Digital provenance and material metadata: Attribution and co-authorship in the age of artificial intelligence

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Keywords
Artificial intelligence, robotics, metadata, attribution, co-authorship, ethics

Disciplines
Architectural Engineering | Architectural Technology | Computer and Systems Architecture | Data Storage Systems | Robotics

Comments
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1 Introduction
In 1979, Atari programmer Warren Robinett created a secret room within the video game Adventure: when the player interacted with a pixel in a specific way, the programmer’s name and credit would appear: “Created by Warren Robinett.” Robinett wrote this into the game because he was neither credited with, nor paid any royalties for Adventure [1]. This early “Easter egg” is both written in computer code and a reflection about the nature of code itself; a “signature” integrated into the procedural description of Adventure that is only unlocked through deliberate interaction with the work. As this example illustrates, the distribution and attribution of digital knowledge and digital creation is fraught as it cannot rely upon pre-digital modes of authorship. At the same time, rethinking attribution creates new opportunities for understanding and learning from the creative act. The presence of the Easter egg impacts the aesthetic of Adventure beyond the surface qualities of the game, while also revealing something about its design and implementation. But what about works by artificial intelligences and robots which combine physical artifacts, procedural descriptions, and human and machine labor? As Nicholas Negroponte, founder of the MIT Media Lab writes, ‘a man-machine dialogue has no history.’ Therein lies the possibility for reconsidering what it
means to attribute creative processes achieved with AI’s and robotics: to acknowledge these entities not as “perfect slaves” but rather as cooperative partners [2].

1.1 Digital Provenance

Provenance is typically associated with hand-crafted products – such as paintings, manuscripts, or artisanal food – and not mass-produced artifacts such as those made by machines in factories. However, if we examine the idea with respect to digital fabrication in architecture, the notion of digital provenance has relevance to designers and researchers in the field. Provenance refers to the sources, such as individuals and processes, involved in producing or delivering an artifact. It provides a basis for attribution, measurement of quality (for example, the reputation and/or trustworthiness of a source), and cues for locating and integrating other sources (e.g. other works by the same author; sources from the same region, etc.). Thus, provenance – the signature of origin – forms a basis for appreciation and critique, as well as the development of scholarship and craft.

In the history of design and manufacturing, robotically produced artifacts are noteworthy because they are perhaps the first physical objects that could potentially retain an account of their own creation and use. This trend is often referred to as the “Internet of Things” or IoT. [3] While an object’s record is unlikely to be comprehensive (it is unlikely it could, for instance, capture the designer’s intent or hand tooling, etc.), it nevertheless could entail digital models, software operations, algorithms employed, previous versions of the design, bills of materials, toolpaths, robotic simulations of fabrication and assembly, etc. Thus, like DNA, it would be possible to store information within a robotically-produced object (and copies of this information, elsewhere) that represents both the information about the object and the information needed to recreate the object, provided one has the proper tools and materials. And, also similar to DNA, this information could be examined, copied, and edited, so it could be studied by both designers and computers to improve designs and create new ones. However, the most provocative attribute of digital provenance is that it has the potential to establish a more complete record of authorship and labor within the architectural process. Herein lies the potential to challenge the status quo; to acknowledge those who are often disenfranchised and the role of non-professional labor, and, ultimately, to make space for the future authorship and labor of artificial intelligences.

1.2 Material Metadata

A primary challenge of provenance in robotically fabricated objects is how intellectual and creative attribution is attached or embedded into the object and not only the software or machine which generated the object. Several options for embedding metadata in software processes and data already exist. These include: blockchain, steganography, digital watermarking, etc. Metadata, at its most basic level, describes properties of objects. It only becomes part of establishing provenance when it also describes the relationship of that data to the fabrication process of an object, since this type of data reveals how, why, what, and who contributed to the object. This type of attribution creates space for people, AI’s, and machines to be fully acknowledged for
their intellectual and physical contributions to these objects and to be (hopefully) represented accurately in future histories of technology.

Another challenge to establishing intellectual property rights occurs when digitally-created knowledge or information is brought into the physical world. The metadata and other digital identifiers embedded in the associated software or data do not currently transfer to the physical object. Existing legal systems, such as copyright, design protection, patents, and registered trademarks address the resulting physical objects. However, there are few legal constructs which directly connect digital and physical provenance. RFID or radio-frequency identification tags provide a possible strategy to bridge the two. These tags contain electronically-stored information which is “read” by electromagnetic fields to automatically identify and track the object. However, as this method relies upon a physical object (the RFID) being adhered to the digitally-fabricated object, it is contingent upon the end-user’s commitment to ethical attribution rather than directly embedding attribution and provenance into the physical object. To overcome this limitation, new technologies could be developed so that metadata is automatically incorporated to physical objects as part of the fabrication process. For example, a unique “makers mark” inscribed somewhere on the object that can be read by machine vision and linked to an attribution repository (see discussion in [4]). As fabrication and scanning technology advances into smaller scales, it may even be possible to physically embed this information into materials: subtly encrypted into grain structures, fiber patterns, or arrangements of crystal lattices. This speculative material metadata would bring us closer to the metaphor of design artifacts that contain their own creative and technical “DNA.”

