

Years:	Craig Reynolds (1953 -)	Karl Sims (-)	Mark Bedau (-)	Melanie Mitchell (1945 - 2011)	
Affiliations:	Computer Graphics, MIT	Computer Graphics Artist/Researcher MIT (84) , MIT Media Lab (87)	Philosopher:	Computer Scientist, Mathematician, Writer: Brown University, University of Michigan (90)	
Article:	Flocks, Herds, and Schools: A Distributed Behavioral Model: (1987)	Evolving 3D Morphology and Behavior by Competition: (1994)	The Scientific and Philosophical Scope of Artificial Life (2002)	What is computation? Biological Computation (2011) <i>UBIQUITY SYMPOSIUM: BIOLOGICAL COMPUTATION (2011)</i>	Complexity: A Guided Tour (2009) Ch. 07 Defining and Measuring Complexity pp. 95-111
Ph.D. Research:	<i>Computer Graphics, Artificial Life</i>	<i>Computer Graphics, Artificial Life</i>	<i>Artificial Life</i>	<i>Biological Computation</i>	<i>Complexity</i>
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Main Works	<i>Films:</i> <i>Tron (82)</i> <i>Batman Returns (92)</i> <i>Software Library:</i> <i>Open Steer (99)</i>	<i>Films:</i> <i>Particle Dreams (88)</i> <i>Evolved Virtual Creatures (94)</i> <i>Installations:</i> <i>Gallapagos (99)</i>	<i>Editor:</i> <i>Artificial Life Journal</i>	<i>Ph.D. Thesis:</i> <i>Copycat Cognitive Architectures</i>	
Publications:		Karl Sims (August 1990). "Particle Animation and Rendering Using Data Parallel Computation". SIGGRAPH '90 Proceedings: 405–413. Karl Sims (1992). "Choreographed Image Flow". Journal of Visualization and Computer Animation 3: 31–43. Karl Sims (July 1991). "Artificial Evolution for Computer Graphics". SIGGRAPH '91 Proceedings: 319–328. Karl Sims (July 1994). "Evolving Virtual Creatures". SIGGRAPH '94 Proceedings: 15–22. Karl Sims (1994). "Evolving 3D Morphology and Behavior by Competition". In Brooks & Maes. Artificial Life IV Proceedings (MIT Press): 28–39.	M. A. Bedau and E. C. Parke, eds. The prospect of protocells: social and ethical implications of the recreation of life. Cambridge: MIT Press, 2009. Mark A. Bedau, Carol E. Cleland. The Nature of Life: Classical and Contemporary Perspectives from Philosophy, 2011. Mark A. Bedau and Paul Humphreys, eds. Emergence: contemporary readings in philosophy and science. Cambridge: MIT Press, 2008. Additional Publications: http://people.reed.edu/~mab/publications/index.html	Mitchell, Melanie (1993). Analogy-Making as Perception. ISBN 0-262-13289-3. Mitchell, Melanie (1998). An Introduction to Genetic Algorithms. Cambridge, Mass: MIT Press. ISBN 0-262-63185-7. Mitchell, Melanie (2009). Complexity: A Guided Tour. Oxford, U.K: Oxford University Press. ISBN 0-19-512441-3.	Mitchell, M., Holland, J. H., and Forrest, S. (1994). "When will a genetic algorithm outperform hill climbing?". Advances in Neural Information Processing Systems 6: 51–58. Melanie Mitchell, Peter T. Hraber, and James P. Crutchfield (1993). "Revisiting the edge of chaos: Evolving cellular automata to perform computations". Complex Systems 7: 89–130. Cowan, Pine, Meltzer, editors: George, David, David (1999). Complexity : metaphors, models, and reality. Cambridge, Mass: Perseus Books. p. 731. ISBN 978-0738202327.
Addition Affiliations:		<i>Optomystic, Gen Arts</i>	<i>Reed College, Protolife</i>	<i>Santa Fe Institute, Los Alamos National Laboratory,</i>	<i>Douglas Hofstadter, Cognitive Psychology, Mathematics, Physics</i> <i>John Holland: Psychology, Electrical Engineering, Computer Science,</i>
Awards:	<i>Academy Scientific and Technical Award (98)</i>	<i>Mac Arthur Fellowship (98)</i>			
Abstracts/ Objectives:	The aggregate motion of a flock of birds, a herd of land animals, or a school of fish is a beautiful and familiar part of the natural world. But this type of complex motion is rarely seen in computer animation. This paper explores an approach based on simulation as an alternative to scripting the paths of each bird individually. The simulated flock is an elaboration of a particle system, with the simulated birds being the particles. The aggregate motion of the simulated flock is created by a distributed behavioral model much like that at work in a natural flock; the birds choose their own course. Each simulated bird is implemented as an independent actor that navigates according to its local perception of the dynamic environment, the laws of simulated physics that rule its motion, and a set of behaviors programmed into it by the "animator." The aggregate motion of the simulated flock is the result of the dense interaction of the relatively simple behaviors of the individual simulated birds.	This paper describes a system for the evolution and co-evolution of virtual creatures that compete in physically simulated three-dimensional worlds. Pairs of individuals enter one-on-one contests in which they contend to gain control of a common resource. The winners receive higher relative fitness scores allowing them to survive and reproduce. Realistic dynamics simulation including gravity, collisions, and friction, restricts the actions to physically plausible behaviors. The morphology of these creatures and the neural systems for controlling their muscle forces are both genetically determined, and the morphology and behavior can adapt to each other as they evolve simultaneously. The genotypes are structured as directed graphs of nodes and connections, and they can efficiently but flexibly describe instructions for the development of creatures' bodies and control systems with repeating or recursive components. When simulated evolutions are performed with populations of competing creatures, interesting and diverse strategies and counter-strategies emerge.	Artificial life (ALife) is a young interdisciplinary collection of research activities aimed at understanding the fundamental behavior of lifelike systems by synthesizing that behavior in artificial systems. This paper aims primarily to provide an overview of ALife, explaining its approach to science and technology, outlining its major open problems and sketching its broader philosophical implications. It ends with a few words about the implications of ALife for the arts.	What Is Meant By "Biological Computation"? In this article, the term biological computation refers to the proposal that living organisms themselves perform computations, and, more specifically, that the abstract ideas of information and computation may be key to understanding biology in a more unified manner. It is important to point out that the study of biological computation is typically not the focus of the field of computational biology, which applies computing tools to the solution of specific biological problems. Likewise, biological computation is distinct from the field of biologically-inspired computing, which borrows ideas from biological systems such as the brain, insect colonies, and the immune system in order to develop new algorithms for specific computer science applications. While there is some overlap among these different meldings of biology and computer science, it is only the study of biological computation that asks, specifically, if, how, and why living systems can be viewed as fundamentally computational in nature.	What enables individually simple insects like ants to act with such precision and purpose as a group? How do trillions of neurons produce something as extraordinarily complex as consciousness? In this remarkably clear and companionable book, leading complex systems scientist Melanie Mitchell provides an intimate tour of the sciences of complexity, a broad set of efforts that seek to explain how large-scale complex, organized, and adaptive behavior can emerge from simple interactions among myriad individuals. Based on her work at the Santa Fe Institute and drawing on its interdisciplinary strategies, Mitchell brings clarity to the workings of complexity across a broad range of biological, technological, and social phenomena, seeking out the general principles or laws that apply to all of them. Chapter 7 deals with a number of proposed measures for the complexity of a given system, their strengths and limitations, and the problem of comparing the complexity of various systems. These are notoriously thorny problems, and no solution is reached, but Mitchell, again, does an excellent job of presenting each in the brief space of one chapter.
Quotes: Summary:					<i>Part I: Background and History</i> <i>Chapter 1: What is Complexity?</i> <i>Chapter 2: Dynamics, Chaos, and Prediction</i> <i>Chapter 3: Information</i> <i>Chapter 4: Computation</i> <i>Chapter 5: Evolution</i> <i>Chapter 6: Genetics, Simplified</i> <i>Chapter 7: Defining and Measuring Complexity</i> <i>Part II: Life and Evolution in Computers</i> <i>Chapter 8: Self-Reproducing Programs</i> <i>Chapter 9: Genetic Algorithms</i> <i>Part III: Computation Writ Large</i> <i>Chapter 10: Cellular Automata, Life, and the Universe</i> <i>Chapter 11: Computing with Particles</i> <i>Chapter 12: Information Processing in Living Systems</i> <i>Chapter 13: How to Make Analogies (If You Are A Computer)</i> <i>Chapter 14: Prospects of Computer Modeling</i> <i>Part IV: Network Thinking</i> <i>Chapter 15: The Science of Networks</i> <i>Chapter 16: Applying Network Science to Real-World Networks</i> <i>Chapter 17: The Mystery of Scaling</i> <i>Chapter 18: Evolution, Complexified</i> <i>Part V: Conclusion</i> <i>Chapter 19: The Past and Future of the Sciences of Complexity</i>

Phillip Galanter (-) Computational Artist, Curator, Writer SVA (99) , Eastern Illinois Univ (76)	Linda Dalrymple Henderson (-) Art Historian, Curator, Writer Yale	Artist, Architect, Philosopher	Marcos Novak (1957 -)		Scientist (Theoretical Physics)
<p>Truth to Process - Evolutionary Art and the Aesthetics of Dynamism: (2009) - 12th Generative Art Conference 2009</p> <p><i>Generative Art, Physical Computing Sound Art, Music, Complexity Science Theory</i></p> <p>Curator: <i>Art Bots, Complexity *</i></p> <p>XEPA: Intelligent Sculptures As Experimental Platforms For Computational Aesthetic Evaluation from IEEE VIS 2013. The Problem With Evolutionary Art Is . . . EvoMusArt 2010 Complexity, Neuroaesthetics, And Computational Aesthetic Evaluation. What Is Complexism? Generative Art and the Cultures of Science and the Humanities What Is Generative Art? Complexity theory as a context for art theory What Is Emergence? Generative murals as experiments in the philosophy of complexity GA2 - A Programming Environment For Abstract Generative Fine Art Computational Aesthetic Evaluation: Past And Future - From Computers and Creativity published by Springer <i>Texas A&M</i></p>	<p>On the Purpose: An Enquiry into the Possible roles of the Computer in Art (1973)</p> <p><i>Geometry, Non-Euclidean Geometry, Space-Time, Science, Art History, Duchamp, Modern Art, Technology</i></p> <p>Curator:</p> <p>The Fourth Dimension and Non-Euclidean Geometry in Modern Art (Princeton University Press, 1983; new ed., MIT Press, 2012) Duchamp in Context: Science and Technology in the Large Glass and Related Works (Princeton, 1998)</p> <p><i>University of Texas at Austin</i></p>	<p>Liquid Architectures in Cyberspace Art and Science as Cultural Acts (1991) <i>Cyberspace First Steps (Michael Benedikt)</i></p> <p><i>Liquid Architectures, Mathematics, Science, Virtual Reality</i></p>	<p>An Experiment in Computational Composition (1992)</p> <p><i>Genetic Algorithm, Computational Geometry, Computer Science, Conceptual Design, Architecture</i></p>	<p>The Music of Architecture: Computation and Composition (1992 - 07)</p> <p><i>Architecture, Music, Computation Science, Composition, Material Science , Cyberspace, Artificial Nature, Poetics, Data Worlds, World Making, Bits, Bytes, Timbre, Liquid Architectures, ArchiMusic, Heteronomy</i></p>	<p>New Kind of Science (2002) Ch. 1 The Crucial Experiment: pp. 23 -</p> <p><i>Particle Physics, Quantum Field Matter Creation, annihilation, Fundamental Interactions, Elen Particles, Hadronic & leptonic F Strong Interactions, Experimen Particle Physics.</i></p> <p><i>Cal Tech, Richard Feynman, Geoggrey C. Fox, Hugh David Polit</i></p> <p><i>Mac Arthur Fellowship (81)</i></p>
<p>After a great deal of initial promise and enthusiasm, evolutionary art seems to have hit a premature and disappointing plateau. This paper proposes a difficult but necessary program for the advancement of evolutionary art.</p> <p>First two significant problems are discussed. The first is the problem of creating aesthetic fitness functions that would allow evolutionary art systems to execute unattended with industrial sized populations and generations. In this context a quick survey of computational aesthetic evaluation is offered. Then it is suggested that progress in perceptual psychology and neuroaesthetics, coupled with advancements in connectionist computing, may provides new techniques for scoring aesthetic fitness.</p> <p>The second problem is the sense of "sameness" and lack of innovation exhibited by typical evolutionary art systems. In this regard the related technical problem of genetic representation is noted, various types of genetic representation are reviewed, and a critique is offered relative to evolution in nature. It is noted that evolution in exercises multiple levels of complexification and emergence.</p> <p>Finally an implication for generative art aesthetics and theory is discussed. It is suggested that current evolutionary art systems and projects are incoherent in so far as they don't focus on the essential virtue of generative art, i.e. a focus on process rather than final form. It is suggested that the general shift from nouns to verbs that is essential to generative art should be pushed to the fore. An aesthetic of truth to process and dynamism is proposed as foundational for evolutionary art.</p>	<p>Linda Dalrymple Henderson demonstrates that two concepts of space beyond immediate perception—the curved spaces of non-Euclidean geometry and, most important, a higher, fourth dimension of space—were central to the development of modern art. The possibility of a spatial fourth dimension suggested that our world might be merely a shadow or section of a higher dimensional existence. That iconoclastic idea encouraged radical innovation by a variety of early twentieth-century artists, ranging from French Cubists, Italian Futurists, and Marcel Duchamp, to Max Weber, Kazimir Malevich, and the artists of De Stijl and Surrealism. In an extensive new Reinroduction, Henderson surveys the impact of interest in higher dimensions of space in art and culture from the 1950s to 2000. Although largely eclipsed by relativity theory beginning in the 1920s, the spatial fourth dimension experienced a resurgence during the later 1950s and 1960s. In a remarkable turn of events, it has returned as an important theme in contemporary culture in the wake of the emergence in the 1980s of both string theory in physics (with its ten- or eleven-dimensional universes) and computer graphics. Henderson demonstrates the importance of this new conception of space for figures ranging from Buckminster Fuller, Robert Smithson, and the Park Place Gallery group in the 1960s to Tony Robbin and digital architect Marcos Novak.</p>	<p>"If we described liquid architecture as a symphony in space, this description would still fall short of the promise. A symphony, though it varies within its duration, is still a fixed object and can be repeated. At its fullest expression a liquid architecture is more than that. It is a symphony of space, but a symphony that never repeats and continues to develop. If architecture is an extension of our bodies, shelter and actor for the fragile self, a liquid architecture is that self in the act of becoming its own changing shelter. Like us, it has an identity; but this identity is only revealed fully during the course of its lifetime." -- Marcos Novak</p> <p>... "What is liquid architecture? A liquid architecture is an architecture whose form is contingent on the interests of the beholder; it is an architecture that opens to welcome you and closes to defend you; it is an architecture without doors and hallways, where the next room is always where it needs to be and what it needs to be. It is an architecture that dances or pulsates, becomes tranquil or agitated. Liquid architecture makes liquid cities, cities that change at the shift of a value, where visitors with different backgrounds see different landmarks, where neighborhoods vary with ideas held in common, and evolve as the ideas mature or dissolve."</p>	<p>Abstract: A compositional study based on a visual interpretation of information theory is introduced. An algorithm is presented that relates variety in spatial parameters to visual information, along with a genetically inspired mechanism for refining a design through cycles of incremental cumulative changes. Two- and three- dimensional examples are shown.</p> <p>Introduction: Recent research efforts on computational approaches to design have emphasized the structural aspects of parametric composition, or have concentrated on grammatical aspects of design [Mitchell 1988]. While these approaches are promising, the problem of what St .Thomas Aquinas called 'concreation' , the concurrent determination of both the compositional structure and the sensual form, have not been adequately addressed. With the advent of parametric design, and with grammatical or other knowledge-based approaches, the issue of how to use computation to determine proportion becomes very important. The present paper attempts to revive the issue of proportion in architectural composition, and suggests that the multitude of approaches used throughout history may have been approximations to a much more fundamental concern, the provision of adequate visual information to demand, and sustain, visual interest. The second motivation prompting this work is of a historical nature. It is the beginning of an overt attempt to relate the use of computers in architecture to the history of formal approaches to art and design, from classical times to the present, but in particular to the explorations of the Constructivists, the artists of De Stijl, and their followers. That is the tradition that computational composition must recognize and claim as its precursor, the tradition to learn, explore and expand.</p>	<p>From Frozen Music to Liquid Architecture</p> <p>The consideration of music and architecture as sister arts has a long history, in spite of the fact that they occupy opposite ends of the spectrum between the immaterial and the material. The intuition that allows us to even consider architecture as 'frozen music' or music as 'molten architecture' comes from a deep and ancient understanding that, in its very essence, architecture exceeds building, as music exceeds sound. We stand at the dawn of an era that will see the emancipation of architecture from matter. Music, especially computer music, will have much to teach the new 'liquid architecture' of cyberspace. ³ Architecture in turn, will provide music with its greatest challenge, its emancipation from sound, and, therefore, linear time. Together, architecture and music will stand as the arts closest to the functioning of the human cognitive and affective apparatus. The computer, with its insistence on clarity, will act as the bridge, allowing us to truly "enter the intimate structures of the two arts" for the first time.</p>	<p>http://www.wolframscience.com/nkonline/section-1.1</p>

Stephen Wolfram (1959 -)), Technologist	Cal Tech (1977)	Oliver Grau (1965 - 2011) Art Historian, Media Theoretician	Peter Weibel (-)	Cami Nelson (-)	Viveka V Ernst Ec
<p>12 50</p> <p>New Kind of Science (2002): Ch. 03 The World of Simple Programs:</p> <p>The Search for General Features: pp. 51 - 70</p> <p>Some Conclusions: pp. 105 - 113</p> <p><i>Cellular Automata, Complex Systems, Computation Science, Computational Life, Theoretical Physics</i></p> <p><i>Wolfram Research (1987), Mathematica (1988),</i></p>	<p>New Kind of Science (2002): Ch. 05 Two Dimensions and Beyond:</p> <p>Introduction pp. 169 - 170</p> <p>System Based on Constraints pp. 210 - 221</p> <p><i>Computational Science</i></p> <p><i>A New Kind of Science(1992-2002, Wolfram Alpha (2009)</i></p> <p><i>Mathematica, American Mathematical Society</i></p>	<p>Virtual Art: From Illusion to Immersion Introduction (2003)</p> <p>Ch. 01 pp. 2 - 23 Introduction Science of the Image Immersion</p> <p><i>Media Art, Immersion (Virtual Reality), Artificial Life, Image Science, Media Art, Modernity</i></p> <p><i>CAVE - Electronic Visualization Laboratory, University of Illinois, Chicago. Developed by Dan Sandin, Carolina Cruz-Neira, Image Spaces of Illusion (European Tradition), Painted Landscapes (Robert Baker), Panorama, Battle of Sedan by Anton Werner 1883), Charlotte Davis, Osmose (1995), CyberSpace, William Gibson</i></p> <p>Virtual Art: From Illusion to Immersion (MIT Press/Leonardo Books, 2003)</p> <p>Mediale Emotionen (Fischer, 2005)</p> <p>MediaArtHistories (MIT Press/Leonardo Books, 2007).</p> <p>Imagery in the 21st Century. Cambridge, MA: MIT-Press 2011.</p>	<p>Media Art Histories: - Oliver Grau I. Origins: Evolution versus Revolution: It Is Forbidden Not to Touch: Some Remarks on the (Forgotten Parts of the) History of Interactivity and Virtuality (Peter Weibel, 2010)</p> <p><i>-What is an Algorithm? - Algorithm in Art - Illusory Movement- Illusory Volume - From Virtual Volumes to Virtual Environments - Arte Programmata</i></p> <p>1960's: Op Art, Kinect Art, Happening, Fluxus, Computer Graphics, Animation. Algorithm, Algorithm Art, Constructivism,</p> <p>Naum Gabo , "Kinetic Constructions # 1" (1920) Maholy-Nagy "Material to Architecture" Book Maholy-Nagy "Space Modular" (1940) Lev Nusbarg, Moscow Kinesticsists, Cyber-Creatures in CyberTheatre, Jeffrey Shaw: - Kinetic Light & Mirror Sculptures Inflatable Structure - Pig for Pink Floyd (1977) - Virtual Reality: Points of View - (1983) Legible City - (1989) (Virtual Museum) 1991</p>	<p>From Sfumato to Transarchitectures and Osmose: Leonardo da Vinci's Virtual Reality (2009)</p> <p><i>Leonardo, Volume 42, Number 3</i></p> <p>Sfumato, Leonardo da Vinci, Maros Novak: TransArchitectures, 4 Dimensional transarchitectural shapes (2001) Liquid Architectures, Digital Morphogenesis , Char Davies: Osmose - (1995), Ephemere - (1998)</p> <p>Additional: Digital Morphogenesis</p>	<p>The HCI researcher as a designer: approaches to and distance (2011)</p> <p><i>8th ACM conference on Creativity & cognition</i></p>
<p>1979-81) Cal Tech: <i>Computer Algebra System SMP (Symbolic Manipulation Program), (83)</i></p> <p><i>Princeton: The School of Natural Sciences of the Institute for Advanced Study (Cellular Automata)</i></p> <p><i>Connection Machine w/ Richard Feynman (Turbulent Fluid Flow) (86)</i></p> <p><i>University of Illinois at Urbana-Champaign (The Center for Complex Systems Research)</i></p>	<p><i>Mathematica, American Mathematical Society</i></p>	<p>Overview: Although many people view virtual reality as a totally new phenomenon, it has its foundations in an unrecognized history of immersive images. Indeed, the search for illusionary visual space can be traced back to antiquity. In this book, Oliver Grau shows how virtual art fits into the art history of illusion and immersion. He describes the metamorphosis of the concepts of art and the image and relates those concepts to interactive art, interface design, agents, telepresence, and image evolution. Grau retells art history as media history, helping us to understand the phenomenon of virtual reality beyond the hype. Grau shows how each epoch used the technical means available to produce maximum illusion. He discusses frescoes such as those in the Villa dei Misteri in Pompeii and the gardens of the Villa Livia near Primaporta, Renaissance and Baroque illusion spaces, and panoramas, which were the most developed form of illusion achieved through traditional methods of painting and the mass image medium before film. Through a detailed analysis of perhaps the most important German panorama, Anton von Werner's 1883 The Battle of Sedan, Grau shows how immersion produced emotional responses. He traces immersive cinema through Cinerama, Sensorama, Expanded Cinema, 3-D, Omnimax and IMAX, and the head mounted display with its military origins. He also examines those characteristics of virtual reality that distinguish it from earlier forms of illusionary art. His analysis draws on the work of contemporary artists and groups ART+COM, Maurice Benayoun, Charlotte Davies, Monika Fleischmann, Ken Goldberg, Agnes Hegedues, Eduardo Kac, Knowbotic Research, Laurent Mignonneau, Michael Naimark, Simon Penny, Daniela Plewe, Paul Sermon, Jeffrey Shaw, Karl Sims, Christa Sommerer, and Wolfgang Strauss. Grau offers not just a history of illusionary space but also a theoretical framework for analyzing its phenomenologies, functions, and strategies throughout history and into the future.</p> <p><i>"The most elemental process of modern times is the conquest of the world as images." —Martin Heidegger, Holzwege, p. 92. Frankfurt: Klostermann (1980).</i></p>	<p>Summary: The article summarizes the precursor to Virtual Reality and Algorithmic Art (Computational Art) through the Artists work in the movements of Op Art and Kinetic Art.</p> <p><i>...The optical changes induced by movement of the viewer in op art, the mobile elements of kinetic paintings and sculptures, the incorporation of viewers expected to manually interfere, to press buttons or keys: All this amounts to early- precomputer- forms of mechanical and manual interactivity. The works of art were exposed to random influences, or were rendered manually or mechanically controllable and programmable- algorithmic, in other words-by their viewers. Images were produced by programs before the computer came along, just as interactive and virtual relationships existed between works of kinetic and op art and their viewers. It is there- ,and not with the availability of the computer as technical interface- That the history of interactive and virtual an begins.</i></p> <p>Overview Digital art has become a major contemporary art form, but it has yet to achieve acceptance from mainstream cultural institutions; it is rarely collected, and seldom included in the study of art history or other academic disciplines. In MediaArtHistories, leading scholars seek to change this. They take a wider view of media art, placing it against the backdrop of art history. Their essays demonstrate that today's media art cannot be understood by technological details alone; it cannot be understood without its history, and it must be understood in proximity to other disciplines—film, cultural and media studies, computer science, philosophy, and sciences dealing with images. Contributors trace the evolution of digital art, from thirteenth-century Islamic mechanical devices and eighteenth-century phantasmagoria, magic lanterns, and other multimedia illusions, to Marcel Duchamp's inventions and 1960s kinetic and op art. They reexamine and redefine key media art theory terms—machine, media, exhibition—and consider the blurred dividing lines between art products and consumer products and between art images and science images. Finally, MediaArtHistories offers an approach for an interdisciplinary, expanded image science, which needs the "trained eye" of art history.</p>	<p><i>This paper explores the ways in which Leonardo da Vinci's anachronistic skepticism of Renaissance perspective and his subsequent invention of sfumato prefigure contemporary digital technology and its ability to literalize this formal technique. Marcos Novak and Char Davies offer parallel theories on the permeable boundaries among objects and between physical and ritual worlds. There resultant theories, like those of Leonardo, offer new conceptions of space and representation that challenge those who suggest the digital world will subvert the physical. Briefly comparing Leonardo's initial revision to Renaissance perspective to those realized through digital technology, this paper examines radical revisions of the notions of space and boundary and the ways in which those revisions challenge the traditional goal to aptly represent the physical world via linear perspective. Novak's and Davies's approaches to optics at the intersection of physical ex- perience and VR are parallel to Leonar- do's in their insistence that computer graphics' use of linear perspective has reiterated a mathematics that does not account for the profound relationship of objects, whether lived or represented, to one another. Leonardo's emphasis on the blurred boundaries between objects offers a prototype that technology has only now begun to match. For Davies, the digital has allowed a literalization of porous boundaries between viewer and environment. As Annick Bureaud has expressed it: "With Osmose we are within the work but, more powerfully, the work is within ourselves that we exhale with our breath, intimacy, interpenetration of the work and the I" [33]. For Novak, the digital allows for indeterminate archi- tecture, and the ability to communicate that architecture, according to Novak, is the ability to transmit space---"the most radical gesture" [34].</i></p> <p>Every body fills the surrounding air with its likenesses, likenesses which are all in everything and all in each part. —Leonardo da Vinci</p> <p>The air we move through is permeated by intersecting emanations of information from every object: electromagnetic flux, intensities of light, pressure, and body heat form complex dancing geometries around us at every instant. —Marcos Novak</p> <p>Within the all-enveloping flux and flow, habitually perceived distinctions between things dissolve, and boundaries between interior self and exterior world become permeable and intermingled. —Char Davies</p>	

