Printing Error: Creating Uniqueness

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Abstract

Machines are used to be well-known for doing repetitive jobs, following code produced by humans, so not often imagined as capable of producing unexpected results without direct human intervention in each unique case. The generative art broke this boundary by incorporating random variables extracted from a natural phenomenon into the coded environment. Using this method, our project introduces physical laws into 3D printing instructions; a custom slicer and G-Code compiler were developed, allowing manipulation of Z-heights of extrusions from the 3D printer so gravity can be used to generate randomness in 3D outputs. As a result, unique organic and porous forms could be created from the 3D printing process, differing from traditional, watertight solid prints.

Introduction

Each of nature's products is different. No two objects, even those formed in similar environments, are the same. As humans, we learn from nature and imitate nature, and then we create machines to mimic our actions autonomously and do jobs for us. However, so often, the uniqueness that occurs natural formation processes disappears when objects are made within a coded, controlled environment designed for identical reproduction. Every manufactured object comes in smooth and air-tight surfaces, which is different from what nature creates.

Buckminster Fuller observed that "… there are no solids in the universe. There is not even a suggestion of a solid. There are no absolute continuums. There are no surfaces. There are no straight lines." The authors of this work were drawn together by our shared interest in porosity and nonuniformity, as shown in a natural example, stalagmites; developed a method to hack a 3D printer to print in a way that resembles natural processes. Conventional 3D printing "best practices" encourage the designer to generate "watertight solids" for error-free slicing and durable fabrication. In this project, we explore an alternative form of G-Code (ISO 6983-1:2009) generation, manipulating the starting Z-height of the extrusion point so gravity can create randomness within the rigidly coded environment. We hypothesize that the randomness will mimic nature's surfaces and forms; the visual of mingled wiggly lines stacked chaotically almost resembles the surface of a cotton ball or cocoon. Individual prints from the same code will be unique.

Randomness and Creativity

According to Colton and Wiggins (2012), the definition of Computational Creativity research is 'The philosophy, science, and engineering of computational systems which by taking on particular responsibilities, exhibit behaviors that unbiased observers would deem to be creative.' People tend to attribute any creative outcomes resulting from computations to human coders, and the human has a constant predilection in their choice. Hence, the authors state that the coder role should remain as an unbiased observer for truly computational creativity.

The question is, 'Although the coders do not put any bias into the code, what makes the machine creative if all the outcome is the same all the time?' There are no unreasonable components in a machine's calculations; it does not produce any noble outcomes that differ from others so that they can have values. Thus, we suggest using randomness is one of the solutions to represent computational creativity that stays out of humans' biases effectively while it still creates unique outcomes.

Using Physical Properties to Generate Randomness

Random numbers are typically generated through HRNG (hardware random number generator) or TRNG (true random number generator), programs commonly used in gambling, juror selection, and military draft lotteries. These devices use physical phenomena as variables operating independently of bias from the human coder. Frequently, noise signals from thermal or quantum phenomena are used for this purpose.

Stalagmites

Stalagmites form on cave floors through the accumulation of material dripping from above. Thus, gravity plays an essential role in this development, generating unique forms due to differences in the heights between cave ceilings and floors and variable material properties (lava, minerals, mud, peat, pitch, or sand, among others). Our choice of gravity as the physical variable mimics these biological formations; it suits the creation of 3D objects as we desired.

Related Works

The notion of superseding deterministic algorithms and harnessing randomness to create novel outcomes has been previously explored in multiple domains. Rashel and Manurung (2014) developed an Indonesian poetry generator with a combination of random factors to generate diversity. Similarly, Tomašič, Žnidaršič, and Papa (2014) created a random slogan generator to enhance brainstorming process. However, both focus on algorithms for order and choice of words; it seems distant from using nature variables and creating 3D as an outcome. Michael and Simon (2015) extended their research to video games' contents and colors, but they state that random features limit the machines' ability to make intelligent choices rather than promoting it; thus, they focused on generating preference code, which is made through subjective computation.

In that sense, the generation of novel 3D objects that can be 3D printed is similar. Joel, Sebastian, and Jeff (2016) use an advanced algorithm that is not bounded by strict mathematical coding and creates more arbitrary outputs. However, the work concentrates on the translation of 2D image as a base of the creation to smooth 3D objects using a deep neural network, and do not introduce any physical properties as randomness creating agents to give variance in 3D printed results. Claire, AlOthman, and García del Castillo y López (2018) propose a method to 3D print large spatial lattices of porous clay structures. However, as opposed to using this method to generate diverse objects, the authors incorporate real-time self-recalibration mechanisms to counter the unpredictability of the material deposition.

