Virtual Heidelberg Laureate Forum 2020 - Dialogue : Tarjan / Knuth

Donald E. Knuth, Robert E. Tarjan

Introduction : Coming up next is another highlight of this virtual Heidelberg Laureate Forum. The two touring laureates, Donald Knuth and Robert Tarjan, will discuss topics based on questions previously submitted by the young researchers. Donald Knuth received the 1974 ACM A.M. Turing Award for his major contribution to the analysis of algorithms and the design of programming languages, and in particular, for his contribution to the art of computer programming, through his well-known book series. Robert Tarjan was awarded the 1983 Nevanlinna Prize and the nineteen-eighty-six ACM A.M. Turing Award, along with John Hopcroft, for fundamental achievements in the design and analysis of algorithms and data structures.

Bob and Don, take it away.

Robert Tarjan : Thank you, Peter. Let me just welcome everybody who is online, all the young researchers and everyone participating. You know, both of us are getting kind of long in the tooth now, but Don, you've always been one of my personal heroes, so it's a bit intimidating to engage with you in this. And it's a great honor and a great pleasure for me to have this opportunity to converse with you. You know, you've been an idol of mine ever since I got to Stanford as a first year grad student.

I think what we'll try to do here is maybe I'll ask Don several questions and then he can answer, ask me several questions and we'll try to get an interesting dialogue going. I have lots of questions from the young researchers. I apologize in advance that we probably won't be able to get to all your questions : so many questions, so little time. But let's get started here. Don, my first question to you is, can you tell us about your T-shirt ?

Donald Knuth : How clever of you to ask that question, though OK, I don't know if you can see it very well, but it says *Concrete*. But this is a special T-shirt. I don't know, maybe only two or three were ever made. It came out in 1989 when our book *Concrete*[1] was new. And I'm wearing it in honor of Ron Graham, my co-author, who died in July. And it was his daughter, Cheryl, who made these T-shirts for us at that time.

R. T. : It was a terrible loss to the field, his passing. Can you tell us...

D. K. : You mentioned Princeton and of course, he was using the text at Princeton that year and I was using it at Stanford.

R. T. : That was a beautiful book, *Concrete mathematics*. I actually had to teach an undergraduate course out of it. And I have to say it was a challenge because it's beautiful, but there's lots of advanced material in it.

Transcription of a video here https://www.youtube.com/watch?v=O5g4Zl8ppQA.
by Denise Vella-Chemla, 4.10.2020, work in progress.

1. *Concrete mathematics*, Ronald Graham, Donald Knuth, Oren Patashnik, Addison-Wesley, 1988.

D. K. : And we never could figure out what was difficult about it, but we knew that something.

R. T. : My second question, can you tell us a little bit about your personal journey and how you got into computer science and maybe why computer science, not mathematics, given that I first knew you as a professor of mathematics at Caltech ?

D. K. : Oh, yeah, well, that's true. When I got started, of course, there was no such thing as computer science and computer science... I think the first computer science department came out about 1965, Stanford was one of the very first.

And so, you know, I got my... I started in college in 1956. That's nine years before the computer science existed. And I started out majoring in physics. And then, I found out that the labs were too high for me. I couldn't do weldings, for example. It was terrible, all that voltage. And I had, well, I shouldn't want to go into a too long story, but it scared me that I couldn't see what I was doing and I couldn't do that.

So for a year, I took a math class that convinced me that I should really switch over. And so I became a math major. And there were five of us at that case at the time. And I got my bachelor's in math in nineteen sixty. Then I went to Caltech and studied mostly combinatorial mathematics with Marshall. So, and some reason decided Caltech to keep me on as a professor, so I stayed. I had a great time at Caltech and including meetings I don't know, maybe you were a freshman by the time I left, my last year was 1968 or somewhat.

I mean, the summer of 68 is when I took a year off to work on national service. But anyway, by that time, I realized that computer science was really my version of my career path because I had seen that I was editing several journals at the time from math department at Caltech, but I was sitting in lots and lots of lectures about mathematics, where I was sitting in the back row saying, so what ?

So about the lectures that I was hearing and all the correspondence I was having about computer science, which was very exciting for me. So I decided that I should make one move in my life, namely to be a full professor somewhere. And I had... There were four major places I was deciding between. One was with Stanford, or one with Berkeley, and one was Harvard, all in computer science. And the fourth was Caltech, where I would stay in mathematics.

