A Method for the intelligent Authoring of 3D Animations for Training and Maintenance

zur Erlangung des akademischen Grades eines
DOKTORS DER INGENIEURWISSENSCHAFTEN (Dr.-Ing.)
der Fakultät für Maschinenbau
der Universität Paderborn

genehmigte
DISSERTATION

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Tag des Kolloquiums: 06. März 2008
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Preface

Virtual Reality (VR) combines all technological elements for building immaterial three-dimensional worlds, enabling the user to perceive these worlds through visualization, immersion, and interaction. In industry, complete digital product representations (digital mock-ups) are used for VR-based analysis, that even allow to simulate the functional behavior of a product for virtual prototyping purposes.

In training and maintenance, VR-based applications increasingly use 3D computer animations to demonstrate and explain complex technical products. However, authoring the 3D animations is a "on-demand" process that depends on highly customer-specific requirements. In addition, the 3D animations are created from paper-based training and instruction manuals that provide mostly non-formal information written in natural language.

From this, semantical problems between the 3D modeler authoring the 3D animations and the customer requiring exact information arise. Reasons for such semantical problems are domain-specific terminologies the 3D modeller does not master, ambiguous translations from natural language into corresponding elements of a 3D animation, and different views on a product requiring training animations custom-tailored to end-user roles.

In this context Mr. Parisi developed a new method that facilitates the authoring process of 3D animations for training and maintenance purposes starting from natural language descriptions. The method solves semantical ambiguities by using an ontology core, consisting of an existing upper ontology and one or several domain-specific ontologies, which allow matching concepts included in a generic training tasks. A subsequent mapping of transformations derived from action verbs in natural language with corresponding 3D models enables the automatic generation of the 3D animation.

Mr. Parisi proved the feasibility of his approach in a manufacturing scenario, derived from the European project KoBaS (Knowledge Based Customized Services for Traditional Manufacturing Sectors Provided by a Network of High Tech SMEs), he was involved in for the past years. The work of Mr. Parisi is an important step towards the exploitation of VR technology enabling the authoring of 3D animations by non-experts.

Paderborn, May 2008 *Prof. Dr.-Ing. Jürgen Gausemeier*

Acknowledgments

The present work “A Method for the intelligent Authoring of 3D Animations for Training and Maintenance” is the result of my research work at the Heinz Nixdorf Institute, University of Paderborn. It derives mostly from the experience gained from the participation at the KoBaS and WearIT@work projects, co-funded by the European Commission within the Sixth Framework.

I would like to thank Prof. Dr.-Ing. Jürgen Gausemeier for his trust in me and for giving me the chance to get a PhD in a short period of time.

I am also grateful to Prof. Dr. Wilhelm Schäfer and Prof. Dr.-Ing. Jörg Wallaschek for accepting co-advisorship, as well as to Prof. Dr.-Ing. habil. A. Trächtler as the chairman of the board of examiners and to Prof. Dr. rer. nat. T. Tröster as the assessor of the board of examiners.

I appreciate the assistance given by the International Graduate School at the University of Paderborn and by the UNITY AG for the financial support.

Regarding my work a very special thanks goes to our team leader Dipl.-Ing. Michael Grafe, always ready to give me support and suggestions, as well as to Dr.-Ing. Rafael Radkowski, Dr.-Ing. Jan Berssenbrügge and Dipl.-Inform. Jochen Bauch.

I would also like to mention all other current and former members of the Virtual Reality research group “Virtuelle Umgebung” (VU) Team for having shared a very intense time and for being an extraordinary team: Dr.-Ing. Qing Shen, not only a colleague but also a very good friend, Dr.-Ing. Carsten Matysczok, Dr.-Ing. Peter Ebbesmeyer, Dr.-Ing. Jürgen Fründ, Dipl.-Inform. Sven Kreft, Dipl.-Inform. Helene Wassmann, Dipl.-Ing. Sven-Kelana Christiansen, Dipl.-Wirt.-Ing. Ute Brüseke. At the same time a thanks to our secretaries, Sabine Illigen and Alexandra Dutschke, for their time and patience, to our “computer doctors”, Dipl.-Ing. Karsten Mette and his apprentices, to my last “roommate” at the HNI, M.Sc Hua Chang, and to Prof. Vita Scurto as an English native speaker for accepting to read and review my English.

Last but not least, a very special thanks to my wife Rita, for having supported me and to my family for having always helped me.

Paderborn, May 2008 *Salvatore Parisi*

To Rita and to my family

List of published partial Results

[PBB+07a] PARISI, S.; BAUCH, J.; BERSSENBRÜGGE, J.; RADKOWSKI, R.: Ontology-driven Generation of 3D Animations for Training and Maintenance, Proceedings of the International Conference on Multimedia and Ubiquitous Engineering (MUE'07), pp. 608-614, 2007

[PBB+07b] PARISI, S.; BAUCH, J.; BERSSENBRÜGGE, J.; RADKOWSKI, R.: Using Ontology to create 3D Animations for Training, International Journal of Software Engineering and its applications, Vol.1 No.1, July 2007, pp. 67-78

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1 Introduction

Computer Aided Design (CAD) has transformed an essentially paper-based design into a digital product representation, called Digital Mock-up, which represents the product structure of an assembly together with the geometry of its parts. This technology allows nowadays engineers to build a virtual prototype, which is used to simulate together with its behavior, e.g. the dynamic behavior, and test product characteristics without ever building a physical model. Thus saving the related development costs and reducing time to market. According to GAUSEMEIER (see figure 1-1), the virtual product or "virtual prototyping" follows the strategic product planning, representing one of the three cycles of the product development process; the process is concluded by the development and planning of the related manufacturing processes, which goes under the name of digital factory or "Digitale Fabrik" in German.

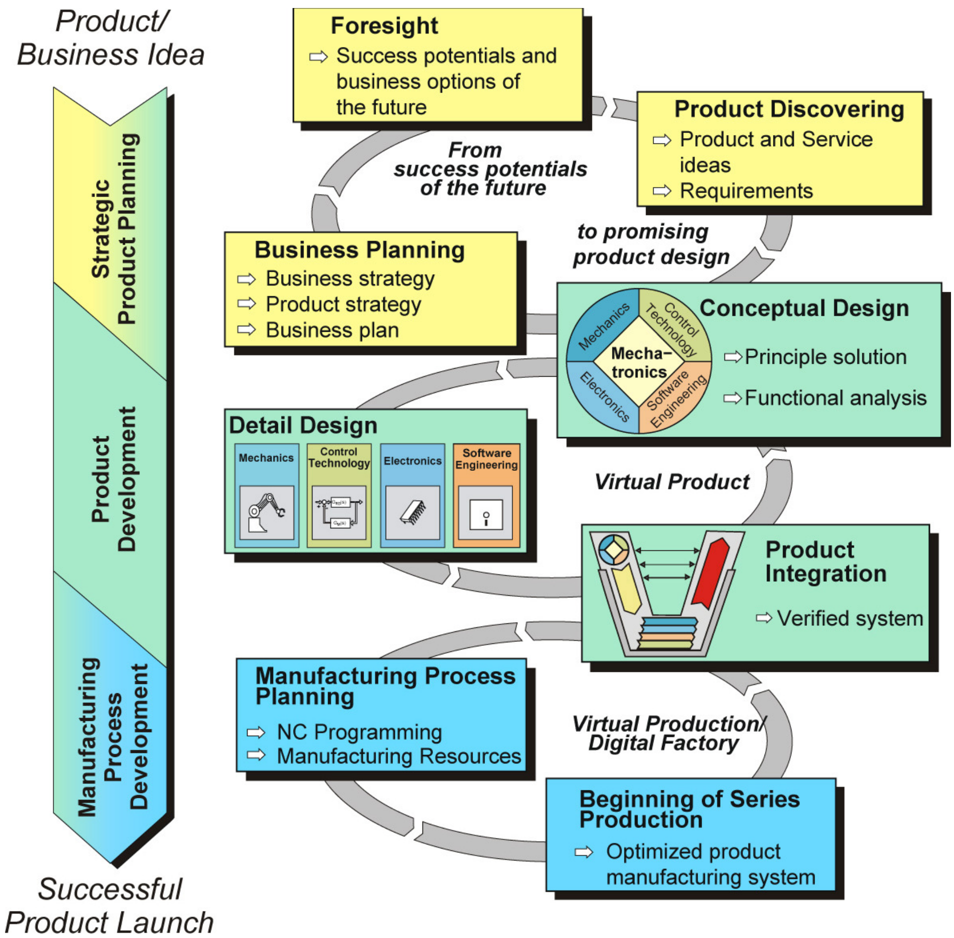

Figure 1-1: The product development process [GEK01]

Parallel to the virtual product development, CAD has also allowed the visualization of parts within a 3D model not only in a static way but through interactive and dynamic 3D animations. Besides their use for a variety of purposes, like marketing and product presentations, for entertainment within movies or videogames, 3D computer animations are in fact used for training purposes. Such animations (see figure 1-2) represent an easy and interactive way to deliver content to trainees that need to replicate in the real environment the tasks previously visualized in the 3D animation.

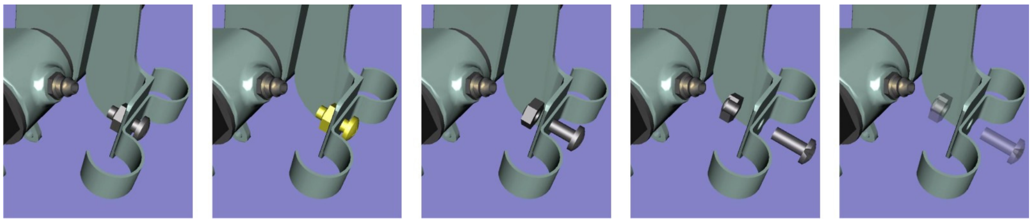

Figure 1-2: Sequence from a 3D animation for the removal of fasteners in an airplane's landing gear brake

The advantages of such approach are represented on the one hand by the possible visualization of such animations on a normal computer monitor or through mobile devices; this allows a training session on site, directly nearby the technical devices target of the training. On the other hand, differently from video, which does not allow any interaction, or paper based training, which gives just a 2D representation, the trainee can interact in 3D with the virtual product. 3D computers animations thus allow a "learning by doing" but in an offline mode, without interfering with the real processes.

1.1 Problems

Computer animations are usually created through a customized process, called authoring and demanded by the customer to a professional 3D artist or modeler, which is able, through the supplied 3D models and a specialized modeling software tool, to create the required training animations.

The problem here is that the 3D artist is usually not an expert in the domain, mechanical or electrical for example, to which the training refers. Thus, parallel to the necessary 3D models, the customer must supply to the artist additional information regarding the individuation of the involved technical parts, their movements and the effects deriving from such movements, also in relation to the connected parts.

In addition, a semantic problem arises within the definition of the training animations: information between customer and 3D artist is exchanged using non formal descriptions, like natural language or instructions manuals, which can present ambiguous concepts, in terms of vocabulary of elements and actions: for example, a “resource” can refer to a “machine” or to an “employee”, according to the context.

Furthermore, the management of different roles, each with its own need of information, has to be provided within the animation through different levels of detail of the 3D model. In fact, according to the role target of the training, it could be necessary to show or hidden particular parts that can be respectively essential or not necessary, thus confusing, in order to execute the task.

The authoring of 3D computer animations is not “per se” a difficult process but it can become a complex and time consuming task, without any possibility of automation, under certain circumstances like high number of animations’ requests, different knowledge domains, and various roles with their respective level of detail.

1.2 Objectives

This research work aims to reduce the overall complexity of the authoring process for 3D training animations: a method has been developed in order to automatically generate customized animations, according to text-based description of the tasks that have to be executed.

To accomplish this ambitious objective, two conceptually far disciplines have been considered and ideally joined: artificial intelligence, through an ontology approach for the understanding of training requests’ semantic, and computer graphics techniques, particularly focusing the computer animation domain.

The result of this “intelligent 3D authoring” is a process model that starting from text-based descriptions, parses the training tasks by means of a natural language parser and matches the concepts with the ones defined in an ontology. The ontology core developed for this purpose is structured in two main parts: an upper ontology, which contains domain independent concepts and relations, acting like a main framework, and multiple domain ontologies that specify domain dependent concepts and link them to the corresponding 3D models of the parts. Such models, which are stored in a model repository, are recalled and a script of the animation, comprehending the necessary transformations within the scene, is generated. The corresponding viewer is then able to use the script to deliver the training animation to the user in an interactively way so that unclear tasks can be better analyzed and understood.

1.3 Approach

The book starts in Chapter 2 with a detailed description of the problem domain, represented by the computer-based training. The need for training and the benefits deriving are analyzed, also according to the different ways to deliver a training session. Between the various modalities, Virtual and Augmented Reality technologies are considered and described; particular attention is dedicated to the authoring of 3D computer-animations for training purposes and the problems arising during this process. Also a series of requirements for the automatic generation of 3D animations are deducted.

State-of-the-art approaches in computer graphics, focusing 3D authoring, are introduced and analyzed in chapter 3: at first an overview of intelligent authoring approaches in literature, like the “text-to-scene” systems is given, followed by actual software solutions available on the market. Since the derived requirements cannot be satisfied neither by current software solutions present on the market nor by approaches found in literature, a call for action, which includes the adoption of Artificial Intelligence techniques, has been formulated.

Chapter 4 reviews AI approaches, which are suitable to the interpretation of text-based descriptions of training sessions in order to allow an intelligent 3D authoring; particular attention is given to the natural language parsing and to ontology, which constitutes the core of the proposed approach.

Chapter 5 describes as preliminary step the development of the ontology core, whose structure is made up of an upper ontology containing domain-independent knowledge and of multiple domain ontologies. The developed process model is then introduced, where all single steps, building up the overall method, are analyzed.

Chapter 6 gives describes a prototype implementation of the approach, introducing the KoBaS project that inspired this research work.

The book is then concluded by a summary and an outlook on the possible directions of future work in order to refine and further develop the proposed approach.

2 Problem Analysis: computer-based Training

The term "Training" represents a generic expression that deals with practice and experience and at the same time acquisition of knowledge, somehow difficult to delimitate. It can be defined as [Rog95]:

"The act, process, or art of imparting knowledge and skill"

It is therefore reasonable considering training as a "process"; it has an input, represented by the teaching of vocational or practical skills and notions, while the output is represented by worker's knowledge and experience. The acquired experience and competencies justify then the need for training, whose effects can be summed up essentially in the following points:

- Improving processes and products' quality
- Reducing costs

The advantages deriving from training contributes to the effect shown through a "learning curve", which expresses the reduction of time required to execute a task according to the cumulative quantity of tasks, or by the closely related "experience curve" (see figure 2-1), which states that costs usually decline with cumulative production and then with the experience collected.

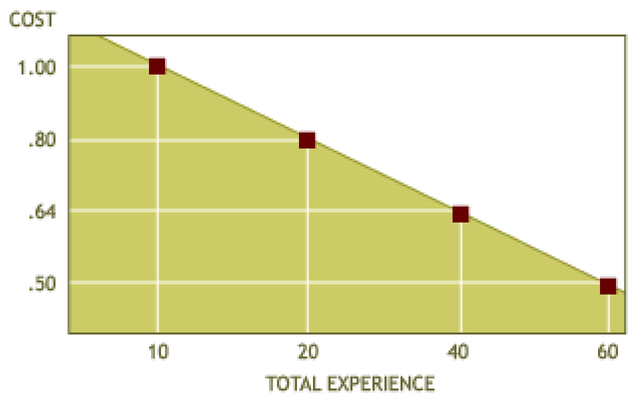

Figure 2-1: Example of an Experience curve (logarithmic coordinates) [Hen74-ol]

Training sessions can be delivered through many modalities, each of them being characterized by the use of various means to deliver content to the user and by different degrees of interaction with him. Training can be roughly subdivided, also according to its evolution, into two categories: traditional training and eLearning.

To the former category belong all means that have been used traditionally before the advent of computer systems:

- Classroom training , e.g. School, University, Seminars, Workshops
- Paper-based training, e.g. Books, Instructions Manuals, Technical Drawings

E-learning [Ros02] is a term currently used to denote a wide domain that deals with computer-enhanced learning, which exploits also the following technologies:

- Web-based Training [Mar98]
- Simulation [Ray03]
- Serious Games [Gee03]
- Virtual and Augmented Reality [DSK+06]

Not all the modalities mentioned above have, anyway, the same efficacy as showed in figure 2-2, by the "Cone of experience" [Dal46]; it shows on the left in which percentage people remember, and therefore learn, according to the way they experience a generic content, represented in the middle. On the right the learning outcomes are displayed.

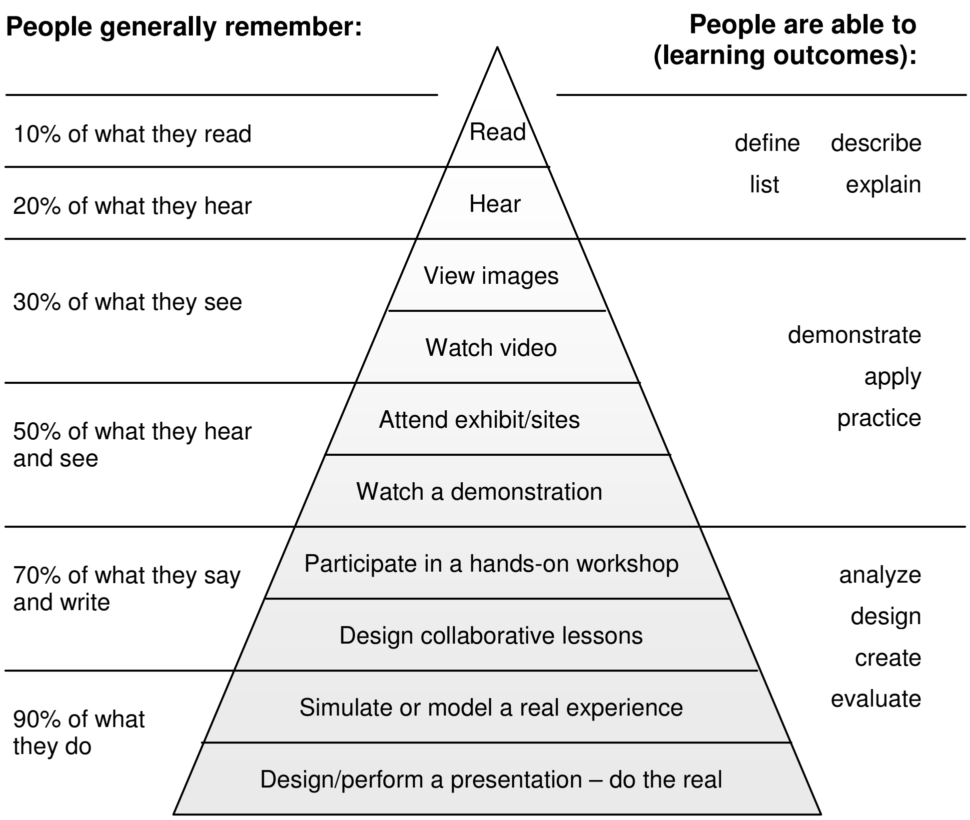

Figure 2-2: Different training modalities in the Dale's Cone of Experience

The best result is therefore achieved by people, who practically execute the task or through the simulation of a real experience, thus “learning by doing”. This is the reason why new technologies, like Web-based Training and Virtual and Augmented Reality, which allow a high level of involvement, are nowadays preferred to the old techniques, like classroom or paper-based training, where the user acts in a passive and static way.

2.1 Virtual Reality

Virtual Reality is much more than an oxymoron[1], coined in 1989 by LANIER [Lan89], one of the pioneers in the field: in a few words, it is a computer-generated (virtual) 3D graphical environment that, for its characteristic of immersion and interaction, can be compared to an experience in a real environment (reality).

Many definitions have been given in the last decades but one of the most complete, since it includes its three main characteristics, is the one of EBBESMEYER:

Virtual Reality (VR) is the sum of all technological elements for the building and real-time preparing a computer model of material or immaterial three-dimensional worlds, which allow the user to perceive multi-modally (Presentation) such model through its own inclusion in the model (Immersion) and as a result to directly manipulate the model through multi-modal feedbacks (Interaction) [Ebb97][2].

According to MILGRAM’s continuum [MTU+94] (see figure 2-3), Virtual Reality, or Virtual Environment, is just one subcategory of the wider Mixed Reality domain, given by the union of real and virtual worlds.

Between the technologies defined in the Reality-Virtuality Continuum other forms of Mixed Reality are possible: Augmented Reality, characterized by a real environment “augmented” with computer-generated elements, and Augmented Virtuality, where the virtual environment is enriched with real parts. Within the technologies defined in the continuum, an increasing interest has arisen toward the Augmented Reality (AR) technology because of its powerful approach: the user sees through its head mounted display (HMD) a real scene captured by the camera and enriched with computer-generated information.

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[1] An oxymoron is a figure of speech that combines two normally contradictory terms. It is a Greek term derived from “oxy” (sharp) and “moros” (dull). Thus the word *oxymoron* is itself an oxymoron.

[2] Translation of the author from the original definition in German

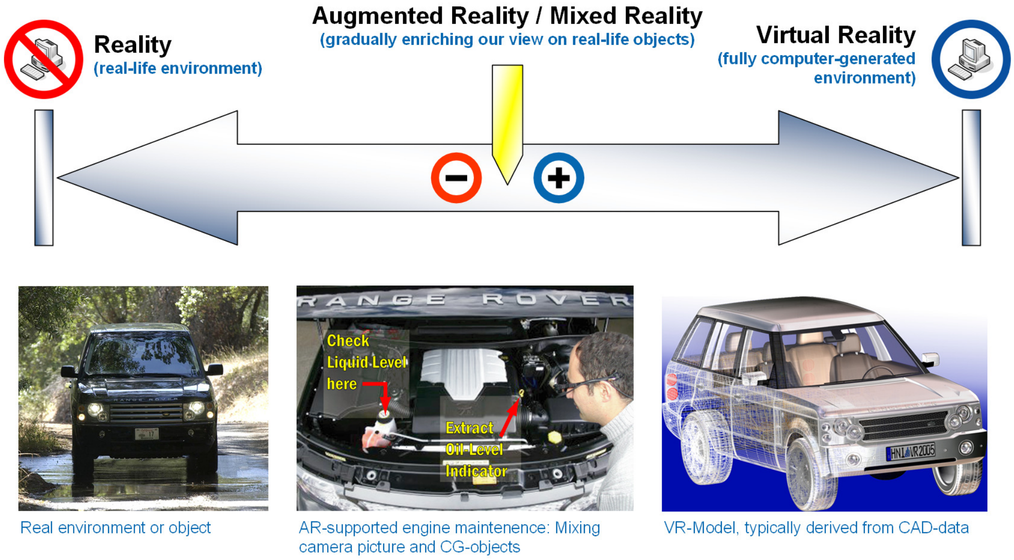

Figure 2-3: Milgram's Continuum

The advantage represented by Augmented Reality is that the creation of complex photorealistic virtual environments, which require enormous computational power, is no more necessary since the considered environment is already the real one. The real environment represents then the starting point and is then completed by the addition of virtual objects or visual information. Augmented Reality technology is very suitable for training and maintenance tasks, where information can be superimposed to real parts, allowing the user an easier identification of the proper parts and actions. However, the technology has still some problems due to external conditions, like tracking and lighting, and the research community is still working on to solve these open issues [GSH+05] [Mat05].

On the other hand, due to its characteristics of presentation, immersion and interaction, Virtual Reality represents, combined with the simulation domain, the most complete approach to deal with training situations. From the medical domain, where training of future doctors can be performed through interaction with real tools in a virtual patient [KCM+01] (see figure 2-4), to simulation of transportation systems, like cars, trains and also a Boeing "Jumbo" 747 [SS96] (see figure 2-5), a wide range of simulators can be nowadays found for training purposes.

The basic idea common to all scenarios is the training of end users in performing important and delicate tasks without risking lives, through human errors that can cause, for example, wrong surgical operations or crash of the vehicles.

Figure 2-4: VSOne virtual surgery [KCM+01]

Figure 2-5: NASA 747 simulator [SS96]

Another domain that exploits the same basic idea in completely different conditions is represented by military applications (see figure 2-6): before fighting with real enemies, troops simulate war conditions and combat situations in VR laboratories on Powerwalls[3] or CAVEs [CSD93] (see figure 2-7), thus avoiding all the difficulties and disadvantages, like logistics of the troops, accidents or wounded men, of a real fighting scenario.

Figure 2-6: Military virtual reality applications: Virtual Combat Convoy Trainer (up) and Virtual Reality Parachute Trainer (down)

[3] A powerwall is a high resolution visualization system consisting of multiple images projected from the rear onto a single screen

Figure 2-7: Virtual Reality in a CAVE[4] [Bar01-ol]

An easier to manage Virtual Reality approach is represented by the so called "desktop virtual reality" or "2½ D", which uses common desktop computers together with a monitor as display device. In this case the absence of the third dimension is compensated by the illusion of 3D through projection of the objects on the monitor.

2.2 3D Computer Animations

3D computer animations represent a subclass of the wide Virtual Reality domain, since they do not offer the immersion feature, and sometimes interaction, but they maintain the visualization of a 3D environment, even if displayed on a flat 2D surface like a computer monitor or a cinema screen. It is extremely difficult describing in words what can be really appreciated in a three-dimensional representation; anyway, such animations can be imagined as a computer-generated film, which can be used for various purposes and with different interaction levels.

4 CAVE is an immersive virtual reality environment where images are projected on three to six walls of a room-sized cube. The name is also a reference to the allegory of the Cave in Plato's Republic where a philosopher contemplates perception, reality and illusion.

The sector that has been more influenced by 3D computer animations is, without any doubt, the entertainment one, through the massive use of 3D in cinema and videogames. Since the 1970s cinema has been always characterized by the use of computer animation through special effects, like in the Star Wars Trilogy, but the trend has enormously increased in the last decade. Computer animations are no more used just to create special effects but also to entirely generate a film. In 1995 Toy Story (see figure 2-8), the first ever released computer-animated film, impressed the public for its photorealistic quality: the world experienced for the first time a 3D computer animation as a whole film on the big screen.

Figure 2-8: Toy Story

Another milestone in the domain of computer-generated movies is represented by “Final Fantasy: the Spirits within” (see figure 2-9), released in 2001, where for the first time realistic-looking humans, instead of fantasy cartoons, have been depicted. This opened new scenarios for the future of cinema, since theoretically no more real actors were needed for the realization of a movie.

Figure 2-9: Final Fantasy

Together with cinema, another field, where computer animations play a fundamental role, is represented by the videogame industry. The evolution of videogames has been very fast, passing from the 2D arcade-style games of the 1980s, like the cult "Pac-Man", to actual 3D simulations of combat situations, sport challenges or racing, like Gran Turismo (see figure 2-10) on Playstation, as well as every-day life, like in Sims.

Figure 2-10: Gran turismo 4

New gaming consoles and hardware have allowed the use of extremely realistic graphics, characterized by high number of details, coupled to advanced shading techniques: videogames are nowadays so accurate and realistic that they can be considered like “interactive films”.

A very recent application scenario of 3D computer animations is represented by internet 3D virtual worlds, like Secondlife [Ond05] (see figure 2-11), where each user represented by its own customizable avatar, can explore virtual islands, meet new people, buy virtual land and have fun through many available adds on.

Figure 2-11: Screenshot of a virtual campus in Second Life

2.2.1 3D Computer Animations for Training

Topic of the research approach described in this book is represented by 3D computer animations for training purposes. Such animations are usually different from the ones shown in the previous section: the photorealistic representation of the objects is no more the key factor because the purpose is not just entertainment, but the deep understanding of technical tasks. Training animations deal with parts of complex technical environments, like an airplane, a car or a mechanical device; the most important factor becomes the individuation of the involved parts and the actions that the user has to perform through them or on them.

Before analyzing in depth training animations, the definition of the overall training environment is necessary; a consistent and powerful approach in this sense is represented by the 5W1H (what, who, where, when, why, and how) approach.

- What is intended for training?
- Who are the end users?
- Where does it take place?
- When does it take place?
- Why is it necessary?
- How is it performed?

Training is here meant as a process, whose result is the acquisition of knowledge and skills within a productive environment, in different knowledge domains and for the realization of tasks, including but not limited to, operations, assembly and maintenance. Possible end users are therefore technical devices operators, maintenance staff, assembly line workers as well as sales department employees that can be trained in order to show capabilities of complex technical devices.

Two main options can be foreseen about the location of the training session: on the one hand training can be delivered in specific laboratories, where the trainee has the possibility to experience off-line the tasks before replicate them in a real environment. On the other hand the trainee can be trained directly online, during a normal shift, and can receive additional information or guidance in executing the task, by more specialized and experienced employees.

Training can also be delivered through many modalities, like classical classroom lessons, by means of paper-based documentation or by experiencing practical tasks. In this book training is intended through the visualization of 3D computer animations, which can be shown on a great variety of devices: beside a traditional desktop computer and monitor, they can also be shown on a portable device, like a laptop computer, Tablet PC[5], Smartphone[6] or PDA[7] [Par02] (see figure 2-12).

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[5] A tablet PC is a notebook-like, slate-shaped mobile computer, where operation is performed by the user through touchscreen or with a stylus, digital pen, or a fingertip, instead of a keyboard or mouse.

[6] A smartphone denotes any handheld device that integrates personal information management and mobile phone capabilities.

[7] A Personal Digital Assistant (PDA) is a small mobile hand held device that provides computing and information storage retrieval capabilities for personal or business use, often for keeping schedule calendars and address book information.

According to a predefined training sequence, the 3D animation shows the elements of a 3D model that can be focused within the model, highlighted, moved or hidden, in relation to the task to be performed. The virtual camera[8] represents the user point of view of the virtual environment, where the action is taking place.

Figure 2-12: 3D animations on Pocket PC

To better recognize smaller details within the animation and have a better comprehension of the task, the following functionalities are usually provided to the user:

- pause the animation at any time;
- rotate the virtual camera;
- zoom in and out;
- pan, i.e. scrolling the view over the design plane

If no interaction is provided, the user observes each single task contained in the animation, in order to replicate it later on in the real environment. This is any-

8 With the term virtual camera is denoted the view of the virtual environment represented within the animation, analogously to what is achieved by a real camera in the realization of a film

way an unlikely scenario since most of the approaches, focusing on the industrial domain, provide some degrees of interaction.

Any kind of 3D animations for industrial training tasks can be created and for different knowledge domains: the starting point remains a 3D model of the object, which represents the target of the training.

The use of 3D animations allows a flexible but at the same time powerful approach for training purposes, characterized by the following features:

- Training animations can be displayed also on mobile devices, thus allowing an on-line training, near the target object of the training. It is therefore the easiest way to experience a 3D training, without the need of complex and dedicated hardware, like datagloves[9] or HMDs[10], which are not suitable for use in industrial environments.
- Unlike other training approaches, i.e. paper-based or video-based training, which allow no interaction, the trainee can dynamically experience the training material, zooming in or rotating 3D elements if some content is not clear enough.

Once defined the main features of computer animations for training, the next section gives an overview of the animation authoring process.

2.2.2 Animation Authoring

A CAD 3D model (see figure 2-13) virtually represents the design and the structure of a real technical product, in form of a single element or as an assembly[11]. Even if the user can set different views or rotate the model though mouse interaction, the model alone allows a static visualization, i.e. the parts building up the product cannot be moved or animated. One of the key features of computer aided design is represented by the definition of layers within the whole 3D model: for example, liquid circuits can be described on the “circuit” layer, electric cables on the “cables” layer. By managing such layers it is possible to achieve different levels of details, varying the visibility of the layers:

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9 A dataglove or cyberglove represents an interaction device which exploits combinations of gestures and position of the hand to interact with a computer. It is one of the metaphors used in Virtual Reality environments.

10 A head-mounted display (HMD) is a device to be worn on the head of the user, like a pair of glasses; it is made up of two small displays in front of each eye. It can also include a camera and can offer the “see-through” capability.

11 The term assembly denotes a complex product, made up by a number of different technical parts, each of them characterized by a position in the hierarchy of the model and by geometrical properties, like position, dimension and material.

the view of the overall model can be simplified turning out some layers and keeping visible just the really important ones for the training purposes.

