



# Three Roads To Quantum Gravity

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**"It would be hard to imagine a better guide to this difficult subject." --*Scientific American***

In *Three Roads to Quantum Gravity*, Lee Smolin provides an accessible overview of the attempts to build a final "theory of everything." He explains in simple terms what scientists are talking about when they say the world is made from exotic entities such as loops, strings, and black holes and tells the fascinating stories behind these discoveries: the rivalries, epiphanies, and intrigues he witnessed firsthand.

"Provocative, original, and unsettling." -*The New York Review of Books*

"An excellent writer, a creative thinker." -*Nature*

## Three Roads To Quantum Gravity Details

Date : Published July 4th 2002 by Basic Books (first published 2000)

ISBN : 9780465078363

Author : Lee Smolin

Format : Paperback 256 pages

Genre : Science, Physics, Nonfiction, Popular Science, Astronomy, Quantum Mechanics

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## From Reader Review Three Roads To Quantum Gravity for online ebook

### Manny says

Lee Smolin is one of the most interesting and controversial figures in modern physics. Establishment physicists often call him a maverick or worse. I am one of many laypeople who think that he's telling it like it is, and the mainstream people are full of s...trings.

When he wrote this book, around 1999, I think he was more part of the mainstream. He presents several different approaches to the very difficult problem of unifying gravity and quantum mechanics. It's clear that his heart belongs to Loop Quantum Gravity, but he tries to be as even-handed as possible. He ends up on an optimistic note, and says that he thinks there will be a real unified theory within the next 10-15 years. Something will work.

Alas, in *The Trouble with Physics*, seven years later, one of the first things he did was to retract his earlier prediction, and in the most categorical way possible. "We have failed." Sobering words.

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### Rob says

this book is so dumbed-down that i seriously considered putting it on the "non-fiction for humans" shelf. the absolute nadir came when he used as his analogy for the superposition principle of quantum mechanics a mouse which, when eaten by a cat, might turn out to be either "tasty" or "yukky". Yukky? Yukky? forget that it's universally spelled "yucky". but he hammers away at his analogy and the reader is subjected to the word "yukky" several times over a few pages.

but thank the lord most of the fingernails-on-the-chalkboard stuff like that is in the first 60 pages, and after that the book is pretty informative, although he does have some rough spots.

also mildly interesting were some of his narrative sections about his own work and the culture of theoretical scientists. sadly, he seems ridiculously optimistic about how soon he and his colleagues will finally work out the correct theory of all fundamental physics.

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### James F says

According to Smolin, there are three "roads" currently leading to a theory of quantum gravity: the first road begins from quantum theory and adds relativity (string theory), the second begins from general relativity and adds quantum theory (loop quantum gravity), and the third rejects both and tries to consider the question from first principles. (This third road is basically not discussed, and later in the book the third road becomes thermodynamics of black holes and the "holographic principle".) There are a few mentions of other approaches such as Alain Connes' non-commutative geometry and Roger Penrose's twistor theory, but none is actually explained. Smolin himself worked for a time on string theory, but today is identified with the loop quantum gravity approach. As of the time this book was written (i.e. about fifteen years ago; I haven't gotten

to anything more recent yet, since I'm reading the library's astronomy and related physics books chronologically) about ninety percent of those working on quantum gravity were committed more or less strongly to string theory as the sole viable approach, so Smolin's views are in a minority, and much of his book is arguing that minority approaches should be encouraged (and funded). Looking on Amazon at his later books and the reviews of them, I get the impression that he has continued to move further from the mainstream.

Late last year, I read Smolin's *Life of the Cosmos*, and was very impressed by his approach and his use of philosophy, and the clearness of his explanations of the basic theories such as general relativity and quantum theory, the Anthropic Principle, and the questions which they raise, and though I was not convinced by his speculative theory of cosmological natural selection, I was intrigued by the idea. Of course, I'm very much a layman when it comes to physics and astronomy, so my opinions don't count for much except for my own view of the world. Much of my popular science reading in the past few months has favored string theory (e.g. the awful *Hyperspace* by Michio Kaku, and the excellent *The Elegant Universe* by Brian Greene) so I was looking forward to reading this account and learning about the alternative(s).

