Andrew Witt

Design Hacking: The Machinery of Visual Combinatorics

Design has entered a new era of mechanical invention. Faced with the limitations of CNC-CAM machines that gave architects the ability to build at the push of a button, design hackers now find ways to transform the machines themselves and repurpose technology for specifically aesthetic ends. Using acquired skills, simple trial and error, and even technological folklore, design hackers go a step further than conventional digital fabrication, altering the machines themselves as a part of the design project. They modify computer-controlled routers, create custom robotic tools, and motorize entirely new fabrication systems of their own conception, believing that visual and spatial invention is also mechanical invention. But in this contemporary fascination with machine technology is a naive assumption that a parametric machine culture of design is fundamentally new.

Intervening in established sequences of operation, hacking diverts computation from deterministic conclusions. The term itself emerged in the 1970s as a way to describe the subversion of corporate technological systems toward more experimental aims. The practice arguably began with the discovery that certain sound tones could trigger phone-switching systems to provide unlimited long-distance calls. With this simple discovery, the planned operational logic of technical systems could be diverted from industrial and institutional ends toward more personal objectives, which inspired a radically democratic approach to technology.[1] Hacking became an individual means to co-opt institutional programs, an independent approach to technological innovation.

Today, new technologies have enabled new forms of hacking, particularly for designers. Basic kits provide components and assemblies to build personalized fabrication machines: 3-D printers, CNC routers, laser cutters, and hot-wire foam cutters.[2] Simple electronic controllers make the physical control of materials and assemblies automatic and programmable.[3] Through the Web, access to innovative

1. Scott Burnham, "Finding the Truth in Systems: In Praise of Design-Hacking" (London: Royal Society for the Encouragement of Arts, Manufactures & Commerce, 2009). http://www.scottburnham.com/files/Scott-Burnham-Hacking-Design-2009.pdf
2. Companies like Makerbot are among the vanguard in this movement, providing a full complement of personal CNC devices.
3. Arduino is the most common interface, a small programmable chip that can control motors, sensors, and actuators.

fabrication machines is open and designers can print 3-D models on demand from anywhere. For the moment, design hacking is highly informal and experiments are rarely conducted on actual building projects. In fact, some of the most paradigmatic examples of contemporary design hacking come from artists like Roxy Paine, whose *SCUMAK (Auto Sculpture Maker)* and *Erosion Machine* are invented devices of purely aesthetic material manipulation.

In architecture, design hacking is reemerging as a corollary of scripting, parametric design, and a combinatorial approach to machine technology, enabled by a new engagement with technology and mathematics. Parametric design software in particular – employing mutually reinforcing, modular approaches – parallels the same logical organization of machine systems and makes their visual permutation immediately accessible. A reconstructed history of design hacking and machine invention links the preoccupations of contemporary design hackers – permutation, kinematics, curvature, and parametric control – to past experiments with visual machines.