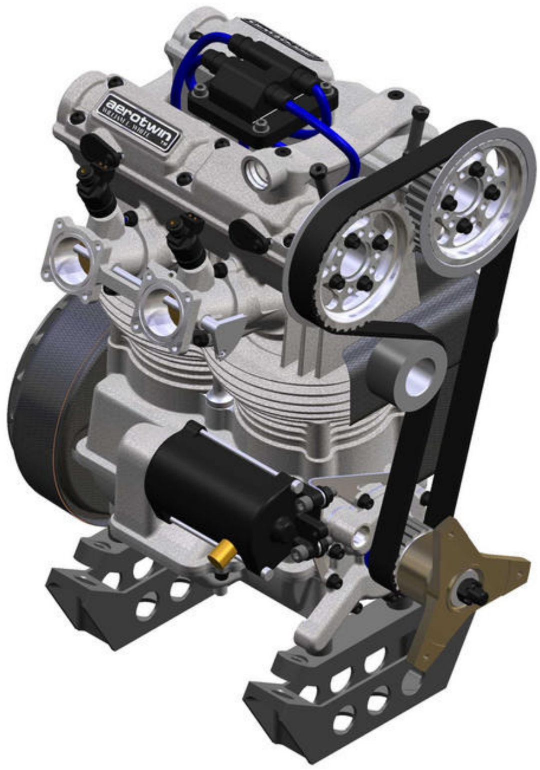

Figure 2-13: CAD model of an ultra-light aircraft motor

CAD models or 3D models in general, represent the starting point of computer animations, usually demanded to professional 3D artist artists, also known as 3D artists, who are able through specialized 3D software to create and supply customized animations. This process, usually denoted as “animation authoring” or “animation creation”, requires a preliminary meeting between the 3D artist and technical staff from the customer side in order to define the “storyboard”.

The storyboard (see figure 2-14) represents the first step of the traditional 3D authoring process, by converting ideas into drawings, annotations and general content to be included in the future animation. It is usually designed by hand on a notepad and made up of a series of frames, very close to the “key frame” concept introduced later on, which give a first visual characterization of the elements contained in the animation. Further details about objects and actions to be considered, can be written down in a separate text box.

Within this phase, the presence of technical staff from customer side, experienced in the knowledge domain of the requested training animation, is absolutely necessary, in order to specify important details like:

- requirements and appearance of the training animation

- important and less important parts
- actions to be taken

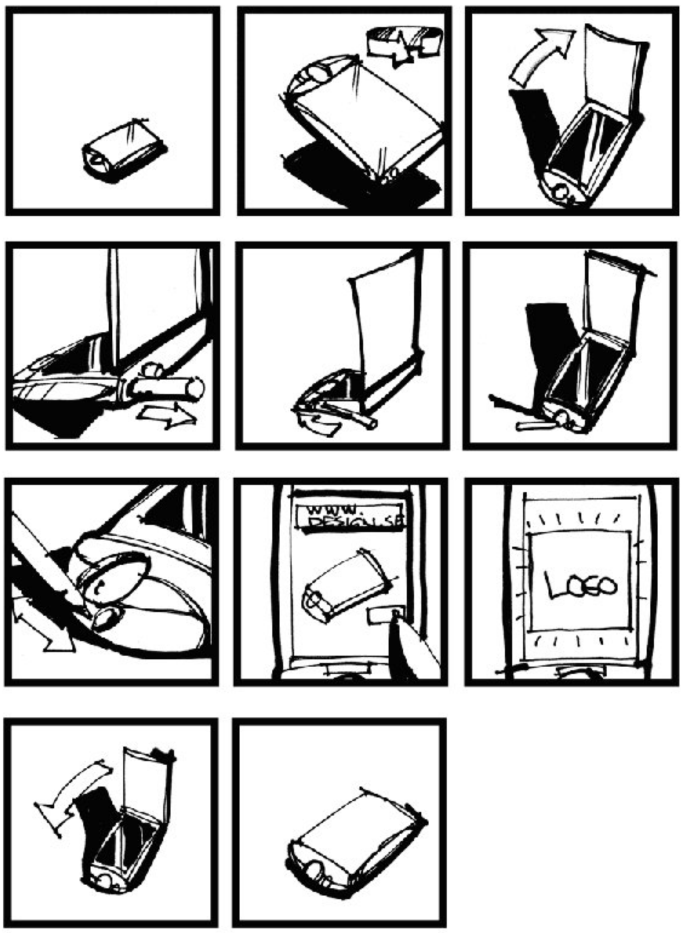

Figure 2-14: Storyboard of a 3D animation [LU-ol]

In addition, the 3D artist is a computer scientist, expert in computer graphics but not in the target training domain, where a deep technical background is required to:

- identify parts by specific technical vocabulary
- determine the effects of a performed action
- identify eventual dependencies between technical parts or processes
- determine the content in relation to different kind of users
- establish the duration of tasks, according to the real ones

Once the storyboard has been created and the customer has supplied all the needed information, including the necessary 3D models and eventual training material, the 3D artist through specialized software, for example 3D Studio Max or Maya, is able to create the requested training animation.

2.2.3 Basic Animations Techniques

Animations are created through basic techniques, which give to the user the illusion of a real motion: this can be achieved showing to the human eye a sequence of still pictures, also called frames, slightly different from one other, at a frame rate higher than 24 frames per second[12].

The most important technique for both 2D and 3D animations is the use of key frames: they represent frames, which are selected by the 3D artist for their importance, like in case of an extreme of movement in the sequence. Once the key frames have been selected, the following task is represented by the filling up of the time gap between them: this operation is called “in-betweening” (see figure 2-15) and it is demanded to the computer that through an interpolation generates the remaining still pictures to complete the sequence.

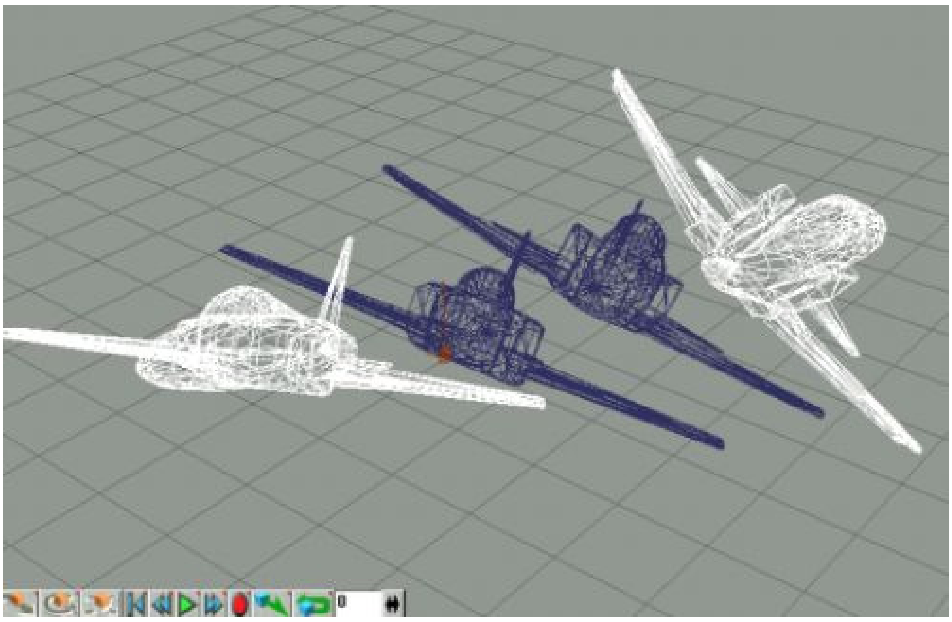

Figure 2-15: Key frames (in white) and interpolated frames (in blue)

Interpolation techniques calculate position, size, orientation and other parameters of the objects in the virtual environment, so that each in-between frame slightly differ from the adjacent frame in order to give the illusion of motion. According to the type of equation used to average the information, different kinds of interpolation are possible.

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[12] The frames per second (fps) value, used to obtain an animation, varies from 24 fps of cinema movies to more than hundreds fps in modern videogames

- Linear interpolation, where the value between frames changes linearly;
- Non-linear interpolation, where the value between frames changes according to cubic laws, like Hermite or Bezier curves

Strictly connected to interpolation techniques are the geometric transformations, which are functions, used for modifying size, location and orientation of objects as well as of the virtual camera. The basic geometry transformations can be grouped in:

- Translation: moving the object or the virtual camera
- Rotation: changing orientation of the object or of the virtual camera
- Scaling: changing dimensions of the object

Every transformation regards points in the virtual environment and can be represented by a matrix in homogeneous coordinates[13]. The combined matrix of the three transformations mentioned above is shown in figure 2-16, where the included parameters represent:

- Sx, Sy and Sz: scaling factors along the three axes
- α, β and γ: rotation on the x, y and z axis

$$\begin{bmatrix} s_x\cos\gamma\cos\beta & -s_y\sin\gamma\cos\beta & s_z\sin\beta & x \\ s_x\cos\gamma\sin\beta\sin\alpha + s_x\sin\gamma\cos\alpha & s_y\cos\gamma\cos\alpha - s_y\sin\gamma\sin\beta\sin\alpha & -s_z\cos\beta\sin\alpha & y \\ s_x\sin\gamma\sin\alpha - s_x\cos\gamma\sin\beta\cos\alpha & s_y\sin\gamma\sin\beta\cos\alpha + s_y\sin\alpha\cos\gamma & s_z\cos\beta\cos\alpha & z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 2-16: Combined transformation matrix

Another motion effect can be obtained keeping fixed the objects in the virtual scene and moving the virtual camera's point of view.

2.3 Problems in 3D Animations Authoring

So far a sort of "best case" has been examined, where customer and artist can sit together and discuss about the content of a single animation. Whatever problem arises, in the individuation of parts or definition of an action, the customer can explain each step in detail. However, the frenetic rhythm of everyday life and the progress in information and communication technology have led to the widespread use of remote communication, for example through e-

[13] Homogeneous coordinates are used in computer graphics to solve the problem of representing a transformation as a matrix operation

mails, telephone calls or web meetings, where the two parts are not physically close. Therefore, the customer can directly per e-mail request a training animation and supply the 3D model together with the training tasks instructions, like the one contained in an instruction manual. This complicates the work of the 3D artist, which has no more the possibility of clarifying in real time and through visual indications eventual doubts about parts or actions to be displayed in the training animation.

In the following sections some of the main problems affecting the animation authoring and customization are analyzed:

- Product complexity
- Semantic problem
- End user roles
- Customization of the animations

2.3.1 Product Complexity

The shift from mass production to flexible manufacturing systems in the last decades has generated the "product differentiation" concept that for marketing reasons let similar products differ from a very few key features or minor details; such products are more attractive for potential customers, since every product can be adapted to customer needs through different versions or add-ons.

However, one of the disadvantages of such approach is represented by the explosion of product complexity: instead of having a low number of standard products, hundreds or thousands different product configurations are possible, each differing for a very few details or parts.

Due to the difficulty to manage so many product configurations without IT support, there has been a need since the 80s to manage product data in a more efficient way. This has been achieved through Product Data Management (PDM), also known as Engineering Data Management (EDM); a PDM system adds to the management of CAD models, additional product information, like assembly plans, manufacturing procedures and bills of material. It can be therefore considered like a central database where all the relevant information can be stored, recovered and also changed by multiple users, thus allowing distributed product development processes. Over the last few years, the PDM approach has been further developed by including other aspects of the product engineering, like production processes, product use and recycling. The result is the management of the whole lifecycle through the Product Lifecycle Management (PLM) approach (see figure 2-17).

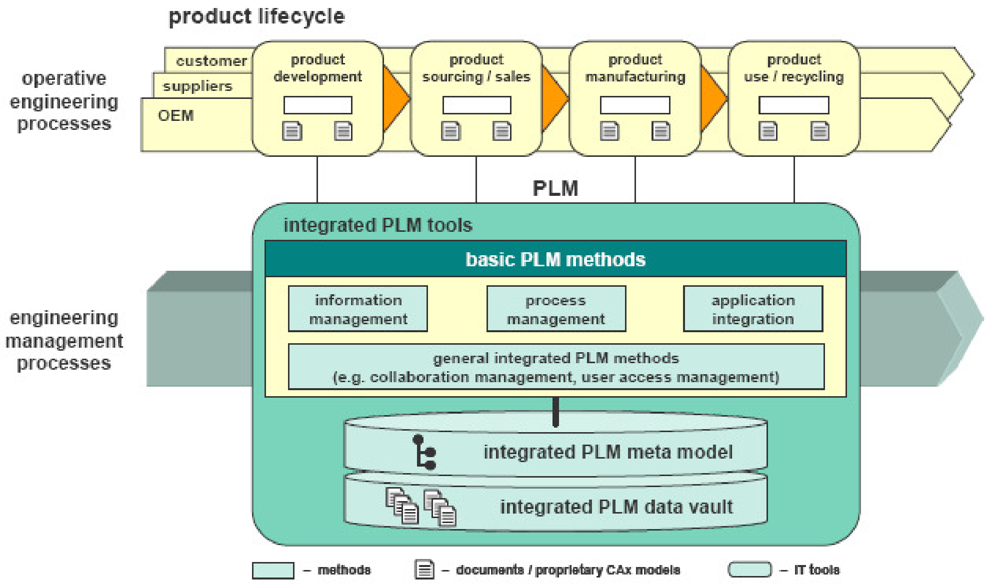

Figure 2-17: Phases of Product Lifecycle Management [AS06]

Born as an extension of PDM, Product Lifecycle Management (PLM) approach supports industrial manufacturing from the early design phase to the ongoing management, product use and recycling. PLM is an integrated approach, including a consistent set of methods, models and IT tools for managing product information, engineering processes and applications along the different phases of the product lifecycle [AS06]. PDM/PLM systems are useful for retrieving 3D models corresponding to different products, also searching through metadata but, due to their nature, they show a static view of the products.

The consequence of product complexity on the authoring of 3D training animation is the impossibility to create an animation for every product configuration, due to the high number of possible product configurations. There is then no margin to simplify the work of a 3D artist since a computer animation remains a personalized creation for every single product configuration, preventing any possibility of automation.

For example, in the manufacturing domain, modern machining centers (see figure 2-18) are produced in more than thousands different customized configurations starting from a low number of subcomponents, like base, spindle or tool store; however, they are characterized by assembly instructions, operations and maintenance procedures, which remain independent from the machine they are installed onto.

Figure 2-18: Modern woodworking manufacturing machine

The difficulty to manage such a high-number of product configurations, within the domain of 3D training animations, has led to a simplification of the problem through standardization: training animations are created for just a product family instead of for every single product configuration. This solution implies however some practical problems: standardized animations, omitting customized features or parts, could result in being useless for some tasks. For example, once created a training animation for a product family, it results to be useless for a product of that family, which contains in a customized version a specific feature or part (e.g. an infrared sensor).

Ideally, authoring of customized animations for every product configuration is the best solution but it results at the same time not feasible unless an automatic creation of the animation process can be provided. This cannot be achieved just by retrieving customized 3D models from a PDM system but introducing also a set of actions to be coupled with the 3D model in order to create the desired animations. Such actions must being addressed to the concepts defined within the training tasks, which are usually expressed in a text-based form.

2.3.2 Semantic Problem

Text-based communication is nowadays still the most important way of representing and transmitting information, as evidenced by the huge amount of information exchanged through e-mails, instant messaging, internet pages, blogs as well as newspapers and other printed materials. Information is usually exchanged also in working environments by means of natural language[14], which is, by nature, non-formal: communication problems can happen very frequently

[14] With the term "Natural language" is denoted a human written or spoken language used by a community, which is opposed to a formal language, e.g. a computer language.

when ambiguous concepts or sentences, characterized by multiple meanings, are misunderstood.

Context plays in this case a fundamental role for disambiguation purposes: the same word “resource” can mean, according to the context where it is included, raw material (also referred to as “stock”) to be worked through a machining operation, a human resource or a device used for a specific task. To solve this problem in industrial scenarios the Process Specification Language [SGT+00], which has been recently published ISO standard 18629, has been developed.

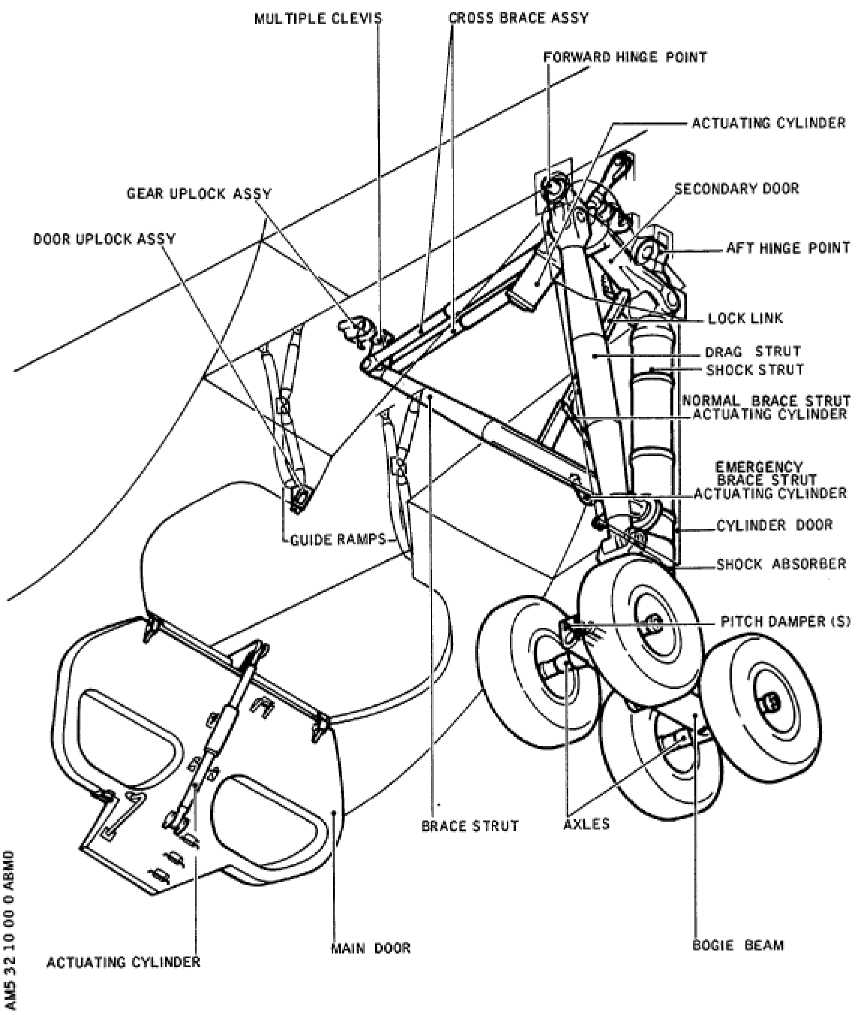

Figure 2-19: Technical drawing of an airplane’s landing gear

Technical terminology in each language is characterized by its own vocabulary, very difficult to manage also for a mother-tongue, who does not use such terms in everyday life; for example, it is very difficult understanding what a “brace strut” or a “bogie beam” is (see figure 2-19), without receiving at the same time visual information about the parts within the structure of an airplane, through a combination of technical drawings and textual information. Linguistic elements play also a very important role in the identification of parts within a 3D model; it is in fact possible in a PDM system to look for specific parts through metadata within the stored 3D models.

The importance of linguistic elements goes further the individuation of technical parts: a 3D animation represents the visualization of actions, which in natural language are expressed by verbs. Sentences like "open access door" or "remove safety clips and tags" must be understood also from a semantic point of view: in the examples above, what does the "open" action imply? How can be safety clips and tags removed? Such kind of information can be found in the semantics of the sentence, which expresses the real meaning; for example, multiple actions can correspond to the same verb followed by different target objects: "removing a screw" implies a rotation and a translation of the target object, while in "removing the safety clips" just a translation is necessary.

Therefore a semantic problem arises when dealing with descriptions of training sessions since they are expressed in natural language, thus in a non-formal way. This problem involves the individuation of technical parts through specific vocabulary as well as the specification of the action verbs according to their target objects.

2.3.3 Roles

In order to be truly efficient, training must be tailored to the real needs of the trainee; different user types may require a different kind of information within a training session. For example, a maintenance worker needs very detailed information of the target mechanical device (e.g. a car, an airplane or a manufacturing machine), including its functioning, while the end user, like a driver or a machine operator, considers the device itself as a black-box: the focus is not on how internal parts function rather how interacting with the device itself.

The same differences can also be found between workers in an assembly line, which deal with a very small fraction of the overall product and therefore need a specific view of it, or with people working in the sales department, who require an overview of the product, in order to show its features to potential customers. Redundant or unnecessary content may create confusion in the trainee and lead to a loss of time, thus obstructing the learning process.

The situation is analogous for 3D animations, where every user type has its own vision of the same product: for example, a manufacturing machine can be seen as a whole product for workers involved in the sales department, which can show the characteristics and features of the machine through simulation of production processes. The view delivered in the animation is then the most general one (see figure 2-20) with a low level of detail since internal parts are not very relevant to show the potentiality of the machine.

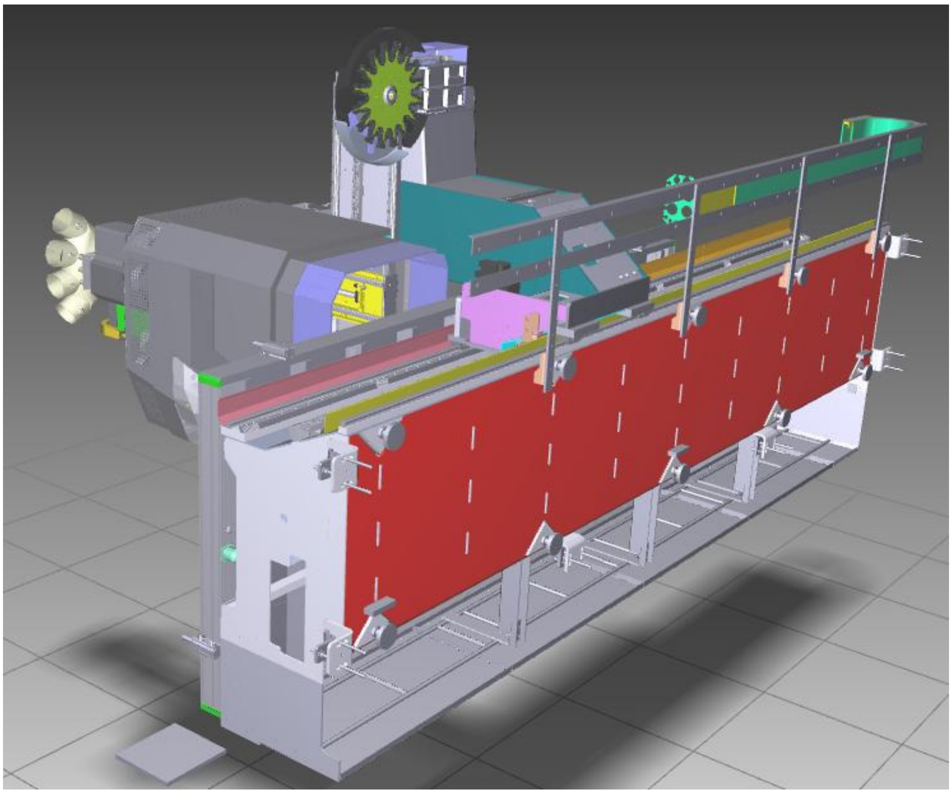

Figure 2-20: View of a whole manufacturing machine

On the other hand, more technical end users need a more detailed view of the same device: a machine operator can be trained, for example, on how to change the drill bit, installed in the spindle, or on other everyday operations, which do not require deep understanding of the machine. Training domain is in this case represented by lower level and more specialized portions of the overall target domain. As a consequence also animation views through the virtual camera must be more detailed in order to appreciate the necessary details.

Very technical end users, like assembly or maintenance workers, usually require very detailed information during training sessions (see figure 2-21); single parts are more important than the machine itself. The detail must be very high in order to recognize the smallest parts, like screws and bolts.

Different views of the same 3D model can be obtained by the management of layers in CAD models: layers represent virtual surfaces where virtual objects can be placed and then be made visible or invisible, if needed, so that the final 3D model is visualized through the sum of all layers. For example, if a layer represents the detail of lubrication pipes, once made visible, the user can immediately visualize that particular subsystem within the whole model; otherwise can be hidden, in order to simplify the overall complexity of the model.

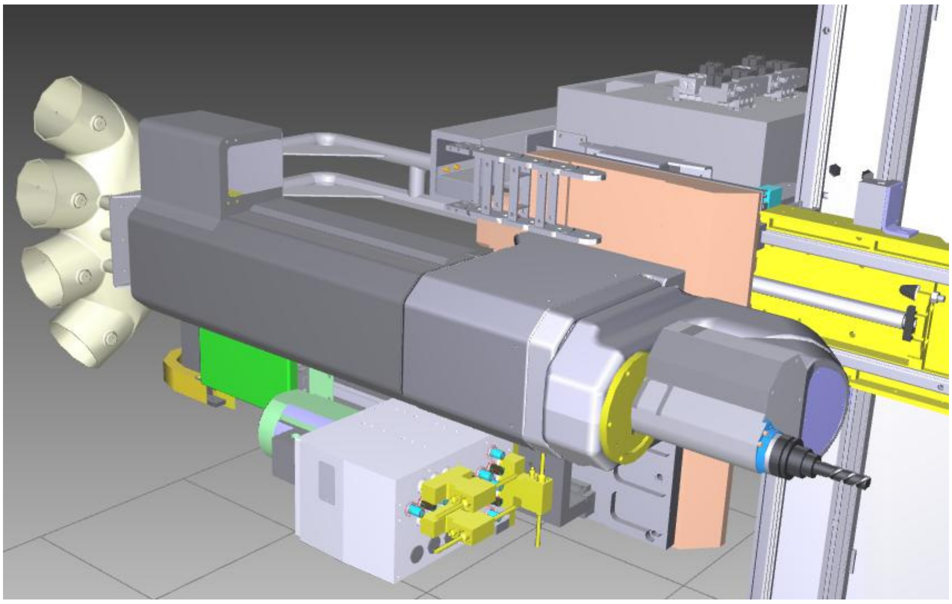

Figure 2-21: Detail of a spindle in a manufacturing machine

There is therefore need in 3D animations for training to offer different views of the target product by varying the visibility of the layers of the 3D model, according to the specific end user role.

2.3.4 Customization of the Animations

A 3D animation, not only for training purposes, represents in general a unique creation; this is also the reason why the terms “3D art” and “3D artist” have been coined. In case of 3D animations for training purposes, the authoring process starts from organizing in the virtual scene the 3D models representing real elements and then the animation is created through a series of transformations of the objects as well as of the virtual camera.

The authoring process can however become extremely complex and time-consuming in case of a high number of training animations, not only for different product configurations but also for different end users, each of them with a specific level of detail. The problem of a high customization of the animations, which need to be started every time almost from scratch, cannot be automated or simplified by using just computer animations techniques.

However, analyzing the content of a generic training session, which constitutes also the content of the corresponding training animation, it is possible to isolate some kind of basic actions, which can be often found in multiple training sessions, like “screwing in a screw”, “removing a bolt” or “pressing a button”. Such basic subtasks, made up of an action verb and an object, can be thought as a “micro” or “atomic” animation. Extending such concept to a wide range of atomic animations, every macro animation can be thought as build up recursively by a number of atomic animations: the advantage is represented by the reusability, which can be achieved by managing in an intelligent way the atomic animations instead of the macro animations.

Training sessions are usually organized in natural language into sequences of subtasks that can be represented as micro animations, whose union results in a macro animation, i.e. the whole training session. As displayed in fig. 2-22 the macro animation “Removal of lubricant tank” is composed by a number of micro animations, like “open the main box”. However, a macro animation can itself be a subtask of another macro animation: in the macro animation “Spindle change” one of the steps building up the training session can itself be a macro animation, like “remove the lubricant tank”. In this way animation atoms or sequences can be recalled and reused saving the necessary modeling time and money. The following figure illustrates the conceptual differences between micro and macro animations together with their recursive use within another macro animation.

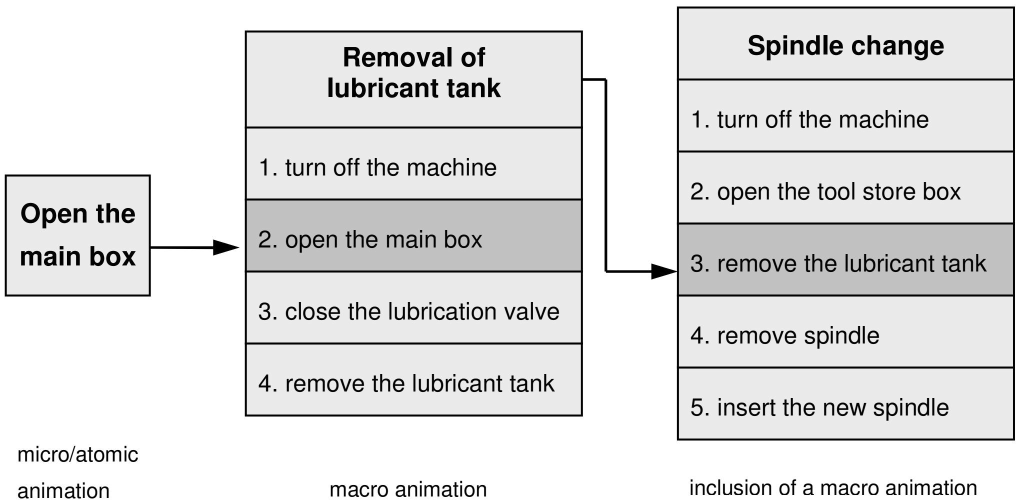

Figure 2-22: Example of a micro (left), a macro animation (middle) and its inclusion in another macro animation (right)

Considering the 3D model fixed, atomic animations can be efficiently defined through scripting, a computer programming approach that has been created to shorten the traditional edit-compile-link-run process. Scripts[15] are often distinguished from programs since programs are converted permanently into binary executable files before they are run while scripts remain in a text-based form and are interpreted command-by-command each time they are run. Scripts also make applications programmable from within, so that repetitive tasks can be

[15] The term 'script' is derived from the written script of a movie, in which dialogue is set down to be interpreted by actors and actresses.

quickly automated: also 3D modeling environment like Maya or Blender offer the possibility to the user to interact through dedicated scripting language, e.g. MEL for Maya, or general purpose, like Python. An intelligent management of micro and macro animations can then result in automating the creation of 3D animations for training purposes.

2.4 Requirements for automating the Authoring of 3D Animations for Training Purposes

In the previous sub-sections an overview of the problems affecting the authoring of 3D animations for training purposes has been given. The authoring process remains a time consuming task and animations represent customized and unique creations, since no possibility of automation can be given to the 3D artists.

An intelligent method, able to couple state-of-the-art artificial intelligence techniques to computer graphics, can lead to the objective of automating the authoring process of 3D animations. The process is delimited by a twofold kind of constraints: on the one hand, the training information, by means of existing instruction manuals or training material, on the other hand, the 3D content, i.e. 3D models of the objects that are the target of the training itself.

In order to reach an automation of the 3D authoring process, a set of specifications is required. As mentioned above, they cover not only the pure computer graphics domain but also the knowledge-base management of the content of the animations.

2.4.1 R1 - 3D Support

It can maybe seem quite obvious but the most important requirement for the automatic 3D authoring is to support various aspects of 3D computer graphics, like animation and interaction. No 3D modeling is required since it is assumed that 3D models of objects involved in the animation are already defined and available. It is anyway important to build a connection of the authoring system with the model repository, where 3D models are stored.

The system must also be able to manage all the parameters, which build up a 3D animation, the most important of which are:

- Objects positioning
- Virtual camera positioning
- Key frames definitions
- Management of transformations

Usually 3D animations can also be shown through a computer-generated video, where no possibility of interaction is given to the end user. However, this modality does not suit very well for training purposes since it does not exploit the interaction feature provided by 3D animations. Therefore, the content generated by the authoring system must provide to the user the necessary interaction within the 3D animation.

2.4.2 R2 - Natural Language Understanding

The main aim of 3D animations for training is to visualize in a virtual environment a task usually described by means of textual instructions: such description, is the starting point the 3D artist needs to understand and then to replicate animating virtual objects. Training sessions have been in the past delivered essentially through paper-based content, like instruction manuals or assembly drawings: in this case, the easiest way to deliver training information is of course by means of natural language.

