Shadow Art Kanji Inverse Rendering Application

William Louis Rothman
College of Computing, Data Science, and Society
University of California, Berkeley
Berkeley, California, United States

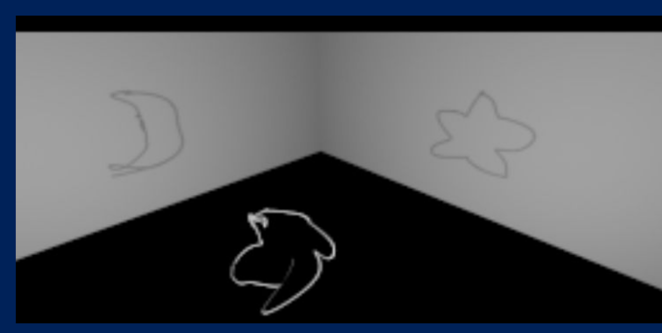
Yasuyuki Matsushita, Ph.D.
Graduate School of Information Science and Technology
Osaka University
Suita,Osaka, Japan

(QR Link to Paper)

Abstract: Finding a balance between artistic beauty and machine-generated imagery is always a difficult task. This project seeks to create 3D models that, when illuminated, cast shadows resembling Kanji characters. It aims to combine artistic expression with computational techniques, providing an accurate and efficient approach to visualizing Japanese characters through shadows.

Introduction

Problem Description: Given target shadows *P, Q,* and *R*, create one mesh that can project all Kanji as shadows.
Solution: Use voxels (3D pixels)!
Represent this as tensor $x \equiv T \in \{0, 1\}^{n \times n \times n}$


Source: *Mitsuba* website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Models

Linear Programming Model

Objective:
Optimize the following system of linear inequalities.

$$\max \sum_{i,j,k\in[n]} x_{i,j,k} \text{ s.t. } \begin{cases} 0 \le x_{i,j,k} \le 1 & \forall i,j,k \in [n] \quad (1) \\ \sum_{i\in[n]} x_{i,j,k} \le nP_{j,k} & \forall j,k \in [n] \quad (2) \\ \sum_{j\in[n]} x_{i,j,k} \le nQ_{i,k} & \forall i,k \in [n] \quad (3) \\ \sum_{k\in[n]} x_{i,j,k} \le nQ_{i,j} & \forall i,j \in [n] \quad (4) \\ \sum_{i\in[n]} x_{i,j,k} \ge P_{j,k} & \forall j,k \in [n] \quad (5) \\ \sum_{j\in[n]} x_{i,j,k} \ge Q_{i,k} & \forall i,k \in [n] \quad (6) \\ \sum_{k\in[n]} x_{i,j,k} \ge R_{i,j} & \forall i,j \in [n] \quad (7) \end{cases}$$

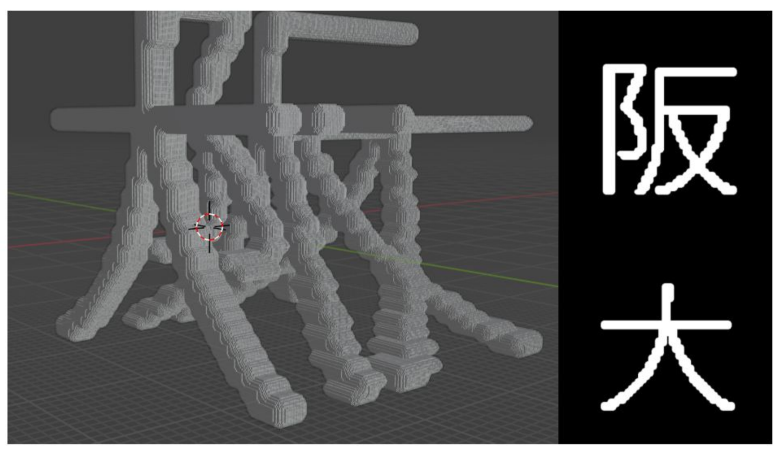
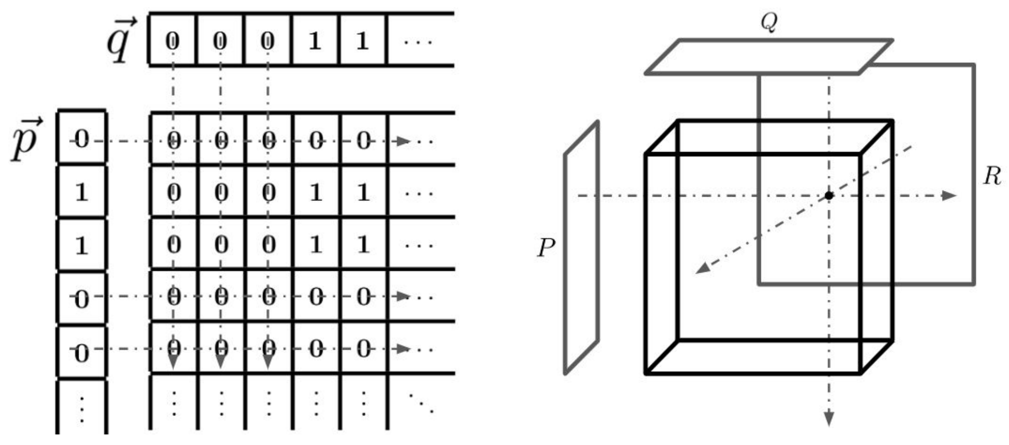


Fig. 5. A rendered, anti-aliased mesh with $(n, N) = (32, 8)$.

