Beyond prototyping boards: future paradigms for electronics toolkits

Andrea Bianchi
KAIST
Daejeon, Korea
andrea@kaist.ac.kr

Steve Hodges
Microsoft Research
Cambridge, United Kingdom
steve.hodges@microsoft.com

David Cuartielles
Malmö University
Malmö, Sweden
david.cuartielles@mau.se

Hyunjoo Oh
Georgia Institute of Technology
Atlanta, United States
hyunjoo.oh@gatech.edu

Mannu Lambrichts
Hasselt University
Diepenbeek, Belgium
mannu.lambrichts@uhasselt.be

Anne Roudaut
University of Bristol
Bristol, United Kingdom
roudauta@gmail.com

ABSTRACT

Electronics prototyping platforms such as Arduino enable a wide variety of creators with and without an engineering background to rapidly and inexpensively create interactive prototypes. By opening up the process of prototyping to more creators, and by making it cheaper and quicker, prototyping platforms and toolkits have undoubtedly shaped the HCI community. With this workshop, we aim to understand how recent trends in technology, from reprogrammable digital and analog arrays to printed electronics, and from metamaterials to neurally-inspired processors, might be leveraged in future prototyping platforms and toolkits. Our goal is to go beyond the well-established paradigm of mainstream microcontroller boards, leveraging the more diverse set of technologies that already exist but to date have remained relatively niche. What is the future of electronics prototyping toolkits? How will these tools fit in the current ecosystem? What are the new opportunities for research and commercialization?

CCS CONCEPTS

• **Human-centered computing → User interface toolkits**.

KEYWORDS

electronics, prototyping, toolkits, physical computing

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1 BACKGROUND

Electronics prototyping boards such as Arduino[1], BBC micro:bit[2], and Raspberry Pi[3], work with a wide range of software tools to enable a variety of creators with and without an engineering background — including students and researchers — to rapidly and inexpensively create interactive prototypes. By opening up the process of prototyping to more creators, and by making it quicker and cheaper, these prototyping platforms and toolkits have underpinned innumerable explorations across the enthusiast, industrialist, and research communities.

The aforementioned platforms – and many others – follow a particular format: they are based on a rigid circuit board comprising a microcontroller and general-purpose expansion ports or pins. While these technologies support prototyping effectively, **we think there are opportunities for a more diverse set of technologies to further empower an even broader set of technology designers, engineers, makers, and researchers**. This workshop seeks to identify some of these opportunities.

2 ESTABLISHED APPROACHES TO ELECTRONICS PROTOTYPING

Today's established electronics prototyping toolkits frequently leverage the power of microcontrollers, cheap and ubiquitous sensing components, modern digital fabrication techniques, and traditional wired interconnects. Occasionally they also explore the use of novel materials and new composition techniques. This section briefly summarizes notable characteristics of popular products and prior work reported in the literature.

2.1 Three main paradigms for electronics prototyping

Lambrichts et al. [22] provide a comprehensive review of many of the prototyping boards and toolkits that have been developed over the past few decades to facilitate electronics prototyping, including both research projects and commercial products. They identify three distinct paradigms for prototyping with electronic components, based on the use of: (1) discrete electronic components, (2) breakout

[1] https://www.arduino.cc
[2] https://www.microbit.org
[3] https://www.raspberrypi.com

and development boards, and (3) integrated toolkits consisting of modules specifically designed to work together.

Paradigm (1) requires significant electronics expertise, paradigm (2) less so, whereas paradigm (3) typically requires little or no expertise, opening the prototyping process up to many more users. Examples of paradigm (3) include littleBits [1], .NET Gadgeteer [13], LEGO Mindstorms[4] and most recently Jacdac [7]. Perhaps the biggest disadvantage of these platforms is the reduced flexibility they offer in comparison with paradigms (1) and (2).

