SIMULATION OF NEW-BORNS BEHAVIOURS DURING CARDIO-PULMONARY RESUSCITATION

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ABSTRACT
This research concerns the formulation of a methodology and its application to elaborate conceptual models of pathological new-borns behaviours combined with the cardio-pulmonary resuscitation gestures. The methodology follows an experimental approach based on the analysis of academic documents, operating experience documents, and practitioner interviews. The implemented process consisted in adopting approach and methods from Cognitive Engineering in order to elaborate an ontology as a basis for the development of conceptual models of the resuscitation scenarios as well as the specification of a simulator. The process is based on the knowledge engineering method, KOD. The formalization of the conceptual models consisted in integrating the concepts into the definition of classes and objects and, by the use of a discrete event formalism. As a result, a simulator has been built to train medical practitioners to face situations, which are reported to potentially cause errors and thus improve the safety of the resuscitation gestures.

Keywords: new-borns resuscitation, simulation, conceptual modelling, ontology engineering

1. INTRODUCTION

"Approximately 10% of newborns require respiratory support at birth and 1% require complex resuscitation" (ILCOR 2006). In France, 25% of the causes of neonatal mortality are due to respiratory difficulties: intra-uterine hypoxia, asphyxia at birth, respiratory distress syndrome or other respiratory diseases.
Given these emergencies at birth, specialized technical equipment and skilled personnel are required to carry out all or part of the following sequence of actions (ILCOR 2006): (i) the initial stage of stabilization (airway clearance, neonatal placement and stimulation), (ii) ventilation, (iii) chest compressions, and (iv) medication or volume expansion.
These actions are well known and quite simple to perform. The criticality of these situations is due to time constraints and the fact that these are not routine situations. Medical personnel have to analyse the situation, diagnose the problem and perform the "right" actions within the minute after birth. A diagnostic or performance error can lead to irreversible damage or death. The problem is that despite the rarity of these situations, they require highly trained medical personnel.
The project "Cyber-Poupon", developed in partnership with Ab Initio Medical, is to propose an answer to this problem of qualification. It consists in designing and developing an integrated simulation system for the training of hospital staff who may be confronted with the critical situations of resuscitation of new-borns.
The main instrumented anatomical simulators of new-borns are marketed by the companies Laerdall, Simulaids and Meti. They all contain a large number of configurable physiological functions and most pathological behavioural scenarios of the new-born. These simulators are now widely used in resuscitation training centres. However, there are still many gaps that can interfere with learning objectives:

- Lack of realism in physical appearance (materials, resemblance)
- The lack of realism of the dynamic aspect (behaviour, movements, reactivity)
- The non-automatic evaluation of the learner's gestures (reaction of the new-born to resuscitation actions).

These inadequacies necessarily induce behaviours of the learner too far from what he must master in real situations. These shortcomings have led the reponsibles in charge of the neonatology service to develop their own simulation system, in relationship with the Ab Initio Medical company and the "Laboratoire des Sciences de l'Information et des Systèmes".
The current work lies in the following research fields: (1) from the medical field perspective, the paper presents a software tool (simulator) to train medical

staff to cardio-pulmonary resuscitation gestures to improve new-borns safety and (2) from a methodological perspective, the paper shows the importance of developing ontologies (i) for structuring a domain (at a conceptual level) as its actors perceive it and (ii) for using these ontologies to build computer tools with pedagogical perspective in that domain.

An overview of the Cyber-Poupon project is presented in Section 2 and Section 3 describes the methodological approach and the process used to build the Simulator. In the Section 4 the implementation of the process is developed and exemplified. Section 5 presents the conclusions.

2. THE CYBER-POUPON PROJECT

The "Cyber-Poupon" project consists of developing a realistic simulation system designed to train hospital agents to the resuscitation gestures of new-borns suffering from cardiopulmonary pathologies. The simulation system reproduces the different pathological behaviours of a new-born (New-Borns Simulator), the working environment of a resuscitation room (Resuscitation Environment Simulator), and a monitoring and control environment of the learner by a teacher (Monitoring and Control System) (Figure 1).

