Jeeeun Kim | Research Statement

My research lies at the intersection of Human Computer Interaction (HCI), Digital Fabrication (e.g., 3D printing), and Artificial Intelligence (AI). I aim to promote collaborations between people and intelligent fabrication machines and apply the lessons learned in broader contexts, both within and beyond the domain of digital fabrication. In recent decades, considerable advances have expanded the accessibility for digital fabrication and AI. For example, novice makers 3D print highly customized objects, teachers fabricate custom educational materials, and children naturally interact with Alexa, crafting own narratives. Despite these advances, interactions for creative design with these emerging technologies has been poorly supported. Human behaviors are difficult to predict, and thus fabrication technology and AI remain challenging for people to work with. Therefore, my research focuses on **developing collaborative AI systems for people by investigating novel human-AI interaction techniques, particularly to support the creative use of digital fabrication.** With well-designed interaction techniques and supporting systems, people can use natural interaction modalities (e.g., voice, gestures) to express their intentions to use fabrication machines.

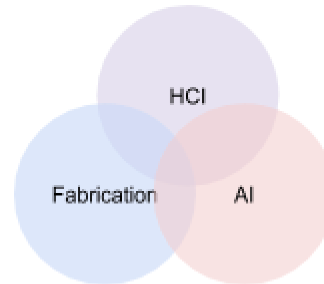


Figure 1. Three key topics of my research interests: HCI, Fabrication, and AI

I strive to answer three research questions: (1) How can emerging technologies impact society where humans live (See Figure 1, Fabrication-HCI)? (2) How can unpredictable user behavior be understood by computing systems so that collaborative partnerships in creative design are enabled between humans and AI (HCI-AI)? (3) How can AI offer humans the appropriate agency to encourage their creative endeavors in the use of fabrication machines (Fabrication-AI)? The answers to these questions further suggest two future questions at the intersection of HCI-AI-Fabrication: How can machines learn interaction principles from humans to facilitate AI-supported fabrication? so to improve the individual's quality of life?

Figure 2. In 2014, I created the world's first 3D printed tactile picture books to harness the power of 3D printing to impact the world

Previous Research Topics and Methods

I am excited to identify and fill the gap between people's expressed intentions in the use of machines and machines' understood commands for operation in digital fabrication, mainly in 3D printing, so as to build systems and algorithms to bridge this gap.

Social Impact: Understanding Emerging Technology to Impact Human (Fabrication-HCI)
3D printing is an emerging technology, allowing everyday users to not only consume results of computing but also produce creative content. My first goal was, enabling people from everywhere with any background to take the benefit and to use this technology in their everyday lives. The Tactile Picture Books Project for children with visual impairments [8, 11] applies 3D printing to a wide range of domains. In 2014, I created the world's first 3D printed book for children with visual impairments, *Goodnight Moon* (Figure 2). This has been covered by press all over the world and was exhibited in multiple venues such as the New York Future of Storytelling Summit 2015. This year, my newest 3D book, *Penguin's Big Adventure*, was invited for display at the Cooper Hewitt Smithsonian Design Museum in New York. (Figure 4) This effort enables caretakers, parents, and teachers to create customized educational materials and promotes the development of emergent literacy. For example, a group of librarians in Russia and 6th grade students in Norton, Massachusetts were inspired by my work so they remixed it to learn the emerging technology and share it back to the community (e.g., Figure 3, [12]). Further, Kinemaker is a computer-aided design system that novice modelers and educators can use to transform static off-the-shelf models into articulated 3D objects, without expensive simulation and optimization. Akin to LEGO blocks, users can assemble kinematic primitives with shape objects to build moveable objects by embedding mechanisms [9] using

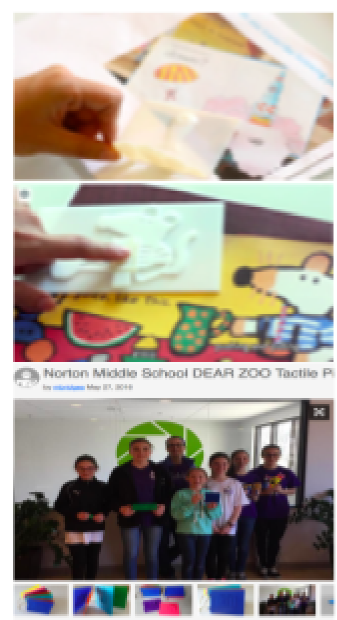


Figure 3. I open source my research results, moveable 3D printed tactile pictures (top), that impact the rest of the world; 6th grade students from MA remixed mywork and republished to the community (bottom)

CraftML, a markup language used to design 3D models following a web programming paradigm [10]. I also studied the need for new technologies by people with disabilities, for example, individuals with visual impairments. In this direction, I developed Facade, an end-to-end fabrication pipeline using computer vision and crowdsourcing for these people to independently fabricate tactile overlays to improve the inaccessible environments [2](Figure 5). From this lineage of studies and systems, I have found that digital fabrication has the potential to change an individual's quality of life.