2.2 Re-programmability takes different forms

Prototyping toolkits typically contain some kind of programmable processing unit that defines the behavior of the completed prototype. Single-board computers such as the Raspberry Pi run a high-level operating system and typically support a wide variety of applications and development tools. On the other hand, microcontroller boards such as Arduino and BBC micro:bit have fewer resources and usually run a single application with direct access to programmable general-purpose input/output pins and ports (GPIOs).

A more recent trend is the use of reprogrammable logic in electronics prototyping kits. Although it requires more expertise to work with, reprogrammable logic allows for greater customization, increased performance, and/or more power-efficient designs. Perhaps the best-known technologies in this category are programmable logic devices (PLDs) and field-programmable gate arrays (FPGAs). In recent years, we've also seen the growth of programmable digital peripheral components within microcontrollers. These enable dynamic configuration and high-speed use of logic processing resources coupled closely with specific GPIOs, without loading the microcontroller's main core. Examples include the programmable peripheral interconnect (PPI) found on the nRF52 series[5], programmable input/output (PIO) on the RP2040[6] and core-independent peripherals (CIPs) from Microchip[7].

A related technology is the field-programmable analog array (FPAA), which supports the reconfiguration of analog components such as comparators, filters, and amplifiers. Scanalog [28], for example, uses an FPAA to facilitate the interactive design of analog circuits, while VirtualComponent [19] uses a crosspoint switch, a special type of reprogrammable integrated circuit, to allow users to place and tune programmable components on a breadboard via software.

2.3 Tools for circuit prototyping and debugging

Several tools for designing, assembling inspecting and debugging circuits have been developed. CircuitStack [34], VirtualWire [24] and SchemaBoard [20] support the creation of circuits with pluggable breadboards. CircuitStack avoids the need for individual jumper wires by printing sheets with conductive traces and clamping them under the breadboard that holds the electronic components. VirtualWire uses a crosspoint array switch to virtualize a circuit topology allowing connections in software to be instantiated in physical connections on a breadboard. SchemaBoard uses LEDs embedded inside a breadboard to guide the circuit assembly of components and wires. Pinpoint [29] simplifies PCB debugging via a custom jig board and a software that probe signals and disconnect arbitrary traces.

While all these projects can be used by makers in an educational context, VISIR [31] best exemplifies the usage of a remote workbench to allow the construction and debugging of physical circuits via a software interface. Coordinated debugging of hardware and firmware, facilitated by live or real-time programming environments is another consideration [25]. Finally, Perumal and Widgor [4] and Lambrichts et al. [23] present techniques that allow researchers and enthusiasts to produce custom flexible substrates for assembling circuits based on conventional, soldered electronic components.

2.4 New materials and new form-factors for electronics

Researchers have broadened ways of building circuits by exploring diverse materials that complement the well-established circuit board substrate with copper wire based interconnections. For example, it's possible to sew electronic components onto fabrics [2], to use a 'plug-and-play' circuit assembly approach for wearable prototyping [16], to design smart jewelry [33], and to construct physically larger interactive prototypes using a straw-based approach [35]. Some researchers have explored the use of Kapton-based flexible PCB substrates, for example to make flexible on-skin interfaces [21].

Non-conventional materials have also been proposed. For example, it's possible to build circuits on paper by painting with conductive ink [3] or printing conductive traces [15]. ConductAR [26] and Circuit Eraser [27] allow these circuits drawn directly on paper to be more easily debugged and even reworked. Electronic functionality may be added by attaching "circuit stickers" [14]. Finally, non-conventional methods of adding electronic functionality and/or integrating sensing and actuation have been proposed. These metamaterial approaches include the consideration of displays as a material that can be created by spraying or sheet cutting [10, 11, 30]; 3D printable metamaterials that integrate sensing capabilities [9]; the additive manufacturing of actuated material [8, 18, 36]; and malleable sensing [5, 32] materials.