Viley, Imonds	Graham Wakefield Wesley Smith (-)	Robert Osserman (1926 - 2011) Mathematician Harvard (1955)	Jason Brownlee (1964 -)
Artist and creativity	COSM: A TOOLKIT FOR COMPOSING IMMERSIVE AUDIO-VISUAL WORLDS OF AGENCY AND AUTONOMY (2011) <i>International Computer Music Conference</i>	Poetry of the Universe: A Mathematical Exploration of the Cosmos (1996)	

What is Computation? Biological Computation by Melanie Mitchell pp. 1 - 7[Links](#)

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- _Glossary
 - Major Concepts:
 - Biological Computation
 - Turing Machine
 - Terms
 - Biological Computation
 - Turing Machines
 - Abstract Algorithms
 - Biological Systems
 - Collective Computation
 - Task Switching
 - The Natural Sciences
 - References:
 - Influential Artists/Thinkers:
 - Norbert Wiener
 - John von Neumann
 - Alan Turing
 - Concepts
 - Cybernetics
 - Biological Computation
 - Turing Machine
 - Complexity
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 - Online Sources:
- _Outline

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- **What is Meant By "Biological Computation"?**

- In this article, the term *biological computation* refers to the proposal that living organisms themselves perform computations, and, more specifically, that the abstract ideas of information and computation may be key to understanding biology in a more unified manner.
- It is important to point out that the study of biological computation is typically not the focus of the field of *computational biology*, which applies computing tools to the solution of specific biological problems. Likewise, biological computation is distinct from the field of *biologically inspired computing*, which borrows ideas from biological systems such as the brain, insect colonies, and the immune system in order to develop new algorithms for specific computer science applications. While there is some overlap among these different meldings of biology and computer science, it is only the study of biological computation that asks, specifically, if, how, and why living systems can be viewed as fundamentally computational in nature.
- It seems obvious to many that biological systems "compute". A brief perusal of the literature reveals an abundance of book and paper titles such as "Computation in Neurons and Neural Systems" (Eeckman, 1994), "Immunology as Information Processing" (Hofmeyr & Forrest, 2000), "Information Processing in Social Insects" (Detrain et al., 1999), "Computation in Cells and Tissues" (Paton et al., 2004), "Learning from Bacteria about Natural Information Processing" (Ben Jacob, 2009), and "Evidence for Complex, Collective Dynamics and Emergent, Distributed Computation in Plants" (Peak et al., 2004), to name just a few. It is important to note that these authors are all talking about *computing* as it takes place in the biological system itself, not in any simulation of the system. The idea here is that *biological computation* is a process that occurs in nature, not merely in computer simulations of nature.

- □ This widespread interest in biological computation reflects a strong intuition that the notions of *information* and *information processing* are building blocks that will shed new light on how living systems operate and the common principles underlying their operation. Biology has long suffered from being a science of specific details rather than abstractions and general laws. The theory of evolution serves as one grand organizing principle, but biology still lacks a general theory of how adaptive functionality emerges from large collections of individual, decentralized components. How, for example, do insect colonies, composed of thousands to millions of individual insects, collectively make decisions and accomplish complex tasks that seem to require the communication and processing of colony wide information? How does the immune system, composed of trillions of cells and molecular components circulating in the body, collectively recognize patterns of infection and other organism wide conditions, and collectively decide how to mount an appropriate response? How do the hundreds of billions of neurons in the brain work together to continually make sense of and respond to the opportunities and threats of the environment in realtime? These questions cry out for a unified theory involving information, communication, and computation. However, there is as yet little agreement among the people who ask such questions as to exactly what constitutes “information” and “computing” in such systems, and on whether common information processing mechanisms might be identified across these disparate disciplines.
- □ The notion that the framework of computation might be useful for biologists is not new. In the 1940s and 1950s, many of the earliest computer scientists were thinking about computation as a phenomenon that went beyond mechanical and electronic automata. Alan Turing’s formalization of computation as “Turing machines” arose, in part, from his speculations about operations in the human brain. John von Neumann’s studies of self reproduction in machines sought to capture the “logic” of (in essence, the abstract algorithms governing) biological self reproduction. Norbert Wiener, in developing the so called “Cybernetics” movement, aimed at constructing a general theory of “control and communication” in animals and machines. However, this early work turned out to be much more influential in computer science—particularly in artificial intelligence—than in biology. The lack of influence for biologists was due to a number of factors, but perhaps the most important were the limited amount that was known about the mechanisms of biological information processing, and the lack of a formal theory of computation that was applicable to those mechanisms and that went beyond imprecise metaphors. These problems remain today in our understanding of biological computation.
- □ **Traditional Versus Biological Computing**
 - □ In my view, to make the notion of biological computation more precise in any particular system, we need to answer the following questions (Mitchell, 2009):
 - How is information represented in the system?
 - How is information read and written by the system?
 - How is it processed?
 - How does this information acquire function (or “purpose”, or “meaning”)?
 - □ These questions are relatively straightforward to answer for traditional computing systems, which are based on the Turing machine and von Neumann style architectures. In such systems information is represented as collections of bits, which represent components of programs or data. Information is read and written by a central processing unit via “fetch” and “write” operations to and from memory. Information is processed via logical operations performed by the CPU. This information acquires “meaning” via the interpretations of human users. (The thorny question of what “meaning” is and how we humans perceive it is beyond the scope of this article, though, in my view, it will be a key question for understanding biological computation. Here I am using the term “meaning” informally and assuming that if a human uses a computer to perform a computation, then the information resulting from that computation has some meaning for the human.)
 - □ The answers are much less straightforward in the case of biological systems. One good illustration of this is the process of task allocation in ant colonies. In an ant colony, ants take on different specialized tasks, such as foraging for food, nest maintenance, patrolling the nest, and refuse sorting. Ants do not always stick to the same task; instead they often switch tasks as needed,

depending on the current state of their environment. Each ant has a limited view of the global nest environment, limited contact with other ants, and no central “controller” issuing commands as to what task to pursue. How do ants decide what task to take on at a given time so that the colony as a whole will have an optimal allocation of workers to various tasks, given that the optimal allocation continually changes?

- □ According to the work of biologist Deborah Gordon and colleagues on Red Harvester ants (Gordon, 1999; Greene & Gordon, 2007), individual ants use not only their own local environmental observations but also observations of their *interaction rates* with other ants as a way to gain information about the global state of the environment and to decide what task to take on. In a colony, there is much random coming and going of ants, whether they are currently inactive or pursuing particular tasks. Thus an individual ant moving around will be likely to encounter other individuals pursuing a variety of task assignments, and can identify what task another ant is pursuing by direct contact with chemicals on the other ant’s body. Suppose that at a given time there has been a disturbance to the nest and thus an increased need for nest maintenance workers. Individuals who directly observe the disturbance may use that information to switch to maintenance tasks, but other individuals can do a form of statistical sampling, in which they measure the rates of their own encounters with maintenance workers versus encounters with ants performing other tasks, and, from their samples of these rates, decide whether to take on a new task. It seems that information about the global state of the colony is, in part, represented in the *rates* of interaction sampled by individual ants. Of course it is not any single decision by an individual ant that results in the colony achieving an ever changing yet globally optimum allocation of tasks; rather it is a collective *computation* done via the statistics of thousands to millions of ants that results in this adaptive resource allocation.
- □ Task switching in ant colonies is just one example of behavior for which notions of information and computation can provide insight. This collective computation clearly has a *function*, in that it results in an adaptive advantage for the colony that carries it out. However, in general it is difficult to formally characterize the functions being computed by such collectives, the “algorithms” by which they are computed, or even the *model* of computation one should use to understand the characteristics and limits of such computations.
- □ This example also highlights a number of profound differences between the mechanisms of information processing in traditional computers and in living systems. In traditional computers, information is digital and of a single type (e.g., bits), fixed (unchanging unless explicitly rewritten), centralized (i.e., fetched to a central location to be processed), and typically noise free. In living systems, by contrast, information is often analog in nature and of different types (e.g., reflected in real valued rates of interaction or concentrations of different substances), continually changing, decentralized (distributed over large areas and over large numbers of system components), and fundamentally noisy.
- □ The processing of information in traditional computers is centralized (i.e., performed by a CPU), typically serial, **deterministic**, exact, and terminating (i.e., there is an unambiguous final result of the computation). On the other hand, in biology, information processing is massively parallel, stochastic, inexact, and on going, with no clean notion of a mapping between “inputs” and “outputs”.
- □ Whereas traditional computing systems typically require synchronization in many aspects of their processing, biological systems often operate with asynchronous components. Traditional computing systems require components to be reliable, with very low error probabilities, whereas biological systems operate with unreliable components that are subject to frequent failures. In traditional computer science, the notions of *universal computation* and *programmability* are fundamental, whereas the relevance of these concepts for biological computing is unclear.
- □ The differences I have sketched here, among others, present a challenge for adapting the traditional frameworks of computer science to formulate a theory of biological computation.
- □ **Is Computing a “Natural Science”?**
 - ☑ In his article "Computing is a Natural Science" (Denning, 2007), Peter Denning describes how the relationship between computer science and the natural sciences has evolved over the past 70 years. Beginning in the 1940s, computer science began to be a provider of tools for natural scientists, allowing them to solve equations and analyze data. Later, computer science was able to provide methods for actually carrying out science via simulation and computational “experiments”.

More recently, computing has increasingly been a source of inspiration to scientists looking at information processing as a natural phenomenon. In Denning's view, this last stage has allowed computing to be counted as a natural science since it studies not only artificial systems but also natural phenomena, namely "informational processes" in nature.

- □ I would agree that computing is, or at least has the potential to be, a natural science, which may eventually be as foundational for biology as physics has been for chemistry. That is, the science of computing may someday contribute the conceptual building blocks upon which is built a more unified understanding of biological phenomena. To do this, however, a number of fundamental advances must be made, not just in our understanding of biology but also in the development of theoretical computer science itself.
- □ A theory of biological computation will need to incorporate new notions of information and information processing that are relevant for the characteristics of biological systems sketched above. A key strength of current day computer science is its ability, via abstractions such as formal languages, abstract machines, programmability and model checking, measures of computability and complexity, and clear notions of *levels of description* to describe and design functionality, independent of specific mechanisms. Something like this is clearly needed for biology, which often focuses not on abstract structure or function but on detailed biochemical mechanisms, perhaps missing the forest for the trees. However, given the very different characters of traditional and biological information processing that I sketched above, it seems that new kinds of abstractions need to be formulated, for example, to make rigorous the apparent analogies among information processing in ant colonies, the immune system, the brain, genetic regulatory networks, and other systems (Mitchell, 2009).
- □ What would these abstractions look like? It is not yet clear, though the development of frameworks that can capture functional aspects of the complex dynamics of networks (biological and otherwise) is an active area of research (e.g., Cardelli & Corrado, 2009; Klemm & Bornholdt, 2005, to name just two of the myriad recent examples on this subject). Interestingly, the field of computation itself has been evolving to become more "biological", with the shrinking of computing elements to molecular scales, and the increasing focus in computer science on parallelism, asynchrony, stochasticity, and other properties seen in biological systems. It may be that a theory of biological computation will be a foundation not only for biology but also for a new era of more life like computers. As pointed out in a recent NSF sponsored workshop on "Shared Organizing Principles in the Computing and Biological Sciences" (Greenspan et al., 2010), it is only through the continuing close and equal collaboration between computer scientists and biologists, as well as cross disciplinary education of a new generation of scientists, that the incipient field of biological computation may emerge as a source of foundational ideas for both fields.

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- Global Summary: (Rough Draft)
 - What Melanie Mitchell outlined in her article What is Computation? Biological Computation is an ability to conceptually understand different paradigms between the Biological Sciences and the Computer Science. The tools for computational science are suited to analyze the mechanisms of biological mechanisms. But the theoretical framework to tangibly understand the fundamental principles of biological processes are yet not defined. The examples referred to where Ant colonies. these perform processes that are not fundamentally compatible to the creation of computation frameworks. the influences in Biology to computational science is clear, but the opposite is not fundamental.
 - Professor Mitchell outlines the following as a guide to summarize and evaluate biological computational:
 - How is information represented in the system?
 - How is information read and written by the system?
 - How is it processed?
 - How does this information acquire function (or "purpose", or "meaning")? (Mitchell, 2009)
 - In concluding the article, the question "Can computational science become natural science?" this is still an open question. If the natural sciences historically have used technology as a facilitator to discovery, currently computation is now inspiring different areas of research to foster new discovery.
 - The article concludes that the eventuality of Computational Biology and Biology to be unified will require that both communities to fundamentally understand the objectives of research and to understand the mechanisms of discovery through new hybridized research methodologies.
- Final Drafts

The Scientific and Philisoophical Scope of Artificial Life. (Mark Bedau)_ pp. 1-11 (11)

Links:

- _Article Summary:
 - Presented/Published: Leonardo
 - Author: Mark Bedau - Professor of Philosophy and Humanities, Reed College
 - The Scientific and Philisoophical Scope of Artificial Life pp. 1-18
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 - The Scientific and Philosophical Scope of Artificial Life (Mark Bedau) Leonardo 35: 395-400. 2002. pp. 1-11 (11)
- _Glossary
 - Major Concepts:
 - Terms
 - Adaptive Systems:
 - Artificial Life: (Named by Christopher Langton: 1986)
 - Lifelike Systems
 - genomic regulatory system
 - proteomic regulatory system
 - Transgenic:
 - Thought Experiment
 - Ceteris paribus
 - References:
 - Influential Artists/Thinkers:
 - Christopher Langton:
 - Sources: Additional
 - Sources: Online
- _Objectives
- _Outline
 - Abstract:
 - The new interdisciplinary science of ALife has had a connection with the arts from its inception. This paper provides an overview of ALife, reviews its key scientific challenges and discusses its philosophical implications. It ends with a few words about the implications of ALife for the arts.
 - Introduction:
 - Page 395
 - ALife is a young interdisciplinary collection of research activities aimed at understanding the fundamental behavior of lifelike systems by synthesizing that behavior in artificial systems.
 - This paper aims primarily to provide an overview of ALife, explaining its approach to science and technology, outlining its

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major open prelims and sketching its broader philosophical implications. It ends with a few words about the implications of ALife for the arts.

- GR Summary:
 - ALife is defined by a series of activities that are related to the simulation of artificial processes. And the resultant experimentation and results based on the objectives of the simulation.
- An Overview of ALife:
 - Page 395
 - Life is an interconnected web of adaptive systems produced spontaneously by the process of evolution. Living systems exhibit impressively robust and flexible functionality at many levels of analysis.
 - Examples range from the genomic and proteomic regulatory systems that control how biological organisms develop and functional to the evolving ecological networks through which members of different species interact.
 - Human-made adaptive systems, such as the myriad communication networks that span the globe, are beginning to approach the complexity of the adaptive systems found in nature.
 - Learning how to engineer flexible and robust adaptive complexity is one of the biggest challenges of the 21st century.
 - ALife is now bringing together biologists, physicists, chemists, psychologists, economists, and anthropologists with computer scientists, philosophers and artists to create a unified understanding of adaptive systems of all types.
 - ALife studies life and lifelike processes by synthesizing them in artificial media, most often using computer technology.
 - The goals of this activity include modeling and even creating life and lifelike systems;
 - The goals also include developing practical applications involving new technologies that exploit intuitions and methods taken from living systems.
 - The phrase "artificial life" was coined by Christopher Langton. He envisioned a study of life as it could be in any possible setting and organized the first conference to explicitly address this field.
 - ALife borrows from other, older disciplines, especially computer science, cybernetics, biology and the study of complex systems in physics.
 - Its closest intellectual cousin is artificial intelligence (AI).
 - ...crucial difference between the modeling strategies that AI and ALife typically employ.

- Most traditional AI models are top-down-specified serial systems involving a complicated, centralized controller that makes decisions based on access to all aspects of global state. The controller's decisions have the potential to affect directly any aspect of the whole system.
- On the other hand, many natural living systems exhibiting complex autonomous behavior are parallel, distributed networks of relatively simple low - level "agents" that simultaneously interact with each other. Each agent's decisions are based only on information about its own location situation, and its decisions directly affect only that situation.
- ALife's models follow nature's example.
- The models themselves are bottom-up-specified parallel systems of simple agents interacting locally. The local interactions are repeatedly iterated and the resulting global behavior is observed. The whole system's behavior is represented only indirectly. It arises out of the interactions of a collection of directly represented parts.
- The synthetic methodology of ALife has several virtues. The discipline of expressing a theory synthetically, especially in computer code, forces precision and clarity.
- It also ensures that hypothesized mechanisms are feasible. Computer models also facilitate the level of abstraction required for maximally general models of phenomena.
- The bottom-up architecture of ALife models creates an additional virtue. Allowing micro-level entities continually to affect the context of their own behavior introduces a realistic complexity that is missing from analytically solvable mathematical models.
- Page 396
 - Many ALife models are designed not to represent known biological systems but to generate wholly new and extremely simple instances of lifelike phenomena.
 - The simplest example of such a system is the famous cellular automaton called the Game of Life, devised by the mathematician John Conway in the 1960's.
 - Computer simulation is crucial for the study of complex adaptive systems. It plays the role that observation and experiment play in the more conventional science.
 - The complex self-organizing behavior of the Game of Life would never have been discovered without the simulation of thousands of generations for millions of sites. The same holds for virtually all other systems studied by ALife.
 - Rather than merely producing computer simulations, some ALife research aims to implement systems in the real world. The

products of this activity are physical devices such as robots that exhibit characteristics lifelike behavior. some of these implementations are motivated by the desire to engineer practical devices that have some of the useful features of living systems. such as robustness, flexibility and autonomy.

- But some activity is primarily theoretical, motivated by the belief that the best way to confront the hard questions about how life occurs in the physical world is to study real physical systems.
- Examples range from evolvable hardware, which attempts to use biologically inspired adaptive processes to shape the configuration of microelectronic circuitry, to biologically inspired robotics, such as using evolutionary algorithms to automate the design of robotic controllers and swarms of robots that communicate locally to achieve some collective goal.
- Grand Challenges in ALife
 - ...understand a scientific community is to grasp its central aims.
 - still so much unknown about the emergence and evolution of living systems, the list emphasizes scientific understanding that applications and the challenges take an unabashedly long-term view.
 - ... three broad categories: the origin of Life, , Life's evolutionary potential and life's connection to mind and culture.
 - A. How does life arise from the non-living?
 - 1. Generate a molecular proto-organism in vitro.
 - 2. Achieve the transition to life in an artificial chemistry in silica.
 - 3. Determine whether fundamentally novel living organizations can arise from inanimate matter.
 - 4. Simulate a unicellular organism over its entire life cycle.
 - 5. Explain how rules and symbols are generated from physical dynamics in living systems.
 - B. What are the potentials and limits of living systems?
 - 6. Determine what is inevitable in the open-ended evolution of life.
 - 7. Determine minimal conditions for evolutionary transitions from specific to generic response systems.
 - 8. Create a formal framework for synthesizing dynamical hierarchies at all scales.
 - 9. Determine the predictability of evolutionary manipulations of organisms and ecosystems.
 - 10. Develop a theory of information processing, information flow and information generation of evolving systems.
 - C. How is life related to mind, machines and culture?

- 11. Demonstrate the emergence of intelligence and mind in an artificial living system.
- 12. Evaluate the influence of machines on the next major evolutionary transition of life.
- 13. Provide a quantitative model of the interplay between cultural and biological evolution.
- 14. Establish ethical principles for ALife.
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- Challenges in the third category are more speculative and some are interwoven with non-scientific issues. Some areas in which ALife plays a significant role, such as robotics and art, do not appear on the list.
- The first challenge involves no less than the construction of a novel life-form in the laboratory from scratch. The first candidates should be the simplest possible forms of life-- self-reproducing molecular structures that construct and maintain themselves in a simple environment and evolve.
- the environment would involve only simple forms of energy and material. and the goal would be to create an encapsulated biochemical system that can derive energy from simple chemicals or light and use information carried in primitive genes. The attempt to create a proto organism that self-replicates and evolves using energy and nutrients from its environment illustrates ALife's concern with understanding life by synthesizing it. it also shows that ALife's interests are not just fanciful abstractions. A fundamental understanding of real life in the real world is a key part of what ALife hopes to provide.
- ..The second challenge explores the spontaneous generation of life.
- Artificial chemistries are computer-based model systems composed of objects (abstractions of molecules) that are assembled by collisions among simpler objects according to predefined interaction rules.
- The chemistry must be constructive rather than merely descriptive, that is, with rules that determine arbitrarily complex products from arbitrarily complex collisions.
- The chemical interaction rules should be simple compared with the ultimate products that they create.
- This challenge reflects ALife's emphasis on understanding the amazing spontaneous emergence of structure and hierarchy that characterizes life.
- It also shows how ALife uses abstraction to capture the essence of such a process.

- The Third challenge involved the determining whether ...Life as we know it encodes information about hierarchically organized, spatially localized individuals in genetic structures... or any other particular form of organization necessary for life.
- The question is relevant to the search for extraterrestrial life in the universe. Examples of fundamentally different organizations include those without a genetic code, without spatially localized individuals, without hierarchical organization, without a genotype-phenotype distinction or.... without any symbolic representational scheme.
- The debate about what organizations are "fundamentally different" all clarify our understanding of the nature of life, and the pursuing this challenge will expand our horizons and challenge our preconceptions about life.
- Page 397
 - The sixth challenge concerns the contingency. ALife attempts to discern the features common to all evolutionary processes, or to broad classes of evolutionary processes. It aims to determine whether different kinds of evolutionary processes have different potentials for creativity.
 - ALife researchers expect that many of the most fundamental features of the evolution of life on Earth will be shown to be independent of the physical media that happen to embody the process.
 - Digital information processing in computers is very different from molecular biology, yet ALife has been building digital organism based on genetic and cellular principles from its inception.
 - Digital media provide considerable scope for varying the "physics" underlying the evolutionary process, so it is a straight forward matter to investigate evolutionary contingency in that context.
 - We do not know, however, whether digital and physical systems have the same potentials for evolutionary innovation.
 - ALife's commitment to a synthetic methodology becomes evident here. Not content with mere verbal speculation about kinds of evolutionary creativity, ALife insists on making systems that actually demonstrate those capacities.
 - ... ALife's 9th challenge: Determining how well we can predict the evolutionary consequences of making new forms of life.
 - All forms of life that we know of have a complex organization that enables them to act autonomously and in their own interests. Organisms can be transgenically manipulated to express different genes, but the evolutionary consequences and limits of such manipulations are unknown.

