training helicopters [9] and planes [10] piloting as well as car driving [14, 15]. As one of the most recent related researches, we can also cite CanadarmTutor that was designed to train astronauts of the International Space Station for handling an articulated robotic arm [4]. However, the emphasis is generally carried in these works on actions and gestures and not on the perceptions accompanying these latter. In CanadarmTutor, the manipulation of the robotic arm from one configuration to another is guided by cameras through the operation scenes. Visual perceptions that are likely in play for this guidance would be worth further analysis. Other works have been conducted on the analysis of perceptions in learning contexts. For example, visual perceptions are captured and analyzed to deduce learners' cognitive abilities [12] or their metacognitive skills in exploratory learning [2]. Some researchers would rather use collected perceptual information for measuring the learners' mental workload or cognitive effort [6], or for inferring their behavior in the learning process [3, 8]. In other studies, sensing devices are used for capturing postures, facial expressions and body language as emotional signals [11]. For our part, we believe that perceptions denote knowledge states along with actions they are related to and, therefore, should be analyzed from an epistemic point of view. The aim is to point out the benefits from studying perceptual-gestural knowledge up on its original multimodal characteristics. To realize this, we need first to foster the consistent representation of perceptions-related behaviors and actions/gestures into perceptual-gestural sequences.

3 Recording Perceptual-Gestural Traces: TELEOS Case Study

The simulation interface of TELEOS is composed of sections that represent the main artefacts of a percutaneous operating room. Namely, as illustrated in Fig. 1.a**,** it includes a 3D model section where the patient's model is displayed; the X-rays sections and the settings panel that embeds three settings sub-sections: the fluoroscope settings panel; the cutaneous marks panel and the trocar manipulation panel.

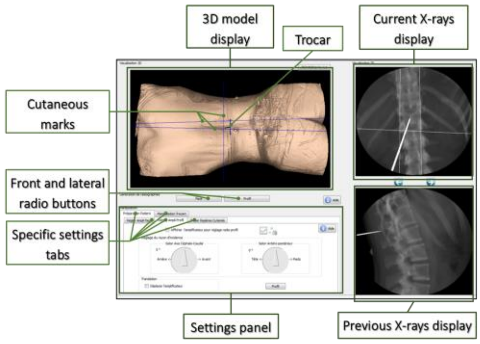


Fig. 1. TELEOS simulation interface

The "fluoroscope" is the unit used to generate X-rays; the "trocar" is the surgical tool used to reach the targeted vertebra; and the cutaneous marks are lines drawn on the patient's skin to spot the insertion point of the surgical tools.

These sections represent the areas of interest (AOI) that are recorded when they are fixed by the user. AOIs related to X-rays embed the points of interest of the targeted vertebra, i.e., specific parts that should be analyzed to support decisions on surgical actions and gestures [5].
For capturing surgical gestures involved in vertebroplasty procedures, an haptic arm has been configured to render the bones and body resistance through the insertion trajectory [7]. The surgical gestures consist of different types of prehension of the trocar, the force applied for its manipulation and the consequent speed of its progression, as well as its incline, orientation and direction of insertion. Finally, punctual actions are captured from the simulation software interface. This is for example the triggering of an X-ray. They are punctual as opposed to the continuity of a visual path or the spatial and temporal dynamism of a gesture. They are therefore recorded only at the moment of their execution as opposed to the continuous recording of information from the complementary sensing devices that are sent on a milliseconds basis: (100 ms for the haptic arm and 200, for the eye-tracker). Furthermore, traces from the three sources are recorded independently. They are heterogeneous in their content types and format, and their time granularities. Traces from the simulator and the eye-tracker are alphanumeric whereas those from the haptic arm are numeric. Their lengths are also different: traces from the simulator contain up to 54 items; those from the haptic arm, 14 items and those from the eye-tracker, 7 items. The challenge is to link those traces into one sequence such that they reflect properly all aspects of involved knowledge.

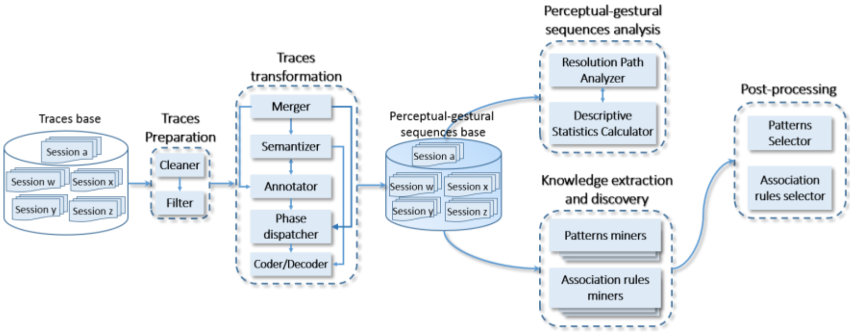


Fig. 2. Overview of the framework PeTra

4 The Treatment Process with PeTra

The PeTra framework is composed of several single-function software that we call "operators". As illustrated in Fig. 2, the operators are structured as a process and dispatched into 5 phases of treatments.

