Beat Machine

Embracing the Creative Limitations and Opportunities of Low-Cost Computers

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ABSTRACT

The Beat Machine is a handheld music synthesizer and sequencer. The authors discuss the development of the Beat Machine and how creative constraints and opportunities were introduced by the particularities of low-cost microprocessors and associated electronics. The discussion is framed as an exemplar of Kåre Poulsen's concept of *enactive individuation*, a framework for relating material engagement to digital design and fabrication. In reflecting on the design and making of the Beat Machine the authors connect this framework with more established notions of creative interaction and the affordances of digital media.

GENESIS

The genesis for the Beat Machine project can be traced to *Handmade Electronic Music* by Nic Collins, specifically "The World's Simplest Circuit: Six Oscillators on a Chip, Guaranteed to Work" [1]. In 2018 John Ferguson designed a battery-powered synthesizer based around a printed circuit board (PCB) and a Texas Instruments CD40106 (Hex Schmitt-Trigger) with audio control via photocells, touchpads and potentiometers [2], but his desire to include algorithmic coding in the design to add sonic flexibility led to a collaboration with Andrew R. Brown; the Beat Machine was born. Like many designs, the Beat Machine has been through several iterations; versions have been used for musical performances in the Creative Music Technology program at Griffith University, Brisbane, Australia.

BACKGROUND

The Beat Machine is an electronic musical instrument that produces sound through synthesis and arranges these sounds in looped patterns using a multitrack step sequencer. Video

documentation of the Beat Machine can be found online [3]. The Beat Machine aligns with popular electronic music practices using synthesizers, sequencers and drum machines dating from the mid-twentieth century and repopularized in the early 21st century. These instruments have established themselves as part of Western musical culture, and DIY versions such as the Beat Machine provide an accessible path into this culture while serving to reveal some technical underpinnings often obscured by commercial tools.

We designed the Beat Machine to be distributed as a DIY kit for musicians. Users are assumed to be inexperienced builders of electronic devices, and so the assembly process is intended to be educational. We keep component costs low to maximize access and minimize the impact of assembly errors. The resulting lo-fi audio output is embraced as part of the Beat Machine's character. We anticipate that users are interested in popular electronic music, which the Beat Machine is designed to produce. We designed it to cater to users with modest musical experience. Importantly, the Beat Machine is a platform that can be extended by users, especially on the software front. For example, users have repurposed it as a MIDI controller when connected via USB to another computer and, as with all Arduino-class devices, users can reprogram it to perform differently. This extensibility of DIY resources reinforces the educational agenda of the designers.

Despite its modest materials, we intend for the Beat Machine to be an effective live musical instrument. To reflect our interest in live electronic music performance, we aimed to achieve a fluid interaction during performance and efficient interaction during editing. The user experience ideally resembles a seamless performative experience that is described variously as "flow" [4], "meaningful engagement" [5] or "musical homeostasis" [6]. All three terms, interestingly, arise from research into the phenomenology of creative arts practice, and the latter term is specific to musical human-technology interactions.

While the Beat Machine may have some unique combination of features to differentiate it from related projects, this article is not so much about the project's uniqueness but

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rather about exploring the development of the Beat Machine as a case study in the computational design of postdigital DIY musical instruments [7,8]. In particular, we examine our experience as posthumanist designers, makers and users through the lens of enactive individuation [9].

ENACTIVE INDIVIDUATION

The concept of enactive individuation, formulated by Kåre Poulsgaard, describes how mind and form are emergent properties of the dynamic integration of technology, memory and aesthetics. It extends the frameworks of material engagement theory developed by Lambros Malafouris [10] into the realm of digital creative work. Per Poulsgaard, “Enactive individuation seeks to describe how ongoing—ffective—transactions between mind, materials, and information logics extend imaginative capacities for computational design thinking” [11].

An enactive perspective assumes that affect arises from participation. For humans, this means that embodied involvement and contextual influence—not simply intellectual attention—are crucial aspects of engagement in activities and experience. For nonhuman actors such as physical objects, ideas and contexts, this means that their presence and characteristics are acknowledged as influential in shaping activities and outcomes. Projects like the Beat Machine also manifest an enactive perspective on computational design by reinforcing the significance of prototyping.

The concept of individuation draws on Bernard Stiegler’s [12] phenomenology of technics and time to interpret the transformative relationship between technology and cognition. In this view, the individual characteristics of people and things are shaped by, and emerge from, the dynamics of their interactions. Beyond accepting that people’s individuality is shaped by their interactions with the world, theorists like Gilbert Simondon [13] hold that the creation of forms transcends mere association of parts to become acts of individuation. Thus, the creation of the Beat Machine is a process of individuation.

A key to the power of these transformative relationships with technology is the way in which humans recursively build and layer structures of knowledge and materials. It has long been recognized that technologies externalize knowledge, technique and purpose [14]. In this way, software algorithms reflect a programmer’s ideas, and hardware systems reveal the priorities and perspectives of their makers. Prominent philosophical advocates of this position include Martin Heidegger, whose concept of *thrownness* suggests that technologies, far from being neutral actors, propel users toward particular actions [15]. Bernard Stiegler, following Jacques Derrida, emphasizes the tendency for technologies to *grammatize*, by which he means that technics formalize processes and patterns of behavior and thought (just as grammar structures language), resulting in both ongoing stability and immobility [16]. Such stability is a necessary part of arriving at an individualized form.