- To what extent can one redesign organisms to fulfill novel functions without disrupting their viability? Is there a tradeoff between the size of modification and viability? Better understanding of the genetics of development will enable us to create novel multicellular organisms, but these organisms might not flourish or might unleash unanticipated and uncontrollable ecological consequences.
- ...Perhaps major changes to organisms can be perfected only by lengthy coevolutionary optimization.
- Like genetic engineering, ALife must confront questions like these because it unleashes unovel autonomous beings with lives of their own.
- ALife is ideally poised to address such questions, because it can synthesize all kinds of genetic manipulations in isolated digital contexts.
- Once life originated, biological evolution underwent a number of major evolutionary transitions, such as the origin of eukaryotes, the origin of multicellular life and the origin of human culture.
- Once culture originates, it has the capacity to evolve on its own.
- Many believe that it is only a matter of time before ALife create machines that are alive and intelligent, reproduce their own kind, have their own purposes, set their own goals and evolve autonomously. These machines will be apart of our world, and their evolution will affect our future. Consider how machines currently influence the nature and rate of human communication and interconnection. All this suggests that machines might play an unprecedented role in the next major evolutionary tradition.
- ALife's 12th challenge is to predict and explain this role. Machines will certainly play at least a supporting role in the next major evolutionary tradition because they provide and infrastructure that influences the rate and direction of change. ...This will further expand the boundaries of what it means to be alive and display new forms of the unbounded creativity of evolution.
- Culture is one of the products of human existence, and culture itself evolves. ALife's 13th challenge is to understand the connection between biological and cultural evolution. Examples of cultural evolution include the development of economic markets, the changes in technological infrastructure (see the previous challenge) and growth and revolution in scientific opinion.
- Some treatments of cultural evolution (e.g. sociobiology and evolutionary psychology) consider how cultural traits evolve owing to their impact on biological fitness. But one can also consider how cultural traits evolve in their own right, as Richard Dawkins did when he coined the word "meme". This sort of "pure"

cultural evolution is driven by mechanisms similar to those behind biological evolution, but there are important differences. In each case traits exhibit variations, heritability and differential fitness; but cultural traits are transmitted not genetically but psychologically, and their fitness depends not on biological survival and reproduction but on retention in and proliferation across minds.

- One question concerns the similarities and differences in the behavior of biological and cultural evolution.
- Do both exhibit the same kind of creative explosions and for similar reasons?
- Another question concerns how are interconnected. Confronting these questions invites us to reconceptualize life, culture and technology. ALife gives us an increasingly constructive role in our future. Even if we do not try to shape our future to fit our current preconceptions of what is possible, ALife can help us to understand and appreciate the open-ended creative process in which we are all embedded.
- Philosophical Implications of ALife
 - ALife is not just a scientific and engineering enterprise. It offers a new perspective on the essential nature of many fundamental aspects of reality, such as life, adaptation and creation. Thus it has rich implications for a number of broad philosophical issues. In fact, philosophy and ALife are natural intellectual partners for a variety of reasons. Both seek to understand phenomena at a level of generality that is sufficiently deep to ignore contingencies and reveal essential natures. In addition, by creating wholly new kinds of lifelike phenomena, ALife continually forces us to re-examine what it is to be alive, intelligent, creative, etc. Furthermore, ALife's computational methodology is a direct and natural extension of philosophy's traditional methodology of the a priori thought experiment. In the attempt to capture the simple essence of vital processes, ALife models abstract away as many details of living systems as possible.
 - These models are thought experiments that are explored with the help of a computer.
 - ...ALife simulations attempt to answer "What if X?" questions, but the premises they pose are complicated enough that their implications can be explored only by computer simulation:
 - ...Synthesizing thought experiments on a computer brings a new kind of clarity and constructive evidence to philosophy.
- Page 398
 - Emergence:

- One of life's amazing features is that the whole is more than the sum of its parts.
- ...emergent phenomena share two broad hallmarks:
- They both depend on and are autonomous from underlying phenomena.
- Although apparent emergent phenomena are all around us, these two hallmarks of emergence seem inconsistent or philosophically illegitimate. How can something be autonomous from underlying phenomena if it depends upon them? This is the traditional philosophical problems of emergence. A solution to this problem would both negate the appearance of illegitimate metaphysics and show how emergence plays a constructive role in scientific explanations of phenomena involving life and mind.
- The aggregate global behavior of the complex systems studied in ALife offers a new way to view emergence.
- ...a system's macro-level state is considered emergent if it can be derived from the system's boundary conditions and its micro-level dynamical processes but only through the process of iterating and aggregating all its micro-level effects.
- This new view explains the two hallmarks of emergence.
- Macro-level phenomena clearly depend upon micro-level phenomena; consider how a bottom-up ALife model works. At the same time, macro-level phenomena are autonomous, because the micro-level interactions in such bottom-up models produce such complex macro-level effects that the only way to recognize or predict them is by observing macro-level behavior.
- This form of emergence is common in complex systems found in nature, and ALife's models exhibit it as well. This conception attributes the unpredictability and inexplicability of emergent phenomena to the complex consequences of myriad non-linear, context-dependent, local micro-level interactions.
- ...emergent phenomena can have causal powers, but only by aggregating microlevel causal powers, there is nothing inconsistent or metaphysically illegitimate about the idea of underlying processes constituting and generating phenomena by iteration and aggregation.
- ...ALife will play an active role in future philosophical debates about emergence and related notions such as explanation, reduction, complexity and hierarchy. Living systems are one of the primary sources of emergent phenomena, and ALife's bottom-up models generate impressive macro-level phenomena wholly out of micro-level interactions.
- Evolution:

- Potential:
- Does evolution have an inherent tendency to create greater and greater adaptive complexity, or is the complexity of life just a contingent and incidental by product of evolution?
- Stephen Jay Gould:
- ...thought experiment entails rewinding the evolutionary process backward in time. Erasing the tape and then playing it forward again, but allowing events to be shaped by wholly different contingencies. The outcome of the thought experiment is not clear.
- .. Gould...suggests that "any replay of the tape would lead evolution down a pathway radically different from the road actually taken?
- ...He concludes that the contingency of evolution destroys any possibility of a necessary growth in adaptive complexity.
- Daniel Dennet draws exactly the opposite conclusion. The argues that complex features such as sophisticated sensory processing provide such a distinct adaptive advantage that natural selection would almost inevitably discover it in one form or another.
- ...Dennett concludes that replaying life's tape will almost inevitably produce highly intelligent creatures that use language and develop sophisticated technology.
- ALife has shown that thought experiments are highly fallible. The only sure way to know what to expect is to create the relevant system and observe the results of repeated simulation. In fact ALife is exactly where the activity of creating and studying such systems occurs.
- ...we cannot yet conduct the experiment of replaying life's tape, because no one has yet been able to create a system that exhibits continual open-ended evolution. Achieving this goal is a key outstanding problem in ALife, related to its sixth grad challenge.
- All conjectures about evolution's inherent creativity will remain unsettled until we actually study what happens when the tape o life is replayed.
- Life:
 - Philosophers from Aristotle to Kant have addressed the nature of life, but philosophers today ignore the issue, perhaps because it seems to scientific. At the same time, most biologists also ignore the issue, perhaps because it too scientific. At the same time, most biologists also ignore the issue, perhaps because it seems to philosophical.

- □ The advent of ALife has revitalized the question. This is partly because one can simulate or synthesize living systems only if one has some idea what life is.
- □ ALife's self-conscious aim to discern the essence of life encourages liberal experimentation with novel life-like organizations and processes. Thus, ALife fosters a broad perspective on life.
- □ ... the question of the nature of life will be settled by whatever perspective provides the best explanation of the rich range of natural phenomena that living systems exhibit. Better understanding of how to explain these phenomena will also help resolve a cluster of puzzles about life, such as whether life admits of degrees, how the notion of life applies at different levels in the biological hierarchy and the relationship between the material embodiment of life and the dynamical processes in which those materials participate.
- □ ALife highlights the question of whether artificial constructions, especially purely digital systems existing in computers, could ever literally be alive. This question will be easier to answer once there is agreement about the nature of life: but that agreement should not be expected until we have experienced a much broader range of possibilities. So the debate continues as whether real--but artificial--life is possible.
- □ Some critics complain that it is a simple category mistake to confuse a computer simulation of life with a real instance of it.
- □ A flight simulation for an airplane, no matter how realistic, does not really fly. A simulation of a hurricane does not create real rain driven by real gale-force winds. Similarly, a computer simulation of a living system produces merely a symbolic representation of the living system. The intrinsic ontological status of this symbolic representation is nothing more than certain electronic states inside the computer (e.g. patterns of high and low voltages). This constellation of electronic states is no more alive than is a series of English sentences describing an organism
- □ ALife systems are not typically simulations or models of a familiar living system but new digital worlds. Conway's Game of Life, for example, is not a simulation or model of any real biological chemical system but a digital universe that exhibits spontaneous macroscopic self organization. Thus, when the Game of Life is actually running on a computer, the world contains a new physical instance of self-organization, processes such as self-organization and evolution are realizable in multiple forms and can be embodied in a wide

- variety of media including the physical media of suitably programmed computers.
- So, to the extent that the essential properties of living systems invoke processes such as self organization and evolution, suitably programmed computers will actually be novel realizations of life.
 - Page 399
 - Mind:
 - Life-forms are sensitive to the environment in various ways, and this environmental sensitivity affects their behavior in various ways. Forms of life thus come to have broadly mental capacities. Furthermore, the sophistication of these mental capacities seems to correspond to the complexity of those forms of life.
 - So it is natural to ask whether life and mind have some deep connection. Since all forms of life must cope in one day or another with a complex, dynamic and unpredictable world, perhaps this adaptive flexibility inseparably connects life and mind.
 - It is well known in the philosophy of mind and artificial intelligence that the emergent dynamic patterns among human mental states are especially difficult to describe and explain. Descriptions of these patterns must be qualified ceteris paribus clauses, As the following example illustrates: If someone wants a goal and believes that performing a certain action is a means to that goal, then ceteris paribus he or she will perform that action.
 - ... (see example) ... This pattern exhibits a special property that I will call "suppleness." Suppleness involves a distinctive kind of exception to the patterns in our mental lives-- specifically, those exceptions that reflect our ability to act appropriately in the face of an open ended range of contextual contingencies.
 - These exceptions to the norm occur when we make appropriate adjustment to contingencies.
 - The ability to adjust our behavior appropriately in context is a central component of the capacity for intelligent behavior.
 - A promising strategy for explaining mental suppleness is to follow the lead of ALife, for there is a similar suppleness in vital processes such as metabolism, adaptation and even flocking.
 - For example, a flock does not always maintain its cohesion but may do so for the most part--only ceteris paribus-- for the cohesion can be broken when the flock flies into an obstacle (such as a tree), in such a context, the best way to "preserve" the flock might be for the flock to divide into sub flocks. ALife

models of flocking exhibit just Implications for the Arts: this sort of supple flocking behavior.

- ... consider another example, concerning the process of adaptation itself. Successful adaptation depends on the ability to explore an appropriate number of viable evolutionary alternatives: too many or too few can make adaptation difficult or even impossible. In other words, success requires striking a balance between the competing demands for "creativity" (trying new alternatives) and "memory" (retaining what has proved successful). ..., as the context for evolution changes, the appropriate balance between creativity and memory can shift in a way that resists precise exceptionless formulation. Nevertheless, ALife models can show a supple flexibility in how they balance creativity and novelty.
- Implications for the Arts:
 - ALife's central aim is to develop a coherent theory of life in all its manifestations. It embraces the possibility of discovering life in unfamiliar settings and creating unfamiliar forms of life. In the long run, ALife will contribute to the development of practical adaptive systems in many fields, such as software development and management, design and manufacture of robots in clouding distributed swarms of autonomous agents, Automated trading in financial markets, pharmaceutical design, ecological sustainability and extraterrestrial exploration. The economic potential of harnessing natural adaptive systems can be compared with that of cracking the genetic code.
 - ALife Technology can be used for a variety of aesthetic purposes. They range from commercial applications in computer animations of life-forms to new kinds of active art, evoking art and interactive art.
 - Second, ALife is radically changing human culture and technology, and art often responds to and comments on such changes.
 - Third, art has a long tradition of representing and resonating to our understanding of nature: therefore insights about life revealed by ALife can spark the creation of new aesthetic objects.
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- Global Summary: (Draft)
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- ***The Music of Architecture***

- **The Music of Architecture: Computation and Composition**

- **From Frozen Music to Liquid Architecture**

- The consideration of music and architecture as sister arts has a long history, in spite of the fact that they occupy opposite ends of the spectrum between the immaterial and the material. The intuition that allows us to even consider architecture as 'frozen music' or music as 'molten architecture' comes from a deep and ancient understanding that, in its very essence, architecture exceeds building, as music exceeds sound.

- We stand at the dawn of an era that will see the emancipation of architecture from matter. Music, especially computer music, will have much to teach the new 'liquid architecture' of cyberspace.³ Architecture in turn, will provide music with its greatest challenge, its emancipation from sound, and, therefore, linear time. Together, architecture and music will stand as the arts closest to the functioning of the human cognitive and affective apparatus.
- The computer, with its insistence on clarity, will act as the bridge, allowing us to truly "enter the intimate structures of the two arts" for the first time.

- ¹ quoted by Le Corbusier in *Modulor 2*, 1955

² from his *Autobiography*.

³ Novak, M. 1991. "Liquid Architecture in Cyberspace," in Benedikt, M. (ed.) 1991. *Cyberspace: First Steps*. Cambridge : MIT Press.

- **Architecture**

- The term 'architecture' is not limited to the description of buildings. We frequently speak of the architecture of knowledge, computer architecture, the architecture of the brain, the architecture of NA. We easily distinguish between 'architecture' and 'architectonic thought'. By 'architecture' we refer to the more common meaning: a physical or virtual environment designed for complex human inhabitation. By 'architectonic thought' we refer to a second meaning: complex organization and coordination of a heterogeneous composite. In either case, architecture is always an excess over simple need, a surpassing of mere building or organization.

- **Music**
 - If architecture is not limited to building, if it has always aspired to exceed the pull of matter, music, in turn, is not limited to sound. Just as we spoke of 'architecture' and 'architectonic thought' we can speak of 'music' and 'musical thought,' drawing similar conclusions: 'musical thought' extends far beyond 'music' itself, and constitutes a coherent and developed outlook upon the world. Its existence 'outside-time' speaks of the organization and coordination of any kind of sequence of events, while its structure 'in-time' speaks of the qualitative assessment of the sum effect of a group of simultaneous or near simultaneous occurrences within a given space. ⁴ Musical rhythmic, harmonic, and structural ideas have been useful to architecture for centuries. More subtle, and more interesting is the relation of tone color to visual and other matters. What we describe as timbre, for example, is the variation in formant structure, spectral onset patterns, onset rapidity, spectral energy shifts, and so on. We assess sounds on the basis of these minute phenomena, just as we assess a performance on the basis of expression, dynamics and orchestration. These notions can be translated into other domains very effectively; for instance the understanding of timbre applied to spatial frequencies explains qualitative differences in visual texture. The detailing and ornamentation of a building, with large parts being resolved to smaller ones in a sequence of scale changes leading to minute details, results in literal overtones of the fundamental frequency set by the overall massing, or the rhythm of a colonnade. The understanding of timbre is useful well beyond such a direct transposition from the aural to the visual, however. Even at the scale of human interaction and behavior, we attend to 'overtones' with great care. This is more than linguistic fancy, it is a concrete example of the pervasiveness of musical concerns at widely different scales and within widely different domains.
 - Music and architecture reach for a common asymptote. Throughout time, we witness in music the need to surpass its own limits, to develop unlikely virtuosity at incredible cost; music, like architecture, strives not only to excel, but in the end to transcend its very own material and intellectual basis.
 - ⁴ I am, of course, referring to the notions of 'inside-time,' 'outside-time' and 'temporal' discussed by Iannis Xenakis in *Formalized Music*.

- **Instruments**
 - *It is very important that the breakthroughs in our time go beyond all the limits that we have accepted up to now. People usually think that the arts should only entertain, but that is not the role of the arts at all. The role of the arts is to explore the inner space of man; to find out how much and how intensely he can vibrate, through sound, through what he hears, whichever it is. They are a means by which to expand his inner universe.*

- It is useful to reflect upon the meaning of 'instrument', especially in the context of composers using computers, composers accustomed to the use of instruments, now using the newest and strangest instrument, the computer. Instruments have at least two major functions: The first is the function familiar to a performer, the function of extending the expressive domain of an individual, achieved by an apparatus that allows a high degree of control over some aspect of the sensory world. Expressive of the performer, effective upon the audience, instruments are sensual, emotional, intellectual levers, operating at many levels simultaneously. Research or creation guided by this understanding of instruments leads to the study of performance and reception. Techniques of 'realistic' sound generation or 'expressive' control are at issue on the one hand, or issues of perception and cognition on the other; instrument making, performance practice, on the one, and psychoacoustics and biomusicology, on the other.

- There is another sense of 'instrument', though. This second sense is not contradictory to the first, it is in fact complementary and enhancing. It is the sense of the instrument as a scientific apparatus, one that allows us to peer into worlds beyond our normal senses, to bring together patterns beyond our normal recognition, and, in so doing, to enlarge the world we live in. Instruments such as the microscope or the telescope allow us to scan the human body during its operation, even as it is occupied, to examine the human skeleton, to peer inside the human skull, without disturbing its occupant. We can explore the world of the very large or very small, the very fast or the very slow, the too intermittent or the too continuous, the too hot or too cold, too quiet or too loud, too disordered or too regular, too structured or too unstructured. In addition to all that the instruments of the first sort do, these second instruments return information about inaccessible parts of the world. They map aspects of the world that are outside our range or scale into regions within our sensorium, and within our perceptual, cognitive and affective ranges. These instruments must also be well fitted to their purposes, can also be 'played' with virtuosity, and what they return is as much expressive of a complete human presence as any 'expressive' instrument .

- We live in a time of scientific visualization, and, increasingly, sonification, where we find that other, neglected, sensory pathways allow us to understand this world more fully and immediately than the conventional, numerical, calculated way we have inherited. We know that a screenful of information makes patterns accessible to us in ways that a list of numbers cannot, and that the sound of a formula reveals intricacies of behavior that the symbolic or pictorial representations obscure.

- Usually the mappings that older instruments carry out is directed to our intellect, is 'objective', single minded, discursive, prosaic. There is no reason, however, that this mapping cannot be 'subjective', directed to our senses and emotions as well as our intellect; there are no inherent limitations that forbid it to be polyvalent, nondiscursive, poetic. ⁵

- We can therefore envision an instrument that peers into new worlds, though they may only be new to us, and that returns not simply numbers, images, or sounds, but compositions directed at all our sensual, emotional and intellectual capacities, and that capitalizes on our ability to form complex evaluations of highly interwoven information, evaluations that other eras have called 'meaningfulness' or 'beauty.'
- This exploration by means of visualization, sonification, and computational composition does not limit itself any more to the world that is, but can proceed to examine possible worlds. Perhaps the most ambitious effort here is artificial life, whose stated claim is not simply to the understanding of life as it is, but to the understanding of life as it could be in universes that are other than ours, some of which we can create within our computer systems, some of which we can only reach through our understanding.

- ⁵ See Anatol Rapoport, *Operational Philosophy*. : "... certain symbolic systems have complex grammatical structure without having a semantic structure. These symbolic systems are the *nondiscursive* languages, of which the most outstanding example is music." He adds, however,: "On the other hand, the nondiscursive languages also have in the last analysis "objective" (in principle observable) referents. It is only that they are hidden from view. They consist of nervous impulses, hormonal secretions, and what not. The search for tools which would enable us to observe 'subjective' states the way we observe, say, chemical reactions, is an outstanding task of the next development in the science of man." pp195-200.
- **Discipline**
 - *TECHNE ESTIN EXIS ODOPOIHTIKH*
Zeno

 - The Stoic philosopher Zeno defined art as '*EXIS ODOPOIHTIKH*,' the 'roadbuilding habit.'⁶ Every discipline, artistic, scientific or other, has a purpose of examining some aspect of the world, and is characterized and made distinct from other disciplines by that purpose. Yet this very observation also unites all disciplines: in one way or another, all disciplines serve to explore the inner and outer world of man. If that exploration is guided by a habit to extend the boundaries of knowledge inward or outward by building roads into uncharted territories, we have art.

 - As we consider music, architecture, and computation, we can ask what is shared and what differs in the inner and outer worlds they investigate, where their boundaries are, and in what direction the edge of the known world is to be found, so that we can head that way, cross the line into darkness, and enlarge our universe.

- **Cyberspace**
 - Just as we approach the end of wilderness, a new wilderness opens before us. In place of the world we are exhausting, a virtual world becomes visible, cyberspace. What is cyberspace?

 - Cyberspace is a completely spatialized visualization of all information in global information processing systems, along pathways provided by present and future communication networks, enabling full co-presence and interaction of multiple

users, allowing input and output from and to the full human sensorium, permitting simulations of real and virtual realities, remote data collection and control through telepresence, and total integration and intercommunication with the full range of intelligent products and environments in real space.⁷

- Cyberspace is the unknown new world we have invented to compensate for the exhaustion of frontiers. It is the new New World, at once inner and outer, and it is unlike any world we have ever imagined outside our dreams.

- ⁷ From "Liquid Architectures in Cyberspace", by Marcos Novak, in *Cyberspace: First Steps*, Michael Benedikt, editor, MIT Press, 1991.

- **Artificial Nature**
 - Within the computer's memory resides a digitized microcosm of images, sounds, and symbols, whose organization intersects with that inherent in the machine's structure, forming new dynamic interference patterns. Science begins with the willingness to set aside what we think we know in order to find what we can know. If we wish to follow knowledge to the tips of its tentacles, then we must insist on examining this new nature on its own terms, postponing the assertion of what we know for the sake of finding out what is, and more, what can be.

 - Richard Voss has written the following about the relationship of music to nature:

" There are no simple mathematical models that produce 1/f noise other than the tautological assumption of a specific distribution of time constants. Little is also known about the physical origins of 1/f, but it is found in many physical systems: in almost all electronic components from simple carbon resistors to vacuum tubes and all semiconducting devices; in all time standards from the most accurate atomic clocks and quartz oscillators to the ancient hourglass; in ocean flows and the changes in yearly flood levels of the river Nile as recorded by the ancient Egyptians; in the small voltages measurable across nerve membranes due to sodium and potassium flow; and even in the flow of automobiles on an expressway. 1/f noise is also found in music."

" With the exception on very modern composers like Stockhausen, Joliet, Carter (where the melody fluctuations approach white noise at low frequencies), all types of music share this 1/f noise base. Such a view of melody fluctuations emphasizes the common element of music and suggests an answer to a question that has long troubled philosophers. In the words of Plato, " For when there are no words (accompanying music), it is very difficult to recognize the meaning of the harmony and rhythm, or to see that any worthy object is imitated by them." Greek philosophers generally agreed on the imitative nature of the arts. It seemed obvious that painting, sculpture or drama imitated nature. But what does music imitate? **The measurements suggest that music is imitating the characteristic way our world changes in time.** Both music and 1/f noise are intermediate between randomness and predictability. Like fractal shapes there is something interesting on all (in this case, time) scales. Even the smallest phrase reflects the whole." [emphasis mine]

 - If this is true, if indeed the art and music of the past have intuitively manifested the way the world works and changes in time, then, in our search

for items of wonder and revelation, as we augment actual reality with virtual reality, we can also augment the territories and manners of exploration. The new territories constitute a dataworld, and the manners of its exploration, a new poetics.

- **DataWorld Poetics**

- The raw materials of cyberspace are data, and processes that act on data. The fascination of this world comes from the interchangeability that the common underlying binary representation allows. Anything can be read, even if the format of its larger representation is unknown. Of course, everything can also be misread, but this is only a problem if one tries to read the information predisposed to find something conforming to a given format. If, however, we scavenge this world for patterns to be used for the creation of further patterns, the problem disappears. Abstractly, every file is a pattern of bits, and some of those patterns are useful, some not. The original use of those files is not of interest except in a peripheral, anecdotal, way.
- The question arises: what to do with these data? What is an appropriate poetics for a world such as this? The vastness of the data is infuriating, and the proposal that they be examined flattened, with all their hierarchies collapsed, seems absurd. Yet this is the conclusion one is led to if one wants to eliminate all imposed structure, if one requires the ability to always perceive the raw phenomenon, if one refuses to comply with the filters that announce that, if something is this, then it is not that. Besides, the choice to read the data stream against its 'grain,' against its intended format, does not mean that the data will have no structure whatsoever. Organization may still be evident under close examination; it will simply not be the organization intended.
- This radical position offers some benefits:
 - it prompts the explorer to provide the 'format' by which the data will be understood- including , but not limited to, the 'correct' format by which the data is explicated canonically;
 - it requires that formats and processes are designed in 'robust' ways in order to allow interchange and cross-application;
 - in the contexts of discovery, both in science and in the arts, it provokes the unobstructed examination of the phenomenon of structure itself, and of its various transformations;
 - it introduces a new locus of invention: the code or format itself.
- This last point requires further explanation. In the past century we have witnessed a transformation of the artist from craftsman to composer to editor; now we can take the next step, the artist seen as decoder of mysterious signs seen as streams of data. If an appropriate way of reading the data can be invented, a work of art, a work of revelation, will follow, otherwise, noise.