And so anyway, I came in Stanford. And then shortly after, *you* came as a first year student. And one of the reasons I went to Stanford was I thought at Caltech, we couldn't really... we do much in computer science. And you came in my office and, you know, and I was your advisor for classes. And the next thing I took, Stanford got this great curriculum. So I listed all the courses that we have and you said, oh, you've already taken those courses from some visitor who came to Caltech. So that's how I got into the field. And basically, I believe it's because I realized even when I was an undergraduate, that there was something about the way my brain had evolved by that time, that computers were really resonating with me. And I really loved everything, all these connections. I just, I was born to be a geek and maybe at least by the time I was 16, I was...

R. T. : So, I have several questions, but I'll just ask one now and then turn it over to you. When did the idea for the book come to you ? When did you get started on that project ?

D. K. : Yeah, I was a second year grad student at Caltech and it was January 1962. I entered in the fall of 1960 and my favorite textbooks had been published by Addison-Wesley, when I was an undergraduate, my calculus books, my physics books, some books, a number of various things that I liked to read and an editor took me after lunch and he said "Don, we'd like you to write a book about how to write a compiler." and gosh, I had always enjoyed writing when I had been working for campus publications for example. And so I was thrilled by this idea and I came home and on a sheet of yellow paper that I still have somewhere, I wrote down the title of twelve chapters I thought ought to be in this book. Chapter 12 was about compilers and the other eleven chapters were preparing for compilers and I'm so far I'm up to chapter 7 now from that list that I started in 1962.

R. T. : Well I'm sure we'll return to the topic of the book but maybe now I'll turn over to you and let you ask a few questions.

D. K. : Yeah, okay, well, did you learn you were a geek every time ? How do you get the bug to come in ?

R. T. : I'll go back a little farther in my personal history. Way back. My father ran a state mental hospital in California and he was interested in doing research on reasons for the developmental disablement and he was fairly well known. Linus Pauling who was at the Caltech at the time came over to our house and they were doing a joint research project and Dr Pauling left the Caltech catalog with me so I had that scientific interest. When I got into public school, this was back in the days when the California public schools were still really strong, I had an amazing math teacher. So I got bug to study mathematics, I read Scientific American columns by Martin Gardner. I had an opportunity when I was in high school to do a little bit of programming and I worked when I was in college, doing computer programming. So my plan was always to do mathematics. I went to Caltech as an undergraduate but unfortunately I never had a chance to take a class from you. Caltech at the time was all about physics, the math department was a little bit strange but wonderful. Brilliant combinatorialists, Herbert, Ryser, Marshall Hall, so I had a great time. I have to say being an undergraduate at Caltech was probably one of the biggest challenges of my life. It was extremely intense. Then deciding on graduate school, I applied to a couple of math departments and a couple of computer science departments and ended up going to Stanford in computer science and never regretting it because it gave me an opportunity to use mathematics in something where you could actually see, in a concrete way, the effects of algorithms and algorithm analysis and so on. So that's the short version of the story.

D. K. : Good and we're lucky that John Hopkins had a sabbatical so he came to visit...

R. T. : That was an extremely fortunate event, yes, that is certainly true. It was early days, I mean, Alan Kay was there. Stanford in those days was a very special place. Alan Kay gave a talk already in the HLF[2] and he said something like "Find a great research community.". Stanford in those

2. HLF : Heidelberg Laureate Forum.

days in computer science was a great research community. And of course, there was involvement of people from Berkeley too : Dick [3] Karp and Waller, for grad students, it was quite an amazing place.

D. K. : We might remind to the people that although it was 1970, it was really the 60s. *(R. T. laughs)*. I mean as I recall, you lived in Berkeley, in the commune and you commuted every day, and as I sort of remember that I was very worried about you because you were proving theorems in your head as you were driving the freeways and I was afraid you'd get into a wreck. *(R. T. laughs)*.

R. T. : Thank you for that concern. That was when I got to be an assistant professor at the Stanford. That was after my grad student days.

D. K. : All right, well, I got the time mixed up and then a few years ago but... So but anyway, there was a lot going on in those days outside, yeah, outside of college as well. And I guess, there always is, but those days were pretty. I mean students were setting fire to campus buildings.