Printing Error

The PRINTING ERROR slicing tool helps the user generate patterns and translate them into 3D forms. This tool is created using Grasshopper, a Rhinoceros 3D CAD (Computer-Aided Design) software's visual programming plug-in. The user can then experiment with the distance between layers, introducing an element of chaos into the print— though the PLA (Polylactic Acid) filament begins to curl if the distance is too high. The slicer helps familiarize the user with a new set of tolerances and practices, such as beginning and ending a fragile experimental print with a tight structure to prevent it from unraveling.

Slicing

When a 3D model is sent to a 3D printer, the printer's software automatically slices the object in the XY plane with about 0.3mm gaps between each line, the thickness of the melted PLA filament. This results in a watertight solid. We hypothesize that if the gaps between lines increase, the melted PLA filament will fall below the layer unpredictably. To manipulate the Z-height of the gap, we developed our slicing algorithms, incorporating custom patterns that add spatial movements of the print head in the three dimensions. With the slicer, users can input their desired 3D form to extract lines on XY planes. Users can then determine the number of layers by typing numbers they want.

Pattern - Distortion

The adjacent layers of extracted lines can be grouped. Users can select different patterns for each layer or group. Each layer will contain one continuous line, representing the 3D printer nozzle route, and will be divided into number segments, then distorted in angles to make a pattern.

3D Print

After lines are converted into desired patterns, they are translated into G-Code. It contains instructions for 3D printers, including not only the coordinates for shapes, but also nozzle printing speed, nozzle temperature, and bed temperature, which are important factors that affect outcomes. The extent might differ depending on the type of printers, but users can adjust those factors.

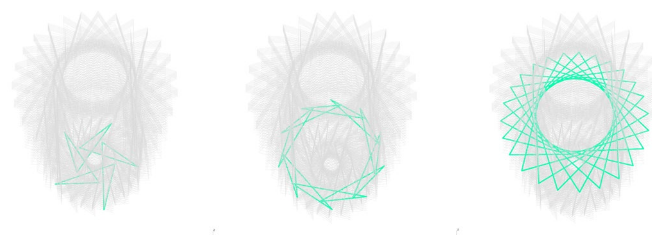

Figure 1: This is a simulation of the G-Codes generated by the PRINTING ERROR slicing tool. The original 3D form was a sphere.

Z-height of Extrusion

There was a limitation on the maximum z-height of each gap between layers; typically, the gap exceeding 1.8mm counted as an error, and the printer stopped printing.

Figure 2: The 3D printer builds up layers with different heights, creating unexpected wobbly shapes.

Printing Speed
Printing speed was one of the critical aspects to consider. Slower extrusion rate resulted in increased PLA filament curling and created more chaos in the outcome.

Nozzle Temperature
The nozzle temperature needed to be set up differently according to types of PLA filament but typically ranged between 260-310 °F. The higher temperature of extruded PLA filament tends to bond with the bottom layer well.

Bed Temperature
Lack of a supporting structure on the bottom and low-density structure causes the object to move around easily while printing. Thus, higher bed temperature was essential for it to stick to the printing bed firmly.

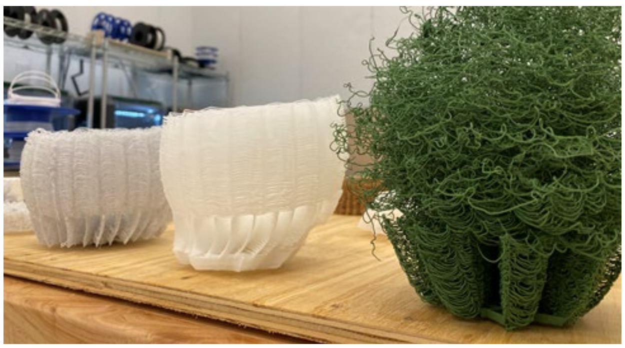

Figure 3: Low bed temperature made models not stick to the ground, so they moved and shifted while printing.