The same sign appears insignificant to the unprepared eye, the same warning goes unheeded by the inadequate ear. ⁸

- □ What, then, is this artist as decoder, as oracle? What does she provide? What we are searching for here is not so much the scientific proclamation that lays hold on the truth, but the artful sense of balance that knows just how much error-as-spice to provide to dissolve the arrogance of the necessary. With this in mind we can say that what we need is ways, many ways, by which the new maker can intervene in the flow of information and, like Lucretius' 'clinamen,' make the flow swerve ever so slightly into a new pattern, a new idea. Artificial nature, found and transformed into art and knowledge, and that in turn transformed back into artificial nature, to be found once more.
- □ All the materials of art are in some sense found, from the artist's pigment to the sounds of an orchestra; but in a virtual world, a world of artifice by definition, there is little recourse to 'nature.' All data are found data. Thus, those aspects of artistic creation that have examined the found object gain a new relevance.
- □ ⁸ This development has strong resonances through history: the oracle at Delphi, the Sphinx, the readings and misreadings of the signs from antiquity through the middle ages, from Achilles to Constantine the Great, all relied on reading the signs correctly.
- □ **Found Object to Found Process**
 - □ The day before yesterday, Marcel Duchamp placed a urinal in a gallery and declared it art. Yesterday, we wondered if the object in the gallery was real or simulated. Today, we place in our gallery not an object but a process. Tomorrow, we will wonder if the process is real or simulated.
 - □ Yesterday's avant-garde broke away from imitation and discovered the 'found object'; from it derived the assemblage, the concrete poem, concrete music. Later came simulation, and brought about an art aimed at considering the implications of the indistinguishability of real and unreal, preparing the way for a full encounter with the virtual. Now, fully aware that fact and fiction are not simply relatively defined viewpoints, but are interwoven and mutually interdependent, we are able to confront the next step, the move from found object to found process.
 - □ The artificial nature within computers and electronic networks is not still. Those parts of it that we call programs act upon the raw soil of data, turning it and bringing about new patterns and orders, perhaps new programs. If static data constitute the 'found object,' then active data, the programs, constitute the 'found process'.
 - □ Even before Socrates, art was imitation of the real. The concrete, found object, was the real itself, surpassing imitation; simulation was the unreal not just imitating but posing as, displacing, but, therefore, still referring to the real; with the virtual any reference whatsoever to the real can be abandoned.

The referents are determined by the contents and workings of the artificial nature, and of its interface with the human being. Unreal, found materials with real effects and repercussions, electronic physics, a world turned inside out, a dream seeking to escape into the world, in search for its music, these form the landscapes of cyberspace.

- The winds of cyberspace will not be imitations of winds, nor real winds imported into a world they cannot occupy; they will not be simulations of winds, either. The winds of cyberspace will be real to the nature of cyberspace, known as forces within that artificial nature, as our winds are to us. The winds of cyberspace will be created by the complex balance of the motions of bodies of data, which, like bodies of air, will leave vacuums of memory. The rush to fill these vacuums will be the wind, the processes that set it in motion being intrinsic to the working of the place. And from these winds we will construct a new architecture and music, an entire new poetics, for a new place.
- **Heteronomy**
 - Returning to Lucretius, and the 'clinamen,' to make a stream of data swerve is to effect a transformation upon its current. A homonomous transformation will produce different data of the same kind, but a heteronomous transformation will produce data of a different kind altogether: in the first case a text file will simply become a different text file, while in the second a text file will become an image file, a sound file, a number file. It is in the nature of the heteronomous transformation to produce the possibility for 'folding' data back on themselves long after they have ceased to be what they were: the image-become-sound can become image again, though no longer recognizable as the image that it once was. After several transformations have taken place, all that remains are remnants of the structural coherences that were originally present. These remnants are a mixture of those aspects of the original data that were most prominent with the structural biases of the new format. The strongest features survive, but the alignments and alliances are renewed, and the resulting file is not so much a derivative of the previous file as it is a new original condition. The sign that it constitutes must be re-read anew for the properties that it contains that were not in the original, and could not have been predicted - emergent properties.
 - It is evident that the heteronomous transformation cannot be reasonably restricted to the world within the computer. It follows from the spirit of the discussion so far that the outside world is as valid a source of information as any other, and as likely a receptacle. The folding of information creates loops, whorls and eddies, and the information is inherently impure, always contaminated with life.
 - The idea of heteronomy has been explored in various ways in the past and in our times. Xenakis' work 'Strategies' employed two conductors in competition; Machover's hyperinstruments employ computation to augment human performance. Many other examples can be listed, but, as far as I know, they all remain rather close to home. The external influence remains within music, and does not venture very far into the fullness of reality. Perhaps the most radical effort, probably the most notorious, certainly the

most well known, has been John Cage's 4'33". Anything may happen within the 4': 33" of its duration, and whatever happens is incorporated into that performance. Yet, the piece remains passive, in true Zen spirit, quietly absorbing everything into its immense gravitational field.

- A different, more active, attitude to heteronomy is offered here: that the transformations take place both within and outside the envelope of the making activity. A transformation may begin with a sound, fold the sound into a picture, the picture into a specification of a set of dance steps, the steps into a video, the video into another sound, and so on. Someplace along the lines of change, chance elements, always present in any case, switch from a position of secondary importance to one of primary importance. The original problem loses its charm, our interest moves on, but all remains well. Something new is born.

- **Yielding and Transposition**
 - A simple extrapolation of the dataworld poetics described so far leads to the ideas of yielding and transposition. *Yielding* is yielding to the found data or found processes active within the virtual world, and the consequent construction of an art whose materials are active forces, like a music made by harnessing the wind. The power of such an effort, and the magnitude of its accomplishment, is in economy of the strategies of its intervention, how much is accomplished by how little.

 - *Transposition* refers to the change in locus of the center of decision-making, to the cost of such a shift, and to the advantages offered by it. The performer, like the potter or the draughtsman, makes decisions in direct contact with the medium. The conductor gives up any particular instrument, and therefore of the expressive control that allows, in order to play the orchestra. The composer is even further removed, but in return gains many orchestras, over a span of time measured in lifetimes. Every complex artifact we know, anything involving 'architecture,' from a complex sound to a symphony, computer chip, high-rise building, space-shuttle, or embryo, involves a removal from direct contact with the material, and an engagement instead with processes that are strategic, that is to say, processes whose minute details can be disregarded in the interest of larger concerns. Any effort to intervene and 'correct' the particulars of the outcome of a process is misguided. Rather, one must learn to create with processes themselves as raw materials, and if the outcome is not acceptable, to make corrections to the algorithm of the process, or to its control parameters, or to its organization and sequence.

- **Archimusic**
 - As this brief exposition on the poetics of dataworlds shows, this is a place where buildings can flow and music can be inhabited. When this is understood, the distinction between architecture and music can be set aside. Throughout the remainder of this paper, therefore, I will refer to the combination of architecture and music with a new term, *archimusic*. As the name implies this is the art and science that results from the conflation of architecture and music.

- □ While I have used cyberspace as a thought-tool, I want to emphasize at this point that what is most important is not the technological expansion that cyberspace represents, but the conceptual space opened up to imaginative examination. Once we have a firm grasp on archimusic, we will be able to apply our findings to both virtual and actual worlds.
- □ Having fused these two disciplines into one, in the context of cyberspace and artificial nature, we can proceed to ask two questions: What is archimusic *within information*, and beyond that, what is the archimusic *of information*?
- □ **Within Information**
 - □ Archimusic *within information* is the extension of architecture and music into the virtual place of cyberspace. Architecture and music are released from their normal physical constraints and, therefore, need to contend with their newly-found freedom.
 - □ Cyberspace opens a vast domain, a new frontier to be inhabited in a time far shorter than any previous 'new world'. The enormity of this landscape, the amount of information that will pour into it, the pace at which it will be inhabited, and the rate at which it will be changing, all converge to make it clear that this is not an undertaking for the labor intensive manners of creation that even the most advanced of today's computer aided design and composition systems offer. The problems facing us as we anticipate the occupation of cyberspace are like those that the designers of increasingly compact computer chips face: the complexity rapidly becomes bewildering to the unaided mind. And, whereas the computer chip is a stable, unchanging artifact that does not come into direct contact with the particularities and peculiarities of humans, the archimusic of cyberspace is both rapidly changing and inhabited, and not just by one user, but by many. What this means is that we need to combine the sophistication of today's automated synthesis of complex chips with the specifically architectural and musical knowledge of human cognitive and perceptual needs for habitable, if virtual, space. ⁹
 - □ Exploratory efforts in this direction have proven fruitful, and investigations currently underway include uses of ideas derived from genetic algorithms, cellular automata, artificial life, and distributed processing to create self organizing compositional systems. Such systems lack the usual overhead required in top-down design. The composition literally evolves in time, as a large number of elements mutually both assist and constrain each other within various computational 'environments'. Not only do these explorations shed light on age-old mysteries such as 'creativity', 'beauty', and 'good fit,' but they also provide tangible means for grasping the next question, that of the 'archimusic of information.' The conceptual and computational tools needed to contend with the creation of virtual tools are the very same ones that can be used to structure streams of undifferentiated information into comprehensible patterns. In effect, the incoming data 'seeds' the generative algorithms, which in turn fold the information over itself in various ways to produce visible order. Upon reflection, this is an intuitively correct conclusion:

for the highest role of architecture and music has always been to wrest comprehensible order out of an incomprehensible, chaotic universe.

- Archimusic *within information* is architecture and music combined and extended to exist within virtual worlds, but still investigating the preoccupations of our familiar world. It is still recognizable as a transplant, a colonization. It is the first phase of archimusic.

- ⁹ It is clear that, at this point, music itself will not be so much listened to, as inhabited. Examples of spatialized music are already plentiful.

- **Of Information**
 - Archimusic *of information* is the architecture and music that is directly implicit in the artificial nature of cyberspace. If archimusic *within information* corresponds to the familiar architecture and music of the actual world, then the archimusic *of information* is the virtual analog to thunder, the sea roar, or birdsong.

 - Archimusic is to visualization as knowledge is to information.

 - As computers have provided us with access to larger and larger amounts of information, we have moved from alphanumeric, to simple line drawing graphical displays that were simple extensions of oscilloscopes, to raster based devices that allowed us to use color, to today's 3D displays. Scientific visualization is rapidly moving toward 'volume-visualization.' Sound synthesis has followed a parallel path, from simple oscillator based sounds to three-dimensional "virtual acoustical displays."¹⁰ What we are proposing here is the natural 'next-step' in our interaction with information: computer assisted visualization and sonification of the archimusic *of information*.¹¹ And even beyond that, we envision the tools that produce archimusic as highly advanced instruments created to examine heterogeneous structures in ways that are presently inaccessible to us.

 - The problem that this addresses is that of receiving large amounts of possibly uncorrelated data and synthesizing it into coherent and 'inhabitable' spaces, forms, sonic and visual landscapes, virtual 'information' architectures. Beyond this, this next step challenges us to look at the ways in which we can interact with these information architectures to locate, retrieve, alter, and transform these into new art forms that suit our informational needs, all under the metaphor of immersion and inhabitation.

 - In essence, what this entails is the creation of 'structure transformers,' tools that enable a user to extract salient structural features from incoming or preexisting data. These tools must operate spatio-temporally, and allow minute manipulations of complex attribute spaces in manners. They must permit subtle changes in the information to reach our senses in ways that permit us to assess quantitative differences as *qualitative* differences. Tone-color, or timbre, in sound, is an example of a difference that we are far more sensitive to qualitatively than quantitatively. It has been shown that visual examination of waveforms, for example, does not allow us to recognize

differences in oral and nasalized sounds (Pickover, 1990). Similar phenomena exist in other sensory domains. Visually, for example, we make qualitative assessments based on changes in texture, material, transparency, or reflectivity. In terms of motion, we are able to sense fine differences in smoothness or tremor. Many others exist and await to be utilized in situations of high information throughput. Some steps have been taken to address these aspects of our sensory apparatus, but they are still young. Nonetheless, several systems now offer sonic as well as visual output, and several advanced visualization packages have 'texture-mapping channels, along the normal red, green and blue channels that carry color information. The existence of these tools indicates an emerging recognition that the real-time investigation of attribute spaces will be increasingly important. While this idea is new to many disciplines, it is thoroughly understood in music both intuitively and analytically; where orchestration allowed coarse tone-color differentiation, digital signal processing is allowing unprecedented timbral control.

- Conventional visualization tools operate as filters: the input and the output are of the same order and of the same kind. Transformations are usually linear, and are employed uniformly across the domain of the tools affect. The tools we envision extend beyond existing tools in providing metaphorical 'scaffolds', 'bridges', 'generators', and other new tool categories that enable the user to traverse the space between orders and kinds of input. The transformations involved are usually non-linear, and are employed in non-homogeneous manners. Several initial explorations have already been undertaken, with positive results. ¹²

- ¹⁰ Wenzel, Elizabeth, "Localization in Virtual Acoustic Displays", in Presence: Teleoperators and Virtual Environments, Volume 1, Number 1, Winter 1992, pp 80-107.

- ¹¹ Implicit in this statement is the confidence that our sense of architecture and music are not 'merely' aesthetic, but that when we pronounce a certain work powerful, we are in some way making an objective statement. This statement seems to be an overall assessment over the whole phenomenon, including our own position in it as observers.

- ¹² My students and I have experimented with the translation of structure from one domain to another. For example one may begin with a text, establish a set of rules that map the occurrence of some verbal pattern into a code, then into two-dimensional space. A new set of rules is then invented to manipulate the image. Further sets of rules are used to map the image into a sonic or visual three-dimensional space. At each step certain characteristics of the original remain, while others are lost. If at the end the result is not acceptable, then we go back and modify the rules, alter the machine, not the effect. While the result is determined to a great extent by the original choice of material, there is no lack of creative opportunity. The choices of rules allow, even require, a high degree of creativity.

- **The Timbre of Space**
 - The temporal and outside-time aspects of the analogy of music to architecture are readily understandable. Architecture is orchestrated of

materials in rhythmic arrangements, proportioned melodically. A more subtle aspect of this analogy occurs in-time. Timbre, spectral distributions and spectral dynamics, constitute the in-time component of music. What is their spatial equivalent?

- □ The timbre of a sound declares itself within such a short time span that we are tempted to call it instantaneous. The equivalent visual and spatial phenomenon must also be nearly instantaneous. Indeed, there is a quality that fills a single chamber at the temple of Angkor Watt, or any one of many other pre-twentieth century rooms, that is not due to any complexity of configuration, but is almost exclusively the result of the particular distribution of material and textural patterns. Like a rich sound, a single such space has a wealth of overtones, partly inherent in the material itself, partly created by ornamentation, partly added by the passage of time and the accumulation of patina. By comparison, most of what we build today is very much like pure sine wave tones, correct but impoverished. Understanding the timbral dimension of architecture in cyberspace may help restore that richness to our barren real world environments.

- □ **Form Synthesis**
 - □ This century has witnessed a profound breakdown of the structures by which music is understood. A series of 'emancipations' have brought music to immediate contact with the microstructure of sound, rendering obsolete theories, representations and practices that dealt with sound at the coarse grain of a note, or the coarser grain of tonality. As the grains that can be controlled become shorter and shorter, it is possible to compose directly in timbre, with unprecedented exactitude. At its best, the music composed with this degree of control becomes elemental, as if produced directly by nature, even as it is unlike any natural sound we have ever known.

 - □ What if we understood matter as we understand digital sound? If we can envision a liaison between architecture and music, archimusic, a dancing architecture, a spatial music, then we can allow ourselves to learn from the changes that music has already undergone what changes architecture may undertake. What is sampling in matter? What would an architecture produced by digital signal processing of sampled matter be like? What would an architecture computed particle by particle, allowing complete, nearly continuous variation of spatial and material timbre be like?

 - □ Existing technology supports these visions. We have already discussed cyberspace and virtual reality as a domain of a liquid architecture. The actual, physical world is not far behind, however. Advanced manufacturing techniques allow the creation of solid forms directly from computer representations. One technique, called selective laser sintering, creates three dimensional forms by hardening any powdered, meltable material by precise focusing of a laser beam on the particles of the powder. Different powders can be used simultaneously. Form and matter synthesis is following at the steps of sound synthesis. A complete computer music of matter is sure to follow.

- **The Spaces of Sound**

- We come now to the most ethereal of issues. When asked about how they visualize sounds, people will readily envision shapes, colors, textures, undulating surfaces, slow or fast motion of hard or soft forms. More than this, they will respond to sound as if it were an infinitely variable chamber. The sound closes in on the listener at one moment, then expands, becoming cavernous. The enclosure fades to openness, is replaced with a soft layered veiling, with some sounds nearby and some far in the distance; the dry rustle of the veiling is periodically challenged by a tearing abrasion, pierced by rapid thunder, fractured into a cloud of uneasy splinters, settling into warm, humid, viscous, comfort. Music not only creates places, but concerns itself with the precise, highly resolved, balance of their attributes at every instant. Composers, even if they have no formal architectural training, create spaces with a sophistication of concerns that architects often forget. The literal spatialization of music in cyberspace, along with the liquefaction of architecture, will allow such sensibilities to become more visible, and therefore more accessible. The new spaces of sound in cyberspace will revitalize the our collective aural and visual imaginations.

- **Actions**

- Having constructed this elaborate frame, I would like to discuss some manifestations of these ideas in architecture and music.

- **Liquid Architectures**

- Seen abstractly, both architecture and music concern themselves with the placement of objects in a multidimensional space. Rules can be invented to govern how those objects are placed, what interrelations to form, how to resolve conflict, when to behave deterministically and when by chance, and so on. Without ever claiming any single, particular mapping over another, or any necessary association of an aspect of visual form to aural form, we can still observe, that if mapping, some mapping, any mapping, is implemented, certain coherences will survive that transition from one domain to another, from music to architecture, or vice-versa.
- With this in mind, I have been exploring the idea that the compositional use of computation in architecture can be similar to the use of computation in music. It has been a very fruitful and invigorating search.
- The images shown below are entirely computer composed, using original algorithms based on information theory and genetic algorithms. Briefly, a function is defined that evaluates the visual information content of a group of parametric objects within a field. The objects are represented by 'genes' within a 'chromosome' that mutates randomly, but retains successful mutations for further development, while unsuccessful ones simply become extinct. Over several thousand cycles, the objects arrange themselves within the space in a visually rich way, clearly appearing composed.
- Variations on these algorithms are used to produce the environments of these objects, within an environment envisioned as changing as information flows. Additional techniques familiar to computer musicians, such as digital effects

and filtering, are applied to layers of computed or scanned material, making the visual 'sound' of the images richer. The algorithms are made to deal with abstract, n-dimensional forms, within an n-dimensional field. Having no fixed concept of the semantics of those dimensions, they can operate as easily within sound space as in visual space. Particular constraints can be imposed quit easily, by altering the scoring function that determines what is allowed to continue to propagate and what not.

- □ **The unique and the rare: A Piece of π**
 - □ Variations on these algorithms are used to produce the environments of these objects, within an environment envisioned as changing as information flows. Additional techniques familiar to computer musicians, such as digital effects and filtering, are applied to layers of computed or scanned material, making the visual 'sound' of the images richer. The algorithms are made to deal with abstract, n-dimensional forms, within an n-dimensional field. Having no fixed concept of the semantics of those dimensions, they can operate as easily within sound space as in visual space. Particular constraints can be imposed quit easily, by altering the scoring function that determines what is allowed to continue to propagate and what not.

 - □ All artifacts share this to some extent. The properties that make some objects rare are properties revolving around the ways we sense, feel, construct meaning, play. Naturally, such objects are closer to us, in a straightforward way.

 - □ Suppose now that we want to peer into the world of numbers and come back with a n artifact that is informed by this brief discussion. A rare number? $!$? Something familiar? Pie. But not the whole thing: Just a small piece of π .

 - □ "A Piece of $!$ " is a computer composition constructed entirely out of the digits in the number $!$. The main voice is a direct transcription of π . Every subsequent part recapitulates these events in a different register, using a different instrument, in strict sequence, but only when it meets certain predefined intervallic criteria. The second voice builds on the first; the third on the first two, the fourth on the first three. All are playing π , forever.

- □ **DelphiRawMusic: Living Sieves**
 - □ "A Piece of π " is constructed from as an exploration of the structure of a single, very particular number. The next piece, "DelphiRaw π ," examines the structure in an arbitrarily chosen set of datafiles. Fifteen files of widely differing origins are read as raw data, filtered, processed, compressed, examined and modified via image-processing, and scaled to the same size; 100 pixels wide, 20 deep, using 3 8-bit channels per pixel. The sources for these files are varied: sound files, images, text files, in fact, the conference announcement itself, Mathematica notebooks, programs, the program that makes the music itself, midi files, digitized video, and so on, all files from either previous projects related to these ideas, or files having to do with this project directly. These files are examined using image-processing software, and the raster image becomes a new kind of score.

- Each pixel has three values behind it, one for each component color. The colors in the raster image thus indicate the relative balance of the components. Light colors mean that the values of the components are all high. A red tinge means that red predominates.
- Although the files are seen and modified as images, they are read as continuous, unraveling lines. This creates periodicities, since what appears to be a circle for instance, read as an array, becomes a patterns repeated as it is read line, by line, top to bottom.
- A series of MAX patchers was constructed to read these source files. Since each file has three channels, and there are fifteen sources, a total of forty-five 'control mechanisms' is available. These are linked to the various parameters that control the actual generation of sound, from pitch, velocity, channel, instrument, to control of digital effects, timing, controller parameters, or whatever real-time sound synthesis parameters are offered by the particular instruments available. What is hardest to describe is that the MAX patchers are constructed as lattices, and that unpredictable occurrences redirect the output of the files to other parts of the lattice, changing the sense of which file to read next, when to read it, and where to direct the data.
- Predefined tables and functions restrict the data into acceptable ranges for each particular use, with as little interference as possible. Not all data result in sound; sufficient change from previous values is required.
- One can watch the data run through the lattice, cycle, then escape into sound, sometimes rhythmic, sometimes freeform, as if controlled by strange attractors. For any particular set of data, there is a different sound. Raw data pours in, courses through the lattice, and selectively escapes, as if through a living sieve.
- **Music Beyond Sound, Architecture Beyond Material**
 - To conclude, then: architecture is about to exceed the limitations of the material; music is about to exceed sound. First came the emancipation of dissonance, then the emancipation of noise, then the breakdown of sound into clouds of points. Now, we stand at the edge of another fundamental boundary. We are at the point where we have to consider what music is beyond sound, what architecture is beyond material.
 - The contemplation of music at the end of sound is simply a beginning; for, once such questions are asked, they must be pursued to their conclusion, even if that conclusion is at first hard to comprehend: Archimusic at the end of time.
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The Music of Architecture: Computation and Composition (Marcos Novak) (1992-2007) pp. 1-22 (22)

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- Global Summary: (Rough Draft)
- Final Drafts

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

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- _Glossary
 - Major Concepts:
 - Terms
 - References:
- _Objectives
- _Outline (Notes)
 - The Fourth Dimension and Non-Euclidean Geometry in Modern Art
 - (Linda Dalrymple Henderson)
 - Reintroduction: The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory
 - pp. 79 - 91 (12)
 - Poetics and Cyberspace: and Visionary Architecture.
 - Space is central to the "composite definition" of cyberspace:
 - Cyberspace is a completely spatialized visualization of all information in global information processing systems, along pathways provide by present and future communications networks, enabling full copresence and interactions of multiple users, allowing input and output from and to the full human sensorium, permitting simulations of real and virtual realities, remote data collections and control through telepresence, and total integration and intercommunication with a full range of intelligent products and environments in real space.
 - Dancing with the Virtual Dervish (91- 94)
 - Transarchitectures and Hypersurfaces: Operations of Transmodernity:
 - "Generative Principles for the Paracube":
 - "For me the fourth dimension has never been outside reality--in fact, for me, nothing can ever be outside reality."
 - Linguist Benhamin Lee Whorf _ "Language, Mind and Reality"

