

A black and white photograph of Donald E. Knuth, an older man with glasses, wearing a denim jacket over a plaid shirt. He is smiling and looking towards the camera. The background shows an indoor setting with large windows and some foliage. A white rectangular label is in the top left corner. A dark blue rectangular box with white text is centered over the image. A small red flourish is at the bottom of the blue box. A red and white geometric logo is in the bottom left corner.

THINGS A
COMPUTER
SCIENTIST
RARELY
TALKS
ABOUT



Donald E. Knuth

How does a computer scientist understand infinity? What can probability theory teach us about free will? Can mathematical notions be used to enhance one's personal understanding of the Bible?

Perhaps no one is more qualified to address these questions than Donald E. Knuth, whose massive contributions to computing led others to nickname him "The Father of Computer Science"—and whose religious faith led him to undertake a fascinating analysis of the Bible called the 3:16 project. In this series of six spirited, informal lectures, Knuth explores the relationship between his vocation and his faith, revealing the unique perspective that his work with computing has lent to his understanding of God.

His starting point is the 3:16 project, an application of mathematical "random sampling" to the books of the Bible. The first lectures tell the story of the project's conception and execution, exploring the complex dimensions of language translation, aesthetics, and theological history. Along the way, something even more interesting is revealed: the many insights that Knuth gained from such interdisciplinary work. These theological musings culminate in a mindbending final lecture, which tackles infinity, free will, and the other Big Questions that lie at the juncture of theology and computation.

Things a Computer Scientist Rarely Talks About, with its charming and user friendly format—each lecture ends with a question and answer exchange, and the book itself contains more than 100 illustrations—is the most readable, intriguing approach yet to this crucial topic. It is, quite simply, required reading, both for those who are serious—yet curious—about their faiths, and for those who look at the science of computation and wonder what it might teach them about their spiritual world.



Donald E. Knuth, Professor Emeritus of The Art of Computer Programming at Stanford University, is the author of *The Art of Computer Programming*. The lectures were originally presented at the Massachusetts Institute of Technology and broadcast live on the Internet.



KNUTH as a Computer Scientist



AMERICAN MATHEMATICAL SOCIETY

CSLI Lecture Notes Number 136

THINGS A
COMPUTER
SCIENTIST
RARELY
TALKS
ABOUT



Donald E. Knuth

CSLI Publications *Stanford, California*

T_EX is a trademark of the American Mathematical Society.
METAFONT is a trademark of Addison-Wesley Publishing Company, Inc.
PostScript is a trademark of Adobe Systems Incorporated.

Copyright © 2001
Center for the Study of Language and Information
Leland Stanford Junior University
Paperback edition
07 06 05 04 03 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Knuth, Donald Ervin, 1938-

Things a computer scientist rarely talks about /
Donald E. Knuth.

xi, 257 p. 23 cm. -- (CSLI lecture notes ; no. 136)

Includes bibliographical references and index.

ISBN 1-57586-326-X (pbk : alk. paper)

ISBN 1-57586-327-8 (cloth : alk. paper)

1. Religion and science. 2. Science--Philosophy.
3. Computers and civilization. 4. Computers--Moral and
ethical aspects. 5. Information technology--Philosophy.
I. Title. II. Series.

BL240.2 .K59 2001

261.5--dc21

2001025685

Internet page

<http://www-cs-faculty.stanford.edu/~knuth/things.html>
contains further information and links to related books.

THINGS A
COMPUTER
SCIENTIST
RARELY
TALKS
ABOUT

FOREWORD: MEETING GOD AT MIT

BY ANNE FOERST

In 1997, I started the “God and Computers” project at MIT. I had come to the MIT Artificial Intelligence Laboratory in 1995 and was working on dialog between understandings of humans in AI and in Christian theology. Many people—students and professors alike—felt quite provoked about my presence there, and we often had heated arguments about mechanistic explanations of human features and the usefulness (or uselessness) of religion. The vast majority argued in a fairly reductionistic way but, yet, a few people held religious beliefs. These people, however, were clearly a minority and usually practiced their religiosity in private and kept it completely separate from their work.

