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研 究 終 了 報 告 書

「計算機による伝統木工支援／Computer-Assisted Wood Craft」

研究期間： 2021 年　10 月～　2024 年　3 月
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1．　研究のねらい

The development of fabrication devices has given rise to an active research area of computational manufacturing. Researchers have developed various methods to create 3D geometries appropriate for each fabrication device. However, computer interfaces for design exploration of artifacts are typically material-agnostic. They assume uniform material properties and, to some extent, unlimited material resources. The physical material from which the object will be made is not considered until the design is finalized, when 3D data is exported for computational fabrication. This setup stands in contrast to handcraft, where artisans see and feel the material while exploring a design, which allow them to intuitively judge the physical limitations of the material and to update the form and processing accordingly. This observation invoked the research question, how can we analyze existing materials to make a material-aware systems? Doing so could potentially enable smarter user of material resources, both in terms of quality of the fabricated artifact and in terms of maximizing the resources at hand.

2．　研究成果

（1）概要/Overview

The vision of the computer-assisted wood craft project is to develop methods for modeling digital twins of the complex and volumetric structure of wood to enable material-aware design and fabrication. We have achieved two main research results: (1) a procedural framework based on internal skeleton data, and (2) a learning-based method for solid texture inference.

（2）詳細/Details

1. Procedural Knots (2021-2022)

Procedural texturing is a highly efficient texturing technique that has been developed for rendering virtual content of games and videos [1, 2]. In contrast, we aimed to use the same technique for creating a virtual version of physical material. We achieved this by developing a procedural framework that takes the internal skeleton of a tree log as input, data which can be extracted from computer tomography (CT) scans [3], and outputs an annual ring pattern on a rendered surface (Fig. 1). Moreover, ours is the first procedural texturing method to reproduce the 3D structure of knots, a common feature of especially softwoods that are caused by branches growing out from the stem of the tree. This project was presented as a journal-track full-length technical paper at SIGGRAPH 2022 in Vancouver, Canada (成果論文, item 1), which is top international conference for computer graphics (acceptance rate 22% in 2022). We were further invited to published a short Japanese version of the paper for Visual Computing (VC) 2022 in Kyoto (成果論文, item 2) and to present the paper at the Top Conference Session of Forum for Information Science and Technology (FIT) 2023 in Osaka. Also, researchers from several international leading companies, including IKEA and Adobe, expressed interest in the project.

Figure 1. Synthetically generated wood textures with knots based on input internal skeleton data.

2. Inference. Learning-based (2022-2023).

The above project (*1. Procedural Knots*) concerns the forward modeling of the annual ring pattern of wood. In this next project, we addressed the backward modeling problem: to infer an internal volumetric texture based on the visible exterior surfaces of a physical block of wood (Fig. 2). To achieve this, we trained a generic network based on procedurally generated volumetric annual ring patterns. Then, we used this trained model infer the interior global structure based on manual annotations of year rings on the exterior surfaces of a physical wood block.

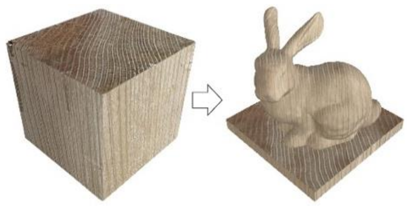

Figure 2. The appearance of a cut surface (right) is predicted based on photographs of the visible exterior surfaces of a wood block (left)

References

[1] Liu A., Dong Z., Hasan M., Marschner S. Simulating the structure and texture of solid wood. ACM Transactions on Graphics (2016)

[2] Marschner R., Westin S., Arbree W., Moon J. Measuring and modeling the appearance of finished wood. In ACM Transactions on Graphics (2005)

[3] Grönlund A, Björklund L., Grundberg S., Berggren, G. Manual for pine log data. Technical Report. Lulea Technical University (1995)

3．　今後の展開

The focus of the research plan is the modeling of wood grain. This technology has the potential to enable downstream applications in three main areas: classic fabrication and manufacturing, the

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wood mill industry, as well as material texturing.

Fabrication and Manufacturing. Solid texture inference is useful for predicting the appearance of wood artifacts before fabrication by subtractive manufacturing, such as milling or cutting. It could also enable predicting material deformation and strength, properties which are closely linked to the grain pattern.

Wood Industry. Significant efforts are being made to analyze grades (e.g., by simulating material strength) and to adapt plank cutting patterns to maximize their average grade. In this context, solid wood pattern data is typically captured by CT scanning or surface laser imaging (the latter contains information of the fiber directions on the surface). Our research on solid wood texture inference has the potential to significantly facilitate such data modeling, as the input is photographs from a regular camera.