R. T. : It was the height of the Vietnam war and there were protests against the war and there was the whole hippie movement and it was a very interesting time. Many of us were very idealistic somehow. Perhaps a little naive, or a little *too* idealistic.

D. K. : Well thank godness people ideas are realistic I see. So now the thing I remember the most is that basically in the 70s you revolutionized computer science at least from my standpoint which is you know trying to write a textbook. You and Shannon in the 70s were the two people who most upset my table of contents *(R. T. laughs)* for what I would have to do and the reason was that it was, you know, you were doing things that I had absolutely no conception of in 1962 when I set up this on the plan for the books and especially, this was the first time, this now seems, maybe, it was obvious but boy, it was so unusual to find something like a deep algorithm, some property of a brand new way to organize information in computer that what... it's way out there, everything hung together, blown away by the fact that somebody could actually prove theorems about complicated data structures and before that, there were just data structures you could easily explain to somebody in ten minutes or maybe an half an hour but all of a sudden, you came up with these methods that really take a lot of proof and it's almost amazing that they work at all. I remember my secretary Phyllis, she said that you visit here every once in a while, so you were also doing research while you were sitting in her house, I guess, also thinking about these things but I mean, can you say something about the origin of those ideas that you would even conceive of having a deep data structure ?

R. T. : Well, that's a hard question to answer : how does one figure out how to do research. One tries... one has to be intensely curious, one has to explore the design space, and the thing is computers kept getting faster and faster. Moore's law is a gift to theoreticians as well as to practitioners, it creates the opportunity to think about things on a higher level and the idea of analyzing algorithms from a bit of a fuzzy point of view that is ignoring constant factors really opened up the field and thinking about actually proving time bounds which really wasn't done until we started doing it I think that was important because it kind of drove. If you have a goal to make an algorithm faster then you're forced to strip away the irrelevance and figure out what are the critical parts that are involved in the computation and use those in exactly the right way so...

3. Richard M. Karp

D. K. : So that was your initial work but because of this goal that you had about you know, trying to get linear time or were you trying to just get cubic time or something I mean, I'm thinking, it was the linear time challenge the thing that did it first for you ?

R. T. : Well, how did I come to start really working hard on algorithms ? I took a Lisp programming course from John McCarthy who was another A.M. Turing award winner, unfortunately, and again, great Stanford environment, but his final project we were supposed to write a Lisp program. One of the options was to write a Lisp program to do test graphs for planarity. I've been interested in planar graphs because I was interested in the four colors, the now theorem problem. I was trying to prove this myself in high school using computational methods but I didn't have enough information and enough computational power I can app and solve this problem in 1976 using exactly this techniques. So the mathematical criterion for planarity is the famous Kuratowski criterion (a graph is non-planar if it contains a complete graph on five vertices or a complete bipartite graph on two sets of three vertices). So everybody else trying to implement the Kuratowski test but I managed to find a paper by Shimon Even and Lempel and Cederbaum actually which gave an algorithm which essentially constructed an abstract representation of embedding. So I implemented that algorithm, it turns out to be quadratic time, they didn't state that but that's what it is and I managed to do really well on the project. So then I thought if quadratic time, why not faster ? And John Hopcroft came and we started talk about graph algorithms and exploring the potentials of depth first search and things led to things. When you have a tool that works effectively, you try it on any problem you can think of. So let me turn it back to you, I'll go ahead, back to case western. I seem to remember a famous story about you being on the basketball team. Can you say something about that ?

D. K. : Well I was the manager, I was a scorekeeper and if somebody wants to look this up there's a one minute video so just google youtube for, it's called the electronic coach [4] and I worked out a way to keep the basketball statistics more that had been done before and I came up with a formula for each player as to how much they contributed to that game that took into account the shots they missed and the fumbles and the rebounds that they got and things like this all into one glorious formula I don't believe the formula anymore but at least I had this formula and so it wasn't just the points that you scored but everything that you did went into this and I would punch cards after every game and compute these numbers and then the coach seemed to like them.

R. T. : That was back in the days when we were programming on IBM machines and you had to input things on punch cards on in great massive boxes of punch cards...