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

- □ ...[A] nominal world-- a world of hyperspace, of heir dimensions awaits discovery by all the sciences, which it will unit and unify, awaits discovery under its first aspect of a realm of Patterned relations, inonceivaby manifold and yet hearing a recognizable affinity to the righ and systematic organization of LANGUAGE, include au fond mathematics and music which are ultimately the same kindred language. The idea is older than Plato, and at the same time as new as our most revolutionary thinkers... All that I have to say on the subject that may be new is of the PREMONITION IN LANGUAGE of the unknown, vase world-- that world of which the physical is but a surface or skin, and yet which we ARE IN< and BELONG TO.
- □
- □ The article is about he multi dimensional nature and the spatial relationships created by Marcos Novak. Architecture like art and space are created by relationships. Not by directly manipulating the geometry of a form. Unless the ecology of the geometry impacts its existing state.
- □
- □ _Outline (Summary)
 - □ pg. 79
 - □ The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New DevelopmentsinStringTheory
 - □ Pg. 80
 - □ Although William Mitchell argues in his 1995 book *City ofBits* that cyberspace as a network "is fundamentally and profoundly antispatal," Margaret Wertheim's 1999 book *The Pearly Gates of Cyberspace: A History of Space from Dante to the Internet* considers cyberspace in exactly that spatial contexr.²⁹⁴ Moreover, she includes a chapter tided "Hyperspace" that also draws extensively on the 1983 edition of this book, just as physicist Michio Kaku had done. In Wertheim's history of space, four-dimensional hyperspace, which she also linkst oKaluza-Klein theory, stands as the last "pre-digital space" before the emergence of the "new kind of *nonphYSical space*" of cyberspace.²⁹⁵ Although Wertheim's book was the first text to treat the fourth dimension so prominently in relation to cyberspace, the concept had actually figured as a subtle thread in that literature as it developed during the course of the 1990s and emerged prominently in the work of digital architect Marcos Novak.
 - □ **The Fourth Dimension in Marcos Novak's "liquid Architectures in Cyberspace," "Transarchitectures," and Beyond**
 - □ Marco Novak was educated in the late 1970s and early 1980s at Ohio State University, where he was one of the first young architects to embrace the computer as a student of Christos Yessios and a member of the "Computer Graphics Research Group" of pioneering computer artist Charles Csuri.¹⁹⁶ Novak's autobiographical essay of 2001, "Liquid~, Trans~, Invisible~: The Ascent and Speciation of Digital Architecture," provides important information on his early work in computer design and algorithmic architecture, noting elements that entered into his development, including his deep commitment to music as a model for

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

architecture, A longtime admirer of musicians interested in spatial music, such as Edgard Varese and Karl-Heinz Stockhausen, Novak was especially drawn to Iannis Xenakis "Formalized Music," created by using mathematics and computers as tools for composition.⁹⁷ Apparent, too, in this 2001 essay, as well as in his writings discussed below, is his identification with visionary architects and artists, including Fuller and Malevich. Responding to the model of Malevich's free-floating Suprematist painterly and architectural forms and Fuller's admonition that architecture was tied to the ground only by its plumbing, Novak realized by the mid-1980s that the computer could transform the very nature of architecture.²⁹⁸

- Pg. 81
 - In two papers, "Computational Composition in Architecture" (1988) and "An Experiment in Computational Composition" (1989), Novak addressed the possibilities of algorithmic, parametric design, referring as well to n-dimensionality, which he had encountered both in physics/mechanics as "degrees of freedom" and in computer graphics programming as coordinates.²⁹⁹ Although he would not write specifically of higher dimensional space until the 1990s, Novak was already deeply interested in space and had discovered the 1983 edition of this book- as well as the 100 films of Noll and Banchoff, whom he met in 1993 he had sensed the existence of a new kind of space behind a computer screen, writing of a 1979 encounter with computer art, that "a space so pure and perfect was more than just an image." "If space changes, architecture must change," he continued.³¹¹ Beauty was also a central issue for Novak, and the two -beauty and space- came together when in 1986 he created an artificial life algorithm to evolve forms that could be tested against an informatic measure for beauty. Among the forms produced were some that floated in space. Rather than rejecting these compositions, however, he celebrated "a space so clear that it surely would be inhabited" and interpreted the forms as the "first instances of a new kind of architecture."³⁰²
 - While working on his Ph.D. degree at UCLA in the later 1980s, Novak connected with University of Texas architecture professor Michael Benedikt. Their shared interest in cyberspace brought Novak to Texas, and together they co-organized the "Cyberspace: First Steps" conference of 1990. By that point Novak had developed his concept of algorithmic "liquid architectures in cyberspace," which would incorporate both time and change, just as his subsequent compositional model of "archi music" would do.³⁰³
 - In his introduction to the Cyberspace: First Steps volume published in 1991, Benedikt defined cyberspace as "a globally networked, computer-sustained, computer-accessed, and computer-generated, multidimensional, artificial or 'virtual' reality."³⁰⁴ Discussing four "Threads" out of which he believed cyberspace had evolved, Benedikt evoked Relativity Theory in his reference to the "notion that architecture is about the experiential modulation of space and time- that it is 'four-dimensional,'" an idea that "captivated architectural theory, just as it had captivated a generation of artists in the 20s and 30s (Henderson 1983)."³⁰⁵ While this Statement focused on the post-1919 impact of Einstein, there were numerous other

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

- Pg. 82
 - allusions to four-dimensional geometry and space in both his Introduction and his essay "Cyberspace: Some Proposals." The latter text, a rigorous, one hundred-page analysis of the concepts of space and of dimensionality in the context of data, included, for example, a section on "Visualizing N Dimensions."³⁰⁶ Benedikt's bibliographies for the introduction and essay included, respectively, the 1983 edition of this book and David Brisson's 1979 Hypergraphics volume, with its text by Banchoff and Strauss on their computer graphics films. Flatland also played a role in Benedikt's essay, just as it would in Novak's text in the volume, where higher spatial dimensions are likewise still a subtle presence.³⁰⁷
 - Novak's Cyberspace: First Steps essay, "Liquid Architectures in Cyberspace," has a strongly poetic, visionary quality-with technical information about programming and design counterbalanced by sections on "Poetics and Cyberspace" and "Visionary Architecture" (and art). Space is central to the "composite definition" of cyberspace. Novak provides at the start of his essay:
 - Cyberspace is a completely spatialized visualization of all information in global information processing systems, along pathways provided by present and future communications networks, enabling full copresence and interaction multiple users, allowing input and output from and to the full human sensorium, permitting simulations of real and virtual realities, remote data collection and control through telepresence, and total integration and intercommunication with a full range of intelligent products and environments in real space.³⁰⁸
 - Bur: importantly for Novak, cyberspace is also "a habitat of the imagination. habitat for the imagination" and "the locus of the triumph of poetry over . . . in linear thinking, of 'it-can-be-so' over 'it-should-be-so.'"³⁰⁹
 - Novak's emphasis on imagination here echoes discussions of the fourth dimension that regularly argued its value to the imagination, and there are other signs of his awareness of the topic, even though it was not yet central to his own work. ³¹⁰ Having studied modern art and architecture, he was interested in the wealth of spatial systems" beyond perspective that could be explored in cyberspace "What would it be like to be inside a cubist universe?," Novak asks. He continues "The development of abstract art by Malevich, Kandinsky, Klee, Mondrian', and other early modern artists prefigures cyberspace in that it is an explicit turning away from representing known nature. . . ."
- Pg. 83
 - Modern artists took on the task of inventing entire worlds without explicit reference to external reality." He notes specifically Malevich's "architectons," models for simple geometrical buildings that were meant to float, free of gravity."³¹¹
 - Among the specific references to dimensionality in Novak's text is his use of the Flatland analogy to argue the way in which "artificial realities point up questions about our reality": like a "cellular automaton" or the inhabitants of Flatland that "would have no knowledge of higher dimensions," we are equally limited in our understanding of "the existence of processes that are orthogonal to our experience."³¹² In

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

addition to generic references to "hypermedia with higher dimensions" and "n-dimensional space," Novak writes of navigating in cyberspace in terms that evoke the descriptions of paradoxical spatial experiences explored in literature on the fourth dimension—from Wells to Heinlein. That is particularly true of his italicized inserts into these discussions: "Everything that was once closed now unfolds into a new place, and everything invites one to enter the worlds within worlds it contains." He continues, "I am in an empty park. [walk around a tree, and I find myself in a crowded chamber. The tree is gone. I call forth a window, and in the distance see the park, leaving. "313

- The essay's conclusion emphasizes once again the metamorphic quality of "a liquid architecture" that "tends to music." According to Novak, it is "no longer a single edifice but a continuum of edifices, smoothly or rhythmically evolving in space and time."³¹⁴ This centrality of time for Novak would confuse certain commentators, who mistakenly interpreted his references to the fourth dimension as signifying only time (i.e., in the space-time of Relativity Theory) rather than space, ³¹⁵ even after he had incorporated four-dimensional mathematics into his process.
- The first project in which Novak explored four-dimensional geometry and space was *Dancing with the Virtual Dervish* (1991-94), which he first discussed in his essay "Virtual Dervish: Re-Defining Architecture in a Spatial Fourth Dimension," published in fall 1994. That project was sponsored by the Banff New Media Institute in Banff, Canada, and Novak was joined in it by two other 'University of Texas faculty members, designer Diane Gromala and dancer Yacov .Sharil'.³¹⁶ In the course of the project Novak decided to include a four-dimensional 'virtual world among those to be experienced by Sharir, who danced wearing a head-mounted display, and by the audience via a large-scale projection screen. Novak also drew consciously on the model of Sufi dervishes as he worked to create an
- Pg. 84
 - unprecedented, disorienting experience of multidimensional cyberspace.¹⁷ As he explains, One chamber stands out: it is, to the best of my knowledge, the world's first immersive experience of the fourth dimension. By this I do not mean time as the fourth dimension, but a fourth spatial dimension. A series of proto- architectonic four-dimensional objects rotate (in the fourth dimension, of course) around a vestige of the Cartesian coordinate system. All their vertices have four coordinates, all that would appear to us as planes are, topologically, cubes, all that would be cubes, hypercubes. Projected into three-space, their shadows are three-dimensional objects that enjoy a complex, but graceful transformational dance.
 - Alluding to the new developments in string theory, he concludes, It is hard to know, harder still to communicate, what we may make of these worlds. . . . Still, I am heartened when I discover, in science after science, ways of understanding the world that rely increasingly on spatial conceptions of more than three dimensions. Perhaps, without forgetting the body, architects can return to housing the mind.³¹⁸
 - Viewing Novak's projected four-dimensional virtual worlds in 1995 at the time of the filming of the WQED television series *Life by the Numbers* offered a remarkable realization of the experience of four-dimensional

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

space Malevich sought to create in his Supremacist paintings.³¹" With each movement of the virtual reality headset (and a speed-controlling mouse), one could "sail" through Novak's various cyberspace worlds, free of gravity and orientation. With its visceral sense of a completely new kind of space, that experience—even for the viewer of the filmed record of it—stands as another major step in computer visualization of the fourth dimension. Following upon Noll's and Banchoff's films of the rotating hypercube Novak's work at that stage added the element of interactivity that Von Foerster had emphasized was so critical in comprehending higher dimensions.

- Having established the ability of his "liquid architectures" to create completely new forms and experiences in cyberspace, Novak by the mid-1990s was increasingly interested in bridging the divide between cyberspace and actual space. That would lead him to add to his initial focus on immersion what he would subsequently term eversion, bringing forms from cyberspace into actual space 20 He now proposed "transarchitecture; that would draw on the formal discoveries made in cyberspace such as the Warp Map images he had begun to generate in 1998 (fig. R24 and cover). Conceiving "transarchitectures" as parallel to a new phase in modernity the digital era he termed "transmodernity," Novak sought in this new work to express "a world view in keeping with present science, epistemology and cosmology."
- pg. 85
 - Novak's essay "transarchitectures and Hypersurfaces: Operations of Transmodernity" appeared in the 1998 issues of Architectural Design devoted to "Hypersurface Architecture" and included multiple examples of his Warp Map images. If there had been any doubt about what Novak's talk of higher dimensions, along with curved "space-time," signified, he made his geometrical procedure completely clear in this essay. While still emphasizing the central role of time in these works, he explained.
 - My algorithmic explorations of tectonic production are concerned less with the manipulation of objects and more with the manipulation of relations, fields, higher dimensions, and eventually, the curvature of space itself. Once the architecture of objects has been set aside in favor of an architecture of relations, the notions of hyperspace and hyper surface become natural.
 - In a section at the end of the essay titled "Generative Principles for the Paracube," Novak further clarified the principles and procedures behind his Warp Map images:
 - My ongoing investigations are aimed at arriving at architectonic propositions that are inherently liquid, algorithmic, transmissible, and derived from the geometries of higher space. . . .

By "derived from higher space," I mean three things: first, employing four or more spatial dimensions; second, involving the manipulation of curvature of the underlying matrix of space rather than the manipulation of objects; and, third involving time as an intrinsic parameter with generative algorithms, as a , dimension added to the spatial dimensions, forming a spacetime continuum.. • 324

- Pg. 86

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

- □ Fig. R.24
Marcos Novak, Warp Map, 1998. (Digital image courtesy of the artist).
- □ Pg. 87
 - □ To produce a *Warp Map* Novak first defined a "topological cube" or "pa-acube:" with each of its six surfaces governed by mathematical parameters established III
 - □ equations allowing him to control both its skeleton and "skin." he then mathematically "extruded" the skeleton into four-dimensional space, rotated the resulting four-dimensional object about a plane, and then projected it back into three-dimensional space. However, since that process of projection back to three dimensions "was neither constant nor linear . . . the cells of the space frame are all different, providing a rich variety of dimensions and relations."³²⁵ In addition, the skin of each surface, also defined by equations, could be varied in its smoothness- as well as its curvature-and the latter variations could result in an irregularly curved "rippled space," rooted in non-Euclidean geometry.³²⁶ As Novak had explained earlier in the essay, in such curved spaces "it is the space itself that is understood as a hypersurface that is modulated in a way that warps everything within its purview."³²⁷
 - □ "What would it be like to be inside a cubist universe?," Novak had asked in his "Liquid Architectures" essay.³²⁸ He answers that question in his *Warp Maps*, which are the digital descendents of the Synthetic Cubist planes Malevich had liberated in his Suprematist compositions (figs, 5.12, 5.13). But instead of the vast emptiness of Malevich's infinite white space, these planes create relational spaces-dynamic and immensely complex-in which planes seem to jostle one another. In addition, mirror-like surfaces suggest fleeting glimpses of other parts of the structure's complex architecture. "Liquid, algorithmic, transmissible, and derived from the geometries of higher space," the *Warp Maps* are snapshots of a digital moment that can continue to morph in time, offering further potential models for new architecture.
 - □ In "Transarchitectures and Hypersurfaces," Novak had also articulated his belief ~at"as science and technology shift the conceivable, the presentable is also altered" and that this "moving span between the conceivable and the presentable 2 can be mined for new transarchitectural potential."^{3 9} He explored that theme direcuy in work he termed "invisible architectures," including his installation of .that title for the Venice Biennale in 2000, discussed in the essay "Eversion: Brushing Against Avatars, Aliens, and Angels." Here Novak put into practice his principle of t;vetsion or the "casting outward of the virtual into the space of everyday ex.peri~ce."³⁰ Against the backdrop of a continuous projection of "virtual, liquid forms" on a screen, Novak used digital sensors to create six invisible "senses" sculptures "as invisible interfaces to virtuality"; these were juxtaposed with four
- □ Pg. 88
 - □ hanging "rapid proto-typed forms deriving from a single four-dimensional form." With viewers' interactions with the invisible sculptures producing "navigable, spatialized audio," the installation exemplified Novak's concept of "newspace" as a continuum from the local to the virtual.³³¹ He has also written of the "invisible hyper tactility" of the invisible sculptures in relation to Duchamp's concept of the "infrathin, the liminal transition between dimensions.³³²
 - □ Novak declared recently, "For me the fourth dimension has never been outside reality-in fact, for me, nothing can ever be outside reality." His study in recent years of ancient Greek language and philosophy has given him a larger historical context for his interests and has convinced him that Plato, too, believed that increasing

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

dimensions amounts to increasing reality-not 'abstraction.'"333 Linguist Benjamin Lee Whorf, writing in his essay "Language, Mind, and Reality," published in 1942, included a discussion that resonates with Novak's views on cyberspace and dimensionality as well as his focus on architecture and music grounded in mathematics:

- ... [A] noumenal world—a world of hyperspace, of higher dimensions—awaits discovery by all the sciences, which it will unite and unify, awaits discovery under its first aspect of a realm of PATTERNED RELATIONS, inconceivably manifold and yet bearing a recognizable affinity to the rich and systematic organization of LANGUAGE, including all the arts of mathematics and music which are ultimately the same kindred language. The idea is older than Plato, and at the same time as new as our most revolutionary thinkers.... All that I have to say on the subject that may be new is of the PREMONITION IN LANGUAGE of the unknown, vaster world— that world of which the physical is but a surface or skin, and yet which we ARE IN, and BELONG TO.334
- That sense of the physical world as "a surface or skin" of a vaster world "Which we ARE IN and BELONG TO" suggests uncannily the continuum of the dimensional "real" to the n-dimensional virtual so central to Novak's philosophy." It is desire that steers the boat into the future," Novak declared in 2001, and his optimistic approach to future possibility marks him as yet another of the visionary creators stimulated by the fourth dimension in the twentieth century.335
- "Physical reality, as presented to us via superstring theory and its subset membrane theory, is ... inherently multidimensional," Novak observed in his
- pg. 89
- 2002 "Eversion" essay,336 In his 1998 "Transarchitectures and Hypersurfaces" text he had already pointed specifically to the emergence in the mid-1990s of the new model of multidimensional membranes versus strings in physics. Citing Michael Duff's 1998 Scientific American article, "The Theory Formerly Known as Strings," Novak explained, "Membrane theory, the present outgrowth of string theory, places the number of spatial dimensions at 11 and replaces the 'string' with the 'membrane', itself a hypersurface affectionately called a 'p-brane' (to indicate its inherent multidimensionality) as the fundamental building element."337 String theory had indeed taken another turn, and this Reintroduction concludes with a brief look at that change, which, in some cases, redirected attention directly to Flatland.
- **"M Theory," "Brane" Worlds, and the Flatland Analogy in 2000**
- In "The Theory Formerly Known as Strings" physicist Michael Duff was reporting in February 1998 on the revolution in the field of string theory that had occurred in the wake of string theory pioneer Edward Witten's 1995 announcement of what he termed "M-theory." According to Duff, "In the past two years ... strings have been subsumed by M-theory"; indeed, Witten had been able to derive all five different types of string theories from the membrane approach. The new focus on membranes or "p branes" (p for any number of dimensions) versus strings, Duff also set forth the major problems faced by superstring theory for which the new approach offered possible solutions. Questions of dimensionality are central to

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

Duff's text, from Kaluza-Klein theories to discussion of how certain of the extra dimensions of space-time (now eleven again—ten of space and one of time) might be "compactified" in curled-up membranes of several dimensions rather than in single, linear dimensions. Because of the complexity of the physics involved, however, Duff writes with a degree of technical scientific detail [that would undoubtedly elude most lay readers. Needless to say, Flatland is nowhere in sight.¹³⁹

- By contrast, the Flatland model plays a central role in the August 2000 Scientific American article, "The Universe's Unseen Dimensions," by physicists Nima Arkani-Hamed, Savas Dimopoulos, and Georgi Dvali, a text filled with colorful explanatory graphics.³⁴⁰ Following the title, bold type declares, "The visible universe could lie
- pg. 90
 - on a membrane floating within a higher-dimensional space. The extra dimensions would help unify the forces of nature and could contain parallel universes."³⁴¹ It is little wonder that Flatland functioned so effectively as a tool for these physicist authors, since they were proposing an explanation for the weakness of gravity (compared to the three other fundamental forces) that centered on our three-dimensional universe being a membrane embedded in a higher dimensional space or, as they suggest, a kind of "wall." While most particles and forces, including photons, the carriers of light, would be confined to this membrane, gravity would be free to escape. In their view gravity might then be propagating off the membrane into a "large extra dimension" of up to a millimeter's thickness.³⁴² Because photons could not escape our membrane, we could not see anything beyond it, offering an explanation for the invisibility of the extra dimension. Nevertheless, gravity's diffusion would explain its relative weakness.
 - If such a "brane" were folded back on itself with space intervening, it would also account for dark matter as existing on a parallel membrane—along, possibly with parallel universes. A crucial point in the ADD theory, so named for the author's last names, is the difference between their argument for a "large" additional dimension and the "small extra dimensions" characteristic of superstring and most other M-theory models (curled-up dimensions of 10^{-35} meter). That change in size also offered the possibility of experimental confirmation, a problem that had dogged superstring theory in general,³⁴³
 - Arkani-Hamed and his colleagues also note the "brane" models developed by Lisa Randall and Raman Sundrum in the late 1990s, which Randall subsequently discussed in her 2005 book, *Warped Passages: Unravelling the Mysteries of the Universe's Hidden Dimensions*.³⁴⁴ Likewise addressing the problem of the relative weakness of gravity, the two Randall-Sundrum models center on the warping of higher dimensional space. This phenomenon would keep gravity-carrying particles, known as gravitons, in the vicinity of one or two three-dimensional branes embedded in a fourth spatial dimension, termed the "bulk." In this five-dimensional space-time universe the two-brane model involves a "Weakbrane" (our three-dimensional world) and a "Gravitybrane," where gravity centers, separated by an infinitesimal additional spatial dimension. In the single brane model, with the warping

The 1990s: From Hyperspace to Cyberspace and Marcos Novak's Digital Architecture; New Developments in String Theory pp. 79 - 91 (12)

Links:

of space alone affecting gravity, Randall and Sundrum note that the extra spatial dimension might be infinite in expanse, coming the closest of any of the string or membrane

- pg. 91
 - theorists to the early twentieth century's association of the fourth dimension with infinity and spatial vastness. "Do I believe in extra dimensions? I confess I do," Randall declares at the very start of *Warped Passages Describing herself as a model* builder and not a "top-down string theorist," Randall also emphasizes that the warped geometry model offers good possibilities for experimental testing. 346
 - "Answers by 2010" is the heading of one of the sections of Arkani-Hamed and his collaborators' "Universe's Unseen Dimensions" article. Having explained the way their theory "make[s] gravity a strong force near TeV [electronvolt] energies," the authors note that these are the very energy levels to be probed by new particle accelerators, including the Large Hadron Collider at CERN in Switzerland, where experiments are "due to begin around 2005." However, delays at the Large Hadron Collider, which finally became operational at half its intended energy in 2010, have kept physicists from finding the crucial experimental "answers by 2010" that could confirm the validity of the new theories and the existence of extra dimensions. Thus, string and membrane theorists continue to wait for news from CERN, along with an interested public.³⁴⁷ But no matter what the scientific results-proving or disproving current theories-for the history of culture the emergence of string theory, along with computer graphics, played a major role in reintroducing the public to higher spatial dimensions. By ending the long dominance of Relativity Theory's time as supposedly the only "fourth dimension," string theory and its membrane variations have had a major impact on later twentieth and early twenty-first century culture.
- Global Summary: (Draft)
- Global Summary: Final Drafts

An Experiment in Computational Composition (Marcos Novak) pp. 01 - 23

- Article Summary:
 - Presented:
 - Author: Marcos Novak
 - An Experiment in Computational Composition pp. 01 - 23
 - Year: 1992
 - Publisher:
- Bibliography (Alternative Format)
 - An Experiment in Computational Composition (Marcos Novak) pp. 01 - 23 (23)
- Glossary
 - Major Concepts:
 - Information theory,
 - **Information theory** is a branch of [applied mathematics](#), [electrical engineering](#), [bioinformatics](#), and [computer science](#) involving the [quantification of information](#). Information theory was developed by [Claude E. Shannon](#) to find fundamental limits on [signal processing](#) operations such as [compressing data](#) and on [reliably storing and communicating](#) data. Since its inception it has broadened to find applications in many other areas, including [statistical inference](#), [natural language processing](#), [cryptography](#), [neurobiology](#),^[1] the [evolution](#)^[2] and [function](#)^[3] of molecular codes, model selection in [ecology](#),^[4] [thermal physics](#),^[5] [quantum computing](#), [plagiarism detection](#)^[6] and other forms of [data analysis](#).^[7]

A key measure of information is [entropy](#), which is usually expressed by the average number of bits needed to store or communicate one [symbol](#) in a message. Entropy quantifies the uncertainty involved in predicting the value of a [random variable](#). For example, specifying the outcome of a fair [coin flip](#) (two equally likely outcomes) provides less information (lower entropy) than specifying the outcome from a roll of a [die](#) (six equally likely outcomes).

