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Technical Section

Stylistic indoor colour design via Bayesian network

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ABSTRACT

Colour plays an important role in interior design. A good colour scheme can usually convey some particular design philosophy and define a specific household style. Given the planar shape and functional type of a room, and a set of furniture for which a subset has a specified colour, this paper proposes a data-driven approach to automatically assign colours to the rest of the room and furniture items such that the whole colour tone is harmonious. We first train a Bayesian network to inherently encode the dependency between decorative styles and furniture colours, as well as the relevancy between furniture colours themselves, using a real interior design dataset. An optimal colourization is then obtained by maximizing the conditional joint probability of the colour assignment. This process encourages frequently used colours and punishes any deviation from the specified colours. To increase the diversity of colours, we design a strategy to jitter colours assigned to furniture items. In addition, a colour transfer scheme is adopted to support the mapping of arbitrary textures while sustaining the whole colour tone. A series of experiments demonstrate that our approach is effective and able to generate practical results.

1. Introduction

When moving to a new house or replacing old furniture, people often wish to decorate the indoor scene with new furniture that creates a harmonious colour scheme. An enhanced awareness of interior design aspects has raised new demands on furniture placement and colour design [1]. In addition, colourization has applications in game development, animation production, and virtual world design [2].

Psychological studies have revealed that colour can influence people's mood and stimulate emotion [3]. For example, 'Warm' colours usually motivate a warming, active, and positive affection, whereas 'Cool' colours may awaken melancholy, sentimental, and depressive feelings. Furthermore, cool colours can enlarge the space of a small room and build a kind of quiet atmosphere, whereas warm colours are able to close the distance between objects and make a large interior scene look more lively [1]. As most human activities take place in interior spaces, a good colour design for these scenes plays an important role in our life. Colourizing an indoor 3D scene is challenging as it involves a variety of disciplines such as chromatology, psychology, optics, and architecture [4]. There are many "rules of thumb" in traditional interior colour design. For example, colourization of a room space usually begins with either a colour impression of the whole scene or colour compensation for defects in the room space, and proceeds in the order of background (walls and floors), dominant objects, supporting roles, and decorative ware [5]. Manually specifying colour attributes for objects in a room is rather laborious and tedious, even for professional designers. It is more difficult for ordinary users to select proper colours for furniture when decorating a room. Hence, an automatic recommendation system would be very helpful to non-professional users for decorating interior spaces in their homes or offices.

Relatively few studies have addressed the issue of colour assignment to indoor scenes, though some researchers have attempted to support interior colour design by combining computer-aided techniques, modern colour theory, and interior design methodology [6]. Nevertheless, there have been investigations into colour collocation in fields of daily life such as compatible colour matching for dressing [7], optimal colourization of geometric patterns in an image [8], and the material assignment of 3D object components [9]. Compared with these studies, colourizing the indoor walls and furniture in a room is more complicated. The first problem is that the large number of indoor objects makes it challenging to collect and organize training sets. Next, the number of locations and types of furniture increase the complexity of mathematical modelling. Moreover, it is hard to handle the variety of colours, patterns, and textures found in modern furniture.

In this paper, we describe a data-driven approach that addresses these issues. To focus our attention on the technical aspects, we take bedrooms as an example. Given a 3D bedroom, a set of furniture, and

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a decorative style, we set colours for the furniture items and walls of the room such that the overall colour tone of the room space is harmonious. Our approach includes three stages. First, a set of bedroom images are labelled as a training dataset. Second, a Bayesian network is trained based on this dataset to capture the colour dependency of different furniture for a specified decorative style. Finally, the colour assignment issue is cast as an optimization problem and solved using a simulated annealing algorithm. Our main contributions are as follows:

- A Bayesian network probability model for furniture colouring is established for five popular decorative styles. The training database consists of 600 interior design scenes (each scene has 2–5 images of different views) from a Chinese professional decorating website [10]. Each object in these images is labelled with the average colour of pixels within its regions.
- Colour assignment of 3D indoor scenes is cast as the problem of maximizing some form of conditional (joint) probability. Given a set of furniture with the colours of a subset and/or the specified decorative style, the algorithm computes the optimal colour assignment for all other objects in the room.
- To increase the diversity of colour assignments, we establish a principal component analysis (PCA)-based probability model to simulate colour variation under a specific decorative style.
- We introduce the colour transfer technique to change the colour tone of textures with assigned colours. This enables our approach to support the mapping of textures of arbitrary patterns onto furniture while preserving the overall colour tone determined by the optimal solution.