Two categories of exercises are possible: (i) targeted training on one or more specific gestures (intubation, ventilation, etc.) or (ii) training in the diagnosis of a pathology, followed by planning a Protocol and its implementation.

In the first class of exercises, the professor chooses the gesture (s) to be executed (1), in the second class of exercises the professor chooses a scenario corresponding to a pathology (1). In both cases, the simulator automatically generates the gesture reference model (2) as well as the Cyber-Poupon behaviour model (3). The comparison between the reference model of the gestures to be realized and the way they are actually performed produces a gap whose sign and amplitude will induce a new state of the Cyber-Poupon. This state is returned to the learner by visualizing physiological variables such as SPO2 or heart rate (4). The learner then adjusts his gestures (5) according to his analysis of this feedback. The teacher, through his Monitoring and Control system, receives the same information as the learner and can act directly on the learner's monitoring system (6). A set of cameras records the learner's work session as the basis for the debriefing session following the simulation session.

The simulation system belongs to the category of "Instrumented Anatomical Simulator" in reference to the classification of medical simulators proposed by (Silveira 2004):

- virtual simulators with a 3D Graphical User Interface (3D GUI);
- virtual simulators with a 3D GUI and coupled to a force feedback system;
- anatomical simulators consisting of a non-instrumented dummy;
- Instrumented Anatomical Simulators (IAS).

The IAS simulators consist of an instrumented dummy ("New-Borns Simulator" - Figure 1) and can be supplemented by a virtual interface ("Resuscitation Environment Simulator" and "Monitoring and Control System" - Figure 1). They are recognized to provide a more realistic immersion of the learners.

3. METHODOLOGICAL APPROACH

3.1. Analysis of the problem

One of the main problems arising during the conception of new computing tools, and more accurately for computing tools with pedagogical objectives is linked to the right transmission of the right system of concepts. A failed transmission or a wrong system of concepts can lead to “dormant faults” for learners which will became active within the critical situations of the resuscitation and could lead to fatal accidents for new-borns.

The notion of ontology and works currently developed by the scientific community of the knowledge engineers can bring interesting answers to this problem. One of the objectives of ontology is to facilitate the exchanges of knowledge between human beings, between human beings and machines as well as between human beings through machines (Uschold 1996).

The advantages in developing ontologies to solve problems arising in the field of safety and Health care are the following: (i) they structure the domain in highlighting concepts and semantic relations that are linking these concepts, (ii) they can be used to be the base for new computer tool design, and (iii) new pedagogical approaches. Tools so built are carrying knowledge shared by the actors of the domain, what makes them more effective to train medical staff to the right gestures within critical situations.

The followed methodological process (Figure 2) consists in adopting approach and methods from Cognitive Engineering in order to elaborate an ontology as a basis for the development of conceptual models of the resuscitation scenarios as well as the specification of a simulator. The process is based on the "Knowledge Oriented Design” (KOD) method (Vogel 1988; Mercantini 2007). KOD was designed to guide the knowledge engineer in its task of developing knowledge based systems. This method was designed to introduce an explicit model between the formulation of the problem in natural language and its representation in the formal language chosen. The inductive process of KOD is based on the analysis of a corpus of documents, speeches and comments from expert domain, in such a way to express an explicit cognitive model (also called conceptual model).

