A. M. Turing Award Oral History Interview with Juris Hartmanis

by David Gries

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Gries: Good morning! I'm David Gries, Professor Emeritus of Computer Science at Cornell University, although I'm still teaching. I'm here to interview the other professor of computer science at Cornell, my friend and colleague since 1969 when I came to Cornell, Juris Hartmanis.

Juris received the ACM Turing Award in 1993. Let me read the citation to you. "With Richard E. Stearns, in recognition of their seminal paper which established the foundations for the field of computational complexity theory. In their paper 'On the Computational Complexity of Algorithms' they provided a precise definition of the complexity measure defined by computation time on Turing machines and developed a theory of complexity classes. The paper sparked the imagination of many computer scientists and led to the establishment of complexity theory as a fundamental part of the discipline." That's why we often call Juris "the father of computational complexity."

Juris wears another hat. In 1965, he became the first chair of the newly formed computer science department here at Cornell. He's largely responsible for its development. It is due to his vision and leadership that it became one of the top five CS departments in the US.

Juris is a member of the National Academy of Engineering, the American Academy of Arts and Sciences, the Latvian Academy of Science, and more. He has two honorary doctorates. Two other of his awards, the Bolzano Gold Medal from the Academy of Sciences in the Czech Republic and the CRA Distinguished Service Award, CRA being the Computing Research Association. Juris also served as the Assistant Director of the National Science Foundation, the NSF, where he led CISE, the Directorate of Computer and Information Science and Engineering.

One last point. Juris was born in Latvia on 5 July 1928, so in about one and a half months, he will turn 90 years old.

So, Juris, would you like to tell us a bit about your childhood and perhaps talk a little bit about your father, who played such an important role in your life?

Hartmanis: Yes. Well, as David said, I was born in Riga, Latvia, one of the three Baltic countries which line the western shore of… sorry, eastern shore of the Baltic Sea. That is a very lovely area. The Bay of Riga in particular is a beautiful beach area and vacation spot for many of Europeans. And yes, my father was a very, very important person to me and to the whole family for what positions he had held and what happened in that area politically and otherwise.

My father was born in the western part of Latvia, and his family were landowners and there was three brothers, three sons. Clearly, the older son was going to inherit the land and take over the farming business, and so my father had to seek another career. And after finishing elementary and higher education, he graduated from a technical railroad school. And he showed, in general, interest in technical things all through his life, and encouraged me to build things and particularly emphasizing learning.

And so he chose the military career. Since at that time the Baltic states were under Russian influence, the only way, the only military he could join was the Russian army. So he joined and served in a Russian infantry division, and during the time he was sent to military school in Lithuania. And after graduating as a lieutenant basically, he was assigned as a staff officer in a Russian infantry division.

That was unfortunately the time right before World War I. When World War I started, he was in the 1st or 2nd Russian Army, both of which invaded East Prussia. The German response was quick. Their use of their railroads to move around their units, their armies, led to a quick defeat of the 1st and 2nd Russian Army. Those armies basically disintegrated and a large number of Russian soldiers were taken prisoner, including my father. It was fortunate for him that in World War I, officers who were prisoners of war were reasonably well treated. They did not work and they were reasonably nicely housed. So my father spent the three plus years as a prisoner of war in reading, perfecting his languages, learning from other officers, other prisoners.

And the war ended. He immediately returned to Latvia, and by then, Latvia had declared their independence, their sovereignty in 1918, and my father joined the army, which was being constructed at that time. He was a staff officer, and at the same time as… at a time, *[0:10:00]* he was also sent to Poland as a military attaché. And after a while serving in Latvia, he was ordered to the French military academy. He spent two years there finishing the class, which was very interesting, that Charles de Gaulle was his classmate. We have a lovely picture where the first row of officers are sitting in the front row in various different uniforms, not French, and the French officers are behind them standing. And right in the middle, the first standing officer, is de Gaulle, so very clearly identifiable.

So this was a highly selected group of officers. Probably some majors, but mostly lieutenant-colonels, colonels. And actually, for my father, it was a very lovely experience, really learning military diplomacy besides fighting and unit commands. And my mother, whom he had married shortly before, spent the two years with him in Paris.

After returning to Latvia, he continued his career and very soon was Deputy Chief of Staff of the Latvian army. And shortly after I was born, 1928, he was promoted to Chief of Staff of the Latvian army. Not only that, for his service to the liberation of Latvia, he was awarded a country estate, Lestene, in a beautiful park-like setting, a charming two-story house. I was told it had 38 rooms, but I never checked on that. But it was very nicely situated. There were still some original stone walls which originally surrounded the whole complex. And it had land with it which was being farmed, which really helped us during the wartimes. So as children, our summers with the family were spent in Lestene on the country estate, and winters we went to school in Riga.

So it was really a happy and enjoyable life with lots of security. I mean I was proud of my father, who I saw mostly in uniform during weekdays. And his chauffeur had a very strong influence on me. First, I bombarded him with all kinds of technical questions about cars. And the cars were nice. It was a Nash sedan built the same year I was born. And the one which I enjoyed most was a big Mercedes sedan. So the chauffeur really was almost a companion because he stayed with us, and we washed the car. And he explained to me that he is a tank commander in the army and the moment the Latvian army would be involved in some conflict, he would join the tank unit and the tank commander. So I was very impressed. Also, that he was a very good soccer player and helped reinforce the local soccer team.

Well, unfortunately this all changed when I was 12 years old, in 1960.