Our experiences in the making of the Beat Machine seem to resonate with the concept of enactive individuation. Even though we were not fully conscious of this perspective dur-

ing the Beat Machine’s development, the concept is revealing as a backdrop for our description of product design and making.

INSIDE THE BEAT MACHINE

Our development of the Beat Machine involved a creative and exploratory practice in which thinking and doing became a unified process. An important aspect was selecting different tools, platforms and metaphors that each recast design problems because each afforded differing solutions and understandings. Our processes of design and making broadly align with how Poulsgaard describes the digital development processes he observed, concluding that “computational design does not arise from manipulation of mental plans and representations, but rather from within the complex interplay of forces in a given ecology reaching across material and informational domains” [17].

To structure our discussion about the development of the Beat Machine, we use aspects of interaction design outlined by Jung et al., which, they suggest, should help us “examine multifaceted roles of metaphors and materialities” [18]. These aspects are: *surface*, the user interface; *behavior*, responses to interaction; and *system*, how elements interrelate to form a coherent structure.

Surface

Interface design requires bringing elements together into a coherent whole. The first example of individuation in the Beat Machine project is its interface design, which adopts a DIY aesthetic that embraces raw exposed components and unadorned controls. The identity of the Beat Machine as a form relies on establishing its particular interface (see Fig. 1). In recent years DIY aesthetics have been adopted by commercial music products such as the Pocket Operators by Teenage Engineering.

The circular arrangement of components reinforces the looping structure of the sequencer engine. These visual metaphors are particularly necessary in digital devices because software-based patterns are otherwise opaque to users. Beat Machine interface design pays attention to this and other principles of digital design outlined by Jung and colleagues who suggest that “the forms of interactive [digital] applications are more complex than those of analog objects due to

Fig. 1. Beat Machine v1 top view. (© Andrew R. Brown)

Fig. 2. The software architecture of Beat Machine 1. (© Andrew R. Brown)

the immaterial qualities of digital materials, the temporal nature of their coded behaviours, interaction possibilities transcending physical material properties, and their network connectivity to other digital artists” [19].

Component spacing requirements partially dictated the size of the device, but we also designed it to be easily handheld, allowing for expressive gestural performances. An accelerometer on the back maps device tilt orientation onto sonic features. Thus, the individual identity of the Beat Machine arises from the interaction of the materiality of components and the embodied requirements of handheld musical performance.

Behavior

The Beat Machine has three major software components: synthesis engine, sequencer engine and interface management.

We designed the synthesis architecture to reproduce percussive and pitched timbres as done by drum machines such as the Roland TR-808. The low-cost microprocessors utilized in the design required very efficient software. Fortunately, the Mozzi audio library [20] provided an excellent platform for this project and its selection also influenced the choice of Arduino microprocessors. The agency of these material choices on the development of the project is clearly evident in such decisions.

The synthesis architecture of the Beat Machine is shown in Fig. 2. Each of the three voices has two oscillators mixed into an attack-release amplitude envelope with volume controls for per-voice and overall output. The 8-bit, 16kHz audio output from the Mozzi library dictates a lo-fi aesthetic, and listening is therefore a particularly critical aspect of the design processes. Theoretical signal processing expectations were useful only as a guide, and embodied senses were always the final arbiter of “best” choices, reinforcing Poulsgaard’s view

that “material engagement acts as a fundamental cognitive resource in its own right—that we think with and through things in action” [21].

Interactive systems, like the Beat Machine, are defined by their behavior and temporal responsiveness, further underscoring the significance of feedback in relational interactions between users and the machine. The selection and responsiveness of interface controls and managing their update timing was an iterative process; we manually adjusted many settings until the response “felt” right. Constraints around the number of digital dials (eight) dictated synthesis parameter choices. Dials 9 and 10, for volume and distortion, were direct analog resistance controls (Fig. 3).

Fig. 3. Overview of Beat Machine controls. (© John Ferguson)

The Beat Machine's 16 step buttons, eight dials and three control buttons exceeded the available GPIO pins on the Arduino. Additionally, the high-speed data communications protocol utilized by the neopixel to control LEDs had a tendency to cause havoc with the audio synthesis engine. Our solution was to use a second microcontroller and two power regulators to minimize crosstalk between sound generation and LED control. This approach also provided sufficient input pins for the desired level of control; the two microcontrollers communicated via the I2C interface. Another factor in this decision was that the three synthesis voices utilized all CPU capacity on the first Arduino; sequencing, LED control and MIDI communication was allocated to the second Arduino. Software coordination between microcontrollers to manage distributed interface controls and coordinate timing of sequence and synthesis engines resulted in quite a tangle of code. But these forced design moves arose from the hardware affordances (or lack of them) and further illustrate the influence these components have in design decisions. Doing similar work on computing systems with significantly more power would not have made us so aware of the components' materiality.