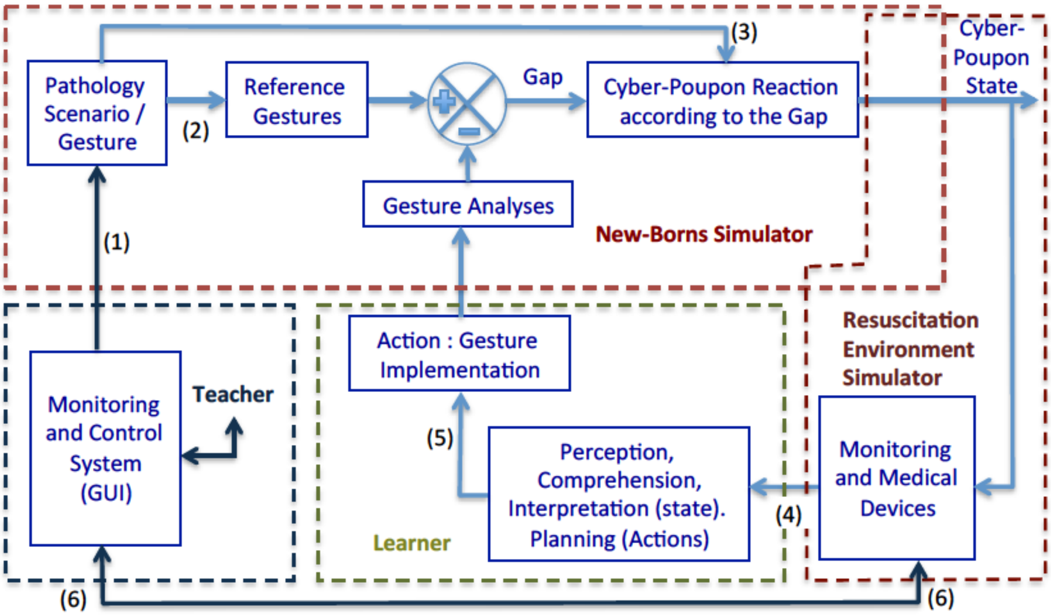

Figure 1: Functional diagram of the new-borns simulation system (the Cyber-Poupon project). Relationships labelled with a number between brackets (n) are detailed in the paragraph: "The Cyber-Poupon project".

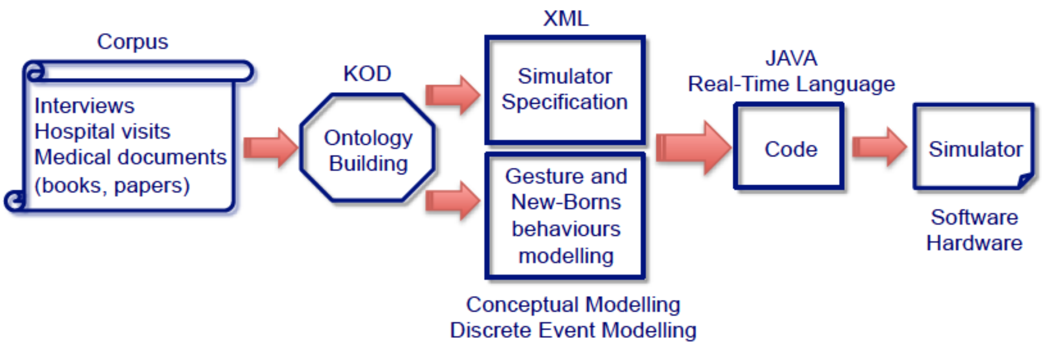

Figure 2: The implemented methodological approach for the Cyber-Poupon project.

Table 1. KOD, the three modelling levels.

Paradigms / Models	Representation	Action	Interpretation
Practical	Taxeme: object static representation	Acteme: dynamic representation of active objects	Inferences
Cognitive	Taxonomy: object static organization according to theirs properties	Actinomy: dynamic object organization	Reasoning Pattern
Software	Classes	Methods	Rules

3.2. The KOD method

KOD is based on an inductive approach requiring to explicitly express the cognitive model (or the conceptual model) based on a corpus of documents, comments and experts' statements. The main features of this method are based on linguistics and anthropological principles. Its linguistics basis makes it well suited for the acquisition of knowledge expressed in natural language. Thus, it proposes a methodological framework to guide the collection of terms and to organize them based on a terminological analysis (linguistic capacity). Through its anthropological basis, KOD provides a methodological framework, facilitating the semantic analysis of the terminology used to produce a cognitive model (conceptualisation capacity). It guides the work of the knowledge engineer from the extraction of knowledge to the development of the conceptual model.

