MachineShop: Steps Toward Exploring Novel I/O Devices for Computational Craftwork

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Abstract

The notion of "computational crafting" focuses on the numerous ways in which computational media may be used to expand the expressive range of traditional educational crafts. One important dimension of this approach involves a close re-examination of an issue often taken for granted in educational technology—namely, the design and use of I/O devices. The next decade is likely to produce a fascinating array of novel I/O devices and technologies; these in turn offer substantial promise of augmenting the power of computational tools for children's craftwork.

This paper describes initial work toward developing an educational crafting application for the design of mechanical toys and automata. Our application, MachineShop, is intended to allow students to create mechanical parts (e.g., cams, gears, and shafts) that may be customized and simulated on the computer screen, and finally "printed out" on a laser cutter for realization in materials such as wood and foam core. We describe the current (early) state of the application and discuss its implications for the design and use of novel or unorthodox I/O devices in educational technology.

1. Introduction

At the risk of a slight degree of caricature, there is something of a "mainstream view" of educational computing in which the notion of the "computer" has remained qualitatively unchanged for at least two decades. In this view, the heart of the computer is the CPU/memory combination portrayed in standard textbooks of computer architecture; and input/output (I/O) devices are the means by which communication with this calculating engine is effected. Undoubtedly, the details of this picture may change—processors get (much) faster, memory (much) larger, screens more expansive, applications more complex, and so forth—but the basic model of the computer remains constant.

While this mainstream portrait of the "educational computer" has provided a foundation for a generation of magnificently productive work, it nevertheless conceals a variety of superficially plausible but potentially limiting assumptions. One such implicit assumption—reflected uncomfortably in the standard vocabulary of the computer industry—is that I/O devices are "peripheral" to the true core of computer science. A corollary of this view is that there need only be a few standard, general-purpose means of communicating user input to the device (keyboards and a variety of pointing/selection devices), and a few means of communicating the device's response back to the user (screens and printers).

This is not by any stretch the only problematic assumption of the traditional portrait: others include the notion (now rapidly fading) that a computer is inevitably a desktop device; or that a larger and more powerful computer is necessarily preferable to a smaller, simpler device; or that computer languages, because they are designed to exploit the large desktop devices in which they run, are therefore vast and sprawling exercises in complex notation. Over the past several years, our explorations in the area of "computational craftwork" have led us to re-examine all of these assumptions (among others). For the purposes of this paper, however, we will focus on the issue of I/O devices. In particular, we argue here that viewing the computer as one element of a larger system of craft technologies leads quite naturally to an increased attention to the space of materials and objects that can be output from (or even, conceivably, input to) computational media.

By way of example, we describe our initial work in creating an application called MachineShop; this is a software system whose purpose is to assist students in the creation of physical mechanical devices and automata. MachineShop is conceived as an application through which objects can be realized in a variety of materials, including cardboard, wood, and foam core. It thus represents a sample excursion into the vast (and largely unexplored) territory in which computational media and educational crafting may eventually intersect.

The remainder of this paper is organized as follows: in the second section, we give a brief outline of the notion of "computational crafting" in education, and sketch some of our representative earlier work in this area. The third section presents an example of cam construction using our current version of MachineShop, illustrating the conceptual path from on-screen design to "printing out" in wood. In the fourth and final section, we use MachineShop as a springboard for a much broader discussion of the potential role of novel I/O devices and technologies in educational computing.

2. Blending computational media and educational crafts

The basic idea behind "computational crafting" is that it seeks ways in which computers may be used to enhance the expressive range of traditional (and in some cases, nontraditional) educational crafts. While activities such as geometric papercrafting, making string figures, and mechanical design have a venerable history in mathematics and science education, they are usually regarded as "enrichment" activities, not to be accorded too much time or attention; this unfortunate status has been exacerbated by the reputation that craft activities have of being "low-tech" and thus somehow anachronistic in an age of burgeoning educational technology.