D. K. : And you could see it in that video and also, I wrote a book on, actually, I'm glad that I lived long enough to write this book, it's called *"Selected papers on fun and games"* and one of the chapters in there gives the whole story about this including the reviews in the newspapers and like how it was carried on, showing everything like this, Newsweek magazine. *(D. K. laughs.)*

R. T. : So it seems like you were doing quantitative sports analysis thirty years ahead of its time. Did you have ever open an opportunity or interaction with some of these people who are doing it now for real with professional sports teams ?

4. https://www.youtube.com/watch?v=dhh8Ao4yweQ.

D. K. : No, no, that was when it was easy and fun but I was a junior. But anyway, it just shows again that computers were totally involved, you know, with my life all the way through...

R. T. : Computer science. It's been said that any field that has science in its name is not a science. So I might ask you "is computer science a science, a branch of engineering, a branch of mathematics, an art ?", but let me ask it in a more personal way, especially since you've titled one of your famous books *The Art of Computer Programming.* You see yourself as an artist, a scientist, a mathematician, an engineer, a philosopher, some combination ?

D. K. : Yeah, Okay, that was the subject of my turn talk in 1974 [5]. So I can't do any better than ask people to plug back that button but to shorten it, I looked up about art and science and I found, you know, lots of books had there in there in the title, I quote a whole bunch of them in that at the time and I realized that the word art stands for not only fine arts but also things that are artificial and basically it comes from the greek word $\tau\varepsilon\chi\nu\varepsilon$, in german *Kunst* and so on now. It meens something that's made by human beings as opposed to being present in nature. And science is the study of knowledge and organization of things and so, in a sense, I can tell you a short definition that science is what we understand well enough to explain to a computer and art is everything else. And as science advances, we learn more and more about whatever field we're studying, but then, as we learn more and more about it, our brains figure out and keep a few jumps ahead, and that's the art.

R. T. : So that raises a very interesting question because artificial intelligence has been reborn now as deep learning neural nets and some people are worried that the singularity is coming where computers will evolve beyond us in intelligence. What role do humans have in this and should we be worried about this, what do you think about this new version of artificial intelligence ?

D. K. : Yeah, well I don't know how long it'll be before they rename our department as the department of machine learning but I'd rather talk about almost everything else but I'm seriously worried about the potential for weapons especially. This video, well, what's the name... anyway, it's such an important video but I put it out of my mind I guess, Steve Russell put that important thing to show that it's not that far out that we could have little drones targeting our enemies and nobody being able to do it stop and it wouldn't cause that much for terrorists to do this, not to mention people who don't like other people in their own government or in some other country so...

R. T. : Boy, it seems like technology. There is always the fact that they are good uses and bad uses and it's up to us as human beings to take use of technologies in the right way, it's a big challenge.

D. K. : Yeah we have to understand it, that's for sure, right.

R. T. : Well, do you think that we, as theoretical computer scientists or as mathematicians have something to contribute to the new field of artificial intelligence ? Should we ? What's our role here ? I know some of my colleagues have jumped in trying to... and one big challenge seems to be neural nets solve problems, do things, accomplish tasks but nobody has a clue to how they do it. There's no explanation, which is kind of anti-scientific, is that right ?

5. https://amturing.acm.org/award$_{w}inners/knuth_{1}013846.cfm$.

D. K. : That's right, I apologize for saying Steve Russell, I meant Stuart Russell, of course, and he's given the most deep thought to this problem of how to prepare early on for whatever. But the unfortunate thing is that his solutions are always assuming that human beings are rational. And I'm beginning to wonder more and more about that every day because people are not being rational. And that is so we have to figure out a way to save the world with the irrationality.

So, but anyway, as you say, people like you and me have things that we're good at and we aren't necessarily good at everything. And so I figured I've got a few more years to live I'm gonna spend my time about the things that I can do more uniquely than things that I did, I'm not sure anybody can do.

R. T. : That's the conclusion I came to also. There's little time and let's use our abilities that we have in the best way we can.

This is perhaps a related question, computer science, unlike mathematics, is still a very young field among many. You got into it at the very beginning and I was only more or less a decade later. What does this mean ? I mean, how do you see computer science going forward ? How has it changed in your lifetime ? Do you have directions you would like to see it go ?

