Dreams of Reason
The Computer and the Rise of the Sciences of Complexity.
(1988)
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Preface

The reductionist-Materialist view of nature is basically correct. The epistemic priority of mind over nature is also correct. The new sciences of complexity will resolve this problem or rather the dualism will disappear The computer is the primary research tool.

Chapter 1. Introductory Memoir

The 1960's in California were weird and Pagels did LSD for $50.

Part 1. The Sciences of Complexity.

Chapter 2. A new Synthesis of Science.

The divisions of science and universities have been remarkably stable but are now being supplemented by interdisciplinary efforts and challenged by commercial research.

The computer has enabled research into far more complex areas than simple Newtonian physics. Important ideas have been introduced by Turing, Darwin and the social sciences are being studied in new rigorous ways. Complexity involves non-linear, parallel systems. Very exciting frontier.

Chapter 3. Order, Complexity, and Chaos.

Complexity lies between order and chaos.

Turing distinguished between computable and uncomputable (random) numbers. Algorithmic complexity of a number is the length of the minimal program able to compute it. The informational content in DNA can be compressed – complex but not minimal. The Gödel-number represents a string of symbols (a logical proof) as a unique number.

Chatin proved that an algorithm can not be proved to be minimal. Also almost all numbers in the continuum are random but we cannot prove that a specific number is random. Algorithmic complexity is complexity in space and computation complexity is complexity in time (i.e. it is decidable but how long will it take). It is often difficult to distinguish between geometrical (exponential) and arithmetic (power) complexity.

Traub introduced information-based complexity for information which is partial, contaminated and priced.

“The algorithmic definition of complexity seems to be a misnomer. It really is a definition of randomness, not of complexity.” pg 64 (i.e. a randomly construct pseudo-DNA molecule will have a higher measure of algorithmic complexity). Hogg and Huberman defined complexity based on hierarchies but selecting the correct hierarchy is troublesome. Bennett defines complexity based on the “value” of the message where value is the amount of mathematical work saved by the message – that is the “logical depth”.
A measure of complexity is a strange beast because different things are complex in different ways therefore the measure will be elusive.

Conjecture: The computational process of the minimal algorithm for DNA is approximately represented by the actual growth process of the organism corresponding to that DNA sequence. (i.e. complexity of genotype and phenotype are approximately equal)

Diaconis noted that flipping coins or shuffling a deck of cards only achieves a random result after a minimum number of flips/shuffles.

Chapter 4. Life can be so Non-Linear.

Meteorologist Lorenz discovered deterministic chaos on 1963. The sum of two solutions to a linear equation will also be a solution. Non-linear equations are usually mathematically intractable. Microscopic differences in initial conditions can grow rapidly with iterations – so these systems are deterministic but not predictable because initial conditions cannot be precisely known. “a chaotic orbit I its own briefest description, and its own fastest computer; it is both deterministic and random.” pg 75.

A dynamic system has one or more attractors. An attractor is a set of solutions in state space to which states in its basin of attraction approach. Attractors can be fixed points, limit cycles, quasi-periodic (i.e. an endless line drawn on a torus), and strange (a continuous path in a bounded region.

“chaos has structure – the geometry of the strange attractors. ..... it may be possible to detect the statistical regularities in chaos provided that chaos is used as a probe.” pg 83 "the equations of quantum theory (which have an inherently statistical interpretation) have so far not revealed any chaos. .... the Schroedinger equation itself is a completely deterministic equation for the time evolution of a probability." pg 83

"Solitons can be thought of as non-linear solitary waves – lumps that retain their shape as they move along in space. The non-linearity of the self-interactions of the soliton is what holds the lump together and prevents its dissipation." pg 83

Chapter 5. Simulating Reality.

Simulating Intelligence. The debate between philosophers and AI experts as to whether human intelligence is a problem in principle or practice is sterile. "The future of intelligent machines, I believe, lies less with the artificial Intelligence (AI) experts or philosophers than with the computer engineers and scientists – hardware and software designers – who, oblivious to the debate, will go wherever technology and scientific understanding can lead them." pg 91

High level symbol manipulation has had success in game playing, expert systems and robots. However.......

