High-level Semantics Representation for Intelligent Simulative Environments

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ABSTRACT

This article describes an integration of knowledge based techniques into simulative Virtual Reality (VR) applications motivated using a virtual construction task. An abstract Knowledge Representation Layer (KRL) provides a base formalism for the integration of simulation semantics. The KRL approach is demonstrated using a generalized scene graph representation which introduces an abstract definition and implementation of geometric node interrelations.

CR Categories: I.2.4 [Artificial Intelligence]: Knowledge Representation Formalisms and Methods—Semantic networks; I.3.6 [Computer Graphics]: Methodology and Techniques—Graphics data structures and data types

Keywords: IVE, Intelligent Virtual Environment, Knowledge based Simulation, Virtual Construction

1 THE KNOWLEDGE LAYER

AI and VR concepts have been combined in a variety of research projects using customized integration methods. The semantics of data structures commonly used for simulation tasks are predefined by the underlying technical processes in the simulation modules. Extension mechanisms do exist but they are limited in their expressiveness and often require tailored solutions which often involve data replication and synchronization which in turn is error prone. In the last few years, several approaches aim at a general way of an integration of AI techniques into VR systems [1-4]. An integration based on a common representation layer as proposed in [2] offers several advantages regarding adaptability and reusability. This approach is extended here to propose a knowledge representation layer which expresses simulation related content coequally expressed in a common format.

Figure 1 illustrates an example rod's KRL that defines all necessary relations which 1) enables its implementation with a given base formalism (here a scene-graph system with basic field routing) and 2) describes all necessary information for the advanced simulation behaviour: The part's geometry and the hole's geometric attributes are partially dependent, e.g., holes maintain their roundness during scaling operations of the main part. The part is embedded into a type hierarchy as denoted by the **is_a** relation. The part is decomposed into three sub-parts which is expressed by the **is_sub_part** relations. All parts and sub-parts have 9DOF frames of reference (FOR) for the specification of position, orientation and scaling. The sub-parts' FORs are defined to be relative to the main part's FOR via a *dependent* mapping defined by the **9DOF_dependency** which parameterizes the **9DOF_relative_to** relation using **9DOF_dep_mat** concepts and hence modulates parent-child scene-graph behaviour. The 3x3 matrices of the **9DOF_dep_mat** concepts define how the values for position (first matrix row entries), rotation (second row) and scaling (third row) are concatenated following the semantics of the **9DOF_relative_to** relation, which –in its plain assertion between two FORs– defines plain multiplication of homogenous coordinate representations.

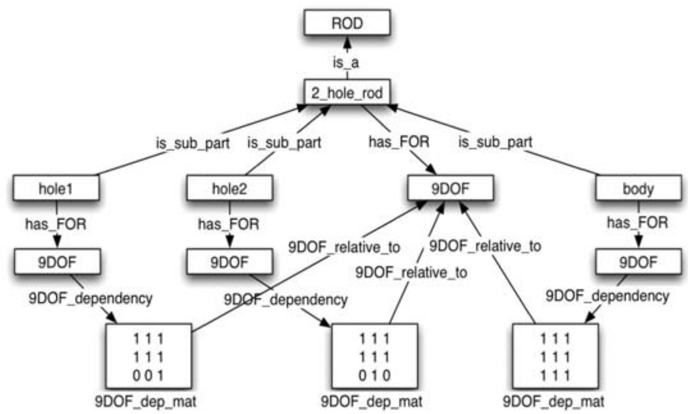

Figure 1: The example part: A rod with two holes that supports intelligent scaling operations and the associated KRL (see text).

A **9DOF_dep_mat** is further decomposed as can be seen in Figure 2. A functionally parameterized **p_coupled** relation connects every dependent attribute pair. A missing **coupled** relation represents a 0-value from Figure 1. A constant value like reflects constant mapping functions like f(x)=2 of a general mapping f(x). x represents the attribute value change of the coupled top and bottom attributes in Figure 2. f(x) denotes the parameterized application of the relation modulated by the **9DOF_dep_mat**, e.g., the application of the **9DOF_relative_to** semantics in Figure 1 which evaluates relative transformations between nodes. In Figure 2, f(x) works top-down whereas its inverse $f(x)^{-1}$ works bottom-up to allow symmetrical attribute changes.

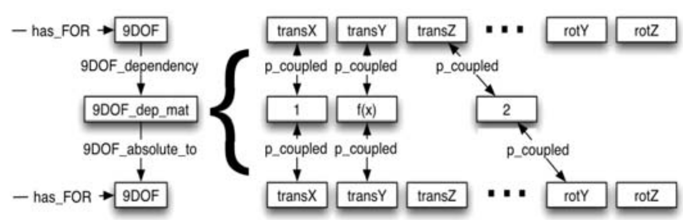

Figure 2: Parameterization of the dependency matrix. "p_coupled" relations are modulated by an additional parameter concept.