D. K. : Maybe these questions, but I'd like to turn back to you. It's not clear whether computer science is a subset of mathematics or mathematics is a subset of computer science and different days, I could argue either way, but actually I believe that they're different. And although I've been part of both worlds at different times, I consider myself a lapsed mathematician now. But there are days when I say, oh, today, I'm going to think like a mathematician. And sometimes I can solve a problem by taking it by having my mathematician's cloak on for a day and then I put on my computer scientist cap and I work on it from another point of view. And I can strongly feel the difference when I'm operating in one mode or the other.

I argued this with Bill Thurston, though, and he couldn't see any difference. So I don't know. But to me, I think that computer science and mathematics are the two sciences known, so far, bodies of knowledge known so far that are not based on nature.

R. T. : They are created by human beings.

D. K. : We get to make up our own ground rules. You know, we design a universe that we're going to study and physicists don't have that, but string theorists maybe. But, you know, chemists, biologists, they deal with nature. But mathematical designs are the parts where we're studying things that are detached. But created. These idea that they were really out there all the time or not ? But anyway, that separates it from the other field.

And I see that, as years go by, I think mathematicians are starting to get it, the way I understand computer science. And computer scientists are a lot of times more interested in Wall Street than in science. As you know, a lot of our staff students have gone off and become hedge fund people or something instead of advancing, you know. So when we were in the 70s and there was a question whether universities would survive and so on, it was clear to me that if Stanford would be burned down, I would still gather a bunch of students somewhere and we would go somewhere and we would want to talk about computer science.

And I've never been I never said, oh, what's a good way to have an easy life for you or to make a lot of money or something like this, start a company, have all these stock options and then by the end of summer. No, the last thing on my list of motivation. On the other hand, I know other people that did their best work because they were excited by different things that excite me. I'm not saying my way is the only way, I guess.

R. T. : But let me give it back to you and give you the opportunity to ask me a few questions.

D. K. : Yes. What do you think about the motivation that keeps you going ? Like, I think you're finishing a book now ?

R. T. : starting a book ! Well, the long delayed book project, I make no commitments. But yeah, in this process, I discovered the beauty of TeX. I have to say, I waited too long to try to learn this. We'll see how it goes. *(D. K. laughs.)* But, you know, I had the same feeling as you as I was developing these algorithms in the 70s and the 80s. The field is not yet stable enough to try to capture information in the book. But at this point now, finally, this is one of the positive things about what has happened with the epidemic, the pandemic.

I've got a lot more time because I'm not on an airplane. So I actually started doing some writing and it requires large blocks of time, obviously, and I think there's enough stability that it's actually maybe possible to do it.

D. K. : So let me... Isn't it true that you started writing a monograph and you left the whole manuscript in a metro station once ?

R. T. : there was a briefcase that I left in a metro station in Paris, yes. Containing lots of useful stuff I used to write on pencil and paper. Now it's on the computer and most of it's stored in the cloud, fortunately. So I guess I'm trusting to a particular platform as opposed to you who are interested in your local environment. I hope your house is secure, Don, because we wouldn't want to lose that treasure trove of information.

D. K. : Well, I think it's OK. Yeah. When you spoke about plans for our dialogue, you mentioned that you had some concerns about publications and conference culture and things like that. Can you...

R. T. : Yes, yes. Yes. This is a difference, I think, between most scientific fields. And I would include mathematics there as well and computer science as it has evolved. It seems now like we're putting all our effort into conference publications fast turnaround. And if we are a mathematical field, maybe it works for the experimentalists, but for the theoreticians, it's kind of amazing to me. I'm sort of old. I mean, I'm sort of a lapsed mathematician in the same way that you are.

And it's kind of amazing to me that we make progress in spite of the fact that there are plenty of mistakes, there's plenty of kind of half baked publications with great results, but not fully worked out. And it kind of breaks my heart that people don't take the time to go back and fill in the details and investigate further. So it seems to be an inevitable trend in our field, and it's getting even a little bit worse with the advent of platforms such as arxiv, where people can post almost anything, some half-refereed at best.

So I am concerned about it. I think it's very important to try to get everything into a refereed journal, if possible. I try to encourage my students to do that, but it is a challenge. It's gotten much more about publish or perish as it was, back when I was a student.