Material Texturing. Although our research focuses on modeling wood to the likeness of physically existing samples, the output can also be useful for purely virtual applications, rendering objects in videos and games. The reason is that texture inference could simplify the material texture design process for artists, especially when it is desirable that the texture closely resembles a given material exemplar or a reference image.

In these ways, the proposed research will contribute to making the real world more computable, and with that, to use material resources more efficiently.

4． 自己評価/ Self-evaluation

Thanks to the support from ACT-X, I was able to pursue an original research theme. Based on the objective to enable material-aware design and fabrication systems, I focused on the modeling on the volumetric texture of wood grain. Although the first objective of the research were design and fabrication related, it became evident that this topic of research is also relevant to other fields including realistic rendering of materials and material simulation in wood industry. Therefore, I focused on modeling “digital twin” of wood material such that it can be utilized in a variety of downstream applications.

5． 主な研究成果リスト

（1）代表的な論文（原著論文）発表

研究期間累積件数： 3 件

1. <u>Maria Larsson</u>, Takashi Ijiri, Hironori Yoshida, Johannes A. J. Huber, Magnus Fredriksson, Olof Broman, and Takeo Igarashi. “Procedural texturing of solid wood with knots.” SIGGRAPH / ACM Trans. Graph. 41, 4, Article 45 (July 2022), 10 pages.
In this journal-track full-length technical paper, present a procedural framework for modeling the annual ring pattern of solid wood with knots. Although wood texturing is a well-studied topic, there have been few previous attempts at modeling knots inside the wood texture. Our

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method takes the skeletal structure of a tree log as input and produces a three-dimensional scalar field representing the time of added growth, which defines the volumetric annual ring pattern. First, separate fields are computed around each strand of the skeleton, i.e., the stem and each knot. The strands are then merged into a single field using smooth minimums. We further suggest techniques for controlling the smooth minimum to adjust the balance of smoothness and reproduce the distortion effects observed around dead knots. Our method is implemented as a shader program running on a GPU with computation times of approximately 0.5 s per image and an input data size of 600 KB. We present rendered images of solid wood from pine and spruce as well as plywood and cross-laminated timber (CLT). Our results were evaluated by wood experts, who confirmed the plausibility of the rendered annual ring patterns.
2. Maria Larsson, Takashi Ijiri, Hironori Yoshida, Johannes A. J. Huber, Magnus Fredriksson, Olof Broman, and Takeo Igarashi. 節目を持つ木材の手続き型 3 次元テクスチャ. VC '22: Visual Computing. Kyoto, Japan. October 2022 (short paper, Japanese version of [1]).
この抄録は,SIGGRAPH 2022 で発表された論文の解説を行うものである.本研究では,内部構造を考慮しながら木材の 3 次元テクスチャを生成できる手続き型の手法を提案する.提案手法は,樹木形状に関する情報が入力されると,樹木の成長を表すスカラー場を構築し,これを年輪構造に変換する.提案手法は GPU シェーダとして実装でき,ひとつの 3 次元画像当たりのデータサイズは約 600 KB,レンダリング時間は約 0.5 s である.提案手法の有効性を示すため,パイン材,スプルース材,合板など,節目を持つ多様な木材の 3 次元テクスチャを生成した例を紹介する.
3. Maria Larsson,* Takashi Ijiri,* I-Chao Shen, Hironori Yoshida, Ariel Shamir, Takeo Igarashi. "Learned Inference of Volumetric Annual Ring Patterns of Wood." (in submission)
In this full-length technical paper, we propose a method for inferring the internal anisotropic volumetric texture of a given wood block from annotated photographs of its visible external surfaces. The global structure of the annual ring pattern is represented using a continuous spatial scalar field referred to as the growth time field (GTF). First, we train a generic neural model that can represent various GTFs using procedurally generated training data. Next, we fit the generic model to the GTF of a given orthogonal wood block based on surface annotations. Additionally, we apply image translation to render orientation-dependent small-scale features and colors on a cut surface. We show rendered results of various real wood samples. A quantitative study on real data demonstrates that our learned model infers the internal structure more accurately than naïve interpolation. Our method can benefit applications such as cut-preview before fabricating solid wood artifacts.

（2）特許出願

研究期間全出願件数： 0 件（特許公開前のものは件数にのみ含む）

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（3）その他の成果（主要な学会発表、受賞、著作物、プレスリリース等）

Other domestic conference publications/presentations:

- Workshop on Interactive Systems & Software (WISS) 2021
- Forum on Information Technology (FIT) 2023

Community Service

- Session Chair at Pacific Graphics, Kyoto, 2022
- Paper Committee Member of SIGGRAPH Asia 2023

Other

- PhD Dissertation completed 2023
- 2023 Recommended Dissertations (2023 年度研究会推薦博士論文速報), IPSJ
- WiGRAPH Rising Star in Computer Graphics 2022