Different Types of PLA filament
When experimenting with our slicer, decay was on our mind: we printed a series of objects using biodegradable wood- and algae-based PLA filament, pursuing forms that would be strong enough to retain soil or serve as scaffolding for growing mycelium, but fragile enough to succumb to biodegradation over time. We were drawn to the transparency of these prints and began a second series using semi-clear and clear PLA filament, investigating translucent effects.

Figure 4 (From the top left to bottom right, made out of wood-based PLA, biodegradable algae PLA, Stone-like texture PLA, Semi-translucent PLA): Different types of PLA filaments demonstrate unique characteristics and different potential applications.

Challenges

There are several difficulties in 3D printing. Often gaps between the layers were counted as an error, so it was not computed in a 3D printer. The curled-up extruded PLA filament casually picked up by the moving nozzle. Even if it passes all those problems, without supporting structure that holds lines, the object gets unraveled easily. All patterns need a tight structure to hold them together.

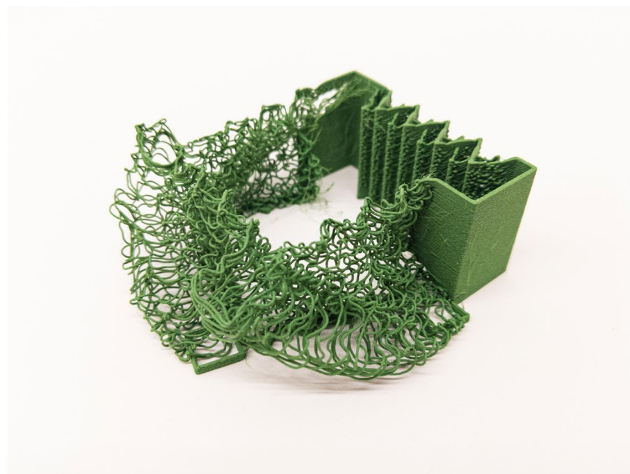

Figure 5: This model is composed of two different structures, loose and tight; the tight structure to solve the unraveling problem.

Results

Aside from conventional 3D printing best practices that encourage watertight solids using stable fabrication methods, we hoped to explore how far we could coax the printers to stray from solidity, opacity, and durability retaining structural integrity. The most exciting and effective results came from manipulating the Z-height. The tool, therefore, encourages users to experiment with the distance in between.

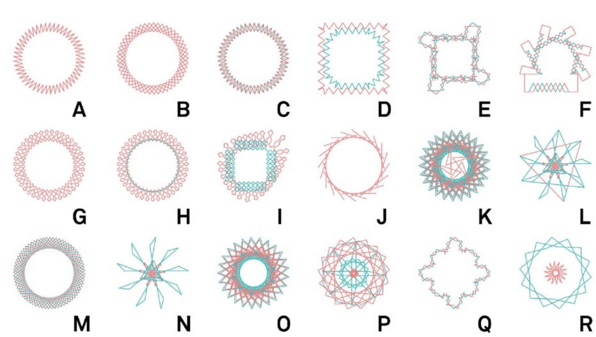

Figure 6: Full customization is possible, but 18 different tested patterns are provided as a starter. Users can simply plug-in or mix-match to their desired 3D form.

Application

Nature-friendly materials, like wood or algae-based PLA filaments, show a rougher surface with extra-porosities that allow plants and other organic species to stick; they have a high potential as a green building structure.

Each product's uniqueness could be shined if compared with other manufactured products due to its exclusiveness. Using different types of PLA filament, the products will have different use-cases. However, transparent or semi-translucent PLA filaments, show excellency in smearing lights through in an ambient way, which suits to lighting designs.

Figure 7: The top view of 3D printed objects with various layers of patterns and manipulated Z-height extrusion.

Conclusion

This experiment introduces randomness to machine processes by introducing physical properties in 3D printing, creating unique objects through hard coding. Inspired by the formation of unique stalagmites in caves, the process sought to explore nature's randomness in machine form. By manipulating Z heights of 3D printer extrusion points, we created unexpected organic forms that differ from regular watertight solids. Our project aims to show alternatives to current factory manufacturing methods that produce identical objects and destroy uniqueness. For us, creativity mimics what nature creates and how nature creates. We integrated gravity, a natural law, into coded instructions for 3-D printing to introduce this unique creativity into the computational world.

Acknowledgments

This project encountered many challenges on the way to our desired outcomes on the table since it was experimental in nature. We would like to express our appreciation to Daniel Tish for his guidance.

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