2 Case Study: The Drawing

The inspiration for this essay is a 2017 exhibition of robotically-executed drawings and paintings. As the authors wrote descriptions for the pieces, they reflected upon the collection of hardware, software, and ideas required to produce the work – particularly the ways that the quirks of the individual robots influenced each piece. This led us to speculate upon the question: “How should we attribute artifacts that include robotic labor?” The designer (or team) at the end of the process typically receives the credit, but if it were possible to dig deeper into the history of an object’s creation, there are undoubtedly several layers of attribution possible. To be clear: we make no claims that the technology and its application here are particularly innovative; that is not what is being studied in our narrative. Rather, by tracing the provenance of a seemingly straightforward drawing, this case study illuminates the ways in which, through digital means, elements of process and intellectual and physical labors reveal the signature of multiple authors in a full accounting of the work. We propose that this corpus of overlooked data can be used – and creatively misused – by humans and artificial intelligences as a basis for future innovations.

2.1 Introduction

In the Fall of 2017, the authors produced a robot-assisted drawing over the course of four hours on an 18” x 24” sheet of 80-pound Strathmore paper using a Crayola Super Tip marker in the color Raspberry. The drawing was part of a workshop which
introduced twenty interdisciplinary design students to robotics and coding through drawing and painting. Examining the provenance of this drawing produces the following record:

![Fig. 1. This robotic drawing is the subject of the case study.](image)

### 2.2 Author’s interaction and modifications

The drawing would typically be credited to one person. In this case, one of the authors modified code provided to the workshop, executed it with the robot, and selected the output for exhibition. While the creative process and choices made constitutes an act of authorship, the original code and the robot were also integral to the process and its output.

The workshop used Turtle drawing robots running Arduino software. One of the authors wrote the Arduino IDE code necessary to produce a Sierpinski triangle. The other author modified this code along with new instructions for the robot. This author’s intent was to exploit the distortions of the triangle, due to hardware irregularities and interactions with the robot, to produce a more interesting pattern. (see Figure 5) The author iteratively re-calibrated the robot by overriding the wheel diameter and base settings as well as the revolutions to force it to no longer create an interlocking Sierpinski. Additionally, the author picked up the Turtle and re-started the code at random intervals creating different densities of linework.
2.3 Sierpiński triangle

The Sierpiński triangle is a well-known fractal pattern with the overall shape of an equilateral triangle, subdivided recursively into smaller equilateral triangles. The base algorithm – its mathematical description – is named after the Polish mathematician Wacław Sierpiński. However, the design appeared as a decorative pattern many centuries prior to the work of Sierpiński [5]. The other author wrote a version of the Sierpiński triangle based upon a definition on the Processing website which was modified to use Turtle instructions and work with the Arduino Integrated Development Environment (IDE).

2.4 Arduino Processing framework

According to its website, Arduino is an “open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It is intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.” [6] The initial Arduino core team consisted of Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis. The Arduino IDE is based on Processing. Ben Fry and Casey Reas implemented the first version of Processing in Spring 2001. The Arduino programming language is based on Wiring also developed by Casey Reas and Ben Fry.

![Arduino Trinket Pro](image)

Fig. 2. The Instructables robot design by Ken Olsen (left) from Instructables.com; Adafruit Trinket Pro micro-processor (right) from Adafruit website

2.5 Turtle robot hardware, fabrication, and assembly

Construction of the “Turtle” robot used for this drawing was based on the “Low-Cost, Arduino-Compatible Drawing Robot” an open-source design posted by Ken Olsen on the Instructables website [7]. This is a website specializing in user-created and uploaded do-it-yourself projects, which other users can comment on and rate for quality of the instructions. Instructables was created by Eric Wilhelm and Saul Griffith and launched in August 2005. [8] In total, ten drawing Turtles were assembled by ISU Computation + Construction Lab research assistants. This process relied upon in-house 3D printing on a Dremmel Idea Builder 3D20 and Lulzbot Taz 6. An Adafruit Trinket Pro micro-processor, which is an integrated circuit that contains all the functions of a central processing unit of a computer, ran the Arduino code to operate the robot.
2.6 Turtle concept and LOGO programming language

Turtles are a special type of robot with a long history in the arts and education. A classic pedagogical tool created by Seymour Papert at MIT, they were designed to teach children computer programming and procedural thinking. Turtles have a “head” and “tail” and use simple instructions to move around a surface on two wheels while leaving a trail behind them with a marker.