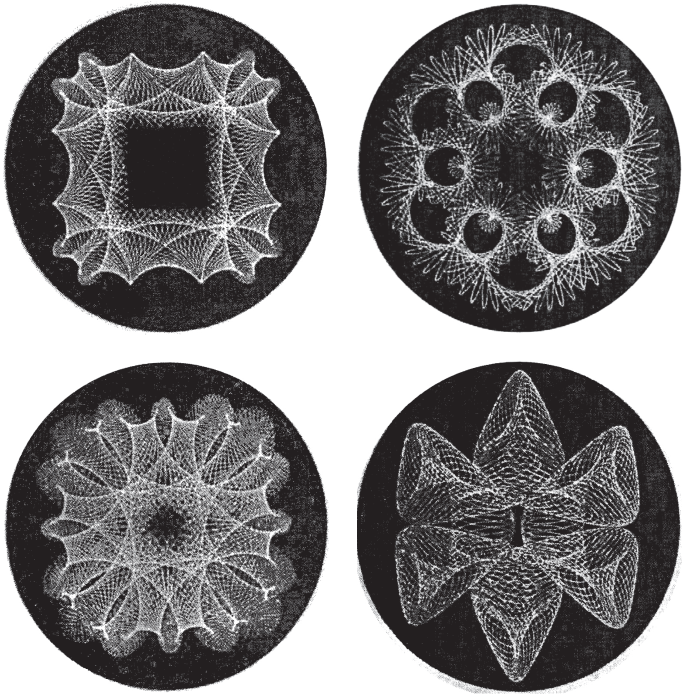
Permuting Machinery, Hacking Geometry

Purpose-built drawing devices were often designed for aesthetic subversion, and design hacking dates from the earliest of these experiments: the compound machines of the mathematician Giambattista Suardi. These machines, which Suardi detailed in his *Nuovi istromenti per la descrizione di diverse curve* (1752), were not intended to reproduce a fixed canon of known curves but instead to experimentally expand the range of visual geometry.[4] Through the permutation of geared disks, Suardi's device generated over 1,700 distinct curves with specific aesthetic and topological properties, opening the vast aesthetic possibilities of mechanical systems and providing a prototype for the combinatorial practice of design hacking.

In the 19th century, the expansion of the Industrial Revolution and the mechanization of science fostered a cultural fascination with the machine and its operative, productive, and visual capacities. This coincided with visualization of all sorts of concepts and processes – orbital paths, geological strata, and mathematical surfaces, among others. Images became a means of representing concepts and processes, a way to see abstract ideas themselves. Mechanical visualization and new approaches to the geometry of curves and surfaces developed in parallel, leading to intricate new drawing instruments

4. Giambattista Suardi, *Nuovi istromenti per la descrizione di diverse curve antiche e moderne* (Bressia: 1752).

Thomas Sebastian Bazley, drawings from, *Index to the Geometric Chuck: A Treatise upon the Description, in the Lathe, of Simple and Compound Epitrochoidal or "Geometric" Curves*, 1875.