If you attempt to describe a key you will find that you are not describing an object but a function and the function is wholly dependent on the context. Symbol manipulation is inherently based on the Cartesian theatre. This approach will fail. A bridge may be built based on the principles of logic but if some contradiction is found in set theory then the bridge does not fall down as a result. "What is it that you see when you see? You see an object as a key, you see a man in a car as a passenger, you see some sheets of paper as a book. It is the word 'as' that must be mathematically formalised, on par with the connectives 'and', 'or', 'implies', and 'not' that have already been accepted into formal logic. Until you do that, you will not get very far with your AI problem". Pg 94 (attributed to Stan Ulam)

Simulated Annealing. Provides an approximate solution to some of the most intractable problems in mathematics. This approach inherently depends on randomness and slow "cooling".

Cellular Automata, Artificial Life, and Computational Biology. CA can exhibit fixed-point, periodic, chaotic and quasi-periodic behaviour (just before the onset of chaotic). Some CA are know to be identical to a Universal Turing machine. Langton has explored the possibility of implementing the molecular logic of the living state in an artificial biochemistry based in the interaction between artificial molecules – and artificial life as a result. Langton is interested in artificial life including the hypercycles (limit cycles in non-linear molecular reactions) introduced by Eigen and Schuster. Kauffman et all introduced the concept of auto-catlytic sets where each member is the product of at least one reaction catalysed by at least one member. Kauffman and Smith have used automata to simulate evolution and found that automata rarely get trapped in an optimal survival configuration, especially as the complexity of the entity is increased. Also, even if the population is driven to a optimum attractor, selection in the face of constant mutation may be to weak to hold it there. Kauffman highlights the spontaneous order offered by the self-ordered properties of complex systems.
Modelling Molecules. Protein dynamics is a new field based on computer modelling. Large protein molecules can have many low energy configurations.

Expert Systems: modelling Skills. Successful in chemistry.

Computer modelling has been used to assist complex multinational deep sea mining negotiations.

Chapter 6. Connectionism / Neural Nets.

Computers and brains are very different.

There were 2 camps in the 1940's and 50's. Computationalists relied on Turing machines and symbol manipulation. Connectionists saw intelligence as the property of a network. Same strategy, different tactics. Hebbs rule strengthens connections that are used more. Early researchers like McCullock, Selfridge, McCarthy, Minsky, Newell, & Simon focussed on symbol manipulation and search with successes and failures. Massive search was not the answer and it became readily apparent in language in the "explosion of meaning" problem (context dependence). Rosenblatt created single layer perceptrons which were dismantled mathematically by Minsky (does not apply for multi-level). Selfridge created pandemonium. Connectionism was driven underground in the 60's and resurfaced in the 80's as PDP which "assume that information processing takes place through the interactions of a large number of simple processing elements called units, each sending exitory and inhibitory signals to other units."

Connectionism themes:

- Inspiration from neural architectures: neurons, inhibition/excitation. Inspiration not imitation.
- Emphasis on parallel processing:

- Knowledge is distributed throughout the network. Debate about how much localisation vs distribution. Distributed systems may alleviate the problem of constraints.
- Understanding cognition at the sub-symbolic microlevel.

Hopfield Networks. Can be viewed as a network of resistors and capacitors with an easy mathematical solution if the connection matrix is symmetric. The mechanical analogue is a massless marble moving through honey in a million dimensional state space. The point at which the “marble” stops is the “answer”. The mathematics is similar to that for spin-glasses in physics. Not neurologically plausible but has some behaviours similar to memory.

Lapedes and Farber have extended Hopfield networks into a master/slave model where the master network has a symmetric connection matrix and controls the slave with a non-symmetric arrangement. The master “programs” the slave which does the job. There are parallels with Baird and Freeman's work modelling the rabbit olfactory bulb.

Boltzmann Machines. Uses simulated annealing to set the weights in a Hopfield network (Hinton and Sejnowski) and is equivalent to Harmony theory (Smolensky). Crick and Mitchison have speculated that REM sleep is a form of “reverse learning”.

The Immune and Evolutionary Systems. The immune system like the evolutionary system is a powerful powerful pattern recognition system capable of learning and memory. Neural Darwinism is the idea that the firing rate of neurons is reduced to reflect learning (Edelman).