3 GOAL OF THE WORKSHOP

We see opportunities for new approaches to electronics prototyping:

- Are there new paradigms, in addition to the three outlined in Section 2.1? For example, we believe it is possible to combine the flexibility of paradigm (1) with the ease of use of paradigm (3).
- Is the community leveraging the full gamut of re-programmable solutions described in Section 2.2, such as programmable digital peripheral components and field-programmable analog arrays?
- Can we create new tools that build on those listed in Section 2.3, to accelerate the physical aspects of prototyping with electronic components and ease debugging?
- Can different materials, such as those mentioned in Section 2.4, be used to support novel approaches to prototyping with

[4] https://www.lego.com/en-us/product/lego-mindstorms-ev3-31313
[5] https://infocenter.nordicsemi.com/index.jsp?topic=%2Fstruct_nrf52%2Fstruct%2Fnrf52.html
[6] https://www.raspberrypi.com/documentation/microcontrollers/rp2040.html
[7] https://www.microchip.com/en-us/products/microcontrollers-and-microprocessors/8-bit-mcus/core-independent-and-analog-peripherals

electronics, and unlock new form factors and application areas?

The goal for this workshop is to build on the prior work and initial opportunities we have identified above, by producing a more complete list of possible futures of prototyping, mediated through new tools and platforms. We will invite participants to contribute their visions of how the field might transform in the coming years. We expect to solicit a multiplicity of prototyping paradigms, discuss their viability, and cluster them into broad categories. The outcome of this workshop should help research centers, funding bodies, universities, companies, and independent researchers to create a shared corpus of prior work, align on terminology and goals, and identify fruitful avenues for future work.

The first part, the informed brainstorming, will take the positioning papers and the guided analytical discussion as points of departure. Participants will be divided into groups, given typical interaction design tools and a list of terms in the form of a glossary to set a framework. Participants are expected to have read the position papers of other attendees by the time of the workshop and be ready to contribute to discussion and ideation. The glossary will just be the foundation of the discussion to be held during this activity. Concepts will later be clustered using affinity mapping. Once the different categories have been identified, participants will work on the production of a list of references that should help support the final paper.

4 ORGANIZERS

The organizing team combines expertise and interests from HCI, digital fabrication, electronics, physical computing, interaction design, and systems engineering.

Andrea Bianchi is an Associate professor in the Department of Industrial Design and Adjunct professor in the School of Computing at KAIST (South Korea). He researches in the field of Human-Computer Interaction focusing on building tools for prototyping and physical computing, as well as hardware systems for body augmentation (haptics, mixed reality, robotics).

Steve Hodges is a Senior Principal Researcher at Microsoft Research, where he combines his hardware engineering and creative design skills with knowledge of established and emerging technologies to conceive novel, inclusive hardware-plus-software solutions. He works at all scales from research prototypes to mass production and his work has contributed to millions of devices with tens of millions of users. He also builds tools that help others to learn about and create with digital technologies.

David Cuartielles is co-head of the MSc in interaction design at Malmö University in Sweden, as well as co-founder of the Arduino platform and head of research at the Arduino company. He has experience in large-scale prototypes, co-design experiences in communities of practice, creation of open-source laboratories, and developing open products.

HyunJoo Oh is an Assistant professor with a joint appointment in the School of Industrial Design and the School of Interactive Computing at Georgia Institute of Technology where she is directing the CoDe Craft group. She develops tools that integrate everyday craft materials with computing and studies how those technologies can empower designers in investigating new expressive and technical possibilities.

Mannu Lambrichts is a Ph.D. student at Hasselt University, where he looks into methods for facilitating interactive device prototyping. By exploring and combining the benefits of existing prototyping techniques, he designs new electronic systems that easily interconnect various heterogeneous electronic components and modules. Building on these existing electronic prototyping toolkits, users can reuse electronic components and modules familiar to them while still being guided during the prototyping process.

Anne Roudaut is a Professor in the Department of Computer Science at the University of Bristol. She is an expert in Human-Computer Interaction and leads the Bristol Interaction Group (BIG). She is an expert in embedding innovative materials within digital technologies. She promotes a highly multi-disciplinary research agenda to radically rethink the way we build digital technologies and has established seminal papers on how creating synergies between HCI and material engineering can foster innovations in digital devices.

