Designing in HiFi

Digital Fabrication for Physical Computation

Daniel Smithwick
Department of Architecture, Massachusetts Institute of Technology, USA
djs2@mit.edu

Lawrence Sass
Department of Architecture, Massachusetts Institute of Technology, USA
lsass@mit.edu

ABSTRACT
Digital sound reproduction is inferior to analog sound reproduction: by definition digitally processed sound is a compressed representation of the original sound signal. Similarly, this paper asks: Are digital computation design tools inferior to analog tools? Is information missing from the digital design 'signals'? What is *analog* computation and could new tools be developed that avoid digital compression, and allow designers to more clearly 'hear' or experience the act of design? Working within our current digital computation paradigm, we argue designers are underexposed to and even unaware of much of the raw design signal available with analog computation design tools.

KEYWORDS: digital design computation; Shape Grammar, 3D printing

Introduction

The current generation of designers is probably the last that will have experienced computational design tools that are not digital. In fact, it is likely that the idea of a non-digital computer is already a foreign concept to most readers. Such thinking is prevalent in design computing, primarily because most think computing is digital by definition. This is not the case, however; there is a rich history of pre-digital analog computation (see: Care, 2006-7; Copeland, 2008). We suggest that with a better understanding of how limiting digital computation is, designers would strive for developing a more expansive computational theory. George Stiny argues that designers compute simply by seeing, as demonstrated through his visual computation studies of Palladian Villas, Ice Ray Lattices, and Mogul Gardens (Stiny 1977a, 1978a, X). Stiny explicitly writes, 'Seeing = Calculating' and 'Calculating = Designing' (Stiny, 2006). Digital computing is a limited, zero-dimensional type of computing where the units of measure are discrete bits (e.g., $i = 0$). Conversely, Stiny's Shape Grammars are a greater-than-zero type of continuous calculating (e.g., $i \rightarrow 0$). In other words they are a type of analog design computing. However, Shape Grammars remain within the visual domain only. We propose that there are other types of analog design computation beyond visual computing, one of which is physical computation.

Physical Computation for Design

There is debate in design education as to how to define analog design tools with respect to digital computation (Hybridized Practices: Both the Analog and the Digital, 2011 ACSA Conference). Porter suggests that the discussion should be framed around computational versus formalized processes (Porter, 2011). Brillhart presents a study of design processes with and without computation to reveal how the brain works at "*creative, intuitive, and rational*" levels (Brillhart, 2011). Corser suggests that a hybrid process of digital computation such as parametric modeling and digital fabrication be coupled with analog physical modeling and form-making to create a more discovery-based design process (Corser, 2011). These positions reveal the common assumption that computation is limited to a digital paradigm. Our approach to analog computation provides an additional perspective to this discussion: We suggest that digital tools and analog tools should *both* be defined as computational tools.

A Digitally Fabricated Analog Computer

As a simple example of an analog computer we digitally fabricate a logarithmic slide rule (Fig. 1). More sophisticated pre-digital computers exist, including: Charles Babbage's 1822 Differential Engine; James Maxwell Clerk's 1855 Planimeter; and Vannevar Bush's 1931 Differential Analyzer (Care, 2006-7).

