Your Digital Afterlives

Computational Theories of Life after Death

Eric Charles Steinhart

Your Digital Afterlives

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Your Digital Afterlives

Computational Theories of Life after Death

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Series Editors' Preface

The philosophy of religion has experienced a welcome revitalization over the last 50 years or so and is now thriving. Our hope with the *Palgrave Frontiers in Philosophy of Religion* series is to contribute to the continued vitality of the philosophy of religion by producing works that truly break new ground in the field.

Accordingly, each book in this series advances some debate in the philosophy of religion by offering a novel argument to establish a strikingly original thesis or approaching an ongoing dispute from a radically new point of view. Each book accomplishes this by utilizing recent developments in empirical sciences or cutting-edge research in foundational areas of philosophy, or by adopting historically neglected approaches.

We expect the series to enrich debates within the philosophy of religion both by expanding the range of positions and arguments on offer and by establishing important links between the philosophy of religion and other fields, including not only other areas of philosophy but the empirical sciences as well.

Our ultimate aim, then, is to produce a series of exciting books that explore and expand the frontiers of the philosophy of religion and connect it with other areas of inquiry. We are grateful to Palgrave Macmillan for taking on this project as well as to the authors of the books in the series.

Yujin Nagasawa
Erik J. Wielenberg

Preface and Acknowledgments

All will agree that computers have radically changed our ways of living – but they have also changed our ways of thinking. One of the more surprising consequences of the computer revolution is that our digital technologies have provided us with new and more naturalistic ways of thinking about old religious topics. *Digitalism* is a philosophical strategy that uses these new computational ways of thinking to develop naturalistic but meaningful approaches to religious problems involving minds, souls, life after death, and the divine. *Your Digital Afterlives* develops digitalism.

My greatest source of encouragement for the development of digitalism has been Jim Moor, in the Philosophy Department at Dartmouth College. He encouraged me to develop many articles dealing with digitalist ideas. John Leslie deserves a great deal of credit for keeping me going through this project. He is the source of many conceptual breakthroughs that made my own thought possible. Jack Copeland merits many thanks for helping me with my work on infinite minds and for sharpening my thinking about digital gods. Nick Bostrom provided encouragement for my research on the theological implications of his simulation argument. I would also like to thank Graham Priest for his support.

I gave a paper at the Pacific APA in San Francisco in April 2007 linking John Hick's resurrection theory to temporal counterpart theory. David Vander Laan gave me very helpful feedback. Peter Byrne helped me with my earlier work on the revision theory of resurrection, which inspired much of my later work on life after death. John Hick himself encouraged earlier versions of *Your Digital Afterlives* and I especially thank him.

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I doubt that I'd be able to do any philosophical work at all without the constant support of my wife, Kathleen Wallace. I also thank Jed Williamson and Perry Forbes Williamson for the many summers we spent at Camp Everhappy. I greatly appreciate the support of Dartmouth College and William Paterson University.

I
Ghosts

1. Digital ghosts

After you die, you can *remain* in something else. You can and do remain in any thing that carries information about your life. Remaining is a matter of degree: you remain more in things that carry more information about your life. You can remain in other living things. If you have any offspring, then some of your genes remain in their genes. And aspects of your life can remain in the memories of others. Your ideas and values can remain in the lives of other people. But you can also remain in things that do not live. You can remain in your skeleton, in your mummy, in your preserved DNA (deoxyribonucleic acid).[1]

You can remain in artifacts. You can remain, like Samuel Pepys, in a diary written in ink on paper. Pepys compiled a detailed diary entry for every day of his life from January 1660 to May 1669. Almost 400 years later, those days of his life remain, at least partly and approximately, in those diaries. You can remain in photographs or videos or recordings of your voice. Obviously enough, these are becoming more and more common, and they can be looked at or listened to by others after you die. Sadly, those artifacts record only your superficial features – and they are not interactive. Fortunately, digital technologies are enabling us to produce interactive digital diaries (Blascovitch & Bailenson, 2011: ch. 9). You can remain in (or *as*) an interactive digital diary.