After a while, I realized that some of the heat that arose in our discussions, the passion with which people argued for their point of view, could not be explained by scientific conviction alone. Quite the contrary; these emotions stem from the very human nature that makes us ask questions for meaning. Most people search for answers in the realm they know best, and so scientists often formulate possible solutions for their own existential quests in the metaphors of their scientific discipline. This is especially true for all those disciplines where the subject is—in a broad sense—human nature; that is, cognitive science, neurology, psychology, ethology, and of course AI.

From my Lutheran point of view, to be human means to ask questions. We puzzle about the nature of the universe and ourselves. We want to understand the world around us and us in it. We want to understand our friends and ourselves. And we want to know what’s going on when we think or feel or interact with the world.

Human questions tend to be anthropocentric and even egocentric, as the questioning human cannot completely abstract from who he or she is and from the quests and ideals being brought to each question. We cannot help but bring our own perspectives to the table whenever we seek answers to questions such as, “Why am I here?” “What is the meaning of my life?” “Why am I the way I am?” We all are embedded in specific cultures and worldviews that will

shape the way we formulate our answers to these questions. And we all have values and preferences that we apply to our quest.

Particularly in a discipline concerned with human nature, we tend to apply our own intuitive sense of ourselves to our theories about humans; also, the theories about human features that are developed in our scientific disciplines tend to influence our intuitive sense of ourselves. Being a human being concerned with the understanding of human nature therefore places the questioning person in a circle in which culturally influenced intuitions about ourselves and scientific theories about human feature are intertwined and cannot be separated from one another.

Being in an AI lab, where people attempt to build humanoid robots in analogy to human infants, the relationship between theories about human nature and intuitive and cultural self understandings is especially pertinent. When the Electrical Engineering and Computer Science Department (EECS) offered me the opportunity to teach a course about these questions, I immediately accepted it. However, from the beginning of the planning process I realized that the point I was trying to make in the course would be supported best if I also invited famous scientists concerned with human nature, and let them speak about how they addressed questions about themselves and the meaning of their life within and outside of their research. When my course proposal won a Templeton award, I had an opportunity to invite several researchers that I either had met while I was at MIT or had heard about in the course of my studies.

In the first year, the guest speakers were Paul Penfield, Rodney Brooks, Federico Girosi, Lynn Stein, and Rosalind Picard (all from MIT); Marc Hauser, Ming Tsuang, and Bijoy Misra (from Harvard); Francisco Varela (from Paris); and MIT alumnus Ray Kurzweil. As there had been MIT-wide criticisms against this project, and since many people were very much against any combination of religion and science at MIT, the series had become widely known and was attended by many people.

Over the three years that the series took place, the consistency of the audience remained fairly constant. A third of the auditorium consisted of MIT faculty together with their former students (usually from EECS) who worked now in the Boston area. Another third were interested ministers, professors from the larger Boston community, and some laypeople who had heard about the lecture series in the *Globe* and other local newspapers. Another third consisted

of MIT students, mostly undergrads. From the feedback I got, these students welcomed the opportunity to see their professors struggle with the same questions that they were struggling with. Many were grateful for these presentations and became more encouraged to ask questions themselves. They were relieved to find out that even their admired teachers did not have final solutions, but could only formulate answers and theories and suggestions out of their own life experiences and expertise.

For example, Paul Penfield, then head of EECS, outlined a concept of "God as Scientist" that pointed to different realms of questions that demand different answers. Rodney Brooks, director of the AI Laboratory, talked about being torn between his scientific conviction that humans are nothing but "bags of skin" and his knowledge that he neither wanted to be treated as such nor would he himself treat people that way. The answers from each speaker were always authentic, sometimes surprisingly open and personal, and most of the time captivating not just from an academic perspective but from the personal situation of the listeners, especially the students.

In the second year, MIT professors Robert Randolph, Steven Pinker, Sandy Pentland, and Joel Moses spoke, as well as Professor Brian Cantwell Smith of Indiana University, and the experience was very similar. It was, however, much more difficult to find speakers. The first year had been an experiment to bring questions outside of hard science into the academic setting of MIT; the invited speakers were excited about the prospect to do something new. Many of them were atheists or agnostics, but it was fascinating to see how, for example, Jewish and Protestant atheism differed from one another. No one had expected to have a large audience or so much media interest. The second year was different, because the expectations for the second series were higher, and the speakers knew that they would have less freedom to experiment. The talks were fascinating nonetheless. I had attempted to move away from a purely "cognitive science approach," and so Bob Randolph, then senior associate dean at MIT, talked about the history of religion at MIT. Stephen Pinker evaluated explanatory models for the phenomenon of religion in humans and concluded that *homo religiosus* is, in a way, the result of our evolutionary development. The other speakers had equally engaging topics. The feedback from the audience was again very positive, but an increasing number of people wished to hear one speaker several times. They felt that this would give a speaker

the opportunity to develop his or her thoughts over time, and the audience could get to know their thoughts more thoroughly.