From Data to Computation: Understanding Human Behaviors (HCI-AI)

Human behaviors are hard to predict. This is particularly true in the creative process in which the user's intent and the design environment is ever-evolving, and it is thus difficult for machines to understand the user's vision. Humans have had to learn how to operate machines by understanding the machine's expected behaviors (operations). Such an approach is sufficient when the user's goal is clear, for example, in the use of a coffee maker or elevator. However, this hinders users from adapting think-in-progress ideas, which are a common element of human creativity. Unfortunately, there have been few efforts to hone machines' understanding of humans' natural behaviors. Datasets for analyzing human behavior are not mature—too small, too noisy and unstructured. I conduct empirical studies to understand human behaviors and perceptions in digital fabrication and apply the implications to develop novel algorithms and systems. In collaboration with researchers at Carnegie Mellon University, to understand end users' challenges in reusing 3D models, I categorized users' behaviors in measurement, Based on this, I then identified common issues that require designers and researchers' attention. I proposed a set of design principles to mitigate measurement errors in 3D design and developed a parametric tool to accommodate these principles when reusing 3D objects (Figure 6, [6]). Our further collection of data on peoples' adaptation strategies allowed us to classify their approaches-in-practice based on the purpose of a tool in use [1]. In a current collaboration with researchers from Copenhagen University, I continue to work on furthering this effort and collecting dataset, with an aim towards developing an optimization algorithm over the longer term. I am passionate about understanding humans' perceptions on 3D objects aim to facilitate fluid Human-AI interaction. In a recent collaboration with Adobe Research and researchers at UCLA, I conducted user studies to realize the perception gap between humans' feeling and prediction on 3D printed objects' properties. Using a numerical model to predict object's property, I developed a design tool enabling end designers to adapt it and create 3D objects with the desired property [3].

Human-Machine Interaction: Towards Supporting Creativity (Fabrication-AI)

AI is now everywhere, and it will change the landscape of digital fabrication. Kai-Fu Lee, an industrial AI expert, stated in his TED talk, "*Only creative jobs will remain safe from the massive replacement of jobs by AI; because AI can optimize, but not create.*" Creativity is one of the key ways in which humans are better than AI. I envision a future in which AI coexists with people, akin to Ken Goldberg's idea of *multiplicity*—the idea of humans and robots complementing each other to work together. AI needs to evolve in such a direction that helps humans be creative, in which AI works with humans as an analytical tool and supportive agent [7]. My approach is unique in that it **designs fabrication *machines* that enable coworking with people in the physical world, which departs from the previous idea of turning *on-screen CAD tools* interactive.** To help users feel they have attained proper agency, a machine requires algorithms that enable it to analyze and predict human interactions and provide support for the user. This helps users make on-the-fly decisions that emerge during the process and innovate based on their initial conception. Collaborating with researchers from Meiji University, I attempted to identify a formalism that abstracts humans' physical interactive expressions of their design idea. It abstracts information into numerical form to maintain seamless communication between human and machine in an event-driven operation loop. In traditional

Figure 4. I exhibit my research results at various design museums and summits, including public library and Cooper Hewitt Smithsonian Design Museum

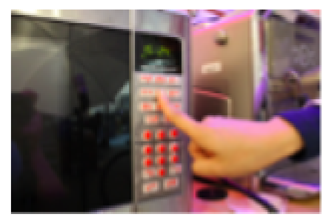


Figure 5. Facade is a holistic fabrication pipeline for blind people to make tactile overlay using Computer Vision and CrowdSourcing

Figure 6. Understanding humans behaviors in practice help everyday users fabricate custom 3D objects with less errors

human tasks, such as craft practices, users incrementally adapt emerging choices and apply new discoveries. With my event-driven 3D printer, whenever there is user intervention, machines interpret it and adapt it into the operation. Departing from conventional CAD tools that require users to express all ideas entirely on 2-D screens, the proposed human-machine interactions maintain seamless collaboration during the entire execution, using any type of modality with which users are confident. To realize this idea, I developed an open source platform to foster on-the-fly interactions while creating objects using 3D printing [5]. Applying various AI techniques (i.e., context recognition, computer vision, and HRI), the system enables users to augment a 3D object by gestures, hand-sketches, and camera images in real time in a step-by-step fashion (Figure 7). Recasting the 3D printer as a tool for expression that responds to in-situ creative interactions supports future interaction designers to easily apply new AI techniques for fabrication and manufacturing, facilitating users' creativity.

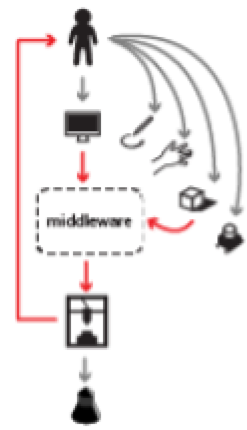


Figure 7. Compositional 3D printing is a paradigm to renovate fabrication process, to enable end users to converse with 3D Printers using any natural interaction modality

Future Research Agenda

My long-term efforts will be devoted to expanding my latest research towards general HCI for AI, inspired by novel interaction design for intelligent 3D printing, and developing applications to further the tools' impact.

