Natural Language Processing based Shape Grammar

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Abstract. Currently shape grammars are designed for static models and applied in limited domains. They demand extensive user skills and cannot guarantee aesthetic results. Although the current approaches to shape grammar produce infinite designs the final designs lack context and harmony. The aim of this paper is to address the contextual and harmonisation issues in shape grammar by proposing a shape grammar framework inspired by the field of natural language processing. The new shape grammar framework make use of the four levels of analysis namely lexical, syntactic, semantic, and pragmatic levels, to enhance the overall design process. In satisfying these semantically and pragmatically well-formed constraints, the generated shapes can be contextual and harmonious.

1 Introduction

Design is defined as the process of creating new structures characterised by new parameters, aimed at satisfying specific requirements [17]. It consists of several phases, namely the conceptual design, the detailed design, the evaluation and iterative redesign [17]. For the past three decades, shape grammars have been mostly used to study architectural design, paintings and product design [21]. In recent years the design generation of harmonious characters began to play an important role in computer graphics, computer games and animation [9], [16]; however manual generation of such characters is expensive as it requires highly skilled designers [10]. Computational approaches have been employed for all these stages of design except the creative conceptual design phase. This phase of design is often considered as a “black art” based on fuzzy design procedures and rules [8].

The theory of shape grammar, developed by Stiny and Gips [19], has provided a methodology to formalise the design process based on the use of primitive shapes and the transformation rules of geometric elements; however it is unable to handle organisational and contextual information. In spite of the existence of design principles and transformational rules shape grammar cannot guarantee aesthetic and harmonious results [9]. This paper aims at demonstrating how Natural Language Processing (NLP) can address these contextual and harmonisation issues in shape grammar by adding context to the original three levels. To have a harmony in character design, the four levels must be embedded in the generation engine. The *Vocabulary* of a shape grammar is a lexicon consisting of points, lines, and planes. The *Rules* define a set of syntactic structures which constrain the possible spatial and functional transfor-

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mations specific to the design object. The *Derivation* interprets these transformations by a semantic model to ensure legitimacy, consistency and compatibility. The *Context*, legitimate shapes and elements of the objects must adhere to certain contextual properties and principles of the design to achieve harmony. This approach is validated by applying it to the design of a family of humanoid characters, which are particularly relevant to the domains of computer graphics and computer games.

2 The Definition of Harmony in Character Designs

Design is the process of transforming an initial set of requirements into the explicit and complete specification of an object that fulfils those requirements [3]. A composition is harmonious when the interrelationships between its parts fulfil aesthetic requisites or are mutually beneficial [15]. In music, harmony is the technical term for the coincidence of three or more different pitches [20]. In Fine Arts, it means a union or blend of aesthetically compatible components. In colour studies, harmonious colours mean two or more colours seen together to produce a pleasing affective response [4]. In 3D character design, designers must combine elements, shapes, and personality to create a new character. In order to generate harmonious characters, the interrelationships between the colour, elements, shapes, and forms of the characters being designed must fulfil some aesthetic requisites. As a principle of design, harmony refers to a way of combining elements of art to accentuate their similarities and bind the picture parts into a whole.

3 Shape Grammar

A shape grammar begins with a *vocabulary* of shapes (e.g. points, lines, planes or volumes) and spatial relations between shapes [19] (Fig. 1). A shape is generated by beginning with an initial shape and recursively applying various transformational *rules* (e.g. shifting, mirroring and rotating) and shape operations (e.g. addition, subtraction) [11]. The main foundation of shape grammar lies in the clear understanding of the diagrammatic and parametric rules. Both rules are found quite similar in their principles; however they produce distinct results in different situations.

Diagrammatical shape grammar rules are based on a generic 2D diagram. The process starts by applying a rule to a vocabulary, one rule at a time. The applied rule(s) can be repeated several times. The structure is simple, as the vocabulary will be formulated until the satisfied shapes are achieved. Diagrammatical shape grammar is used in applications of pattern design, abstract painting and sculpture, and architecture [11], [19], [7].

A Parametric Shape Grammar is an advanced form of shape grammars which allows variation of parameters, for example changes in lines and angles of shapes [1]. The new vocabulary created by the rules is defined by parameters extending the parameter concept to all design elements. Being parametric, a greater variety of forms can be created. *Derivations* can be used as a new vocabulary, and the process is repeated again to generate a new shape or form.