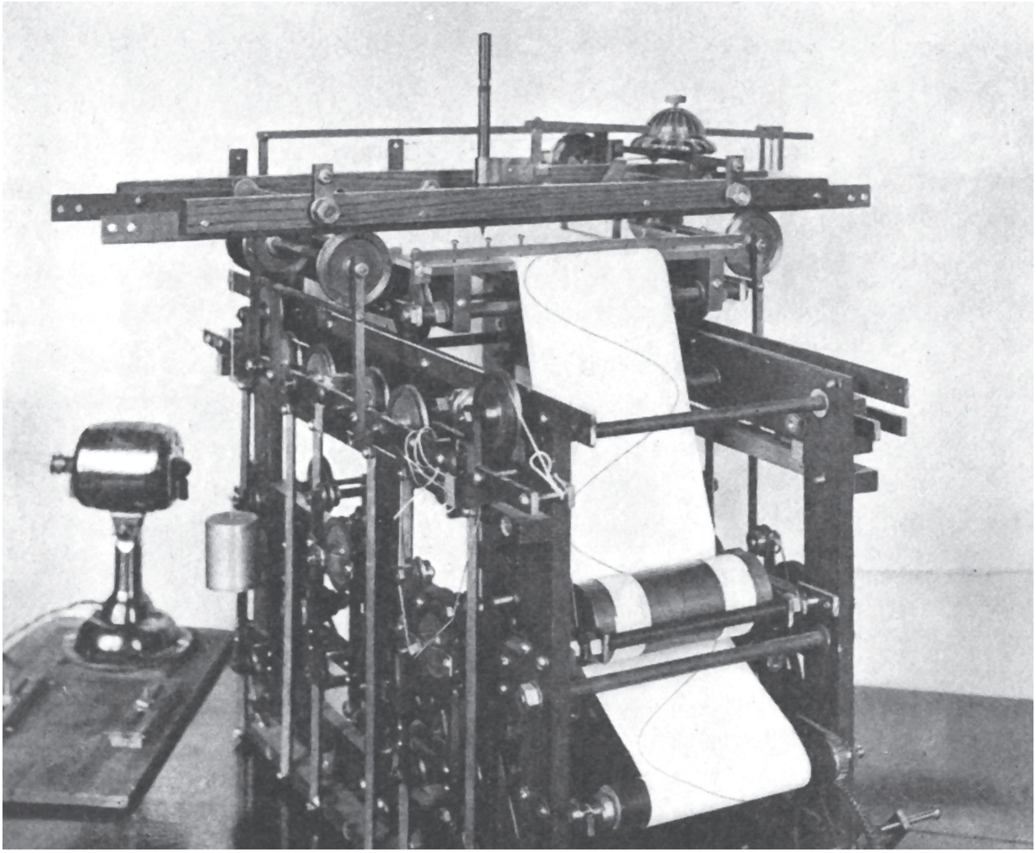


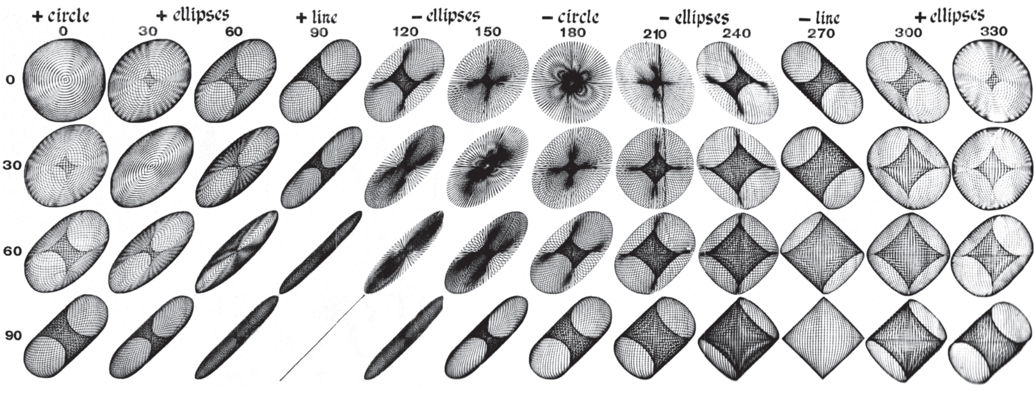
such as ellipsographs, helicographs, conchoidographs, and campylographs.[5] Architects designed their own devices for drawing complex curves, and the parametric, mechanical, combinatorial generation of visual artifacts emerged as a new project spanning mathematics, engineering, and design.[6]

During the late 19th and early 20th centuries, one particular type of curve, the Lissajous curve, inspired whole classes of drawing and fabrication machines, and indeed a whole approach to visual patterns.[7] First documented by Jules Antoine Lissajous in 1857, the parametric equations and generalizations of conic sections occurred frequently in the visualization of rhythmically periodic vibrations.[8] Experimentalists devised new types of machines relying on either pendulums or compound gears to produce Lissajous curves. These curves were recipes not only for the generation of images, but also for the fabrication of nonstandard curved components through compound-motion lathes. In particular, the "rose engine," a sophisticated radial carving machine, exploited this complex periodic symmetry to generate wood turnings with the same types of topological configurations as Lissajous curves, producing intricately twisted columns and complex finials.[9]

The most ambitious of these machines was William F. Rigge's 1927 device for combinatorial curve drawing.[10] Through the permutation of gears in various sizes, periods,

5. Andrew Witt, "A Machine Epistemology in Architecture," *Candide* 3 (December 2011): 63.
6. Robert J. Whitaker, "Harmonographs. II. Circular Design," *American Journal of Physics* 69 (February 2001): 174–83.
7. Joseph Lovering, "Anticipation of the Lissajous Curves," in *Proceedings of the American Academy of Arts and Sciences* 16 (May 1880–June 1881).
8. Jules Antoine Lissajous, "Memoire Sur L'etude Optique Des Mouvements Vibratoires," *Annales de Chimie et de Physique* 51, 3rd series (October 1857): 147–232.
9. Thomas Sebastian Bazley, *Index to the Geometric Chuck: A Treatise upon the Description, in the Lathe, of Simple and Compound Epitrochoidal or "Geometric" Curves* (London: Waterlow and Sons, 1875).
10. William F. Rigge, "A Compound Harmonic Motion Machine, Adapted for Drawing Any Predetermined Curve with Mathematical Accuracy," *Scientific American Supplement* 85, no. 2197 (February 9, 1918): 88–91; Rigge, "Stereoscopic Harmonic Curves," *School Science and Mathematics* 24, no. 1, (January 1924): 29–36; Rigge, *Harmonic Curves* (Chicago: Loyola University Press, 1927); Rigge, "Concerning a New Method of Tracing Cardioids," *American Mathematical Monthly* (January 1919): 21–32.

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William F. Rigge, Creighton Machine, xxxx. Below: a 1926 parametric map of a restricted combinatorial range of machine, illustrating transformations between families of harmonic curves.