The implementation of the KOD method is based on the development of three successive models: the practical models, the cognitive model and the software model (Table 1). Each of these models is developed according to the three paradigms: <Representation, Action, Interpretation / Intention>.

The Representation paradigm gives the KOD method the ability to model the universe such as experts represent it. This universe is made of concrete or abstract objects in relation. The KOD method provides methodological tools to develop the structure of this universe of knowledge according to this paradigm. The Action paradigm gives the KOD method the ability to model the behaviour of active objects that activate procedures upon receipt of messages. Thus, the action plans designed by human operator, as well as those of artificial operators, will be modelled in the same format. The Interpretation / Intention paradigm gives the KOD method the capability to model the reasoning used by experts to interpret situations and elaborate action plans related to their intentions (reasoning capacity).

The practical model is the representation of a speech or document expressed in the terms of the domain, by means of "taxemes" (static representation of objects – French word), "actemes" (dynamic representation of objects – French word) and inferences (base of the cognitive reasoning pattern). A "taxeme" is a minimum grammatical feature; it is the verbalisation of an object or a class of objects. An "acteme" is the verbalisation of an act or a transformation, a unit of behaviour. An inference is the act or process of deriving logical conclusions from premises known or assumed to be true. The cognitive model is constructed by abstracting the practical models. The cognitive model is composed of taxonomies, actinomies and reasoning patterns. The software model results from the formalization of a cognitive model expressed in a formal language independently of any programming language.

3.3 The ontology building process using KOD

Research work in Ontology Engineering has put in evidence five main steps for building ontologies (Dahlgren 1995; Uschold 1996; Fernández-López 1999; Aussenac-Gilles 2000; Gandon 2002):

1. *Ontology Specification*. The purpose of this step is to provide a description of the problem as well as the method to solve it. This step allows one to describe the objectives, scope and granularity size of the ontology to be developped.
2. *Corpus Definition*. The purpose is to select among the available information sources, those that will allow the objectives of the study to be attained.
3. *Linguistic Study of the Corpus*. It consists in a terminological analysis of the corpus in order to extract the candidate terms and their relations. Linguistics is specially concerned to the extent that available data for ontology building are often expressed as linguistic expressions. The characterization of the sense of these linguistic expressions leads to determine contextual meanings.
4. *Conceptualization*. Within this step, the candidate terms and their relations resulting from the linguistic study are analyzed. The candidate terms are transformed into concepts and their lexical relations are transformed in semantic relations. The result of this step is a conceptual model.
5. *Formalization*. The step consists in expressing the conceptual model by means of a formal language.

The projection of the KOD method on the general approach for developing ontology shows that KOD guides the corpus constitution and provides the tools to meet the operational steps 3 (linguistic study) and 4 (conceptualization) (Table 2). Under previous researches, the KOD method has been already implemented (Mercantini 2003; Mercantini 2004; Mercantini 2007; Mercantini 20015) in the domains of road safety, safety of urban industrial sites and study of conduct errors of industrial plants.

Table 2: Integration of the KOD method into the elaboration process of ontology

Elaboration process of Ontology	KOD process	Elaboration process of ontology with KOD
1. Specification		1. Specification
2. Corpus definition		2. Corpus definition
3. Linguistic study	1. Practical Model	3. Practical Model
4. Conceptualisation	2. Cognitive Model	4. Cognitive Model
5. Formalisation		5. Formalisation
	3. Software Model	6. Software Model

4. ELABORATION OF THE ONTOLOGY

4.1. Ontology specification

The KOD method does not offer tools facilitating the specification of ontology. To carry out this step, many authors recommend the use of the concept of scenario (Uschold 1996; Caroll 1997; Gandon 2002) with the objectives to clarify and justify the validity of building ontology, the future uses and the future addressees. We do not further develop this stage but we illustrate it by giving summaries of the scenario that have been drafted within the framework of the triplet Td: <Domain, Problem, Method>.