Gries: 1940. [laughs]

Hartmanis: 1940. Yes, thank you. What happened is that Hitler had decided that he will attack Poland. He did not want to risk a war with Russia, so the foreign ministers Ribbentrop and Molotov signed an agreement, a peace agreement, I mean non-aggression agreement with a clause that Russia would get the eastern part of Poland and Hitler would attack and keep the western part. And there was apparently a secret protocol which said basically that Russia has a free hand, and I should say really the Soviet Union has a free hand in the Baltic states. Well, the result was that the Russians immediately requested a right of naval and air bases in those countries. Same was done for Finland. Finland went to war with Russia, and that's an interesting piece of history, what happened. Resistance of the three Baltics states was just totally impossible.

And almost ironically, and sadly, my father was deputized to be the liaison officer to the Russian units, the air and naval Russian units. *[00:20:00]* The one thing I remember, that my father apparently was working very, very hard to keep out the Russian families of the officers serving there being housed in Latvia. To him, clearly that looked just one more step. And the next step came. The Russians occupied the Baltic countries, certainly Latvia, shortly after that.

That meant that… The school which I attended was a French *lycée*. There were heavy dose of French classes, but a very interesting mix of students. And so out went the French, in came Russian, and for a year I had to listen to lectures on the glory of the Soviet Union, how rich it was in minerals and how great the Soviet army was.

And on Christmas 1940, my father was arrested. The only thing we knew was that he was sent to Moscow. And I think that clearly was, emotionally and otherwise, a real shock. But since we didn't know what happened to my father, I certainly was convinced that he's probably serving somewhere as a general and that we'll meet after the war. So it was several decades later when the Soviet Union collapsed that we found out what happened to him. He was taken to Moscow, there was a trial, and he was convicted and executed in short order. But we learned of that only after the Soviet Union collapsed and for a short while the KGB and other files became available for historians and politicians to inspect. Then we learn about the date and the place where the trial took place. You know, I don't know what he really was charged with, but it didn't matter at that time.

Gries: But when you were 11 and he was taken off, you just thought that he would come back after the war?

Hartmanis: Oh yeah, very definitely. Well…

Gries: And what happened with Lestene at that time?

Hartmanis: Oh, oh, oh. Yes. [chuckles] When the Russians occupied Latvia, Lestene was taken away from us, was nationalized or confiscated, whatever words were used. Otherwise, we were not touched. My mother and my daughter… sorry, my sister, who is two years older than I am, were on a list to be deported to Siberia, and I was very peeved that I was left off. You know, I didn't matter. Anyway, it was a horrible year for Latvians. A large number of people were sent to Siberia, a large number were arrested and disappeared, never returned.

That ended when Hitler attacked Poland, and that was followed by very, very quick defeat of the Russian units in Latvia, and was occupied and we spent four years under German occupation. In school, Russian went out, German came in as a foreign language. And Lestene was being returned to us. So during the tough time, the four years when people all had to live on ration cards and so on,

we had a nice side supply of food and income I guess. I'm sure that we had to deliver certain quotas like all farms did.

Gries: But you didn't have all of Lestene.

Hartmanis: Sorry?

Gries: The Germans lived in Lestene too?

Hartmanis: No, no.

Gries: Or not then?

Hartmanis: No. Lestene was ours, and my mother then clearly was the head of the family and spent a fair amount of time in Lestene. That was under the German occupation. We noticed that certain students did not return to what used to be French *lycée*, which was some… Public School 49 I think, I'm probably wrong on the number, but on the Russians, and then again German language came in. By then, we already all spoke German quite well. That's about the highest level of French I had achieved when it was eliminated as a foreign language. And we noticed that the students who did not return, after some reflection we concluded were Jewish students. So, though the German occupation was hard, we know what they did with Jewish people.

But otherwise, the occupation was harsh, but it didn't seem that unnecessary brutality was used to control it. It is a fact, and a sad fact, *[0:30:00]* that Germans did recruit people or draft people from occupied countries. So two SS divisions were formed and Latvians just drafted. In a very interesting way, a number of people who worked for us on the farm were drafted, but we got a Ukrainian-Russian soldier which was a prisoner of war, apparently well-vetted, to come and work on our farm in Lestene. So Germans were manipulating manpower, and sadly the people who were drafted in the SS had a very hard time explaining and being understood for possibility of leaving Germany for the United States and so on. And a lot of them died. Now Lestene, near Lestene is a very nice cemetery of the Latvian soldiers who were killed in that area during the last part of the war. There were very, very fierce fights around Christmastime '44. Lestene survived and when World War II ended, though we were not in Latvia, it was returned to us again. So Lestene came and went, and gave me a lovely childhood and sad things happening also.

Gries: So the Germans, when they came, did they occupy Lestene at all towards the end?

Hartmanis: No. Uh, no. No. They didn't occupy it until late, or basically 1944 somewhere. When the front approached, they requisitioned Lestene for a German division staff. And so it was taken over as is. We were given some end

rooms which could easily be separated from the rest. So there was a division staff, officers, German officers, lots of them, and we were there, we were from the general there and the officers respectfully treated as a general's family.

Then '44, late '44, middle '44, the German war was really going badly in the east. And in October that year when we in Lestene could hear artillery duels, the commanding general encouraged my mother and our family to leave and promised land and sea transportation to Danzig. Which we accepted, which my mother accepted, and we went to Danzig.

Gries: So you got there by ship, right?

Hartmanis: Sorry.

Gries: To Danzig.

Hartmanis: Sorry. We went to Ventspils, which is a Latvian harbor. And the nearness to Germany, the Baltic countries line up there, were really ideal airbases for German army, German air force. And, similarly, the two Latvian harbors on the Baltic Sea could be kept open in winter, and so that was also something which the Russians wanted, first airbases, later occupation. And we accepted the offer, got to Danzig…

Gries: You missed your first ship I think, right? Do you want to talk about that?