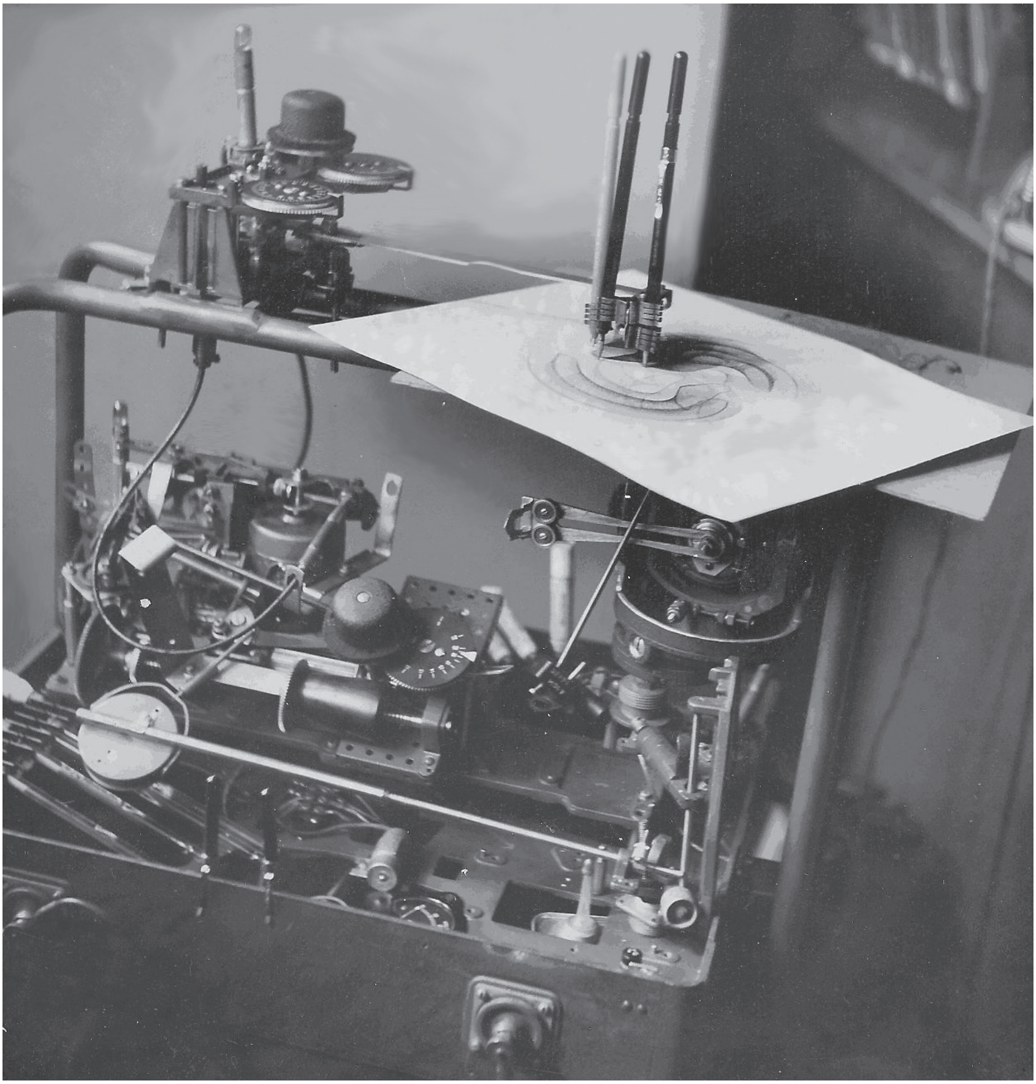
11. William F. Rigge, *Harmonic Curves*, 89.

and configurations, it could construct cycloids, harmonic curves, and exact Lissajous curves. Rigge, an astronomer and reverend, spent over a decade perfecting this machine, expanding the parametric variation and combinatorial range of the device to billions of distinct harmonic curves – 7,618,782,490, to be exact.[11] The machine thus became an empirical means of exploring an almost unlimited space of parametric permutations. In a particularly suggestive diagram, published alongside other research in Rigge's 1927 *Harmonic Curves*, a matrix of curve families and their continuous parametric intertransformations emphasizes the stereoscopic effects of his machine. Suggesting that the curves described are actually spatial constructs, he devotes considerable space to describing how his machine could generate stereograms of curved spaces, which the user could then experience directly with a stereoscope. Rigge thus brought a cinematic dimension to his work, connecting a technology of vision to his technology for visual calculation. These machines became an inspiration for visual experimentalists of the 20th century, keen to manipulate the visual cadence of space, time, and the machine itself.