An interactive digital diary is a *digital ghost*.[2] As digital technology makes progress, our digital ghosts are becoming more and more accurate descriptions of our lives. They are recording more aspects of our lives at ever greater levels of detail. And our digital ghosts are slowly becoming more interactive – they are slowly becoming intelligent. Any possible future digital ghost carries information about your life. Since

it carries that information, you remain, after death, in your ghost. Of course, digital ghosts are not like the ghosts described by spiritualists or occultists. Digital ghosts are entirely physical patterns of energy in material computing machines. They are not supernatural.

A good way to illustrate the concept of your digital ghost is to present several generations of technically possible ghosts (Steinhart, 2007a). The first generation includes the ghosts that exist in the early twenty-first century. These ghosts are primitive – really, they are merely proto-ghosts. The next generations include various improved types of digital ghosts. At least in some possible human futures, as technology makes progress, *perfect* digital ghosts will eventually become available. However, bear in mind that the series of generations of ghosts is not intended to serve any prophetic purposes. It merely describes various stages in the *conceptual* evolution of digital ghosts.

2. Your Facebook timeline

Many people in the early twenty-first century are building digital ghosts.[3] For the sake of clarity, it will be helpful to focus on one type of first-generation ghost. Your first-generation ghost is your *Facebook timeline* (Abram, 2012: ch. 4; Harvell, 2012: ch. 7). Your Facebook timeline is a temporally ordered sequence of posts. Each post describes some aspect of your life at some time – it describes some *stage* of your life. Your posts might be detailed descriptions of your entire day (like the entries in the diary of Pepys). Or they might be descriptions of shorter events. More technically, your Facebook timeline is a temporal database, and your posts are records entered into that database.

Many different kinds of digital records can be posted to Facebook timelines. These records include written statements, photographs, and video and audio files. They also include lists of your friends (your social network). Data that can be recorded on a Facebook timeline also includes various personal facts (such as your relationship status, places of education and employment, and so on). Facebook timelines also include records of various activities performed on Facebook, such as acts indicating that you *like* an item on Facebook, as well as comments you post on the timelines of your friends.

After you die, Facebook currently creates a memorialized version of your timeline.[4] Your memorial timeline preserves most of the content of your original timeline. Currently, after you die, it can only be accessed by your Facebook friends. If one of your friends reads your memorial timeline, then they are *visiting* your digital ghost. Your visitors can scroll

through your timeline to find records of earlier parts of your life. Obviously, your first-generation ghost isn't very interactive. Programs exist that can infer many personal attributes from your Facebook activity (Kosinski et al., 2013). For example, they can infer your political and sexual preferences from your patterns of liking. If someone could run those programs on your memorial timeline, then they might learn many new things about you. However, those programs are not presently available to the general public.

3. Your totally quantified self

Your second-generation digital ghost is initialized at birth.[5] The first record entered into your new ghost contains your basic biological data (for instance, your genetic code, blood type, fingerprints, an image of your iris, and so on). When you are young, your parents manage your ghost. They fill it with data. As you grow older, you take more responsibility for entering your data into your ghost yourself. This second-generation data includes all the data that can be entered into your first-generation ghost. But most of your second-generation data is entered into your ghost automatically.

Your second generation data includes many of your perceptual inputs. Your visual and auditory inputs are constantly recorded by tiny cameras and microphones (such as those in Google Glass). Your second-generation data includes many physiological descriptors (such as your heart rate, blood pressure, skin conductance, body temperature, blood glucose levels, breath chemistry, and so on). It includes the electrical activities of your heart and brain – your electrocardiogram and electroencephalogram are constantly recorded. All your medical records are posted to your ghost (including the results of physical and psychological exams).[6] Your second-generation data includes many of your behavioral outputs (the motions of your limbs are recorded). Anything you say or type is recorded.

As data enters your digital ghost, it serves as the raw material for the synthesis of a daily model of your stimulus–response patterns. Your second-generation ghost consists of a series of these daily ghost patterns, each of which approximates your psychology on some given day. Each daily ghost pattern is an artificially intelligent program. From your biographical data, it endeavors to reconstruct what you experienced, how you felt, and what you did. From the records of your perceptual inputs and behavioral outputs, it strives to infer what you thought and what you desired. It tries to figure out your preferences, habits, values, virtues,

and vices. On the basis of careful study of your biographical data, each daily ghost is an expert on your life up to that day. And, through that expertise, its artificial personality imitates your organic personality. It is your digital surrogate.