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In Figure 1, the two zeroes in the last row of the left and the middle **9DOF_dep_mat** concept define partial blocking of the following **9DOF_relative_to** semantics which defines parent-child relation between the main part and the two holes. This suppresses the consecutive impact of parent part's total scaling and only scales hole1 in the z- and hole2 in the y-direction which are the principal axes of the holes' main directions.

2 IMPLEMENTING THE KNOWLEDGE LAYER

The illustrated KRL content is implemented by specialized node types called constraint mediators (CMs). A CM is parameterized by a dependency matrix and implements the defined geometric dependencies of the KRL in the target system. CMs monitor fields and propagate the modified field-values in both directions, to establish complex constraints directly in the scene graph.

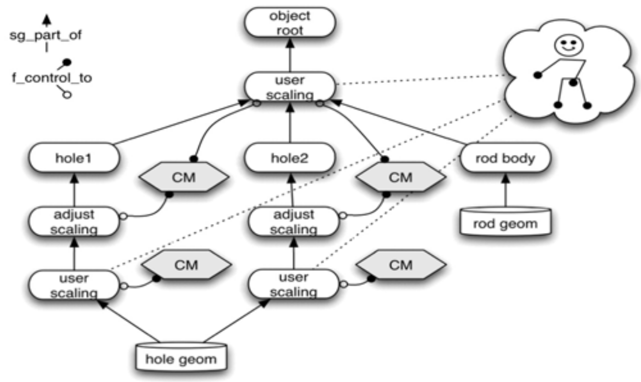

Figure 3:Scene graph section with embedded Constraint Mediators for sub-part to part dependent scaling.

In Figure 3, the CMs prevent the deformation of the holes when scaling the entire rod. When the user scales the rod in the X-direction or Y-direction the two upper CMs set the adjust-scaling of the holes to the inverse of the scaling of these directions to maintain the size and roundness of the holes. When scaling in the Z-direction—the direction of the main axis of the first hole—this hole is scaled with its parent to fit the thickness of the rod. The other two CMs restrict the user-scaling of the holes to be equal in X- and Y-direction and to the identity scaling for the Z-direction.

While the constraints for the scaling behavior are normally fixed, the simulation of part-part connections requires dynamic constraints. A KRL-ontology of mating geometries (Ports) defines different degrees of freedom for connections for each Port-type.

The example in Figure 4 illustrates how the connection between the screw and one of the rod's holes is reflected in the target system's scene graph: A CM establishes the constraints which simulate the connection of a screw fitted in a hole of a rod. The CM for the connection guards the positions of the two connected extrusion ports and—in this case—alters the matrices of the root nodes of the parts, if the positions of the ports do not satisfy the constraints that are defined for this type of connection.

The screw can be moved within the hole. Any other movement of the screw or the rod, which would break the connection, will be inhibited by the CM.

Inter-part bindings as described by the KRL can as well couple dynamic transformations changes where certain transformation parameters are linked to each other. This concept of linked transformations allows the simulation of gears in the virtual environment [5]. These gears are realized using the Constraint-Mediators for the coupling of the transformation parameters.

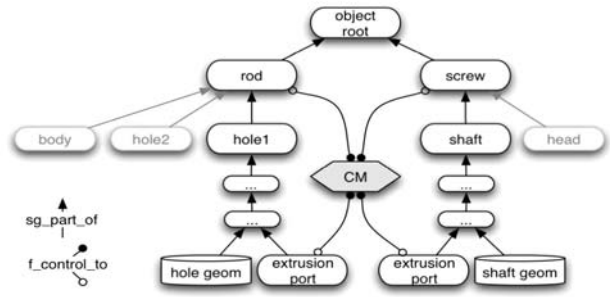

Figure 4: Scene graph section for two parts interconnected by a constraint mediator for part-part geometric dependencies.

Simple rotational gears can be generated by using a coupling of the two rotations of the corresponding sub-parts with a certain transmission factor. A coupling of rotational and translational parameters can lead, e.g., to a pinion. Since the transformation of the sub-parts includes the transformation of the mating geometries, which are connected to these sub-parts, it is possible to build mechanics, where the movement of the part and sub-parts are propagated within an assembled aggregate.

3 CONCLUSION

We have introduced an integration method for knowledge representation into VR simulation systems. It proposes an abstract knowledge representation layer (KRL) for high-level definition of complex application designs. The approach has been demonstrated for a generalized scene representation which extends the expressiveness of commonly used scene graphs.

Besides its usefulness for parametric coupling, the KRL offers a base representation for AI related tasks, e.g., it is additionally used to support novel multimodal interaction methods in VR systems where the KRL expresses conceptual and lexical information.

Future work will expand the KRL to support a variety of simulation components from different graphics packages to physics simulation libraries. Here, the final goal is a platform which conceptually allows abstract definition of VR applications via the KRL with as minimal adaptations from the utilized simulation systems core functionality.

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