Applications of fundamental topics of information theory include [lossless data compression](#) (e.g. ZIP files), [lossy data compression](#) (e.g. MP3s and JPGs), and [channel coding](#) (e.g. for [Digital Subscriber Line \(DSL\)](#)). The field is at the intersection of [mathematics](#), [statistics](#), [computer science](#), [physics](#), [neurobiology](#), and [electrical engineering](#). Its impact has been crucial to the success of the [Voyager](#) missions to deep space, the invention of the compact disc, the feasibility of mobile phones, the development of the [Internet](#), the study of [linguistics](#) and of human perception, the understanding of [black holes](#), and numerous other fields. Important sub-fields of information theory are [source coding](#), [channel coding](#), [algorithmic complexity theory](#), [algorithmic information theory](#), [information-theoretic security](#), and measures of information.
 - Entropy, (Shannon entropy)
 - In [information theory](#), **entropy** is a measure of the uncertainty in a [random variable](#).^[1] In this context, the term usually refers to the **Shannon entropy**, which quantifies the [expected value of the information](#) contained in a message.^[2] Entropy is typically measured in [bits](#), [nats](#), or [bans](#).^[3] Shannon entropy is the average unpredictability in a random variable, which is equivalent to its [information content](#). Shannon entropy provides an absolute limit on the best possible [lossless](#) encoding or [compression](#) of any communication, assuming that^[4] the communication may be represented as a sequence of [independent and identically distributed random variables](#).
 - A single toss of a fair [coin](#) has an entropy of one bit. A series of two fair coin tosses has an entropy of two bits. The number of fair coin tosses is its entropy in bits. This random selection between two outcomes in a sequence over time, whether the outcomes are equally probable or not, is often referred to as a [Bernoulli process](#). The entropy of such a process is given by the [binary entropy function](#). The [entropy rate](#) for a fair coin toss is one bit per toss. However, if the coin is not fair, then the uncertainty, and hence the entropy rate, is lower. This is because, if asked to predict the next outcome, we could choose the most frequent result and be right more often than wrong. The difference between what we know, or predict, and the information that the unfair coin toss reveals to us is less than one heads-or-tails "message", or bit, per toss.^[5]

This definition of "entropy" was introduced by [Claude E. Shannon](#) in his 1948 paper "[A Mathematical Theory of Communication](#)".^[6]
 - Terms
 - Genetic Algorithm. (Fundamental Mechanisms.) (Search Heuristic that mimics natural selection)
 - In the [computer science](#) field of [artificial intelligence](#), a **genetic algorithm (GA)** is a [search heuristic](#) that mimics the process of [natural selection](#). This heuristic (also sometimes called a [metaheuristic](#)) is routinely used to generate useful solutions to [optimization and search problems](#).^[1] Genetic algorithms belong to the larger class of [evolutionary algorithms](#) (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as [inheritance](#), [mutation](#), [selection](#), and [crossover](#).

Genetic algorithms find application in [bioinformatics](#), [phylogenetics](#), [computational science](#), [engineering](#), [economics](#), [chemistry](#), [manufacturing](#), [mathematics](#), [physics](#), [pharmacometrics](#) and other fields.
 - [inheritance](#), [mutation](#), [selection](#), & [crossover](#).
 - Search Algorithm:
 - In [computer science](#), a **search algorithm** is an [algorithm](#) for finding an item with specified properties among a [collection](#) of items. The items may be stored individually as [records](#) in a [database](#); or may be elements of a [search space](#) defined by a mathematical formula or procedure, such as the [roots of an equation with integer variables](#); or a combination of the two, such as the [Hamiltonian circuits of a graph](#).
 - Heuristic (computer science)
 - In [computer science](#), [artificial intelligence](#), and [mathematical optimization](#), a **heuristic** is a technique designed for [solving a problem](#) more quickly when classic methods are too slow, or for finding an approximate solution when classic methods fail to find any exact solution. This is achieved by trading [optimality](#), [completeness](#), [accuracy](#), or [precision](#) for speed.
 - Pareto optimality
 - **Pareto efficiency**, or **Pareto optimality**, is a state of allocation of [resources](#) in which it is impossible to make any one individual better off without making at least one individual worse off. The term is named after [Vilfredo Pareto](#) (1848–1923), an Italian economist who used the concept in his studies of [economic efficiency](#) and [income distribution](#)^[*citation needed*]. The concept has applications in academic fields such as [economics](#) and [engineering](#).

Given an initial allocation of [goods](#) among a set of [individuals](#), a change to a different allocation that makes at least one individual [better off](#) without making any other individual worse off is called a **Pareto improvement**. An allocation is defined as "Pareto efficient" or "Pareto optimal" when no further Pareto improvements can be made.

For example, suppose there are two consumers A & B and only one resource X. Suppose X is equal to 20. Let us assume that the resource has to be distributed equally between A and B and thus can be distributed in the following way: (1, 1), (2, 2), (3, 3), (4, 4), (5, 5), (6, 6), (7, 7), (8, 8), (9, 9), (10, 10). At point (10, 10) all resources have been exhausted. No further distribution is possible - if redistribution continues, it will lead to a position (11, 9) or (9, 11) that makes one better off and the other worse off. Hence, point (10, 10) is Pareto optimal; no further Pareto improvements can be made.

Pareto efficiency is a minimal notion of efficiency and does not necessarily result in a socially desirable distribution of resources: it makes no statement about equality, or the overall well-being of a society.^[1]^[2] The notion of Pareto efficiency can also be applied to the selection of alternatives in engineering and similar fields. Each option is first assessed under multiple criteria and then a subset of options is identified with the property that no other option can categorically outperform any of its members.
 - Pareto optimality is a measure of [efficiency](#). An outcome of a game is Pareto optimal if there is no other outcome that makes every player at least as well off and at least one player strictly better off. That is, a Pareto Optimal outcome cannot be improved upon without hurting at least one player. Often, a **Nash Equilibrium** is not Pareto Optimal implying that the players' [payoffs](#) can all be increased.
 - Fitness:
 - A **fitness function** is a particular type of [objective function](#) that is used to summarise, as a single [figure of merit](#), how close a given design solution is to achieving the set aims.

In particular, in the fields of [genetic programming](#) and [genetic algorithms](#), each design solution is represented as a string of numbers (referred to as a [chromosome](#)). After each round of testing, or simulation, the idea is to delete the 'n' worst design solutions, and to [breed](#) 'n' new ones from the best design solutions. Each design solution, therefore, needs to be awarded a figure of merit, to indicate how close it came to meeting the overall specification, and this is generated by applying the fitness function to the test, or simulation, results obtained from that solution.

The reason that genetic algorithms are not a lazy way of performing design work is precisely because of the effort involved in designing a workable fitness function. Even though it is no longer the human designer, but the computer, that comes up with the final design, it is the human designer who has to design the fitness function. If this is designed wrongly, the algorithm will either converge on an inappropriate solution, or will have difficulty converging at all.

Moreover, the fitness function must not only correlate closely with the designer's goal, it must also be computed quickly. Speed of execution is very important, as a typical genetic algorithm must be iterated many times in order to produce a usable result for a non-trivial problem.

[Fitness approximation](#) may be appropriate, especially in the following cases:

 - Fitness computation time of a single solution is extremely high
 - Precise model for fitness computation is missing
 - The fitness function is uncertain or noisy.

Two main classes of fitness functions exist: one where the fitness function does not change, as in optimizing a fixed function or testing with a fixed set of test cases; and one where the fitness function is mutable, as in [niche differentiation](#) or [co-evolving](#) the set of test cases.

Another way of looking at fitness functions is in terms of a [fitness landscape](#), which shows the fitness for each possible chromosome.

Definition of the fitness function is not straightforward in many cases and often is performed iteratively if the fittest solutions produced by GA are not what is desired. In some cases, it is very hard or impossible to come up even with a guess of what fitness function definition might be. [Interactive genetic algorithms](#) address this difficulty by outsourcing evaluation to external agents (normally humans).
 - Genetic Hill Climbing:
 - In [computer science](#), **hill climbing** is a [mathematical optimization](#) technique which belongs to the family of [local search](#). It is an iterative algorithm that starts with an arbitrary solution to a problem, then attempts to find a better solution by [incrementally](#) changing a single element of the solution. If the change produces a better solution, an incremental change is made to the new solution, repeating until no further improvements can be found.

For example, hill climbing can be applied to the [travelling salesman problem](#). It is easy to find an initial solution that visits all the cities but will be very poor compared to the optimal solution. The algorithm starts with such a solution and makes small improvements to it, such as switching the order in which two cities are visited. Eventually, a much shorter route is likely to be obtained.

Hill climbing is good for finding a [local optimum](#) (a solution that cannot be improved by considering a neighbouring configuration) but it is not guaranteed to find the best possible solution (the [global optimum](#)) out of all possible solutions (the [search space](#)). The characteristic that only local optima are guaranteed can be cured by using restarts (repeated local search), or more complex schemes based on iterations, like [iterated local search](#), on memory, like [reactive search optimization](#) and [tabu search](#), or memory-less stochastic modifications, like [simulated annealing](#).

The relative simplicity of the algorithm makes it a popular first choice amongst optimizing algorithms. It is used widely in [artificial intelligence](#), for reaching a goal state from a starting node. Choice of next node and starting node can be varied to give a list of related algorithms. Although more advanced algorithms such as [simulated annealing](#) or [tabu search](#) may give better results, in some situations hill climbing works just as well. Hill climbing can often produce a better result than other algorithms when the amount of time available to perform a search is limited, such as with real-time systems. It is an [anytime algorithm](#): it can return a valid solution even if it's interrupted at any time before it ends.
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- A Mathematical Theory of Communication by Claude Shannon
- Sources: Additional
- Sources: Online
- _Objectives
 - Correlate how the methodology outlined applies to my research (work).
 - _Questions
- _Outline
 - AN EXPERIMENT IN COMPUTATIONAL COMPOSITION
 - ABSTRACT:
 - A compositional study based on a visual interpretation of information theory is introduced. An algorithm is presented that relates variety in spatial parameters to visual information, along with a genetically inspired mechanism for refining a design through cycles of incremental cumulative changes. Two- and three- dimensional examples are shown.
 - Descent
 - From disorder (a chaos) order grows
 - grows fruitful
 - The chaos feeds it, chaos feeds the tree.
- **William Carlos Williams**
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 - 1.0. Introduction:
 - 2.0. Background:
 - 2.1. Some Questions:
 - 2.2. Autonomy of Proportion:
 - 2.3. Constructive Art and Computer Art
 - 2.4. Information Theory:
 - 3.0. Fundamental Concepts:
 - 3.1 Order: intention and singularity vs. information.
 - Order of intention and singularity and the order of information.
 - increase different imply increased information content. Quote MN
 - Thus, there are two conflicting readings of the regular grid: conceptually, it is singular and intentional, and therefore orderly; perceptually, it is chaotic and uninteresting, and therefore disorderly.

Intuitively, increased differences imply increased information content. When the dimensions of the grid are all equal the information content of the grid is minimal, and can be completely specified by statements such as: *asquaregridofunitsizex*. Any alteration that introduces a difference increases the information content of the grid, and the statement needed to describe that grid, as an index of its information content, is correspondingly more complex.
 - 3.2 Scope.
 - The goal is to create visually interesting compositions by incrementally adjusting the locations and dimensions of these graphic elements in a way that increases visual information.
 - 3.3. Representation. (Through a program)
 - Each row in this matrix contains the parameters that define an entity
 - 3.4. Information content.
 - According to information theory, the entropy (H) of a message is given by the following expression:

$$H = p_1 \log_2(1/p_1) + p_2 \log_2(1/p_2) + p_3 \log_2(1/p_3) + \dots + p_n \log_2(1/p_n)$$

where $p_1 \dots p_n$ are the probabilities related to the occurrence of each message in a set of potential messages. The sum of $p_1 \dots p_n$ is equal to one.
 - 4.0. Implementation
 - In the two-dimensional case, this implementation defines the objects to be arranged in the composition as rectangles placed within a square field. Each object divides that field into nine distinct regions. The extents of these regions are controlled by six parameters, three along the x axis and three along the y axis. Thus each object is represented as $O(p_1, p_2, p_3, \dots, p_6)$, as shown below.
 - The example on the left shows a parametric rectangle placed in the state of minimum information, all parameters being equal. The example on the right introduces differences to the values of the parameters, and thus has higher information content.

According to the description given above, the system can be seen as 1) trying to maximize the differences between the extents of the regions that define an object in each direction, as part of increasing its internal score, and 2) as trying to maximize the differences between the equivalent regions of different objects, as part of increasing its external score. The combined effect of these two operations is to maximize the variety of intervals between objects, and thus to increase the visual interest within an arrangement of objects.
 - Mapping the parameters onto the square is an arbitrary choice. The algorithm does not associate the parameters with any particular mapping. In other words, the same parameters could have been used to describe an entirely different compositional configuration.
 - 4.2. Genetic hill climbing: random mutation / cumulative change.
 - Building is a biological process, not an aesthetic process. *Hannes Meyer*
 - Rather than enumerating a very large space of possibilities explicitly, I have chosen an approach based on a genetic analogy. At any given time a fixed number of objects exists within the system. These objects are represented by their parameters, or gene strips, and the set of these gene strips constitutes the *current gene pool*. The composition literally evolves through *random mutation* and *cumulative change*. The gene strips are mutated as follows:
 - 1) a particular gene strip is chosen randomly;
 - 2) a particular parameter within the gene strip is chosen randomly;
 - 3) a mutation value is chosen randomly, within a prespecified range ;
 - 4) a particular operation is chosen randomly (at present simply addition, subtraction, or no change).
 - 5) one of the parameter's neighbors is chosen randomly and adjusted so as to maintain the overall value of the gene strip. (Recall that the parameters function as probabilities in a message, and the sum of the probabilities must be 1.)
 - The change is then applied to the gene strip, and three scores are obtained. The first two scores have been described above; they are the internal and external information scores. The third score implements a form of Pareto optimality: it only considers if the internal and external results are better, worse or equal, in terms of information
 - compared to those existing prior to the mutation, and gives an overall score according to the following interaction matrix:

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 - Based on this overall score the system then decides what to do with the gene: if the overall score is negative, the gene is left unaltered and another gene is chosen, as before. If the score is unchanged, then the same gene is kept, but another mutation value is chosen and applied, in an effort to force a stronger choice. Finally, if the overall score is positive, then the mutated gene replaces the previous gene. At this point a small increase in the overall information content of the design has been accomplished.
 - 4.3. Additional dimensions.
 - Figure 9 shows examples of two-dimensional compositions generated by this process. Figure 10 (photographs) shows three dimensional compositions generated by extending the parameter set from six to nine parameters and interpreting those parameters as dimensions along a third axis. Thus the visual field within which the composition is generated becomes a cube. Additional parameters can be added, along additional dimensions. The resulting composition can then be generated within the corresponding hyperspace. Parameters chosen from any three dimensions can then produce a three-dimensional projection of the n-dimensional composition.
 - 4.4. Extensions.
 - Several extensions are possible at this point:
 - 1) to treat the rectangles or parallelepipeds as bounding envelopes, and to provide grammatical rules for substitution of parametric elements within them;
 - 2) to consider both positive and negative elements, and the operations between elements (boolean and other);
 - 3) to allow the algorithm to operate recursively, so that once an element reaches a certain state it can subdivide, and its parts can be composed within it just as it was composed within its parent field;
 - 4) to alter the initial configuration of the elements on the field;

- 5) to alter the shape of the field;
- 6) to investigate other functions relating information to visual interest.

- 4.5. Mutation schedules.
 - Large mutation values give rise to bold changes in the configuration of the elements, while small values refine the configuration (literally producing compositions that appear, subjectively, more 'refined'). Intuitively, this corresponds to the initial broad strokes that set a design concept direction, followed by subsequent refinement of alternatives within a chosen scheme. It is thus possible for the behavior of the system to be controlled by using mutation schedules.
- 4.6. Constraints.
 - The generative mechanism can easily be extended to accommodate other kinds of constraints. In this implementation, for example, none of the regions was allowed to go to zero. This constraint is handled independently by the system, simply by adding another consideration to the scoring routines. The mutation and information mechanisms remain unaltered. If they generate an alternative that is not satisfactory, the scoring mechanisms will cause that gene to be ignored. In this case the operation of the system seeks to attain the maximum information within the set of constraints.

The actual form additional constraints would take varies. Any function of the parameters, either within a single gene strip, or among different ones, can be used as a constraint. Finally, the information scores themselves can be used to control the resulting composition. As we mentioned above, the information function used can itself be altered or refined in various ways.

- 5.0. Assessment.
- 5.1. Assessment.
 - In my own estimation, the designs produced by the system are indeed visually interesting, and bear a striking resemblance in character to the De Stijl and Constructivist aesthetic. Naturally, readers will have to reach their own conclusions. Clear differences are visible between arrangements that have evolved over 50-100 cycles, 400-500 cycles, and 1000, 4000, and 10000 cycles. The approach is robust, and can easily be extended to additional two or three dimensional parameters that control orthogonality, angle, texture, color, as we have seen.

The inversion of the normal interpretation of information theory seems to have been fruitful. It is unlikely, however, that any single measure can capture all the richness and variability of design. Additional research is needed to determine how to tailor the central formula to visual phenomena.
- 5.2. Application.
 - In my own estimation, the designs produced by the system are indeed visually interesting, and bear a striking resemblance in character to the De Stijl and Constructivist aesthetic. Naturally, readers will have to reach their own conclusions. Clear differences are visible between arrangements that have evolved over 50-100 cycles, 400-500 cycles, and 1000, 4000, and 10000 cycles. The approach is robust, and can easily be extended to additional two or three dimensional parameters that control orthogonality, angle, texture, color, as we have seen.

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- 5.2. Application.
 - The examples shown in the figures above are extremely simple compositional forms. The actual application of this algorithm would be to give actual dimensions to more complex parametrically defined architectural compositions. At the one extreme, the algorithm could be used to size and place the actual space defining elements in a composition reminiscent to de Stijl; at the other it could proportion a classical composition, as well as all the elements that belonged to it. Extensions to the algorithm can allow it to operate on groups of elements within elements (as in the context of TopDown, for example).
- 5.3. Significance.
 - Knowledge about the characteristics of coherent form and the ways of producing it is inherently interesting because it elucidates important aspects of the ways in which we perceive and process information. If it can be demonstrated that we perceive coherence directly, as an aggregate measure of the global properties of an artifact, then our aesthetic sense will be shown to be a crucial and complex part of our intelligence. In the words of Aquinas: *beauty consists in due proportion, for the senses delight in things duly proportioned ... because the sense too is a sort of reason, as is every cognitive power.*
 - The kind of tool proposed here, on the other hand is not design-neutral. It specifies
- 5.4. Conclusion.
 - This short study has informally demonstrated one way in which computers can be used to explore fundamental compositional questions in a computational setting. By addressing the architectural issue of proportion directly, not by attempting to reproduce a historical example, but by inventing a compositional process, insight has been gained not only concerning the *how* of proportion, but also the *why*.
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- Global Summary: (Draft)
 - A composition Study.
 - based on the interpretation of information theory is introduced.
 - Algorithm is presented that relates variety in spatial parameters to visual information.
 - Genetically inspired mechanism
 - for refining a design through cycles of incremental cumulative changes.
 - Two- and three- dimensional examples are shown.

- Global Summary: Final Drafts

Complexity: A Guided Tour (Melanie Mitchell)

Ch. 07 Defining and Measuring Complexity pp. 95-111

Links:

- _Article Summary:
 - Book Title: Complexity: A Guided Tour
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 - Complexity: A Guided Tour (Melanie Mitchell)
Ch. 07 Defining and Measuring Complexity pp. 95-111 (16)
- _Glossary
 - Major Concepts:
 - Algorithmic Information
 - Genome
 - DNA
 - noncoding regions
 - base pairs
 - Entropy
 - Fractals
 - statistical complexity
 - effective measure complexity
 - Terms
 - Shannon entropy
 - Dynamical Systems Theory
 - References:
 - Influential Artists/Thinkers:
 - Steven Wolfram
 - Andrey Kolmogorov
 - Gregory Chaitin
 - Ray Solomonoff
 - Seth Lloyd
 - Heinz Pagels
 - Claude Shannon
 - Charles Bennett
 - Herbert Simon
 - Daniel McShea
 - Benoit Mandelbrot
 - Murray Gell-Mann
 - Helge von Koch
 - Concepts
 - Papers
 - Computational capacity of the universe [Seth Lloyd](#) (MIT)
 - Sources (online)
- _Outline
 - **Chapter 7 Defining and Measuring Complexity**
 - **Introduction:**
 - **Complexity as Size: p. 96**
 - One simple measure of complexity is size. By this measure, humans are about 250 times as complex as yeast if we compare the number of base pairs, but

only about four times as complex if we count genes.

Since 250 is a pretty big number, you may now be feeling rather complex, at least as compared with yeast. However, disappointingly, it turns out that the amoeba, another type of single-celled microorganism, has about 225 times as many base pairs as humans do, and a mustard plant called *Arabidopsis* has about the same number of genes that we do.

Humans are obviously more complex than amoebae or mustard plants, or at least I would like to think so. This means that genome size is not a very good measure of complexity; our complexity must come from something deeper than our absolute number of base pairs or genes (See figure 7.1).

• **Complexity as Entropy pg. 96**

- Another proposed measure of the complexity of an object is simply its Shannon entropy, defined in chapter 3 to be the average information content or “amount of surprise” a message source has for a receiver. In our example, we could define a *message* to be one of the symbols A, C, G, or T. A highly ordered and very easy-to-describe sequence such as “A A A A A A . . . A” has entropy equal to zero. A completely random sequence has the maximum possible entropy.

- There are a few problems with using Shannon entropy as a measure of complexity. First, the object or process in question has to be put in the form of “messages” of some kind, as we did above. This isn’t always easy or straightforward—how, for example, would we measure the entropy of the human brain? Second, the highest entropy is achieved by a random set of messages. We could make up an artificial genome by choosing a bunch of random As, Cs, Gs, and Ts. Using entropy as the measure of complexity, this random, almost certainly nonfunctional genome would be considered more complex than the human genome. Of course one of the things that makes humans complex, in the intuitive sense, is precisely that our genomes aren’t random but have been evolved over long periods to encode genes *useful* to our survival, such as the ones that control the development of eyes and muscles. The most complex entities are not the most ordered or random ones but somewhere in between. Simple Shannon entropy doesn’t capture our intuitive concept of complexity.

• **Complexity as Algorithmic Information Content pg. 98**

- Many people have proposed alternatives to simple entropy as a measure of complexity. Most notably Andrey Kolmogorov, and independently both Gregory Chaitin and Ray Solomonoff, proposed that the complexity of an object is the size of the shortest computer program that could generate a complete description of the object. This is called the *algorithmic information content* of the object. For example, think of a very short (artificial) string of DNA:

A C A C A C A C A C A C A C A C A C (string 1).

A very short computer program, “Print A C ten times,” would spit out this pattern. Thus the string has low algorithmic information content. In contrast, here is a string I generated using a pseudo-random number generator:

A T C T G T C A A G A C G G A A C A T (string 2)

Assuming my random number generator is a good one, this string has no discernible overall pattern to it, and would require a longer program, namely “Print the exact string A T C T G T C A A A A C G G A A C A T.” The idea is that string 1 is compressible, but string 2 is not, so contains more algorithmic information. Like entropy, algorithmic information content assigns higher information content to random objects than ones we would intuitively consider to be complex.

- □ The physicist Murray Gell-Mann proposed a related measure he called “effective complexity” that accords better with our intuitions about complexity. Gell-Mann proposed that any given entity is composed of a combination of regularity and randomness. For example, string 1 above has a very simple regularity: the repeating A C motif. String 2 has no regularities, since it was generated at random. In contrast, the DNA of a living organism has some regularities (e.g., important correlations among different parts of the genome) probably combined with some randomness (e.g., true junk DNA).
- □ To calculate the effective complexity, first one figures out the best description of the regularities of the entity; the effective complexity is defined as the amount of information contained in that description, or equivalently, the algorithmic information content of the set of regularities.
- □ String 1 above has the regularity that it is A C repeated over and over. The amount of information needed to describe this regularity is the algorithmic information content of this regularity: the length of the program “Print A C some number of times.” Thus, entities with very predictable structure have low effective complexity.
- □ In the other extreme, string 2, being random, has no regularities. Thus there is no information needed to describe its regularities, and while the algorithmic information content of the string itself is maximal, the algorithmic information content of the string’s *regularities*—its effective complexity—is zero. In short, as we would wish, both very ordered and very random entities have low effective complexity.
- □ The DNA of a viable organism, having many independent and interdependent regularities, would have high effective complexity because its regularities presumably require considerable information to describe.
- □ The problem here, of course, is how do we figure out what the regularities are? And what happens if, for a given system, various observers do not agree on what the regularities are?
- □ Gell-Mann makes an analogy with scientific theory formation, which is, in fact, a process of finding regularities about natural phenomena. For any given phenomenon, there are many possible theories that express its regularities, but clearly some theories—the simpler and more elegant ones—are better than others. Gell-Mann knows a lot about this kind of thing—he shared the 1969 Nobel prize in Physics for his wonderfully elegant theory that finally made sense of the (then) confusing mess of elementary particle types and their interactions.
- □ In a similar way, given different proposed sets of regularities that fit an entity, we can determine which is best by using the test called Occam’s Razor. The best set of regularities is the smallest one that describes the entity in question

and at the same time minimizes the remaining random component of that entity. For example, biologists today have found many regularities in the human genome, such as genes, regulatory interactions among genes, and so on, but these regularities still leave a lot of seemingly random aspects that don't obey any regularities—namely, all that so-called junk DNA. If the Murray Gell-Mann of biology were to come along, he or she might find a better set of regularities that is simpler than that which biologists have so far identified and that is obeyed by more of the genome.