5 WEBSITE

The workshop web pages can be found at https://electrofab.prototyping.id. The website is still under development and will be updated should this workshop proposal be accepted as part of the CHI '23 program.

6 PRE-WORKSHOP PLANS

The organizers have been meeting via teleconference regularly every 2-3 weeks since May 2022 to develop a plan and coordinate their efforts for this submission. If the workshop is accepted, we will continue these meetings to finalize the workshop agenda, deliverables, and activities.

Before the workshop, we will distribute a call for position papers through the workshop website, social media (e.g., Twitter, Facebook), mailing lists (e.g., ACM, CHI-announcements, ACM Local Chapters), and other public websites (e.g. Interaction-Design.org, WikiCFP). We will also try to directly contact researchers, educators, and practitioners who might be interested in the workshop, reaching out to our personal networks and beyond. We are currently preparing a list of potential attendees from both academia and the industry. We are also actively looking for sponsoring organizations and received a positive response from Arduino.cc, who agreed to be a supporter of the workshop. We plan to continue promoting our workshop and getting in touch with potential contributors until the submission deadline. We are planning for around 20-30 attendees.

As stated in our Call For Papers, accepted submissions will be accompanied by short introductory video presentations for each author/position paper. We will collect these videos before the conference and upload them on our website (e.g., via HotCRP submission site) to allow all participants to familiarize themselves with each other's work prior to the conference — ideally, before even starting the workshop all participants will know who will be attending and the content of the accepted position papers.

7 WORKSHOP STRUCTURE

This one-day workshop (9:00 am to 4:00 pm) is designed to be an in-person event. We plan a series of activities starting with an ice-breaking session where participants get to know each other and their interests, followed by a presentation of themes emerging from the attendees' position papers, an analytical discussion in small groups, and finishing with a moderated large groups discussion and bottom-up synthesis. We encourage participants to bring prototypes and show videos of their work to ground the interactive discussions. The workshop will be divided into four activities:

7.1 Activity 1: Overview and ice-breaking

After a short introductory session in which the organizers introduce themselves and present an overview of the schedule for the day (about 20 minutes), we will conduct a speed-dating activity [6] by arranging small discussion groups of 2 or 3 participants, where all participants can freely share their interests, show videos of their work, and/or demo working prototypes for 5-10 minutes. We will then shuffle the groups and repeat the process 3-4 times.

The main objectives for this preliminary session are to have all participants familiar with each other's work, as well as to establish a supportive and friendly atmosphere that will better lead to the analysis and synthesis work planned for the next three activities. Including breaks, we estimate that the ice-breaking session will take approximately 1.5 hours.

7.2 Activity 2: Analysis and presentation of emerging challenges and themes

Ahead of the workshop, the co-organizers will analyze the position papers submitted by the attendees to identify the ideas and map out recurring themes. The second activity on the day of the workshop will be a presentation from one of us (Steve Hodges, an advocate of physical computing and electronic device fabrication). For about one hour Steve will present highlights from the attendees' position papers and report on the emergent themes that were identified by the co-organizers. Steve's presentation will also include the challenges of device prototyping and the transition to production that have been identified in the literature [12, 17].

7.3 Activity 3: Guided analytical small-group discussions

Following the presentation, Steve and the co-organizers will initiate a debate with the audience about ways to unlock further innovation in the tools available to the community for exploring and evaluating interactive electronic devices. For that, the audience will split into small groups of 3-5 people and asked to discuss specific topics that emerge from both the accepted position papers and the talk. We will start by asking each group what hypothetical project they would initiate if they could simply combine their current interests and projects they currently have underway. Activity 3 will last for approximately 1.5 hours.