Hartmanis: Well, we missed our first ship. The driver was a German driver with bad Latvian maps, and…

Gries: No GPS at that time. [laughs]

Hartmanis: No. No, no. And so we got to Ventspils too late to get on the ship. The ship left. But there was another ship leaving in a few days. There is some evidence, but not really confirmed, I don't know any confirmation of it, that that ship was torpedoed. Because the Baltic Sea crawled with Russian submarines. The other ship, it's a day's trip from Ventspils to Danzig, and we got there. We were asked where we want to go and we said Marburg, which is a small university city in the west of Germany.

Gries: It's north of Frankfurt.

Hartmanis: North of Frankfurt, yeah. Frankfurt is a major… Köln is also close. We got to Germany, the whole family. My sister, by then she had a husband. We both, my sister and myself in different displaced person camps, finished high school, Latvian high school in Germany, in Latvian, everything Latvian. The good thing in that was that we got superb teachers. Teachers were respected in Latvia and well trained, but these were people with academic, real academic, who were

even professors at the university, who had fled Latvia as the Russians advanced and were delighted to have something to do *[0:40:00]* in the displaced person camps.

So first, I was in a displaced person camp in the British occupying zone, in Blomberg. A very nice little city, but crossing the occupation zones was not terribly easy. Anyway, so after two years in Blomberg high school, I transferred to Hanau displaced person camp to go to the high school there, which was much closer where my mother was in Marburg. And I graduated and returned to Marburg, went to the university, enrolled, they accepted me as student in physics. So there I was in physics at University of Marburg, spent two and a half years. Two real years. The last one was when we were ready to leave for the States. And I went and took my *Vordiplom*, the exam before you get the diploma, graduating, did well. And after that stay, when we finally were allowed to come to the States, you had to have a sponsor. We had a sponsor, a friend from Latvia who was an architect and worked in Kansas City.

Gries: How did your mother make a living?

Hartmanis: Ah. Yes. Anyway, so we went to Kansas City and the sponsors really helped there and questioned, how did we survive financially? Well, when the Russians arrested my father – well, actually the Latvian police did the arresting – they took lots of things. They took all my father's medals, a big box of all kinds of local… sorry, Latvian and foreign countries' medals. But they failed to move a painting and discover there was a little safe behind it. So not very professional. And there were British pounds there. Clearly, foreign country… sorry, foreign currencies were illegal. Under occupation, you couldn't own them. You had to surrender them. Well, my mother took the English pounds and they were exchanged when we got to the States, and we were surprised how strong the pound was in those days.

Well, my mother, when my father was arrested, decided that she must have some skill, and she enrolled in a school in dressmaking. Or, sorry… Yeah, basically…

Gries: Seamstress?

Hartmanis: …dressmaking. And when she got to Marburg and the Allies – the Americans occupied that part – she started basically copying the recent fashions from American magazines. And very quickly, just by word of mouth or seeing them, she developed, while we were in Germany, a reasonable business in the kitchen in the house where we had a small part of an apartment. And when we came to the States, she got a job as a cook in a rich family.

But how it all worked financially… I know that her sister, who also left Latvia and was in Germany, sent some money to help. But really, it was her labor and it was

mostly the sewing which allowed me to study at Caltech. And it's really quite an achievement on her part. She guided us well and supplied us.

Gries: So you ended up coming to New Orleans and taking the train to Kansas City?

Hartmanis: No, no, no. I was supposed to come from Hamburg to New Orleans and then by train to Kansas City where our sponsor was. A big cold storm hit and the B deck on the ship cracked, had a crack. We and my ship buddy had no idea how dangerous this was, but we discovered that there was a small group of sailors and some officers who were observing the crack as it slowly moved forward as the ship was rolling in the waves. What they tried to do is they tried to trap the thing. So they would make, the officer would make a cross. I mean they were sweeping the snow away, make a cross. And the sailors, a sailor with a big drill drilled and a couple guys held wood blocks to keep it in place until it really dug a hole. And the first one missed, the second one missed. They drilled a hole and the crack bypassed it. And then on the third one, finally it went in and to a great sigh, the deck, the gap, the hole… sorry, *[0:50:00]* the crack kept oscillating bigger and smaller, but the drilled hole trapped it and it didn't continue.

So the ship was damaged, they had asked other ships to standby because it was touch and go, and they routed it to London… ah, ooh … to New York, which was the closest big harbor there. And there stood an identical ship to ours. We moored next to it, I think very close, and were told just to go to your cabins, go to your rooms, go to your beds, and we just slowly transferred everybody exactly to the same situation where we were on the other ship. And then we took off for New Orleans. I don't think there is an official register anywhere in my papers or my… which says, "First entry, New York." No. It's "First entry, New Orleans." And then we were in Kansas City.

Gries: Yeah. And you had a couple jobs before college?

Hartmanis: Yes. I was building combines, and then either bad weather or whatever predicted smaller sale of the combines than expected, and I was let go. But by then, I had an American godfather, a nice man, nice family, friends of our sponsors, who got me another job, at Sheffield Steel. So I was a steelworker, joined the union, was more or less told to join the union.

Gries: [chuckles] They were strong then.

Hartmanis: And meanwhile, the university counted in my *Studienbuch*.

Gries: So you applied for undergraduate school?

Hartmanis: Well, I applied to the university…

Gries: … to university.