The sequencing engine operates as a 16-step sequencer. It also incorporates generative features that enhance its presence in the musical production. These generative features are derived from the musical affordances of basic computational processes outlined by Brown and Sorensen [22]. In particular, they include the use of simple harmonic motion for imposing a groove accent, the ability of each step to have a probabilistic tendency to play or not, and the adjustment of each synthesis parameter per sequence step to allow either subtle or dramatic timbral variation from step to step.

The accelerometer activates when the device is held in excess of 15° from horizontal, and it is currently configured as follows: Y (forward and back) controls the chance of adding random hits to the sequence; X (left and right) effects the blend between Oscillator 2 and Oscillator 1 and can thus be used as a timbre control. Audio filtering for three voices was too computationally expensive to be effective on an Arduino, and this approach to timbre using the X axis has proved a useful substitute.

The generative aspects of the system, although subtle, illustrate a longstanding design tension between balancing reliance on the embodied skill of users (musicianship in this case) and ceding decision-making to algorithms or chance. This is relevant from an enactive perspective, because such tension is based in an underlying dualist ontology of people and things. The enactive perspective tries to look past such human-machine asymmetries, and the Beat Machine design allows for more-or-less-generative influence in the music depending on user preference.

System

The developers' collection of components, and their integration, is an important phase in the development of digital instruments such as the Beat Machine. An enactive approach emphasizes that this collection includes not only materials but deliberate decisions about social, cultural and environmental contributors to the design. During the Beat Machine devel-

opment, our choices included target music genres and even musical works whose emulation would act as benchmarks for success. Our establishment of a collection of technologies and concepts was ongoing and dynamic. Throughout the literature, such collections have been described as an "assemblage" [23] or "performance ecosystem" [24] or "technical milieu" [25]. Resources within such collections work best when they are complementary in their contribution to the creative process [26]. The processes of enactive individuation arise through feedback on iterative product decisions that operate at multiple time scales. These processes reinforce or disrupt the technical/conceptual collections: We made decisions such as the Beat Machine's similarity to drum machines early on, while decisions about hardware components and their integration accumulated as the project proceeded and software choices were more fluid and provisional.

Our creative development included interaction with layers of hardware and software built up over time. Figure 4 shows the development of Beat Machine version 2 at the stage of "breadboard" design where most components had been selected and assembled to allow testing and refinement of the system. We typically followed hardware design by software development with feedback processes revealing constraints that required adaptation of features and occasional replacement of hardware elements.

Fig. 4. Beat Machine version 3 during breadboard development (Wemos D1 and 4 x HC4051 multiplexing chips). (© Andrew R. Brown)

The entanglement of elements in the collection did at times become complex; however, it was often our attempts at solving such wicked design problems that made the project interesting and satisfying.

We laid out selected components, including dual Arduino Nanos with regulated/isolated power supplies to minimize crosstalk between LED control and sound generation, on a dedicated circuit board design shown in Fig. 5. A commercial printing service produced bespoke circuit boards in small quantities, and users hand-soldered the components.

Throughout, our challenge was to work productively with materials that were simultaneously enabling and resistant. The individuality of the Beat Machine emerged from enactive engagement between these materials and our creative goals. Consistently, we landed on solutions through active interaction with the prototypes.

Fig. 5. Electronics schematic created with EAGLE software of Beat Machine version 1. (© John Ferguson)

CONCLUSION

The Beat Machine is a lo-fi musical groove box that relies on inexpensive and computationally limited hardware. In this project “design” and “making” are iterative activities full of learning, practicing and skill development. As the project evolved, we incrementally committed to hardware, software and cultural elements; the design process congealed to form the particular individuality of the Beat Machine. In this way the project shares phenomenological features with other music practices, such as learning jazz improvisation, described so insightfully by David Sudnow [27]. The project is shaped by material engagement with microelectronics in ways that fit neatly with the theory of enactive individuation.

The process of engaging with the materiality of electronic and digital components is visceral in a DIY project with such tight constraints, and we hope this case study serves to highlight how enactive individuation is a useful lens for understanding such a design process. As Poulsgaard articulates, “in a very real sense, technics forms the horizon of our imagination, our creative engagement with the world around

us and our perception of temporality” [28]. The challenge for us in analyzing the Beat Machine project through the lens of enactive individuation was how to make sense of developmental ecologies that were at once material, informational and cultural and that had the potential to shape our creative imagination and practice. In reflecting on our design and making activities, we have embraced material engagement theories within a digital context. One may see these as simple metaphoric projections from analog making processes. But through theoretical developments such as enactive individuation, the unique complexity of hybrid digital-physical practices, such as ours in making the Beat Machine, can be increasingly recognized as authentic.

In this article, we have used reflections on the Beat Machine project to highlight how material engagement is at the heart of postdigital design and making practices. As musicians, we have found the concept of enactive individuation to be sympathetic with our commitment to a performative approach to creative interactions with materials and contexts.

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