When I was thinking about a speaker for such a series of talks, after some consideration only one person seemed to be possible, and I invited Don Knuth. I had come across his book 3:16 and liked it a lot. I also had read some of his work in computer science. Having a person who is deeply faithful and simultaneously a top computer scientist was certainly attractive and fitting in the context of the series. That I liked his humor was part of my choice, and I had also heard people say good things about him as a person.

When he actually agreed to give a series of six public lectures and participate in a panel discussion, I was overjoyed—and, actually, it turned out that he was in reality even more fun than his books had suggested. So here's my sincere *schönen Dank!* to Don Knuth, who had the courage to spend a whole term at MIT talking about interactions between faith and science.

As soon as I started advertising, I realized that this third year of the "God and Computers" lecture series would again be a big hit. Dr. Dobb's Journal offered to sponsor live webcasts, which drew sometimes several thousands of people a week to their browsers. Several people in EECS told me of their surprise to hear that Don Knuth had anything to do with God, besides being a computer science icon himself. Actually, the MIT student newspaper *The Tech* featured an article about Don headlined "Computer God talks about God."

The biggest surprise, however, was the question-and-answer period after the first lecture. After all the God-metaphors had been thrown around, Don gave an introduction in which he did not talk about computer science but about himself as a person, a Christian, a scientist. He shared his experiences and talked about the turning point of his life in the 3:16 project. The questions, therefore, were not related to any theoretical point of discussion. Instead, many listeners, particularly students, used the opportunity to ask their "god" about the questions that bothered them. Don had to address questions such as, "Why is there evil in the world?" "What happens after death?" Students wanted him to give them answers about the meaning of life, and if there were any miracles. In short, they treated Don as people within a faith-community treat their minister.

It didn't help that Don was absolutely clear about having no authority to answer these questions. It was particularly upsetting for

some people when Don gave his opinion that the questions have no objective, universally valuable, and applicable answers; that everyone has to try to seek answers for themselves. From the feedback, I gathered that some people were disappointed. But the vast majority of people were excited. Against all of their prejudices, here was someone religious who did not claim to own the truth. Instead, Don invited his listeners to find their own path, of questioning and reasoning about themselves and all the rest.

The text of this book certainly speaks for itself. I would like to invite the reader to follow the quest within this book. It was an exciting event at MIT, and I am convinced that the book can get much of the same spirit across. I wish the reader fun, anger, excitement, and trouble, because that is something only a deeply engaging topic such as religion and science can do for us. Don has presented a wonderful way to relate his science and his faith, and I hope the readers will enjoy it as much as the live-audience did.

Finally, I would like to thank all people who made the "God and Computers" project possible. First and most important, I would like to thank all of the speakers, and particularly Don. It took courage to speak in front of a highly educated, critical, and sometimes prejudiced community, especially when much of the time was spent responding to impromptu questions from the audience, and I am extremely happy that Don has edited the transcripts of his lectures for publication in this book.

Also, I would like to thank John Guttag, Paul Penfield, and Rodney Brooks for their support of the project early on, and for the opportunity they offered me to work on religion at MIT. I would also like to thank Jean Hwang who managed Don, me, and the whole organization.

Finally, I would like to thank our sponsors who made this event possible: Dr. Dobb's did a wonderful webcast. The Center for Theology and the Natural Sciences in Berkeley runs the Templeton Religion & Science course program that made first series possible and also supported the third year with Don. The EECS department and the AI Lab at MIT both provided crucial support and generous contributions to the entire project.

– Anne Foerst
28 February 2001

Things a Computer Scientist Rarely Talks About

Lecture 1: Introduction 1

- Why I am unqualified to give these lectures.
- Why the lectures might be interesting anyway.
- The 3:16 project, a turning point in my life.