Hartmanis: …and gave my papers, all lists of the courses I attended, which are all recorded in the *Studienbuch*, "study book." And they said, "You have so-and-so many credit hours. You must have a bachelor's degree. So you will be a graduate student." I thought, "That's fine. Roughly two years in a German university, I have a bachelor's degree?" Unfortunately, I wanted to study physics. No graduate program in physics. But there was they said a good math department, "And so you will be happy studying mathematics." I was. Kansas City was nice.

Gries: That's how majors are chosen. [laughs]

Hartmanis: No, I didn't…

Gries: We think… Ah, yes, we think we're choosing things, but life chooses it for us.

Hartmanis: Oh, no, no, no, no. I know that in my life, many decisions I didn't make.

Anyway, so I became a graduate student in mathematics. For the first time in my life, had a straight-A record. Never before. And my mother by then spends a year as a cook for a lady who was married to a very fashionable and good doctor who was also associated with the University of Kansas, Dr. Hashinger. Very kind. Probably wrote me a great recommendation for Caltech.

Gries: So Juris, you finished your master's degree in mathematics at Kansas City. What happened then?

Hartmanis: Oh. Well, what happened? I…

Gries: [laughs]

Hartmanis: I wanted to continue my education. You know, that was instilled in me, that I was going to get…

Gries: Your father did a good job.

Hartmanis: Yes, indeed. Well, so since I was going to continue my education, I had to have a university. And I got all kinds of advice, but I applied to three or four universities. I applied to University of Nebraska, University of Kansas, and Caltech.

Well, why University of Nebraska? The answer is very simple. The President of Latvia had an agricultural degree from Nebraska. I think a PhD, but I don't know

exactly what kind of degree. And since he was related by marriage, he was married to my mother's sister, and he was the brother of the President of Latvia. So we had heard a lot about American graduate education and about Nebraska, and I thought, "If the president went there, it must be a great university."

I was admitted to all three schools, but I applied not saying exactly what I want to do. I said, "I want to get a PhD in mathematics or physics." Well, my friends there said, "Don't be a fool. Go to Caltech." I applied to Kansas because Dr. Hashinger had been a dean of medical school there I think and it was a guaranteed getting in if he writes a recommendation. Well, Caltech assessed my physics knowledge, well, *[1:00:00]* … sorry, truly, that it wasn't great. And they said, "You look like an applied mathematician." I never took a course in applied mathematics. So the physics… sorry… the mathematics department admitted me and said that I will be happy, it's a very good department, and it was.

So I went there as a graduate student. I bought my first car and my mother and I, we drove from Kansas City to Pasadena. Arrived there. I met Elly, who later was my wife, whom I married later, again through kind of diaspora. And went to Caltech, find it an amazing place. By then, I knew a lot more about it. A small university, I think about a couple hundred undergraduates, probably more graduate students than that, and tremendous research activities. What impressed me, that I knew that they had some Nobel Prize winners, but they had so many. I didn't realize. Somebody called Anderson, Millikan, Feynman, and easy several more. And Linus Pauling. You know, they had really lots of them. And superb students, the undergraduates. And, you know, it was just a superb school.

And it was men-only until the year I arrived. [laughs]

Gries: [laughs] Nothing to do with you.

Hartmanis: Nothing to do with me. But women were phased in slowly during the time. There might have been 10-15 by the time I left.

And that was for me a wonderful experience. Pasadena is a nice place. There're mountains next. Mount Wilson Observatory is there, you can just drive up. The ocean. Hollywood.

Gries: The Rose Bowl?

Hartmanis: Rose Parade.

Gries: Rose Parade, yes.

Hartmanis: Rose Parade, Rose Bowl. Well, Rose Bowl I didn't attend, but I played volleyball in the Rose Bowl park. And so I had an exciting time as a

student and just lots of other things to do. If I would have been in physics, I would have been slaving…

Gries: That much harder.

Hartmanis: …hard to keep up, because there they were, the physics students. They probably had some in high school, and then intense four years at a great school, and then they came as graduate students. They were a very, very select group. So were the mathematicians. I'm sure that Hashinger's recommendation and so on wasn't only on my academic standing or academic knowledge, because I got in among a very small group of people and just had a great time there. Elly was there. We had joint friends.

Gries: And you lived with your mother there?

Hartmanis: No.

Gries: Or did she go back to Kansas?

Hartmanis: No, no, no, no. She came there and she was a cook for a Nixon. family. Hixon? Yes. I think it was Hixon. It was not "Nixon." [*]

Gries: Not… [laughs]

Hartmanis: Anyway, so I had some very good colleagues there and life was just nice. And…

Gries: But then you had to write a thesis.

Hartmanis: Yes. And somehow I was I guess assigned to Dilworth. Somehow I knew I was under his supervision, and he was doing lattice theory, so he said, "You need a topic, and why don't you work on the partition lattice embedding problem?" Partitions are just take any set and carve it up in disjoint sets. Nothing joined. They're all separate. And these can be ordered according to the size so that the higher-upper ones in the lattice have to contain in there possibly larger blocks completely from the smaller ones. So it's easy to order them. And the embedding theorem was simple. Show that any finite lattice I give you, you can find that as a sublattice in this partition lattice. Namely, I can represent every lattice where the elements are partitions, and you combine them in an easy way.