In order to automate the authoring system and to allow the reuse of existing training material, natural language parsing is needed to have a first understanding of the structure of the sentence and to identify and label the entities that build up the phrase. This requirement is however complementary with the knowledge base management since the natural language parsing alone is not able to link linguistic elements to the corresponding concepts to be included in the 3D animation.

In addition, the use of state-of-the-art probabilistic techniques can also allow a preliminary identification of linguistic elements within the phrase and to avoid ambiguities that could happen with the sole identification by means of a knowledge-base.

2.4.3 R3 - Knowledge-base Management

In order to develop an automatic authoring process, a strong artificial intelligence approach is needed; its role can be summed up in the ability to connect entities found in natural language descriptions to concepts defined in a knowledge base, to which 3D objects as well as the formal descriptions of the actions can be associated. Knowledge-based systems allow collecting, organizing and retrieving concepts of different domains that can be found in a generic training session.

The knowledge base is responsible in this scenario to supply to the authoring process the necessary information about the involved parts: if the word “drill”, for example, is found and labeled as a noun by the natural language parsing, task of the knowledge base is the specification of the meaning in a computer understandable way. Also additional information like structure of the target object and its features, as well as eventual relations to other concepts, must be delivered to the authoring system.

The knowledge base constitutes then the bridge between knowledge of the concepts and the 3D models that represent them in the virtual environment. Also actions can be modeled and organized in a knowledge base so that verbs found in a textual training session can eventually be translated in an action to be reproduced within the a 3D animation. Furthermore, different actions can be coupled in the three-dimensional environment to the same verb according to different objects it refers to.

2.4.4 R4 - Roles Management

3D animations for training are usually created for a standard trainee, not taking in account the real information needs of multiple end users, which have diverse backgrounds, deal with specific knowledge domains and are therefore interested in different views of the same object.

An intelligent authoring system should be able to deliver 3D animations, which can be tailored to each end user role: from a higher level overview for operations management, to more detailed views of the system for maintenance, to extremely detailed representation of parts involved in an assembly sequence.

Level of detail can be managed essentially in two ways: on the one hand for parts that need a high detail, the virtual camera can be positioned very close to the object while the camera can zoom out for a more general overview of the involved parts. On the other hand, the visibility of layers in the CAD model can be altered in order to deliver different views of the same object to the different roles: this is possible if specific layers are available in the CAD model for parts of a well defined knowledge domain (lubricant circuit, electric cables or mechanical parts). The layers can be then set visible just for the roles needing that particular detail; in this way, roles that need just an overview of a device are not disturbed during the training session by details of technical parts, which are on the other hand essential for maintenance staff or for assembly workers.

2.4.5 R5 - Reusability of atomic Animations

3D animations for training purposes are usually unique creations of a 3D artist: once a single component within a product is modified or replaced by a new one, the animation is no more up-to-date and results therefore to be useless. The 3D artist must in this case build a completely new animation just starting from the 3D model.

An intelligent authoring system should be able to go beyond the usual animation authoring process, by reusing animation atoms and adding new ones in order to generate or update 3D animations. Reusability must be achieved essentially in two domains: reusability of the same 3D model for animations regarding different knowledge domains or roles and reusability of the actions performed, which remain independent from the 3D model.

Since for the same product different training animations could be necessary according to the needs of various end users, reusability of existing animations atoms could enormously simplify the animation authoring process. Atomic animations can be authored, stored and recovered from a database if required.

One of the possibilities to achieve reusability of animation atoms is by using animation scripts, which are formal specifications of the 3D scene, including the world environment, involved objects and their transformations. Scripting is also a powerful approach since no 3D modeling software is required for the animation authoring.

2.4.6 R6 - Support for the Training Scenario

The training scenario represents a specific domain, characterized by its own vocabulary of technical parts and verbs, which must be very detailed in order to provide to the trainee the necessary competence.

3D computer animations for training purposes focus more on the technical objects target of the training rather than on the modelling of realistic humanoids together with their movements or to the representation of the actions together with realistic sounds. This is the reason why the starting point of computer animations for training is the corresponding CAD model, made up of thousands of different sub-parts, of the element to be represented in the virtual scene.

Parallel to the definition of the technical elements, also the actions to be represented in 3D animations for training purposes are just a very small part of the every-day life: typical actions of the training domain are “removing”, “assembling” or “connecting” rather than “eating”, “meeting” or “flying”.

The intelligent authoring system should therefore be able to focus on a smaller but extremely specific knowledge domain, represented by concepts of parts and actions typical of the training scenario.

3 Review of 3D Authoring Approaches

Basic animation techniques introduced in the previous section have shown the first steps in the animation authoring process: the initial creation by the 3D artist of a story board and the eventual definition of the key frames as well as the in-betweening process executed by the computer.

In this section an overview of state-of-the-art approaches, referring to the automation of 3D animation authoring and its requirements is given. Authoring approaches are analyzed from a higher level point of view: how to create and deliver 3D content, starting from a non formal description. The authoring done by a 3D artist through specialized modeling software is therefore outside the scope of the review.

At first, the core of every 3D scene, the scene graph, is introduced as a general purpose approach: a scene graph represents the structure of a generic virtual scene, which includes its elements and their transformations. One possibility to build a scene graph is also given by specific mark-up languages for 3D environments, like VRML and X3D, which are also reviewed later on.

The most interesting approach, and at the same time closer to the aim of the research, is represented by "text-to-scene" systems, which build a computer graphics scene starting from a text based description.

To complete the overview of state-of-the-art technologies, some of the most important software solutions already available on the market, are evaluated for the automatic authoring of 3D training animations.

The section is then concluded with a review of the approaches and by the analysis of the fulfillment of the initial requirements.

3.1 Scene Graph

Every computer generated graphics environment can be imagined as built up by a sequence of still pictures or screenshots that, similarly to what happens in a movie, represent a scene composed by a virtual camera, eventual lighting sources, a group of actors or elements and by the interaction occurring between them and the surrounding environment.

In computer graphics to every scene is associated a scene graph (see figure 3-1); it is essentially a directed acyclic graph, where the structure consists of multiple nodes, each of which representing a geometry, property or grouping object. Hierarchical scenes are created by adding nodes as children of grouping nodes: in the following example the group node VW is composed by the elements "car body" and "tire".

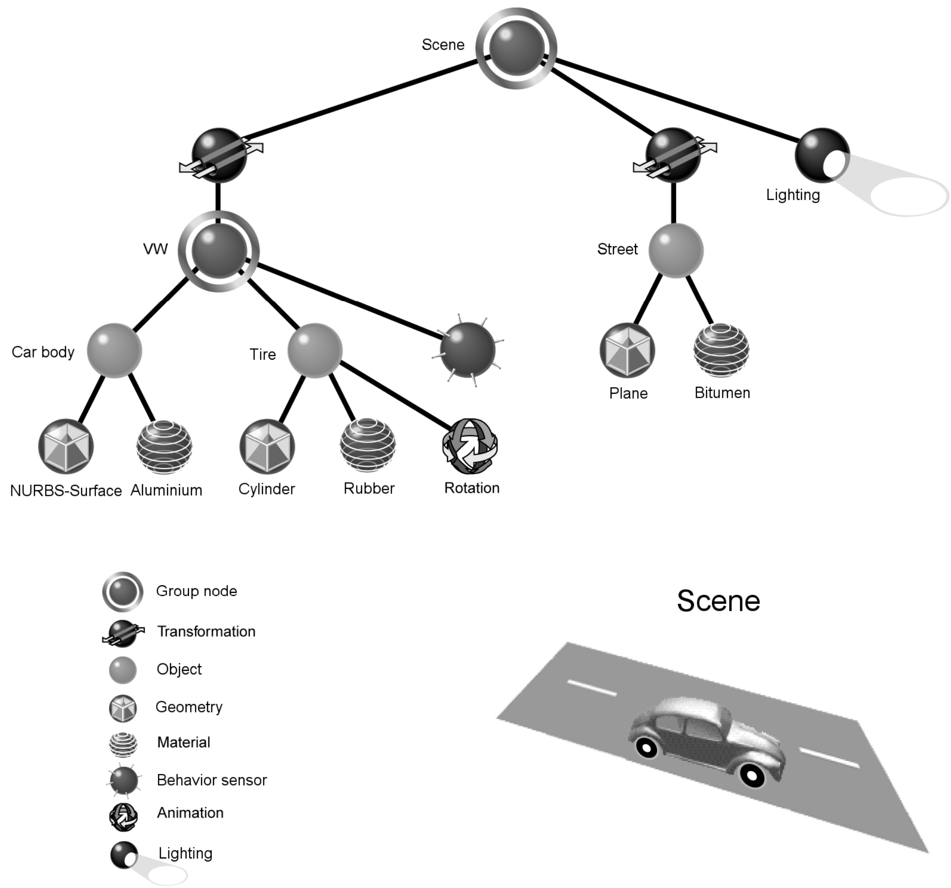

Figure 3-1: Example of a scene graph [GEK01]

A node may have many children but often only a single parent, with the result that an operation applied to a group automatically propagates its effect to all of its members. In many programs, associating a geometrical transformation matrix at each group level and concatenating such matrices together is an efficient and natural way to process such operations. A common feature, for instance, is the ability to group related shapes or objects into a compound object that can then be moved, transformed and selected as easily as a single object.

The two most general classifications of nodes functionality are:

- Group, which builds an hierarchy of nodes;
- Leaf, which contains descriptive data of the virtual objects in order to render them

The building up of a scene graph represents therefore the core of the authoring process since, once the scene graph has been built, the scene can be visualized through the according viewer. Most of scene graph implementations for 3D visualization, like OpenScenegraph [BO05] or Java3D just to cite the most famous ones among them, are freely available, sometimes also with open source, and can count on a huge developer community.

3.2 VRML/X3D

Most of scene graph implementations are in the form of API[16], thus requiring explicit programming knowledge. A different approach is represented by the Virtual Reality Modeling Language (VRML)[17] [HW96], which is a text file format for representing 3D interactive vector graphics, designed primarily for the World Wide Web. From the first specification VRML 1.0 a series of improvements have lead to version 2.0, which has been published in 1997 as ISO standard under the name VRML97.

VRML has represented a turning point in the history of the creation of 3D virtual environments through its main characteristics:

- Plain text format
- Multi-platform
- Open standard
- Hyperlinking[18]
- Interaction and Animation

Through a mark-up language, similar to HTML, VRML builds a hierarchical scene graph through 36 node types, like shape nodes, properties, group nodes, etc. VRML is also intended to be an interchange format for integrated 3D graphics and multimedia; it can be used in a wide range of applications from engineering and scientific visualization, to internet 3D worlds and entertainment. Even if the file format is quite old and superseded by its successor X3D, it is still used in education and in research for its open specification; it is also supported by many CAD systems, which offer the possibility to export original CAD models in VRML.

Extensible3D (X3D) is the successor of VRML and ISO standard for real time 3D computer graphics; it extends the features of VRML, which remains compatible, adding the ability to encode the scene using an XML notation as well

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[16] Application Programming Interface (API) represents a set of routines, protocols and tools for building software applications.

[17] Originally known as Virtual Reality Markup Language was specified in its first version in 1994, deriving its structure and file format from the Open Inventor software component, originally developed by SGI.

[18] Hyperlinking represents a referencing system, which allows the link of a hypertext document to another document or other resource. In the specific case, VRML can recall different objects to be included in the virtual scene just by using a normal link to that resource.

as the VRML97 syntax (see figure 3-2). This makes possible an easier integration of 3D scenes with other web content, technologies and tools.

```
Transform {
 children [
  NavigationInfo {
   headlight FALSE
   avatarSize [ 0.25 1.6 0.75 ]
   type [ "EXAMINE" ]
  }
  DirectionalLight {
  }
  Transform {
   translation 3.0 0.0 1.0
   children [
    Shape {
     geometry Sphere {radius 2.3
     }
     appearance Appearance {
      material Material {diffuseColor 1.0 0.0 0.0
      }
     }
    }
   ]
  }
  Transform {
   translation -2.4 0.2 1.0
   rotation 0.0 0.707 0.707 0.9
   children [
```

```
<head>
  <meta name='filename'
   content='RedSphereBlueBox.x3d'/>
</head>
 <Scene>
  <Transform>
   <NavigationInfo headlight='false'
     avatarSize='0.25 1.6 0.75'
     type='EXAMINE'/>
   <DirectionalLight/>
   <Transform translation='3.0 0.0 1.0'>
    <Shape>
     <Sphere radius='2.3'/>
     <Appearance>
      <Material diffuseColor='1.0 0.0 0.0'/>
     </Appearance>
    </Shape>
   </Transform>
   <Transform translation='-2.4 0.2 1.0'
    rotation='0.0 0.707 0.707 0.9'>
    <Shape>
     <Box/>
     <Appearance>
     <Material diffuseColor='0.0 0.0 1.0'/>
     </Appearance>
    </Shape>
```

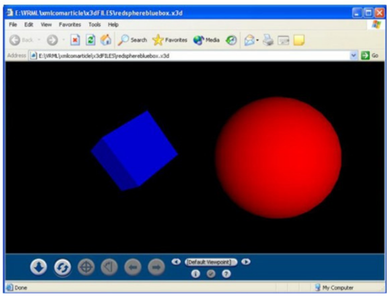

Figure 3-2: Representation in VRML (left) and X3D (right) of the same scene (down)

Even if X3D technology is still young, the increasing interest of the developer community has lead to the development of a series of software solutions, from content authoring and editing tools, to file translators and viewers.

3.3 Text-to-scene

In contrast to traditional 3D authoring approaches, language-based 3D scene generation systems let users create virtual environments without having knowledge of any software. Such systems automatically convert text descriptions of the scene to be depicted into the corresponding 3D picture or animation.

3.3.1 Wordseye

Wordseye [CS01] is probably the first approach to build a complete text-to-scene system. It relies on a large database of 3D models and poses to depict entities and actions. In addition every 3D model can have associated shape displacements, spatial tags and functional properties to be used in the depiction process.

An input text, like the one shown in the example later on, is entered; the sentences are tagged and parsed. Then the output of the parser is converted to a dependency structure: this structure is semantically interpreted and converted into a semantic representation. Depiction rules are used to convert the semantic representation to a set of low-level "depictors" representing 3D objects, poses, spatial relations, color attributes and other parameters.

Core of the system is the semantic interpretation of the sentences, provided through a parallel approach for words and for verbs. For nouns Wordseye uses Wordnet [MBF+90], which provides various semantic relations between words, in particular hypernym[19] and hyponym[20] relations. 3D objects are linked to the WordNet database so that the model of a cat can be referenced, for example, as a cat, a feline or a mammal. An overview of Wordnet can be found in section 4.2.1.

Spatial prepositions define the basic layout of the scene, including relative positions, distances and orientations: they are handled by semantic functions that analyze the elements connected by a preposition and build a representation fragment, according to the properties of the entities.

Verbs are handled by semantic frames[21], i.e. each verb is associated to the corresponding semantic entry, which contains a set of verb frames; a verb frame defines the argument structure of one sense, specifying required arguments, like "subject", and optional arguments, like "action location" and "action time".

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19 A hypernym (in Greek υπερνύμιον, literally meaning 'extra name') represents a word that includes its own sub-concepts. For example, "vehicle" includes the sub-concepts "train", "airplane" and "automobile" and is therefore a hypernym of each of those concepts.

20 A hyponym (in Greek: υπονύμιον, literally meaning 'few names') represents a word whose extension is included within that of another word. For example, "scarlet" and "vermilion" are hyponyms of "red".

21 A semantic frame is a coherent structure of concepts related with the main one so that without knowledge of all of them, it is not possible having knowledge of the main concept.

A depiction module eventually translates the high-level semantic representation into low-level depictors, through depiction rules. For example, the picture generated in fig 3-3 corresponds to following input text.

> *The donut shop is on the dirty ground. The donut of the donut shop is silver. A green a tarmac road is to the right of the donut shop. The road is 1000 feet long and 50 feet wide. A yellow Volkswagen bus is eight feet to the right of the donut shop. It is on the road. A restaurant waiter is in front of the donut shop. A red Volkswagen beetle is eight feet in front of the Volkswagen bus. The taxi is ten feet behind the Volkswagen bus. The convertible is to the left of the donut shop. It is facing right. The shoulder of the road has a dirt texture. The grass of the road has a dirt texture.*

Figure 3-3: Example of picture generated from the text description

The system deliberately addresses the generation of static scenes rather than the control or generation of animation. This makes the approach very interesting for the automatic generations of pictures but not suitable for the research purposes of this book.

3.3.2 Carsim

Carsim [ASS+03] [JWB+04] represents a more recent text-to-scene approach, which differs from the previous approach since the aim is the creation of 3D animated scenes instead of pictures, of car accidents from written news reports (see figure 3-4).

Figure 3-4: Screenshot of a CarSim animation

The system is made up of two parts, a linguistic component and a visualization component, which communicate using a formal description of the accident. The research approach started from a collection of development and test sets, comprehending approximately 200 accident reports from Swedish newspapers, characterized by different styles, lengths and amount of details, and from a database of the Swedish traffic authority.

The language processing module reduces the text content to a formal representation. It uses information extraction techniques to map a text onto a structure that consists of three main elements:

- A scene object, which describes the static parameters of the environment (weather, light conditions, road configuration)
- A list of road objects, like cars and trucks, and their sequence of movements. Also trees are included in this category.
- A list of collisions between road objects.

The resulting elements are used by the information extraction subsystem to fill the slots of a standard template. Carsim uses a domain-specific named entity recognition module, which detects names of persons, places, roads and car brands [PD04]. The detected nouns are then used to identify the physical objects involved in the accident, through association with concepts defined in a dictionary, partly derived from the Swedish Wordnet. Once defined the involved entities, events like car motions and collisions, need to be detected in order to be visualized and to animate the scene. To carry out detection a dictionary of words, nouns and verbs, depicting vehicle activity and maneuvers, has been created.

The configuration of the roads is inferred from the text information: when one of the vehicles makes a turn, the configuration is probably a crossroads. Other information can be contained in keywords like “crossing”, “roundabout” or “bend”. Even if the approach is very simple, a good accuracy has been obtained.

The scene generation algorithm positions the static objects and plans the vehicle motion. It uses rule-based modules to check the consistency of the description and to estimate the start and end coordinates of the vehicles in the 3D scene. Start and end positions of the vehicles are determined from the initial directions as if there were no accident. Then, a second module alters the trajectories, inserting the collisions described in the accident representation.

3.3.3 Confucius

Confucius [MM03] [MM04] is an intelligent multimedia storytelling interpretation and presentation system: it automatically generates 3D animations with sound and speech from natural language input. The input is thought to be represented by children’s stories, like “Alice in wonderland”, and the system is able to represent the semantics in a way that can generate inferences about the story, present them through animated characters and enrich them with a narrator voice or incidental music matching the plot development.

The system (see figure 3-5) is composed by a script writer, a script parser, various processors, and by a knowledge base. Aim of the script writer is to transfer a usual English story in a drama-like script, which meets the system’s requirements. Scripts can also be an input for the system: compared to stories, they are easier to parse because they are partially structured, i.e. they have distinct parts for scene description, a set of characters, dialogues or monologues, technical demands or requirements, like lights, sounds or costumes.

The script parser analyzes and subdivides the information into several functional parts:

- Actor description
- Scene description
- Actions
- Dialogues
- Non-speech audio description

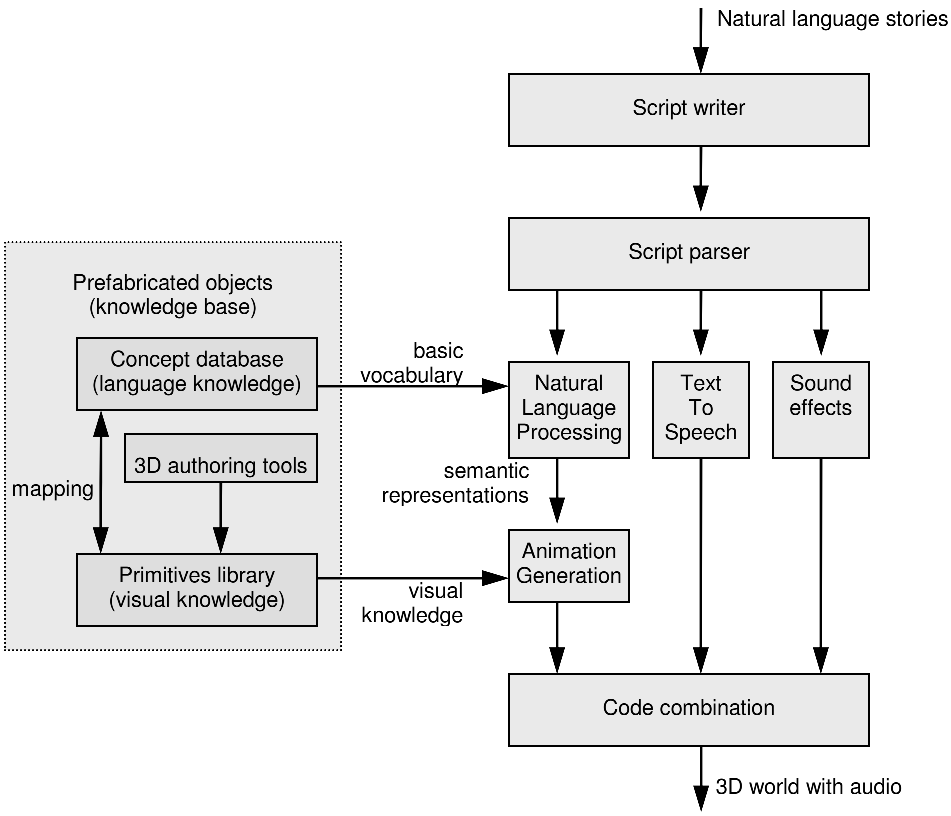

Figure 3-5: Confucius architecture

Elements are then passed respectively to the corresponding processors: dialogues to "text-to-speech", audio description to "sound effects", while scene and actor descriptions, which represent the main part, are sent to the natural language parser.

Automatic generation of the animation incorporates design expertise and automated selection, creation and combination of graphical elements. The animation generation in Confucius concerns two functional modules: the world model and the body model, according to the elements of the theatre arts, i.e. performers, sets, costumes, lights, sound, audience, etc. The animation producer generates VRML code for every "act" or part of the story. It consists of:

- world builder;
- actor manager;
- graphic library

The world builder simulates the world model: it sets up the stage, comprehending a set and including lights and sounds, from the scene description of the script. A set is a tiled background layer that can be grassland, water or gravel ground. The actor manager simulates the body model, i.e. it creates the actors, including their costumes and make-up, managing also speech and motion of the synthetic characters. The graphic library contains reusable graphic components of the knowledge base; through the library it is possible to reuse sets, properties and performers in other stories since they are built on reusable components.

Since actor's speech and motion may have implications on what is happening on the virtual scene, the possibility of an interaction and of information exchange between the world builder and the actor manager is provided. The outputs coming from animation generation, text-to-speech and sound effects are synchronized and joined together, generating a 3D world in VRML.

3.4 Commercial Software Solutions

In order to complete the overview of state-of-the-art technologies, an analysis of the actual commercial software solutions, regarding the authoring of 3D animations for training purposes is necessary.

As shown in the following subsections, many software solutions, which deal with 3D training applications for the industrial domain, are already present on the market. Just the three most powerful approaches, are reviewed separately in the next subsections. They are software packages that are usually used beside an existing CAD system, from which they derive the necessary 3D models in order to create personalized training sessions and animations.

The authoring process is left to the 3D artist or to the user, which autonomously decides which parts must be focused, highlighted or animated. Most of the animations are represented as an exploded view, which can be used for assembly or disassembly sequences.

Even if the hierarchy of the part structure is usually visible, no support in helping the individuation of allowed movements or cause/effect relations is given. Just in one case a wizard-like approach, where predefined actions, like "remove" and "install", are provided, thus simplifying the task and allowing some automation to the authoring process.

3.4.1 Cortona3D

Cortona3D [PA-ol] is a 3D visualization solution provided by Parallelgraphics: it feeds design data from CAD or PDM into 3D authoring tools that enable users with no 3D expertise to create interactive simulations and associated text. Users can then feedback data about parts or assemblies into a central repository for analysis and troubleshooting.

Cortona3D Enterprise is a server-based solution with a 3D repository at the core, which contains and manages part data including 3D geometry, metadata and the knowledge base associated with parts. The tool manages also the entire process of reusing existing CAD design data to create, update and publish 3D simulations for maintenance and operations manuals, training simulations, parts catalogues and more.

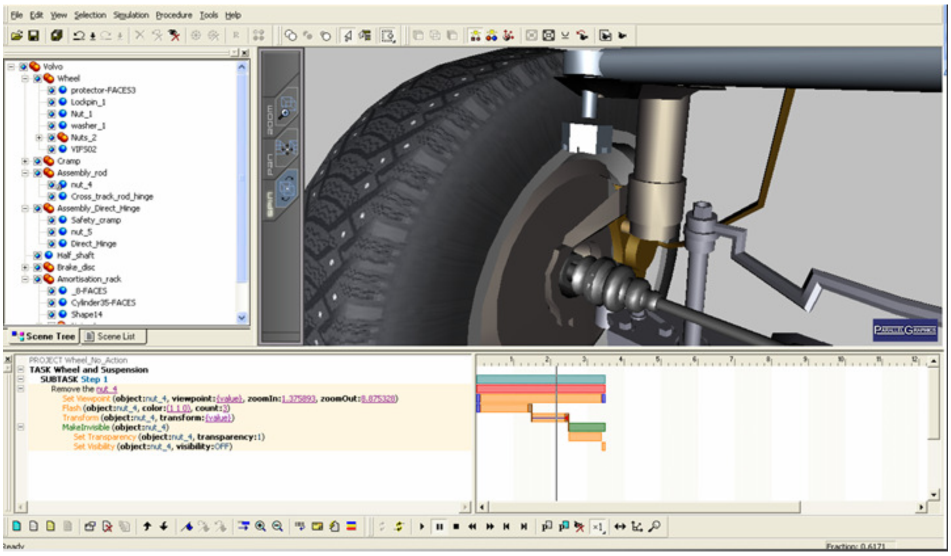

Figure 3-6: Screenshot of the Rapid Manual Working Environment

Cortona3D Rapid Products (see figure 3-6) are modular tools enabling the re-usability of existing CAD data or other 3D source material to author interactive 3D visualizations and simulations.

- RapidManual is a toolkit for production of digital interactive manuals for operations, service, maintenance or repair, which use animated 3D simulations to communicate mechanical procedures.
- RapidCatalog is a toolkit for production of digital interactive Illustrated Parts Catalogs (IPC) through 3D exploded views to show the structure of assemblies.
- RapidLearning is a learning toolkit for producing digital interactive training applications using animated 3D simulations. It combines existing CAD models with training documentation to generate visually realistic and interactive learning.
- RapidSimulation is a toolkit for producing interactive 3D environments that lets users experience mechanical devices and understand how complex equipment really behaves. The training environment enables users to walk through and interact within a 3D scene and change the state of objects, simulating real-world equipment.

Cortona3D represents one of the most advanced software packages available on the market, not only for 3D animations authoring but also for a complete 3D technical documentation. Its "wizard-like" feature, which gives the user some predefined action, like “install” and “remove”, is a good support and makes the authoring process easier. The capability to understand natural language texts remains anyway uncovered.

3.4.2 Right Hemisphere

The Right Hemisphere [RH05-ol] platform is an integrated set of products that delivers visual product communication and collaboration. The package (see figure 3-7) is composed by the Deep Exploration and Deep Creator tools.

Deep Exploration is a 3D multimedia authoring application, which allows to:

- Translate 2D or 3D models and multimedia files
- Search, view and mark-up 3D graphics
- Author, render and publish 3D images and animations
- CAD model translation and optimization (CAD Edition)

Figure 3-7: Training sequence using Right Hemisphere

Deep Creator is an authoring application that allows creating interactive 3D environments, assemblies and objects. The application delivers an integrated authoring environment which includes a 3D modeler, a texture creator, and a scripting engine in order to produce interactive 3D content.

Right Hemisphere uses an object-oriented approach, with hundreds of standard objects, including primitives, alterations and event-driven animations, to build 3D scenes. The scripting feature completes a very comprehensive software package, which anyway does not offer natural language support.

3.4.3 Lattice3D

XVL Studio (see figure 3-8) from Lattice3D is a family of authoring applications, which exploits the XVL[22] technology [WYH+00] for 3D publishing and communications.

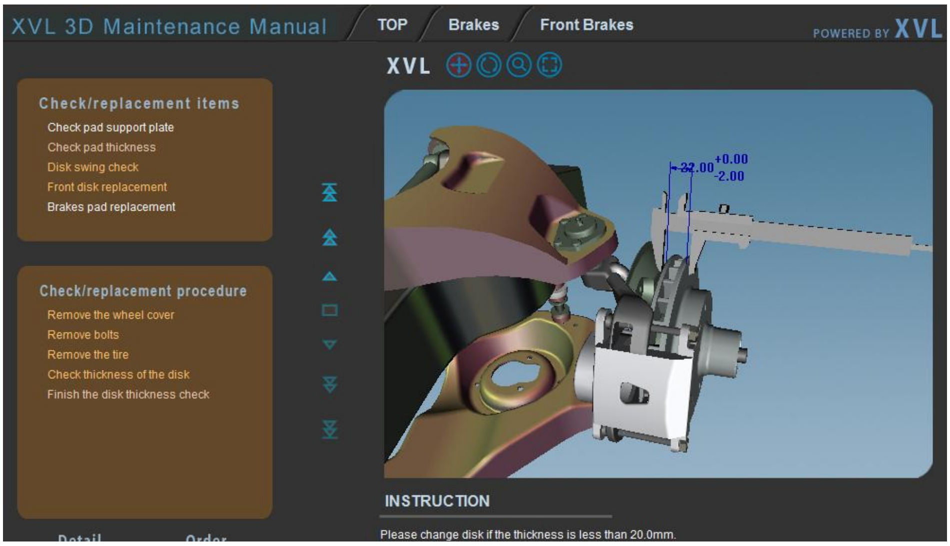

Figure 3-8: Training animation with Lattice3D

- The Basic version is a full function 3D viewer with basic editing and authoring capabilities, including measurement, annotation, and cross-sectioning functions. It has XVL data editing functions such as material or texture editing, IGES[23]/Polygon import, and combinations of multiple XVL models.
- The Standard version provides enhancement functions for 3D publishing and downstream use of XVL data, including all the capabilities of the Basic version plus animation with key frames and process definitions.

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22 XVL (eXtensible Virtual world description Language) is an XML-based, neutral format used for compression, conversion, and integration of 3D data.

23 The Initial Graphics Exchange Specification (IGES) defines a neutral data format that allows the digital exchange of information among Computer-aided design (CAD) systems

- The Pro version provides in addition to the features of the products mentioned above an automated interference detection of elements, very useful in large 3D models.

Lattice3D platform, as well as its main technology XVL, is very focused on data compression in order to gain competitive advantages in the internet based training or product presentation domains. On the Lattice website an “automated/semi-automated process animation” is presented as feature for the animation definition but no further explanations are given on how this process works.

3.5 Call for Action and Objectives of the Research

The review of the state-of-the-art approaches in literature and of software solutions available on the market has shown a continuously growing interest in the area of 3D product representation and simulation, strictly connected with CAD design.

The widespread use of 3D product data has also paved the way to its further employ for the realization of interactive and realistic training sessions: the deriving 3D animations represent the best way to deliver various contents through many modalities. Between them, the internet plays a very important role, canceling distances in a global world and making content accessible to a number of users simultaneously. This explains also the increasing interest in internet based technologies, like VRML/X3D or XVL, which exploit the net to deliver 3D content through an internet browser rather than through complex and dedicated software applications to be run on specialized workstations.

From the authoring point of view, much is still left to the 3D artist, which manages the realization of the animation with little software support. An object-oriented approach with event-driven and predefined animations is already available but nothing is given to support natural language instructions or texts; just some scripting support is in some cases provided.