Hollands classifier system “can be divided into two parts, a set of *rules* or *classifiers,* and a *message list*. The rules contain information giving possible responses of the system, while the message list constrains the inputs from the .external environment and provides a forum for the rules to communicate and interact with each other. ... The classifier rules consist of multiple parts: one or more *conditions,* an *action* and a *strength* .... The conditions allow the classifier to 'read' the message list by searching for matches of the conditions against the messages posted on the list. When a match is found,and if certain criteria are met, a rule is allowed to post its action part as a new message on the list. Some rules have a special role as *effectors,* meaning that their action parts cause external outputs ....
"The *strength* is a number associated with each rule which is designed to indicate its value to the system. This forms the basis of learning. If a rule helps bring about useful responses, it gains strength, and otherwise it loses it. Strong rules are given more influence than weak rules in determining the overall response of the system."

Edelman describes these selective systems with three general operating principles: random repertoire (of alternatives), selective principle (a fitness function) and amplification (increases the successful alternatives).

The real proof is in the pudding.

Chapter 7. The Quick Buck Becomes Quicker.

Pagel has concerns regarding the computers role in money markets (precipitous crashes and assigning human investment judgement to computers), the diffusion of responsibility (the computer is down), and in the future expert legal systems and others.

“Information, be it embodied in organisms, the mind or the culture, is part of a larger selective system that determines through successful competition or cooperation what information survives. .... A selective system manages complexity.” pg 150

Part II. Philosophy and Anti-philosophy.

Chapter 8. The Building Code of the Demiurge.

“Enrico Fermi, the nuclear physicist, when asked about the existence of extraterrestrials, responded that they are here already; they are called Hungarians. Fermi was struck, like many of his colleagues, by the fact that the small nation of Hungary had produced so many brilliant scientists.” pg 153

Consider the universe that we observe around us to be communications for the Demiurge. But 'he' wrote himself out of the cosmic code. Drop it!

The cooperative free exchange of ideas is essential (and missing in China when resources are scarce). The non-verbal cognitive and intuitive component of scientific enquiry – an area about which little is known – is critical to its creative success.

Ultimately all scientific activity is devoted to the research for a coherent conceptual representation of reality.

Following Kant, Pagels argues that the natural laws are the organising principles that render our experience of the natural world intelligible and coherent. The 'invariant structure' of a theory corresponds to those features of the theory that are independent of our specific description of the theory of nature and the rules it obeys. While we create these maps, the territory and the rules must be discovered.

We have the objects of the world, the rules they obey and the theories. The description of the object and the rules will be referred to as the representation. The representation can take many forms in contrast to the invariant structures. Kant was the first person to clearly articulate the relation between theories of the natural world and the world itself.

“Kant's philosophy about how we comprehend the world, expressed in his Critique of Pure Reason, is very complex and difficult, but the central ideas can be simply presented in terms of a "Kantian cartoon" -a picture of how Kant saw the relation of the world to the mind. Imagine four concentric spheres that represent the transition from the outer to the inner world. The outermost sphere represents "the thing in itself," and it is dark-we have no way of knowing what it is. Things in themselves for Kant are not objects, they do not exist in space and time, and notions such as singular and plural do not apply to them. Moving inward, the next sphere, in our cartoon, is the sphere corresponding to the natural world. That sphere is illuminated-we certainly have experience of a world that exists in public space and time. This sphere corresponds to the territory in our map metaphor. The next sphere inward represents the knowing mind-the cognitive world of our mental representations, our experience. It also possesses the internal sense of time. This sphere is illuminated because we have access to the contents of our knowing mind. This is the sphere in which our maps of the natural world exist. Finally the innermost sphere of this cartoon model of the Kantian ego is also dark. It is the ultimate source of our cognitions and thoughts and is inscrutable. According to Kant, neither the outermost sphere, the thing in itself, or the innermost sphere, the mind in itself, are researchable. This accords with Kant's view that a science of psychology (as distinct from neurophysiology) is really impossible-we cannot have direct access to the source of our thoughts. We can, however, examine the empirical or phenomenal self. " pg 167

"The invariant order of nature that is expressed in our theories - the cosmic code - is possible because the material world is actually organized in that way. While our theories are free inventions of our minds, the invariants they express not only inform the coherence of our experience, they reflect the actual material structure of nature as well. .... I will argue (not prove!), first, that this natural invariant order is the only universal, coherent order, and, second, that anything else for which a scientific theory can reasonably be expected to exist is a consequence of that invariant order. Other forms of order such as those created by human beings - law, religion, the economy, society, literature, and art-are not primarily a consequence of the material order of nature, and we have no reason to expect that there is a hidden invariant order represented in a scientific theory that describes them." pg 170

"Nothing destroys a poorly-thought-out idea faster than the requirement of a detailed design or construction.

