The Algorithmic Beauty of Cities

Interactive Modeling and Realtime Visualization of Compact Procedural Descriptions

Von der Fakultät für Mathematik, Informatik und Naturwissenschaften der RWTH Aachen University zur Erlangung des akademischen Grades eines Doktors der Naturwissenschaften genehmigte Dissertation

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Abstract

Today's world is full of synthesized digital media like high quality renderings in form of images or movies and real time visualizations of complex environments in form of fully interactive applications such as games. Present rendering algorithms allow for the production of synthetical images that are hard to distinguish from pictures which were taken from the real world. Even with commodity hardware, high quality renderings can be finished in reasonable time. Consequently, there are many applications in practice which benefit from virtual environments. For example, many film productions use digital copies of real world locations like famous cities to easily include artificial content (e.g. crowds of people), to allow for complex camera trajectories (e.g. falling from the sky to the street level), or to simulate large scale effects (e.g. a heavy destruction of the scene). This digest of new possibilities would be very expensive or even infeasible without using virtual scenes.

One of the biggest bottlenecks in the production workflow of films and games is the content creation. The modeling of large scale virtual environments that provide a high amount of detail is a time consuming and sometimes tedious task. The problem is often compensated by just keeping a high number of artists busy, however, this solution is rather expensive and requires a lot of organisational overhead. Unfortunately, content creation is a creative task and thus, it can not be fully automatized, i.e. the visionary input of artists is still needed. This thesis is focused on the generation and rendering of cities including common entities like buildings, bridges, and plants. Instead of rationalising the work of artists, we rather aim at the development of supportive tools that utilize the expressive power of procedural modeling techniques combined with easily operated user interfaces for the intuitive and efficient insertion of creative input.

The novelties of this thesis are categorized into three parts dealing with the theoretical background of procedural modeling techniques, the interactive extensions for algorithmically generated content, and the real time visualization of compactly described virtual city models.

In the first part, the fundamental formalisms of procedural modeling techniques are discussed and analysed with respect to their application in virtual environments. An expressive but yet intuitive modeling language is presented that allows for the combination of several existing modeling strategies and thus, enables the creation of hiearchical structures (e.g. buildings and plants) as well as of interconnected structures (e.g. bridges and power poles) within one unified description. One major advantage for such a unified language is the easy interoperability of different object domains. For example, the growth process of an ivy plant is controlled by high-level semantics of the scene, i.e. the branches tend to grow towards the closest stone elements defined, e.g., by the walls of a building. In addition to statically defined geometry, an algorithm for producing plausible animations of the city development is introduced. In contrast to other approaches relying on a complex mathematical model to extrapolate a given street network into the near future, the presented method procedurally interpolates inserted real world data based on fuzzy information taken from historical city maps and books.

The second part of the thesis presents interactive extensions to the previously developed modeling language. Most importantly, there are two different views on the system. On the one hand, the presented method allows for interactive scripting combining conventional modeling tasks (i.e. creating, transforming, and manipulating geometrical shapes) with the power of procedural modeling (e.g. automatically apply the same operations on several instances of the same object). Although this is a supportive tool for artists, it still requires modeling and sometimes even scripting skills. On the other hand, procedural objects are enhanced with a set of intuitive parameters that can be manipulated in a 3D viewer. Consequently, the user never gets in touch with the underlying grammar. Having a database of self-contained procedural layouts and objects, an intuitive interface is presented that enables the fast combination and manipulation of existing elements, even for users without scripting or modeling experience.

In the third part, the efficient rendering of large scale procedural city models will be discussed. Taking a coarse polygonal model of a city, i.e. extruded floor plans, high quality textures of the facades are generated on-the-fly. This is extremely beneficial for large scale models, since the theoretical amount of data never needs to be stored explicitly. The presented algorithm evaluates the facade grammars on a per-pixel basis supporting a stochastic rule set, multiple layers, and the raytracing of 3D rooms. Furthermore, an efficient screen space method for geometry instantiation is proposed to enhance the visual quality of the rendering by additional real 3D polygonal geometry. We demonstrate our technique on a large and highly detailed city model achieving real time framerates.

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