2. Related work

We concentrate on the fields of furniture arrangement, colour or material assignment, and some methods on data-driven design. Our method is closely related to these fields in terms of either application background or solution strategy.

Furniture arrangement: A lot of research has addressed the issue of furniture layout in an interior space. Early approaches [11–13] usually require user intervention and rarely involve interior design theory. Recent work [14,15] takes into account ergonomic factors or interior design guidelines. Yu et al. extracted spatial, hierarchical, and pairwise relationships from positive examples as priors that are then assembled into a total cost function [14]. Merrell et al. [15] established an optimization model for furniture arrangement by identifying some important functional and visual criteria. Global optimization algorithms such as simulated annealing can become trapped around local extrema when solving highly coupled optimizations because of pairwise furniture constraints. Hence, Chen et al. [16] proposed a hierarchical furniture tree to decouple some unimportant constraints and improve the layout quality and efficiency. Given a few scenes, Fisher et al. [17] established a probabilistic model by learning these examples and further synthesizing diverse layouts of 3D objects. Xu et al. [18] presented a framework that automatically generates a scene from a sketch and jointly performs co-retrieval and co-placement techniques. Though the aforementioned methods can usually create impressive object layouts, none of them take the colour design into account.

Colour and material assignment: The outfit synthesis system developed by Yu et al. [7] employs a Bayesian network to describe the probability of different dress items appearing simultaneously in an outfit. Given a set of colours defining the colour tone of a body, plus a wardrobe of clothing items, the system suggests a set of outfits subject to one of five particular dressing styles by optimizing a conditional probability energy. Jain et al. [9] used a probabilistic factor graph to model the context-dependent correlation between the geometric shape of parts of a 3D object and their material properties in their material suggestion system. Though the approach works well in assigning material properties, it does not support texture mapping and fails to consider colour compatibility. Nguyen et al. [19] presented a method that uses combinatorial optimization to transfer the material style onto a 3D scene from an image or video. Lin et al. [8] trained a model on example patterns to statistically capture the stylistic properties of these patterns. Given a segmented image and a colour palette, Kim et al. [20] proposed a perception-based approach to assign colours in the palette to segments of the image. Instead of learning given examples, their algorithm casts the colour assignment as an optimization issue that maximizes the colour harmony, luminance contrast, and some application-specific requirements such as stability, continuity, and similarity. The Magic Decorator system developed by Chen et al. [21] automatically generates material suggestions for hierarchically organized 3D interior scenes by learning both local material rules and global aesthetic rules using an image dataset of indoor objects and scenes. Motivated by an outfit synthesis system [7], we train a Bayesian network to extract the relation between the colours of different objects in indoor scenes. However, we are dealing with 3D scenes instead of 2D images. In addition, the number and location of the objects to be assigned with colours vary from case to case. In particular, the infinite number of colour possibilities for furniture items makes the problem more difficult. Both the magic decorator and our approach focus on interior colour design; however, we model the relationship between the colours of objects instead of the materials and textures. We cluster the sampled colours in the training stage in order to make the problem tractable, and then perturb the suggested colours in the assignment stage to enrich the colour of the interior space. In addition, we support the mapping of arbitrary textures by transferring the colours suggested by our system to the textures being mapped in order to preserve the colour tone.

Data-driven suggestion: Data-driven techniques are widely used in various design fields where numerous examples created by professional designers can be easily accumulated. By learning rules from these examples, algorithms are able to support artists or ordinary users to effectively create the desired content [22–25,17,26]. The most common framework for this approach consists of two stages. The first stage employs probabilistic models such as probabilistic factor graphs and Bayesian networks to extract the probabilistic dependency between attributes or features attached to different objects (regions). The second stage finds an optimal suggestion by maximizing some kind of conditional probability [17,26,23]. For example, Fisher et al. [17] proposed a method to synthesize new 3D scenes using a Bayesian network trained from a large database of 3D scenes. Merrell et al. [23] trained a Bayesian network using architectural programs in order to generate good building layouts automatically. Inspired by these approaches, we employ a tree-augmented naive (TAN) Bayesian network to discover the underlying colour dependency between room walls, furniture items, and decorative styles.

3. Overview

Decorating a house involves a number of tasks such as the functional partitioning of the room space, geometric and material design of indoor walls and floors, furniture arrangement, and the colour and texture design of objects in the room [1]. A good decorating scheme should perfectly unify function and style. It is not easy to quantify the rules of interior decoration, which are usually subjective and dependent on designers' knowledge and experience [5]. Data-driven methods have been successfully used to

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