In research much importance is given to the possibility to translate natural language into animations and the reviewed research approaches have shown its feasibility. This requires the use of artificial intelligence techniques, like natural language processing and knowledge base management. However, up to now no text-to-screen approach for the authoring of 3D animations for training purposes has been tried in literature. Confucius represent a very sophisticated “text-to-scene” approach, very close to satisfy the initial requirements; the target domain is however represented by the animation of humanoids in fantasy stories, therefore far from the technical domain for training purposes.

State-of-art approaches / Requirements	Words-eye	Carsim	Confu-cius	Cortona 3D	Right Hemi-sphere	Lattice 3D
R1 3D Support	○	○	○	●	●	●
R2 Natural Langua-ge Understanding	●	●	●	○	○	○
R3 Knowledge-base Management	●	●	●	◐	○	○
R4 Roles Management	○	○	◐	◐	◐	◐
R5 Reusability of atomic animations	○	●	●	●	◐	○
R6 Support for the training scenario	○	○	○	●	●	●

○ = not fulfilled ◐ = partially fulfilled ● = fulfilled

Figure 3-9: Review of state-of-the-art in 3D authoring

It can be concluded from the analysis done in this section (see figure 3-9) that existing approaches in literature as well as on the market cannot fulfill all the requirements and therefore a new method is needed in order to support the authoring of 3D animations for training purposes.

The new method has to start from an artificial intelligence base, which is able to couple natural language descriptions to the concepts they refer to; this is valid for objects or parts of a 3D model as well as for actions executed by them or on them. In order to review and select the most suitable artificial intelligence approach. The next section reviews some of the most important approaches in the artificial intelligence domain, which can be able to supply the required artificial intelligence techniques to realize an automation of the authoring process.

4 Artificial Intelligence Approaches

Under the term "Artificial Intelligence", coined in 1955 by McCarthy, is defined one of the most recent scientific domains, whose purpose as stated at the beginning, during the Dartmouth summer conference is contained in the following quotation:

> *"Every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it"[MMR+55]*

After the early phase of enthusiasm and great expectations, some problems have arisen, when the domain of applications has been enlarged [RS95]:

- Most early programs contained little or no knowledge of their subject matter; they succeeded by means of simple syntactic manipulations.
- Many of the problems that AI was attempting to solve were intractable: the first problems were solved by trying out different combinations of steps until the solution was found.
- Basic structures being used to generate intelligent behavior had fundamental limitations.

The importance of domain knowledge eventually led to the development of knowledge-based systems and intelligent agents, which gave AI a very strong impulse, letting it becoming a science.

Nowadays Artificial Intelligence is a wide research domain, which provides techniques in different domains, like:

- Problem Solving
- Knowledge and reasoning
- Planning
- Uncertain knowledge and reasoning
- Learning
- Communicating, perceiving, and acting

Since not all AI domains are pertinent to the objectives of this research, just two domains are reviewed in this section: "natural language processing", required for a first understanding of generic and unstructured texts, and "knowledge representation and retrieval", to associate to syntactical entities conceptual elements, which can be depicted by 3D models and their actions. Also a comprehensive overview of Ontology, through its different kinds, features and advantages is given.

4.1 Natural Language Processing

Communication is the intentional exchange of information through the production and perception of signs drawn from a shared system of conventional signs. What sets humans apart from other animals is the complex system of structured messages known as “language” that enables us to communicate most of what we know about the world [RS95].

Natural Language Processing (NLP) represents the main gate to the original Artificial Intelligence vision, where computers were imaged to be so intelligent to interact with human intelligence through speech or text understanding and production. Also known as “computational linguistics”, it is an interdisciplinary field, whose aim is to enable computers to process human language for text, speech or general communication tasks.

What distinguishes natural language processing applications from other generic data processing systems is the knowledge of language. A formal language is defined as a set of strings, which are concatenations of terminal symbols; on the other hand, natural language, such as English, Italian or German, has no strict definition but is used and sometimes also modified by a community of users.

Some of the most important tasks, performed through NLP, include:

- Machine translation, i.e. automatically translation from one language to another [Chi07]
- Web based question answering [Chk06]
- Inference, i.e. drawing conclusions based on known facts
- Information extraction
- Conversational agents, which converse with humans via natural language [TF04]

Natural Language Systems embed syntax knowledge, like what is a word or a verb, past participle or adjective, singular or plural. However, syntactical analysis can give a restricted overview of a generic sentence or text since syntax deals with the structure of a sentence and its representation in terms of symbols. A problem arises when for the same word or verb, different meanings are possible: the main point becomes the meaning of each element (lexical semantics) and the combination of them (compositional semantics).

In order to deal with such complexity of variables and factors, Natural Language Processing requires, together with syntax and semantics, additional kinds of knowledge:

- Phonetics and phonology - linguistic sounds
- Morphology - meaningful components of words
- Pragmatics – relation of meanings to goals of the speaker
- Discourse – large linguistic units

In the next sections an overview of the natural language understanding, rather than natural language generation, is given. Two different approaches are presented: on the one hand a logical approach, which starts from the definition of mainstays, like lexicon and grammar, and includes the use of parsing trees, on the other hand a probabilistic approach, which uses probability distribution over a possibly infinite set of strings in order to find the most likely structure of the sentence.

4.1.1 Logical Language Model

A logical language model is the appropriate solution when dealing with short utterances, usually restricted to a limited domain; complete syntactical and semantic analysis in order to extract the meaning of a generic sentence are made possible by its relatively low complexity.

The basis of a natural language processing system is represented by a lexicon, a list of allowable words, grouped into categories or parts of speech:

- Nouns, pronouns and names to denote things;
- Verbs, to represent actions;
- Adjectives and adverbs;
- Other elements (articles, prepositions, conjunctions, numbers, etc.)

Parallel to definition of a lexicon, a formal grammar is necessary to represent the set of specific rules that define how a sentence needs to be structured. Since the English Language is de facto the international language in academia, much of the research regards English grammars.

Most grammar rule formalisms are based on the idea of a phrase structure, i.e. a sentence is made up of different kinds of phrases. Words, which represents “terminal symbols”, are then combined into different kinds of phrases: sentence (S), noun phrase (NP), verb phrase (VP), prepositional phrase (PP) and relative clause (RelClause). Category names such as S, NP or VP are called "non-terminal symbols" and are used to rewrite rules or in tree structures.

A generic sentence, also indicated with S, contains at least two kinds of phrases:

- Verb phrase (VP) - "remove the screw", "opens the box"
- Noun phrase (NP) - "the worker", "John"

The most commonly used mathematical system for modeling constituent structure in English as well as in other languages is the **context-free grammar** (CFG), which is characterized by four parameters:

- A set of non-terminal symbols, or variables, N
- A set of terminal symbols, i.e. a lexicon, Σ, disjoint with N
- A set of rules or productions P, in the form $A \rightarrow \alpha$, where A is a non-terminal and α is a string of symbols from the infinite set of strings
- A designated start symbol S

For example, the following rule states that a sentence may consist of a noun phrase and a verb phrase; the notation followed is the Backus-Naur form (BNF)[24].

$$S \rightarrow NP\ VP$$

In a similar way the expression of a noun phrase (NP) can consist of either a proper noun or a determiner (Det), followed by a nominal, where a nominal can be constituted by one or more nouns.

$$NP \rightarrow ProperNoun$$

$$NP \rightarrow Det\ Nominal$$

$$Nominal \rightarrow Noun \mid NominalNoun$$

A context-free grammar can be used as a device for assigning a structure to a given sentence as well as for generating sentences. However, the latter approach is not analyzed in the next sections since it is not pertinent to the aim of this book.

[24] The Backus–Naur form is a metalanguage used to express context-free grammars, also widely used a notation, created by John Backus in 1959 [].Peter Naur later simplified Backus's notation to minimize the character set used, and as a suggestion of Donald Knuth, his name was added in recognition of his contribution.

4.1.1.1 Parsing and Treebanks

The parsing phase is a process that tags and labels elements of a sentence in order to build a parse tree (see figure 4-1), whose nodes represent phrases while leaves represent non-terminal symbols, i.e. single words, of a specific grammar.

Parsing can be performed starting from the S symbol and then searching for a tree that has the words as its leaves: this is called top-down parsing, opposed to the bottom-up parsing, which starting from the words searches a tree with root S.

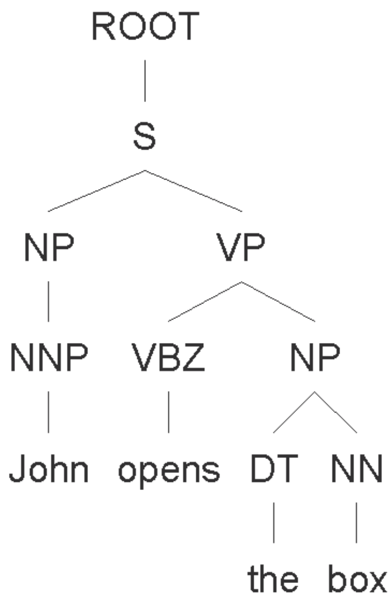

Figure 4-1: Generic parse tree

In order to generate a parse tree a natural language parser is required; it is a program that analyzes the grammatical structure of a sentence: for instance, which groups of words are phrases or which word is respectively the subject or the object of a verb.

Context-free grammar rules can be used, in principle, to assign a parse tree to any sentence. It is therefore possible to build a corpus, called Treebank, where every sentence is syntactically annotated with a parse tree. A wide variety of tree banks, which play an important role in parsing, have been created.

The Penn Treebank project, whose notation is introduced in table 4-1, has produced treebanks from the Brown [FK79], ATIS [HGD90], Switchboard [GHM92] and Wall Street Journal corpora of English as well as treebanks in Arabic and Chinese. Other treebanks include the Prague Dependency Treebank [HBH+00] for Czech, the Negra treebank [BHK+97] for German, and the Susanne treebank [Sam95] for English.

Table 4-1: Penn Treebank part-of-speech tags

Tag	Description	Example	Tag	Description	Example
CC	Coordin.Conjunction	and, but, or	RB	Adverb	quickly
CD	Cardinal number	one, two	RBR	Adverb, comparative	faster
DT	Determiner	a, the	RBS	Adverb, superlative	fastest
EX	Existential “there”	there	RP	Particle	up, off
FW	Foreign word	mea culpa	SYM	Symbol	+, %, &
IN	Preposition	of, in, by	TO	“to”	to
JJ	Adjective	yellow	UH	Interjection	ah, oops
JJR	Adj., comparative	bigger	VB	Verb, base form	eat
JJS	Adj., superlative	wildest	VBD	Verb, past tense	ate
LS	List item marker	1, 2, One	VBG	Verb, gerund	eating
MD	Modal	can, should	VBN	Verb, past participle	eaten
NN	Noun, sing. or mass	cat	VBP	Verb, non-3sg	eat
NNP	Proper noun, sing.	IBM	VBZ	Verb, 3sg pres	eats
NNPS	Proper noun, plural	Carolinas	WDT	Wh-determiner	which, that
PDT	Predeterminer	all, both	WP	Wh-pronoun	what, who
POS	Possessive ending	‘s	WP$	Possessive wh-	whose
PRP	Personal pronoun	I, you	WRB	Wh-adverb	where
PRP$	Possessive pronoun	your, one’s			

The sentences contained in a treebank implicitly constitute a grammar of the language; a large number of rules can be derived from a treebank by examining the components of any contained sentence. This high number of rules represents anyway a problem for probabilistic parsers, which are introduced in the next section; thus a Treebank represents can be used for natural language parsing but its grammar has to be modified.

Treebanks can be searched to find examples of particular grammatical phenomena, either for linguistic research or for answering analytical questions about a computational application. However, regular expressions used for text search or Boolean expressions are not sufficient; specific tree-searching languages exist, like tgrep [Pit94] and tgrep2 [Roh01], which can specify constraints about nodes and links in a parse tree.

4.1.2 Probabilistic Language Model

Probabilistic models represent one of the biggest breakthroughs in natural language processing in the last decades; corpora, i.e. large collections of text, like the World Wide Web, are parsed in order to gain knowledge and to produce the most likely analysis of new sentences, applying statistical methods.

The key need for probabilistic parsing is to solve the problem of disambiguation, especially ambiguities arising with longer sentences; in fact, when processed with realistic grammars, they yield thousands or millions of possible analyses. A probabilistic grammar offers a solution to the problem by computing the probability of each interpretation and selecting the most probable one.

The most commonly used probabilistic grammar is the probabilistic context-free grammar (PCFG) [Boo69] [Sal69], also known as Stochastic Context-Free Grammar (SCFG), a probabilistic augmentation of context-free grammars where each rule is associated with a probability. A PCFG differs from a standard CFG by augmenting each rule in the set R with a conditional probability:

$$A \rightarrow \alpha \text{ [p]}$$

where p is a number between 0 and 1 and expresses the probability that the given non-terminal A is expanded to the sequence α. If we consider all the possible expansions of a non-terminal, the sum of their probabilities must be equal to 1:

$$\sum_{\alpha} P(A \rightarrow \alpha) = 1$$

PCFG probabilities can be derived by counting in a parsed corpus or by parsing a corpus.

Each PCFG rule is treated as conditionally independent; thus the probability of a sentence is computed by multiplying the probabilities of each rule in the parse of the sentence. However, raw PCFGs suffer from such independence assumption between rules. One way to deal with the problem is to split and merge non-terminals; another solution is the use of probabilistic lexicalized CFGs, where the basic PCFG model is augmented with a lexical head[25] for

[25] The lexical head of a phrase represents the most important word, e.g. the noun in a noun phrase.

each rule. The probability of a rule can then be conditioned on the lexical head or nearby heads.

Methods for disambiguation often involve the use of corpora and Markov models; however, this overview goes not too deep, leaving to the reader more specialized publications on the topic. One of the most important parser available is the Stanford Lexical Parser [KM02] [KM03].

4.2 Lexical Semantics

So far an overview of the structure of an utterance has been analyzed but nothing about the meaning has been specified: this task is the aim of lexical semantics[26], which represents the study of the meaning in systems of signs and the systematic meaning-related connections between words.

Before starting the analysis some basic definitions regarding the “word” concept are required [JM00]; the term **lexeme** is usually used to mean the pairing of the orthographic and phonological form with its meaning, while a **lexicon** is a finite list of lexemes. A **lemma** or **citation form** is the grammatical form used to represent a lexeme, usually the base form. Thus “miracle” is the lemma for “miracles” and “give” the one for “give, gave, given”; specific forms, like “gave” or “given” are called wordforms while the mapping from a wordform to a lemma is called lemmatization.

It is quite common that a lemma, for example “paper”, has more than a sense: it can refer to the material or to a scientific article; a **sense** or **word sense** is a discrete representation of one aspect of the meaning of a word. The senses of a word might not have any particular relation between them but just sharing the orthographic form. In such cases, the senses are homonyms and their relation is **homonymy**. On the other hand, when senses are related semantically, such relation is called **polisemy**.

Metonymy is the use of one aspect of a concept or of an entity to refer to the entity itself or to some of its specific aspects. Metonymy is used, for example, in the phrase “the White House” to refer to the administration of the office rather than to the building itself.

For computational purposes, a sense is can be specified through definitions, similar to the ones used in a dictionary, via its relations with other senses. Given a large database of sense relations, an application is capable of performing sophisticated semantic tasks.

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[26] The term derives from Greek sēmantikos, giving signs, significant, symptomatic, derived from sēma (σῆμα), sign.

Another approach is to create a small set of finite set of semantic primitives, atomic units of meaning, and then create each sense definition out of these primitives. This approach is quite common when defining aspects of the meaning of events such as semantic roles.

Some of the relations between senses that have received significant computational investigation include:

- **Synonymy and Antonymy:** when the meanings of two different lemmas are identical or nearly identical, the two senses are synonyms, i.e. they are substitutable one for the other in any sentence. Antonyms, by contrast are lemmas with opposite meanings.
- **Hyponymy:** one sense is a hyponym of another sense if the first one is more specific, e.g. a car is a hyponym of vehicle. Conversely a vehicle is defined as a hypernym of car.
- **Meronymy:** it represents the part-whole relation, e.g. wheel is a meronym of car.

While the relations defined so far are binary, a **semantic field** [RMN+00] is an attempt to capture a more structured relation among entire sets of lemmas from a single domain. The following set of lemmas can be characterized by a set of binary relations, even if the result is not a complete account of how these words are related:

reservation, flight, travel, buy, price, cost, fare, rates, meal, plane

They are all related to common sense background information concerning air travel. Background knowledge of this kind has been studied under a variety of frameworks and is known as frame [Fil85], model [Joh83], or script [SA73].

4.2.1 Wordnet

The most commonly used resource for English sense relations is the WordNet lexical database [MBF+90]. Wordnet consists of three separate databases, one each for nouns and verbs, and a third one for adjectives and adverbs. Each database contains a set of lemmas, each one annotated with a set of senses. The current 3.0 release has more than 100.000 nouns, 10.000 verbs, 20.000 adjectives and almost 5.000 adverbs; it can be accessed also online or locally on every pc, once downloaded the free software package.

Noun

- S: (n) **open**, clear (a clear or unobstructed space or expanse of land or water) *"finally broke out of the forest into the open"*
- S: (n) outdoors, out-of-doors, open air, **open** (where the air is unconfined) *"he wanted to get outdoors a little"; "the concert was held in the open air"; "camping in the open"*
- S: (n) **open** (a tournament in which both professionals and amateurs may play)
- S: (n) **open**, surface (information that has become public) *"all the reports were out in the open"; "the facts had been brought to the surface"*

Verb

- S: (v) **open**, open up (cause to open or to become open) *"Mary opened the car door"*
- S: (v) **open**, open up (start to operate or function or cause to start operating or functioning) *"open a business"*
- S: (v) **open**, open up (become open) *"The door opened"*
- S: (v) **open** (begin or set in action, of meetings, speeches, recitals, etc.) *"He opened the meeting with a long speech"*
- S: (v) unfold, spread, spread out, **open** (spread out or open from a closed or folded state) *"open the map"; "spread your arms"*
- S: (v) **open**, open up (make available) *"This opens up new possibilities"*
- S: (v) **open**, open up (become available) *"an opportunity opened up"*
- S: (v) **open** (have an opening or passage or outlet) *"The bedrooms open into the hall"*
- S: (v) **open** (make the opening move) *"Kasparov opened with a standard opening"*

Figure 4-2: Extract from WordNet online results for the lemma “open

In addition various lexical sense relations (see table 4-2) are implemented: each synset is related to its immediately more general and more specific synsets via direct hypernym and hyponym relations.

These relations can be followed to produce longer chains of more general or more specific synsets. Each sense, like the ones displayed in figure 4-2, is composed by a gloss, i.e. a dictionary-style definition, a list of synonyms, called synset[27], for the sense and sometimes also usage examples.

Even if WordNet is a lexical reference system, it is also usually referred to as an Ontology; however, this assumption is not fully correct since the relations defined are just of the kind hyponymy/hyperonymy.

[27] Synset stays for “synonymy set” and can be thought as a way to represent a concept. Thus instead of representing concepts using logical terms, WordNet represent them as a lists of word senses.

Table 4-2: Semantic relations in WordNet

Semantic Relation	***Syntactic Category***	***Examples***
Synonymy (similar)	N, V, Adj, Adv	pipe, tube rise, ascend sad, unhappy rapidly, speedily
Antonymy (opposite)	Adj, Adv, (N, V)	wet, dry powerful, powerless friendly, unfriendly rapidly, slowly
Hyponymy (subordinate)	N	sugar maple, maple maple, tree tree, plant
Meronymy (part)	N	brim, hat ship, fleet
Troponimy (manner)	V	march, walk whisper, speak
Entailment	V	drive, ride divorce, marry

4.2.2 Thematic Roles

Lexical meaning can be also analyzed through the study of predicate-argument structures: analogously to the structure of human language, relations between various concepts depend on the constituent words and phrases, which build up a sentence. Verbs usually dictate specific constraints on number, grammatical category and location of the phrases that are expected to complete a syntactic structure. To review this idea, consider the following examples:

I want a pizza	NP want NP
I want to buy a car	NP want Inf-VP
I want it to be close by here	NP want NP Inf-VP

The syntactic frames on the right specify the number, position and syntactic category of the argument that are expected to follow the verb “want”: examining different possibilities in the use of a verb, it is possible to collect important information about the expected participants in the events defined by each verb.

Thematic roles express the meaning that a lexical element, e.g. a noun phrase, plays with respect to the action or state described by the main verb. This is achieved through thematic relations, whose main components can be summed in the table 4-3. Thematic roles are used to perform semantic restrictions on the elements that a specific verb can support.

Table 4-3: Thematic roles

Agent	performs the action
Experiencer	receives sensory or emotional input
Theme	undergoes the action but does not change its state
Patient	undergoes the action and has its state changed
Instrument	Used to carry out the action
Natural Cause	mindlessly performs the action
Location	Place where the action occurs
Goal	aim of the action is directed towards
Recipient	a kind of goal associated with verbs expressing a change in ownership
Source	where the action originated
Time	the time at which the action occurs
Beneficiary	the entity for whose benefit the action occurs

4.2.3 FrameNet

The FrameNet project [BFL98] is a semantic role labeling project, where roles are specific to a frame, which represents a script-like structure that instantiates a set of frame-specific semantic roles called frame elements. Each word evokes a frame and profiles some aspect of the frame and its elements; for example, the “removing” frame is defined as follows:

> *An Agent causes a Theme to move away from a location, the Source. The Source is profiled by the words in this frame, just as the Goal is profiled in the Placing frame.*

Frame elements appear in the example highlighted and separated into core roles and non core roles. According to the definitions taken from FrameNet, for the specific case they are classified in Table 4-4.

Table 4-4: Framenet elements

Core	Agent	the Agent is the person (or force) that causes the Theme to move
	Cause	the non-Agentive cause of the removing event
	Source	it is the initial location of the Theme, before it changes location
	Theme	theme is the object that changes location
Non-core	Cotheme	it is the second moving object, expressed as a direct object or an oblique
	Degree	degree to which event occurs
	Distance	the Distance is any expression which characterizes the extent of motion. This frame element occurs throughout the motion domain
	Goal	the Goal is the location where the Theme ends up. This Frame Element is not profiled by words in this frame, though it may occasionally be expressed, as with the word remove
	Manner	Any expression which describes a property of motion which is not directly related to the trajectory of motion expresses the frame element Manner. Descriptions of speed, steadiness, grace, means of motion, and other things count as Manner expressions
	Means	it is an act whereby the Agent achieves the removal
	Path	Any description of a trajectory of motion which is neither a Source nor a Goal expresses the frame element Path.
	Place	the location where the removal takes place
	Result	result of an event
	Time	the time at which the removal takes place
	Vehicle	the Vehicle expresses the conveyance with which the Agent affects the motion of the Theme. The Vehicle holds and conveys the Theme. Vehicles can move in any way and in any medium.

FrameNet also codes relations between frames and frame elements: in the “removing” example, they are defined as follows:

Inherits From: Transitive_action

Subframe of: Cause_motion

Precedes: Placing

Uses: Motion

Is Used By: Emptying, Undressing

See Also: Placing

The major product of this work, the FrameNet lexical database, currently contains more than 10,000 lexical units, 6,100 of which are fully annotated, in approximately 825 semantic frames and exemplified in more than 135,000 annotated sentences.

4.3 Ontology

Even though ontology research has begun in the early 90s in the knowledge base community, the research activity has been recently spread over the web technology community by the semantic web[28] movement [BHL01]. Nowadays ontology is a very popular topic, even if still there seems to be some misunderstanding on what an ontology really is. One of the key concepts to understand ontology is "conceptualization", which includes "the objects presumed or hypothesized to exist in the world and their relations". [GN87]

An example can help to better understand what in practice a conceptualization is: the task of the blocks world (see figure 4-3) consists in stacking blocks in the goal configuration, using a robot hand.

The target world can be exhaustively represented by the concepts "entity" and "relation": the former represents the physical objects of the target world, like block, robot hand and table, while the latter specifies the relations between the objects. The modeling of the target world is left to the experience of the knowledge engineer and therefore to its point of view: there is in fact not just a unique solution but multiple choices, each of them being correct. One way to model the target world is represented by the Conceptualization 1 in table 4-5, which defines three blocks (block A, block B and block C), a robot hand and a table as objects, together with four relations:

[28] In 1999 Tim Berners-Lee, inventor of the World Wide Web, stated: "I have a dream for the Web [in which computers] become capable of analyzing all the data on the Web – the content, links, and transactions between people and computers. A 'Semantic Web', which should make this possible, has yet to emerge, but when it does, the day-to-day mechanisms of trade, bureaucracy and our daily lives will be handled by machines talking to machines."

- for the blocks and the table, the on (x,y) defining that the block x is on the block y, and clear (x), i.e. a block that has no block on it, relations
- for the robot hand, the relations holding (x) and handEmpty

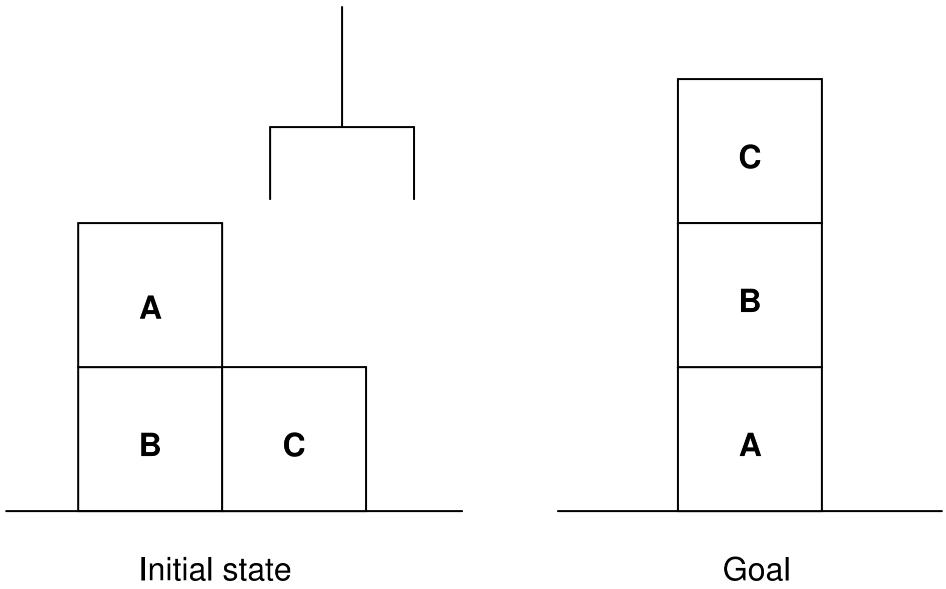

Figure 4-3: The blocks world task

Another possible conceptualization is represented by just the three blocks as objects; in fact, since the table and the robot hand are unique in the world, there is no need to recognize them. In this case the introduction of the new relation onTable (x), in addition to the relations already examined, is necessary: the relation on (x, table) is then replaced by onTable (x).

Table 4-5: A couple of possible conceptualizations of the world

Conceptualization 1		***Conceptualization 2***	
Entity	**Relation**	**Entity**	**Relation**
Block A	On (X, Y)	Block A	on (X, Y)
Block B	clear (X)	Block B	clear (X)
Block C	holding (X)	Block C	holding (X)
Table A	handEmpty		handEmpty
Hand A			onTable(X)

From each of the conceptualizations, it is possible to derive a small ontology, which is essentially made up of two main concepts:

- Entity
- Relation

Focusing on Conceptualization 1, since it contains the most elements, the "entity" concept can be refined through the three sub-concepts, block, hand, table can be defined. This specification of the concepts, the hyponymy introduced in section 4-2, is possible by means of a simple "isA" relation: the table, the hand and the block are a kind of entity. The structure of the target world is completed by the specification of instances, which represent the individuals of a class: table A, hand A, block A, block B and block C, respectively for the classes table, hand and block.

A similar structure can be built for relations: according to the number of variables required, every relation can be subdivided into the classes "unary", "binary" and "boolean": the binary relation can be specialized by the "on" relation, the unary by "clear" and "holding", while the only Boolean relation is represented by "handEmpty", whose value can be just yes or no. Also in this case each specification of concepts represents an "is-a" relation, but no instances can be defined. This simple example explains that ontology consists of hierarchically organized concepts and relations between them; this is very important since many people confuse ontology with taxonomy, an hierarchy of concepts usually depicted as a tree, which includes no relation between the elements.

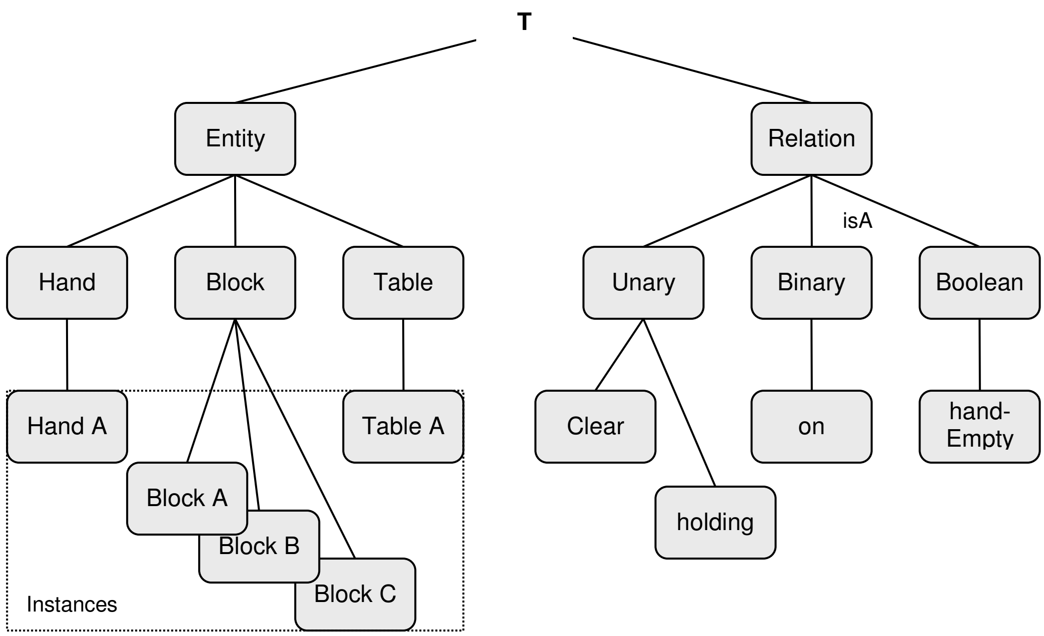

Figure 4-4: Ontology deriving from Conceptualization 1

The term Ontology derives from philosophy, where it means theory of existence: it tries to explain the being and the world by introducing a system of critical categories to account things and their intrinsic relations. From an AI point of view, a widely accepted definition is the one of GRUBER [Gru93]:

> *"Ontology is an explicit formal specification of a conceptualization"*

where the single elements can be characterized as follows:

- explicit, because domain and constraints must be explicitly defined
- formal, i.e. machine readable
- conceptualization, intended as an abstract, simplified world

BORST [Bor97], underlying the knowledge sharing nature of ontology, slightly modified it in:

> *"Ontology is a formal specification of a shared conceptualization"*

From knowledge-based systems point of view, it is defined as "a theory/system of concepts/vocabulary used as building blocks of an information processing system" by MIZOGUCHI.

As introduced by the example mentioned before an Ontology is essential built up by three mainstays: classes, instances and relations. A class is a group, set or collection of elements, called instances or individuals, which share the same characteristics. The relations connecting classes build the structure of the ontology can be subdivided into:

- Hyperonymy/Hyponymy (or Subsumption), defines subclasses and superclasses relations, e.g. "is-a" relation;
- Meronymy/Holonymy, denotes a relation between the whole and its subparts, e.g. "part-of" relation;
- Synonymy/Antonymy, defines concepts whose meaning is equal or disjoint.
- Cardinality, how many parameters are necessary for a class or attribute

Ontology engineering represents the evolution of knowledge engineering, which consisted mainly in the exploitation of the rule base technology and its if-then rules, within knowledge based systems. This shift has been caused mainly by difficulties in the maintenance of rule base systems and in knowledge sharing and reusing in knowledge bases, so that such systems had to be built from scratch.

Ontology engineering is a research methodology, which allows the design rationale of a knowledge base, kernel conceptualization of the world of interest, semantic constraints of concepts together with sophisticated theories and technologies enabling accumulation of knowledge [Miz03].