The preparation operators are applied to clean traces from known formatting errors and to discard if needed parameters that are not relevant for the treatment. The transformation phase embeds the operators that generate perceptual-gestural sequences from the multisource traces. We describe further the main operators used in this study.

4.1 Transforming the Multisource Traces

The Merger. The merger is used to link action to the perceptions that support their execution. The result expected is a set of sequences that render the perceptual-gestural aspect of each interaction. This operation is realized in two steps. First, traces from the different sources are joined in one set and then ordered sequentially. Depending on the didactic interest, perceptions linked to one action can precede or follow this latter. In other words, this link is either descending (perceptions to action) or ascending (perceptions from action). In the second step, the operator checks the chosen configuration and merges the parameters of the related perceptions and action into one sequence. In our case study, the link between actions and perceptions is descending.

The Semantization Operator. This operator is used for transposing changes in the coordinates of the simulation tools into semantic states. Those are the consequence of executed actions and gestures. This semantic information can translate a discrete manipulation (e.g. *"the fluoroscope has a caudal incline"*) or a continuous one (e.g. *"the trocar is quickly inclined on the sagittal axis"*). The semantic denominations used for our case study are based on the standard anatomical terms of location. To transpose discrete manipulations of the surgical tools, the operator considers the current and previous position coordinates of each tool. For continuous manipulations, it considers the continuum of sequences from the first that reports a position change to the last that reports a homogeneous evolution of this change (e.g. a change on the same axis and the same direction through several sequences).

The Annotator. This operator is used to enrich sequences with expert assessments. In TELEOS, elements of knowledge that are put into play by learners are diagnosed by a Bayesian Network based on their suitability to a set of expert-defined controls [9]. Those controls are elements of knowledge formulated by expert surgeons and integrated in the knowledge model of the simulator. We refer to the assessment items returned by the Bayesian Network based on these controls as "situational variables". Table 1 shows an example of control and situational variable as well as the actions they are associated to and steps of the simulation in which execution of these actions can be observed.

Table 1. An example of control and situation variable.

Action	Phase	Control	Situation Variable
Check the position of the trocar on a lateral radio	Insertion	At the cutaneous entrance spot, the trocar must be tipped towards the pedicle.	Orientation of the trocar at the cutaneous entrance spot.

The Phase Dispatcher. The phase dispatcher classifies sequences within phases when the resolution of exercises provided in the learning environment is realized through different phases. To determine the phase to which an action belongs, the operator takes as input either the predefined lists of actions for each phase or the list of characteristics that define each phase. At this stage of the treatment process, we have a representation of the perceptual-gestural sequences from which we can proceed to more advanced treatment like learning analytics and data mining tasks.

4.2 Processing Generated Perceptual-Gestural Sequences

The Resolution Path Analyzer. The resolution path analyzer helps in the analysis of exercises whose resolution is a progression of phases' validation. The operator records each phase validation as well as backward steps due to validation errors. It also records both regular or corrective actions and gestures executed at each point of the resolution path along with associated perceptions.

The Miner and Rules Selector. The miner embeds several algorithms proposed in the literature for mining frequent sequential patterns and association rules [13]. For this study, we are interested in extracting sequential rules from the set of generated perceptual-gestural sequences. We proposed a novel algorithm, PhARules, for the extraction process. Fig. 3 presents the pseudo-code of the algorithm that we presented in detail in [13].

INPUT : a phase descriptors database, a sequence database D, minSeqSup, minSeqConf
OUTPUT : the set of phase-related sequential rules
PROCEDURE:

1. Consider the sequence database D as a transaction database D'
2. Group sequences by phase based on phase descriptors and generate transaction databases D'_i, … , D'_n (n = number of phases)
3. Find all association rules for each database D'_i. Select minsup = minSeqSup and minconf = minSeqConf
4. Compute seqSup and seqConf of each association rule r D'_i in D_i. Eliminate each rule r in D_i such that:
   a. seqSup(r) < minSeqSup
   b. seqConf(r) < minSeqConf
5. Return the set of phase-related sequential rules

Fig. 3. The PhARules algorithm

The rules selector is an operator used to filter the mining results so as to select patterns and rules based on user-specified characteristics. For example, in our case study, we are interested in rules reporting perceptions, states of the tools, expert evaluation and at least one punctual actions or one gesture. An example of extracted rule is given in Fig. 4.