After you die, your ghost remains – it is an enormous system of files stored on some digital media. Of course, your ghost is entirely physical. Every part of your ghost is some pattern of electromagnetic energy, stored on some physical substrate. From time to time, your ghost may receive visitors. When a visitor wants to interact with your ghost, they select a specific day of your life. Your ghost mind for that day is loaded onto a computer, which animates it. The computer that runs your second-generation ghost is a very powerful version of the computers we currently have on our desks. More technically, it is a *von Neumann machine*. This computer produces visible outputs on some screen. When your visitor looks at this screen, they see your ghost face. Your ghost face looks like your face on that day, and it moves like your face on that day.

Your ghost can hear through microphones attached to its computer, and it can talk through loudspeakers. Your ghost can carry out a conversation just as well as you could carry out a conversation on the selected day. Your ghost is an *embodied conversational agent*, also known as a *chat bot* (Cassell et al., 2000). So, if your ghost is old enough to talk, the easiest way to interact with it is verbally. Your visitor asks questions, and your ghost answers pretty much like you would have answered. When your ghost talks, its voice sounds like your voice sounded on that day. Your ghost can answer factual questions about your life up to the selected day; it can explain your behaviors; it can express your views and opinions. Your ghost can produce many other forms of output besides speech: it can produce text, photos, videos, and audio. Still, your ghost is far from having anything like full personal intelligence. Its conversations are factual and dull.

4. Your ghost brains day by day

As before, your third-generation ghost is initialized at your birth. It includes all the data that gets entered into your second-generation ghost. But your third-generation ghost gets data from several new sources. Specifically, it gets data from embedded sensors and from detailed movies of your brain at work. These brain movies are produced by very high definition versions of functional magnetic resonance imaging or related scanning technologies.

As data enters your third-generation ghost, it serves as the raw material for the synthesis of a daily model of your brain. Your digital ghost now consists of a sequence of these daily ghost brains, each of which approximates your brain on some given day. Your ghost brains structurally and functionally resemble your brain. Each ghost brain is an artificial neural network – it is a big connect-the-dots structure in which the dots are software neurons and the connections are software synapses. Still, your ghost brains are not fully accurate models of your brain. They are functionally simplified versions of organic brains. And your ghostly neural networks are simplified versions of organic neural nets. Your ghost brains do not replicate your brain at the levels of synaptic or molecular detail.

After you die, your ghost brains are just files stored in some big database. As before, when a visitor wants to interact with your ghost, they select a specific day of your life. Your ghost brain for that day is loaded onto some computer. Perhaps this computer is a vast network of von Neumann machines (with more power than the entire Internet, but in a box on your desk). Perhaps this computer is a network of neuromorphic chips, specially designed to simulate neural circuitry. This computer animates your ghost brains. As it animates those brains, it uses their memories to reconstruct the environment in which you found yourself on that selected day. The memories in your ghost brain are used to build a virtual reality model of the world as you experienced it on that day. This virtual reality model of your experienced environment is your *ghost world*. It includes many *ghostly objects* – digital reconstructions of things you experienced. And since you always experienced your body, your ghost world contains a *ghost body*.

Of course, your ghost brain, your ghost body, and all the objects in your ghost world are realized by patterns of energy in some physical computer. If the computer that realizes your ghost and its world is an electronic machine, then your ghost world is an electronic world and the objects in it are electronic objects. As such, they are physical. More precisely, since electrons are material things, your ghost body and all the objects in your ghost world are material things. Nevertheless, they are not *ultimately real things* – they are realized by the deeper physics of the computer which brings them into existence. Since they are not ultimately real, we will say that they are *virtual*. But virtual things are not fake. And they are certainly not abstract objects like numbers. Virtual things are physical things which continuously depend on other physical things. Virtual things are software things while ultimately real things are hardware things. Your ghost world, including

your ghost body, is a software process running on some hardware substratum.

When a visitor summons your ghost on a specified day, your ghost replays its record of that day. Your visitor can watch, passively, as your ghost goes about its business. This is like watching a movie. The script for the movie is the biographical record compiled during your life on that day. And this script is pretty accurate. Your visitor can watch this movie from a variety of points of view, but they all have to be pretty close to your original point of view – your visitor sees your original world through your ghostly eyes. If your daily routine seems boring, your visitor can hit fast-forward. Your ghost then replays your biography at a higher speed. Your visitor can jump forwards or backwards, skipping over parts of your life. Your visitor can search for specific activities, people, places, or other things, and can tell your ghost to play the relevant scenes.