Different kinds of ontology have been developed so far [UG96] [UJ99], from very generic and domain independent to specific ontologies, dealing with a specific task or domain. An overview of the most important approaches is given in the following sections.

4.3.1 Upper Ontology

Ontology represents by its nature a wide domain, which has been seen from different point of views by the research community: on the one hand, researchers stated that ontology should be very generic, widely applicable and shareable; on the other hand some thought ontology to be domain-specific, like a knowledge base. Both definitions are correct, they just point to different types of ontologies, which are analyzed in detail in the following sections.

An Upper Ontology is an attempt to build a higher level ontology that describes very general concepts, common to all domains. It tries to formally define the higher level categories, which explain what exists in the world: the topic has been investigated for years by philosophers, like Aristotle's ten categories such as *substance, quantity, quality, relation, place, time, position, state, action and affection*.

Some of the most important contributions in the upper ontology domain are due to Sowa and Guarino: SOWA's [Sow00] ontology is composed of categories and distinctions derived from a variety of sources, the most important of which are represented by philosophers PEIRCE and WHITEHEAD, who were pioneers in symbolic logic. Sowa used on top of its ontology tree Peirce's concepts: **independent**, which can be defined without assuming any other concepts, **relative**, which necessarily depends on other concepts, and **mediating,** which provides the environment or context for the relative. Then he introduced four important **concepts: continuant, occurent, physical** and **abstract**. From such mainstays the additional concepts illustrated in figure 4-7 have been derived.

GUARINO's [Gua98] upper ontology uses a more extensively philosophical approach, being based on three different theories, like mereology or theory of parts, theory of identity and theory of dependency. It consists of two worlds: an ontology of particulars, such as things that exist in the world, and universals, which include concepts necessary to define particulars.

A shared upper ontology paves the way to the definition and development of additional domain ontologies and provides guidelines on how organizing domain knowledge. The importance of the definition of an upper ontology has been also recognized by the IEEE in its “Standard Upper Ontology Working Group” (SUO WG). Several existing ontologies, like SUMO, Cyc, IFF among other ones, have been candidate for the standard upper ontology, but an agreement has not yet been reached.

4.3.1.1 Cyc

Between the already developed upper ontologies, a very important role is played by Cyc: it represents a proprietary system under development since 1985, consisting of an upper ontology and a knowledge base core, subdivided into smaller knowledge domains, called microtheories. Parallel to the main Cyc knowledge base, additional versions are available: OpenCyc represents a subset of the whole ontology and has been released for free, while the ResearchCyc version has been made available to AI researchers under a research-purposes license.

The Knowledge Base contains over a million human-defined assertions[29], rules or common sense ideas. These are formulated in the CycL language, which is based on predicate calculus and has a similar syntax to that of the Lisp programming language. Typical pieces of knowledge represented in the database are "Every tree is a plant" and "Plants die eventually": when asked whether trees die, the inference engine can draw the obvious conclusion and answer the question correctly

Knowledge embedded in Cyc is subdivided into microtheories: a microtheory is a set of assertions, based on a shared set of assumptions, a shared topic or a shared source, on which the truth of the assertions depends. One of the functions of microtheories is to separate assertions into consistent bundles: within a microtheory, assertions must be mutually consistent, while there may be inconsistencies across microtheories. This structure allows a faster and more scalable building of the knowledge base as well as a better and faster inference.

4.3.1.2 SUMO

SUMO is a general upper ontology, which provides definitions for general-purpose terms and acts as a foundation for more specific domain ontologies. Knowledge defined in SUMO includes the ontologies available on the Ontolingua server [FFR96], Sowa’s upper level ontology, the ontologies developed by

[29] An assertion is a statement that is true in the ontology.

ITBM-CNR[30], and various mereotopological theories[31], among other sources. The knowledge representation language for the SUMO is a version of KIF[32] [GF92], called SUO-KIF.

The Sumo top level is characterized by the following classes and sub-classes:

- Physical
    - Object
        - SelfConnected Object
        - Collection
    - Process
- Abstract
    - SetClass
        - Relation
    - Proposition
    - Quantity
        - Number
        - Physical Quantity
    - Attribute

SUMO ontology, as well as CYC, goes beyond a restricted series of concepts and relations; it tries to structure common knowledge within a shared upper concept. However, many differences between them can be found: for example, while SUMO structure is defined through its classes, OpenCyc works on a deeper level, including and defining also instances.

4.3.1.3 ConceptNet

ConceptNet [LS04] is a commonsense knowledgebase and natural-language-processing toolkit, which supports many practical textual-reasoning tasks over

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[30] Former Institute of Biomedical Technologies of the Italian National Research Council (CNR)

[31] Mereotopology is a formal theory, which combines mereology and topology, of thetopological relationships among wholes, parts, parts of parts and the boundaries between parts.

[32] Knowledge Interchange Format is a language for knowledge interchange.

real-world documents without additional statistical training. The package, which is freely available, performs context-oriented inferences, including:

- topic-jisting (e.g. a news article containing the concepts, “gun,” “convenience store,” “demand money” and “make getaway” might suggest the topics “robbery” and “crime”),
- affect-sensing (e.g. “this email is sad”),
- analogy-making (e.g. “scissors,” “razor,” “nail clipper,” and “sword” are perhaps like a “knife” because they are all “sharp,” and can be used to “cut something”),
- text summarization
- contextual expansion
- causal projection
- document classification

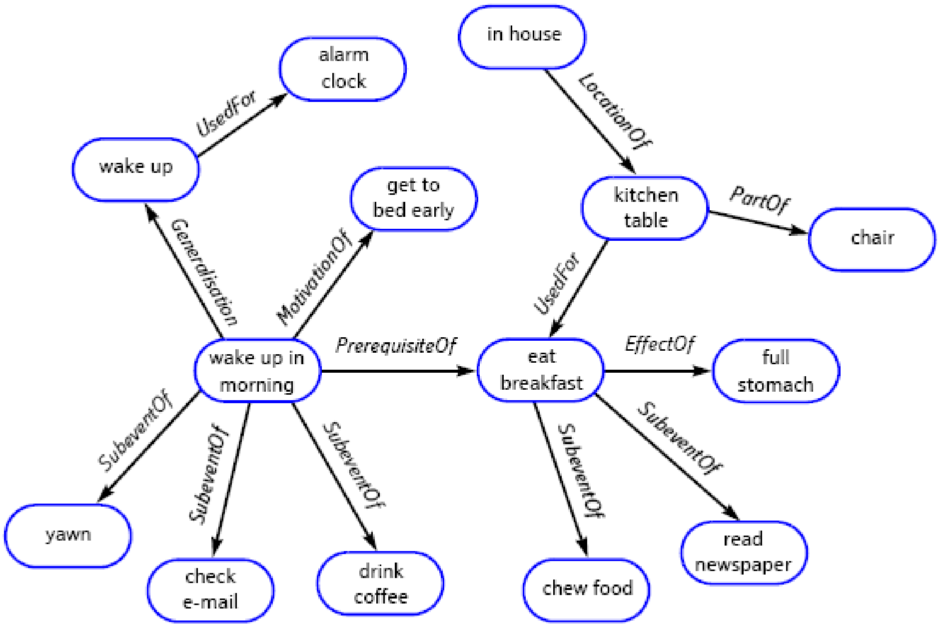

Figure 4-5: Extract from ConceptNet

The ConceptNet knowledgebase is a semantic network (see figure 4-5) nowadays available in two versions: concise (200,000 assertions) and full (1.6 million assertions). Commonsense knowledge in ConceptNet encompasses the spatial, physical, social, temporal, and psychological aspects of everyday life. Whereas similar large-scale semantic knowledge bases like Cyc and WordNet are handcrafted, ConceptNet is generated automatically from the 700,000 sentences of the Open Mind Common Sense Project – a World Wide Web based collaboration with over 14,000 authors.

Impressive is the coverage of the relations (see table 4-6) defined in ConceptNet's relational ontology: from the K-lines, generic conceptual connections introduced by MINSKY [Min80], to relations regarding things and events, to spatial, causal or functional relation, ConceptNet is able to make assertion on a wide range of common sense knowledge.

Table 4-6: ConceptNet relations

K-Lines (1,25 million assertions)
(ConceptuallyRelatedTo 'bad breath' 'mint')
(ThematicKLine 'wedding dress' 'veil')
(SuperThematicKLine 'western civilization' 'civilization')
Things (52 000 assertions)
(IsA 'horse' 'mammal')
(PropertyOf 'fire' 'dangerous')
(PartOf 'butterfly' 'wing')
(MadeOf 'bacon' 'pig')
(DefinedAs 'meat' 'flesh of animal')
Agents (104 000 assertions)
(CapableOf 'dentist' 'pull tooth')
Events (38 000 assertions)
(PrerequisiteEventOf 'read letter' 'open envelope')
(FirstSubeventOf 'start fire' 'light match')
(SubeventOf 'play sport' 'score goal')
(LastSubeventOf 'attend classical concert' 'applaud')
Spatial (36 000 assertions)
(LocationOf 'army' 'in war')
Causal (17 000 assertions)
(EffectOf 'view video' 'entertainment')
(DesirousEffectOf 'sweat' 'take shower')
Functional (115 000 assertions)
(UsedFor 'fireplace' 'burn wood')
(CapableOfReceivingAction 'drink' 'serve')
Affective (34 000 assertions)
(MotivationOf 'play game' 'compete')
(desireOf 'person' 'not be depressed')

4.3.2 Task and Domain Ontology

Upper Ontologies, as introduced in the previous section, are generic, widely applicable and shareable; however, Ontology can also be seen as domain specific and deal with just a small portion of the knowledge domain. Such approach [MSI96] considers ontology built up by two separate parts:

- Task ontology, which characterizes the computational architecture of a knowledge based system that performs a task;
- Domain ontology, which characterizes knowledge of the domain where the task is performed

Task ontology describes inherent problem solving structure of existing tasks domain-independently. It is obtained by analyzing task structures of the real world by means of four kinds of concepts:

1. Task roles: roles played by the domain objects in the problem solving process
2. Task actions: activities appearing in the problem solving process
3. States of the objects
4. Other concepts specific to the task

Table 4-7: Concepts included in task ontology for a scheduling task

Task roles	“Scheduling recipient” “scheduling resource”, “due date”, “constraints”, “goal”, “priority”
Task actions	“assign”, “classify”, “pick-up”, “select”, “neglect”
States	“unassigned”, “the last”, “idle”
Other	“constraint satisfaction”, “constraint predicates”, “attribute”

A domain ontology (or domain-specific ontology) models a specific domain, or a part of the target world. It represents the particular meanings of concepts as they apply to that domain. For example the concept card has different meanings: an ontology about the domain of games would model the "playing card" meaning of the concept, while an ontology about the domain of computer hardware would model the "punch card" and "video card" meanings.

Many domain ontologies have been already developed in different domains: for example, in the medical domain, with the Gene Ontology [AL02], the Protein Ontology [SDC+05] and the foundational model of anatomy [RM03], in the botanic domain with the Plant Ontology [PO02] as well as in the industrial domain, with the modeling of an industrial plant [MKS+00] and with the Process Specification Language (PSL), which is the ISO Standard 18629.

4.3.3 Ontology and Training

The use of Ontology approaches in the training domain has begun in the second half of the 90s [JIM96], [JIM+97]: in particular one task and domain ontology approach [CHJ+98] has inspired the research proposed in this book. The research work has led to the development of SmartTrainer, an ontology-based intelligent authoring tool whose aim is to train operators of an electric power network to recover power transmission as soon as an accident happens. The system lets at first the operator looking for a solution to the problem: according to the mistakes made by the operator during this operation path, the most appropriate teaching strategy to teach the knowledge behind the practice is selected by the system. Training is here meant as "computer-based training" where the trainee interacts with a computer-generated scenario; no support for graphics or 3D animation and interaction is provided.

Ontology plays in the training authoring tool the following important roles:

- formalizing the construction process of the intelligent training systems
- providing primitives that facilitate the knowledge description at the conceptual level
- constructing explicit models
- providing axioms for the construction of intelligent training systems

Different kinds of ontologies are used in SmartTrainer, the most important of which can be summed up as follows:

- Domain Ontology, which specifies the conceptual vocabulary and the representational framework for classes of a domain
- Teaching Strategy Ontology, which provides the author with a mean of model its teaching experiences
- Learner Model Ontology, which helps the author to represent a suitable learner model mechanism so that the system can behave adaptively to the learner's state

Ontology is therefore useful not only to model different domains, which represent the target of the training, but also different kind of audience, i.e. trainees or learners, each of which has its own background and its need of information.

4.4 Ontology as Knowledge-base for the automatic Generation of 3D Computer Animations

The considerations contained in the previous section have led to the choice of an ontology as knowledge-based core for the intelligent authoring of 3D animations; it allows in fact the necessary link between linguistic elements and the corresponding concepts of a training scenario.

Due to its modular structure, ontology can be easily extended through additional domain ontologies that embed domain knowledge and vocabulary as well as relations between the concepts; this structured knowledge can be then used to describe technical parts or assemblies from a conceptual point of view and to link such description to the corresponding 3D model, previously developed and stored in a repository. The use of Ontology in order to create interactive graphic environments for product presentation can also be found in literature [TNT+04].

At the same time it is possible the characterization within the ontology of the action verbs that derive from natural language descriptions: each action can then be translated from a textual to a conceptual representation by means of knowledge of the movements and transformations connected to every action. Actions can also results in different transformations according to the target object.

In addition ontology is also able to manage different kind of end user roles and their need of information by managing the according view of the 3D model and its level of detail within the animation.

The ontology approach represents then the selected artificial intelligence approach and constitutes the core of the developed process model, which is introduced in the following section.

5 Ontology-driven Generation of 3D Animations

The evaluation of state-of-the-art approaches in literature of computer graphics as well as of artificial intelligence has shown that no approach, which is able to generate 3D animations for training purposes starting from natural language instructions, has been developed so far. The closest text-to-scene approach, Confucius, showed in section 3.3.3, deals with animation of humanoids starting from natural language descriptions and it is therefore not useful for the training domain in industrial scenarios.

In addition, current commercial software solutions demand the creation of 3D animations to specialized 3D artists, not offering any possibility of automation of the actions that characterize the animation itself: only in one case, a "wizard-like" approach has been found in order to associate predefined actions to specific objects. However, this possibility to use predefined animation atoms does not prevent the arising of various problems: on the one hand, the identification of the correct objects, which take part in the training task, is left arbitrarily to the author. On the other hand, no indication on how the parts interact with each other, during the animation, is given: for example, the author does not know a priori which parts are involved and how they move, after pressing the start button of a mechanical device.

The analysis performed so far has led to a call for action in order to give to the research area a structured and flexible approach, which can be extended and reused for multiple domains. The result of this process is the development of a method, which proposes the use of an ontology, whose features have been analyzed in the previous section, as a semantic knowledge base. As preliminary step the development of the ontology core is described in the following sections.

5.1 Basic idea

Textual communication is together with voice the most used mean to deliver information: this is valid not only in everyday life but also in industrial environments, where textual communication from e-mails to instruction manuals is massively widespread. It is therefore reasonable imagining of text-based descriptions of training sequence since most of existing training material is already written down in a text form and can therefore be reused and translated into a more intuitive 3D animation.

The basic idea (see figure 5-1) is to extract information from training sequences, in the form of natural language texts, and convert it into an animation script, which through the corresponding viewer shows the required animation.

In order to achieve this aim an intelligent approach needs to be developed: the proposed method requires a first understanding of the structure of a generic training sentence, by means of natural language parsing techniques. Once the single elements are found and labeled at a phrase level (noun phrase, verb phrase) as well as at a word level (noun, verb, adjective or adverb), also the meaning of each element, has to be investigated. This second part of the method is performed by an ontology core, whose aim is the definition of general and domain knowledge in terms of meaning, to be coupled to the natural language elements.

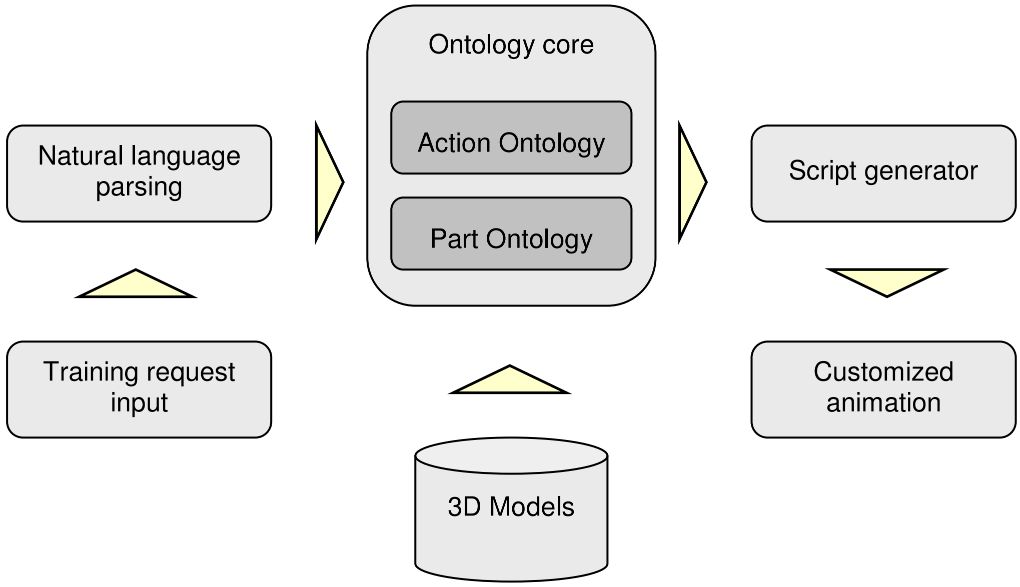

Figure 5-1: Overview of the basic idea of the proposed approach

In addition, since the aim is the generation of 3D animations for training purposes, the method needs to access a repository of existing 3D models. Such 3D objects are eventually animated in the virtual environment through animation techniques that represent a series of actions previously described by natural language instructions.

5.2 Ontology Core

Ontology plays in the proposed approach a central role: it is the link between linguistic elements and the corresponding concepts to be displayed in the 3D animation. Once these concepts are identified in the knowledge base, the object or action counterparts are respectively recalled or created, in order to build up the basis of the requested 3D animation.

In section 4.2 some notions about Ontology and its different kinds have been given. One of the main problems occurring with ontology is that its development, starting from scratch, is a very time consuming task. Furthermore it must be by definition shared by the community in order to assure extensibility and reusability for different purposes and domains. These conclusions suggest the necessity to use an existing “upper ontology” as a mainstay of the ontology core, instead of developing a completely new one.

The proposed approach is made up of two different levels characterizing the ontology (see figure 5-2): at a higher level, the use of an upper ontology is foreseen, completed by multiple domain ontologies, which supply the necessary low level knowledge for the domain of training. The Upper Ontology contains general purpose knowledge, vocabulary and relations, able to get a first basic overview of the content of a generic training sentence. Furthermore it defines also a common framework, which paves the way for the development of the more specific domain ontologies, which cover specific concepts of a well defined domain, e.g. a car ontology or an airplane ontology for instance, both from the components point of view and from the actions performed through them: they include in fact, concepts of technical parts, e.g. “lathe” or “spindle” as well as action verbs related to the parts. Domain ontologies, each for a specific domain, can be seen analogously to plug-and-play components, which offer more functionalities (knowledge) once connected to the main device (upper ontology) and once the communication language, defined by the framework is shared.

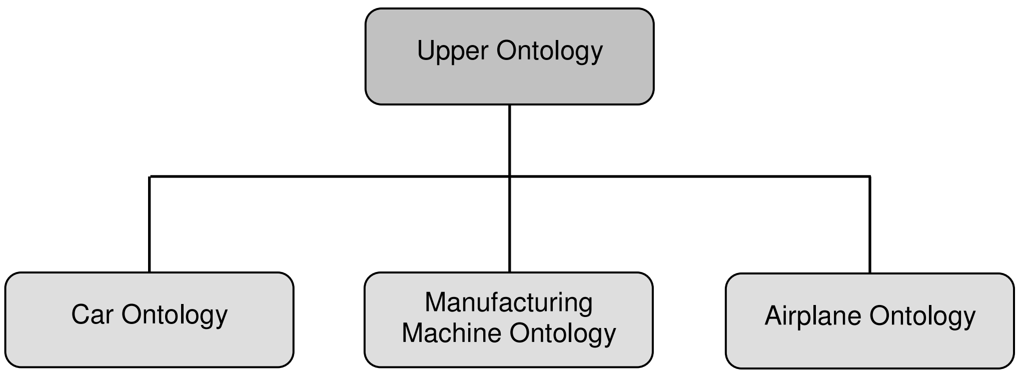

Figure 5-2: Upper Ontology and Domain Ontologies

The next sections define how the ontology core is structured and subdivided: at first, the upper ontology is introduced, together with its characteristics and its main purposes. Then, the structure of a generic domain ontology and its components are presented.

5.2.1 Upper Ontology

An upper ontology contains a basic understanding of domain-independent concepts and relations, necessary to deal with parts of training sequences that do not belong to a specific problem domain.

Its knowledge is defined through a network structure, made up of four basic elements, shown in the table 5-1: they include the “class” and “individual” concepts, already introduced in chapter 4, the “attribute” property and the relations between the elements, i.e. “IsA” or “PartOf”, which do not need to be defined through additional concepts.

Table 5-1: Basic elements of the upper ontology

Concept	***Description***
Class	Union of classes or individuals that share the same characteristics.
Attribute	Characterization of a concept through attributes that have a name and value.
Individual	Single entity, instance of a higher level class.
Relation	Relation between concepts through attributes or functions.

The basic elements defined above characterize all other concepts contained in the upper ontology as well as in eventual domain ontologies: thus, a concept like “Device” can be described by

- an upper class, e.g. “Artifact”
- a set of lower classes, e.g. “Machine”, “TransportationDevice” or “EngineeringComponent”,
- attributes, e.g. “Date”, “Number”, “Time”, “Property”
- relations, e.g. “hasPurpose”, “connects”, “refers to”.

Individual or instances represent the single elements of the population, i.e. the leaves of the hierarchical tree that refer to a class: a feasible instance of “Device” can be represented by the “Computer” or “Shaver” concepts.

Another characterization of concepts describing common elements is obtained by the additional classes “physical” and “abstract”, necessary in order to filter elements, represented through the corresponding 3D models from abstract concepts, which cannot be visualized but can be described through textual or visual information.

Dealing with natural language, an extremely important knowledge domain that the upper ontology must embed is represented by the various verb forms, which can be found in a generic sentence: identifying that the verb forms "removes" or "removed" refer to "removing" is essential for the feasibility of the proposed approach.

It is also an advantage including in the upper ontology notions of "commonsense" knowledge. With "commonsense" is usually denoted knowledge shared by human beings and deriving from every day's experience. This comprehends common verbs ("opening", "removing") and words ("device", "car") as well as their relations (a car has a Chassis, an Engine, a Dashboard, etc.).

Another feature of the upper ontology is the definition of a common framework for the development of domain ontologies and establishes a way to describe concepts recursively, linking sub-concepts to higher level ones, through the language used[33], e.g. OWL [DS04-ol], KIF or CycL, to enter knowledge.

The upper ontology, with a wide knowledge in different domains, represents a good starting point but it is not able to catch all the meanings included in a generic training session. It is difficult finding in a general ontology, very specific concepts like "Lathe" or "Fuselage", "Finishing" or "Assembling". For more detailed concepts that are not included in the upper ontology the development of one or multiple domain ontologies is required.

5.2.2 Domain Ontology

Ontology represents a conceptualization of the target world; this is valid not only for the representation of generic macro concepts, like "device" or "opening", but also for the modeling of more specific concepts within a defined subdomain. In order to have a full coverage of the training domain, the use of one or more domain ontologies is necessary.

In the proposed approach, a generic domain ontology is thought to be composed by two different knowledge sub-domains:

- "part ontology", specifying technical parts through a hierarchy of classes and relations between them;
- "action ontology", comprehending the conceptualization of a series of actions executed in a real training environment.

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[33] An Ontology language is usually first order predicate calculus, also referred to as first order logic (FOL); it is a system of deduction that extends propositional logic by the ability to express relations between individuals more generally.

Part ontology constitutes the domain of nouns, included in generic training sessions; it specifies technical parts, target of training sessions, and their relations not defined in the upper ontology. Aim of the part ontology is to allow the identification of technical parts and their eventual representation in the 3D animation.

Action ontology represents the domain of the verbs, as well as past participles, which characterize the actions included in training sessions; aim of the action ontology is to transform natural language actions into a formal representation for the animation of the virtual objects. In addition, the action ontology is able to characterize different actions for the same verb according to the target objects they refer to.

5.2.2.1 Domain Ontology Development

While for the upper ontology the use of an already existing one is reasonable, since it must embed a wide knowledge and be shared by the community, the domain ontology must be developed “ad hoc”; once defined the domain of the training, the domain ontology can be populated by concepts that can be found in existing training material, like an instruction manual. In order to develop the domain ontology, the following sequence of tasks has to be executed:

- Definition of classes and their hierarchy
- Definition of attributes
- Definition of the relations between concepts
- Populating classes with individuals

The first step is the definition of **classes** for the target concepts and their hierarchy. Main strategies, used in the proposed approach, for this task are:

- Top-down, starting with the definition of the most general concepts and eventually their specializations: e.g. MechanicalDevice > DrillingMachine > DrillPress.
- Bottom-up, starting with the definition of the most specific classes and eventually grouping them in subclasses: e.g. DrillPress > DrillingMachine > MechanicalDevice
- A combination of the previous ones, starting with one high level concept, like MechanicalDevice, and a specific one, like DrillPress, and then defining the class in the middle, e.g. DrillingMachine.

The defined classes need to be ordered in a hierarchical form in order to build the taxonomy, which is an essential part of every ontology. In addition, this guarantees an easier further development or reuse of the ontology.

In order to avoid the creation of duplicates and eventual misunderstandings, just the concepts, which are not exhaustively defined in the upper ontology, should be created. This process is therefore heavily dependent on the chosen existing upper ontology and on the knowledge it embeds.

Having defined the necessary classes and their hierarchy, some **attributes** need to be entered to characterize each class. An attribute is made up of a name (e.g. number-of-wings) and a value (in the considered case exactly two for an airplane). If attributes are not defined, than it is no more possible speaking about ontology but just about taxonomy (see figure 5-3); when an attribute has been defined for a class, it remains valid also for all the subclasses.

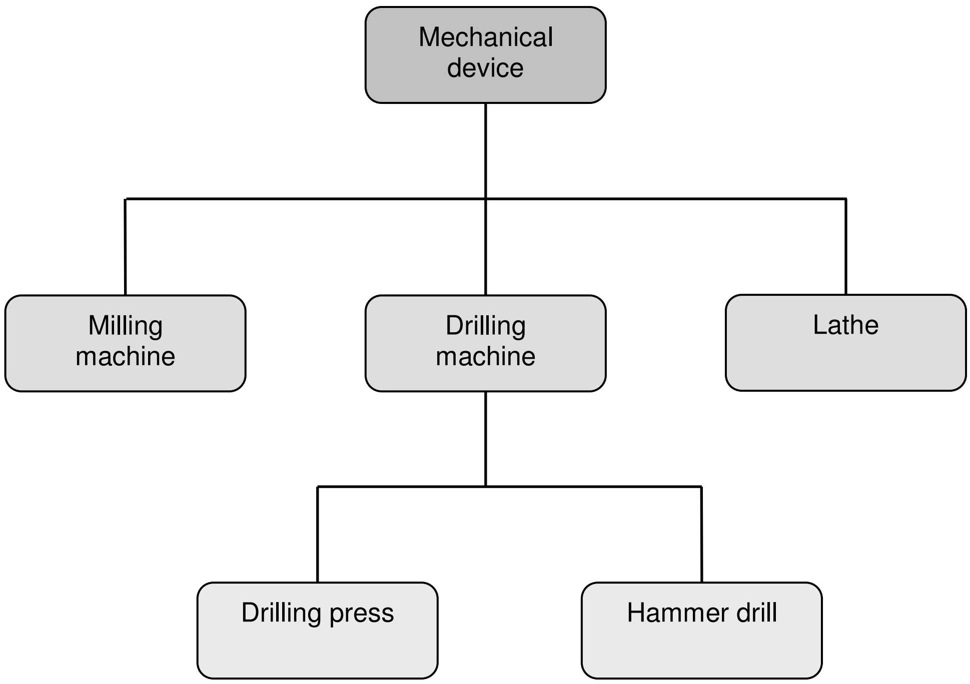


Figure 5-3: Extract of a mechanical device taxonomy

A fundamental role is also played by **relations**, representing the links that connect classes together. A detailed description of the proposed relations, in addition to the ones defined in the upper ontology, is given in the following sections. They derive from a selection of the relation-types used in the ConceptNet project.

The elements representing the leafs of the ontology hierarchy are the **individuals**, also known as instances: they include physical objects as well as abstract concepts included in a class of the target domain. For example, the "car" concept can be considered as a class, which can also have different car brands, like "Mercedes" or "Porsche" as subclasses; on the other hand, single car models "SLR" or "911" are instances of the respective car brands classes.

5.2.2.2 Part Ontology

Part Ontology constitutes a portion of the domain ontology and represents the domain of nouns standing for technical parts, which can be found in a generic training sequence. It is therefore necessary to model technical parts of the considered training domain through a number of classes, representing their characteristics, subconcepts, as well as through their properties, like connections to other parts, functions and allowed movements.

Analogously to the strategy followed for the definition of classes, part concepts can be defined using a combination of a bottom-up approach for the definition of higher level concepts starting from micro entities, and a top-down approach for the specification of concepts starting from macro entities. The difference is in the definition of the part ontology resides in the product structure, which is usually not part of the ontology itself: part concepts are modeled using different classes and builds up a product structure, rather be refined just through upper and lower level sub-concepts.

In the top-down approach (see figure 5-4), for example, a macro entity, like "manufacturing machine", will be composed by the classes "mechanical part", "electrical part", "fluid" and "structural part", which are not specifications of the "manufacturing machine" concept; thus, a higher level concept is defined through lower level concepts in the hierarchy. This strategy is followed just for modeling the main concept through the immediate sub-concepts it includes.

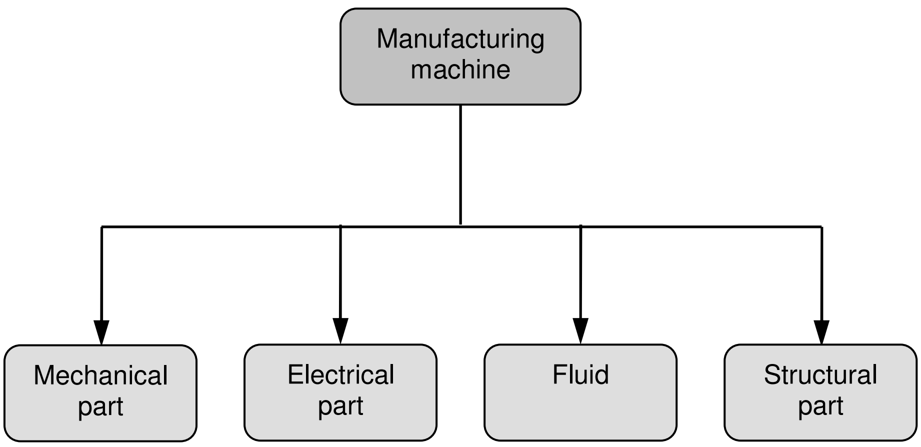


Figure 5-4: Top down approach

On the other hand, in the bottom-up approach (see figure 5-5), concepts of smaller parts, like “Motor”, “Motor Gear” and “Motor connecting Flange”, can be considered as “atomic”: they can be seen as atoms, building up a higher level concept. Their association, together with other basic concepts, like “Fastener”, builds up a higher level concept, like “Motor Group”.