The domain is that of the new-borns cardio-pulmonary resuscitation. The problem is to train medical staff to produce the right diagnosis, the right gesture planning and the right gesture execution. The problem solving method consists in the elaboration of a cooperative system of simulation.

4.2. Corpus Definition

Definition and analysis of the corpus are performed on the basis of the specification of the ontology as well as the consideration of the properties of practical and conceptual models resulting from the application of the KOD method. Thus, the documents to be collected must be both representative of the triplet <Domain, Problem, Method> and meet the criteria of suitability required by the three paradigms <Representation, Action, Interpretation / Intention>. The combination of the triplet (Td) with the three paradigms constitutes a helpful grid to analyse the ontology specification with the goal to define the documents that must constitute the corpus.

The types of documents that make up this corpus are the following:

- Professional documents about medical protocols,
- Academic documents about the resuscitation gestures,
- Technical documents about the main Instrumented Anatomical Simulators of new-borns,
- Interviews concerning the return on operating experience about well done resuscitation,
- Interviews concerning the return on operating experience about erroneously done resuscitation.

4.3. Practical models

This step consists in extracting from each document of the corpus, all the elements (objects, actions, and inferences) that are relevant to the representation of pathological new-borns behaviours combined with the cardio-pulmonary resuscitation gestures.

4.3.1 Extracting taxemes

The linguistic analysis is performed in two steps: the verbalization and the modelling. The verbalization step consists in paraphrasing the corpus documents in order to obtain simple phrases, which allow qualification of the terms employed during document analysis. Some terms appear as objects, others appear as properties, and yet others appear as relations between objects and values. The modelling step consists of representing the phrases in the format of taxeme: <object, attribute, value>.

The taxeme characterizes an object from the real world by means of a relation (attribute), which links the object to a value. There are five types of relations: classifying (is-a, kind-of), identifying (is), descriptive (position, failure mode, error mode, cause, etc.), structural (composed-of) and situational (is-in, is-below, etc.). The example that follows illustrates the process employed to obtain the taxemes in the case of the bag mask ventilation gesture. Extracted and translated from (Lavaud 2004):

"... Two types of manual insufflators are presented: AMBU type and Laerdal type. ..."

"…The AMBU manual insuflator is made of: the balloon, injection and exhalation valves, the pressure relief valve, the universal patient connector, and the oxygen connection. …"

Paraphrases:

1. The "AMBU manual insufflator" is a manual insufflator
2. The "Laerdal manual insufflator" is a manual insufflator
3. The "AMBU manual insufflator" is made of a balloon
4. The "AMBU manual insufflator" is made of an injection valve
5. The "AMBU manual insufflator" is made of an exhalation valve
6. Etc.

Taxemes:

1. <AMBU manual insufflator, *kind-of*, Manual insufflator>
2. < Laerdal manual insufflator, *kind-of*, Manual insufflator >
3. < AMBU manual insufflator, *composed-of*, Balloon>
4. < AMBU manual insufflator, *composed-of*, Injection valve >
5. < AMBU manual insufflator, *composed-of*, Exhalation valve >
6. etc.

The extent of this analysis at the Corpus, have allowed obtaining the set of taxemes needed for the representation of the universe described by the corpus of documents. An object of the real world is modelled by the sum of the related taxemes.

4.3.2 Extracting actemes

In order to obtain the actemes, the linguistic analysis consists on identifying verbs that represent activities performed by actors during resuscitation or object behaviour. In general terms, an activity is performed by an action manager, by means of one or more instruments, in order to modify the state (physical or knowledge) of the addressee. The action manager temporarily takes control of the addressee by means of instruments. Occasionally the action manager can be one who directs the activity and at the same time is also subjected to the change of state (example: knowledge acquisition). The following example illustrates how to extract actemes from the Corpus: "... The manual bag mask ventilation is carried out by means of a manual insufflator by exerting repeated compressions of the balloon (50 cycles per minute for the new-born and 30 cycles per minute for the infant ..."
The activity (or action) is "Manual Bag Mask VENTILATION". Once identified, the activity is translated into a 7-tuple (the acteme):