But your visitor can do far more than just watch your ghost. Since your ghost now replicates your intelligence at a very high level of accuracy, it can also hold conversations. Your visitor can converse *intelligently* with your ghost. Your visitor can ask your ghost what it's doing, why it's doing it, and so on. Your visitor can ask your ghost about people or places or things in your ghostly environment. It can ask any question at all. Your ghost always gives an answer that is based as closely as possible on its memories and on any other biographical data collected for that day. If your ghost can answer quickly, it keeps going about its business. Otherwise, it pauses to figure out its answer or to give a longer speech. During that pause, its ghost world pauses too. Once it's done, it starts going about its business again. A visitor can keep your ghost paused for as long as they like, asking it all sorts of questions, and getting its answers.

But how does your visitor appear to your ghost? Your visitor appears as a disembodied voice, like the voice of an invisible spirit sitting on its shoulder. For your ghost, of course, talking with an imaginary friend is normal and natural. It doesn't upset your ghost or make it feel ill. Your ghost brain has been programmed to politely accept such interactions. And perhaps an advanced third-generation visitor might control their own ghostly hand, so that they can point to something and ask your ghost about it. Still, your visitor does not have much of a presence in your ghost world – they don't have their own virtual body. They don't have an avatar which your ghost can see and touch (and vice versa). And your visitor has very little control over your ghost, since there isn't much that can be controlled. All your ghost can do is to replay your life and answer questions about it.

Visitors are not really needed for the reanimation of your ghost brains. Somebody can select some period of your life (such as your first ten years) and instruct the computer to reactivate your ghost brains for that period. For any series of days, the computer starts with the ghost brain on the first day, and plays brain after brain, day after day. It uses the series of daily ghost brains as landmarks for the synthesis of a psychologically continuous brain-process that runs across many days. The life of your brain can be replayed in the computer whether or not any visitor is watching. If this is done, then a replica of your brain-process will exist in a computer after your death. Of course, the computer that replays your brain-process might be much faster than your organic brain. It might be able to reproduce the brain-process of your entire organic life in a matter of minutes or seconds. And this would be a very thin kind of life after death – it would be your digital afterlife.

5. Replaying your mental life

Your fourth-generation ghost is an enhanced version of your third-generation ghost. It consists of a series of ghost brains. But now these ghost brains are recorded at much higher levels of biological fidelity. They are connect-the-dots networks in which each dot accurately imitates one of your neurons and each connection accurately imitates one of your synapses. Your ghost brains now replicate the functionality of your brain at the molecular level. And your ghost brains are recorded very frequently. Perhaps your fourth-generation ghost contains a ghost brain for every millisecond of your life.

After your death, your ghost brains are stored in digital files. When a visitor wants to interact with your ghost, they select a specific period of your life. Your ghost brains for that period are loaded into a computer. When your visitor launches your ghost, the computer begins to simulate your brain-processes for that period. By replaying your brain-processes, the computer constructs your ghost world from your memories. As before, your visitor can appear to your ghost as a disembodied voice and hand. But the fourth generation of ghosts adds something new. At least the perceptual inputs to your ghost brain can be transmitted directly to the relevant circuits in the brain of your visitor. For example, the signals in your ghostly optic nerves can be transmitted directly to the optic nerves of your visitor. Thus your visitor can visually experience your world from your first-person perspective. Your visitor can see exactly what you saw exactly as you saw it.

Of course, many philosophers argue that any simulation of your brain is also a simulation of your mind. They say that mental processes

are identical with brain-processes. And, since brain-processes are computable, mental processes are computable too. The *classical digitalists* include writers like Edward Fredkin, Hans Moravec, and Ray Kurzweil. They all argue that mentality is entirely computable.[7] Following the classical digitalists, *all* digitalists agree that mentality is entirely computable. Minds are software processes running on hardware substrates – minds are computations. Therefore any mind, including yours, can be exactly replicated in a computer. Digitalists are not *mysterians* – they resolutely refuse to mystify mentality. Digitalists hate mysteries. Why? Because digitalists love beauty: where there is clarity, there is structure; where there is structure, there is beauty. But mystification blurs all structure into a dark indefiniteness.