It is our view that there are tremendous educational benefits to be reaped, both by advocates of craftwork and advocates of technology, by blending techniques from both cultures. Crafters gain new tools, notations, and materials to work with; technologists gain fascinating new domains to explore, and fascinating research issues that accompany those domains.

In practice, computational crafting takes several major forms. One line of work, pioneered by Resnick and his colleagues in the development of the "programmable Lego brick"[1], focuses on embedding computational capabilities within craft objects. In our group, we have pursued this line of thought by creating prototypes of programmable craft objects (hinges, tacks, and ceramic tiles): in each case, small computers are used to provide customized behavior to the object in question. For example, the "programmable hinge" may be sent commands to open and close in user-controlled patterns. [2] Another line of work, closer in spirit to MachineShop, is the design of software applications to enrich the use of (otherwise traditional or noncomputational) materials. Examples of our group's earlier work in this area are HyperGami, a program for the design of paper polyhedral models [3], and HyperSpider, a program for the design of mathematical string sculptures [4]. The basic notion behind such applications is that the user creates models, on the computer screen, of objects that will subsequently be the targets of physical design. In the case of HyperGami, for instance, the typical scenario is that a user creates a three-dimensional polyhedron on the screen; the program "unfolds" that shape into a two-dimensional pattern; the user then decorates and prints out this pattern on a color printer; and finally, the pattern may then be cut out and folded into a physical object.

MachineShop is representative of this second style of work in that it is conceived as a design application for (generally noncomputational) mechanical automata. This particular domain, however, brings to the fore a number of interesting problems for the application designer—problems not encountered in the creation of HyperGami and HyperSpider. One obvious element is that the objects produced by MachineShop are dynamic; thus, our design application must provide at least a rough simulation capability so that students can see how their creations will move. Another issue—not quite as glaringly apparent—is that the objects produced by MachineShop are not themselves "whole" creations (as in the case of the earlier two programs), but are rather imagined as parts to be used in larger creations. When one creates an automaton, the mechanical elements are crucial; but they are "support structure" for what is often a much more elaborate endeavor in representing (e.g.) a moving animal or human figure. (Generally, the sorts of creations that we have in mind here are currently exemplified by the brilliant automata on display at London's Cabaret Mechanical Theatre. [5])

One thus thinks of MachineShop as a tool for the creation of "kits" of moving pieces that can be customized and re-used for producing specific types of motions in various automaton-design projects. Importantly, the pieces created may (for various reasons) be realized in materials such as paper, cardboard, foam core, plastic or wood, depending on the nature of the particular design project involved. MachineShop therefore must produce specifications of objects that can be "printed out" in a variety of appropriate media. We return to this topic in the following two sections.

3. MachineShop: a brief sample scenario

In this section we present a short scenario illustrating the creation of a customized cam using the current MachineShop prototype. (At present, the system is still very much a work-in-progress, and only the cam module is sufficiently developed for purposes of demonstration.) Figure 1 shows the MachineShop screen interface for the construction of a snail cam.

The cam design window of Figure 1 is divided into three sections. At upper left is a graph representing the path that a cam follower would take as the cam turned; in this case, the follower would move up steadily, followed by a short vertical drop at the notches in the cam. At lower left are various pull-down menus to specify cam parameters, and buttons for saving and loading files. At right is a line drawing showing the cam profile; this corresponds to the parameters specified and the graph at upper left. Finally, there is a button for animating the profile so that the user can view the cam's motion; this causes the profile to rotate (soon to be accompanied by an animated cam follower), permitting the user to see how the physical part will move once constructed.