Parametric shape grammars offer more flexibility in modifying shapes compared with diagrammatical shape grammar; they are used widely in applications such as product design, industrial, architecture, urban design and engineering applications [11]. However, parametric shape grammars can be difficult to implement because of the increase in complexity of local design decisions and the increase in the number of elements to which attention must be paid in task completion [22].

Although shape grammars are useful for generating a large variety of designs they still operate in limited experimental domains and fall short in support for real designs [5]. They are designed for static models [10] and demand high user skills [12]. They use only rectilinear basic elements and are mostly limited to 2D spaces or primitive 3D shapes; they also lack support for high quality design such as complex 3D geometry and cannot guarantee aesthetic results [9]. Current research approaches are primarily focused on the need to reduce the time-consuming design process and to allow designers to concentrate on their design activities, such as evaluation of designs and making design decisions [12]. However there is a greater need for a framework to support the aesthetic aspects of design, ensuring that the final design products are harmonious and contextually relevant to the technical requirements. These issues have led us to investigate the field of natural language processing as a potential solution.

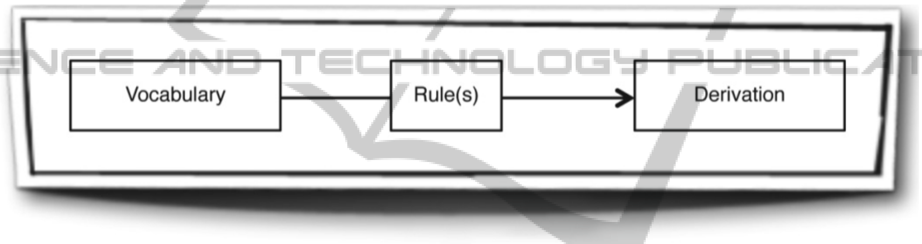

Fig. 1. Shape Grammar Basic Stages.

4 Natural Language Processing based Shape Grammar

Natural language processing (NLP) aims at developing a computerised approach to text analysis by applying both, a set of theories and of a set of technologies [13]. The traditional approach is to translate the utterances into a formal specification that can be processed further by the computer. In linguistic terms, NLP consists of six levels (Fig 2). The first two levels deal with phonology and morphology of words. The lexical level focuses on the meaning of words and their part(s)-of-speech (e.g. determiner, noun, and verb). The syntactic level is concerned with analysing the words in a sentence and uncovering its grammatical structure. The output of this level of processing is a representation of the sentence revealing the structural dependency relationships between the words. The semantic processing level determines the possible meanings of a sentence by focusing on the interactions among word-level meanings in the sentence [2]. For example, amongst other meanings, ‘file’ as a noun can mean either a folder for storing papers, or a tool to shape one’s fingernails, or a line of individuals

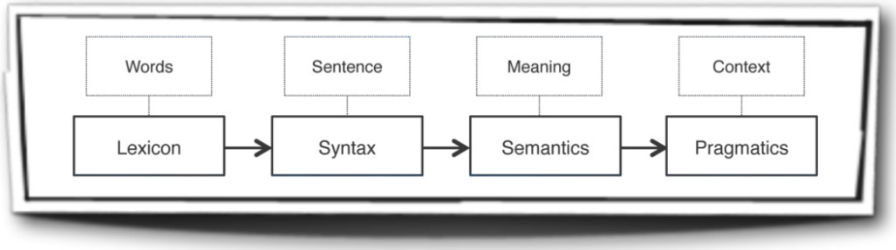

Fig. 2. Natural Language Processing Levels.

in a queue. To disambiguate the meaning of polysemous words this requires consideration of the local context, which is the task of the pragmatic level making use of knowledge of the domain. We believe that this approach can be extended to the theory of shape grammars, focusing on the last four levels in particular. Primitive shape vocabulary can be assembled together using the shape grammar rules to form a new design in the same way as lexical items can be combined using natural language grammar rules to form a well-formed sentence. The semantic level can provide a solid framework to assign meaning to the new design while the pragmatic level can focus on the context and harmony of the final design outcome (Fig 3).

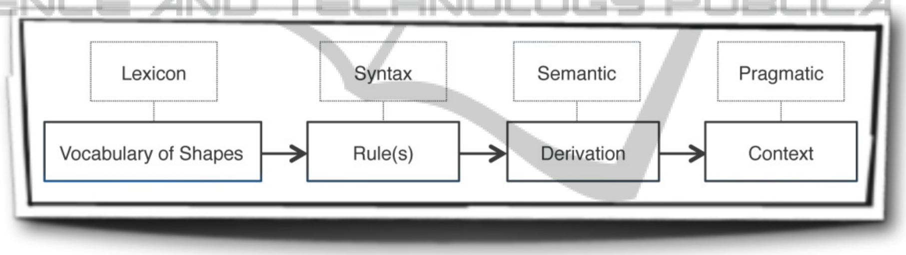

Fig. 3. Natural Language Processing Based Shape Grammar Framework.