D. K. : I imagine that's because there are thousands of people now when there were only dozens when you and I were young but boy, well, I know enough about the history that there's always been problems with quality control in publication. But I remember last year, I got really angry when I heard about what, you know, I looked at a paper and I thought it would solve the problem that I thought I would never see the solution of in my lifetime and I thought it was a grad solution but the problem involved is a generalization of knights tours and the guy got the most insulting referee reports when he submitted the article to a journal and I showed this, you know, and essentially, in those high pure academics for saying, nobody would ever stoop to write a paper about something that the generalization of a nice tool and so, there is no consideration for taste and I can't say that my taste is better than another. I can look at papers and say this is trash and I can look at something else and I say this is beautiful. I have no algorithm although, I don't take machine learning let to solve their problem.

R. T. : That's the flip side of the coin : I mean, great papers were rejected by narrow-minded reviewers and the greatness only emerges later on perhaps.

D. K. : Right. Plus the... So I finally found a good referee for the guy, but you know, he worked for a journal that... you know... screws the universities by charging too much for this journal. So he didn't want to publish in that journal. So he left it on the arxiv for the moment. You know, in the journal as the editor of the journal of algorithms, I researched what was being done by the patient publishers who are in most cases using our services for free to do all the refereeing and editorial work, but they are not interested in anything but the bottom line and they were making huge profit margins they import, the academic press had been bought out by somebody who had been bought out by somebody else who had been bought out by elsewhere and so on and finally the publishers were making arrangements with universities, and swearing the universities to secrecy so that we couldn't even find out what libraries were being forced to pay to the journals, and that was the last draw for me and I reported all those things to our editorial board of our journal on algorithms and we resigned our percent to 100 and we started the ACM transaction on algorithms...

R. T. : Is that the solution then : more support for professional societies, non profit organizations ?

D. K. : Yeah, it seems to me that in the professional societies, we have some control over that. I don't know what your opinion is... ?

R. T. : I concur, I concur...

D. K. : Tim Gowers has...

R. T. : I'm going to change the subject, sorry, go ahead... I'm going to change the subject a little bit. Not only are you a serious computer scientist. But you're a serious organist player and composer also. Can you tell us a little bit about what you've done and what you're up to in this domain ?

D. K. : Okay, so anyway, you were at my 80th birthday party, one of the great friends who came there.

R. T. : And I'd been in a T-shirt it would have been that one.

D. K. : *(D. K. laughs.)* Okay so I'm 82 now but on my 80th birthday, we had a celebration in Northern Sweden where there is a particularly wonderful pipe organ and when I heared about that organ, I figured that... I had also planned, since the 60's, I wanted to write some kind of a major composition for pipe organ. It was a dream that I had all these years until finally I got to be, I don't know, when I was seventy five years old, I thought if I'm ever going to do this, I should better start now. So on a day I was visiting Vienna, and I went to the best music store in Vienna and I bought some blank music papers from the same store that Beethoven had bought stocks, and Brahms, and so on, so I bought from and I figured that wouldn't hurt until I brought that with me and I started writing my piece. And I worked hard off and on for five years, and came up with a very strange piece that I have to say I do like... I am glad that it came up the way it did. So we had this glorious Premiere. You can see it on youtube google sent by a team of people who captured it, they had the best state of the art, several dozens of cameras. So we have a 360° with two different cameras and lots of audios, the best mic team for surround sound and so on. So we have many terabytes of data from that Premiere performance. And I'm hoping that computer scientists are looking for a thesis project is going to make a beautiful virtual reality, things of this so that people can watch it and select as they're watching it what they want to see because we have all the bits captured and Stanford arxiv has it all in the digital form and it's available to any researcher who wants it.

R. T. : I have to say that watching it in person was an overwhelming experience and it would be good to relive.

D. K. : Yeah so, it's divided in twenty-two parts each of which is about five minutes long and you can watch one part at a time if you go to my website you can find the playlist it's on youtube [6]. But then the canadian premiere took place and it was a wonderful performance in Waterloo, two years ago now, and the people there made a great video where you can watch you know in a different way. And then last year in Czechia in Brno [7], and again they have made a tremendous video of the performance. So now there are three excellent sources like if anybody wants to see if they like. I call it high bandwidth music because I was reacting to the lot of modern music... I don't know. They start out with some idea and then they hold it until the audience gets it and then they move on to the next idea and so on. But I wanted to go back to the way Mozart would do it and come

