Eurographics Workshop on Urban Data Modelling and Visualisation (2013)
V. Tourre and G. Besuievsky (Editors)

Inverse-Procedural Methods for Urban Models

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Abstract

Procedural modeling is an elegant and fast way to generate huge complex and realistically looking urban sites. Due to its generative nature it can also be referred to as forward-procedural modeling. Its major drawback is the usually quite complicated way of control. To overcome this difficulty a novel modeling paradigm has been introduced: it is commonly referred to as inverse procedural modeling, and its goal is to generate compact procedural descriptions of existing models—in the best case in an automatic manner as possible. These compact procedural representations can be used as a source for the synthesis of identical or similar objects, applied in various simulations and other studies of urban environments. We believe that this technology is still a widely unexplored ground and that it will prove itself as a very important tool in the reconstruction process. In this paper we sketch how inverse procedural modeling can be applied in the urban modeling field.

Introduction. Nowadays, modeling and reconstruction of urban environments has become an estimated multi-billion dollar industry. The reason for this progression is the wide range of possible applications, including cyber-tourism, computer games, and the entertainment industries in general, all of which have recognized the potential of virtual worlds. The generation of large urban environments has been a key aspect of several recent computer games and movies [Sey12], with modeling times reaching several man years. Furthermore, the digital maps industry has become ubiquitous and can be encountered in many everyday usage items like mobile phones and cars. Besides entertainment-inspired applications, city planners, local governments, and scientists are also using advanced three-dimensional simulation and visualization software to plan and manage cities.

Urban reconstruction is an interdisciplinary task that spans multiple fields. A recent survey [MWA*13] reviews the work done in computer graphics, computer vision, and photogrammetry and remote sensing.

A significant contribution of the computer graphics community brought into this topic is *procedural modeling*. Traditional procedural modeling introduced over a decade ago [PM01] is an elegant and fast way to generate huge, complex and realistically looking urban sites. Another survey [VAW*10] presents an overview over that topic.

The major drawback of this technique is, however, a rather complicated way of control. In order to generate a rich and plausible city model the procedural system requires a large set of rules to be defined. The number of rules that specify how a particular building, its façade, or even texture should behave increases quickly with the size of the environment or level-of-detail and becomes difficult to control and maintain.

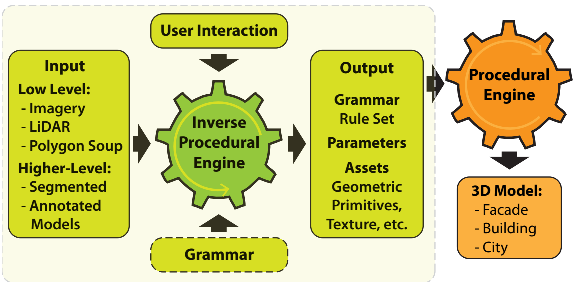

Figure 1: *Schematic inverse procedural pipeline.*

Inverse Procedural Modeling. One approach to leverage this problem—which we consider as the most promising direction for future development—is that of *inverse procedural* modeling. The inverse methodology is applicable to many types of procedural models, but such an exploration has been quite effective with respect to building models.

The most general form of the inverse procedural modeling problem is to discover both the parameterized grammar rules and the parameter values that, when applied in a particular sequence, yield a pre-specified output (cf. Figure 1). Hence, inverse methods can be roughly classified into two

DOI: 10.2312/UDMV/UDMV13/031-032

groups: (1) methods that assume a pre-defined grammar or a set of rules and determine the actual derivation and it parameters, and (2) methods that aim in the recognition of both the underlying grammar and its parameters.

Grammar Fitting. Obviously the first group is in general a simpler optimization task. On the other hand, it requires a proper rule-set, which usually has to be constructed in a manual manner. Nonetheless, this approach is still of large interest since many objects in urban environments exhibit strongly regular patterns which can be easily covered by a manageable set of rules. For example, Teboul et al. [TKS*12] introduced recently the term *façade parsing* that denotes methods that aim at knowledge-based object reconstruction, which means that they employ an a-priori top-down model that is supposed to be fitted by cues derived in an automatic manner from the data.

Discovering both the rules and the parameter values that result in a particular model effectively implies compressing a 3d model down to an extremely compact and parameterized form. For example, Stava et al. [SBM*10] proposed a technique to infer a compact L-system grammar from arbitrary 2d vector-data content. There are also approaches for reconstruction of 3d geometry (i.e. [BH09]), but their applicability ist sill very limited.

Automatization and Interaction. The ultimate goal is to provide solutions that are as automatic as possible. In practice, full automation turns out to be hard to achieve. The related vision problems quickly result in huge probabilistic optimization tasks, where the detection of regions of interest is both context dependent (top down), since we expect a specific underlying model to be fitted, and context free (bottom-up), since we do not know the actual model and want to estimate a grammar from the data.

There is no unique solution to this fundamental problem of automatic systems. For these reasons many recent approaches employ compromise solutions that cast the problem in such a way that both the user and the machine can focus on tasks which are easy to solve for each of them. Simple user interaction, which can be performed even by unskilled users, can often provide the necessary quantum of knowledge that is needed.

Input Data. There are various types of possible input data that is suitable as a source for inverse-procedural urban reconstruction algorithms. Imagery is perhaps the most obvious input source. Common images acquired from the ground have the advantage of being very easy to obtain, store, and exchange. Another type of input that is excellently suitable for urban reconstruction is LiDAR data. It delivers semi-dense 3d point-clouds which are fairly precise, especially for long distance acquisition. Several recent algorithms rely on input from LiDAR, both terrestrial and aerial [TMT10]. Other possible input are general polygonal objects of various types, e.g., man-made models or automatically reconstructed modes which can serve as a seed for inverse procedural analysis and then for further modeling [BWS10]. Yet another is to provide segmented and annotated models. For example, the input could be an interactively segmented façade model [MWW12] that serves as source for an automatic algorithm that extracts a grammar. Such an approach results in fact in scaling of user interaction.

Finally, an aim for the future is the incorporation of various data types in order to combine their complementary strengths: imagery is inherently a 2d source of extremely high resolution, a laser-scan is inherently a 3d source of semi-regular structure, polygonal models contain topological information about the shape, and annotated models provide higher-level semantic knowledge.

Conclusions. Inverse procedural methods promise higher-level shape analysis and understanding, semantic segmentation, scalability of user input and a high degree of automatization—all aspects that are of extreme value for urban models. On the other hand these methods are still not well researched and the current solutions are in their infancy. For this reason, there is room for contributions and we expect more exciting papers on this topic in the future.

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