The proposed new framework extends the traditional shape grammar by adding context to the original three levels, namely *Vocabulary, Rules*, and *Derivation (Fig. 3)*. To have a harmony in character design, the four levels must be embedded in the generation engine. The *Vocabulary* of a shape grammar is a lexicon consisting of points, lines, and planes. The *Rules* define a set of syntactic structures which constrain the possible spatial and functional transformations specific to the design object; these transformations will be interpreted by a semantic model embedded in *Derivation* to ensure legitimacy, consistency and compatibility. In *Context*, legitimate shapes and elements of the objects must adhere to certain contextual properties and principles of the design to achieve harmony.

The proposed framework is validated by applying it to generate a set of harmonised humanoid characters. According to Oxford dictionary, a humanoid is defined as “a being resembling a human in its shape”. In our research we define a humanoid as a being having human form or human characteristics. In the design of humanoid characters one has to take into consideration the concept of the uncanny valley studied by Mori who argues that near-humanlike robots/characters can appear strange [14]. The appearance of these characters can be very close to a human but not fully so that they do not evoke a very negative human reaction [18]. In our research the user can define the humanoid morphology to suit the specified application; this morphology is captured in terms of ontology and embedded into the NLP shape grammar.

Duffy [6] argues that the anthropomorphic features, such as a head with eyes and a mouth may facilitate social interaction and therefore are important. Consequently, our experimental approach focused on designing humanoid characters that can provide a positive relationship between how human characters must look like and how comfortable users are with their appearance. The humanoid characters must perform functions similar to those of human workers and appear human like consisting of a head, two arms, two legs, and a torso.

With this in mind the new shape grammar framework includes an ontological representation of what constitutes a humanoid character in its lexical, syntactic, semantic and pragmatic levels of analysis (Fig.4). The goal is to achieve context and harmony by capturing the morphology, function and organisation of the humanoid world as well as the hierarchical and contextual relationships among the characters. Consequently, the lexical level consists of the primitive geometrical shapes (e.g. polygon sphere and cube) whereas the syntactic level applies spatial and emergent transformation rules to manipulate these shapes in agreement with the ontological definition of a humanoid body. For example, the syntactic rules manipulate the polygon sphere to design the head and the cube to create the torso, arms and legs, The assembling of these design components are then refined by the semantic level, acting as the derivation phase, and dictating their spatial relations, size, weight and height, function and habitat. The generated humanoid character has to be harmonious with other members of the humanoid family, in terms of its morphology, attributes, and personality. The pragmatic level ensures that the final humanoid character design meets aesthetic criteria, context, and harmony in agreement with the design principles. For example context focuses on cohesion and coherence of humanoid features, the combination of various elements to emphasise similarities with other humanoid characters and bind the picture parts into a whole.

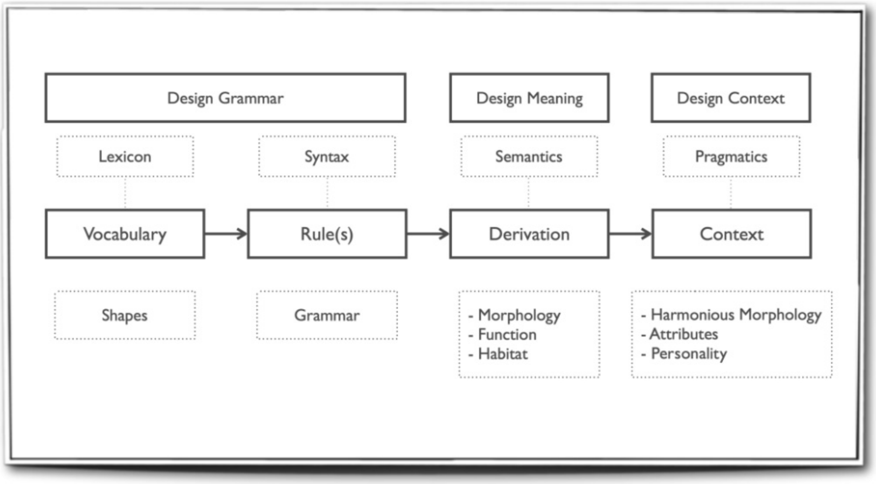

Fig. 4. Humanoid Shape Grammar.