6. https://www.youtube.com/playlist?list=PLvixIGKr5sJffdfwecygYqhXsgz-EBCC8.
7. https://www.youtube.com/watch?v=wk7dEKMPP68

up with ideas faster than then we can take in so we have to listen to it twice and three times and we get more each time and... So they made these really nice, they captured in three beautiful ways and I'm so glad that ought to be music of the world and maybe it'll be popular and maybe it'll be a dud but at least, it satisfied me that, you know, I had this as one of my life's goals, it's hard to explain but if you have talked to me two years before I finished it and somebody would told me I only had two years to live I had to choose between finishing that piece or finishing out a computer program like... I somewhat would have chosen that piece although I should have chosen the other computer part because I have no right to write music.

R. T. : I don't see why not. So let me ask you for the young researchers benefit. Do you have any advice to people wanting to go into computer science as it is now. Do you have any advice for students or for mentors of students ?

D. K. : Yesterday, when the question was asked to Leslie Lamport and to Tony Hoare, Lamport's answer was so wonderful, he said "Writing.", what to do ? "Writing.". And I guess like monopolizing this too much away from you here but it's the way for me to tell you "Finish this book we're working on." *(R. T. laughs)* because all my life, I found that what I was doing was a sort of convex combination of mathematics and writing. But writing was always very important and keep trying at all that's why I write so many computer programs now.

R. T. : I certainly have to agree with that, right right right, rewrite, but it's a hard challenge. Ideas are worthless if you cannot communicate them with other people and the best way to do that still is to get them down in old-fashioned paper, I would say.

D. K. : And the other thing that came through from that dialogue yesterday which I would say in different way is that don't be too much influenced by trendy stuff. Don't write a paper because you have to write a paper or because you think that you have to impress people about something that you aren't personally interested in but you're trying to make an impression. That's the worst reason to write a paper ; the model that I like to think of this is Euler whose papers were always very impressive but because his attitude was he wanted to tell the people what was impressing him.

R. T. : Yes, I think Alan Kay who also gave a talk at this forum, he had this notion of outlaw ideas getting squashed but... You have to follow your own path somehow, you have to figure out what your own path is and follow it. The best students I've had came in with or ended up with their own ideas that they developed and actually, Pat Hanrahan earlier in the week said I'd never give my PhD students a thesis topic. I require them find a topic for themselves, now, that's kind of a rigorous approach but that's part of what it is to do a PhD, it's to learn how to ask the right questions, it's much more about the right questions than the answers to other people's questions.

D. K. : Here here here and in fact asking questions is something that you've just demonstrated that you know how to do well and *(R. T. laughs.)*

R. T. : Let me ask one more, we are almost out of time here but I noticed that according to wikipedia and this is a question from one of the young researchers, you're known for your scientific jokes, I wonder if you can tell us one of your favourites ?

D. K. : Okay, so *(D. K. shows one of his books open at the right page).* Take a look at *Concrete mathematics* bibliography, reference nº 44, T. Brown, *Multivariable subpolynomial waffles which do not satisfy the lower regular q-property piffles in a collection of 250 papers on waffle theory dedicated to R.S. Green on his 23rt birthday...* And then I have a marginal note. In the margin, it says *Such papers are not cited in this book. (R. T. laughs.)* And that's why I wrote *Concrete mathematics* and you look in the index and you see who T. Brown was and he was Trivial Brown, it's fun to look at the different translations of *Concrete mathematics*.

R. T. : I seem to recall also that your first publication was in an unusual magazine. Can you remind us what it was ?

D. K. : Just a second. *(D. K. stands up and go to look for the magazine in question.)* Okay, someday, see if you can get a hold of this book *Selected papers on fun and games*. It not only talks about basketball but it talks about my first publication which was in Mad magazine, there I am *(D. K. zooms in for us to see well the Mad magazine.)*.

R. T. : So if you want to be done, Knuth, young researchers find a way to get your first article published in Mad magazine. So many questions, so little time, let me thank you Don for a wonderful dialogue and I'm thrilled to have participated in it and thanks to HLF and all the organizers.

D. K. : Okay, I guess we ought to cut, bye-bye.

P. : Thank you bless, very much for the insight and I'm sure your discussion was very inspirational for the young researcher. We really appreciate you both taking the time. Take care and thank you very much.

D. K. and R. T. : Thank you Peter.