Method:
- Fast HiGHS algorithm to solve for each tensor entry, $x_{i,j,k}$.
- Allowable error tolerance $\epsilon > 0$.
- Continuous output $0 \le x_{i,j,k} \le 1$ or else it is NP-Complete.
  - Output later classified into binary using global threshold λ: $\lambda > \epsilon$.
- Anti-aliased with N = 8 subsamples per voxel.
  - Satisfies Nyquist Theorem.

Direct Carving Model

Objective:
Use geometric normals to carve off unneeded voxels.



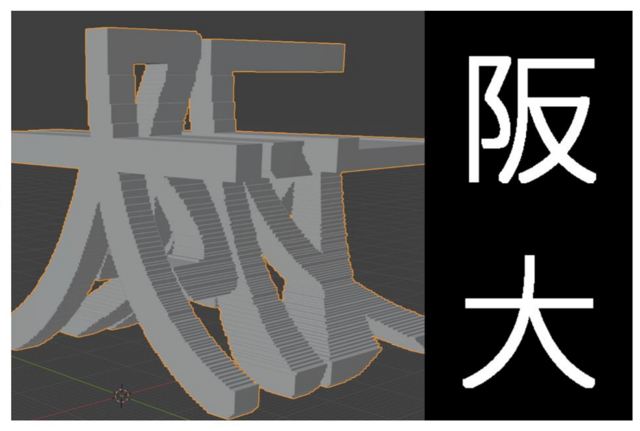


Fig. 7. Directly carved mesh— a much higher resolution is possible with the same runtime.

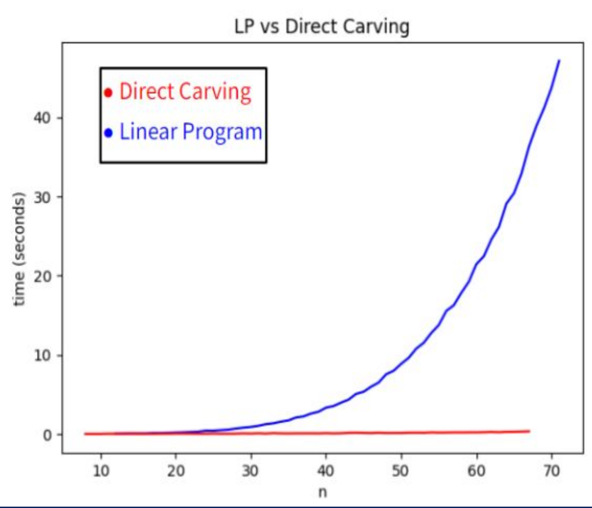
Method:
- Start with an all 1's tensor.
- For a of the three planes, for all 0 pixels in that plane, delete all tensor voxels orthogonal to that pixel.
- Method is generalizable to arbitrarily high dimensions.

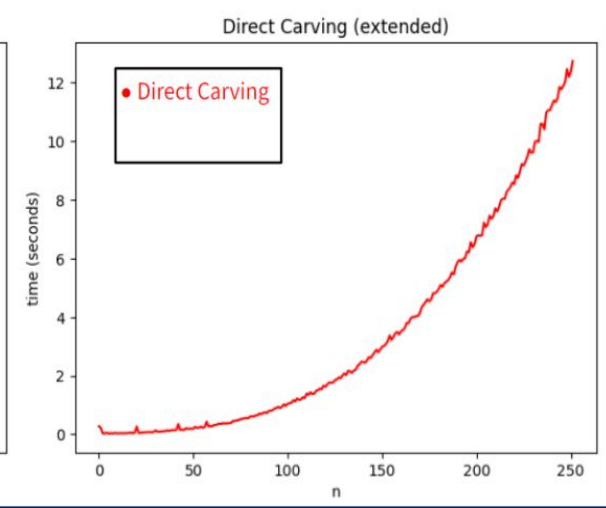
TABLE I
RUNTIME SUMMARY

	Theoretical	Empirical
Linear Programming Model	$O(n^6)$	$0 \pm n^{4.022}$
Direct Carving Model	$O(n^3)$	$0 \pm n^{2.990}$

TABLE II
EMPERICAL RUNTIME

	$n = 64$	$n = 256$	$n = 1028$	$n = 4096$
t_{LP}	49 seconds	3.6 hours	40 days	28.6 years
t_{Carve}	0.22 seconds	14 seconds	14.5 minutes	15 hours





Results

The initial goal of this project was to inversely render models with two different Kanji as shadows, similar to the approach used for curves by W. Jakob in his publications. To achieve this, three-dimensional continuous space was simplified into a binary tensor with one to three finite planes. Two methods were employed: one optimizing a set of linear, continuous inequalities, and the other a geometric, algorithmic approach. Of these, the latter performed significantly better. Not only was the initial goal completed, but the project also successfully works with one or three shadows, provides a clear pipeline for three-dimensional printing, and generalizes well to higher dimensions.