Fig. 3. Examples of LOGO code and Turtle output

The programming language Logo sends simple commands for distance and rotation to an on-screen cursor or physical Turtle robot. The educational programming language, designed in 1967 by Wally Feurzeig, Seymour Papert and Cynthia Solomon, was an early bridge between the digital and the physical and a potent way to teach computing concepts. Students learn to program a Turtle by pretending to “be” the Turtle, connecting their sense of their own body in space with that of the robot’s. Thus, “playing turtle” is a profound way to bridge human and machine in the fundamental design act of drawing [9].
2.7 Summary

Examining a single robotic drawing reveals a wealth of connections from ideas (like the Sierpinski triangle and Logo programming) to platforms (Processing, Arduino, Instructables, etc.), hardware (Adafruit Arduino, Lulzbot, etc.), the code copied and modified by several sources, and the labor involved – human and robotic – to manufacture, assemble, and implement everything. Moreover, the robot itself was unique – its gearing and wheelbase were specific to that particular Turtle. This created behavior exploited by the author when she made the final drawing. The drawing in question is a limited example, but demonstrates the depth of attribution possible in a robotically-fabricated artifact. One could imagine, as in a software project, producing “forks” or modified versions of the drawing at different points in the process, substituting new code, machines, and authors. Thus, digital provenance is generative as well as descriptive.
3 Discussion and Speculation

Bruce Sterling wrote, “it is mentally easier to divide humans and objects than to understand them as a comprehensive and interdependent system.” [10] Building an attribution network would be a significant challenge. However, as the case study illustrates, the effort to understand this system increases the value of the object and the creative enterprise. As Sterling said of “Spimes” (a hypothetical object that can be traced in space and time, described in the book Shaping Things): “the history of the object helps create its future.” [11]

The unique physical properties of the Turtle robot in the case study pose another line of questioning about the role of machines in authorship. Programmable tools, such as computers and robots, are reliably consistent. Running a program on the same kind of machine it was written for will produce the same result every time. But one could also imagine bespoke machines that evolved to have their own provenance as a result of human and/or AI interventions. Ultimately, one might even consider the agency of the robotic tool itself and whether it might constitute a collaborator or even co-author. This is not to anthropomorphize or romanticize the robot but rather an acknowledgement that, someday, robots might have unique (potentially proprietary) programming through machine-learning and artificial intelligence that would lend itself to attribution. Future robots, trained by and learning from architects, might be considered partners rather than machine tools. The painting program AARON, developed by Harold Cohen, is one example of a collaborative relationship with an autonomous system. [12] While Cohen developed the program and helped select its output, the paintings it generates are credited to AARON. As robots develop the ability to sense, learn, and act in automated ways, attribution protocols are one way to recognize their potential distinctiveness as it emerges.

Establishing robotic provenance is critical to human authors, as well. Without some means of identifying individual contributions (such as those who created a core database or algorithm), works produced by algorithmic systems and AI’s may lack the requirements to be recognized as works of authorship under international laws. [13] If robotic and artificial intelligence (at least in some instances) effaces human authorship, then the provenance of human creative contribution becomes more pressing. One must also consider the human labor which operates behind robotic and artificial intelligence: from the factory workers who assembly microprocessors to the truck drivers who move materials to the computer programmers who writes the software. The very notion of authorship – and accompanying systems of rights, credit, royalties, etc. – is brought into question. [14]

Although architecture is a collaborative practice, it continues to be attributed to individuals. [15] A comprehensive and verifiable record of attribution, retrievable by anyone from any work of architecture, would challenge this myth and reveal the web of contributions from previously overlooked authors. Looking further ahead, attribution data will be important for both machine learning to train artificial intelligences and, someday, to locate and enlist their unique abilities for human-machine collaborations. Cataloging design processes promises to be the start of introducing new design trajectories beyond deterministic computing. AI’s and robots, far from being mere tools, will become part of a feedback loop between human
architects and architecture. The eventual result will not be more advanced machines, but rather co-designers with their own agency, a new dynamic increases the potential for imprecision and emergence where today we expect precision and control.

4 Conclusion

The developing fields of artificial intelligence and robotics offer space for the creation of new and novel methods of attribution. These methods call into question conventions of attribution that restrict authorship to the last individual in a chain of development and labor. Thus, a primary agenda for this speculative research is to dismantle the notion of lone genius which has perpetuated ‘starchitecture’ culture and thus denied the contributions of both people and machines to the design and construction of the built environment. A digital attribution framework, supported by systems like material metadata, would give architects and other agents a means to verify, learn from, and cite designs and more fluidly translate between the physical and the digital.

Defining and implementing this framework is a substantial project that is well beyond the scope of this essay. Our intent is to use the case study in this essay to speculate upon potentials for such a system. Once available, attribution frameworks would help reveal the rich histories of collaboration and innovation found in the built environment, particularly those of underrepresented and uncredited groups. At the same time, expanding the parameters of attribution makes possible other forms of collaboration such as collective intelligences and artificial intelligences that will lead to new ideas and
innovations from old ones. While digital provenance provides a means of sharing more comprehensive knowledge about fabricated artifacts, in the long term, as artificial intelligences learn from this data and develop agency, the ethics of human and robotic labor will need to be addressed.

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