{The fluoroscope is positioned for front X-rays with a cranial incline}; {the learner positions the cutaneous marks slider on the patient's body}; {the learner takes a front X-ray}; {the learner visualizes the position of the spinous of the targeted vertebra on the X-ray} ⇒ {the transverse cutaneous mark is correct}; {the left cutaneous mark is correct}

Fig. 4. An example of selected rule

5 Evaluations and Findings

The traces used for this experiment were recorded from 9 simulation sessions of vertebroplasty performed by 5 interns and 1 expert surgeon of the University Hospital of Grenoble. The proposed simulation exercises consisted of treating a fracture of the 11th and/or the 12th thoracic vertebra. Each session is recorded after a preliminary overview of the simulator by the intern and lasts around one hour. The interns have never used the simulator before but have already assisted to at least one vertebroplasty operation in real life. We integrated an expert in the group so as to define a reference scope for the performance of a simulated vertebroplasty. Table 2 presents the characteristics of collected and treated data.

Table 2. Collected and treated data characteristics

Profiles	Session	Treated vertebra	#Raw Traces	#Annotated p.-g. seq.	#Fixations	#Incorrect SV	#Validation errors	#Correction sequences
Intern	S01	11th T	2702	113	2033	750	9	11
Intern	S02	11th T	1636	37	885	178	4	4
Intern	S03	12th T	118	33	690	208	3	5
Intern	S04	11th T	5107	128	2482	644	10	39
	S05	12th T	1677	41	858	174	6	10
Expert	S06	11th T	3432	59	1452	249	4	31
	S07	12th T	1828	47	1040	239	5	9
Intern	S08	11th T	5068	117	2514	644	20	36
	S09	12th T	1496	41	869	193	4	22

Our aim is to demonstrate that the proposed representation of perceptual-gestural sequences generated with the framework PeTra fosters key learning analytics and knowledge extraction results involving perceptions along with gestures and actions to which they are associated. To achieve this, we first evaluate the influence of the visual perceptions on learners' errors over operation simulations; secondly, we evaluate the interestingness of perceptual-gestural association rules extracted from the set of generated sequences and the significance of visual perceptions in this estimate. Further, to test our assumption on the pertinence of representing state of the simulation in the sequences, we also evaluate the significance of reported states of the tools in the estimate of rules interestingness. The evaluation of selected perceptual-gestural rules interestingness has been completed by 5 surgeons specialized in percutaneous surgery at the University Hospital of Grenoble.

5.1 Analyzing Influence of Visual Perceptions on Learners' Performance

We are interested in the analysis of the number of validation errors, the number of corrective actions and gestures applied on these errors and, the number and type of visual perceptions associated to these corrective actions and gestures for each session. The graph of Fig. 5.a summarizes the distribution of visual perceptions, incorrect situational variables and validation errors for each session. The session with the highest rate of perceptions (24.6) reports 19% fewer incorrect situational variables than the others, in average. The same link can be observed between visual analysis and validation errors for all the sessions, except for S08. This can be explained by the fact that the subject performed few corrective actions and visual analysis to support these actions. In fact, in the graph b of Fig. 5, we can notice that this session has one of the lowest averages of corrective sequences (1.7) along with the lowest average of visual perceptions (15.5) associated to these sequences. As a comparison, session S02 reported the lowest average of corrective actions (1.0. See Fig. 5.b) but numerous visual analyzes (20.5) for supporting validation decisions and consequently limiting the number of errors (4. See Fig. 5.a). Moreover, it can be seen in Fig. 4.c that few visual analysis in S08 are of verification type (7.7 against 13.8 of decision perceptions). S09 was performed by the same intern. Conversely, less validation errors and fewer incorrect situational variables were observed even with approximately the same rate of visual perceptions. This is the consequence of the reversal of the amount of visual perceptions and the execution of more corrective actions (See Fig. 5.b).