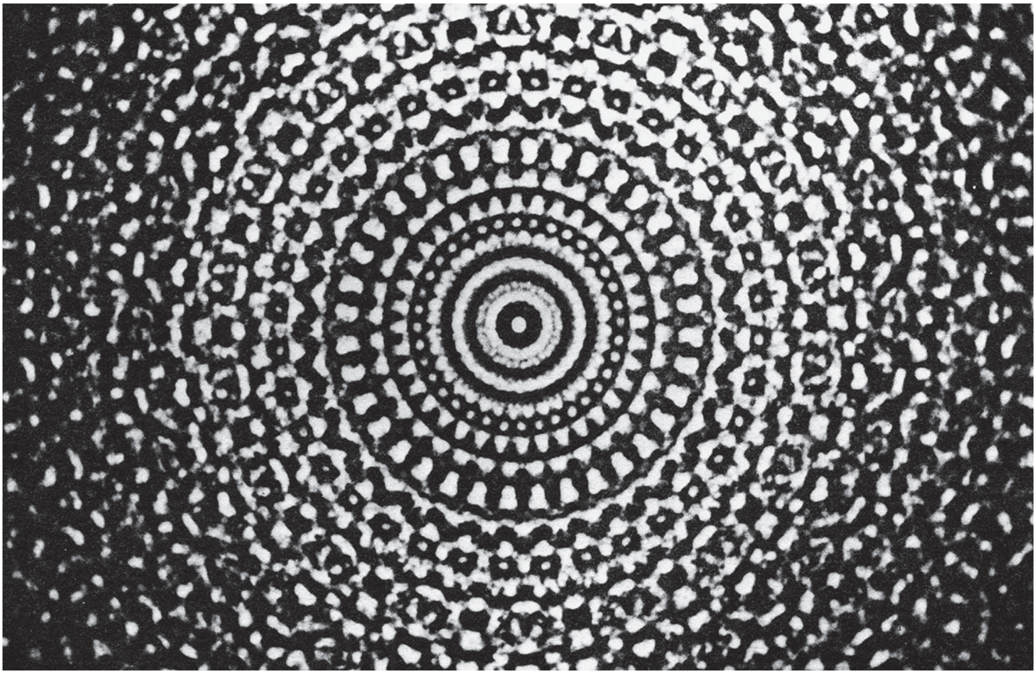
The Computation of Kinetic Modulation

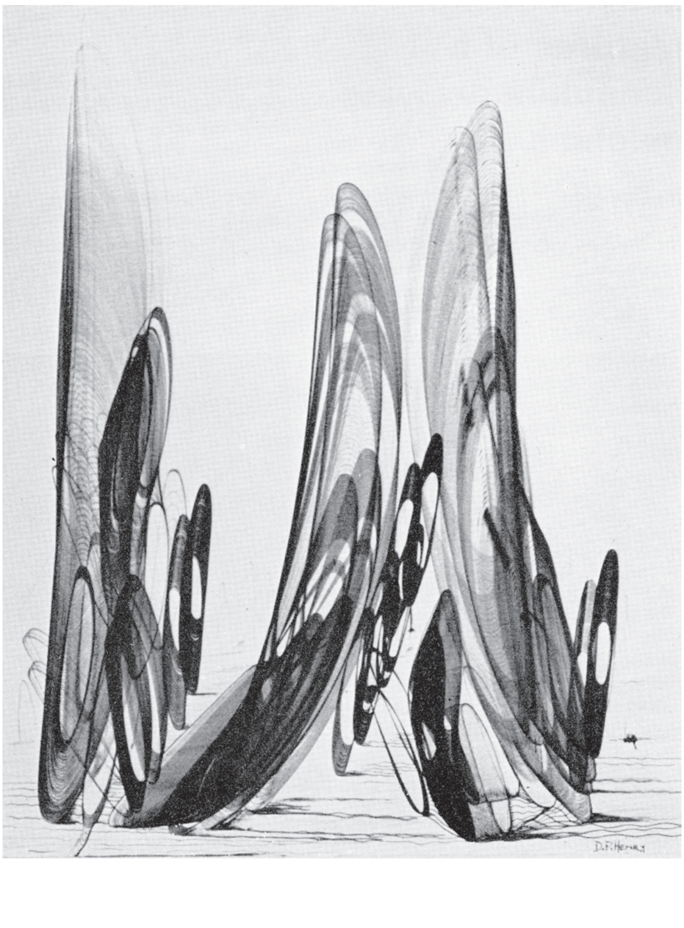
The most recognizable precedents for contemporary machine invention in design emerged in the mid-20th century, a time of exploding electro-technological innovation and cultural fascination with scientific artifacts. World War II brought a new generation of digital and analog electronic calculating machines, including ballistics computers used for measuring the trajectories of missiles. When these machines were discarded after the war, inventive artists suddenly had access to powerful computers that enabled unprecedented visual effects.