Unfortunately, this is a much less well-written book than *Life of the Cosmos*. It does cover many aspects of modern physics and cosmogony that I was unfamiliar with, and it begins well. In the first section, called "Points of Departure", Smolin emphasizes the relational aspects of space-time as constituted not by absolute space and time (he argues that many relativists ignore the basic breakthrough of relativity, using it to derive local geometries of space-time which are then treated as absolute backgrounds in a non-relativistic manner) nor even by relations among things (either particles or strings) but by relations among events or processes. (Surprisingly, he mentions Hegel and Heidegger but not Whitehead in this connection, but this is a much less philosophical book than the earlier one, at least in terms of discussing writers who would be called "philosophers".)

The second section, "What We Have Learned", discusses the history of loop quantum gravity theory (partly from a personal perspective) and has chapters on the entropy of black holes and a chapter on string theory as well. The problem is that I got no real understanding of what LQG is actually saying. He does tell us (over and over, the book is very repetitive) that space (and time? he doesn't discuss this) is discrete rather than continuous, and that the loops are also discrete. But he never really explained what they are, except that they are "like" the discrete lines of magnetic field in a superconductor. The "glossary" at the end of the book defines "loop" as "a circle drawn in space"! That's the whole definition of the most important concept in the book! The problem may be that he is so involved in the theory that he doesn't realize the lay reader (for whom the book is supposedly written; this is explicitly a popularization and not a book for physicists) has no idea of what LQG is, and probably doesn't know a lot about superconductors either, so he assumes that the analogy will make everything clear. It doesn't, at least to me. He claims that he has been very evenhanded in discussing the three "roads", and particularly that he is fairer to string theory than string theorists are to other approaches (this at least is true, since I've never read a book on string theory that mentioned any alternative except leaving the standard model of quantum theory as is), but the chapter on string theory basically is just about what's wrong with it (not background independent, not testable -- though neither is LCG, not unique) and I would not have understood it without having read other books on the subject. The chapters on black holes and their entropy were the most interesting part of the book, and the ones I got the most out of, but here again he alternates between beating the horse with simplistic analogies and just assuming advanced ideas without explanation. There is no math in the book, and this may be part of the problem, since these ideas make little sense in purely descriptive language.

The last part of the book explains the "holographic principle", whines a bit about how non-string-theorists aren't taken seriously enough (or paid well enough) and then gives his conclusions on what the final theory of quantum gravity will look like: LQG (no surprise) will be the basic framework; it will involve discrete space; it will make extensive use of the holographic principle, and generally will be based on what observers in different places can actually observe; it will borrow ideas from other approaches such as non-commutative

geometry and twistors; string theories will turn out to be approximations to the true theory on the assumption of various fixed space-times. This will all be developed (and possibly empirically confirmed) by about 2010, or 2015 at the latest. (While I haven't read the latest developments, I am fairly sure we're not that far along -- which may be why his latest books all have phrases like "the crisis of physics" in the title.)

To sum up: an interesting book about an interesting subject, but not well written and not a good introduction to LQG, which is the main reason for reading it; I hope one of the later books on my list will give me a better idea of alternatives to string theory, as well as where we actually are now. (I know at least Penrose's book on twistor theory will cover that approach, IF I can understand the math -- he claims the book teaches all the math needed, but I'm skeptical, even though I was a math minor in college.)

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### **Carl Stevens says**

Do you know a similar book with a little more technical detail? This was an excellent popular treatment of quantum gravity and related topics but I have read several popular treatments now and find myself wanting to dust off my old math texts and go a little deeper. So if you know something that would challenge someone with a math background comparable to a math major in his junior year, please let me know.

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### **Bob Nichols says**

Smolin describes his thinking about how quantum theory (micro level) might be linked to Einstein's gravitational theory (macro level), to become "a quantum theory of gravity." His argument is by no means easy for the lay reader to follow, so what follows may not be an accurate rendering.