Chapter 9. Waiting for the Messiah.

“Cognitive scientists ... share one major assumption .. that there exist mental representations that can be analysed independently of biology and neurophysiology, the brains 'wetware', on the microlevel of the neurons or the social or cultural context on the macro-level of history.” pg 180

“A deep theory of cognition I unlikely to exist unless it is directly founded on the actual material structure of the brain or the computer.” pg 182

“Like the early geneticists postulating the' gene to explain the regular patterns of heredity, Chomsky postulates the existence of a transformational level to explain the patterns of language production. Geneticists, however, found that there was a material basis for the gene-DNA-while any neuroanatomical basis for the transformational level or the mental modules is lacking at this time.“ pg 185 David Marr did a similar thing with vision (and failed) while Hubel and Wiesel studied vision from “the-bottom-up” as Kandel did for memory. Language will eventual be understood from the bottom up.

Cognitive science must deliver on a strict constructivist requirement as do the natural sciences lest it drift off into narrative non-science.

Language is clearly context dependent and hence at least partially top-down dependent.

“Symbols are what Hilary Putnam, following Wittgenstein, called "cluster concepts." The image for a cluster concept is that of rope, which although it is a unity, actually consists of many fibres none of which runs the full length of the rope. Likewise symbols, designating the meaning they symbolize, are composite unities and open to many interpretations. ..... Because of that open-endedness, symbols are not easily defined-their definition is context dependent-and they are not subjected to a simple set of rules for manipulation.” pg 193 see *Metamagical Themas, by* Douglas Hofstadter more detailed discussion.

Cognitive scientists study two main entities: either brain/mind or computer. Cognitive psychologists are top-down and neuroscientists are bottom up. Computationalists motto “signs are symbols” and connectionists motto “from signs to symbols”.

Both top-down and bottom-up will be required.

More info on causal decoupling at pg 198-199, 203

Improved locomotion was not made in the image of man – it has wheels and wings.

“My view is that the internal programs that the cognitivists are seeking in the mind simply do not exist unless they can be directly shown to be materially supported by a definite neurofunction. Some kind of "causal decoupling" between the representations of knowledge and its material support must be true if a deep theory of cognition is to survive; but that "causal decoupling" must be demonstrated, not just postulated. In this sense, then, the possibility of a cognitive science will depend critically on what is discovered by the neurosciences. “ pg 202

Chapter 10. The Man Who Mistook His Brain for His Mind.

We are born with the first person perspective. The third-person perspective is an attainment that explicitly acknowledges the independence of the material and mathematical world from the individual consciousness. The third-person is imperfect and public but underpins science.

Kant's theoretical reason, the way of science, sees the mind-body problem from the third person perspective; practical reason sees this problem from a first person perspective.

Two key notions support Kant's empirical dualism; “causal decoupling” and “the barrier of complexity”.

Causal decoupling is the notion that the macroscopic (e.g. physical chemistry) laws depend on the microscopic laws (e.g. atomic) the microscopic laws are not required to understand the operation of the macroscopic level. The divisions of science reflect this causal decoupling. The whole macroscopic system has features that its individual parts do not; an emergence of new qualitative features from collective coherence.

The barrier of complexity recognises that some complex systems, such as a brain, are unsimulatable.

Monism, while it may offer a spiritual sense of connectedness or materialist simplicity, does not solve the mind-body problem; it ignores it. By ignoring a distinction, an opportunity for learning is lost. Furthermore, monism can lose the ethical dimension of human life. Dualism (the view of Descartes) characterizes the position we, as thinking and feeling beings, find ourselves. But several forms of dualism - categorical, substance, and property dualism - are either dead ends or wrong. Epistemic dualism (the view of Kant) is a dualism not of the mind and body, but within the reasoning processes we use to examine the world-a split between theoretical reason, which sees what in principle must be true and practical reason, which sees what in practice can be accomplished. I have advocated this position not only because it conforms with our experience, but because it puts the boundary between what is in principle and in practice possible to know about the mind-body problem firmly on the research agenda of the new sciences of complexity. And that is where I think it belongs. “ pg 238

Pagel chaired a meeting between the Dalai Lama and a group of pre-eminent scientists. Pagel asked if we were to construct a convincing AI would it be a reincarnate being? The Dalai Lama laughed at the trick and said “when I come back, put it in that seat so that I can talk with it.”