7.4 Activity 4: Larger-group discussions and synthesis

The final activity of the workshop will be based on larger-group discussions, moderated by another of the co-organizers, David Cuartielles. New groups will be formed and this time the discussion will be centered around synthesizing the major technological trends and approaches discussed during the day. For example, we expect activities requiring summarizing on post-its the main technological trends that can be immediately applicable toward the development of new prototyping toolkits, and ask the audience to cluster them by affinity using large sheets of paper, whiteboards and/or walls. This group discussion aims to identify some main trends and possibly gather together people with similar interests. This discussion will be moderated by David and aided by the other organizers and will last for about two hours. This synthesis work will be finalized with the organizers sharing the emerged categories of prototyping toolkits and identifying new areas of common interest.

8 POST-WORKSHOP PLANS

The results from the workshop will be distilled and shared with the HCI community via a position article that will capture the current trends and what we expect to be the next steps in electronic prototyping toolkits. We will also encourage the workshop participants to submit a paper on their own, either as an extension of their position paper or as a possible collaboration with other workshop participants. We also plan to put in place platforms and events to further build the community around our research direction. We will do this through different mechanisms: 1) we will reach back to the participants a few months after the workshop, asking them to share via a video-conferencing meeting any update on their research; 2) we will start planning a new edition of this work workshop, at CHI 2024 or other venues such as the Dagstuhl seminar; 3) we plan to open the slack group the organizers have used to plan this initial workshop to the attendees to have a platform for informal and formal discussion which we hope will foster a sense of community to the diverse researchers and practitioners interested in our vision.

9 ONSITE PLAN

The expected workload for onsite preparation is minimal. We will need a projector to share our guiding slides with the participants. We will also need chairs for about 20-30 participants, and 4 large tables for holding conversations in groups of 4-5 people. We will bring stationery - large sheets of paper, post-its, pens, etc... - to the conference to support the group discussion and synthesis work. We will also set up any additional space upon request of participants who want to show a demo, but note that attendees will bring any materials necessary for their demos themselves. Finally, we will require a table for refreshments, e.g., cookies and coffee.

10 CALL FOR PARTICIPATION (CFP)

We aim to understand how recent software and hardware trends, from metamaterials to neurally-inspired architectures, from printed electronics to reprogrammable digital and analog elements, and from live programming to hardware debugging might be leveraged in future prototyping software platforms and hardware toolkits, beyond the well-established paradigm of mainstream microcontroller boards. What is the future of electronics prototyping toolkits? How will the requirements and applications of new prototyping toolkits evolve? How will these tools fit in the current ecosystem, and how will they be learned? What are the new opportunities for research and commercialization?

This workshop will bring together those working in academia, industry, and beyond, with experience or interest in physical computing, electronic hardware design, software platforms for device prototyping, and digital fabrication of electronics for interactive artifacts. The workshop organizers will foster discussion, facilitate synthesis work, help the exchange of ideas to move the field forward, and build a community at CHI around electronic prototyping toolkits.

The workshop will consist of a 1-day (9:00 am to 4:00 pm) in-person event. We expect between 20 to 30 participants. We plan a series of activities to learn about each other's work and interests, present personal perspectives, work in small teams and participate in moderated discussions. We encourage participants to bring prototypes and show videos of their work to ground the interactive discussions.

10.1 Additional instructions to appear in the CfP on the workshop's website

If you are interested in participation, please submit a two- to four-page position paper using the publication version of the ACM Master Article Template (https://chi2021.acm.org/for-authors/chi-publication-formats). Your position paper should describe a novel software or hardware platform, toolkit, or technique to support or improve the process of electronic prototyping. We also welcome submissions that are more abstract but try to either describe the limits of the current approaches or build on them with new ideas and suggestions. The paper should also briefly introduce yourself or your team and we encourage you to outline a vision for future ways of prototyping. These papers will form the basis of the group discussions at the workshop. Upon acceptance of the submission, you will be required to prepare a 2-minute introductory video of yourself and your work that will be shared online with the rest of the participants before the workshop. At least one participant among the authors of a submission must physically attend the workshop.

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