4.1 Implementation and Discussion

The NLP based shape grammar is implemented using Maya Embedded Language (MEL) which is a scripting language commonly used in three-dimensional computer design software. As depicted in Fig. 5, the lexicon level starts with the two primitive vocabulary shapes, namely a 3D representation of a polygon sphere and a polygon cube. The syntax level is implemented using rules which manipulate the primitive shapes to create the basic morphological body components of a humanoid (e.g. head, limbs, torso). This level ensures that these components are cohesive and coherent and adhere to the defined morphology captured by an ontological representation (Fig.6). The head, body and limbs are generated using the spatial and emergent transformations grammar rules. For example, a head must be attached to a body not to limbs whilst limbs can be attached to a body but not to a head, and the size of the head must be proportional to the body. The semantic level applies the rules relevant to the habitat and associated functions; for example a terrestrial humanoid requires legs to walk whilst an aquatic character needs fins to swim. A further set of rules specify how to arrange these limbs (e.g. vertically for biped for terrestrial characters and horizontally for aquatic characters). The pragmatic level focuses on context and harmony and assigns morphological characteristics associated with a specific type of behaviour and personality (e.g. aggressive vs. friendly). For example, an aggressive humanoid character may be oversized and exhibit scars and deep wounds on his torso whilst a friendly humanoid is always smiling and gentle. Context and harmony are also achieved through appropriate selection of attributes such as colour scheme, texture, and material as dictated by the design principles (Fig 5). At the end of this level a contextual and harmonious set of humanoid parents are designed.

Applying the traditional shape grammars the derivation rules can produce 332,640 different shapes, however these shapes are randomly generated and consequently lack context, harmony and meaning. The proposed novel shape grammar provides a robust framework to generate shapes according to specific desired requirements and in agreement with an ontological representation. This shape grammar produces the first generation of humanoid characters with specific characteristics which will be manipulated by a genetic programming algorithm to generate the second and future generation of humanoid characters.

5 Conclusions

This paper has described a novel approach to shape grammar design by applying the natural language processing levels of analysis to address the lack of context and harmony in design. To validate the approach the new shape grammar is applied to the design of a set of harmonious humanoid characters which can be deployed in computer games, computer graphics and animations. This paper has described the first stage of this research project which is aimed at developing the extending the basic shape grammar. The current work has developed the ontological structure capturing the morphology of the humanoid characters and has implemented the three levels of natural language processing, namely lexical, syntactical and semantic levels in the design of humanoid characters. The next stage will require the implementation of the prag-