<Action Manager, Action, Addressee, Properties, State1, State2, Instruments>

Where: the Action Manager performs the action (the Learner); the Action causes the change; the Addressee undergoes the action (the Cyber-Poupon); the Properties represent the way the action is performed; State 1 is the state of the addressee before the change; State 2 is the state of the addressee after the change; Instruments, is one or a set of instruments representing the means used to cause the change (the insufflator).
The acteme "Manual Bag Mask VENTILATION" is represented as following:

<Learner, Manual Bag Mask VENTILATION, Cyber-Poupon, (Cycles per minute, Regularity, duration), Cyber-Poupon (not ventilated), Cyber-Poupon (ventilated), AMBU Manual Insufflator>

Actemes can be represented according to an actigram form (Figure 3) or to a table form (Figure 4).

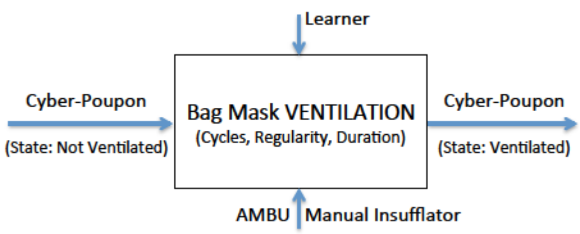

Figure 3: Representation of the Acteme "Bag Mask VENTILATION" according to an actigram form.

Action: Bag Mask VENTILATION	
Components	**Values**
Action Manager	{Learner, Professor}
Addressee	{Cyber-Poupon}
Addressee State1	{Not Ventilated}
Addressee State2	{Ventilated}
Instruments	{AMBU Manual Insufflator, Leardal Manual Insufflator}
Properties	{Cycles, Régularity, Duration}

Figure 4: Representation of the Acteme "Bag Mask VENTILATION" according to a table form.

The state of the Cyber-Poupon summarized in Figures 2 and 3 by the terms "Not Ventilated" and "Ventilated" is in fact modelled by the following set of attributes (state variables):

- SPO2 (partial pressure of oxygen in the blood),
- Heart rate,
- Respiratory Frequency,
- Blood pressure,
- Colour,
- Tonicity,
- Screams.

The values of each attribute (state variable) evolves according to the right or wrong realization of the considered action: the "bag Mask Ventilation" in the case of the example.
Actemes model resuscitation activities. An Acteme is composed of textual items extracted from corpus documents, which describe the state change of an object as described by the domain experts. Each element of the 7-tuple must be previously defined as a taxeme.

4.4. The cognitive model

This phase consists of the analysis and abstraction of the Practical Models. The objective is to build the application ontology. In other words, the aim is to classify the used terminology and thus obtain the KOD Cognitive Model

4.4.1 Taxinomy building

Taxinomy building is based on term analysis and concept identification.
Term analysis consists in solving problems induced by homonym and synonym terms, with the objective to build a common terminology.
Concept Identification is based on the analysis of taxemes and consists in highlighting the nature of attributes, which characterize each object. The attribute nature is the basis for the construction of the taxonomies (relations 'kind-of' and 'is-a') or other tree type structures (relations: 'is-composed-of', 'position', 'is-in', 'is-below', 'is-above', etc.).

According to the previous example, it is possible to construct the taxonomy of the Manual Insufflators (*kind-of* relation – Figure 5), and a tree structure giving the composition of an AMBU Manual Insufflator (*Composed-of* relation – Figure 6). All the taxemes of the corpus have been organized in taxonomies and tree structures to express all the relationships between concepts.