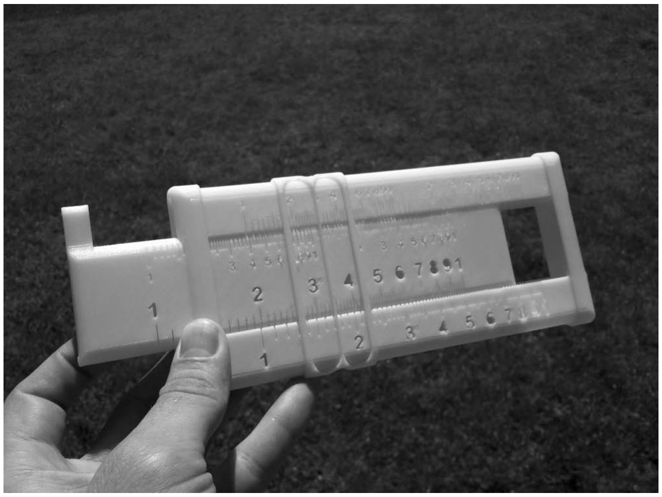

Fig. 1. Digitally Fabricated Slide Rule

Common slide rules perform rudimentary calculations such as multiplication, division, logarithms, squares and square roots. The principle invention driving the slide rule's success as a useful calculating tool is the logarithm, attributed to mathematician John Napier in 1620. The application of logarithms into slide rules allows for higher order mathematical functions to be translated into lower order functions. For example, multiplication is translated into addition, as described in this formula: $\log_b(xy) = \log_b(x) + \log_b(y)$. Therefore, as seen in Figure 2, to calculate 2 times 3, one simply adds the log(2) on the bottom ruler with the log(3) on the above sliding ruler resulting in log(6).

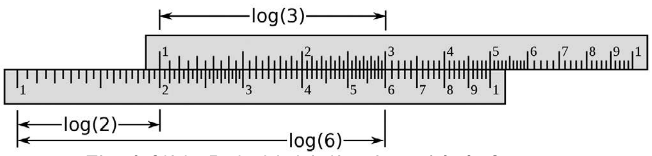

Fig. 2 Slide Rule Multiplication of 2x3. Source:

http://en.wikipedia.org/wiki/Logarithm

Physicality of Analog Computation

The mathematical operation executed on the slide rule demonstrates the *physicality* of analog computation. The computation is *performed* by the operator via the movement of his hands which changes the shape of the computer itself as it continuously measures the distance traveled in space. The quality of movement by the operator and the corresponding shape transformation of the computer can be unique every time even for the same mathematical function. For example, the velocity of the movement and its acceleration may vary; and it can take shape as short bursts or as long, slow movements. These experiential qualities expand the creative potential of analog computation that is neglected (compressed) in digital computation. With physical computation, there can be an infinite number of ways to compute 2 times 3. Understanding computation *qualitatively* places more importance on the physical act of computing than on the result of computing.

Analog vs. Digital Computation
This physicality distinguishes analog computation from digital computation. Outlined below are the actions required to calculate 2.5 times 3.8 on a digital computer and on an analog computer, respectively (Fig. 3).

There are three key differences between digital computation and analog computation to be noted. First, is the complexity in the steps required for digitally computing the multiplication. One must memorize many abstract symbols such as '=', or '*' to execute these steps. Second, is the relationship between physical movement and the numerical values in the function. With analog computation the physical act of executing the computation is directly related to the values of the numbers being calculated, e.g., a larger movement is required for large numbers. With digital computation the performance of calculation is divorced from the values of the calculation. Instead, movement of the operator is defined by an abstract interface representation.

A third key difference between digital and physical computation is the concept of stored memory. With analog computation, the process of retrieving previously used values is no different than enacting the movement required to perform the functions containing the values. In other words, Memory = Movement. With digital computation, memory is separated from movement and requires a layer of abstraction for retrieval. As such, memory is treated as past tense and is therefore limiting because it is pre-defined. Conversely, in analog computing memory is future tense and therefore expansive.

Implications of Physical Computation for Design

What does the performance of design look like today? With digital computation the skill of design is becoming an exercise of memorizing discrete commands and sequences that are abstracted from the actual values of the design. Computational philosopher, Hubert Dreyfus writes, "*The important thing about skills is that, although science requires that skilled performance be described according to rules, these rules need no way be involved in producing the performance*" (253). Stiny presents a similar argument on the performance of design: "*The draftsman always has the option to draw it in one way and* *see it in another—to forget what he's done, so that he can see and do more*" (2006, 134). With digital computation, designers begin where science begins: with pre-defined rules. With analog computation, designers start where performance begins.