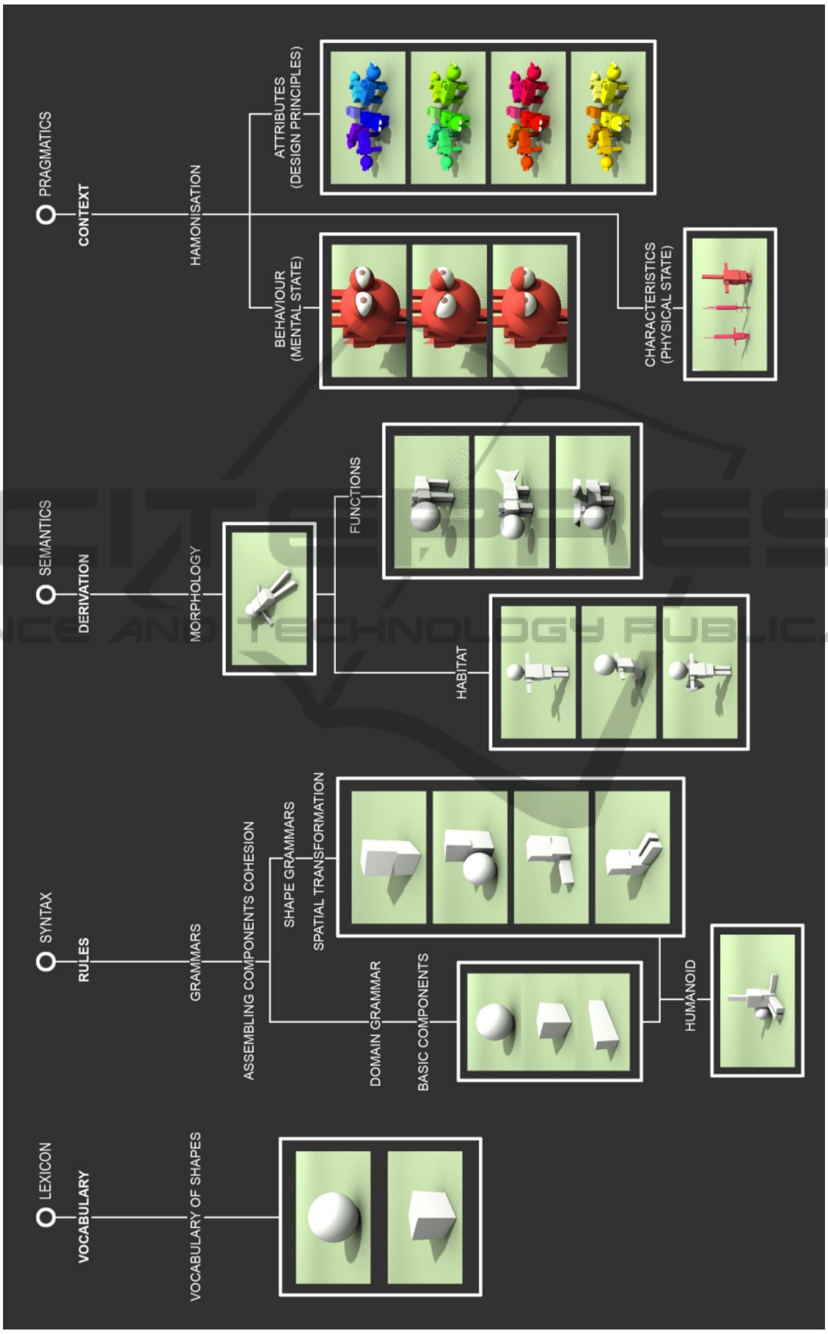

Fig. 5. Humanoid Shape Grammar using Maya MEL scripts.

matic level which involves the creation of a family of harmonious humanoid characters and the generation of offspring; this stage will focus not only on the interrela-

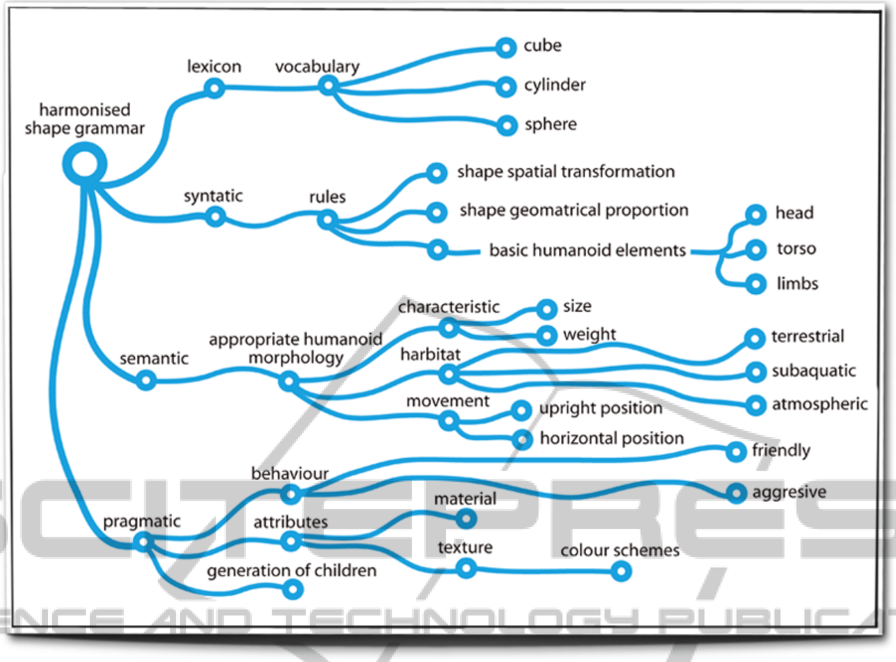

Fig. 6. Ontological representation of humanoid character.

tionships between colours, texture, and material but also on their personality, behaviour and attributes. It is proposed to augment the framework with genetic algorithms to produce the next generations to ensure that the aesthetic components are compatible and can bring a realistic feeling of belonging to the same world or story, and can combine design elements to accentuate similarity and bind parts into a whole.

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