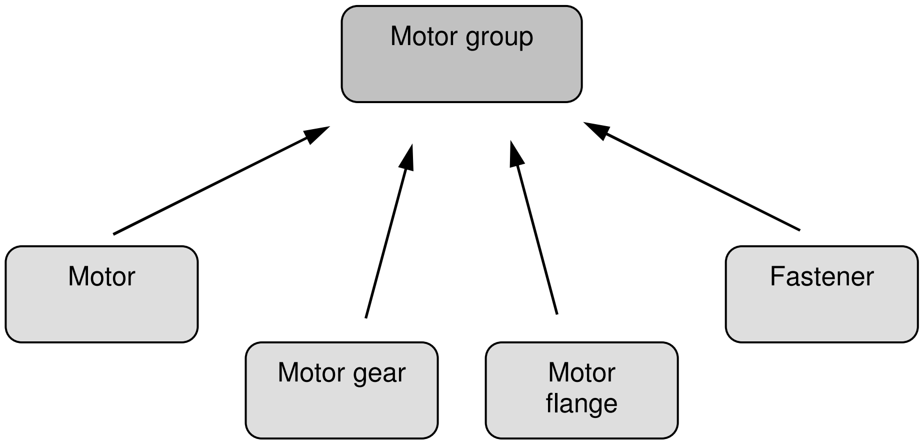


Figure 5-5: Bottom-up approach

The approach followed for the definition of the concepts automatically builds up a hierarchy of the concepts: the main concept can be found on the top of the hierarchy tree, while the connected components are one step down. The leaves of the hierarchy tree are represented by the instances of the components.

Concepts populating part ontology are further specified not only by means of sub-concepts but also by relations, which can regard different levels of knowledge: on a conceptual level, on a spatial level and on a functional level. The used relations on the conceptual level, including a brief description, are shown in the table 5-2.

Table 5-2: Relations on conceptual level

Level	***Relation***	***Description***
Conceptual	Conceptually-RelatedTo	A link to other concepts, to whom the concept refers to
	DefinedAs	Formal or informal explanation of the concept
	IsA	Abstraction of the concept through its upper classes
	partOf	Part-whole relation

While “IsA” and “PartOf” represent the already introduced hyperonymy and meronomy relations, the “ConceptuallyRelatedTo” is a very important and powerful link between concepts, which are not directly connected. For example, the part ontology concept “button” can be thought as conceptually related to the concept “pushing”, even if included in the action ontology. This paves the way to a more intelligent management of the objects and their corresponding actions. The “DefinedAs” relation supplies additional information about the concept and can be used in case of multiple meanings or for disambiguation purposes.

Parallel to the definition at a conceptual level, parts must be also characterized at a spatial level (see table 5-3), in order to characterize the physical aspects of every defined part. In addition, parts can also be characterized by their functionalities; what can be done with that part? Or, which actions the part is able to receive?

Table 5-3: Spatial and functional relations

Level	**Relation**	**Description**
Spatial	LocatedIn	Location of the part inside higher level concepts
	ConnectedTo	Eventual connection to other parts
	HasDimension	Dimensions of the part
	AllowedMovement	Allowed movements for the part
Functional	UsedFor	Action that can be done through or with the part
	CapableOf-ReceivingAction	Action that can be received by the part

An example can help to better understand the introduced relations: on a conceptual level the concept “drill” is described by the “IsA” relation as a “mechanical device”, can be “DefinedAs” “a tool used for boring holes in objects by means of a rotating sharp-edged cylindrical bit” and can be therefore connected to the “boring”, “hole” and “drill bit” concepts by the ConceptuallyRelatedTo relation. In this case the main concept is the “drill” itself so no “part of” relation is defined. On the functional level, the concept is connected by the “UsedFor” relation to the concepts “boring” and “drilling” among other actions and also to the concepts “holding”, “grasping” or “gripping” by “CapableOf-ReceivingAction”. To conclude the example, the “drill” has some dimensions “length”, “width” and “depth” to be derived by the instance of the concept and allows a “three dimensional movement”; differently the “drill bit” concept allows the “translation on z axis”, considering the z axis coincident with the axis of the bit itself.

The actions specified in the functional relations establish also a link to the action ontology, where each action concept is refined through a series of transformations, which constitute the basis for the further representation of the action in the virtual scene.

5.2.2.3 Action Ontology

Action ontology is required to describe action verbs, comprehending training or maintenance tasks, which are partially defined or not defined at all in the upper ontology.

Verbs are grouped in classes, in their “–ing” form, e.g. “removing” for “remove”. The nature of each verb can be essentially of two kinds: physical or abstract. A verb can be defined as “physical” if it implies a movement of the object, which receives the action, or a change in its state: the verb “connect”, for instance, refers to the connection of one object with another one. On the other hand, a verb is abstract when the action is performed without changing the state of the target object: the verb “locate” implies that the subject looks for an object, without touching, moving and therefore interacting with it. Each verb can be therefore subdivided into the abstract and physical subclasses, according to its nature.

Physical verbs can be further subdivided in three sub-classes (see figure 5-6) according to the kind of action performed. Verbs where the action regards just one entity, human or object, without any interaction with other entities, are grouped into the “pure action verbs”: this is the typical situation of autonomous movement, like a man walking or a box opening automatically. Such verbs play a marginal role in training situations, but the class has been included for completeness of the physical verb domain. Much more frequent is the case of interaction of the subject, usually human, with an inanimate object, like “turning on a machine” or “substituting a damaged part”. The “action on object” class does not contain verbs, like “locate” or “examine”, which even if referring to an object, do not directly interact with it. The same action can sometimes be more specific and require a third “actor”, indicated usually through a preposition, like “with” or “through”: it is the case of operations, which can be done just with a tool, like cleaning a sensor with a cloth or tightening bolts with a wrench.

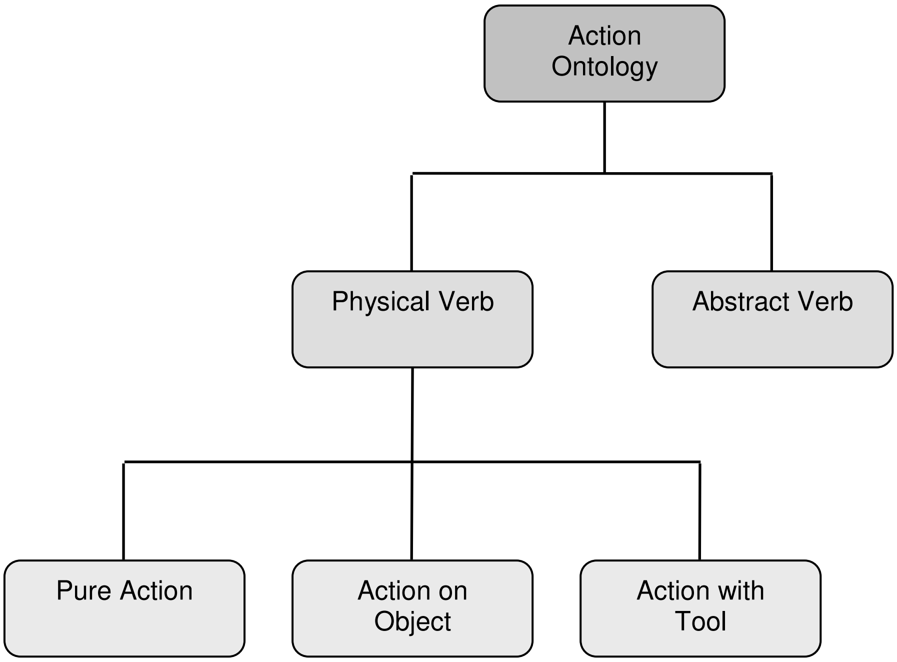


Figure 5-6: Taxonomy of the Action Ontology

This further specification of physical verbs is necessary to distinguish different kinds of action that are to be represented in the animation: to "Pure Action" verbs correspond to simple transformations or movements of an element, for "Action on Object" verbs the virtual camera must be close to the related object, while the additional recalling of external 3D model of the tool is necessary for "Action with tool" verbs.

Abstract verbs represent for their own nature something that cannot be visualized through actions: for example, the verb "locate" or "search" do not add any additional information on the performed action, which remains basically a visual search. However, they can cover important roles in the definition of a generic training sentence. The class includes also static verbs, for example the verb "to be" in "the pen is on the table", which indicate position of the objects in the virtual environment.

Each verb is characterized by a set of relations, defined in table 5-4, which derive from the ConceptNet research approach. They describe similar actions associated to the concept through the "KindOf" relation as well as the contrary of the action itself, through the "HasContrary"; this feature allows the connection of the action concept to its contrary, to be used for example in assembly and disassembly tasks. The relations "HasDomain" and "HasRange" describe respectively the roles able to perform that action and the range of concepts target of the action itself. The relation "duration" represents a critical point, also for the representation of the action in the virtual environment; it influences in fact the speed of the action, which must be as close as possible to the real duration of the action

Table 5-4: Action Ontology Relations

Relation	Description	Value/Range
KindOf	Definition of similar actions through upper class	Verb
HasDomain	Allowed role user that performs the action	Role
HasContrary	Antonym of the considered concept	Verb
HasRange	Allowed objects that are target of the action	Object
LocationOf	Eventual location for the happening of the action	Place
EffectOf	Effects of the action	Movement
MotivationOf	Cause for the action to take place	Task
Duration	Estimated time for the completion of the action	Time

The relations defined in the table above establish a link between ontology and the formal description of the animation: each verb can be coupled through the "EffectOf" relation to one of the following specific commands, together with their necessary parameters:

- Movein/Moveout: translation, respectively approaching or leaving the target object, on a specified axis for a length
- Be: spatial position of a point or an object
- Rotate: rotation on the specified axis and for a determined angle
- Scale: scaling factor for the target object

Those commands represent the results of the translation of a natural language action into the corresponding formal description.

5.2.2.4 Spatial Prepositions

A locative expression is an expression involving a locative prepositional phrase together with whatever the phrase modifies (noun, clause, etc.). The simplest type of locative expression is composed of three constituents: the spatial preposition and two noun-phrases. For example, in "the button on the control panel", the button is the subject of the preposition, and the control panel is the object. The subject refers to the located entity, the object to the reference entity. Some locative expressions use a clause as subject of the preposition.

Spatial prepositions fall into two categories: some are primarily static (e.g. at, in, under), others primarily dynamic (to, from, via). But static prepositions can be used in dynamic contexts, like in “the cat ran under the bed”, and dynamic can be used in static contexts, like in “the lamp is two feet from the wall”. The proposed approach considers just the basic topological prepositions (at, on, in), together with their corresponding set of triples, including the prepositions used in the approaching or leaving the target region [Her86]:

- Point: to, at, from
- Surface: on to, on, off
- Volume: into, in, out of

Path prepositions like “through”, “across”, “around” or “along” are not considered in this research approach but can be integrated in a further development.

According to the defined kinds of spatial prepositions, the action ontology is able to match the transformations defined in table 5-5, according to the kind of preposition and to the related action or static verb.

Table 5-5: Spatial prepositions

Preposition	Kind	Conditions	Related to	Transformation
To	Point	Action Verb	MOVEIN	$(x, y, z) \rightarrow (x_0, y_0, z_0)$
At		Static Verb	BE	$(x, y, z) \equiv (x_0, y_0, z_0)$
From		Action Verb	MOVEOUT	$(x_0, y_0, z_0) \rightarrow (x, y, z)$
On to	Surface	Action Verb	MOVEIN	$(x, y, z) \rightarrow (x_0, y_0, z_0)$
On		Static Verb	BE	$(x, y, z) \equiv (x_0, y_0, z_0)$
Off		Action Verb	MOVEOUT	$(x_0, y_0, z_0) \rightarrow (x, y, z)$
Into	Volume	Action Verb	MOVEIN	$(x, y, z) \rightarrow (x_0, y_0, z_0)$
In		Static Verb	BE	$(x, y, z) \equiv (x_0, y_0, z_0)$
Out of		Action Verb	MOVEOUT	$(x_0, y_0, z_0) \rightarrow (x, y, z)$

Spatial prepositions are then able to connect static verbs to a well defined position of the related object in the virtual environment. On the other hand, they are able to define also a kind of motion, defined as Movein or Moveout, respectively for approaching or leaving the reference object.

5.2.2.5 Events

So far technical parts and actions have been considered separately in two different ontologies in order to guarantee the advantages deriving by the ontology approach, like knowledge adding, sharing and reuse. However, additional benefits can derive from joining concepts of both ontologies in the definition of small knowledge portions that are able to represent sequences of operations.

The combination of the part and action ontologies within a common domain ontology allows in fact the management of events: an event can be defined as a generic task, e.g. “tire change”, made up of a sequence of subtasks or sub events, necessary to fulfill the main task. Sub events can be then recursively defined as “atomic” actions, which can be also reused for different domains or combined together in arbitrary sequences. To achieve this result, another series of relations regarding events and sub events is introduced:

- FirstSubeventOf
- SubeventOf
- LastSubeventOf
- PrerequisiteEventOf

For example, the procedure for the “tire change” event in a car can be entered in the “car” domain ontology, though a sequence of sub events, like in the following example:

1. “Loosen” AND “lug nuts” (FirstSubeventOf TireChange)
2. “Remove” AND “lug nuts” (SubeventOf TireChange)
3. “Pull” AND “the tire” AND “off the car” (SubeventOf TireChange)
4. “Place” AND “the spare” AND “on the car” (SubeventOf Tire Change)
5. “Put on” AND “lug nuts” (LastSubeventOf Tire Change)

However, some events were not possible unless some prerequisites are satisfied. In the situation mentioned above, they correspond to:

- “Stop” AND “the car” (PrerequisiteEventOf Tire Change)

- “Set” AND “the parking brake” (PrerequisiteEventOf Tire Change)
- “Lift” AND “the vehicle” AND “off the ground” (PrerequisiteEventOf Tire Change)

Recursively also prerequisite events, like the “auto lifting”, can be described through a sequence of sub events.

Events and sub events, as well as any sequence between them, are included in a part of the domain ontology, separated and independent from the part and action ontologies. This allows the management of task sequences, which otherwise could be very difficult just considering the part and action ontologies.

5.2.2.6 Roles

Together with the definition of events, an additional and important category to be introduced in the domain ontology is represented by the end user roles, target of the training sessions for that specific domain. The proposed approach is able to manage, through the ontology, different end user roles, the most common of which are:

- Maintenance staff
- Operation workers
- Assembly workers
- Salesman

Every defined role needs a different kind of information, even regarding the same target product. For example, maintenance staff requires very detailed information about the whole target object, like the location of electric cables in a machine, which are not needed by other roles. This requirement is managed by coupling to each role, different levels of detail of the target object within the virtual scene: according to the considered role, some layers of the 3D model containing elements of a specific knowledge domain (circuits, pipes, etc.) can in fact be set visible or invisible and at the same time the management of the virtual camera can display an overall or close view of the training object.

The role of the end user within the training session can also be inferred from the training sequence itself since concepts can be linked to roles through the hasDomain relation in the action ontology.

5.3 Overview of the developed Method

The basic idea for the proposed research approach is the use of ontology in order to understand natural language training sessions and to translate it into the corresponding animation; the ontology core is made up of an existing upper ontology, as a first high level knowledge base, which acts also as a common framework, and one or multiple domain ontologies, which represent through parts and actions, the target world of a generic training scenario.

In order to provide a homogeneous method, which is able to satisfy all the requirements for the intelligent authoring of 3D animations for training purposes, a process model has been developed. It is represented in figure 5-7 as a Phase/Milestone diagram: to each phase or milestone are associated some tasks to be executed in order to obtain the corresponding results, shown on the right.

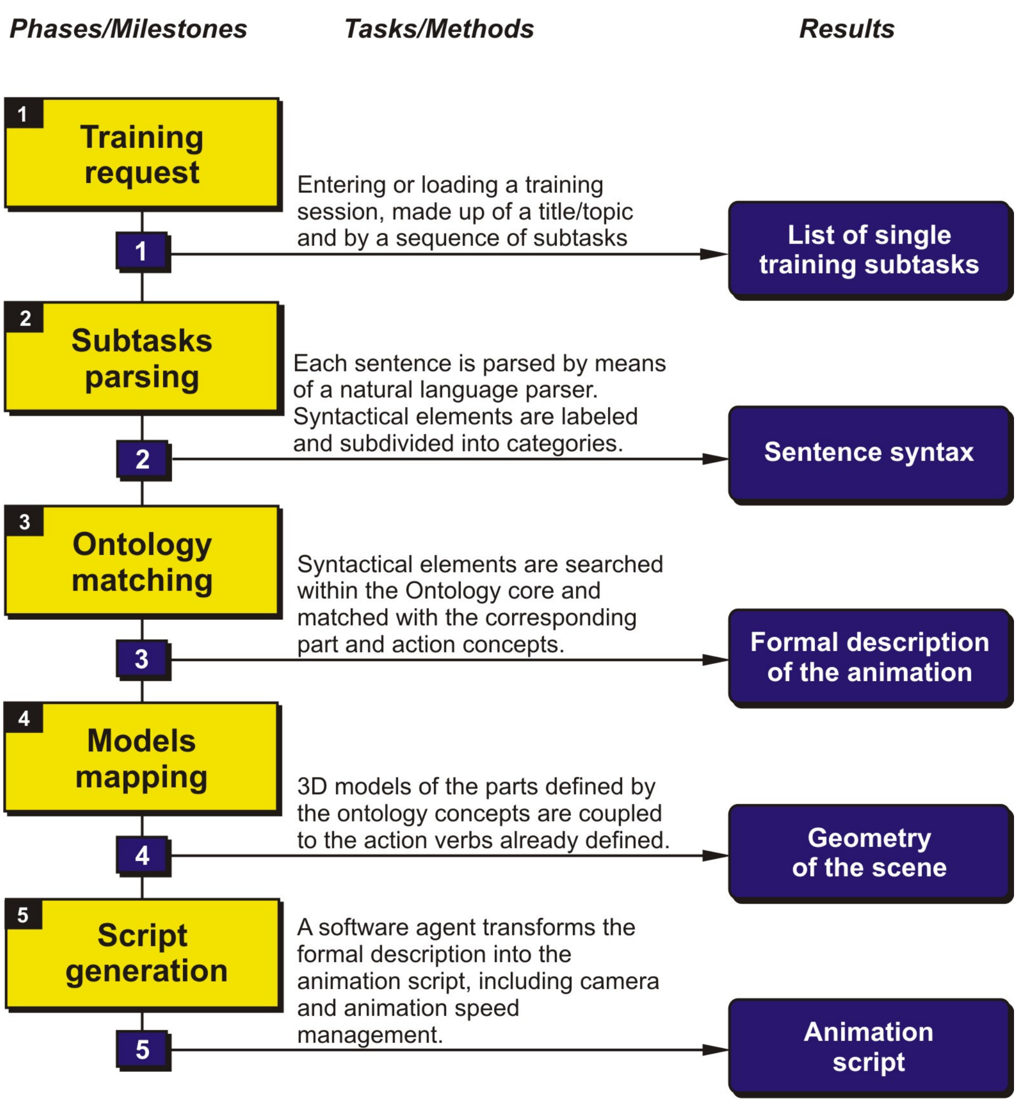


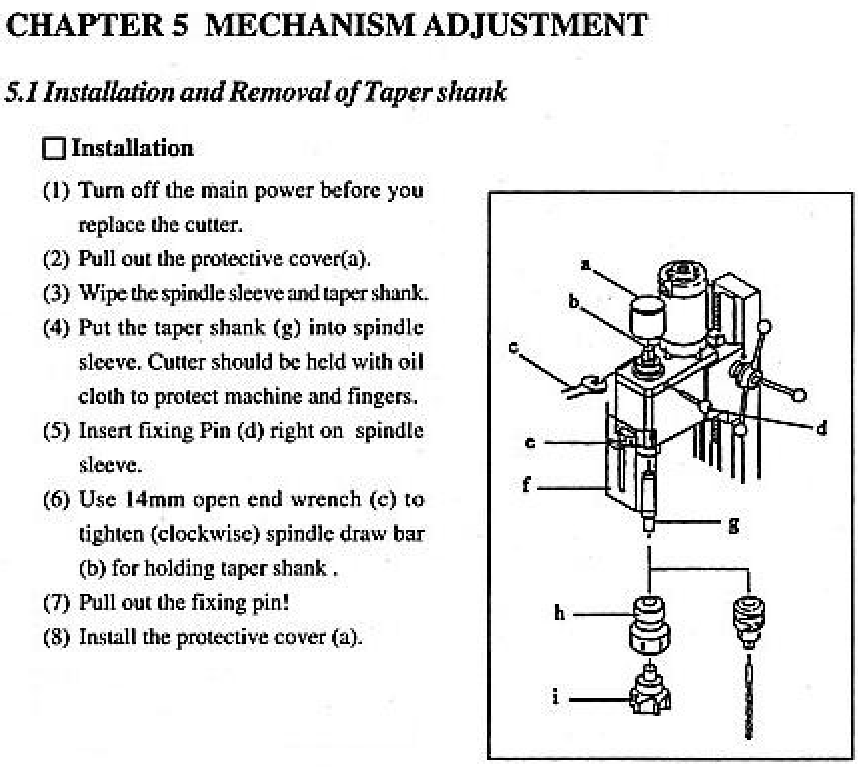
Figure 5-7: Developed Process Model

The proposed method consists of five phases, starting with a generic training request, which has to be entered in a text form by the customer or by the end user. Once entered, this input is at first parsed, labeled and eventually matched to the concepts defined in the ontology core.

The process model output is a script, a text description of the content that acts as a "screenplay" of the animation and that can be visualized through the use of the appropriate viewer. The next sections give a detailed description of each phase building up the process.

5.4 Phase 1: Training Request

Before starting the authoring of a general 3D animation, a 3D artist in a traditional approach needs to understand the topic of the animation itself: which 3D models are involved, where they are placed, which actions are taking place and which relations between them, i.e. sequence or duration of the tasks, must be observed. Usually this preliminary analysis is done in cooperation with specialized technical staff, which supports the authoring process with the necessary technical knowledge of the considered domain.



CHAPTER 5 MECHANISM ADJUSTMENT

5.1 Installation and Removal of Taper shank

☐ **Installation**

(1) Turn off the main power before you replace the cutter.
(2) Pull out the protective cover(a).
(3) Wipe the spindle sleeve and taper shank.
(4) Put the taper shank (g) into spindle sleeve. Cutter should be held with oil cloth to protect machine and fingers.
(5) Insert fixing Pin (d) right on spindle sleeve.
(6) Use 14mm open end wrench (c) to tighten (clockwise) spindle draw bar (b) for holding taper shank .
(7) Pull out the fixing pin!
(8) Install the protective cover (a).

Figure 5-8: Extract from a generic instruction manual

Paper-based documentations, like instruction manuals (see figure 5-8) or assembly procedures, contain a detailed description of maintenance, assembly or operation tasks to train non-specialized people, which have not enough confidence with the involved parts. They represent 3D objects in a static two-dimensional way; thus, it is not immediate to visualize neither which is the correct part involved nor how they interact between them.

The approach of every instruction manual can be considered as "task centered": the topic of the task is introduced by the title itself, and then a list of subtasks, to be executed in a given sequence, explains in detail the subtasks to be executed. Analogously, the approach followed in the developed method uses a title for the identification of the topic and a sequence of the single steps, building up the training session. Two main scenarios can be reasonably foreseen for the training animation authoring:

- A sequence of subtasks building up the training content is already available, e.g. an instruction manual, paper-based training material
- No content is available and the training sequence must be created from scratch, entering a main topic title and the corresponding list of tasks

In the first scenario, the file containing the sequence is passed as it is to the following step of the method, the natural language parsing, for the identification of the structure and of the syntax of each sentence. In case no existing material is available, the desired training sequence must be created "ad hoc" from scratch. This can be done as described in the next sections in a text form, with the definition of a title, which corresponds to the main topic of the training session, followed by the sequence of single subtasks.

5.4.1 Topic of the Training Request

The first content to be provided could seem at first very trivial but it is at the same time very important since it delimitates the training knowledge about the considered domain. The title of the training request must be very specific and contain accurate information about the target, to avoid possible misunderstandings, which are very common in natural language descriptions. Titles like "machine installation" or "car maintenance" are too vague, thus unable to allow the identification of well-defined tasks. Furthermore they could not assure, for obvious reasons, the reusability of the overall approach.

The necessary content for a well defined and exhausting training request's title is defined by the following elements:

- Action
- Main concept
- Main instance

Action regards the kind of operation to be performed and is represented by a keyword, like “removal” or “assembly”, or by the corresponding action verb, like “remove” or “removing”.

Main concept represents a generic high level concept, which is the target object of the training and is composed by multiple atomic concepts. **Atomic concept** is here meant in an analogous way to what is defined in the Description Logics (DL)[34]; it represents a lower level object of the action and can be seen as a class of the ontology, which does not need any additional concept for its definition. For the training topic case, the hierarchy level of the main concept (see figure 5-9) must be higher than the hierarchy levels of the other atomic concepts or classes contained in the single steps.

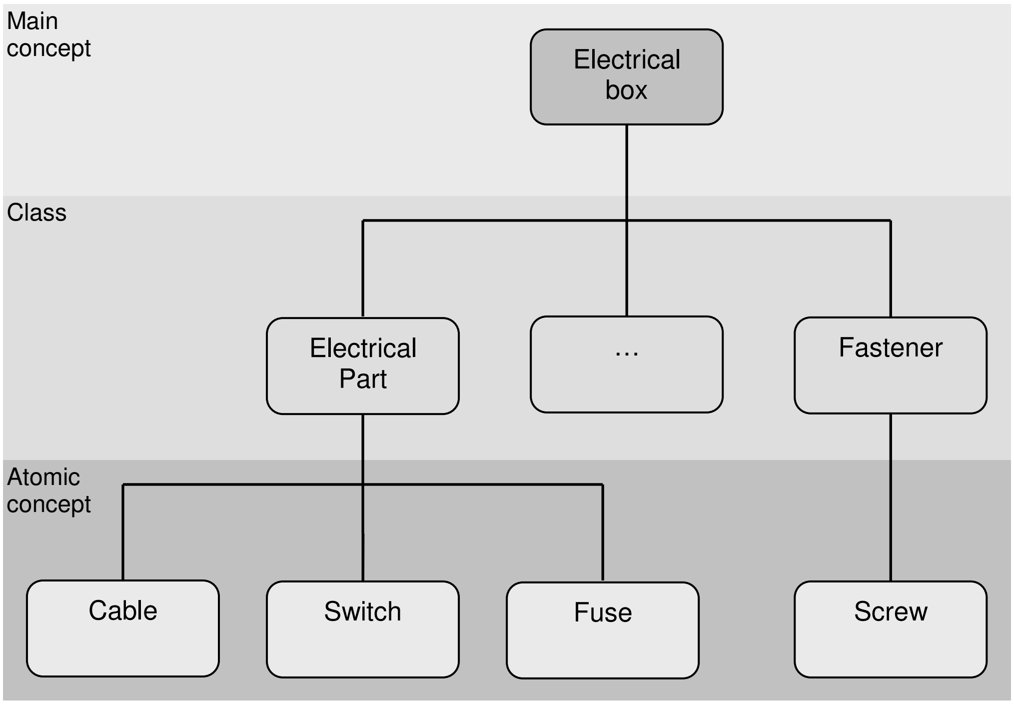


Figure 5-9: Ontology hierarchy

For example, it would be a non-sense creating a training animation with “removal of a screw” in a mechanical device as a topic, since the screw represents a lower level concept; the removal of a screw can rather represent one of the tasks in a sequence. It makes more sense defining a sequence for the removal of a part, e.g. “electrical box”, which is represented by a concept hierarchically higher than a screw. At the same time, in the topic must be avoided the use of

[34] Description logics (DL) are a family of knowledge representation languages, which are used to represent the terminological knowledge of an application domain in a structured and formal way

concepts, which are positioned in a level higher than the target one. If the atomic concept is represented in the topic by the object "drill bit", then it would be wrong referring just to the higher concept "drill".

Main instance adds complementary information, necessary to unambiguously identify the target of the training; it denotes the "conceptual" location, rather than its pure position, by specifying the instance, and not the class, of the training object. For example, the "Tire change for a car" topic specifies nothing about the kind of the considered car: is it a SUV[35] or a city car? A Mercedes or a Porsche? Those are still classes but the car models are instances of the car brand class. No ambiguity is possible if the instance is specified, like in case of the topic "Tire change for a Porsche 911"; the specification of the instance automatically defines the class to which it refers.

The definition within the training request title of the **role** of the user, to which the training refers, remains optional since it can be inferred by the context.

5.4.2 Content of the Training Request

A training session can be structured through, a series of subtasks or **atomic sequences**, which correspond for the purposes of this book to the micro animations introduced in chapter 2: they can be defined as single operations atoms, to which a well defined animation atom can be coupled.

The content of a training request is represented by a sequence of basic subtasks, whose structure is very close to the one considered for the title content. Every sentence, representing the subtask, needs to contain the essential information, in the usual "triple" format:

- Subject
- Predicate
- Object

In practice, like in instruction manuals, sentences are mostly expressed in the imperative form, which in English corresponds to the infinitive, thus letting the subject omitted. This reduces the normal sentence to a "couple" of elements, which represent then the minimal requirements for a sentence:

- Action verb
- Target object

---

35 A Sport Utility Vehicle (SUV) is an all-road vehicle, which combines towing capability of a pick-up with passenger-carrying space

It is also reasonable assuming that a single subtask can comprehend multiple objects associated to a single verb, e.g. “remove nut and bolt”; this possibility is foreseen and allowed by the method, since the content of each sentence is eventually analyzed by a lexical parser as well as by the ontology for matching, where each verb is associated with one object at a time.

A sentence can also be enriched by additional elements that are used to specify the target environment and to avoid misunderstanding. One category is represented by the **adverbials**, which give additional information about the environmental conditions, where the action takes place:

- Locative (where, in a place, location)
- Direction (to, toward, from)
- Temporal (when, at what time)
- Duration (for how long)
- Manner (how, in which manner)

Another category is represented by the **adjectives**, together with past participles, which are able to characterize nouns by specifying some properties, the most important among them being:

- Shape (flat, round, square, triangular, etc.)
- Size (big, little, large, long, short, wide, etc.)
- Speed (fast, rapid, slow, etc.)
- Appearance (clean, dirty, red, white, etc.)
- Condition (broken, damaged, difficult, open, wrong, etc.)

However, adverbials and adjectives represent elements that are very difficult to include in a 3D animation, as shown later on with their matching.

To conclude the definition of the elements that can be contained in a generic training request, an “ad hoc” training request example, regarding the “landing gear brake removal” in an airplane, is described as follows; the numbers in brackets refer to the parts shown in the technical drawing (see figure 5-10).

1. Remove the screw (13), clamps (14) and nut (21) from the torque link standoff bracket (18)
2. Remove the cotter pin (16), nuts (15), washers (17), bolts (20), standoff bracket (18) and switch bracket (19) from the upper torque link (2).

3. Remove the cotter pin (5), nut (4), washer (6) and bolt (10) from the torque links (2 and 7).
4. Remove the safety wire from each slotted spring pin (3).
5. Remove the spring pin (3) and link pin (1) from the upper (2) and lower (7) torque links.
6. Remove the upper (2) and lower (7) torque links from the strut and axle.
7. Inspect the strut, pins and torque link bushings for damage.