Topic 1: HCI for AI - Design Interaction Techniques for AI to Communicate with Humans
Current interaction techniques between humans and machines are informed by computing systems that informs rules. Humans must adapt to these rules, which are defined by existing computing systems and its form factors. For example, as a laptop has a keyboard and touchpad, users must interact with the device using these modalities. The focus has been on improving the precision and speed of computer use. Now, computers need rules that are learned from humans (Figure 8). As humans use voice, gestures, and facial expressions in their natural communication with subtle nuance, machines need to adapt how to interpret them. The latest AI has made previously dumb machines intelligent, allowing them to understand humans and identify subtle differences, to provide individual-specific recommendations via predictions. In this setting, people must be able to use their natural communication methods. I am interested in defining algorithms so that machines can understand such inputs in real-time, and apply to the operation in-situ. In using digital fabrication machines , I have studied how to make the interaction between user and machine "conversational," by developing a basis with which a machine can recognize such input and then offer recommendations to aid in real-time decision making. I will apply key insights learned from inventing interaction techniques for human-machine collaboration. The very first project could be developing a conversational agent for fluid 3D printing and prototyping. The ultimate goal is to build an environment where humans and AI augment each other, allowing people to express hidden, vague thoughts via in-explicit commands in creative work. The robot must then be able to recommend options for better decisions so that users can obtain agencies from responsive machines.

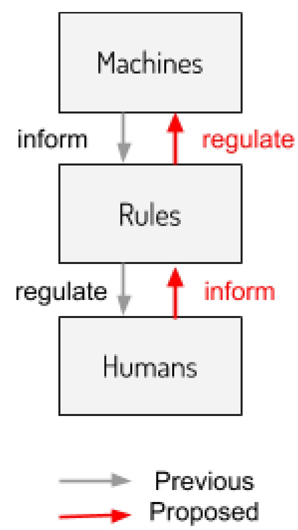
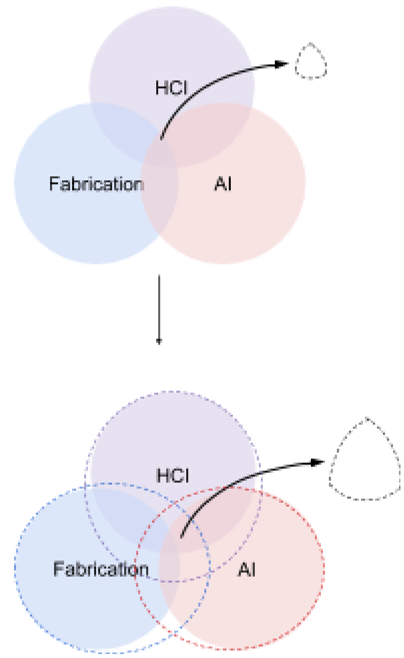


Figure 8. Previously, computer's form factors defined the interaction style. Future of machines need to learn natural interactions of humans to generate a new type of interaction technique.

Topic 2: AI-powered Fabrication for Social Good and Healthcare
I have a passion for creating a broader impact via interdisciplinary research collaboration. Currently, numerous healthcare applications use 3D printing, and many projects are actively funded by public agencies, such as NIH. However, the focus is primarily on material/mechanical engineering, and there is sparse attention in computation/AI that could enable a better a understanding human behaviors for intelligent fabrication of medica/healthcare devices. Computation will become an important part of future fabrication of personalized healthcare systems. AI will empower the machine to analyze, modify, and adapt in-situ changes in environment, body status, and human interactions [4, 5] that are not possible with solely mechanical, material approaches. Computer scientists are unlikely to be aware of

recent advances and challenges in 3D printing healthcare devices, for example, in 3D printing personal assistive devices, precise measurements and the ability to deal with errors are critical for accommodating continuous changes and inevitably inaccurate human behaviors [2]. In fact, what should be computed from what and so adapted to the fabrication is ill appreciated.



Motivated by the question *"How can AI-powered digital fabrication change an individual's quality of life?"* I will investigate how to develop systems and tools that empower even novice designers to customize wearables and healthcare devices, accounting for changing individual circumstances and behavioral patterns. Further, collaborating with researchers in the areas of ubiquitous computing and intelligent sensor modeling, I hope to advance such device design in a way that helps machines collect and analyze personal biosignals and behavioral patterns. In this direction, it could be also possible to identify potential disease symptoms for future. Such data will not only help populate datasets for future medical and clinical records but also let us develop new algorithms with which to specify the use of data, for example, recommendations and alerts for a potential doctor visit. Another potential direction would be to build a new system that can 3D print drugs on-demand based on an individual's physical condition, innovating on traditional pharmacy delivery. In the very long run, I am also passionate about connecting personal digital fabrication with biofabrication, for example, 3D printing highly customized organs.

Based on these two main directions, I aim to expand the intersection of my three key research topics by drawing on each element: HCI, Fabrication, and AI. In my Ph.D. thesis, I have created this new intersection while integrating each component. I believe my future endeavors will expand the boundaries of this intersection, which will ultimately develop into a significant new subfield.

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