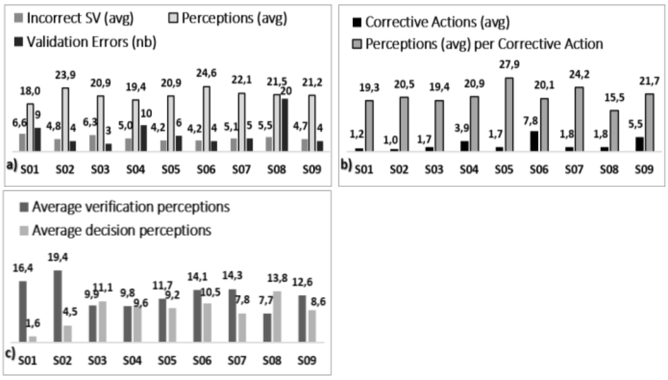
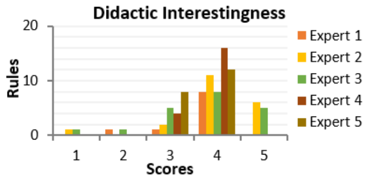


Fig. 5. a) Histogram of average incorrect situational variables, average visual perceptions and number of validation errors per session. b) Histogram of corrective actions and average associated visual perceptions per session. c) Histogram of average verification perceptions and average decision perceptions.

5.2 Evaluating the Extracted Perceptual-Gestural Association Rules

A total of 188 803 rules have been mined with a minimum support of 0.3 and a minimum confidence of 0.7. The rules selector identified 3 895 out of those based on the constraint that each rule should contain actions and/or gestures, visual perceptions, states of the simulation tools and situational variables in either its *if*-clause or its *then*-clause. We randomly pulled out 20 rules to be evaluated by 5 experts in vertebroplasty. 4 of these experts are teaching surgeons. They were asked to estimate from their belief the educational interestingness of each rule in a Likert scale ranging from 1 to 5, 1 being *very low* and 5, *very high*. Besides this overall evaluation, we asked them to provide as well their rating for 1) the reusability of the rules in a teaching context; 2) the novelty of the rules; 3) the pertinence of the reported visual perceptions and 4) the pertinence of the reported states of the tools. To measure the level of agreement among experts surgeon we computed the Jaccard distance of their answers.



	Ex1	Ex2	Ex3	Ex4	Ex5
Ex1	0				
Ex2	.19	0			
Ex3	.20	.15	0		
Ex4	.13	.10	.15	0	
Ex5	.15	.20	.22	.14	0

Fig. 6. Histogram of the distribution of the rules scores for didactic interestingness by each expert and the corresponding Jaccard distance matrix among experts' ratings two-by-two.

The overall average of the scores for the didactic interestingness of the rules is 3.8 out of 5. The weakest average rating is 3.0 for one rule; the average ratings for the 19 other rules range from 3.2 to 4.4, including 12 with an average score greater than or equal to the overall score of 3.8. This reveals that the selected rules are likely of somewhat high or very high didactic interestingness in average from the experts' point of view. The Jaccard distance computed upon the experts' ratings of this variable denotes a good level of agreement among them. In fact, the largest distance observed is of 22% between experts 3 and 5. Fig. 6 shows the histogram for the distribution of the rules on the Likert scale by each expert and the corresponding Jaccard distance matrix among experts' ratings two-by-two for the estimated didactic interestingness of the rules. The same tendency is observed for the ratings of the reusability of the rules, the pertinence of reported visual perceptions and reported states of the tools. The scores report either high or very high rating for most of the rules for these variables along with little disagreement among the experts. Conversely, the scores for novelty range from moderate to very low for most of the rules. The agreement among the experts for this variable is also moderate (up to 52%).

6 Conclusion and Future Works

We presented in this paper the framework PeTra implemented for addressing the challenge of processing multi-source heterogeneous traces from ITSs dedicated to domains involving perceptual-gestural knowledge. The aim is to consistently connect perceptions to actions and gestures they support so as to foster the consideration of all aspects of involved knowledge. We demonstrated the efficiency of our proposition for processing traces recorded on TELEOS, a simulation-based Intelligent Tutoring System (ITS) dedicated to percutaneous orthopedic surgery. We showed that the proposed representation and treatment of traces recorded from three sources in the learning environment further the analysis of the influence of visual perceptions upon interns' performance in simulation sessions of vertebroplasty. We also demonstrated the possibility of mining didactically interesting perceptual-gestural association rules from the set of sequences generated by the framework. The reusability of the rules in a teaching context as well as the pertinence of reported visual perceptions and states of the simulation tools were also rated as high by experts of the domain with significant agreement among those. Conversely, the novelty of the rules was rated as moderate at best but with relatively low agreement between the experts. However, the study is of rather small scale. We plan to go further by confronting the quality of traces treatment performed by our framework to the evaluation of a larger panel of experts. We also consider extending our analyses to the measure of the effective gain from taking into account perceptual aspect of multimodal knowledge compared to treatment that discard either facet of this type of knowledge. As next step on improving the framework, we want to increase the efficiency of the rules selection operator based on main characteristics shared by the top-rated rules. Furthermore, the next evaluation planned will be conducted on the genericity of the framework. An experiment is presently underway for testing its operators on traces from a flight simulator.

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