Lecture 2: Randomization and Religion 25

- The advantages of unbiased sampling as a way to gain insight into a complicated subject.
- Dangers to avoid when using this approach.

Lecture 3: Language Translation 53

- How to translate Bible verses without knowing Hebrew or Greek.
- The surprising rewards of such attempts, even though the task is difficult or impossible.

Lecture 4: Aesthetics 91

- Scientific work as an artistic endeavor.
- The deep influence that beautiful presentation can have on our understanding of texts.
- Illustrations by many of the world’s greatest masters of calligraphy.

Lecture 5: Glimpses of God 139

- What I think I learned about God from the 3:16 project.
- What I think I learned about theology from the 3:16 project.
- The difference between the two.

Lecture 6: God and Computer Science 167

- Computer programmers as creators of new universes.
- Computational complexity as a way to approach the questions of free will and omnipotence.
- Other concepts of computer science that may give insights about divinity.

Panel: Creativity, Spirituality, and Computer Science 207

Index 239

LECTURE 1: INTRODUCTION (6 OCTOBER 1999)

It's certainly overwhelming for me to see so many people here. Why did you come to this talk, when you could have gone over to hear Jesse Ventura instead? The lectures that I'll be giving during the next few weeks are entitled "Things a Computer Scientist Rarely Talks About," and the subtitle is "Interactions Between Faith and Computer Science." I'm here because computer science is wonderful, but it isn't everything. So today I want to go beyond technical stuff to consider other things that I value.

In this series I'm going to be giving six talks that are more or less independent of each other. Anne Foerst asked me to deliver between five and ten lectures, and I settled on six because I could only think of six jokes. (And that was the first.) I have to tell jokes once in awhile to see if you can really hear me.

The first reaction that I had when I was invited to give these lectures was to say, "No way, this is impossible. The whole subject of faith and science is much too deep for me." I've given lots of talks at universities during the past 40 years, but they were always to present solutions to problems, to prove some math theorems, to make precise analyses of computational tasks, to propose general theories, or to organize bodies of knowledge—things like that. Things that I suppose I'm reasonably good at. But surely I can't come before you today and pretend to be an expert on faith or God, much less to claim that I have any solutions to problems that have challenged and baffled the best human minds for thousands of years.

So it is especially terrifying for me to see so many of you here; I hate to disappoint you. I have a Ph.D., which makes me a Doctor of Philosophy, but it doesn't make me a philosopher—the Ph.D. was in math. I can do math and computer science okay, but my formal training in religious studies is basically nil since high



school. I've done a lot of reading in my spare time, but why should I expect you to listen to me talk about one of my hobbies?

When I read what other people have written about matters of faith, it's quite clear to me that my own ideas don't measure up to those of world-class philosophers and theologians. I'm not too bad at reacting to other people's notions of religion, but I'm not too good at introducing anything that is fundamentally new or important in this area.

In other words, as far as theology goes, I'm a user, not a developer.

A week and a half ago, I went to Memorial Chapel at Harvard and was in the audience when Billy Graham came. I'm happy to say that he not only had a standing-room-only crowd, as we have here today, but people filled the aisles and the doorways. He certainly deserves it.

Turning things around, however, what if an eminent theologian were to give a series of lectures about computer programming? Would I go out of my way to go to hear them? Would I find them of value afterwards? I'm not sure.

On the other hand, all computer people present here today know that discussions of computer science are not totally different from discussions of religion, especially when we consider languages for computer programming. In the 60s, people would often talk about "Algol-theologians"; these were people who were skilled in the exegesis of obscure texts passed down by international committees. Programmers could use all the analogies of religious studies when we were discussing computer languages. Over the years numerous high priests of programming have expounded one language or one methodology over another with religious zeal, and they've often had very fanatical disciples. Thus everyone knows that the world of computer science is full of cults. In this sense religion and computer science are not completely separate; they share a fair amount of common ground.

We are all familiar with C. P. Snow's famous metaphor of the two cultures that divide educated people into two camps, humanists and scientists. Last month I was in England and I visited the new British Library in London, a magnificent building that has been built to last at least 200 years. And I learned that it actually enshrines the notion of two cultures permanently in stone. The new British Library has two separate sections with two separate reading rooms,