One of the themes of MachineShop's design is that the user should, wherever feasible, be able to create parts to produce some desired pattern of motion. To this end, the rectangles on the graph representation of Figure 1 can be moved interactively on the grid, allowing the user to change the dwell and lift of any lobe while seeing these changes as part of the follower's path. As the user moves these points the cam profile is updated to reflect the cam's
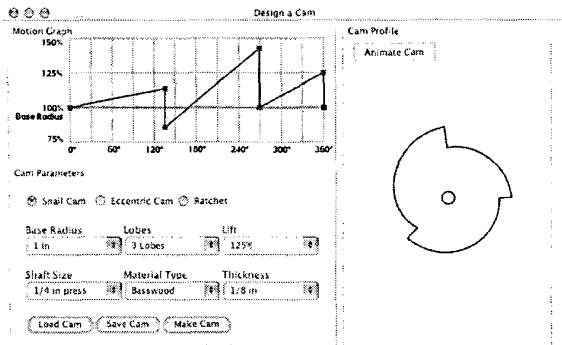
Figure 1. The MachineShop interface for creating a snail cam. In this scenario, we are creating a customized 3-lobed cam as described in the text.

Figure 2. The cam being cut from basswood on a CO_2 laser cutter.

Figure 3. The finished cam.

new shape. For the types of snail cams shown, the drop from the high point of one lobe to the low point of the next is vertical. This is captured in the graph by constraining points that share a common horizontal position to move horizontally in unison. The thicker horizontal grid line indicates the base radius of the cam with each division above and below it representing a 25% change in that radius, from 75% to 150%. Each vertical division represents 30 degrees of rotation.

The various pull-down menus toward the left allow the user to customize the cam in a variety of ways: she can change the base radius for cam size, the number of lobes, the offset of the shaft hole (for use with eccentric cams, the second cam type currently provided by the software) and the size of the shaft hole. The control buttons just above these menus provide for creating and retrieving files of cam profiles and parameters; the Save and Load buttons perform the obvious functions, while the Fabricate button creates a file that can be employed by a computer-controlled machine tool (in this case, a carbon dioxide laser cutter) to fabricate the cam.

Figures 2 and 3 show a continuation of this scenario in which the customized cam designed in Figure 1 has been translated to a laser-cutter fabrication file, and "printed out" in wood. (Figure 3 shows the final object itself.) Once this step is complete, the cam could be incorporated into larger mechanical-design projects. It should be noted that if alternative materials are desired, the laser cutter shown in Figure 2 is also capable of producing the object in materials such as cardboard and foam core.

4. Re-thinking the notion of "peripherals" in educational computing

We believe that it is worth dwelling for a moment on the implications of the scenario in the previous section. Output is not merely an afterthought to computation, as the term "peripheral" might suggest. The fact that new
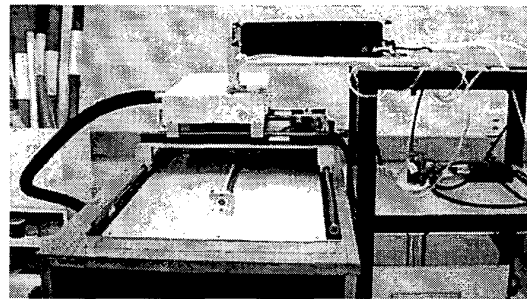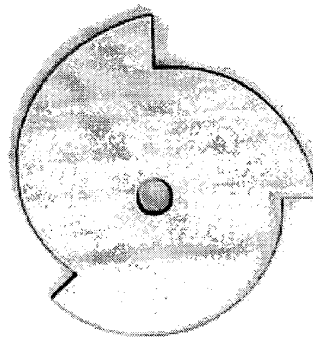
tools such as laser cutters are now becoming increasingly affordable and accessible implies that they could well be a growing presence in classrooms over the next decade or so. Indeed, we would like to believe that the burgeoning presence of color printers (in both homes and classrooms) is a harbinger of a similar pattern for other sorts of output devices in the near future. Whether this in fact occurs will in part depend on the presence of appropriate educational software to exploit the new devices; there is something of a cycle of cause and effect here between applications and devices, in which the presence of useful applications (such as MachineShop) encourages the spread of certain devices (such as laser cutters) which in turn encourages the development of still more expressive applications.