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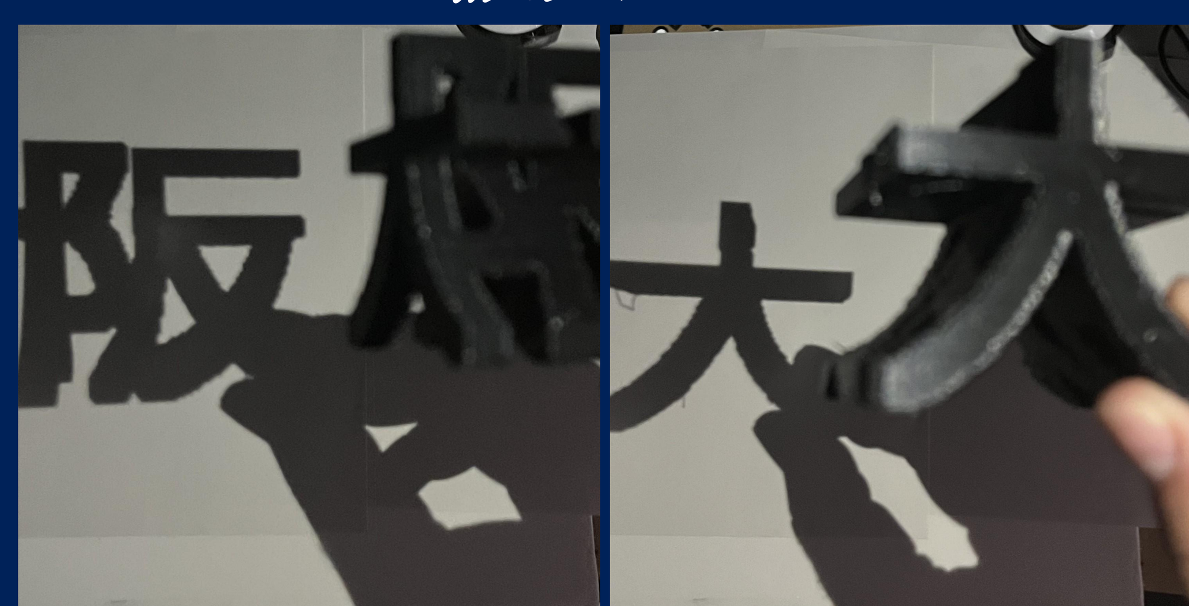

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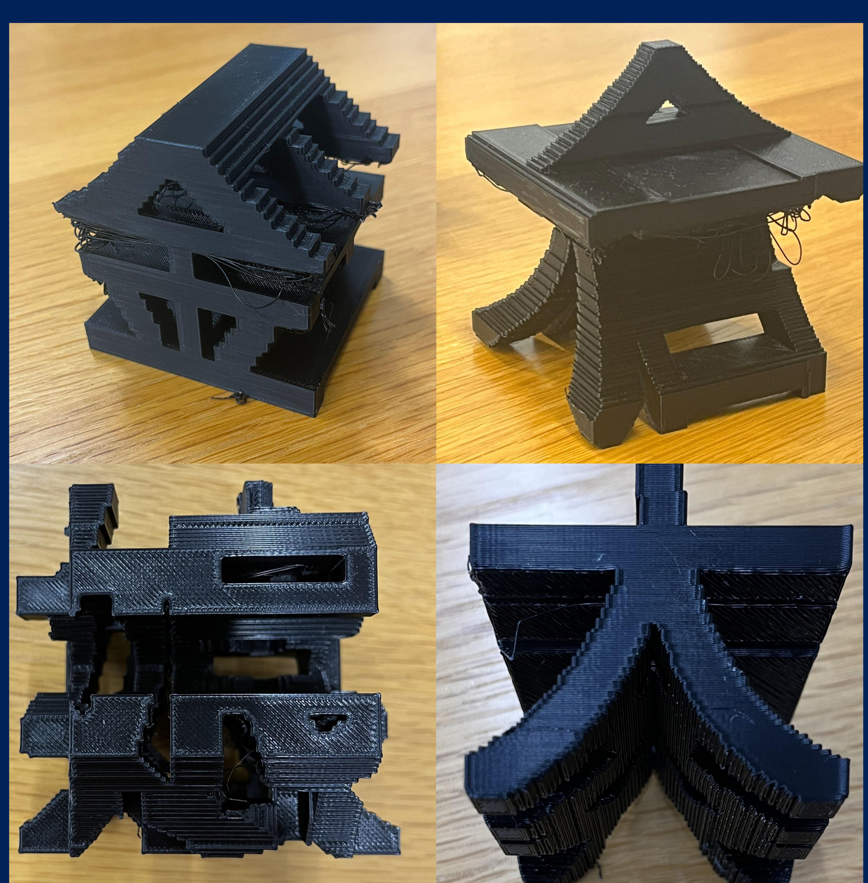

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