Well, it's a good problem. [chuckles] It was clear to me that it was very, very tricky and there was nothing kind of general theory which I could apply. So I started reading *Lattice Theory*, a book I could find. It was Birkhoff's book. Nice, thin volume, not a discouraging book. *[1:10:00]* But then I looked at the problems

[*] In subsequent communication Prof. Hartmanis indicated that the family name was indeed Nixon.

at the end of the book, research problems, and there was my partition embedding problem. I went to Dilworth and said, “This is a hard problem. It’s in this book.” Dilworth said, “Oh, don’t worry. I was asked to review the book and in my review, I solved several other problems.” Well, that was not a very encouraging comment. There’s Dilworth, well-known lattice theory researcher – well-known, I mean – and he says, “I solved some of these problems.” Bright, brilliant full professor, he solved some of the problems.

Gries: But not that one.

Hartmanis: Not that one. But I thought, “Well, that may be really indicating he has respect for my abilities.” Well, there was nothing to be admired what I could do. I basically worked on it I don’t know – I wish I would have kept a log – how long, but I said, “I got to look around that problem.” And I said, “You know, there’s no overlap whatsoever. That’s maybe a little bit too harsh. What if I allow one overlap between the blocks, at most one? If the blocks overlap in two or three, they merge.” So I labelled it “generalized partition” and started working on it. And I proved some nice properties about it. And I said, “Well, what is it? What in mathematics behaves like this? One intersection is fine. More than one, you got to lump them together.” I said, “Those are lines in a geometry. They either don’t intersect … certainly not … they don’t have any parallel, but when they intersect more than one point, the lines are merged.” And I said, “By golly, these are lattices of geometries.”

And off I went, “I’m going to solve this embedding problem,” and I did. It took some cleverness. But when I told Dilworth, showed him the idea roughly how I had done it, he said, “Write it up,” and it basically meant “You have a thesis.” I think this was probably in the third year at Caltech, but I don’t know exactly. I also wish I would know how long I worked on it. It took me some time. But I was just absolutely delighted. I had defined this problem because I couldn’t solve the other one, and it turned out to be a nice object. Lattice of geometries. And there were now nice little results to prove. That the lattice I think of all geometries I think was again a geometry. There were things … You know, things that came out of there were geometries several times, and not only that, I define it myself and it had an interesting solution.

Well, it really first time gave me pleasure of having done it, and real encouragement that “Yes, I can do it now.” You know, “I know how to do research.” Well, Caltech concluded the same, and so after four years at Caltech, I had a PhD in mathematics.

Gries: That’s neat. It’s a good, nice story. I think more of our PhD students have to hear stories like this.

Hartmanis: Well, if it encouraged somebody to do research and he succeeds, more power to that result.

Gries: So you've finished your PhD and you came to Cornell. How did that happen?

Hartmanis: Well, like so many things, things just happened to me in life. Bob Walker, I think the chairman of the math department at Cornell, was looking for instructors. They had just switched teaching calculus in a large class to many small classes, so they needed instructors. The starting academic position for fresh PhDs were instructorships. So my friend Johnny Johnston at Caltech and myself got offers from Walker to come to Cornell and join the math department as instructors. Dilworth's advice was "Go east, young men." He said, "to the elite east," and he thought Cornell was just fine.

So we drove with my mother to Ithaca, arrive, found that Ithaca was full. The students had rented all the places ahead of time. And we finally found a small apartment. Well, I don't even remember what the street was. Walking distance to Cornell, easy walking distance.

Gries: Belle Sherman somewhere.

Hartmanis: It was one of the apartment houses. You know, there's a huge, big… This was when the man had built the first one before he built the very large one. So very professional, nice apartment, but it was Johnny and myself and my mother. You know, it was a lovely way. We had nice dinners prepared and we were taken care of nicely. *[1:20:00]* And…

Gries: What did you spend? Two years?

Hartmanis: I spent… Yeah, I spent two years, but it just happened that a GE manager from their research laboratory who was given the job of building an information sciences research section… Well, very quickly it got translated to that it's "computer science," but it was "information science" originally. And he stopped by at Caltech – name Shuey, Dick Shuey, Dr. Shuey – and said, "We need people for the information studies section." And [laughs] Dilworth apparently said, "I know the guy you need! He's at Cornell." Shuey showed up at Cornell and said, "I come from Pasadena and you are being recommended to me for information studies section."

Gries: This is GE in Schenectady.

Hartmanis: GE in Schenectady, Research Labs, on the bend of the Mohawk River. I said, "Sorry." I had agreed to go to Ohio State to work on the lattice of groups, because Marshall Hall, the guy who invited me there, was at Cornell visiting for a lecture. I told him about my thesis. He said, "Oh! I am just thinking about lattices of geometries… groups." Sorry. So I said to Shuey, "I can take a summer job, but that's all, because I have to be at Ohio State for at least a

semester." He said, "Come," and gave me at time looked to me like a royal salary.

And it was a beautiful group of people, just all hired, and being hired. They're looking for people really excited about computing and particular creating a computer science. And…

Gries: Dick Stearns was there?

Hartmanis: No.

Gries: Not yet?

Hartmanis: No, not yet. I accepted for the summer, read a lot, listened to lots of stuff about computer science, whatever it was in those days, and somebody… And I read a paper about coding networks and wrote a paper that summer, which never occurred… sorry, never happened to me before, that I enter a new field, write a paper on a summer job.

Well, I was hooked. Computer science seemed to have all kinds of problems on which I knew I could work. And GE basically, Shuey said, "If you want me to hire you now, I will hire you now, but I want you back when you finish your Ohio obligation." Well, I went to Ohio State. Huge university. I had some nice colleagues, and I went there as an assistant professor where many of the people were still instructors. But our work with Marshall Hall didn't work. I was intellectually packing to return to the GE Lab and Marshall Hall had accepted a job at Caltech. What a small world! So, you know, we talked, but I wrote up my thesis papers and got them published. But publication then in journals was slow. The refereeing could last months.