In Los Angeles, a center of defense contracting and a depository for analog ballistics computers, animator John Whitney repurposed components of these machines to control the geometric images of films. This machinery was later deployed by his brother, filmmaker James Whitney, to generate novel visual effects of permuting light mandalas for his influential 1966 work *Lapis*. With geometric gyrations and inversions of symmetric figures, a continuous kaleidoscope of machine-generated patterns dances across the screen. The film recalls Rigge's most spatial experiments and explores the mathematical cinematography anticipated by his stereographs.



Desmond Paul Henry, analog computer for generating curved drawings, 19xx. Photo courtesy Estate of Desmond Paul Henry. Opposite: Desmond Paul Henry, mechanical drawing. From "The Henry drawing computer," *Cybernetic Serendipity: the computer and the arts*, special issue, *Studio International* (July 1968): 50. Opposite top: Film still. James Whitney, *Lapis*, 1966. © 2011 the Estate of John and James Whitney.





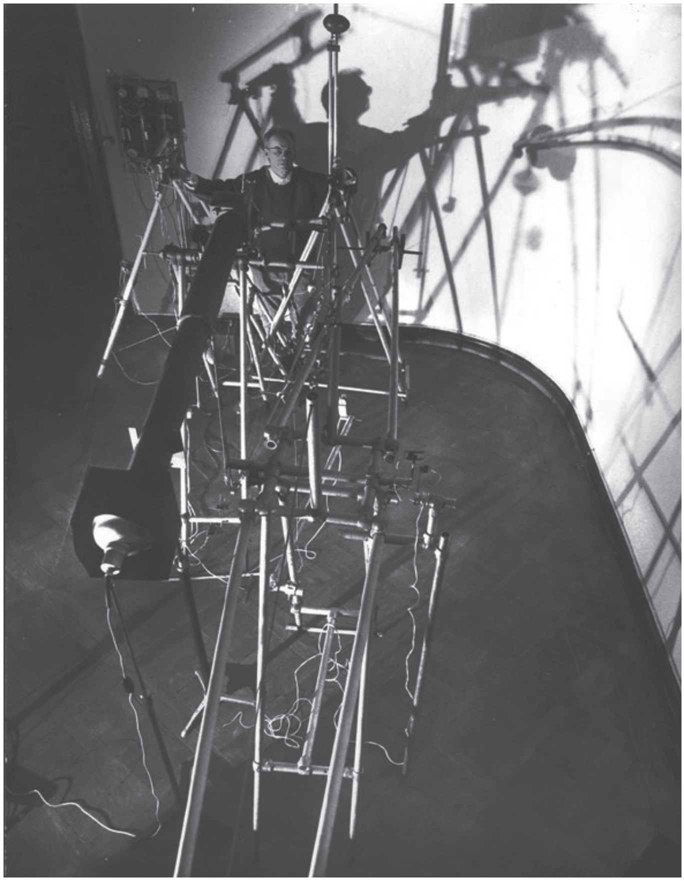
Working around the same time in the United Kingdom, artist Desmond Paul Henry created quasi-periodic curve drawings with an army surplus analog bombsight computer.[12] Attaching missile guidance systems to pen mechanisms inspired by Suardi's machines, Henry generated curves with the intricate quality of compounded Lissajous figures, which he described as "densely packed helices subject to various degrees of distortion, both intrinsically and extrinsically."[13] Extrapolating the spatial implications of mechanized drawing, Henry linked his drawings to D'Arcy Thompson's formal analysis of spicules, cells, and cellular aggregations, intending his machines to simulate the evolution of these types of biomorphic and mathematical structures. Henry's drawings exhibited a vital asymmetry, with imperfections and accentuated aberrations that attract, an effect Henry described as an "aleatoric note."[14] In these aberrations one sees the trace of the hack, the shadow of the experimentalist's intention.