For digitalists, all minds are entirely natural things that are completely open to scientific study. All minds are computations. Of course, digitalists can appeal to an enormous amount of philosophical and scientific work, across many fields, to justify the thesis that minds are computations. Unfortunately, it sometimes seems that no amount of evidence or argument for the computability of the mind will ever convince the mysterians. But there shouldn't be any need for digitalists to defend the computability of the mind right here: digitalism, like any philosophy, or like mathematics, has every right to start with its own axioms. Obviously, there are alternatives to digitalism. But those alternatives are not under discussion here – here we are studying digitalism. And you don't have to agree with the axioms of digitalism in order to study their consequences.

As your ghost replicates your brain-process, it replicates your mental life. It exactly reproduces your perceptions, your thoughts, your feelings, and your behaviors. It replicates your awareness and your self-awareness. It experiences its own self exactly as you experienced your self. It duplicates what it was like to be you.[8] For example, since your ghost brain models your body in a high level of detail, it knows what your flesh felt like when you went out running. When it replicates your run, it feels its muscles painfully contracting; it experiences the thrilling rush of endorphins. It has the same subjective awareness of running that you had when you ran. It knows what it is like to perform its actions and it can report on its inner states as you would have reported on yours.

As long as it replays your life, your fourth-generation ghost perfectly duplicates your first-person perspective. Its mental life is indistinguishable from yours. If you have a fourth-generation ghost, then somebody can set up that ghost to replay your entire life from birth to death. Your ghostly life, replayed in some computer, is mentally indistinguishable

from your organic life. For all you know, your present experience is merely ghostly. Reading these very words, you might be replaying events which happened to some organic body long ago. You might *be* a digital ghost, and no amount of empirical evidence you can offer can possibly demonstrate otherwise. Anything you do to try to prove that you are not a digital ghost was something you once did before to try to make the same point. But from inside your own first-person perspective, the point is irrelevant.

6. The eternal return of the same

Fourth-generation digital ghosts are technologically possible. There are some possible future human civilizations in which any human brain-process can be perfectly recorded from birth to death, millisecond by millisecond, at the biomolecular level of detail. For the sake of argument, suppose you are living in one of those possible future civilizations. Your entire brain-process from birth to death is perfectly recorded. After you die, you remain, you persist, in your perfect neurological ghost. Since your ghost is a program, it can run after your death. It can replay your entire mental life. It can even be embedded in a loop that repeats your entire mental life over and over again for as long as possible. If your digital ghost were to be repeated, from birth to death, over and over again, then your life would be caught up in something like the *eternal return of the same*.

The ancient Greek philosopher Eudemus told his students about the eternal return like this: "If one were to believe the Pythagoreans, with the result that the same individual things will recur, then I shall be talking to you again sitting as you are now, with this pointer in my hand, and everything else will be just as it is now" (Kirk & Raven, 1957: frag. 272). The eternal return is more recently associated with Nietzsche. He uses his character Zarathustra to talk about it. Zarathustra has two animals, an eagle and a snake. They tell him that they understand his theory of eternal recurrence:

> we know what you teach: that all things recur eternally and we ourselves with them, and that we have already existed an infinite number of times before and all things with us. You teach that there is a great year of becoming . . . this year must, like an hour-glass, turn itself over again and again, so that it may run down and run out anew. So that all these years resemble one another, in the greatest things and in the smallest, so that we ourselves resemble ourselves in

> each great year, in the greatest things and in the smallest. And if you should die now, O Zarathustra: behold, we know too what you would then say to yourself . . . "Now I die and decay" you would say, "and in an instant I shall be nothingness. Souls are as mortal as bodies. But the complex of causes in which I am entangled will recur – it will create me again! I myself am part of these causes of the eternal recurrence. I shall return, with this sun, with this earth, with this eagle, with this serpent – not to a new life or a better life or a similar life: I shall return eternally to this identical and self-same life, in the greatest things and in the smallest, to teach once more the eternal recurrence of all things."
>
> (Nietzsche, 1885: III 13/2)

If the eternal return is true, then Zarathustra will live again after he dies. He will have a kind of life after death. His next life will physically and therefore mentally replicate his previous life. The repetition of his mental life is analogous to the repetition of your mental life by your perfect neurological ghost. When that ghost is replayed, it experiences your whole life over again. It reproduces your awareness and self-awareness. If your ghost life is replayed after your death, then that repetition reanimates your entire mental life. This at least *looks like* a kind of life after death. But if your entire ghost life were replayed, would that *really* give you life after death? To answer this question, it is necessary to answer four other questions. And all these questions will be answered.