At the minutest level of reality (spacetime on Planck scale) are strings ("a string is actually made of discrete pieces, called string bits, each of which carries a discrete amount of momentum and energy"). Particles come from the different vibrations of strings and particles interact with particles through "splitting and joining." Smolin then argues that strings (actually, "string bits") are more fundamental than particles and that, with such strings, "On the Planck scale, space appears to be composed of fundamental discrete units." From that observation, Smolin goes on to say that at the core of subatomic reality there are no things in space. There are only interactions, relationships in motion, which are constant. Presumably, this means that things continuously come into and go out of being. These processes do not occur on or within a backdrop of spacetime. Rather, these processes create space (distance between interacting particles -- via fields?) and time (the measure of distance between interacting particles). There is, in other words, no static point in spacetime: "Neither space nor time has any existence outside the system of evolving relationships that comprises the universe."

Space is filled with the interactions described above in what Smolin calls the "atomic structure of space" through various forms of radiation (light traveling through space; cosmic rays; cosmic microwaves from the big bang). Although Smolin does not say this explicitly, all of this, collectively, appears to constitute the fabric of spacetime (related to dark matter and energy?) that is at the heart of Einstein's general theory of relativity (larger masses depress spacetime and "attract" smaller bodies), though this gets confusing when Smolin states elsewhere that space is "empty" and, from Newton, that "gravity pulls on mass."

Moving from the micro, atomic level, Smolin believes that all of space and time is a swirl of these relationships, with one thing causing (creating) another, in a perpetual process. There is never a moment in time or point in space; there's only an event of the present that is preceded by events of the past and that

cause (create) events of the future. This is described in Figure 10, P. 58. Each event has its own set of past and future linkages; outside of this “cone” of interaction, other separate events occur, each with its own set of past-future casual linkages. In Smolin’s words, “Time and change are not optional, for the universe is a story and it is composed of processes. In such a world, time and causality are synonymous. There is no meaning to the past of an event except the set of events that caused it. And there is no meaning to the future of an event except the set of events it will influence. When we are dealing with a causal universe, we can therefore shorten ‘causal past’ and ‘causal future’ to simply ‘past’ and ‘future’....There is time, but there is not really any notion of a moment of time.”\*

\*In elaborating, Smolin’s vision stands in stark contrast to Plato’s notion of the Real. “The idea of a state in Newtonian physics shares with classical sculpture and painting the illusion of the frozen moment,” Smolin writes. “This gives rise to the illusion that the world is composed of objects. If this were really the way the world is, then the primary description of something would be how it is, and change in it would be secondary. Change would be nothing but alterations in how something is. But relativity and quantum theory each tell us that this is not how the world is. They tell us – no, better, they scream at us – that our world is a history of processes. Motion and change are primary. Nothing is, except in a very approximate and temporary sense. How something is, or what its state is, is an illusion. It may be a useful illusion for some purposes, but if we want to think fundamentally we must not lose sight of the essential fact that ‘is’ is an illusion. So to speak the language of the new physics we must learn a vocabulary in which process is more important than, and prior to, stasis.”

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## DJ says

Lee Smolin stormed his way onto my fantasy grandfather list the fateful summer of 2008 when I realized physics and I were more than just a fling. His *The Trouble with Physics* was a fatherly introduction to the current state of the edges of theoretical physics and I was hooked. Needless to see, I was ecstatic to find "Three Roads to Quantum Gravity" under my Christmas tree this year and devoured it on plane ride to Thailand soon after.

"Three Roads to Quantum Gravity" is Smolin's briefing to the public on several current approaches to the quest for the unification of quantum theory and gravity. It weaves a tale that passes through quantum information theory, cosmology, and many other delicious details but, importantly, begins by focusing on the fundamental qualities that he believes any current theory should possess. The book is openly biased against the somewhat publicly alluring string theory, and I recommend that any reader complement this dish with a side of Brian Greene's *The Elegant Universe*.

Smolin's criteria run something like this. **The theory must be background-independent.** It must be a physics based on relations, not on absolutes. **Processes, not objects, must be fundamental.** This gels with the idea of a human being as a pattern of information and not a specific set of matter (guess what percentage of your atoms are recycled every two weeks). **The theory must accommodate many different observers.** The finite age of the universe and special relativity's upper bound on speed mean that no one in the universe has access to all information available and each observer indeed has a *different* picture based on their location. Black holes place additional information boundaries throughout the universe. A single observer's "information space" might look somewhat like a sphere of Swiss cheese, the holes representing black holes, the cheese representing areas which the observer may receive information from, and "beyond the cheese" as the space from which information hasn't had time to reach the observer just yet.