Chapter 11. The Body never lies.

“I think that describing the conduct of scientific research as a "method," a recipe that prescribes a set of rules, is wrong. A formal "scientific method" simply does not exist because scientific discovery is too complex, a complexity that mirrors the complexity of the material world itself. Because of that complexity, non rational and intuitive elements are necessarily part of the discovery process.

Scientists are not educated or trained to follow any scientific method, nor do they, in fact, follow explicit rules. ...... Textbook scientific method (such as there is) teaches one as much about how to do science as a book on bike riding teaches you how to actually ride a bike. Nonetheless it is possible in rough outline to describe what scientists do; I think the "hypothetico-deductive system" comes close enough. Basically the "hypothetico-deductive system" consists of making an educated guess, a scientific hypothesis, followed by rigorous tests and criticisms of that hypothesis. This is not the only method scientists employ, but it gets the main idea across-scientific method is an appropriate mixture of inspiration and rigour. Finding that "appropriate mixture" is the mark of a great scientist.

It is one thing to *describe* scientific inquiry, but it is another thing to say *why* it works. The reason science works is because it studies an ordered world that can be known by an ordered mind. - Why the world is ordered is unknown. ......

Atoms, galaxies, bacteria, cells, and viruses all were once unknown but have now become part of the repertoire of reality. Science explores reality and does so effectively. Why? I think that science is effective because it is a "selective system," like the process of evolution or the competitive business economy. What a selective system does is to discriminate and select specific members from a set-a repertoire of objects or well-defined concepts-on the basis of some feature or property. In the case of scientific research, what is being selected for are definite hypotheses, informed guesses that are the basis of a theory. The competitive pressure, the selection mechanism, are provided by an environment of strong critical feedback, review, and experimentation, and this selects a small number, usually one, of the hypotheses out of a repertoire.

But scientific theories that incorporate such hypotheses are not true simply because they survive the competition any more than a species is "true" because it survives. A scientific theory cannot be absolutely true the way a mathematical theorem is true. A theory could be false and still have true consequences. But the fact that there is no absolute certainty for a scientific theory also implies that unlike a mathematical theorem, it is open and vulnerable to change. And because of that capacity for change, theories can evolve. Sometimes a scientific discovery endures a long time in an environment of testing and criticism. Then, like the cockroaches, which have also endured a long time, it acquires the sense of "permanent" existence. To be certain, sometime in the future cockroaches may get edged out by another species. Likewise scientific ideas can become extinct. Yet if they endure, like the cock-roaches, them, like atoms, DNA, even quarks, they become part of our repertoire of reality simply because they exist and have done so successfully for so very long. Empirical science is a selective system for finding the building code of the Demiurge. “ pg 244

Chapter 12. Warriors of the Infinite.

An easy to read survey of mathematics and mathematicians including Plato, Aristotle, Euclid, Copernicus, Kepler, Galileo, Newton, Leibnitz, Descartes, Vieta, Cauchy, Dirichlet, Fourier, Gauss, Bolzano, Hamilton, Laplace, Galios, Dedekind, Kronecker, Frege, Russell, Cantor, Hilbert Godel, Bourbaki

Frege “My initial step was to attempt to reduce the concept of ordering in a sequence to that of logical consequence., so as to proceed from there to the concept of number.” pg280

Frege expressed misgivings about Axiom V and it turned out to imply an inconsistency by Bertrand Russell in 1901. This initiated the creation of set theory. Russell thought that the paradoxes arise by neglecting the distinction between different “types” of concepts. Russell's thesis is that mathematics is part of logic – specifically that mathematics is identical to set theory, and set theory is part of logic. However the theory of types turned out to be unbelievably cumbersome.

Hilbert did not reveal his great gifts until his twenties, yet when they were revealed they were overwhelming.