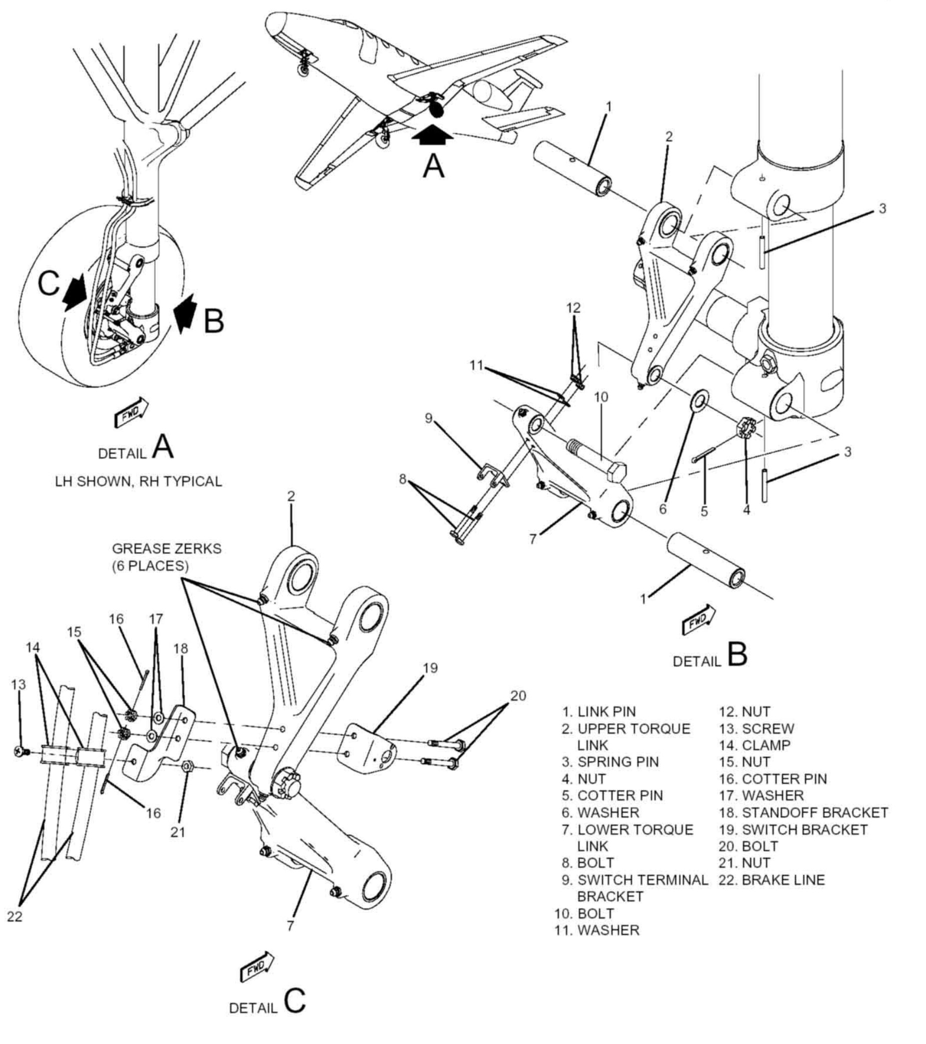


Figure 5-10: Technical drawing of an airplane [PA-ol]

Once the definition of the training request has been completed, each sentence, starting from the title of the sequence, is then sent to the natural language parser for syntax understanding.

5.5 Phase 2: Natural Language Parsing

Natural language sentences usually comprehend ambiguous meanings that are sometimes difficult to be understood by humans. People use their own experience and common sense to understand the real meaning of a generic sentence. However, the same task is extremely difficult for a computer, which can match single words with the ones stored in a database. A word or a verb sharing the same syntax can also have different meanings: for example, for the linguistic element “links”, once extracted from the original context, it is impossible, without additional information, to decide whether it refers to the plural of the word “link” or the third person of the verb “to link”.

State-of-the-art approaches in natural language parsing, as already shown in section 4.1.2, exploits probabilistic parsers to interpret sentences, according to maximum likelihood criteria. Therefore, the use of a probabilistic parser within the NLP phase enhances the power of the proposed approach, by reducing the possibility of error in the identification of synonyms. In this way, the parsed phrase, and in particular elements at a word level, which are subsequently passed to the ontology for matching, are labeled as the most likely ones. For the proposed approach, the natural language parser is considered as a black-box whose input and output are known but the processing is outside the scope of this book.

The natural language parsing phase has a double purpose:

- on a phrase level, it is necessary to understand the phrase structure by identifying different kinds of sub-phrases, like a verb phrase, a noun phrase or a prepositional phrase
- on a word level, it finds out the role covered by each word (noun, determiner, adjective, verb, etc.)

The result of this phase is the retrieval of the sentence in a structured form, where constituting elements are recognized and labeled, according to the corresponding function covered in the sentence.

5.5.1 Phrase Level

Each sentence contains at least two kinds of elements on a phrase level: a noun phrase and a verb phrase. Direct questions are not considered since their use in technical documentation for training purposes are not realistic.

- A **verb phrase** (VP) is headed by the main verb, thus including the core information of each sentence; it can also contain a noun phrase, as object of the verb.

- A **noun phrase** (NP) contains a noun or a pronoun, optionally accompanied by some modifiers; it can play the role of the subject or the object of the main sentence.

Other phrase levels, which can be present in a sentence, are:

- **Prepositional Phrase** (PP), composed by a preposition and a complement (e.g. on the table)
- **Adjective Phrase** (ADJP), headed by an adjective (e.g. full of liquid)
- **Adverb Phrase** (ADVP), consisting in a single or multiple adverb

The analysis on a phrase level is needed to subdivide the generic training sequence into simpler phrases: as shown in the “ad hoc” sequence, one sentence can be made up of multiple phrases, including multiple kinds of phrases. Between them the individuation of prepositional phrases is extremely important: prepositional phrases add additional information that must be directly connected to the main phrase.

5.5.2 Word Level

The phrase level analysis previously introduced gives an overview of the overall sentence through its overall structure but it does not give further information about the role played by each lexical element within the sub-phrases.

Within the word level analysis, different lexical entities (noun, verb, adjective or adverb) are identified and labeled by the natural language parser, according to the role played by each word. A common way to represent natural language parsing output is the use of a parse tree structure, where the sentence is divided at first into phrase level and eventually into word level. According to the training request, defined in the section 5.4.2, a sample parse tree for the first task is displayed in figure 5-11.

The aim of this phase is to improve the subsequent ontology matching phase by identifying on a lower level words and relations between them; this allows, for example, the management of multiple objects corresponding to a single verb, which would not be possible with just an analysis on a phrase level. In the example, screw, clamps and nut are recognized as nouns connected to the verb “remove”.

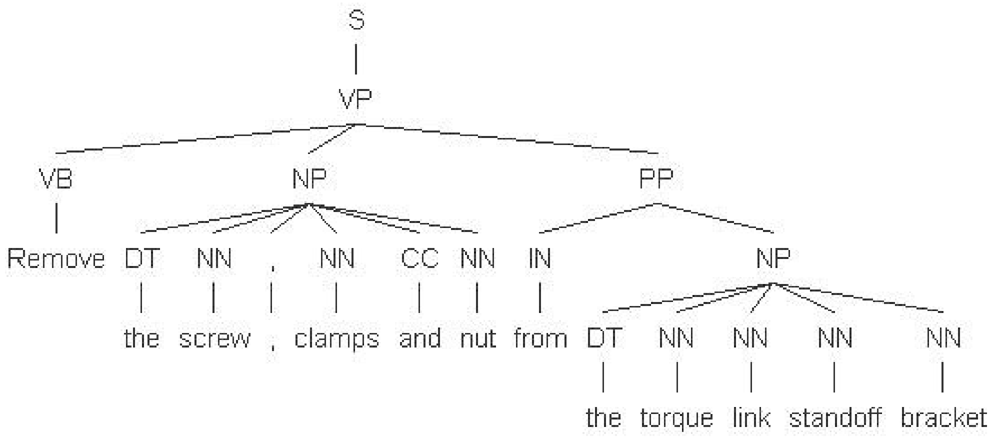


Figure 5-11: Parse tree of a sample training subtask

The result of this phase can be also summed up by means of a list, like the one described in table 5-6, where the elements are recognized and labeled from a syntactical point of view and ready to be matched to the corresponding concepts defined in the ontology. Each element can also be characterized by an ID code, composed by the phrase kind and the syntactic role of the entity; the final number of the code is an enumeration, used for the ontology matching.

Table 5-6: Result of the parsing

Phrase	**Role**	**Label**	**Word**	**ID**
VB	Verb	VB	Remove	VB1
NP	Object	NN	Screw	NPNN1
	Object	NN	Clamp	NPNN2
	Object	NN	Nut	NPNN3
PP	Preposition	IN	from	PPIN
	Object	NN	torque	PPNN1
	Object	NN	link	PPNN2
	Object	NN	standoff	PPNN3
	Object	NN	bracket	PPNN4

Determiners and conjunctions are filtered and not sent to the next phase since they do not supply any additional information to the sentence. On the contrary prepositions represent a very important element, whose matching in the ontology is necessary to include additional information, like motion or positioning, within the training animation

5.6 Phase 3: Ontology Matching

The ontology matching phase follows the natural language parsing and lets syntactical entities, previously recognized and labeled by the parser, being matched to concepts defined in the ontology core. According to the structure of a training sequence, the matching phase can be subdivided into two main parts: at first, the matching of the topic followed by the matching of each single subtask building up the training session.

In order to link the syntactical elements to the ontology concepts, the method performs the matching of subject, verb, one or multiple objects and eventual complements. The matching procedures, shown in the following sections, are to be intended just as a high level description, since the development of a matching procedure is outside the scope of this book.

The result of the matching phase is a formal description of the training task characterized by the involved entities, i.e. objects, and the actions performed on them or through them. This formal description is eventually sent to the script generator, which translates it into the corresponding scene graph, by adding the geometry of the 3D models and the necessary transformations.

5.6.1 Topic Matching

The first element to be matched is the title of the training sequence because it implicitly delimits the portion of domain knowledge that is involved in the training session: the topic contains information about the main action together with the main concept, whose elements are eventually involved within each training subtask. Topic matching is therefore extremely important for the matching of the subsequent subtasks. For example, it would be quite impossible matching correctly the concept “bolt” in a subtask, without having any additional information about the higher concept to whom it refers; in fact, if the title entered is “changing tire in a car”, the domain is then restricted to the “car” concept and eventually to the “tire” concept, thus making the identification of the involved “bolt” concept easier.

The topic matching is analogous to the subtask matching, which is described in the next session, since their structure is exactly the same. The difference is represented by a strategic factor: the matching of the main concept, and of its main instance if specified, contained in the topic not only individuates the eventually involved sub-parts but it allows identifying the 3D model for its use in the animation. Therefore, it constitutes the first step for the model mapping described in section 5-7.

Once the title of the training sequence has been matched with the corresponding concepts, each sentence of the training session, i.e. each subtask, is sequentially matched with the elements defined in the domain ontology.

5.6.2 Subtask Matching

The subtask matching process as well as the topic matching follows the usual sequence of the triple: subject, verb, and object. At first the subject or the end user role if present, is matched; then the verb, followed by the corresponding one or multiple objects, complete the matching of a generic sentence.

5.6.2.1 Subject

The first entity to be processed, following the structure of a normal phrase, is the subject. It can represent the user role, in case of a human performing the action, or the main object, in case of technical parts.

Training sentences usually refer to a generic user by means of the imperative form, thus letting subject implied. In this case the procedure is able to deduct from the context defined by the verb and the related objects, the corresponding role that constitutes the actor of the training sentence. This result is achieved exploiting relations defined in the action ontology: each verb is in fact characterized by the "hasDomain" relation, which specifies the role performing the action.

If the subject of the action is represented by a technical part, the matching procedure is analogous to the one regarding an object and is described in section 5.6.2.3.

5.6.2.2 Verb

While the subject of a sentence can be implied, the verb represents the core element of a sentence and cannot be implied. However, the verb alone cannot give enough information about the action, unless the related objects are specified; for this reason the matching of the verb is strictly connected to the one regarding objects.

The matching phase for the verb is achieved through the combined use of:

- Syntax matching
- "KindOf" relation

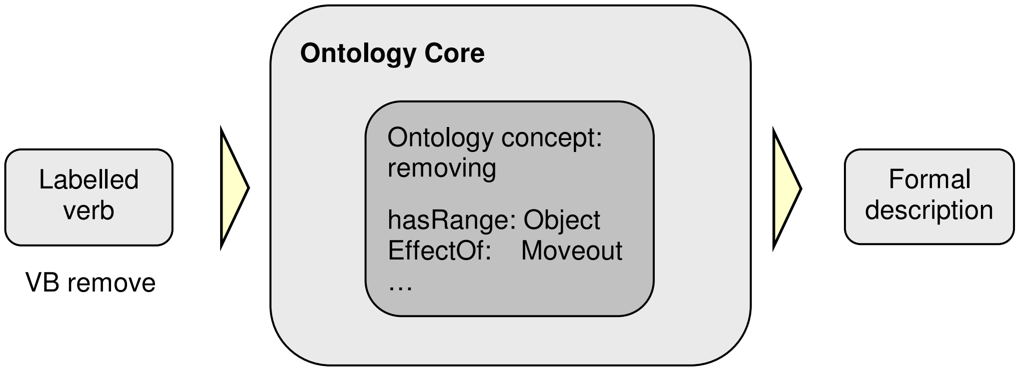


Figure 5-12: Verb matching through syntax

An initial identification of the verb concept within the ontology can be obtained through its syntax (see figure 5-12). The labeled verb entity coming from the natural language parser is matched to the concept, already defined in the ontology, which shares the same syntax; for example the label verb "remove" is associated to the "removing" concept. Even if the verb can be found and labeled in different verb forms, like present, infinite, third person or past participle, it is task of the upper ontology, which includes knowledge of the various verb forms, to address the match to the main concept, usually defined by its "-ing" form.

Once the verb concept has been matched, the correct domain of the action is to be identified: the same verb, in connection with different objects can generate various actions. For example, "remove the screw" results in a combination of rotation and translation of the target object, while "remove the memory card" in an electronic device generates just a translation of the related object.

In case the verb cannot be matched through its syntax, the query procedure searches through the definition of the verb, in particular in the elements defined by the "KindOf" relation, to find eventual synonyms. Once found one or more verbs, the method checks whether the domain of the alternative action verbs, defined through the "hasRange" relation, and the target object of the training subtask are compatible. For example, if the verb "loosening" deriving from the sentence "loosen the nut" (see figure 5-13) cannot be found through syntax in the ontology, the procedure searches verbs characterized at first by the "KindOf: loosening" relation; if such relation is satisfied the procedure completes the matching through the "HasRange: Object" restriction, since the concept "nut" is a specialization of the upper concept "object".

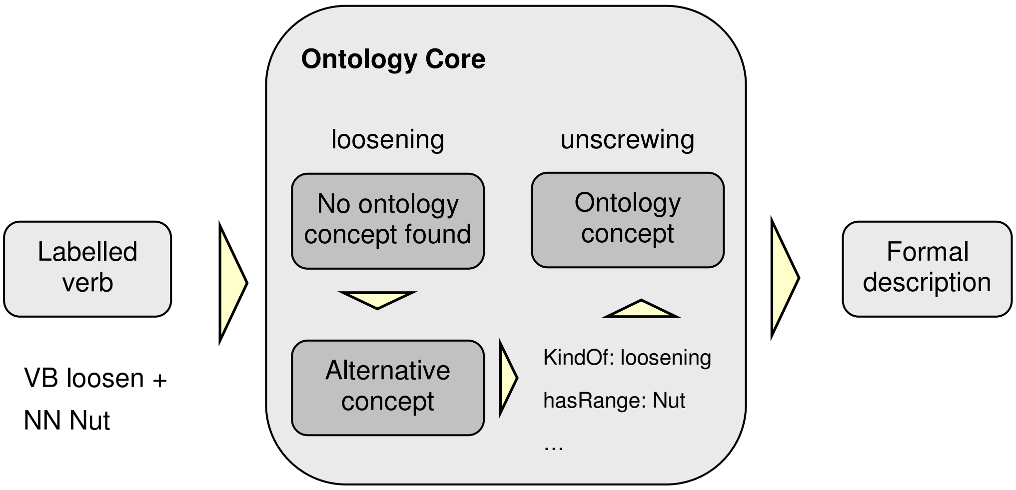


Figure 5-13: Verb matching through alternative concepts

Strictly connected to the verb matching is the management of spatial prepositions, which represent a critical element within the proposed approach and, in general, for natural language processing. One of the most important contributions in the research area [Her86] states that the topic is too complex to be successfully arranged into general rules; just very simple cases can be treated and once a general rule arises, an exception can be found. Spatial prepositions build, in fact, a bridge between natural language and the spatial location of the considered elements; moreover, in a text-to-scene approach like the proposed one, they pave the way to the representation of the elements in the virtual scene.

Prepositions can be identified essentially in two ways: on the one hand, in case of verbs that explicitly need a preposition, like “check through” or “look for”, they can be included in the action ontology as part of the verb itself. On the other hand, their matching becomes more complex and requires a deep understanding of locative expressions, defined at first in the upper ontology and then enriched of eventual specific cases within the domain ontology, as shown in section 5.2.2.4.

5.6.2.3 Object

Matching an object in the ontology is a quite complex process because of the multiplicity of tasks, domains and situations where a single object can be involved into. This problem can be well represented, for example, by fasteners, like screws or bolts, which can theoretically be present in every object and available in a multiplicity of kinds.

Nouns coming from the natural language parsing phase are searched in the upper ontology and, whether the concept is not found, in the part ontology for the identification of the involved elements.

It is necessary to differentiate two main cases, according to where the noun representing the object is contained:

- Training sequence title
- Single training sentence

The noun, describing an object in the training sequence title, has its main function in delimiting the knowledge domain. It usually defines a higher level concept, which includes various sub-elements in its hierarchy; therefore, once the object is matched, also all connected concepts, together with their instances, must be considered for their likely use in the content of the training request. As introduced before in the car domain, the "Porsche 911" is the concept but it is not a standalone one: it is composed by a myriad of parts from the smallest screws and bolts up to the chassis.

On the other hand, nouns included in each training subtask represent standalone elements, which are to be linked to their models or to specific parts within the main 3D model; an example could be represented by the tire of the car to be removed. Therefore, in this case, the matching procedure ignores eventual sub-elements in the hierarchy but keep connections with upper concepts, to which the nouns may refer (tire-axis).

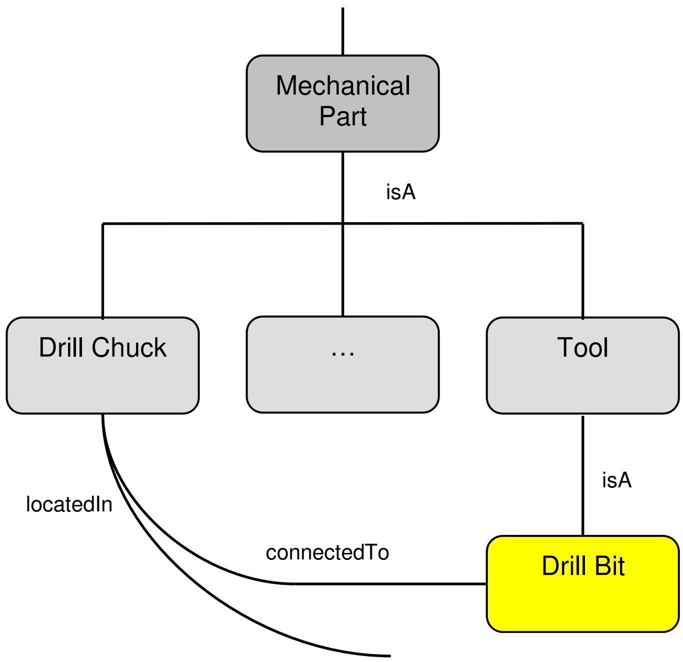


Figure 5-14: Matching of the "Drill Bit" concept in an extract of the Part Ontology

The matching of the object is performed through an ontology query, according to the lexical elements that have been identified by the natural language parser. The result is not only the matching of the single concept but also the retrieval of all the concepts linked to it by a relation: it would be a non-sense, identifying the “drill bit” (see figure 5-14), for example, without referring to its upper level concept, e.g. the “drill chuck”, which needs to be represented as well in the final training animation.

Particular attention must be given to compound nouns: they represent noun phrases, which are made up of a noun preceded by a modifier, like “parking brake” or “milling machine”. In this case the procedure considers, within the same noun phrase that includes the compound noun, the two adjacent elements as one word. The approach is able to manage compound nouns that are composed by a maximum of four nouns; this is achieved by linking all the elements for a three element compound noun (e.g. “landing gear brake”) or to the linking of two couples of elements (e.g. “torque link”) and (“standoff bracket”), for a four word compound noun.

5.6.2.4 Adjectives and Adverbs

Adjectives and adverbs can be present in a generic training sentence, where they supply additional information about the elements and the environmental conditions. A particular role is played by adjectives, since they enrich elements defined by nouns through various attributes.

A first distinction, which is also used for the matching procedure, regards adjectives and past participles that can play a similar role adding more information to the noun they refer to.

This preliminary step is necessary to define the section of the ontology core used for matching of adjectives: in fact, past participles derive from the corresponding verbs, whose definition is stored in the action ontology, while adjectives can be managed through attributes or relations in the upper ontology as well as in the domain ontology whether domain specific.

Past participles, e.g. “closed” or “connected”, are considered as verbs and matched by the “-ing” form concepts, like “closing” and “connecting”, defined in the action ontology, if not already in the upper ontology. While their matching can be provided referring to the original verbs, their representation in the training animation remains anyway very problematic: they refer to actions that have already been done: for example, a part is “connected” if the connection has already taken place, therefore the action described by the adjective does not suit the creation of an animation, which displays tasks as a continuous flow, since it has been already been concluded.

The same difficulties can be found also regarding adjectives: while some "tangible" adjectives, regarding color, shape and material, can be managed and therefore matched through attributes or relations in the ontology, the matching and the subsequent representation of abstract adjectives remains too complex for an automatic procedure. It is in fact not possible for a computer establish what is far, small, slow or different, within a single natural language phrase.

Also adverbs are affected by the same problem: the majority of them expresses some abstract properties, like "by hand", "carefully" or "properly", which theoretically can be matched in the ontology but that are quite impossible to be visualized in the animation. The solution can be represented in this case by the use of different metaphors rather than the pure visualization of the action.

5.6.3 Formal Description of the Animation

The result of the matching phase is represented by a formal description of the overall training session, in terms of objects to be represented in the virtual scene and of the basic transformations commands, deriving from the action ontology. The formal description is composed by the two components:

- world description
- task description

The world description contains the elements building the virtual scene, still on a conceptual level since the 3D models and their geometry retrieval is achieved during the following model mapping phase. Such elements have been directly identified by the ontology matching, together with the necessary related concepts, which are included in the training sentence or inferred by the context.

The task description contains information about the actions involving the elements contained in the world description. The verbs matched by the ontology, together with additional information regarding objects or tools used for the task, complete the formal description of the animation. Verbs are subdivided according to the motion effect they cause into the five main categories already defined in the action ontology:

- Movein and moveout, in case of motion respectively approaching or leaving the object;
- Be, in case of static positioning;
- Rotate, in case of rotations;
- Scale in case of change of dimensions of an object, used also in zooming in and out.

For example, the animation atom “removing a drill bit” is characterized by a formal description containing the following parameters:

- KindOf: loosening, taking, taking away
- HasDomain: Maintenance
- HasRange: Object (to be determined by the following step)
- EffectOf: Moveout length_object
- Duration (according to the target object)

The formal description is eventually used by the script generator for building the scene graph of the animation.

5.7 Phase 4: Model Mapping

Current state-of-the-art 3D modeling makes use of CAD tools coupled to PDM systems, which have been introduced in chapter 2.

Within this phase, each matched concept in the part ontology is linked to its corresponding 3D model, stored in the model repository or in a PDM System (see figure 5-15), through a series of interfaces. It is reasonable thinking that each part defined in the 3D model is characterized by an ID code, which can be associated to the corresponding part defined in the part ontology, thus enabling a feasible information exchange between the two systems.

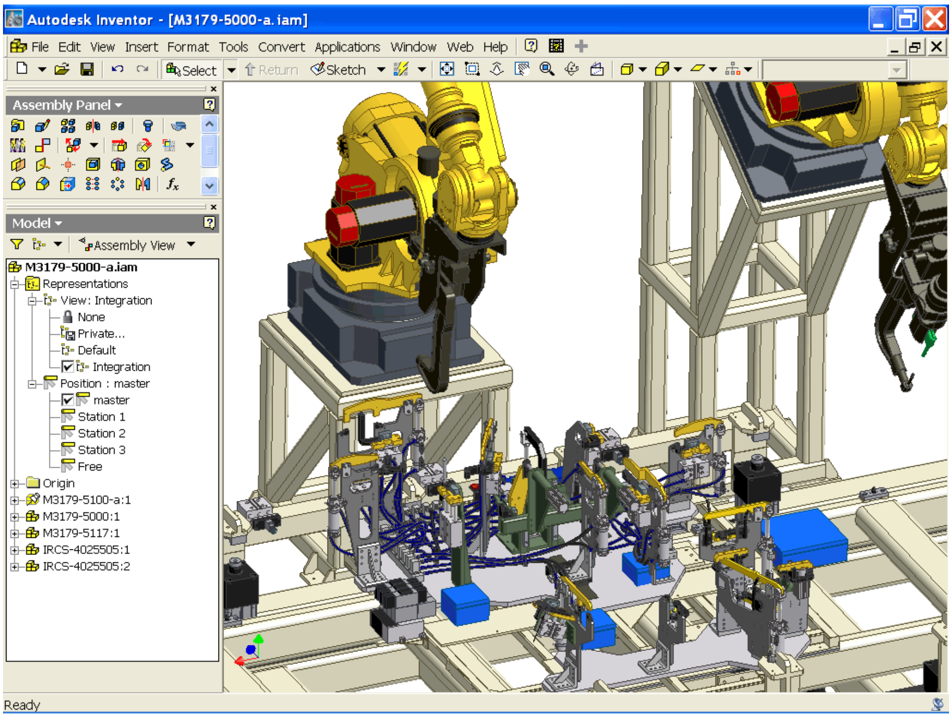


Figure 5-15: Screenshot of a PDM system

The first step of the model mapping phase is the identification of the main concept, i.e. the matched object contained in the training topic, in the 3D model database. For this task, the identification is possible searching through metadata in the model repository or in the PDM system the main instance. In case an automatic identification cannot be possible, the possibility to manually enter the main 3D model is provided to the user.

Once identified the main concept, the corresponding 3D model is recalled, in order to get its geometry; also sub-parts, contained in or connected to the main concept, are recalled, together with their positioning.

The model mapping phase has also the aim of choosing the correct level of detail of the model according to the end user role, target of the training session. Three different levels of detail are foreseen for the roles defined in the ontology core:

- low detail, showing the 3D model where just the more external layers are visible
- middle detail, including internal layers but not the detail of the smallest components.
- high detail, where all layers of the 3D model are visible

At the end of the mapping phase, before the animation script is created, the method provides the end user with the possibility to give some feedback regarding the individuation of the correct elements in the 3D repository. The automatic identification of 3D models according to natural language instructions can in fact generate results, which are not the desired ones. In this case the end user can refine the natural language instruction in order to achieve a better match in the ontology and subsequently in the model mapping.

5.8 Phase 5: Animation Script Generating

Once the 3D models corresponding to the parts involved in the animation have been identified by the previous phase, the last necessary step is the translation of the formal description into the final animation script, which includes movements, like translations and rotations, of the elements in the virtual scene.

The animation script is created by the script generator, a software agent that translates the formal description of the animation into a graphics file format script. The script generator collects all the necessary information in a standard template, which eventually builds up the scene graph for the requested animation. This is achieved by mapping action descriptions contained in the formal description to specific commands of the scene graph data structure.

The main elements of the scene graph, and therefore of the standard template, can be summed up in the following general nodes:

- **Geometry data** contains information about the geometry of parts to be visualized in the virtual scene (dimension of the objects, colors, shading parameters, etc.)
- **Group** constitutes a virtual assembly of the elements
- **Transformation** collects modifications of the scene in terms of translations, rotations and scaling

The software agent is also responsible of the **time management**: to every action verb are coupled within the ontology predefined values for time and speed of the task to be performed. For example, the combination of the concepts "removing" and "screw" is associated a predefined total time for the action, e.g. 1.5 seconds, as well as the speed values for the translation and of the rotation.

Another important part of the script generator is played by the **virtual camera management**, including camera point of view and speed. The virtual camera represents the point of view of the end user and must be therefore carefully considered. The camera must focus on the target of the training for a time necessary to the user to locate it and must also move not so fast, in order to let the operations understandable.

The management of the virtual camera allows also the delivery of different views according to the role target of the training session. For roles requiring a high level of detail the virtual camera must be positioned very close to the virtual object, in order to appreciate the smallest details. On the contrary for roles requiring a more general view, the camera can be positioned at a longer distance.

Once the animation script has been created by the script generator, the animation can be visualized through the corresponding viewer. In order to allow a feedback about the animation parameters, the method lets the user specify a final feedback about timing of the animation as well as positioning and speed of the virtual camera. In this way the script of the animation can be adapted to the user request and the process can be therefore continuously improved.

6 Prototype Implementation and Validation

The proposed research approach represents an innovative way to create 3D animations for training purposes, combining state-of-the-art natural language understanding, knowledge-based services, by means of an ontology, and 3D animation authoring techniques.

In order to evaluate the feasibility and the efficacy of the overall approach, a prototype implementation has been realized and validated. This section describes the realization of the proposed method starting from the definition of the ontology core and then analyzing each single step of the process model.

The whole research approach has been inspired by the European Project KoBaS (Knowledge Based Customized Services for Traditional Manufacturing Sectors Provided by a Network of HighTech SMEs), whose aim is to supply modern manufacturing machines with knowledge-based software solutions, from 3D simulation and training, to part-program creation, and FEM analysis among the most important components (see figure 6-1). The project, where the author has been involved into, has been completed in June 2007 after a three-year work period. Even if the proposed research approach is not part of the KoBaS project itself, the experience acquired in the manufacturing machine domain has led to use of a mechanical device as demo case.

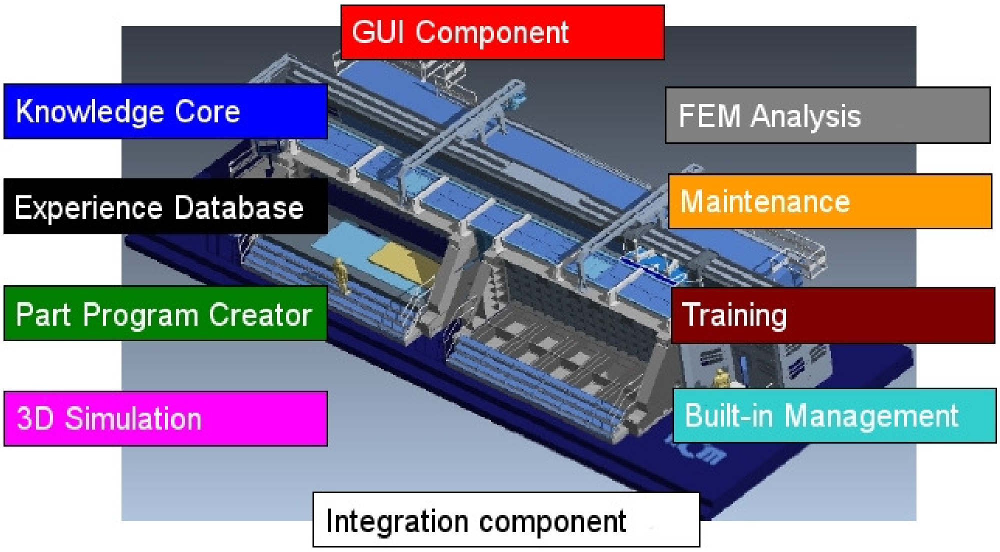


Figure 6-1: KoBaS knowledge based services

The chosen device is a standard Drill Press, actually available on the market; in order to test and validate the proposed approach in real conditions, the considered training sequences have been extracted from a real operations and maintenance manual.

The followed implementation strategy starts with the choice of the existing upper ontology and the analysis of the mechanical domain coverage; the development of the part and action ontologies completes the definition of the ontology core. Then, the developed process model is applied and the feasibility of the process is evaluated.

6.1 Ontology Choice and further Development

The ontology core constitutes the most important part of the proposed approach; its definition represents a preliminary step of the method. This section describes at first the choice of an existing upper ontology, in order to have a shared and domain-independent knowledge base and at the same time a common framework; this function is then exploited for the development of the necessary domain ontologies that supply the domain knowledge of technical parts and of the actions performed on them or through them.

6.1.1 Upper Ontology

Some of the most important existing upper ontologies have already been examined in section 4.2.1.1; among them two candidates have been selected for their completeness of content, the SUMO and the Cyc ontologies. Dealing in fact with natural language, where a single sentence can contain various concepts from different domains, the upper ontology must embed a wide and interconnected knowledge.