This last problem has an interesting parallel in theories of the brain. Sensory information propagates to each

of us at very different rates light faster than sound, sound faster than smells (particle diffusion), etc. Signals in the brain also travel at finite speeds (far slower than the speed of light). These finite speeds apply to both sensory information and "decisional" information other areas in the brain. *This means that different parts of the brain have access to different information at any given time.* Future theories of consciousness may very well have something powerful to say about about observer-dependent physics (and vice versa).

Continuing our discussion of information in the universe, Jakob Bekenstein's studies of black hole entropy have led to the recently popularized holographic principle - a surface bounding a region of space contains all the information contained within. Information is "projected" from the 3D interior onto the 2D boundary. Whether to view the 2D projection as fundamental and the 3D interior as "derived" or vice versa is still (as far as I know) an open question for theory. Bekenstein also placed a boundary of the possible amount of information represented, suggesting a quantization of space. In this picture, geometry can be viewed as defining the information channels of the universe.

One final fascinating theoretical nugget that Smolin presents is that accelerating observers are granted a window into the quantum fluctuations of space in the form of experiencing a hot photon gas whose temperature is proportional to their acceleration. The basic idea is that quantum fluctuations normally go undetected since they have no energy but when you accelerate "fast enough" your relative motion allows you to experience them as having an energy. You experience this random motion as heat.

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### **Dipanshu Gupta says**

My professor asked me to starting reading literature for writing my master thesis, so I perused the library for some interesting reads. And oh boy, did I hit gold. Masterfully written by one of the people deeply invested in solving the problem of Quantum Gravity, Smolin takes a broad view of the possibilities. His writing is awkward when trying to do philosophical science but when he gets to the gritty areas, his analogies are beautiful. He talks about Loop Quantum Gravity, String Theory and other approaches as "the three roads". My biggest lesson was that these roads are not exclusive but complementary. Bridging ideas and successes from wide approaches is the key to understanding quantum gravity. I have learned deep lessons and acquired good writing material from this book. Would recommend to anyone vested in the problem of quantum gravity. While Smolin comes off as a sanguine person (he predicts the final form for QG to be settled by 2010 and at most 2015; the book was written in 2002), his lessons are key to understanding nature.

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### **Austin Barselau says**

Writing about complex topics, not to mention quantum theoretical physics, is tremendously challenging. Distilling dense, abstruse, and highly mathematized information down to the comprehension level of the average reader is a feat in itself. This is why good popular science- writing that can be accessed and enjoyed by that layperson- is scarce. Far too many academics fall prey to the so-called "curse of knowledge," or the inability of the expert to condense and summarize information to novices. Perhaps they fail to understand the material well enough- if they can't explain it simply, can they even explain it at all? As Einstein once stated, "if you can't explain it simply, you don't understand it well enough."

Lee Smolin, a theoretical physicist at the Perimeter Institute, wrote *Three Roads to Quantum Gravity* several years back to bring to the public eye recent developments in theoretical physics. Discovering quantum

gravity has been an especially troubling problem for physicists; reconciling gravity with quantum mechanics is the largest obstacle to completing the Standard Model. Smolin, writing in 2000, argues that there are realizable solutions to this quantum mystery. He finds three “roads” to reconciliation. The intent of this work is to demonstrate them to the average intelligent reader.

The first road is loop quantum gravity (LQG). It conceives of a complex configuration of quantized loops, captured through the mind-numbing formulations of the so-called spin network. A spin network is formed when loops are combined, producing a shape. Smolin played a large role in fleshing out LQG; in fact, several pages recount his formulation of the theory, along with his fellow colleagues.

The second road is the more commonly known string theory. This theory, while sharing some similarities with its LQG counterpart, is premised on a different theoretical structure. In order for this conception to work, space-time must be absolute rather than relative. In other words, it assumes a fixed background for the equations to work. Smolin disagrees with this notion- his first chapters are devoted to undermining this absolutist view of the universe. Smolin argues that the universe is entirely *relational*. This means nothing exists outside of it, no backdrop on which to impose order. Space cannot be defined without considering its contents. He likens the geometry of the universe to that of a sentence, writing that, as “a sentence has no structure and no existence apart from the relationships between the words, space has no existence apart from the relationships that old between the things in the universe.” This is called “background independence.”