7. Beyond digital ghosts

The first question concerns identity. Obviously, your digital ghost is *not* identical with you. Your digital ghost (when it is replayed) is merely a perfect copy of your mental life, and a copy is never identical with its original. Your present self is not identical with its corresponding momentary ghost self, and your organic life is not identical with your future ghost life. Hence the first question asks: does life after death require identity through time? Or is identity through time an illusion? Look at how Eudemus and Zarathustra phrase their statements involving identity. Rather than using the present tense, they use the future tense. Zarathustra says that the eternal cycle of causes "*will* create me again" (Nietzsche, 1885: III 13/2). He says: "I *shall* return . . . I *shall* return eternally to this identical and self-same life". He asserts that he *will be* identical with some future thing – not that he *is* identical with it. You cannot truly say that you *are* identical with your digital ghost. But

can you truly say that you *will be* identical with it? To answer these questions, Chapter II discusses structures whose parts exist in different times – it tackles the logic of persistence.

The second question concerns the body. Your fourth-generation ghost does not have its own body. While it is a perfect *neurological* ghost, it is not a perfect *physiological* ghost. Your ghost organs are based only on your memories. Your experiences of those organs are replicated in your ghost, but the organs themselves are not. Your subjective experience of getting sick is replicated, but the activity of your immune system is not – your ghost doesn't have an immune system. Since your ghost does not really have a body, it might be argued that your ghost does not really live. It might be argued that merely mental life, the life of the brain, is not *human* life. Here is the second question: are you identical with your brain? Or are you identical with your body? To answer these questions, Chapter III carefully studies the computational anatomy of the body, the digital mechanics of the flesh.

The third question concerns autonomy. Your digital ghost is really only a *memorial*. It does not have an autonomous life of its own. Existing in a fixed historical simulation, it is trapped in your old life – it cannot actualize any new potentials. On the contrary, its very purpose is to preserve your life in a perpetually frozen form. Your digital ghost inhabits your digital grave. The third question is this: can the exact replication of your life provide you with life after death? Or does life after death require autonomy? The fourth question, which follows directly from the third, concerns solipsism. Your ghost lives in a world built only from its own memories and recorded data. Your ghost inhabits a hallucination – it lives in its own solipsistic dreamworld. Since your biography recorded the things in your external world from and only from your perspective, none of those things have their own perspectives. They do not have their own natures. Here is the fourth question: is solipsism sufficient for life after death? Or does life after death require that your self spreads out into a world filled with otherness? These questions are answered in Chapter IV. But the very process of answering them will raise disturbing questions about *our* world.

II
Persistence

8. Pipelines

You start with an empty universe, with the simplest and therefore the most boring of all possible universes. Fortunately, the next possibility is more exciting. You make a copy of your first universe, but now you add a single space-time point. Still boring, but keep going. For your next universe, you add a single feature to the point: the point can store *one bit* of information, either zero or one, off or on. Set the value of the point to zero – zero comes first. Are we having fun yet? No. Nothing is happening in these dead universes. To make something happen, you'll need to introduce some *time*.

Time starts with a point with the value zero. It changes into a second point with the value one. But why stop there? The second point changes into a third point with the value zero again. And so it goes, endlessly, with each previous point turning into some next point with the opposite value. All these points, arranged in linear order from past to future, form a *timeline*. Along this timeline, from each previous point to its next, the value gets *inverted*. Hence each previous point is linked by an *inverter* to its next point. This universe of alternating points is shown in Figure II.1. Points with value zero are white while those with value one are black. The inverters are the arrows running from point to point.

Each inverter is a trivial computer that runs a simple program: its output is the opposite of its input. This program consists of two *if-then rules:* if the previous point is off, then the next point is on; if the previous point is on, then the next point is off. Each inverter gets one bit of information from its previous point, flips it, and sends it on. Each inverter is a *pipe* through which some information flows. Specifically, it is a pipe composed of its two if-then rules. All these points, linked by pipes, form

Figure II.1 Some points in the alternating universe.

a *pipeline*. It's a channel through which data flows from the past into the future, according to a program. Of course, none of the points on this pipeline are identical – they are all distinct objects. For if they were identical, then they would have the same features – but they do not.