Gries: Years sometimes.

Hartmanis: Yeah, yeah. And very often they asked you to rewrite things. It was different than submitting it to a journal… sorry, submitting it to a…

Gries: Conference.

Hartmanis: …to a conference, yes. Which is a publication, but less prestigious at least in the traditional view.

Gries: So you spent a year there at Ohio State?

Hartmanis: Nine months.

Gries: Nine months. [laughs]

Hartmanis: Nine months.

Gries: Got out as soon as you could.

Hartmanis: Yes.

Gries: Back to GE.

Hartmanis: Went to GE. This time there was Dick Stearns. I don't know exactly. He was either there or joined us next summer. Stearns was doing game theory at Princeton, was clearly a very, very gifted person, and very laconic. He didn't say anything when he didn't have to say something important.

So I returned to GE Labs. At that time theoretical work in computer science was with switching circuits, finite-state machines, and things like that. And there was a problem which intrigued me, and that was when you want to build a finite automaton, you know what it's supposed to do, so you just see how many states you need and how the machine has to move around these states and what it has to print, it gets inputs. But nobody said, "How… What will the states be called?" They must have a whatever length, the minimal length of codes you can assign to have it built. *[1:30:00]* And so the movement in the states didn't really tell you how to choose the names which determine how the circuits will look.

There were lots of nibbles at that problem. I, kind of thinking about my background, said, "Well, maybe you don't have to really worry about the states for this big machine. Maybe you can build this machine from smaller ones where the problem would be easier." So I quickly defined partitions with substitution property, basically just what the people did in mathematics, and by golly, these machines did fall apart quite easily. So I wrote a paper "On the State Assignment Problem for Sequential Machines" by saying, "Build it from smaller machines, and here is the technology how to determine how they can be built," and really got enamored by the machines. And clearly now these lattices… sorry, came out of the partitions which were preserved by mappings of the machine a nice lattice. You know, different partitions did different things. And it was accepted and people were delighted about it. So I had my start.

Then Dick Stearns showed up. I either was just finishing that paper… And with Dick, we had real fun because he was very, very quick, very smart, very silent. And we generalized not only on what partition, how the machine transforms it to another partition one operation, and we had defined an algebra of partition pairs and got all kinds of results.

For example, when you give me a machine, an automaton, just the state table, we had techniques to see how much feedback will have to be in the machine. Namely, there will have to be loops. Clearly if there are no loops, there's a definite way of building it and we could ask questions like "What is the

smallest…" sorry, "What is the biggest part which I can to say 'break off' which has no feedback?"

Gries: And has no loop, yeah.

Hartmanis: So we could really do structure of these things, and we could give you techniques, biggest front part, no feedback, and then biggest tail part, no feedback, all the feedback is in the middle. So it looked very interesting. We wrote a book, just… And we were full-time researchers. We had no other obligations but to kind of spread a good spirit in the company about computing.

Gries: Now they had something different in those days as opposed to today. You don't find these research labs where people are free to do whatever they want for years and years. You always have to do something to get a product out for someone. Bell Labs used to be that way. The transistor was developed in the same kind of fashion.

Hartmanis: Yes.

Gries: The language C and Unix came out of Bell Labs simply because these people were free to do whatever they want and they wanted to build an operating system.

Hartmanis: Yes.

Gries: It's different today, in my mind.

Hartmanis: Well, yeah. But the people who really were allowed to do whatever they wanted had somehow already proven their originality, their ability, and they were not very many.

Gries: No.

Hartmanis: They were many at the GE Research Lab who worked on artificial diamonds, and GE made billions, particularly on small ones for grinding and so on. Yes.

Gries: So you and Dick worked for two, three years?

Hartmanis: No, no.

Gries: Two years?

Hartmanis: I was there I guess seven years.

Gries: Seven year-… Ah, okay. This was some time.

Hartmanis: And I have to recompute and rethink when I went there, and I can make mistakes on that.

Gries: Sure. But it was a substantial time?

Hartmanis: Yes. And Dick stayed after I left for Cornell.

Gries: I see. And that's where you did the work that got you the Turing Award?

Hartmanis: Yes. *Algebraic Structure of Sequential Machines* was our book published. Several editions were out. But all of the theoretical work in computer science really moved to bigger things. Pushdown automata. Turing machines sat there and people knew it was an awful thing because it was so complicated to write…

Gries: To write programs in it.

Hartmanis: …programs. And when Dick and Stearns really… we knew about Turing machines, but we had never viewed it really as a real model for computing. We knew it was, I mean because you could prove there are universal Turing machines and on and on. But we started asking questions which were quantitative – "How much better is a many-tape machine than a one-tape machine? How much faster can the many-tape machine compute problems?" People hadn't asked those questions. And what we really were after, "If we modify a Turing machine, how much does the computation time on the Turing machine change?"

So what if the question gave you many tapes was easily solved in the square of the time of the one-tape machine, whatever it took. We were delighted when we discovered *[1:40:00]* that you could have a two-dimensional tape and you lost only a square in the computation time. And so on. We found that however we modified the machine with what we wanted for ease of programming and things like that, we could put a quantitative thing, and most of them are really squares and things like that. So we realized that it was a good model.

Gries: It's a good model for studying computation, not for actual programming. There's a difference between having a language in which you can program and one where you don't really want to write lots of programs, the structure is so simple that you can study it.