In 1900 Hilbert set forth 23 major unsolved problems in mathematics – By 1950, 12 were solved. However, Godel's proof dismantled Hilbert's aim to prove the consistency of mathematical deductive systems and transformed mathematics.

Recursion theory owes its origin to Godel, Turing and Church.

Turing distinguished between computable (i.e. π) and uncomputable numbers which is almost identical to the distinction between simulatable and unsimulatable systems from complexity theory.

In this century it is not so much the objects of mathematics that are of central interest, it is their morphisms. The powerful concepts of morphism and mapping have been powerfully exploited.

Nicholas Bourbaki was the name of a group of leading French Mathematicians. “Bourbaki was devoted to the study of mathematical “structures” in their most abstract generality – set theory (taken as a foundation for all mathematics), algebra, general topology, functions of a real variable, topological vector spaces, and integration are the subjects of the first 6 volumes. “ pg 300

“In a sense, the whole concern with logic, axioms, and the foundations of mathematics initiated by Frege, Russell and Godel can now be seen as an immense detour – perhaps a necessary one – around the actual conduct of mathematics.” pg 300

“The logicians approach to the philosophy of mathematics only covers a small fraction of the territory of modern mathematics – and a rather sterile one at that.” pg 301

“Mathematics itself seems to be an example of complexity-logical complexity. From a few elementary logical propositions-the axioms-that one takes as given flows a rich implicative structure. I believe that it is because of the possible complexity arising out of a simple logical system that mathematics acquires its quality of independence and autonomy from the mind. Although its starting point is simple enough-a set of axioms that can be easily grasped by the mind-the inquiry opens into a rich, complex realm of propositions that seem to take on a life of their own, a vast logical landscape over which the human imagination can wander but which cannot be grasped as a whole by the mind. The realm of mathematics is like an unsimulatable automata functioning on the basis of a few simple rules. “ pg 302

Pagel designed a quantum computer but could not think of a problem for it to solve – because he was thinking only of classical problems not quantum problems.

“The difficulty is that a Turing machine defines what we mean 'computable', what we mean by 'decidable.' Standard mathematical problems are set up to be computable” pg 307

“Can the human brain be simulated by a Turing machine? If quantum correlations play a fundamental role in the neuronal network (and there is no evidence that they do), then the brain cannot be simulated by an ordinary Turing machine. Suppose however, the brain's essential operation is correctly described in terms of classical physics. It is possible that deterministic chaos may play a role in brain function. “ pg 307

“Part of the answer, I believe, will turn out that we are asking the wrong questions, making a false distinction between the transcendent and the natural world.”

Chapter 13. The Instruments of Creation.

“There are no substitutes to a 'bottom-up' understanding in any field of human enterprise.” pg 311

“It is our instruments, the artificial extensions of our several senses and our mind, that move us into a new world. The theoretical ideas follow after the instruments and experiments” pg 313

The instrument makers should get more credit.

There are cognitive instruments as in addition to physical instruments like mathematics and computers.

Chapter 14. The Dreams of Reason

“Science provides a vision of reality seen from the perspective of reason, a perspective that sees the vast order of the universe, living and non-living matter, as a material system governed by rules that can be known by the human mind. It is a powerful vision, formal and austere but strangely silent about many of the questions that deeply concern us. Science shows us what exists but not what to do about it.
Other visions of a different reality are provided by politics, law, art, and religion. These visions of reality are informed by the first-person perspective and the principles of practical or aesthetic reason that orders the immediacy of our lived experience and our values reflected in our ethical and aesthetic judgements *As* Vico pointed out centuries ago, it is this reality-the world of civil society and culture-that we can truly grasp because it was made by us and not by God.” pg 326

Further Reading

Traub, J. F. Information based complexity and the sciences

Traub, J. F. The influence of algorithms and complexity

Traub, J. F. and Packel, E. W. Information based complexity

Hogg and Huberman – heirachical based definition of complexity

Bennett, C. H. and Landauer, R. The fundamental physical limitations on computation. (on logical depth based complexity.)

Diaconis on lower limits on cyclical randomness.

Zabusky, N. and Kruskal, M. on solitons

Hofstadter, D. Godel, Escher, Bach and Metamagical Themas (1983)

Gardner, H “The Mind's New Science” for an excellent and accessible review of Chomsky's impact on linguistics. Pg 184

Kant's emperical dualism Causal Decoupling