Figure II.1 shows a universe with one temporal dimension. As Figure II.1 shows, each pipe from one point to another is a causal connection – it is a causal arrow.[1] The input to any pipe is the cause; its output is the effect; and the if-then rules that compose the pipe are the laws that transform causes into effects. Hence the value of each previous point causes the value of the next point. Any pipeline is *causally continuous*. But the universe defined by the pipeline in Figure II.1 remains dull. If we want to make it more exciting, we need to make it more complex. One way to increase the complexity of this alternating universe is to add some *space*. So your next universe will include some space.

You can add space by replicating the pipelines in the alternating universe, like making lots of copies of a length of string in order to make a rope. But that's silly. It's far more interesting to let the spatially distinct points interact. At any moment of time, the points are lined up spatially. Each point has exactly one present neighbor above and one below. Each point and its two present neighbors pipe their values into a computer, which pipes its output to some next point. Figure II.2 shows how information flows from some points in one moment, through some computers, to some points in the next moment. The points are the squares and the computers are the arrows. Figure II.2 is fragmentary – dashed lines indicate links to other parts of the universe. No object in Figure II.2 is identical with any other – they are all distinct objects in distinct moments of time and places in space. The network in Figure II.2 displays both space and time – it is an *eternal* structure.

Any computer in Figure II.2 runs a program composed of many *if-then* rules. All these rules form a pipe, and, if you've got the pipe, then you've got the computer too. The computer *is* the pipe. Figure II.3 shows the rules that make up the program running in Figure II.2. There are eight ways that the three points on the if-side of any rule can be: 111, 110, 101, 100, 011, 010, 001, and 000. Hence any program that changes three previous point values into one next point value contains eight rules. Each rule can be pictured by means of a schematic diagram. Figure II.3 shows eight of these diagrams, which specify a complete program.[2] Each

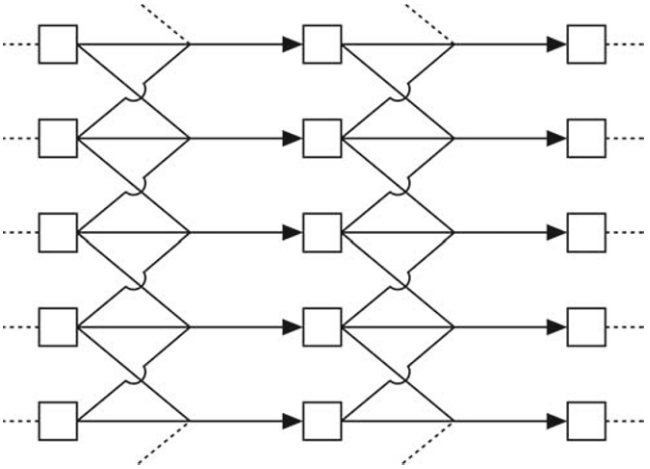

Figure II.2 Information flows through pipes.

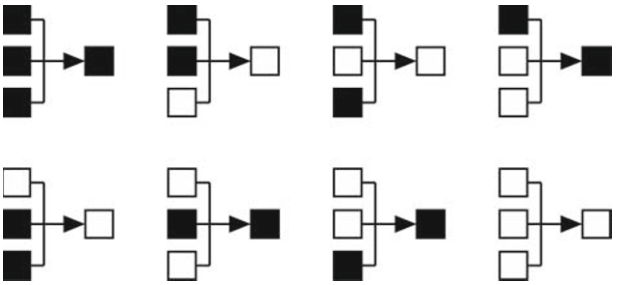

Figure II.3 The eight rules in a program.

diagram consists of the three past points on the left side (the if-side) and the one future point on the right (the then-side). The value one is black while the value zero is white. Each arrow indicates the flow of information. The second diagram on the top row in Figure II.3 shows this rule: if 110, then 0.

It's fun to design and create universes. When you add space to your universe, you specify a spatial dimension that contains some fixed number of points. You specify a temporal dimension that also contains some fixed number of moments of time. For each moment of time, you make a copy of the spatial dimension. You've now made a two-dimensional (2D) array of space-time points. No point in this array is identical with