Hartmanis: Yes, exactly. But by then compilers were already being constructed, and we knew that whatever language you have, you could build a compiler to compile down to a Turing machine. You know, a horrible compiler, but… No, no, that's what scared people away, and we just said, "You never think about doing it in the Turing machine. You know you can compile down from any language," and

that “If you do tinker with a machine, we can quantize how much damage you have done.”

Then we said, “Fine, now we define complexity classes,” and there we hit on the right thing without thinking much, that the difficulty of the computation should be in terms of the length of the input, not the particular input as they do in recursive function theory. It’s always *x*. Complexity classes just defined how fast a function has to grow in the length of the input. And, you know…

Gries: That was it.

Hartmanis: …Manuel Blum was doing in some sense a parallel development of axiomatic complexity theory. Very simple. A couple axioms. If they satisfy, that was a measure given by somebody. And they could prove all kinds of things. They proved some very strange things. Surprising things.

And we had one such result just after I stopped being at GE. When I went to Cornell, my first student in computer science called Borodin proved the gap theorem, and we had hierarchy theorems. Hierarchy theorems said, “Slight increase in the computation time gives you things which you cannot do in the lower bound with a growth 1:44:30].” So computation times which can be done time $n^{2.001}$, there are functions which you can compute in that time but not in n^2. So just the two bounds basically have to go to zero. It’s a little bit of technicality that a log factor shows up, simply because you have to also not only diagonalize over a set, you have to compute while you’re doing that the bound in which you have to do it. So a clock had to be running which says, “No more.” Originally, that was a square in the time. Stearns and Hennie showed that you can do many tapes on one tape basically by losing the log factor, log *n* in this case. Anyway, sorry.

Gries: That must have been an exciting time. Why did you leave and come to Cornell?

Hartmanis: Well, I had always had the dream, the expectation that… It’s a tenure. Such a wonderful thing. Clearly in our original understanding much more powerful than it really is, but permanent position. In those days it was probably to age 65, and there was an idea that academic jobs are good. And Bob Walker, the guy who hired me for the Cornell math department called up and said, “Juris, we are starting a computer science department. We have a million dollars’ research support for it, so you won’t have to worry about money for a while. Everybody is enthusiastic about the department.” I said, “The mathematicians?” He said, “Some, yes, definitely. They will join if you ask.” And Walker himself would join the department until we find younger replacements for him.

Anyway, so he said, “Why don’t you come out?” Elly and I, we drove out to Cornell. It looked so ideal, I mean so clean.

Gries: Compared to Schenectady?

Hartmanis: Well, Schenectady was different because you do have awareness that you really have to do excellent work if you want to be independent. You really have to. You're still working for a profit organization. So I accepted. Tenured professor. They couldn't give you tenure like that, but they said, "It's a tenure."

Gries: The promise of tenure, yes.

Hartmanis: "It's a tenured offer," so and so, and money was discussed later. Sorry, after other discussions, *[1:50:00]* money was settled. Sorry. So funding, Mathematics, Electrical Engineering are in favor of starting it.

Gries: Operations Research also.

Hartmanis: Operations Research would give Dick Conway to us. Dick Conway turned out to be very important when I started building the department, when I accepted and came to Cornell. Conway did things which I needed encouragement and support.

Gries: Like the course load?

Hartmanis: Like the course load. I was amazed that nobody informed me what the course load at Cornell is, and I didn't ask. I knew what it was in mathematics and in some humanities. But I decided that one course a semester plus participate in a seminar, which meant you can either run a seminar or participate in somebody else's seminar. And we could pay better salaries than what was the going rate for computer science assistant professors. And I didn't know it could be done, but when I was asked what would it take to get somebody, I said to the dean such-and-such salary, "Fine." Tenure? "No. Associate professorship, no tenure." "Oh, okay."

Gries: I came here as an associate professorship.

Hartmanis: So on a five-year assistant professor, they had the title, and that's how Hopcroft was hired.

Gries: Me and Dennis. John Dennis also came as associate without tenure, I believe.

Hartmanis: Yeah, but was he not a little bit older already?

Gries: No, he was my age. Three years…

Hartmanis: No, but I mean academically.

Gries: Academically, yeah, about the same. Close. Yes, very innovative. So you came here to start the department. I think the provost had a different idea of what the department should be.

Hartmanis: No, no.

Gries: Than you did.

Hartmanis: The dean…

Gries: Dean.

Hartmanis: Sorry, sorry. Vice president for research.

Gries: Vice president, yes.

Hartmanis: Was basically in some sense under the vice president of research, that he had rights to say, because he was administrating the Sloan Foundation grant of the money which was paying. I mean those were under the vice president. And very early I detected that he did not want the department to grow fast, and my idea was "Grow as fast as you can while you have the money, the initial publicity, and all that."

And first or second year, basically Engineering took over our budget. Dean Schultz was basically the man I dealt with, and he was decisive and good.

Gries: He was also a friend of Dick Conway, came from the same area.

Hartmanis: Same department. Yeah.

Gries: So you did a great job in my mind of getting good people here for the department, the first 5, 6, 8, 10 years.

Hartmanis: Well, as you know, I take great pride that three of them – you, Hopcroft, Constable – are still here…

Gries: Yeah, we're still here.

Hartmanis: …and, you know, have contributed tremendously to the growth and the intellectual environment of the department and so on.

Gries: And the other thing about the department is that it's always been congenial. Very rarely have we had political fights. You did a great job of setting it

up so that everybody respected everybody and it continues to this day. It's different, yes.

Hartmanis: And I hope, I sincerely hope it continues forever. We are by now big. You just have to attend the luncheon, the faculty luncheon to realize that there are long discussions about hiring, who should and should not be considered, and so on.