The final road Smolin describes, albeit briefly, is the one of the renegade. The followers of this path reject the assumptions of the first two; they find themselves rejecting the entire mathematical edifice, while laboring over the larger philosophical questions of ‘What is time?’ or ‘Why do we exist?.’ Smolin says that few travel this path; it is much easier to work with established theories and models rather than reject them wholesale.

Smolin vigorously treks the first path. At times, he goes out of his way to criticize the members of the string theory field for dwelling on incorrect assumptions. Yet he argues that more collaboration is needed. The way he describes the formative years of each field, from the mid-80s to the mid-90s, suggests an almost tribal mentality among members of each group. “Each group was successful in solving problems it set for itself,” he writes. Each side played lip service to the other. What they were not doing was collaborating. “During this whole period, for example, there was not a single person who worked on both theories. Many seemed to make the understandable mistake of confusing the solution of part of the problem of quantum gravity with the solution of the whole problem.”

Despite his critical remarks about the closed mentalities of both fields, Smolin is by nature an optimist. He believes we are on the cusp of figuring out how to reconcile gravity with quantum reality. By the end of this century, he predicts a unified theory will be a fixture in high school physics classes.

Generally, *Three Roads to Quantum Gravity* straddles the line between polished academic writing and engaging popular science written for the lay individual. In the end, it accomplishes neither. What results is an eclectic assembly of thoughts, theories, and personal history, interlaced with not-so-descriptive models and overly simplified analogies. There is no unified theme in the book: an introduction to the “three roads” is described in the preface, and he only goes on to write about the first two. I had to go back and find where he mentions the third path.

The writing is mostly dry- it is plain boring academic writing severely lacking in humor or vivid imagery. Smolin is no Brian Greene. Greene’s use of elaborate analogies and colorful imagery makes him one of the most respected writers in the field of popular physics. Smolin, on the other hand, struggles to come up with engaging explanations and analogies. For example, he describes quantum superposition with a cat eating either a tasty or a “yukky” - yes he uses that spelling- mouse. In his discussion on the holographic principle, he describes the interaction between a “Thing” and a “Screen.” Judging by these sorry examples, Smolin

could learn a thing or two from Greene's writing style.

This book also reads like an assemblage of notes, packed into three semi-cohesive sections. He lingers on black holes and thermodynamics in a few chapters, skips to quantum field dynamics in another, and then goes off the rails when discussing the holographic principle. He notes that the book was written for "any interested reader," yet takes the liberty to include mathematical equations and excessively complex models in the chapters. In the end, the final product is a hodgepodge of his own personal research, long-winded plugs for his beloved LQG and general but not too immersive discussions of topics on the cutting edge of the theoretical physicist's equation sheet. In the end, where there should have been a meticulously-tied arc of consistency and coherence throughout the book, is instead a poorly knotted bow with several loose ends.

Smolin does an average job of connecting with the reader. His writing is generally insipid, and contains a few too many complicated models and aggressively simplified analogies. At times he tries too hard to engage the reader, and other times his work is lifted off into abstraction and arcane digression. In other words, he falls prey to the curse of knowledge. On the whole, I am glad to say that I can understand some of the more recent developments in the quest to complete the Standard Model. Smolin's optimistic temperament provides some hope that it will be accomplished soon.

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## Huyen says

a nice, easy intro into quantum gravity for the interested: <http://homepages.ecs.vuw.ac.nz/~visse...>

This book isn't too bad but I don't think I retain much. The feline analogy and cosmological evolution are cute ideas, and the black hole stuff is fascinating. But much of it is extremely speculative and cryptic rambling. Or maybe I just get more cynical of theoretical physics day by day. That's fine, and at least Lee Smolin acknowledges that it is speculative, but at least don't be so incredibly optimistic when you don't have a single suggestion for an experiment that can verify or falsify your theory.