Other experimentalists drew inspiration from the Lissajous curves, but traced mechanical motion by less computational means. Among the most compelling examples was Heinrich Heidersberger, a German architectural photographer whose highly geometric work illustrates his predisposition for curved structures. Beginning in 1955, he undertook the construction of a device for directly tracing a vibrating and oscillating light beam on the photographic plate itself. Heidersberger created several distinct iterations of his machine, the most sophisticated covering about 20 square meters. The product of this machine is a series of "rhythmograms," luminous images of permuted curvatures. These rhythmograms had deliberately spatial properties, engaging a relativistic sense of space and time, capturing something of the cinematic and combinatorial possibilities of design hacking.

These artists exemplified a broader, mid 20th-century fascination with the mechanical aberration and its aesthetic trace. Appropriately, Henry and John Whitney's work was shown along with other design hackers in the 1968 exhibition, "Cybernetic Serendipity," which considered the aesthetic implications of Norbert Weiner's theories of automatic feedback and adaptation.[15] Weiner's ideas centered on the operation of electromagnetic or physical signals that could be interrupted, transmuted, oscillated, and deformed. Electronic, telemetric, and informational signals could be bent, elided, and convoluted in new configurations of purely visual patterns, and the visual machine hacks produced a visual manifestation of Weiner's theories – continuous feedback cycles of transformed information flows.

12. Desmond Paul Henry, "Art and Technology," *Bulletin of the Philosophy of Science Group* 53 (November 1964): 2.
13. Ibid.
14. Desmond Paul Henry, "Computer Graphics: A Case History," (manuscript of lecture to the Art Department, Aberdeen University, Aberdeen, UK, May 1972), 5.
15. *Cybernetic Serendipity* was curated by Jasia Reichardt at the ICA London from August 2nd to October 20th, 1968. See Jasia Reichardt, *Cybernetic Serendipity: The Computer and the Arts* (London: Praeger, 1969).

Heinrich Heidersberger, *Selbstportrait mit Rhythmograph* (*Self-portrait with Rhythmograph*), 1963. Photo courtesy Institute Heidersberger.



As digital technology and motor control advanced, so did the mechanisms for visual output from computing instruments. From the 1970s onward, experimentalists began hacking digital computers and drawing devices such as printers and plotters. The digital computer required a different type of hack than the analog machine: not continuous mechanical and electrical modulation, but semantically coded script. Artists such as Manfred Mohr and Roman Verostko structured sequences of digitally deterministic operations for aesthetic ends, scripting plotters directly to create intricate and recognizably algorithmic pen drawings. But these new digital machines enforced a logic of scripted sequence, linearity, angularity, or symmetry. Physical modulation – the invasive distortion of electromagnetic fields or mechanical motion – became ineffective, as the electronic signals now represented a second-order, epiphenomenal action. The fluid curves and haptic effects of the earlier analog machines receded, with more dynamic means of modeling and computer interaction enabling contemporary parametric and generative visual systems.

Epilogue: The Parametrics of Machine Permutation

The combinatorics of machine permutation is a project that is at once contemporary and historical and an intellectual trajectory crossing design, the visual arts, mathematics, engineering, and computation. In these episodes are intimations of our contemporary approach to technology. A key attraction of today's parametric design software is its ability to dynamically and elastically permute configurations of geometry. Operations and processes are considered as complex componentized machines and the combinatorial ranges of these systems are explored through permutations of their logically atomic components. Through experimentation, designers interrogate a combinatorial range of visual possibilities latent in a system, finding the truth in the system itself.

Often design hacking does not produce a specific designed project per se, but instead opens methodological avenues for visual and material experimentation. It facilitates the development of a type of knowledge culture that more formal professional institutions cannot. Design hacking shares a methodological interest with organized research and development programs, but unlike conventional modes of institutional knowledge propagation such as apprenticeship, it is unabashedly experimental and not necessarily aligned with professional ends. The messy successes and unwieldy failures of the mechanical hack are rarely elegant. There may even be something of an engineer's aesthetic in these experiments that some architects are loath to connect to their own discipline. Yet through this backchannel of practical experimentation with technology, design gains a new range of activity and freedom. In the direct physical trace of the machine, the hack enables synthetic possibilities for both design and the knowledge culture of architecture.

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