Conclusion

We suggest the potential for novel physical computation machines which can empower designers with more expressive potential through physical interaction with the computer itself. With new digital fabrication technologies we can broaden our definition of computation beyond digitally based representation into physically based analog computing. Analog computers will allow us to enrich our experience of computing and calculating.

References

Brillhart, Jacob. 2011 March. Drawing Towards a More Creative Architecture: Mediating between the Digital and the Analog. Eds. Anne Cormier, Annie Pedret, and Alberto Perez-Gomez *Where do You Stand?* Paper presented at the 99th ACSA Meeting, Montreal, Canada (422-429). Washington DC: ACSA Press.

Care, Charles. 2006-7. 'A Chronology of Analogue Computing,' The Rutherford Journal, Vol 2. Retrieved from http://www.rutherfordjournal.org/article020106.html

Copeland, B. Jack, "The Modern History of Computing", *The Stanford Encyclopedia of Philosophy (Fall 2008 Edition)*, Edward N. Zalta (ed.), retrieved January 2011 from http://plato.stanford.edu/archives/fall2008/entries/computing-history/

Corser, Robert. 2011 March. Stress-Crafting: Interweaving Digital Dexterity and Manual Intelligence. Eds. Anne Cormier, Annie Pedret, and Alberto Perez-Gomez *Where do You Stand?* Paper presented at the 99th ACSA Meeting, Montreal, Canada (438-445). Washington DC: ACSA Press.

Dreyfus, Hubert. 1992. What Computers Still Can't Do. MIT Press, Cambridge.

Porter, Zachary. 2011 March. Architectural Fractures: Computation and Form in the Work of Le Corbuseir and John Hedjduk. Eds. Anne Cormier, Annie Pedret, and Alberto Perez-Gomez *Where do You Stand?* Paper presented at the 99th ACSA Meeting, Montreal, Canada (446-449). Washington DC: ACSA Press.

Stiny, George. 2006. Shape: Talking about Seeing and Doing. MIT Press, Cambridge.

Stiny G. 1977a, "Ice-ray: a note on Chinese lattice designs". Environment and Planning B: Planning and Design4. 89-98.

Stiny G, Mitchell W J, 1978a, "The Palladian Grammar" Environment and Planning B: Planning and Design 5. 5-18.

DIGITAL COMPUTATION	ANALOG COMPUTATION
1. Open calculator program • Move hand with mouse above 'Windows' Start icon • Click on the 'Windows' Start icon • Move hand with mouse above 'Calculator' icon • Click left mouse button above 'Calculator' to open program	Pick up slide rule with both hands
2. Select '2.5' on keypad interface • Move hand with mouse above the rectangle with the number '2' inside • Click left mouse button above the '2' • Move hand with mouse above the rectangle with the decimal point inside • Click left mouse button above the decimal point • Move hand with mouse above rectangle with the number 5 inside • Click left mouse button above the number '5'	Move the sliding ruler to the right a distance of log(2.5) so that the tic mark below the '1' aligns with the fifth tic mark after the '2' on the bottom ruler
3. Select the multiplication symbol '*' on the keypad interface • Move hand with mouse above the rectangle with the * symbol • Click left mouse button above the *	On the sliding ruler, locate the 8th tic mark after the '3'
4. Select '3.8' on keypad interface • Move hand with mouse above the rectangle with the number 3 inside • Click left mouse button above 3 • Move hand with mouse above the rectangle with the decimal point inside • Click left mouse button above the decimal point • Move hand with mouse above rectangle with the number 8 inside • Click left mouse button above 8	On the bottom ruler, locate the tic mark directly in line with the tic mark identified in Step 3.
5. Select the '=' symbol on the keypad interface • Move hand with mouse above the rectangle with the '=" inside • Click left mouse button above '='	The fifth tic mark should be identified as the correct answer: '9.5'
6. The correct answer, '9.5' should appear in the text box	

Fig. 3. Digital Computation vs. Analog Computation