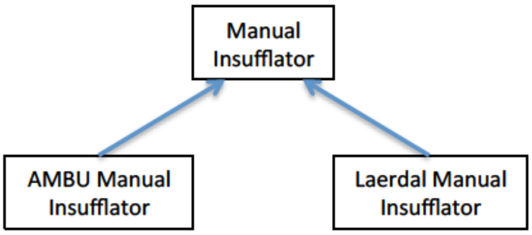

Figure 5: Taxonomy of Manual Insufflators. "*kind- of*" relation.

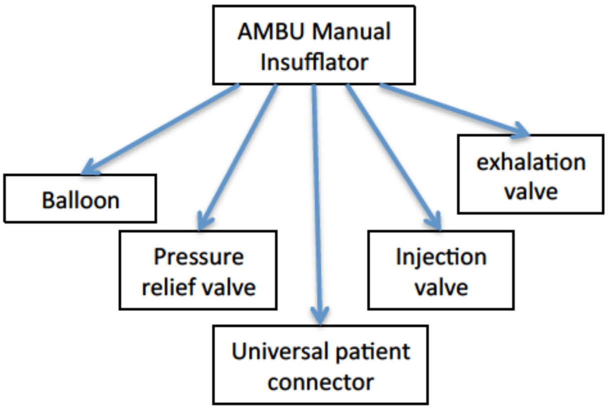

Figure 6: Tree structure with the "*Composed-of*" relation.

4.4.2. Actemes abstraction

One result of the acteme analysis is that actemes can be devided into three main action categories:

- Actions related to new-borns behaviours,
- Actions related to resuscitation gestures,
- Actions related pedagogical services.

Amongst actions related to new-borns behaviours we can cite: Tonicity change, Heart Rate (HR) change, SPO2 change, etc. Amongst actions related to resuscitation gesture, we can cite: Manual Bag Mask Ventilation, Nasotracheal Intubation, Tracheal aspiration, Gastric emptying, Heart massage, etc. The actions related to pedagogical services are implemented to improve the simulator functionalities such as: recording a simulation session, inserting comments during a simulation session, etc.

The actemes abstraction has led to two kinds of organization: action taxonomies and actinomies. As an example, Figure 7 presents the taxonomy of the Ventilation actions. Some actemes of the resuscitation gesture can be organized in a structural and temporal way to form actinomies. The interest of this kind of structure is that actions are already planned and they can be used as a reference model (Figure 8).

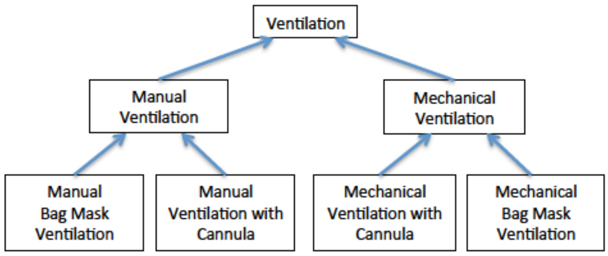

Figure 7: Extract of the resuscitation gestures taxonomy centred on the Ventilation gesture ("*kind-of*" relation).

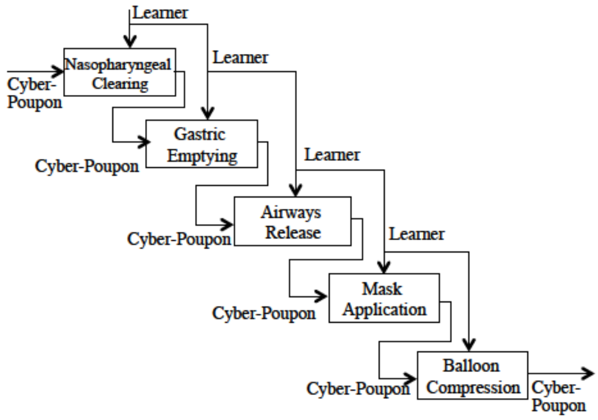

Figure 8: Simplified representation of the "Manual Bag Mask VENTILATION" actinomy.