Quantum mechanics and general relativity are both excellent theories, but when they combine, the infinities explode in your face. Quantum gravity has got physicists banging their heads into the wall for the last 50 years and his overt optimism slightly bugs me. Quantum physicists (including string theorists) adore their theory so much they're willing to mutilate general relativity one way or another to pursue their cause, general relativists hold GR so sacrosanct that they can curve quantum mechanics to fit their theory (sorry for the pun). Somewhere in the middle is lattice theorists who annoy both camps. So basically, nobody really knows exactly how to solve this conundrum.

I'm not hugely a fan of a theory that can't be tested. Stuff like Hawking radiation or gravitational waves might be extremely hard to detect, but at least physicists have built the acoustic equivalent of Hawking radiation (<http://www.technologyreview.com/blog/...>) and (arguably) figured out how to detect grav. waves. This guy has no similar suggestions of that sort, except for the deviations of photon paths across large distances. Hm...

He seems to have held favorable views of string theory at that time, on which he has changed his mind. Last month was the 25th year anniversary of the resurrection of string theory, and you can notice the lack of celebration in the string community. He does admit in chapter 11 that nobody even knows what string theory really IS or what its basic principles are, there are hundreds of consistent versions of it and "what we have is a long list of examples of solutions to the theory; what we do not yet have is the theory they are solutions of". The major problem with string theory is that it's so loose that whatever experiment data you come out with, some string theorist can claim he predicted it.

But Lee Smolin certainly taught me something very honorable about a theoretical physics career. That when you reach the forefront, you have to accept to take hazy paths that no one's taken and can be deemed ridiculous or obscure and perhaps risk wasting your entire career pursuing something wrong. And you will collaborate, compete, argue, disagree, be proven wrong, admit you're wrong, but that's an unavoidable part of progress, to put down the post "don't go there" on the wrong paths so some giant can find the right way to get there some day.

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### **Evan Macbeth says**

It's a complicated subject, no doubt. And Smolin does his best to make it narratively accessible. That being said, this book is disjointed and a bit impenetrable, not because Smolin doesn't understand the subject matter. He clearly does! But because his explanations of that subject matter don't seem to answer some "why?" and "how?" questions.

But then again, I'm not a physicist so I am probably not the best person to judge.

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### **Jim says**

Either I'm getting progressively dumber, or the books I'm reading are getting progressively harder for me to understand. Hopefully it's the latter of the two. I enjoyed this book in principle, however there was a lot that I had trouble understanding. I think I was able to grasp the basic ideas behind most of the theories mentioned, but some of the finer details may have been lost on me.

Still, Smolin does give very detailed explanations for the different versions of String Theory, Loop Quantum Gravity, M Theory, The Holographic Theory and other ideas such as Spin Networks and Spin Foam.

If you've got a basic understanding of the ideas of quantum physics then I think you'll enjoy this book. If you know nothing about quantum physics, then save this book for a later date.

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### **H. says**

I love Smolin's style of writing. A worthwhile read for those interested in the diversity of the field and the questions being tackled.

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### **BetseaK says**

Since Lee Smolin has been one of the leading figures both in the string theory and in the theory of loop quantum gravity, I hoped this book would clarify some questions I was left with after reading Carlo Rovelli's Reality Is Not What It Seems: The Journey to Quantum Gravity. I think the main reason both the books failed to do the job is the fact that I lack the adequate background to understand what is really meant by "strings" and "loops" in the two main approaches to quantum gravity. I find the concept of the loop quantum

gravity particularly interesting but it still remains unclear to me what is really meant by "quanta of space". As for the third road, I found the chapters on the holographic principle, inspired by the black hole thermodynamics and the Bekenstein bound, highly interesting.

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### **Ami Iida says**

There is some description of the physics mistakes clearly.  
It is a disqualification as a physics manual.

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### **Erickson says**

Excellent book describing how the routes to quantum gravity work in rather precise but laymen terms. The human elements are also very clearly done. However, there is clear "side" taken in making loop quantum gravity sound "better" than string theory, which from what I know on technical level they are both stuck in equally critical stalemate (maybe I am wrong). But otherwise it is a good exposition, especially when Smolin laid clear the "philosophy" behind doing science - what are our biases, etc.

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