- Effective complexity is a compelling idea, though like most of the proposed measures of complexity, it is hard to actually measure. Critics also have pointed out that the subjectivity of its definition remains a problem.
- **Complexity as Logical Depth pg. 100**
 - In order to get closer to our intuitions about complexity, in the early 1980s the mathematician Charles Bennett proposed the notion of *logical depth*. The logical depth of an object is a measure of how difficult that object is to construct. A highly ordered sequence of A, C, G, T (e.g., string 1, mentioned previously) is obviously easy to construct. Likewise, if I asked you to give me a random sequence of A, C, G, and T, that would be pretty easy for you to do, especially with the help of a coin you could flip or dice you could roll. But if I asked you to give me a DNA sequence that would produce a viable organism, you (or any biologist) would be very hard-pressed to do so without cheating by looking up already-sequenced genomes.
 - In Bennett's words, "Logically deep objects . . . contain internal evidence of having been the result of a long computation or slow-to-simulate dynamical process, and could not plausibly have originated otherwise." Or as Seth Lloyd says, "It is an appealing idea to identify the complexity of a thing with the amount of information processed in the most plausible method of its creation."
 - To define logical depth more precisely, Bennett equated the *construction of an object* with the computation of a string of 0s and 1s encoding that object. For our example, we could assign to each nucleotide letter a two-digit code: A = 00, C = 01, G = 10, and T = 11. Using this code, we could turn any sequence of A, C, G, and T into a string of 0s and 1s. The logical depth is then defined as the number of steps that it would take for a properly programmed Turing machine, starting from a blank tape, to construct the desired sequence as its output.
 - Since, in general, there are different "properly programmed" Turing machines that could all produce the desired sequence in different amounts of time, Bennett had to specify which Turing machine should be used. He proposed that the shortest of these (i.e., the one with the least number of states and rules) should be chosen, in accordance with the above-mentioned Occam's Razor.
 - Logical depth has very nice theoretical properties that match our intuitions, but it does not give a practical way of measuring the complexity of any natural object of interest, since there is typically no practical way of finding the smallest Turing machine that could have generated a given object, not to mention determining how long that machine would take to generate it. And this doesn't even take into account the difficulty, in general, of describing a given object as a string of 0s and 1s.
- **Complexity as Thermodynamic Depth p. 101**

- In the late 1980s, Seth Lloyd and Heinz Pagels proposed a new measure of complexity, *thermodynamic depth*. Lloyd and Pagels' intuition was similar to Bennett's: more complex objects are harder to construct. However, instead of measuring the number of steps of the Turing machine needed to construct the description of an object, thermodynamic depth starts by determining "the most plausible scientifically determined sequence of events that lead to the thing itself," and measures "the total amount of thermodynamic and informational resources required by the physical construction process."
- For example, to determine the thermodynamic depth of the human genome, we might start with the genome of the very first creature that ever lived and list all the evolutionary genetic events (random mutations, recombinations, gene duplications, etc.) that led to modern humans. Presumably, since humans evolved billions of years later than amoebas, their thermodynamic depth is much greater.
- Like logical depth, thermodynamic depth is appealing in theory, but in practice has some problems as a method for measuring complexity. First, there is the assumption that we can, in practice, list all the events that lead to the creation of a particular object. Second, as pointed out by some critics, it's not clear from Seth Lloyd and Heinz Pagels' definition just how to define "an event." Should a genetic mutation be considered a single event or a group of millions of events involving all the interactions between atoms and subatomic particles that cause the molecular-level event to occur? Should a genetic recombination between two ancestor organisms be considered a single event, or should we include all the microscale events that cause the two organisms to end up meeting, mating, and forming offspring? In more technical language, it's not clear how to "coarse-grain" the states of the system— that is, how to determine what are the relevant *macrostates* when listing events.
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- **Complexity as Computational Capacity pg. 102**
 - If complex systems— both natural and human-constructed— can perform computation, then we might want to measure their complexity in terms of the sophistication of what they can compute. The physicist Stephen Wolfram, for example, has proposed that systems are complex if their computational abilities are equivalent to those of a universal Turing machine. However, as Charles Bennett and others have argued, the ability to perform universal computation doesn't mean that a system by itself is complex; rather, we should measure the complexity of the behavior of the system coupled with its inputs. For example, a universal Turing machine alone isn't complex, but together with a machine code and input that produces a sophisticated computation, it creates complex behavior.
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- **Statistical Complexity pg. 102**
 - Physicists Jim Crutchfield and Karl Young defined a different quantity, called *statistical complexity*, which measures the minimum amount of information about the past behavior of a system that is needed to optimally predict the *statistical behavior* of the system in the future. (The physicist Peter Grassberger independently defined a closely related concept called *effective measure complexity*.) *Statistical complexity* is related to Shannon's entropy in that a system is thought of as a "message source" and its behavior is somehow

- quantified as discrete “messages.” Here, predicting the statistical behavior consists of constructing a model of the system, based on observations of the messages the system produces, such that the model’s behavior is *statistically indistinguishable* from the behavior of the system itself.
- For example, a model of the message source of string 1 above could be very simple: “repeat A C”; thus its statistical complexity is low. However, in contrast to what could be done with entropy or algorithmic information content, a simple model could also be built of the message source that generates string 2: “choose at random from A, C, G, or T.” The latter is possible because models of statistical complexity are permitted to include random choices. The quantitative value of statistical complexity is the information content of the simplest such model that predicts the system’s behavior. Thus, like effective complexity, statistical complexity is low for both highly ordered and random systems, and is high for systems in between—those that we would intuitively consider to be complex.
 - Like the other measures described above, it is typically not easy to measure statistical complexity if the system in question does not have a ready interpretation as a message source. However, Crutchfield, Young, and their colleagues have actually measured the statistical complexity of a number of real-world phenomena, such as the atomic structure of complicated crystals and the firing patterns of neurons.
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 - **Complexity as Fractal Dimension pg. 103**
 - So far all the complexity measures I have discussed have been based on information or computation theoretic concepts. However, these are not the only possible sources of measures of complexity. Other people have proposed concepts from dynamical systems theory to measure the complexity of an object or process. One such measure is the *fractal dimension* of an object. To explain this measure, I must first explain what a *fractal* is.
 - The classic example of a fractal is a coastline. If you view a coastline from an airplane, it typically looks rugged rather than straight, with many inlets, bays, prominences, and peninsulas (Figure 7.2, top). If you then view the same coastline from your car on the coast highway, it still appears to have the exact same kind of ruggedness, but on a smaller scale (Figure 7.2, bottom). Ditto for the close-up view when you stand on the beach and even for the ultra close-up view of a snail as it crawls on individual rocks. The similarity of the shape of the coastline at different scales is called “self-similarity.”
 - The term *fractal* was coined by the French mathematician Benoit Mandelbrot, who was one of the first people to point out that the world is full of fractals—that is, many real-world objects have a rugged self-similar structure. Coastlines, mountain ranges, snowflakes, and trees are often-cited examples. Mandelbrot even proposed that the universe is fractal-like in terms of the distribution of galaxies, clusters of galaxies, clusters of clusters, et cetera. Figure 7.3 illustrates some examples of self-similarity in nature.
 - Although the term *fractal* is sometimes used to mean different things by different people, in general a fractal is a geometric shape that has “fine structure at every scale.” Many fractals of interest have the self-similarity property seen in the coastline example given above. The logistic-map bifurcation diagram

from chapter 2 (figure 2.6) also has some degree of self-similarity; in fact the chaotic region of this (R greater than 3.57 or so) and many other systems are sometimes called *fractal attractors*.

- Mandelbrot and other mathematicians have designed many different mathematical models of fractals in nature. One famous model is the so-called Koch curve (Koch, pronounced “Coke,” is the name of the Swedish mathematician who proposed this fractal). The Koch curve is created by repeated application of a rule, as follows.
 1. Start with a single line.
 2. Apply the Koch curve rule: “For each line segment, replace its middle third by two sides of a triangle, each of length $1/3$ of the original segment.” Here there is only one line segment; applying the rule to it yields:
 3. Apply the Koch curve rule to the resulting figure. Keep doing this forever. For example, here are the results from a second, third, and fourth application of the rule:

This last figure looks a bit like an idealized coastline. (In fact, if you turn

the page 90 degrees to the left and squint really hard, it looks just like the west coast of Alaska.) Notice that it has true self-similarity: all of the subshapes, and their subshapes, and so on, have the same shape as the overall curve. If we applied the Koch curve rule an infinite number of times, the figure would be self-similar at an infinite number of scales—a perfect fractal. A real coastline of course does not have true self-similarity. If you look at a small section of the coastline, it does not have exactly the same shape as the entire coastline, but is visually similar in many ways (e.g., curved and rugged). Furthermore, in real-world objects, self-similarity does not go all the way to infinitely small scales. Real-world structures such as coastlines are often called “fractal” as a shorthand, but it is more accurate to call them “fractal-like,” especially if a mathematician is in hearing range.

- Fractals wreak havoc with our familiar notion of spatial dimension. A line is one-dimensional, a surface is two-dimensional, and a solid is three-dimensional.
- ...What about the Koch curve? (Please see explanation)
- ...What is the dimension? To figure it out, I’ll do a calculation out of your sight (but detailed in the notes), and attest that according to our formula, the dimension is approximately 1.26. That is, the Koch curve is neither one- nor two-dimensional, but in between. Amazingly enough, fractal dimensions are not integers. That’s what makes fractals so strange.
- ...In short, the fractal dimension quantifies the number of copies of a self-similar object at each level of magnification of that object. Equivalently, fractal dimension quantifies how the total size (or area, or volume) of an object will change as the magnification level changes. For example, if you measure the total length of the Koch curve each time the rule is applied, you will find that each time the length has increased by $4/3$. Only perfect fractals—those whose levels of magnification extend to infinity—have precise fractal dimension. For

real-world finite fractal-like objects such as coastlines, we can measure only an approximate fractal dimension.

- I have seen many attempts at intuitive descriptions of what fractal dimension means. For example, it has been said that fractal dimension represents the “roughness,” “ruggedness,” “jaggedness,” or “complicatedness” of an object; an object’s degree of “fragmentation”; and how “dense the structure” of the object is. As an example, compare the coastline of Ireland (figure 7.2) with that of South Africa (figure 7.4). The former has higher fractal dimension than the latter.
- One description I like a lot is the rather poetic notion that fractal dimension “quantifies the cascade of detail” in an object. That is, it quantifies how much detail you see at all scales as you dive deeper and deeper into the infinite cascade of self-similarity. For structures that aren’t fractals, such as a smooth round marble, if you keep looking at the structure with increasing magnification, eventually there is a level with no interesting details. Fractals, on the other hand, have interesting details at all levels, and fractal dimension in some sense quantifies how interesting that detail is as a function of how much magnification you have to do at each level to see it.
-
- **Complexity as Degree of Hierarchy pg. 109**
 - In Herbert Simon’s famous 1962 paper “The Architecture of Complexity” Simon proposed that the complexity of a system can be characterized in terms of its degree of *hierarchy*: “the complex system being composed of subsystems that, in turn, have their own subsystems, and so on.” Simon was a distinguished political scientist, economist, and psychologist (among other things); in short, a brilliant polymath who probably deserves a chapter of his own in this book.
 - Simon proposed that the most important common attributes of complex systems are *hierarchy* and *near-decomposibility*. Simon lists a number of complex systems that are structured hierarchically—e.g., the body is composed of organs, which are in turn composed of cells, which are in turn composed of cellular subsystems, and so on. In a way, this notion is similar to fractals in the idea that there are self-similar patterns at all scales.
 - Near-decomposibility refers to the fact that, in hierarchical complex systems, there are many more strong interactions within a subsystem than between subsystems. As an example, each cell in a living organism has a metabolic network that consists of a huge number of interactions among substrates, many more than take place between two different cells.
 - Simon contends that evolution can design complex systems in nature only if they can be put together like building blocks—that is, only if they are hierarchical and nearly decomposable; a cell can evolve and then become a building block for a higher-level organ, which itself can become a building block for an even higher-level organ, and so forth. Simon suggests that what the study of complex systems needs is “a theory of hierarchy.”
 - Many others have explored the notion of hierarchy as a possible way to measure complexity. As one example, the evolutionary biologist Daniel McShea, who has long been trying to make sense of the notion that the complexity of organisms increases over evolutionary time, has proposed a hierarchy scale that can be used to measure the degree of hierarchy of

biological organisms. McShea's scale is defined in terms of levels of *nestedness*: a higher-level entity contains as parts entities from the next lower level. McShea proposes the following biological example of nestedness:

- Level 1: *Prokaryotic* cells (the simplest cells, such as bacteria)
- Level 2: Aggregates of level 1 organisms, such as *eukaryotic* cells (more complex cells whose evolutionary ancestors originated from the fusion of prokaryotic cells)
- Level 3: Aggregates of level 2 organisms, namely all multicellular organisms
- Level 4: Aggregates of level 3 organisms, such as insect colonies and “colonial organisms” such as the Portuguese man o’ war.

- Each level can be said to be more complex than the previous level, at least as far as nestedness goes. Of course, as McShea points out, nestedness only describes the *structure* of an organism, not any of its *functions*.
- McShea used data both from fossils and modern organisms to show that the maximum hierarchy seen in organisms increases over evolutionary time. Thus this is one way in which complexity seems to have quantifiably increased with evolution, although measuring the degree of hierarchy in actual organisms can involve some subjectivity in determining what counts as a “part” or even a “level.”
- There are many other measures of complexity that I don’t have space to cover here. Each of these measures captures something about our notion of complexity but all have both theoretical and practical limitations, and have so far rarely been useful for characterizing any real-world system. The diversity of measures that have been proposed indicates that the notions of complexity that we’re trying to get at have many different interacting dimensions and probably can’t be captured by a single measurement scale.

- Global Summary: (Rough Draft)
 - Statistical complexity would need a fundamental understanding of the system as a way to do a predictor of the future. This lack of a theory to predict the dynamical system limits the results to all dynamical systems.
 - The fractal measure of complexity is geometric in nature but does not describe the complete system in a manner that can lead to fundamental conclusions.
 - The measures of complexity are not universal and are dependent not only the system itself but it computes (outputs). These mechanisms are still biologically dependent on the specifics of how a system is depended on a whole.
- Final Drafts

Q.E. Assignment: What is the Design of the Research?(In NKS), Euclid's Elements, & NKS Outline Chapters 2, 3 & 5 (10.09.13)**Links:**

- Assignment Objectives: (Action Items) 10.05.13
- Advisor Instructions: 10.05.13
- Advisor Followup Questions & Response 10.08.13
 - Advisor Followup Questions & Response 10.08.13
 - Create a simple rule set:
 - Advisor Followup Questions & Response 10.08.13 - Additional 1
 - Advisor Followup Questions & Response 10.08.13 - Additional 2
 - Advisor Followup Questions & Response 10.08.13 - Additional 3
- Advisor Meeting Notes:
- _GR_Design of Research: Additional Research & Outline
 - _aGlossary:
 - Alife:
 - Boids: by Craig Reynolds:
 - Evolutionary Algorithms:
 - Design of Experiment:s (Experimental Design)
 - _Additional Reference:
 - _Summary:
 - In general usage, **design of experiments (DOE)** or **experimental design** is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in **statistics**, these terms are usually used for **controlled experiments**. Formal planned experimentation is often used in evaluating **physical objects**, **chemical formulations**, structures, components, and materials. Other types of study, and their design, are discussed in the articles on **computer experiments**, **opinion polls** and **statistical surveys** (which are types of **observational study**), **natural experiments** and **quasi-experiments** (for example, **quasi-experimental design**). See **Experiment** for the distinction between these types of experiments or studies.
 - In the design of experiments, the experimenter is often interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"), which may be people, parts of people, groups of people, plants, animals, etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.
 - Discussion topics when setting up an experimental design:
 - Research Design:
 - _Summary:
 - Design Types and SubTypes:
 - Confirmatory versus exploratory research:
 - Examples of fixed designs:
 - Examples of flexible research designs:
 - _Conferences:
 - _Overall Questions: Relating to my experiments
 - Where and when does complexity occur in simple programs?
 - What are the levels of behavior?
 - What simple computational rules in Alife can be equated with the NKS example?
- Euclid's Elements:
 - _aBook_first 10 pages
 - ELEMENTS BOOK 1
 - _Additional References
 - _Summary:
 - **Euclid's *Elements*** (Ancient Greek: Στοιχεῖα *Stoicheia*) is a **mathematical** and **geometric treatise** consisting of 13 books written by the ancient **Greek mathematician Euclid** in **Alexandria** c. 300 BC. It is a collection of definitions, postulates (**axioms**), propositions (**theorems** and **constructions**), and **mathematical proofs** of the propositions. The thirteen books cover **Euclidean geometry** and the ancient Greek version of elementary **number theory**. The work also includes an algebraic system that has become known as **geometric algebra**, which is powerful enough to solve many algebraic problems,^[1] including the problem of finding the **square root** of a number.^[2] With the exception of **Autolykus'** *On the Moving Sphere*, the *Elements* is one of the oldest extant Greek mathematical treatises,^[3] and it is the oldest extant axiomatic deductive treatment of **mathematics**. It has proven instrumental in the development of **logic** and modern **science**. The name 'Elements' comes from the plural of 'element'. According to **Proclus** the term was used to describe a theorem that is all-pervading and helps furnishing proofs of many other theorems. The word 'element' is in the Greek language the same as 'letter'. This suggests that theorems in the *Elements* should be seen as standing in the same relation to geometry as letters to language. Later commentators give a slightly different meaning to the term 'element', emphasizing how the propositions have progressed in small steps, and continued to build on previous propositions in a well-defined order.^[4]
 - Euclid's *Elements* has been referred to as the most successful^{[5][6]} and influential^[7] textbook ever written. Being first set in type in **Venice** in 1482, it is one of the very earliest mathematical works to be printed after the invention of the **printing press** and was estimated by **Carl Benjamin Boyer** to be second only to the **Bible** in the number of editions published,^[7] with the number reaching well over one thousand.^[8] For centuries, when the **quadrivium** was included in the curriculum of all university students, knowledge of at least part of Euclid's *Elements* was required of all students. Not until the 20th century, by which time its content was universally taught through other school textbooks, did it cease to be considered something all educated people had read. ^[9]
- Influence:
 - The *Elements* is still considered a masterpiece in the application of **logic** to **mathematics**. In historical context, it has proven enormously influential in many areas of **science**. Scientists **Nicolaus Copernicus**, **Johannes Kepler**, **Galileo Galilei**, and Sir **Isaac Newton** were all influenced by the *Elements*, and applied their knowledge of it to their work. Mathematicians and philosophers, such as **Bertrand Russell**, **Alfred North Whitehead**, and **Baruch Spinoza**, have attempted to create their own foundational "Elements" for their respective disciplines, by adopting the axiomatized deductive structures that Euclid's work introduced.
 - The austere beauty of Euclidean geometry has been seen by many in western culture as a glimpse of an otherworldly system of perfection and certainty. Abraham Lincoln kept a copy of Euclid in his saddlebag, and studied it late at night by lamplight; he related that he said to himself, "You never can make a lawyer if you do not understand what demonstrate means; and I left my situation in Springfield, went home to my father's house, and stayed there till I could give any proposition in the six books of Euclid at sight".^[19] **Edna St. Vincent Millay** wrote in her sonnet *Euclid Alone Has Looked on Beauty Bare*, "O blinding hour, O holy, terrible day, When first the shaft into his vision shone Of light anatomized!". **Einstein** recalled a copy of the *Elements* and a magnetic compass as two gifts that had a great influence on him as a boy, referring to the Euclid as the "holy little geometry book".^[20]
 - The success of the *Elements* is due primarily to its logical presentation of most of the mathematical knowledge available to Euclid. Much of the material is not original to him, although many of the proofs are his. However, Euclid's systematic development of his subject, from a small set of axioms to deep results, and the consistency of his approach throughout the *Elements*, encouraged its use as a textbook for about 2,000 years. The *Elements* still influences modern geometry books. Further, its logical axiomatic approach and rigorous proofs remain the cornerstone of mathematics.
- Outline:

www.red3d.com-
en.wikipedia.org-
archive.bio.ed.ac.

en.wikipedia.org-

farside.ph.utexas.

www.claymath.org
en.m.wikipedia.org

- Contents of the books

Books 1 through 4 deal with [plane geometry](#):

- Book 1 contains Euclid's 10 axioms (5 named postulates—including the [parallel postulate](#)—and 5 named axioms) and the basic propositions of geometry: the [pons asinorum](#) (proposition 5), the [Pythagorean theorem](#) (Proposition 47), equality of angles and [areas](#), parallelism, the sum of the angles in a triangle, and the three cases in which triangles are "equal" (have the same area).
- Book 2 is commonly called the "book of [geometric algebra](#)" because most of the propositions can be seen as geometric interpretations of algebraic identities, such as $a(b + c + \dots) = ab + ac + \dots$ or $(2a + b)^2 + b^2 = 2(a^2 + (a + b)^2)$. It also contains a method of finding the [square root](#) of a given number.
- Book 3 deals with circles and their properties: [inscribed angles](#), [tangents](#), the power of a point, [Thales' theorem](#).
- Book 4 constructs the [incircle](#) and [circumcircle](#) of a triangle, and constructs [regular polygons](#) with 4, 5, 6, and 15 sides.

Books 5 through 10 introduce [ratios](#) and [proportions](#):

- Book 5 is a treatise on proportions of [magnitudes](#). Proposition 25 has as a special case the [inequality of arithmetic and geometric means](#).
- Book 6 applies proportions to geometry: Similar figures.
- Book 7 deals strictly with elementary number theory: [divisibility](#), [prime numbers](#), [Euclid's algorithm](#) for finding the [greatest common divisor](#), [least common multiple](#). Propositions 30 and 32 together are essentially equivalent to the [fundamental theorem of arithmetic](#) stating that every positive integer can be written as a product of primes in an essentially unique way, though Euclid would have had trouble stating it in this modern form as he did not use the product of more than 3 numbers.
- Book 8 deals with proportions in number theory and [geometric sequences](#).
- Book 9 applies the results of the preceding two books and gives the infinitude of prime numbers (proposition 20), the sum of a [geometric series](#) (proposition 35), and the construction of even [perfect numbers](#) (proposition 36).
- Book 10 attempts to classify [incommensurable](#) (in modern language, [irrational](#)) magnitudes by using the [method of exhaustion](#), a precursor to [integration](#).

Books 11 through to 13 deal with spatial geometry:

- Book 11 generalizes the results of Books 1–6 to space: perpendicularity, parallelism, volumes of [parallelepipeds](#).
- Book 12 studies volumes of [cones](#), [pyramids](#), and [cylinders](#) in detail, and shows for example that the volume of a cone is a third of the volume of the corresponding cylinder. It concludes by showing the volume of a [sphere](#) is proportional to the cube of its radius by approximating it by a union of many pyramids.
- Book 13 constructs the five regular [Platonic solids](#) inscribed in a sphere, calculates the ratio of their edges to the radius of the sphere, and proves that there are no further regular solids.

- Euclid's method and style of presentation:

-

Codex Vaticanus 190

Euclid's [axiomatic approach](#) and [constructive methods](#) were widely influential.

As was common in ancient mathematical texts, when a proposition needed [proof](#) in several different cases, Euclid often proved only one of them (often the most difficult), leaving the others to the reader. Later editors such as [Theon](#) often interpolated their own proofs of these cases.

Euclid's presentation was limited by the mathematical ideas and notations in common currency in his era, and this causes the treatment to seem awkward to the modern reader in some places. For example, there was no notion of an angle greater than two right angles.[21] the number 1 was sometimes treated separately from other positive integers, and as multiplication was treated geometrically he did not use the product of more than 3 different numbers. The geometrical treatment of number theory may have been because the alternative would have been the extremely awkward [Alexandrian system of numerals](#).[22]

The presentation of each result is given in a stylized form, which, although not invented by Euclid, is recognized as typically classical. It has six different parts: First is the [enunciation](#) which states the result in general terms (i.e. the statement of the proposition). Then the [setting-out](#), which gives the figure and denotes particular geometrical objects by letters. Next comes the [definition](#) or [specification](#) which restates the enunciation in terms of the particular figure. Then the [construction](#) or [machinery](#) follows. It is here that the original figure is extended to forward the proof. Then, the [proof](#) itself follows. Finally, the [conclusion](#) connects the proof to the enunciation by stating the specific conclusions drawn in the proof, in the general terms of the enunciation.[23]

No indication is given of the method of reasoning that led to the result, although the [Data](#) does provide instruction about how to approach the types of problems encountered in the first four books of the [Elements](#).[24] Some scholars have tried to find fault in Euclid's use of figures in his proofs, accusing him of writing proofs that depended on the specific figures drawn rather than the general underlying logic, especially concerning Proposition II of Book I. However, Euclid's original proof of this proposition is general, valid, and does not depend on the figure used as an example to illustrate one given configuration.[25]

- A New Kind of Science By Stephen Wolfram (2002)

- _aGlossary:

- _aCellular automata

- _Summary

- A **cellular automaton** (pl. **cellular automata**, abbrev. **CA**) is a [discrete](#) model studied in [computability theory](#), [mathematics](#), [physics](#), [complexity science](#), [theoretical biology](#) and [microstructure](#) modeling. Cellular automata are also called [cellular spaces](#), [tessellation automata](#), [homogeneous structures](#), [cellular structures](#), [tessellation structures](#), and [iterative arrays](#).[2]

A cellular automaton consists of a regular grid of *cells*, each in one of a finite number of *states*, such as *on* and *off* (in contrast to a [coupled map lattice](#)). The grid can be in any finite number of dimensions. For each cell, a set of cells called its *neighborhood* is defined relative to the specified cell. An initial state (time $t=0$) is selected by assigning a state for each cell. A new *generation* is created (advancing t by 1), according to some fixed *rule* (generally, a mathematical function) that determines the new state of each cell in terms of the current state of the cell and the states of the cells in its neighborhood. Typically, the rule for updating the state of cells is the same for each cell and does not change over time, and is applied to the whole grid simultaneously, though exceptions are known, such as the [stochastic cellular automaton](#) and [asynchronous cellular automaton](#).