4.4.2. Building of Reasoning Patterns

The modelling in the form of inferences consists in representing the elements of the corpus that characterize the cognitive activities of humans or machines.
Inferences are the basic elements of the Interpretation / Intention paradigm. An inference is the mental process, which consists in drawing a conclusion from a series of propositions accepted as true (premises).
To illustrate this step of the methodology process, an extract of the new-borns behavioural analysis has been chosen. In this study, the Interpretation addresses observations of physiological situations of new-borns, and the Intention concerns planning of "pseudo-physiological" discrete states. Premise propositions are resulting from the interpretation of the situation elements. They are obtained from observation and therefore, they are held to be true. The conclusion is related to "pseudo-physiological" state transitions.
A detailed presentation of this step is not permitted due to confidentiality. The presentation will be limited to the final rules on the thresholds triggering the transitions of pseudo-physiological states and not on the laws and rules defining the evolution of the physiological variables according to gestures.
The new-borns behaviours have been modelled by means of six discrete states where State0 is the "normal state" and State5 is the death. The state transitions are

relative to the values of two physiological variables: the SPO2 and the Heart Rate (HR).

IF (HR >150 and Spo2 > 75) THEN State = State0; (Normal)
IF (HR ∈]105 ; 150] and Spo2 ∈]65 ; 75]) THEN State = State1;
IF (HR ∈]60 ; 105] and Spo2 ∈]30 ; 65]) THEN State = State2;
IF (HR ∈]30 ; 60] and Spo2 ∈]20 ; 30]) THEN State = State3;
IF (HR ∈]0 ; 30] and Spo2 ∈]0 ; 20]) THEN State = State4;
IF (HR = 0 and Spo2 = 0) THEN State = State5; (Death)

The resulting new-borns behaviour, for the ventilation gesture, is modelled by the state-chart diagram of the Figure 9. The state-chart evolves according to two types of transitions: the transitions related to the crossing of certain thresholds for the SPO2 and Heart Rate variables, and the transitions relative to the time spent in a state (δint) without improvement of the physiological variables.

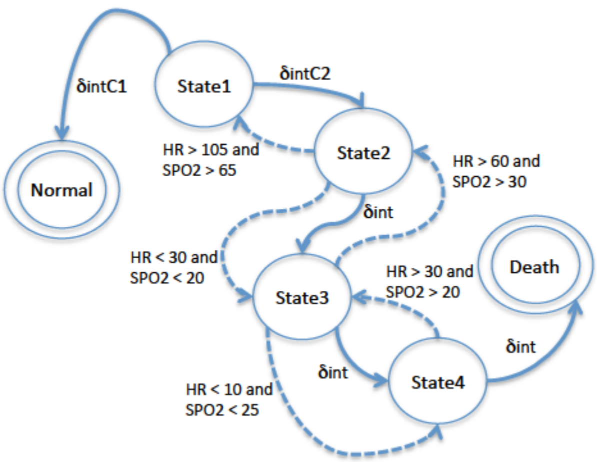

Figure 9: State-chart diagram modelling the new-borns behaviour according to the right or wrong execution of the ventilation gesture.

5. CONCLUSION

The paper presents the methodology process implemented to develop a system of simulation to train medical practitioners to the resuscitation gestures. The process is based on building an application ontology used to elaborate conceptual models of the new-borns behaviours and resuscitation gestures, and to specify the system of simulation. The Manual Bag Mask Ventilation gesture has been used to exemplify the implementation of the process. In the present state of realization of the system of simulation, nasotracheal intubation and cardiac massage have also been analysed, modelled and coded completely.

This work showed that the use of an application ontology was relevant to ensure the consistency of the modelling and specification processes since both use the same stabilized vocabulary. Furthermore, the ontology structures the domain (new-borns resuscitation) according to the problem to solve (training medical staff) and to the problem solving method (simulation). The ontology was obtained through a cognitive approach, which consisted in applying the KOD method, which has proven to be adequate.

The simulation system including learners and professors management, simulation sessions and debriefing sessions was performed. Three resuscitation gestures are currently available. Future works concern the development of the other resuscitation gestures as well as the final robot of the new-born.

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