Traditionally, children's exposure to both tools and materials for building the kinds of objects described here have been limited to shop and art classes. These are inadequate for the mastery of either, and children tend to encounter great frustration when trying to make all but the simplest of objects. The fact that a device such as a laser cutter is capable of producing output in (e.g.) wood suggests that many craft design activities could now be within the purview of elementary school classrooms. Exploiting a device such as the one shown in Figure 2, we can envision systems for the design of mathematical and scientific craft objects such as (just to name a few): customized wooden sliding tile puzzles or tangram sets;

balancing wooden toys that perch on the edge of a shelf; "jumping jack" puppet figures made of wood and string; jigsaw puzzles in both two and three dimensions; articulated shadow puppets; and so forth. All these examples require nothing more than a relatively simple one-dimensional laser cutter (in which the beam can only cut material in one direction); such devices produce only "flat" forms as output. A slightly more ambitious prospect would be to employ two-dimensional laser cutters as output devices; in this case one could envision classroom applications to produce (e.g.) wooden burr puzzles; etched designs on the surfaces of wooden polyhedra or spheres; customized connectors for three-dimensional wooden "erector set-like" construction kits; and so forth.

The upshot of this speculation is that the types of educational applications that software designers can create may be vastly expanded by the advent of novel, accessible output devices. That is, output devices potentially hold a central—not a peripheral—place in our imaginations as designers. There is nothing outrageously futuristic about this speculation, except perhaps in that word "accessible"; laser cutters are currently prohibitively expensive for the majority of classrooms. Still, as suggested by the analogy with color printers (which were also prohibitively expensive for classrooms ten years ago), there is no a priori reason to believe that laser cutters may not become as plentiful (and safe) as other classroom technology. Moreover, such a development could potentially put to rest another common worry of educators: namely, that the presence of computational media necessarily leads to an increasingly "virtualized" existence for children, and a corresponding diminution of experience and pleasure with real-world materials and physical objects. On the contrary, we believe that applications such as HyperGami and MachineShop can enrich children's experience with the physical world.

Indeed, there is still another point to be made here on the subject of children's experiences with physical objects. In many cases, when educators discuss the use of physical materials such as construction kits, tile puzzles, balancing toys, and so forth, the assumption is that these are commercial items to be purchased; that is to say, they are *not* craft items, but are instead products to be sold to classrooms and children. Our belief, in contrast, is that the advent of appropriate output devices and software can expand the landscape of what we conceive of as "children's crafts". Objects that at one time might only have been available commercially (such as balancing toys or jigsaw puzzles) could soon be the province of artistic and creative children. Far from impoverishing the space of children's work with physical materials, then, technology can potentially endow children with expressive control over realms that are currently beyond their typical experience.

Of course, we needn't curtail our speculation at the use of laser cutters as output devices. Current research in a variety of commercial three-dimensional printing technologies (cf. the highly readable discussion in Gershenfeld [6]) suggests that still more expressive output devices may be on the not-too-distant horizon. By using these devices, still other craft activities and materials could easily be within the purview of children's crafts: using plastic materials, one could make snap-together bricks, or customized spinning tops, or realistic animal or human figures, or chemical models, or myriads of other objects. Going just a bit further, we believe that it would be especially useful for educators themselves to speculate, proactively, on the sorts of I/O devices that would hold special utility for children's crafts. One object on our own "wish list" would be a device to output yarn with specified color patterns: in a sense, such a device would be to yarn what a color printer is to blank paper. With a device of this sort, we could output complex color patterns for yarn to employ in sculptures such as those designed by users of HyperSpider. Another possibility would be to think of new input, as well, as output, devices. One might imagine, for instance, "readers" for at least certain classes of three-dimensional objects to be used as templates for craft projects (e.g., a solid figure might be read in; converted to a discretized polyhedral representation; and then output to a HyperGami-like folding net).

All this is of course a long way from our early work with MachineShop; and there is still much more short-term development that needs to be done with our current system. Nonetheless, even our very earliest experiences with novel output devices suggest that the realm of children's craftwork has an exciting and healthy future.

Acknowledgments

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