The two ontologies have been evaluated according to a number of parameters, which can be summed up as follows:

- number of concepts contained
- lexical mapping
- richness of instances

Both candidates represent two complete upper ontologies, from a knowledge point of view: SUMO contains thousand concepts and approximately 4000 assertions including over 800 rules while ResearchCyc includes more than 300.000 concepts and 3.000.000 assertions, using more than 25.000 relations. Also from a lexical point of view, both ontologies have a wide knowledge since they both map the whole Wordnet.

The key factor, which has influenced the final decision, is represented by the absence of instances in SUMO, which is structured in a network of subclasses, being thought as a framework for the further development of multiple domain ontologies. On the other hand, Cyc is able to characterize, even if in different microtheories, the included concepts through a network of classes together with instances, thus representing also low level knowledge.

For this reason, the Cyc ontology has been chosen for the prototype implementation; in addition, ResearchCyc is freely available for the research community and a set of APIs is also available for its use within developed applications. The choice of Cyc as upper ontology implies also the use of the CycL logic-based language as well as the microtheory structure used for knowledge representation in Cyc.

6.1.2 Coverage of the Training Domain

A couple of common maintenance and operations tasks, deriving from a real operations and instruction manual, are described in the following sections, in order to generate the corresponding animations and test the proposed approach. However, a necessary preliminary step is to verify the coverage of the knowledge domain: to perform this analysis, different parts and actions keywords deriving from the product description of the drill press target of the training, have been searched within the selected upper ontology, i.e. Cyc.

From a first analysis, Cyc is able to recognize within the UniversalVocabularyMt that “Drill” (see figure 6-2) is a “SpatiallyDisjointObjectType”, an “ArtifactTypeByFunction” and an “ExistingObjectType”, defined as “Hardware Tool”, “Cutting Device” and “Hole Making Tool”.

Collection : Drill

Bookkeeping Assertions :

(myCreationTime Drill 20030311) in BookkeepingMt
(myCreationSecond Drill 172303) in BookkeepingMt

GAF Arg : 1

Mt : UniversalVocabularyMt
isa : SpatiallyDisjointObjectType ArtifactTypeByFunction ExistingObjectType
genls : HardwareTool CuttingDevice HoleMakingTool
comment : "A tool used for boring holes in objects by means of a rotating sharp-edged cylindrical bit."

Mt : EnglishMt
prettyString : "drills"
prettyString-Canonical : "drill"

Mt : WordNetMappingMt
(synonymousExternalConcept Drill WordNet-Version2_0 "N03121981")

Figure 6-2: Extract of the definition for the concept “drill” in CYC

Also the concepts of elements building the drill can be identified, even if with some differences: more common concepts, like “fastener”, “lubricant” or “wire” are found easily while more specific ones, like “controller” or “spindle”, as expected, are not enough detailed and do not allow an exhaustive description of the parts.

According to the structure of Cyc, a disadvantage is that concepts can be found in different microtheories: the most important and general microtheory is the UniversalVocabularyMt, which as the name suggests acts like a dictionary, while closely related to the desired structure seem to be the ProductGMt, which includes concepts about formal products, and the ProductPhysicalCharacteristicsMt, which includes knowledge of the physical characteristics of products.

Concerning possible action verbs that can be found in a generic training sequence for the target domain, Cyc is able to match, even if with more than one meaning, common verbs like “loosening”, “checking”, “turning”, “inserting” or “removing”, in the UniversalVocabularyMt, HumanActivitiesMt and ProductUsageMt microtheories. It has been not possible, however, a correct matching of the verb “threading”.

An interesting Cyc feature is the possibility to express concepts in function of other concepts: for example, the verb “screwing” can be defined as function of the concept “screwdriver”, which is used for screwing. This feature can be exploited in the development of the domain ontology, where analogous functional relations “UsedFor” and “CapableOfReceivingAction” ideally link an object with the conceptually related actions.

Concluding the analysis of the coverage, it can be stated that knowledge stored in Cyc constitutes a good starting point for the individuation of concepts regarding objects and actions. However, its structure is not really an ontology, since concepts are characterized just by hyponymy relations. Cyc is rather a huge knowledge-base, whose upper part is an ontology. There is therefore a need to further specify the necessary concepts by developing a domain ontology.

6.1.3 Domain Ontology

Even if Cyc as upper Ontology already embeds a wide domain independent knowledge, additional domain knowledge including also an exhaustive set of relations is needed. The target world to be described by the developed domain ontology is represented by a mechanical device, in the considered case a Drill Press.

This section briefly introduces a first development of the domain ontology, into its two components, part ontology and action ontology; further development work is still however going on.

6.1.3.1 Part Ontology

The developed part ontology constitutes a first modeling of the target world through the concepts that represent its constituents. Top-down and bottom-up approaches have been followed, even if for different kinds of concepts. At first through the top-down approach, the drill press main concept has been further developed by the classes:

- Mechanical part: a movable part, which is involved in the production process
- Electrical part
- Structural part: a static or movable part, which builds up the structure of the overall machine, without taking part in the production process
- Functional part: a non-mechanical part, which supports the functioning of the machine
- Fluid, e.g. Lubricant

The defined classes have been further specified by additional subclasses, like the concepts “tool”, “spindle” and “feed handle” for the class “mechanical part” or the concepts “cable”, “motor” and “power supply” for the “electrical part” class.

The “structural part” class contains the subclasses “base”, “column” and “case”, which together builds up the structure of a generic drill press. Additional functional parts that are however needed for the functioning of the machine are represented by the “controller”, “display” and “pipe” concepts. The class “fluid” is further specified by the lubricant concept, which can be essentially of two kinds “oil” or “grease”.

The bottom-up approach has been followed on the other hand to start from lower level concepts and their instances and to connect the resulting class to the corresponding upper class: for example the concepts “screw” and “joint”, together with their instances representing the different kinds of screws and joints, have been arranged into the “fastener” subclass of the more general “structural part”. Very important in this case is the elimination of every unarranged concept, which lead to inconsistence and to a wrong modeling of the domain ontology; the conceptualization of the target domain must be completely exhaustive. Due to the simple test case, the use of the mixed approach has not been necessary.

Table 6-1: An extract of the drill press domain ontology

Concept	***IsA***	***Conceptually-RelatedTo***	***ConnectedTo***	***AllowedMovement***
Tool	Mechanical part	Hole; Wear ; Bit	Spindle	Movein/Moveout Rotation
Spindle		Speed, Rotation	Motor	Rotation axis z
Feed handle		Tool, Position, Lever	Case	Rotation axis z
Cable	Electrical part	Electricity	Power Supply	-
Motor		Power,	Power Supply	Movein/Moveout
Power Supply		Sped	Motor; Cable	-
Base	Structural part	Ground	Column	-
Column		Structure	Base, Case	-
Case		Cover, Protection	Column, Motor	Movein/Moveout
Fastener		Screwdriver, Joint, Tool, Anchor, Hole	Base, Case, Column	Movein/Moveout Rotation axis z
Display	Functional part	Parameter, Setting	Case	-
Pipe		Fluid	Motor	-
Oil	Lubricant	Drop, Fluid	Pipe	-

Instances of the concepts mentioned above have been linked through a path to the corresponding 3D models, in order to allow the retrieval of the geometry during the phases of the proposed method.

6.1.3.2 Action Ontology

Differently from the part ontology, where the target domain is fixed, the action ontology includes concepts of verbs covering a wide domain that deal with the mechanical device, from operations to assembly or maintenance sessions. The spectrum of verbs that can be found in a training session is therefore huge. However, the general knowledge of the upper ontology in some way simplifies the development of the action ontology: verbs are in fact mostly derived from the upper ontology and enriched with knowledge of the transformation itself, also in connection with the target objects.

Among the classes of verbs included in the action ontology, already introduced in chapter 5, just the physical verbs have been implemented in the prototype. With the exception of verbs defining positions that can be linked to the "be" command, the definition of abstract verbs is left to the upper ontology since they do not contribute a visual representation in the 3D animation.

For the implementation phase greater attention has been given to the physical "action on object" verb class (see table 6-2). Each verb has been described through a set of relations: the antonym concept of the verb, the role domain of the action, the range of connected objects and the respective effects of the action allow a specific characterization of every concept.

Table 6-2: An extract of the defined "action on object" verbs

Concept	***hasContrary***	***hasRange***	***hasDomain***	***EffectOf***
Open	Close	Case	Operation Maintenance	Rotate door y-axis
Remove	Place, Put	Screw	Maintenance	Rotate screw z-axis, Moveout y-axis
		Structural_ part	Maintenance	Moveout box z-axis
		Mechanical_ part	Maintenance Assembly	Moveout spindle z-axis
Loosen	Tighten	Fastener: Screw	Maintenance Assembly	Rotate screw z-axis
Change	-	Mechanical_ part	Maintenance	Moveout spindle z-axis Fade out, Fade in Movein spindle z-axis
Use	Ignore	Functional_ part	Operation	Rotate handle x-axis

The concepts included in the part ontology have also been characterized through the hasDomain relation and directly connected to the corresponding roles. The effect of each verb described in the table is strictly dependent on the geometry of the related objects, thus the described axes are to be considered just as an indication.

In a first development phase it is not foreseen the implementation of the “action with tool” verbs, where the introduction of the external models is necessary in order to represent the tools necessary to complete the action. At the same time, “pure action” verbs, which even if present in the training session play a marginal role, are not included in the developed action ontology.

6.1.4 Roles

The simplicity of the selected test device implies that in the specific case roles play a marginal role; the drill press CAD model presents in fact just in the main unit the possibility to place specific object on layers. That is the reason why the in the implementation just two roles have been managed:

- Operation/sales, which requires the full 3D model in order to have an overall view of the target device
- Assembly/maintenance, which gives more detail of the main unit, setting external structural parts, like the main unit case, invisible.

6.2 Implementation of the Process Method

The developed part and action ontologies, completed by the Cyc upper ontology, represent the core of the process method proposed in this research approach. This section describes the implementation of the process model, already introduced in chapter 5, through the sequence of phases that build it up.

The developed system is made up of a main application, which includes the natural language parser, the ontology core and the script generator; the application is also connected through an interface to the 3D model repository.

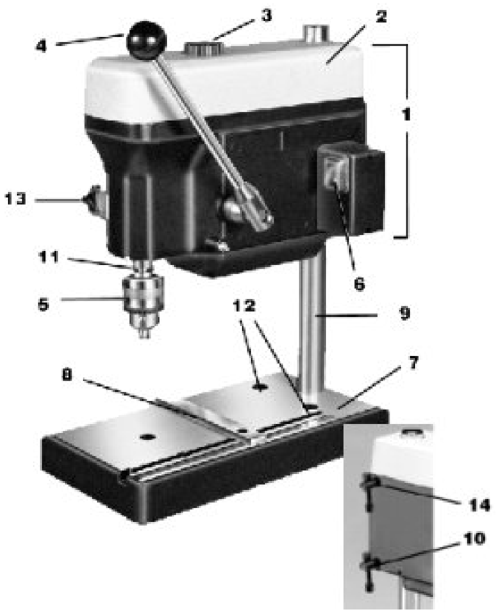
An integrated viewer is also provided in order to allow visual feedback in the identification of the correct 3D objects within a more complex model, as well as during the visualization of the resulting animation

The implementation of every phase building the process model, starting from the training request and ending with the generation of the animation script, is analyzed in the following sections.

6.2.1 Training Request

Product documentation provided by manufacturers includes detailed information about the product, like system operation, safety and maintenance instructions. Such information constitutes the starting point for the implementation and at the same time a good test for the feasibility of the proposed method.

For implementation and validation purposes, a couple of installation and operations procedures, extracted from a real drill press (see figure 6-3) instruction manual, are considered.



1. Motor Unit
2. Top Cover
3. Cover Lock
4. Feed Handle
5. Drill Chuck
6. Power Switch
7. Base
8. Parallel Guide
9. Column
10. Lock Screw
11. Wrench Hole
12. Anchor Holes
13. Depth Gauge Knob
14. Column Adjuster Screw

Figure 6-3: Extract from the instruction manual [MM-ol]

To test the feasibility in different conditions, two procedures differing in their structure, have been chosen: a first procedure regarding the assembly of the Drill Press is characterized by a numbered sequence of subtasks. The numbers included in every sentence refer to the parts displayed in figure 6-3.

Procedure 1: Assembly of the Drill Press 81631

1. Anchoring of the unit is possible using two screws (not provided) through anchor holes **12.**

2. Loosen the lock screw **10** by turning counterclockwise and slide the motor unit **1** towards the top of the column **9**; tighten the lock screw to hold the motor unit in position. If applicable, remove protective cap from spindle threads.

3. Install the drill chuck **5** by threading it onto the bottom of the spindle; insert the wrench into the hole **11** in the spindle to keep the spindle from turning while you tighten the chuck.

4. Thread the feed handle **4** into the spindle feed lever.

A second training procedure regards the installation of drill bits for operations and is in form of a paragraph that includes has no numbering.

Procedure 2: Installing Drill Bits for Operations

> "Using the chuck key, open the chuck just far enough so that the drill bit can be inserted centrally into the chuck jaws. Carefully tighten the chuck so that it grips the drill bit on the blank portion of the drill shank. Do not tighten the jaws on the drill flutes. Remove the chuck key. Rotate the chuck by hand to confirm that the drill bit is inserted properly and there is no drill wobble."

The considered training sentences are expressed as usual in imperative form, being the subject, i.e. the role, implicitly defined by the title itself ("assembly" and "operations"; this reduces the parsing and the matching phases in the individuation of the action to be performed together with the target objects.

6.2.2 Natural Language Parser

A natural language parser is a program that is able to supply for a natural language sentence, written in English in the considered case, a grammatical analysis, identifying and labeling the single constituents, like subject, verb or object. The role played by the parser in this phase is to have a first idea of the structure of each sentence and of the single elements that build it up.

The natural language parser used for this phase is the Lexical Parser, developed at the Natural Language Processing Group of the Stanford University: it is a Java implementation of probabilistic natural language parsers, probabilistic context-free grammar (PCFG) and dependency parsers, and a lexicalized PCFG parser. The parser is licensed under the GNU GPL and its source is included in the package, which includes components for command-line invocation, a Java parsing GUI, and a Java API.

The input text can be entered directly in the parser graphical user interface or by loading a text file. The two test training procedures have been analyzed by means of the Stanford PCFG Parser, which automatically subdivides text inputs in smaller sentences, ended with a point. Thus, there is no difference between the two procedure styles; the only difficulty is that for in the first procedure, numbering is recognized as a sentence composed by just a number followed by a point. In addition, numbers identifying parts of the device in the picture, like the one contained in the example procedures, are difficult to be filtered; the risk is to cause filtering of important details, like the code identifying the kind of a screw or the model number of a generic instance.

The parser has some problems with the identification of case sensitive words: the same word, i.e. the verb “remove”, is recognized as a verb but when the first letter is written in capital letters it is labeled as adverb. This represents a serious problem since training subtasks usually start in capital letters.

The output resulting from the probabilistic approach mentioned above is a text file, containing a parse structure with Penn-Treebank notation, which can also be visualized through graphical trees. The elements resulting from the parsing are labeled according to their kind and made available for the ontology matching; this interface is managed through the parser API, which connects directly with the main application. The following description represents the first sentence of Procedure 2.

```
(ROOT
 (S
  (VP
   (VP (VBG Using)
   (S
    (NP (DT the) (NN chuck) (NN key)
    (, ,)
    (VP
      (VP (VB open)
      (NP (DET the) (NN chuck)
      (ADVP
       (ADVP
        (ADVP (RB just) (RB far))
        (RB enough)
        (RB so))
       (SBAR
        (IN that)
        (S
         (NP (DET the) (NN drill) (NN bit)
         (VP (MD can)
          (VP (VB be)
           (VP (VBN inserted)
            (S
             (ADJP (RB centrally)
              (PP
              (IN into)
              (NP (DET the) (NN chuck) (NNS jaws)))))))))))))
```

6.2.3 Ontology Matching

The ontology matching consists in the identification of concepts that have been recognized and labeled by the natural language parser. This process is managed by the main application and regards action verbs as well as the corresponding objects. The whole phase can be subdivided into a sequential matching through upper and domain ontology.

In the upper ontology matching, each element is searched by the main application through the Cyc API, within Cyc’s UniversalVocabularyMt. This microtheory, which is the largest one, is the main entrance for the identification of the concepts; it acts like a dictionary and contains basic information necessary for the identification of the single elements, which are however not characterized through parameters or relations.

Analogously to a dictionary, more senses can be coupled to a single word; a first possibility to filtering such results is given by the natural parsing labeling phase. An element labeled as a verb (VB), automatically excludes from matching, a synonym noun or adverb: the word "links", for example, whether labeled as a third person verb (VBZ), excludes the plural of the word "link" from the matching results and therefore refer just to the "linking" concept.

Once an element, i.e. verb or word, is identified in the UniversalVocabularyMt, the possible meanings are searched in the connected more specific microtheories:

- HumanActivitiesMt and ProductUsageMt, for verbs.
- ProductGMt and ProductPhysicalCharacteristicsMt, for objects

This first matching step within the upper ontology performs a restriction of the knowledge domain to the training and mechanical devices sub-domains; at the same time, it paves the way for the identification of target objects and action verbs, which are not specified in the more general microtheories and are stored in the more specific part and action ontologies. The final matching is performed in fact through the domain ontology defined in section 6.1.2, which is connected to the microtheories mentioned above, in order to give a final characterization of the concepts.

Objects defined in the domain ontology are characterized by a more complex structure than the one defined in the upper ontology: they include a hierarchy of concepts, rather than just upper and lower level concepts, and by a series of relations. Such description of the object is needed for the individuation of parts or features to be shown in the final animation. In test procedure 1, being the "drill chuck" connected to the "spindle" through the connectedTo and locatedIn relations, the individuation of the former concept and its inclusion in the 3D animation implies also the inclusion of the conceptually related concept of the latter: both concepts are however not related each other by hyponymy or hyperonomy relations but are included in the hierarchy of the "drill press" concept.

While the aim of matching words is to individuate objects involved in the training requests and consequently in the 3D scene, matching of action verbs implies the "translation" of action verbs into a series of transformations of the objects mentioned before. After the first disambiguation through the microtheories mentioned above, one or more matched verbs are refined through the domain ontology. Considering the object related to the action verb, through the “hasRange” relation, not only a correct matching is possible, but also a variety of different animations with the same verb are possible.

Among the considered verbs, a particular case for English is also represented by the verb “to do”; it can be in fact associated to “making” but it is also used for negative sentences, e.g. “do not open”. In the latter case the main role is played by the second verb, which becomes the relevant one for the overall meaning. For this reason the verb “to do” has not been implemented because a metaphor to express negatives is still needed.

Within the proposed approach abstract verbs are just used to influence the management of the virtual camera; in a further development of the approach they can be managed by textual or visual information to be added to the 3D animation.

The result of the matching is a formal text description of the animation (see figure 6-4), a text file containing a higher level description of the animation scene environment, including the objects involved and their actions, specified on a higher level language [Bro05]. Also a first preliminary value of the speed of the movement is indicated. This information is later on managed by the script generator, which associates the semantic elements to the corresponding 3D models and translates high-level tasks into the corresponding geometrical transformations.

For the matching and eventual representation of adjectives and adverbs in the virtual environment and therefore in the training animation, alternative metaphors are necessary, like the use of additional textual information or the use of a system of visual signs within the 3D animation. The analysis about the feasibility of the inclusion of adjectives and adverbs lead to the conclusion that, at least in the early phase of this approach, they are not considered in the implementation, leaving anyway its addition in a further development.

```
worlddef
{

    machine     r1 = "XWorldContent[W1].XMachine[rob1]";

    tcp         tcp1 = "XWorldContent[W1].XMachine[rob1].XTcp[TCP1]",
                tcp2 = "XWorldContent[W1].XMachine[rob2].XTcp[TCP1]";

    location    L1A = "XWorldContent[W1].XFrame[L1A]",
                L2A = "XWorldContent[W1].XFrame[L2A]",
                L3A = "XWorldContent[W1].XFrame[L3A]",
                L4A = "XWorldContent[W1].XFrame[L4A]",
                L1B = "XWorldContent[W1].XFrame[L1B]",
                L2B = "XWorldContent[W1].XFrame[L2B]",
                L3B = "XWorldContent[W1].XFrame[L3B]",
                L4B = "XWorldContent[W1].XFrame[L4B]";

}

constdef
{
    pose home = [0, 0];
}

vardef
{
    number i;
}

task main
{

    for i=1, (i<=3), 1
    {

        execute MoveRob1 and MoveRob2;

    }
}

task MoveRob1
{
    move tcp1 to L1A speed 0.8;
    move tcp1 to L2A speed 0.8;
    move tcp1 to L3A speed 0.8;
    move tcp1 to L4A speed 0.8;
    move tcp1 to L1A speed 0.8;
}

task MoveRob2
{
    move tcp2 to L4B speed 0.8;
    move tcp2 to L3B speed 0.8;
    move tcp2 to L2B speed 0.8;
    move tcp2 to L1B speed 0.8;
    move tcp2 to L4B speed 0.8;
}
```

Figure 6-4: Formal description of the animation

6.2.4 Model Mapping

The objects matched in the domain ontology represent also an interface to CAD models, stored in the model repository. Single objects, like “drill bit” or “spindle” within the 3D model of the main concept, in the considered case “drill press”, can be then searched through metadata; also 3D models of objects external to the main one, like a “wrench” or a “chuck key”, can be recalled and added to the scene through the script generator.

Different layers have been set up in the test CAD model, each representing a specific aspect, like the layer representing pipes or the one that regards the external case of a machine. Such layers can be set visible or invisible thus giving a completely different result of the parts to be displayed: this is the essential feature to allow the management of different roles, each of them needing a particular view of the whole training target. The link between CAD models repository and ontology can be also allowed by an additional agent, responsible for the management of the layers within the CAD model, according to the roles defined in the domain ontology.

For the considered test case, due to the simplicity of the used CAD model, just two views have been set up within the 3D model of the drill press (see figure 6-5):

- Overall view, for the operations and sales roles
- Detailed view without case unit, for maintenance and assembly roles

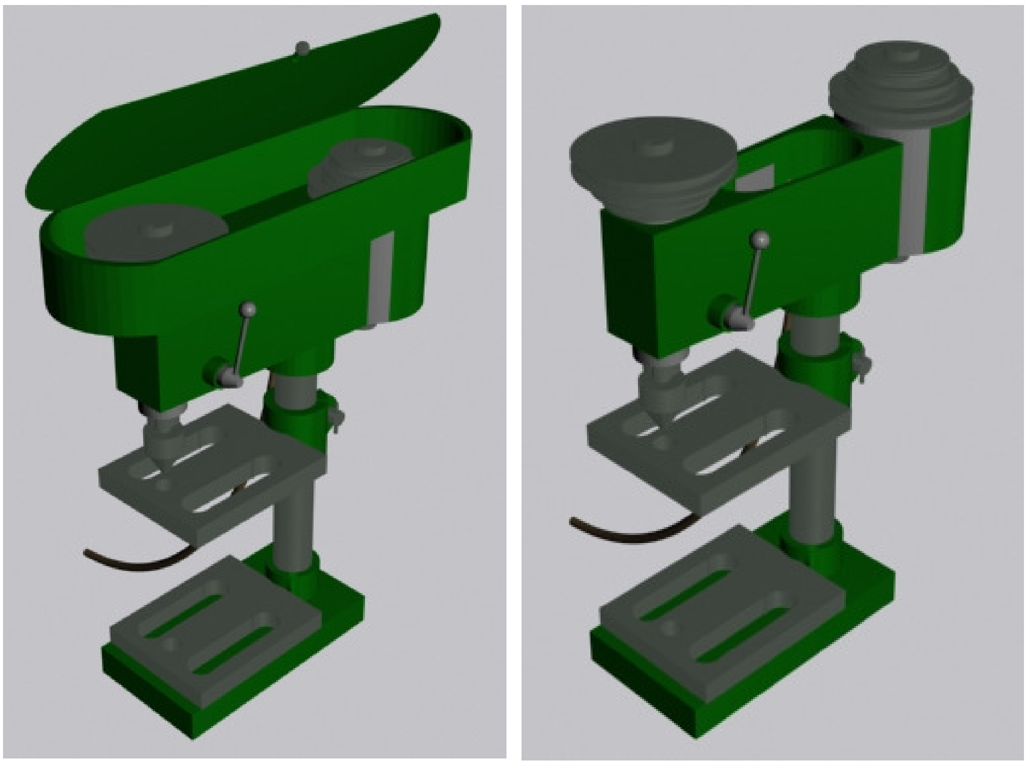


Figure 6-5: Views of the drill press model for different purposes

The approach followed in the implementation is to split the main model into several subparts, which are at first converted into VRML files and then linked as a reference to a standard XML file. In this way single parts can be named according to the concept defined in the part ontology, thus allowing an easier identification of the elements.

To reduce incoherencies and eventual misunderstanding, a first visual feedback can be provided by the developed viewer, which lets the user check if the 3D models of the displayed parts correspond to the real targets of the training session.

6.2.5 Animation Script Generation

The generation of the animation script is demanded to a “script generator”, a software agent, which according to the chosen 3D graphics file format, converts the formal description into the animation script. The script itself represents the starting point to build the scene graph for the requested animations.

The chosen 3D graphics file format for the implementation is VRML, since all major CAD providers offer tools to export in this format. Even if X3D represents the evolution of VRML, the support of CAD files still needs some development in order to embed mature functionalities in the domain.

The agent, according to the previously defined formal description, interprets the provided information and codes the animation description in terms of coordinates and transformations, in XML notation. The animation script comprehends between its features:

- Translation, rotation and scaling of objects
- Change of the visual properties of an object: color, transparency, visibility, etc.
- Viewpoint changes

Parallel to the visualization parameters, the script generator manages the time parameters, like “startTime”, “Time” and “Delay”, according to standard predefined values; such values can however be modified according to the feedback provided by the user after the visualization of the animation preview.

The created script represents in detail the operations to be performed during the animation; together with the loading of the geometry, it concludes the animation authoring process, which is then able to visualize the requested animation using an OpenGL-based viewer.

A continuous improvement of the authoring process is also provided to the user, which can give some feedback at the end of the visualization of each subtask. The most important variables that need to be adjusted are the camera and time management: therefore, the user can specify if the virtual camera was not in an optimal position, i.e. too far or too close to the target object, as well as if the animation times are too fast or too slow to get a good understanding of the processes. The agent can thus vary the camera positioning parameters or time and speed values in order to obtain an optimal visualization.

6.3 Evaluation

The implementation introduced in this section has shown that a 3D Animation can be created by means of a script, which derives from a natural language text, and visualized in an interactive way through the corresponding viewer.

The tests performed to validate the proposed approach, once the prototype implementation has been completed, have revealed that the method is able to satisfy the initial requirements:

- Training animations have been created starting from natural language, descriptions, which have been parsed and divided into subcategories on a phrase level and on a verb level.
- Core of the method is the combined use of an upper ontology and of one or multiple domain ontologies, which act as knowledge core for interpreting natural language sentences.
- Different end user roles, together with their own information needs, can be managed by the ontology.
- Animation atoms and events can be defined and managed through the ontology, thus assuring reusability of some basic animations, also for different user roles.

However, the automatic translation of a generic training sequence into the corresponding animation is still not mature enough; it is in fact bounded by many variables, like the structure and content of the training sequence or the use of external elements, e.g. a wrench key, just to mention the most common problems.

The main difficulty encountered is in the heterogeneity of the existing text-based training material, contained for example in instruction manuals. This was anyway expected for the following reasons:

- Each author has its own styles, therefore written training sequences differ according to the style adopted by the author
- Existing training material has not been created with the aim of the automatic generation of 3D animation
- The use of multiple visualization modalities, including drawings and other visual signs, connected with the text, complicates enormously the parsing phase and therefore the whole authoring process.

The realization of “ad hoc” training sequences, which follows the guidelines introduced by the proposed approach, is of course useful in order to solve the problems mentioned above. In this way, also complex tasks can be subdivided into smaller subtasks, which are easier to be translated into the corresponding animation.

7 Summary and Outlook

The fast development of the computer-based era has allowed the representation of industrial products in a three-dimensional environment by means of 3D CAD models. Such new approach has shift industrial applications, performed in the past essentially through paper-based techniques and through the realization of real scale models, to a completely digital 3D product representation, like digital mock-ups as well as virtual and augmented reality for the product development phase.

Also the training domain has exploited the benefits deriving from the 3D approach; trainees can nowadays experience the features of the real objects or situations by exploring a virtual environment. In addition, the static 3D model can be transformed into interactive 3D animations, which differently from paper or video based training give an overall understanding of the task and of the involved elements from different points of view. The trainee can in fact stop at any time the animation, zoom in and out as well as get understanding of the relations between parts and their movements.

The authoring of 3D animations for training purposes is a customized process, usually realized by specialized 3D artists, which however are not expert in the training target domain. The presence of expert staff, which explains technical details, or the use of existing training material, like instruction manuals or exploded drawings, is therefore required in order to correctly identify technical elements and understand actions to be represented within the animation. In such situations the rising of a semantic problem is very probable: natural language is not formal enough to unambiguously identify the correct elements as well as to represent specific actions in the virtual scene. The sentence "remove the screw", for example, says nothing about the kind of screw neither the kind of action, consisting in a rotation and a translation of the target object.

In the proposed research approach a series of requirements for the automating the 3D animation authoring process has been deducted in order to solve the problems mentioned above: they include 3D support, natural language understanding, the use of a knowledge-base system, the management of different end user roles, and the reusability of animation atoms.

An innovative approach able to automate the authoring process of 3D animation for training purposes has been proposed. The process, consisting of five phases, starts from existing or "ad hoc" created training sequences, expressed in natural language, parses them by means of a natural language parser and matches the found elements in an ontology core.

Role of the ontology is to provide a link between syntactical elements included in a generic training sentence and the corresponding concepts of parts and actions to be displayed in the 3D animation. Knowledge supplied by the ontology, through hierarchies of concepts, relations and attributes, is able to minimize the semantic problem.

The ontology core is made up of an upper ontology, which contains domain independent knowledge in terms of basic concepts and relations, and represents at the same time a common framework for the further definition of additional ontologies. The development of one or multiple domain ontologies, subdivided into parts and actions ontology, which contain specific knowledge of parts and of actions performed through them, completes the structure of the ontology core.

The domain ontology is also linked to a CAD models repository, thus allowing a mapping of concepts regarding objects to their corresponding 3D models. Once all relevant information has been collected, a script generator fills up a standard animation template and generates the animation script, which allows the display of the required animation through the corresponding viewer.

The proposed approach has proven to be feasible and to be able to satisfy the preliminary requirements, thus making the 3D animation process easier and faster, even if remaining fully customizable through the ontology: different animation atoms as well as user roles can be defined and managed. However, the approach is not mature enough and further development work is required, mostly on the input of training sequences; they represent, in fact, with their extremely different styles and contents, which are typical of natural language, the bottleneck of the process method.

In order to further develop the proposed intelligent authoring of 3D animations for training purposes, research work can proceed in the following directions:

Standardization of training sequence: since the training sequence, expressed in a natural language form, represents the bottleneck of the whole process in terms of efficiency, a standardization of the training sequence can improve and speed up the whole process. This includes the definition of the structure of the sequence as well as of each subtask, the use of simple verb-object sentences and the presence of action verbs rather than abstract ones.

Development of further domain ontologies: the proposed approach is very flexible since it is domain ontology depending. The development of additional domain ontologies, for the automotive, aviation or construction domains, can extend the possibilities of delivering customized 3D training animations for various domains.

Integration of domain ontology and model repository: the connection between the ontology and model repository, described in the proposed approach, is represented by a link between two separate systems. However, an integrated platform, including both systems, where every element of the model could be joined to the corresponding concept, defined in the ontology, can guarantee the correct identification of the parts and provide an immediate visual feedback about the correctness of the whole process.

Management of adverbs and adjectives: the management of additional elements, like adjectives and adverbs, is absolutely necessary. However, a new metaphor is needed since most of such elements have an abstract meaning, which is impossible to be displayed within a 3D animation. A system of visual signs or textual information can solve the problem and enrich the content of the animation.

Voice interaction: even if the proposed approach manages the input of text-based training sequence, a significant step forward is represented by the support of voice interaction. This implies the use of a reliable voice recognition system, which translates voice commands into text to be sent to the natural language parsing.

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