Gries: Let's talk about research. I find it interesting that OR did not seem to get involved in complexity issues. Did they? I mean they had the travelling salesman problem, but they never looked at complexity issues. They are in it now a lot.

Hartmanis: Yes.

Gries: In fact, ORIE is no longer "Operations Research and Industrial Engineering," it's "Operations Research and *Information* Engineering."

Hartmanis: Yeah.

Gries: Yes. So did you talk to OR people at all much?

Hartmanis: Well, Dick Conway was a…

Gries: He certainly, yeah.

Hartmanis: …full professor of OR. And, as I said before, and it's certainly worth repeating, I was surprised how little direction I got what to do with the department. That gave me a chance with Conway sitting there…

Gries: Pushing you on.

Hartmanis: …and just saying, "Do it."

Gries: "Do it."

Hartmanis: "Do it." You know, I was quite shocked when Conway walked in one day and said, "Juris, you got to write an annual report." "What?" He said, "Okay, okay, I'll give you an annual report from another department." Anyway, things like that kept popping up, and Conway was good. He knew. And he also knew that very often minimal responses to the … not orders but the regulations, whatever, traditions … were quite acceptable. No, I mean he was very influential.

Gries: Yes. One of the important problems is still open. That's P = NP.

Hartmanis: Yes.

Gries: Have you tried to solve it?

Hartmanis: Oh yes.

Gries: Or your students?

Hartmanis: Yes. I know it's a very… it's an amazingly hard problem, but we don't understand why. Well, speaking about such things, just the last year when I was at GE *[2:00:00]* when we did context theory and very excited all the time computations and so on, Phil Lewis was needling us about doing tape complexity, memory amount in computations. How fast does a memory have to grow? And that we explored quickly and had our great surprises. One, the P and NP problem basically asks, "What does nondeterminism buy you in computation?" and it's *the* open problem for sure, and it's practically important.

Well, we know shortly after, and now it flows in that I'm at Cornell, and so students start working for me. And I will not try to differentiate exactly where what was done…

Gries: No, that's tough to do.

Hartmanis: …but Immerman showed that nondeterministic tape computations are closed under complement, so when you take the complement, it can again be done by another nondeterministic tape-bounded computation. Now that's exactly different than what's happening in P and NP, because clearly the complement of an NP problem we certainly don't believe is again NP.

So for tape, we know something which is completely different than for time, and for tape, now there's a much a stronger… there's actually a stronger result by Savage. Savage showed… Sorry, we showed, Stearns and I, that you have S size nondeterministic tape computations, then you know that you have S^2 tape-bound deterministic tape computations.

So there nondeterminism doesn't buy you much, which is quite different than we believe is the case for time…

Gries: Than with P, NP, yes.

Hartmanis: And there were other things which tape was very interesting, amusing. The one is that we asked ourselves, "What happens at very, very small tape bounds?" Well, how can you have very small tape bounds? The input is length *n*. Okay? So we said, "That's input tape. You can't work on it. You will get another tape which you will put below the machine which is a working tape, and the complexity is measured on how much of that tape you use." And we very quickly proved that you can go down to log log-tape computations, so you can't even count to the length of the input, which you can at log-tape. Log-tape had

been used somewhere, and we said, "What's down there?" And one thing was we discovered context-free languages down there which are not regular. So context-free languages which are accepted by pushdown stacks, and pushdown stacks are good for counting, comparing length, but you can only have log log length.

Gries: You can do it in just…? I didn't know that. Hmm.

Hartmanis: Yeah.

Gries: Neat.

Hartmanis: And not only that, you can also think about the nature of numbers. Let's think that we'll just look at finite or infinite strings of decimal or binary – it doesn't matter what – and now measure… Lost my thought.

Gries: You're looking at number of digits, integers.

Hartmanis: Well, no, the interesting ones clearly are the algebraic numbers, solutions of polynomials and so on. They're all in n^2. Sorry. Yeah, in the square of the length. But we don't know whether, if you define numbers to be real-time computable, that you can print the sequence of digits out in fixed intervals or, best of all, one after the other. So that's real-time, and there are real-time transcendental numbers we know. But we don't know where square root sits. You know, these digits. We know how to compute them…

Gries: But you don't know how fast or how much tape.

Hartmanis: …but the time keeps increasing. And so we have a conjecture which said if something is real-time computable, then it got to be either periodic eventually, I mean a rational number, or a transcendental. Now that's an amazing conjecture, which one computer scientist labelled "the True Hartmanis Conjecture" or something like that in a technical report.

Anyway, so all kinds of interesting questions are still wide open.

Gries: So you really started something way back in '58, '62, '64 about a whole field. And I think not only CS but the whole world owes you a lot of thanks and honor for doing this. It's been a tremendous career. And I'm happy to have known you and have been able to sit here and talk with you.

Hartmanis: Well, David, it's been a pleasure to have hired you and a pleasure to have had you as a colleague and friend. *[2:10:00]* And yes, it's been a great experience, exciting, and…

Gries: And it still is, although I don't understand most of what's happening these days with the machine learning and the deep learning and all these things. All sorts of things happening in the field.

Hartmanis: Well, yeah.

Gries: And so let's hope this department keeps going stronger and stronger with good leadership.

Hartmanis: I sincerely hope so. Part of my enjoyments now come from watching it grow, and I think there are some very, very good people among the young authors, and clearly… Yes. So thank you very much.

Gries: Well, on that note, we'll quit. It's been wonderful.

Hartmanis: Thanks.

Gries: And we have many more years together.

Hartmanis: Good.

Gries: Good.

[end of recording]