The concept was originally discovered in the 1940s by [Stanislaw Ulam](#) and [John von Neumann](#) while they were contemporaries at [Los Alamos National Laboratory](#). While studied by some throughout the 1950s and 1960s, it was not until the 1970s and [Conway's Game of Life](#), a two-dimensional cellular automaton, that interest in the subject expanded beyond academia. In the 1980s, [Stephen Wolfram](#) engaged in a systematic study of one-dimensional cellular automata, or what he calls [elementary cellular automata](#); his research assistant [Matthew Cook](#) showed that one of these rules is [Turing-complete](#). Wolfram published *A New Kind of Science* in 2002, claiming that cellular automata have applications in many fields of science. These include computer processors and [cryptography](#).

The primary classifications of cellular automata as outlined by Wolfram are numbered one to four. They are, in order, automata in which patterns generally stabilize into [homogeneity](#), automata in which patterns evolve into mostly stable or oscillating structures, automata in which patterns evolve in a seemingly chaotic fashion, and automata in which patterns become extremely complex and may last for a long time, with stable local structures. This last class are thought to be [computationally universal](#), or capable of simulating a [Turing machine](#). Special types of cellular automata are those which are [reversible](#), in which only a single configuration leads directly to a subsequent one, and [totalistic](#), in which the future value of individual cells depend on the total value of a group of neighboring cells. Cellular automata can simulate a variety of real-world systems, including biological and chemical ones. There has been speculation that cellular automata may be able to model reality itself, i.e. that the universe could be viewed as a giant cellular automaton.

- _Overview

en.wikipedia.org-

en.wikipedia.or

en.wikipedia.org-
www.wolfram.com
en.wikipedia.org-
www.youtube.com

- _History:
- Classification
- Elementary cellular automata
- Modeling Physical Reality:
- Rule Space
- zReferences:
- Mathematica
- Naturalistic Observation:
- **aVideo Lecture: (2003) selected notes:**
- Notes: (UCTV)
 - A New Kind of Science:
 - Intellectual Structure (Created over 20 years)
 - Physicist working particle physics and cosmology.
 - Initial Question:
 - How structures emerge in our universe?
 - Question: (Core Question)
 - How does anything complicated get produced in nature?
 - Examples:
 - Methodology: (Why do we need to be constrained only to mathematics?)
 - SMP (1981): Computer language Created (Identified primitives)
 - All processes are computational: Input and Output
 - A universal system. A program can act like any other system.
 - Principle of computational equivalence.
 - Captures great strengths and weaknesses of Science.
 - Systems in nature are universal.
 - Simplest possible Turing machine that is universal.
 - Computational Irreducibility:
 - Undecidability:
 - Tracking down History: Extensive Notes
 - Using Mathematica for everything (Code: creating programs & notations)
 - Outcomes form the NKS Project: (3) Things:
 - A new area of basic science.
 - A whole bunch of new computations.
 - A new framework for education. (New directions of technology.)
- Initial Experiment (Subject)
 - Cellular Automata
- Thesis: Core Question - (pg. 23)
 - How do simple programs behave?
 - Is the behavior universal among other simple programs?
 - Is complexity and nature fundamentally similar in its origins ("simple")?
- Hypothesis: - (pg. 28)
 - All basic phenomenon responsible for computational complexity is a representation of a universal truth of "Nature"
- Questions:
 - What happens to the behavior of an arbitrary simple program (Cellular Automata)?
 - How do these programs behave with different simple rules?
 - When does complexity occur in simple programs?
 - How do they compare with other simple programs?
 - Is it only cellular automata with very specific rulers that experience this complex behavior?
 - How typical are the results? (Is it common in all sorts (types) of other simple programs?)
- Purpose:
 - Is to look at a wide range of simple programs?
- Methods: (Visual Presentation)
 - Objectives: (The Search for General Features)
 - Abbreviated Quotes: (pg. 52)
 - Start considering general Cellular Automata and then consider other programs. With the underlying structures being further and further away from the original.
 - What I discover is that whatever kind of underlying rules one uses, the behavior that emerges turns out to be remarkably similar to the basic examples that we have already seen in cellular automata.
 - Throughout the world of simple programs, it seems, there is great universality in the types of overall behavior that can be produced.this makes it possible for me to construct the coherent new kind of science that I describe in this book. ... use it to elucidate a large number of phenomena, independent of the particular details of the systems in which they occur.
 - Experiments
 - Simple and Straight forward. - (pg. 105)
 - (See experimental set up) step 7
 - Observational
 - Methodology of a "Naturalist" exploring and studying various forms that exist in the world of simple programs.
- Experiment Set Up: (Cellular Automata)
- Conclusions:
 - A New Kind of Science, Stephen Wolfram (2002)
 - **Chapter 2: The World of Simple Programs (pp. 23 - 50)**
 - General:
 - When more complexity occurs the mixture of regularity and irregularity backgrounds are formed. (pg. 31)
 - On average the black and white backgrounds occur equally.
 - It is impossible to predict the outcome. Global observations of behavior - structural.
 - Mathematical language and methods of traditional research can create limited assumptions which can limit the scope of the experiment detrimentally.
 - Using computers is a new and essential tool for exploration and analysis.
 - Without computers these types of experiments could not be done.
 - Practical Computing is essential for creating observational instincts to conduct experiments.
 - **Chapter 3: The Crucial Experiment (pp. 51 - 114)**
 - The Search for General Features: (pp. 51- 71)
 - Some Conclusions: (pg. 105)
 - Cellular Automata creates complexity.
 - Creating defined systems,
 - Substitution of a new system by taking away characteristics run by the original experiments Cellular Automata.
 - All systems created complexity.
 - Suggests that the phenomenon of complexity is universal and independent of details from other particular systems.
 - Finding threshold in complexity and rules:

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- The crucial ingredients that are needed for complex behavior are present in the system of simple rules,
- General Traits: (representing a vast range of behaviors.)
- The general principles govern behavior of a wide range of systems.
- Fundamental statements can be made by the analysis.
- How the Discoveries in this chapter Were Made - (pg. 108)
 - The methodology was doing computer experiments.
 - Watching the behavior with a possibility of discovering new phenomenon.
 - Creation of rules can be created with perfect precision. (verifiable)
 - Computer experiments need to be simple and straight forward (simple structures)
 - Looking for systems with the simplest possible structure can show up in a wide variety of places.
 - Meaning and the studying of systems will get results with the broadest most fundamental significance.
 - Create simple systems (you can tell what it is doing)
 - Studying simple systems and then add features to the base rules.
 - Even in an experiment it is never entirely straight forward to discovery (new). Setting up an experiment you must make assumptions about the kind of behavior that can occur and if it turns out that there is a behavior which does not happen to fit in, then typically the experiments will fail to notice it.
 - Make the design experiment simple and direct as possible.
 - Big Searches are better than small ones. (Assumptions made to constrain the experiments can miss discoveries)
 - Present Data by pictures (example: cellular automata 10,000 cells can be represented in a few inches) (pg. 112)
 - Study the pictures.
 - Created a search program to find results. (pg. 113)
 - Creating "Mathematica" as part of the research. and contributed to discoveries.
- **Chapter 5: Two Dimensions and Beyond (pp. 169 - 221)**
 - - Introduction (pp.169 - 170)
 - The purpose of this chapter is to see how much of a difference it makes to allow more than one dimension. (1D)
 - What about the phenomenon of complexity? How much does it depend on dimension? It could be that in going beyond one dimension, the character of the behavior that we would see would immediately change.
 - But what will discover, in the end, is that, at an overall level, the behavior we see is not fundamentally much different in two or more dimensions than in one dimension. Indeed, despite what we might expect from traditional science, adding more dimensions does not ultimately seem to have much effect on the occurrence of behavior of any significant complexity.
 - See examples (p. 170 – 216) (need to detail outline)
 - More Cellular Automata - (pg. 170)
 - Mobile Automata - (pg. 184)
 - Turing Machine - (pg. 184)
 - Substitution Systems and Fractals - (pg. 187)
 -
 - Sequential Substitution Systems - (pg. 193)
 - Multiway Systems - (pg. 204)
 - - Systems Based on Constraints (pp. 210 - 221)
 - _Note: Algorithmic Development of Media Arts & Design Research
 - All are based on explicit views that specify how the systems evolve from step to step. In traditional science, mathematics, instead of rules, the systems are just given constraints.
 - Creating complexity from constraints (simple sets)
 - -1D NO
 - -2D – Repetitive patterns satisfy constraint (p. 211)
 - Complicated constraints with local arrangements
 - Colors ground every cell to match a fixed set.
 - Of possible templates (total – 4,294,967,296)
 - Of these, constraints that cannot be satisfied by pattern (766,979,044)
 - Among the remaining, those that can be satisfied by a simple repetitive pattern (3,527,988,252)
 - In fact, the number of different repetitive patterns that are ever needed is quite small: if a particular constraint can be satisfied by any pattern, then one of the set of 171 repetitive patterns on (pp. 214-215) is always sufficient.
 - * See graphics (pp. 214-215)
 - [CAPTION] The complete collection of all 171 patterns needed to satisfy constraints of the type shown on the previous page. If none of these 171 patterns satisfy a particular constraint, then it follows that no pattern at all will satisfy the constraint. The patterns are labeled by numbers which specify the minimal constraint which requires the given pattern. Patterns differing by overall reflection, rotation and interchange of black and white are not shown.
 - Extending constraints (slightly to ones considered). (p. 216)
 - How can one force more complex patterns to occur?
 - One way is to require not only that the colors around each cell match a set of templates, but also that a particular template from this set must appear at least somewhere in an array of cells (see examples).
 - A typical feature is that the patterns are divided into several separate regions, often emanating from some kind of center. But at least in all the examples, the patterns that occur in each individual region are still simple and repetitive.
 - * (See graphics p. 216)
 - [CAPTION] Examples of patterns produced by systems in which not only must the arrangement of colors in each neighborhood match one of a fixed set of templates, but also a certain template from this set must occur at least once in

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the pattern. The constraints are numbered as before, and in each picture the template that must occur is shown at the center. Constraint 1125528937 leads to a pattern that repeats in 98×98 blocks. The last pattern shown is also repetitive, repeating every 56 cells on the diagonal.

- So how can one find constraints that force more complex patterns?
- Fairly difficult – it took as much computational effort as any other single result in this book.
- In a system like a cellular automaton that is based on explicit rules, it is always straightforward to take the rule and apply it to see what pattern is produced.
- But in a system that is based on constraints, there is no such direct procedure... one must in effect go outside of the system to work out what patterns can occur. (p. 217)
- 1. Strategy: enumerate every single pattern, see which, if any, satisfy a particular constraint.
- But with a system containing more than just a few cells, the total number of patterns is astronomical.
- 2. A practical alternative is to build up patterns iteratively, starting with a small region and then adding new cells in essentially all possible ways, at each stage backtracking if the constraint for the system does not end up being satisfied.
- In some cases, there emerge quite quickly simple repetitive patterns that satisfy the constraint. But in other cases, a huge number of possibilities have to be examined in order to find any suitable pattern.
- 3. What if there is no pattern at all that can satisfy a particular constraint?
- In fact, if one can show that there is no pattern that satisfies the constraint in a limited region, then this proves that no pattern can satisfy the constraint on the whole grid. And... for many constraints, there are already quite small regions for which it is possible to establish that number pattern can be found
- ... Occasionally, (see 3rd picture p. 218) one runs into constraints that can be satisfied for regions containing thousands of cells, but not for the whole grid. And to analyze such cases inevitably requires examining huge numbers of possible patterns. (Tricks?)
- * (See graphic p. 218)
- [CAPTION] Stages in finding patterns that satisfy constraints ((a) 4670324, (b) 373384574 and © 387520105. Gray is used to indicate cells whose colors have not yet been determined. The first stage shown in each case corresponds to cells whose colors can be deduced immediately from the presence of a particular template at the center. In case (a) choices for additional cells can be made straightforwardly, and an infinite regular pattern can be built up without any backtracking. In case (b), many choices for additional cells have to be tried, with much backtracking, and in the end the automatic procedure fails to find a repetitive pattern. Nevertheless, as the last stage demonstrates, a repetitive pattern does in fact exist. In case ©, the automatic procedure finds a fairly large and almost regular pattern that satisfies the constraints, but in the case it turns out that no infinite pattern exists.
- ... it is feasible to take almost any system of the type discussed here and determine what pattern, if any, satisfies its constraint.
- * So what kind of patterns can be needed?
- ... vast majority of cases, simple repetitive patterns, or mixtures of such patterns, are the only ones that are needed.
- * But if one systematically examines possible constraints in the order shown (p. 218)... then it turns out that after examining more than 18 million, one finally discovers the system shown (p. 219). In this system, unlike all others before it, no repetitive pattern is possible. The only pattern that satisfies the constraint is the non-repetitive nested pattern shown in the picture.
- * Important conclusion:
- After testing millions of constraints and tens of billions of candidate patterns, ... it is finally possible to establish that a system based on simple constraints of the type discussed here can be forced to exhibit behavior more complex than pure repetition.
- * See graphic (p. 219)
- [CAPTION] The simplest system based on constraints that is forced to 12 templates shown, and that at least somewhere in the pattern a template containing a pair of stacked back cells must occur. In the numbering scheme used on preceding pages, the constraint is number 18762389. The pattern shown is unique, in that no variations of it, except for trivial translations, will satisfy the constraints. The nested structure on the diagonal essentially corresponds to a progression of base 2 digit sequences for positive and negative numbers.
- – nested structure on the diagonal corresponds to a progression of base 2 digit sequences for positive and negative numbers.
- (Note: see and study carefully graphic on p. 219)
- *What about still more complex behavior?

- There are altogether 137, 438,953,472 constraints of the type shown on p. 216 (See graphic). Of the millions tested, none have forced anything more complicated than the kind of nested behavior seen on the previous page. But if one extends again the type of constraints one considers, it turns out to become possible to construct examples that force more complex behavior.
- The idea is to set up templates that involve complete 3x3 blocks of cells, including diagonal neighbors. The picture below then shows an example of such a system, in which by allowing only a specific set of 33 templates, a nested pattern is forced to occur (see graphic p. 220).
- (See graphic p. 220)
 - [CAPTION] An example of a system based on a constraint involving 3 x 3 templates of cells. In this particular system, only the 33 templates shown above (out of the 512 possible ones are allowed to occur. This constraint, together with the requirement that the first template must appear at least somewhere, then turns out to force a nested pattern to occur. The system shown was specifically constructed in correspondence with the rule 60 elementary one-dimensional cellular automaton.
- *What about more complex patterns?
- Searches have not succeeded in finding anything. But explicit construction, based on correspondence with 1D cellular automata, leads to the example shown at the top of the facing page (p. 221): a system with 56 allowed templates in which the only pattern satisfying the constraint is a complex and largely random one, derived from the rule 30 cellular automaton.
- (See graphic p. 220)
 - [CAPTION] A system based on a constraint, in which a complex and largely random pattern is forced to occur. The constraint specifies that only the 563 x 3 templates shown at left can occur anywhere in the pattern, with the first template appearing at least once. The pattern required to satisfy this constraint corresponds to a shifted version of the one generated by the evolution of the rule 30 elementary one-dimensional cellular automaton.
 - So finally this shows that it is indeed possible to force complex behavior to occur in systems based on constraints. But ... this behavior appears to be quite rare. Unlike many of the simple rules that we have discussed in this book, it seems that almost all simple constraints lead only to fairly simple patterns.
- (Note: see and study carefully graphic on p. 221)
- *Any phenomenon based on rules can always ultimately also be described in terms of constraints.
- But the results of this section indicate that these descriptions can have to be fairly complicated for complex behavior to occur. So the fact that that traditional science and mathematics tends to concentrate on equations that operate like constraints provides yet another reason for their failure to identify the fundamental phenomenon of complexity discussed in A New Kind of Science.
- **History:**
 - Why These Discoveries Were Not Made Before - (pg. 42)
 - _Summary:
 - Creates a historical timeline to prove that no one tackled his exact thesis.
 - Cellular Automata:
 - Without a framework to understand the significance (analysis) no progress was made.
 - Prime Numbers
 - The phenomenon of complexity was predicted in mathematics.
 - Pi
 - (Same as above)
 - Literature Review (See NKS Appendix)
 - **Critical Commentary:**
 - Does not use the language of Science (Mathematics)
 - Not rigorous enough in methodology for science.

Evolutionary Art and the Aesthetics of Dynamism (Philip Galanter).pp 1-11 (11)

Links

- _Article Summary:
 - Presented: 12th Generative Art Conference GA2009, pp 1-11 (11)
 - Author: Philip Galanter
 - Evolutionary Art and the Aesthetics of Dynamism pp. 1-18
 - Year: 2009
 - Publisher:
- _Bibliography (Alternative Format)
- _Glossary
 - Major Concepts:
 - Terms
 - Zipf's law
 - Fractal dimension
 - Complexity Measures
 - Machado
 - Cordoso
 - Neural Networks
 - Machado
 - Phon-Amnuaisuk
 - Gedeon
 - Teleological
 - References:
- _Objectives
- _Outline
 - 0.0 Abstract:
 - The first problem of creating aesthetic fitness functions that would allow evolutionary art systems to execute unattended with industrial sized populations and generations.
 - The second problem is the sense of "sameness" and lack of innovation exhibited by typical evolutionary art systems.
 - ...It is suggested that current evolutionary art systems and projects are incoherent in so far as they don't focus on the essential virtue of generative art, i.e. a focus on process rather than final form.
 - 1.0 Introduction:
 - Although computational evolutionary art has been an active practice for at least 20 years there is a vague feeling of disappointment with the present state of the art. Industrial applications of evolutionary methods such as genetic algorithms have tracked the general progress seen in other sectors of computation and technology. But evolutionary art seems to have reached a premature plateau. Improvements in the aesthetics of evolutionary art have been slow, and any headway has frequently been by way of narrow techniques that are not generalizable or extensible.
 - In terms of theology there are two significant challenges, the problem of aesthetic fitness functions and the problem of genetic representation. But there are also related aesthetic and art-theoretical issues that must be faced as well.
 - 2.0 Fitness Functions for Art:
 - How does one define and implement an aesthetic fitness function? Various theories proposing a formulaic approach to aesthetic evaluation have come and gone over the years without much success. Some are skeptical as to whether aesthetics can ever be systematized for human understanding let alone computer implementation.
 - The typical response is to keep the artist "in the loop." The artist manually assigns fitness scores as each new generation is created. This approach is usually called "interactive evolutionary computing" or IEC.
 - 2.1 Computational Aesthetic Evaluation

en.wikipedia.org-

- ...the Mechanical Turk. In the 18th century this was described as a machine that could play chess. In the reality the Mechanical Turk was more like stage magic than computation.
- ..in an interactive evolutionary computing system there is a hidden artist making all the decisions and winning or losing the aesthetic game.
- From one point of view the challenge of computational aesthetic evaluation (CAE) is to create aesthetic fitness functions that can solve the problems presented by IEC. If human evaluation could be eliminated evolutionary art could benefit from the large populations and multiplicity of generations enjoyed by industrial applications.
- ... Computational aesthetic evaluation remains a grand challenge-level problem. For example attempts to partially solve this problem have been made using agent-based systems; (Sanders and Gero) and Greenfield.
- Using error measurement relative to an exemplar:
 - using perceptual measures, spectral analysis and low-level comparisons to sound targets;
 - using music theory-based rules.
- ... Some researchers have tried to deal with the fatigue problem by only using human evaluation for a subset of the population. The scores are then leveraged across the entire population based on similarities in the population. ... fusion of evolutionary computing and interactive evolution computing.
- 2.2 Connectionism and the Psychology and Neurology of Aesthetics
 - ... computational aesthetic evaluation remains an unsolved problem. ...we don't know much about how human aesthetic evaluation works either.
 - ... A picture of how human aesthetics works is being assembled piece by piece from the point of view of experimental psychology.
 - A new addition to such research is the nascent field of neuroaesthetics.
 - ... evolutionary psychologists have hypothesized that our aesthetic capabilities arise from adaptations related to mate selection. In addition, animals with much simpler neuro seem to select mates based on a simple kind of aesthetic evaluation. It may be that computation orders of magnitude less than that exhibited by the human brain will be up to the task.
 - ... breakthroughs in both the neurology of aesthetics and connectionists computing will synergistically lead to breakthroughs in computational aesthetic evaluation.
- 3.0 Aesthetic Sameness and Genetic Representation
 - The second major technical problem is that of genetic representation. This problem exhibits two related symptoms in evolutionary art. Frequently work from a given evolutionary system displays a certain sameness or cast that may find disappointing And as a corollary a given evolutionary system typically will not shift paradigms or otherwise innovate in significant ways.
 - ... this is not an observation about a lack of quality, although there is that as well, but rather a statement about the inability of evolutionary art systems to significantly break aesthetic paradigms at any level of quality.
 - In nature complexity at higher scales is an emergent property of self-organization at lower scales. This process has been called by some "complexification". the problem of aesthetic sameness and lack of innovation is due at least in part, to the lack of "complexification capacity" found in most evolutionary art systems.
 - ..Four kinds of genetic representation and each allows for a greater or lesser degree of complexification.
 - Fixed parameters:
 - ..offer the simplest kind of genetic representation.
 - ...A fixed parametric evolutionary system is highly constrained.
 - Extensible parameters.
 - ... offer a slightly more complicated representation.
 - ... an extensible parametric system is tightly constrained.
 - Direct mechanical
 - representations are more complicated, but allow for a significant increase in complexification.
 - ... complexification in such a system affords is still limited because the genetically constructed machines only exhibit a single level of emergence.
 - Reproductive mechanical:
 - representations are those most like DNA as found in nature. In such a system genes can construct machines that can go on to construct other machines and so on. And indeed

such machines may create copies of themselves, i.e. reproduce. Such a system can induce an arbitrary number of levels of emergence across multiple scales. This kind of genetic representation has the potential to provide complexification as found in nature.

- Please refer to the building blocks of life summary (pages 220-221)
- Summary:
- ... it's not until minds capable of symbolic understanding merge that another mode of inheritance from individual to individual becomes possible. This has suggested to some that evolutionary art systems should generate emergent individuals capable of further information exchange at a higher level.
- Like DNA, and evolutionary art system using reproductive mechanical genetic representation would allow for greater complexity because it would allow multiple levels of emergence across multiple scales. And perhaps then evolutionary art systems could then exhibit the wished for variety and innovation we find in nature.
- Unfortunately most evolutionary art systems currently utilize fixed or extensible parametric genetic representations, and a few arguable use direct mechanical representations.
- The creation of evolutionary art systems that use reproductive mechanical representations remains an unsolved problem as a matter of technology.
- It also presents and interesting art theoretical problem.
- 4.0 Dynamism and Truth to Process:
 - ...evolution in nature is a bottom up process. There are multiple levels of emergence at increasing scales. And this has happened over millions of years due to iterative and immediate competition and survival and not long term planning.
 - In short evolution is not teleological. It does not set out to create an advanced creature and then project downward to determine what is needed at lower levels. For all their complexity creatures in the natural world are unplanned and unanticipated emergent properties resulting from many levels of bottom up complexification.
 - .. But in the realm of fine art where innovation and conceptual focus are the hallmarks of truly great work, one has to ask whether the typical approach is not only practically insufficient but also art-theoretically incoherent.
 - generative art as a move from art objects to art processes. What is essential to generative art is not the final object.
 - The defining aspect of generative art is the way the artists cedes control to an autonomous system.
 - Evolutionary art created in the context of truth to process should be created from the bottom up. It should start with reproductive mechanical genetic representations.
 - Gene expressions should not directly create the object, but rather should kick off a process of complexification that crosses multiple scales and levels of emergence.
 - Most importantly generative art in the spirit of "truth to process" should not obsess on formal issues surrounding the final object.
- Global Summary: (Draft)
- Global Summary: Final Drafts