1. Early Life Through World War II

IRV LUSTIG: It's my pleasure today. My name's Irv Lustig from Princeton Consultants, to be interviewing Egon Balas, who's from Carnegie Mellon University. He's one of the distinguished members in the integer programming community. And we're here to learn about his life and career in optimization.

And I know Egon has written a very interesting, fascinating book called *Will to Freedom, A Perilous Journey through Fascism and Communism*, which tells about his life prior to becoming somewhat involved in optimization. And I think his story cannot fully be told without getting a summary of those early years that then brought you eventually to getting over into mathematics and optimization.

So can you provide that summary that's, I realize it's difficult to summarize a few hundred page book in a few minutes. Tell us about your journey that began in the early part of your life.

EGON BALAS: Well, I will try. So I was born in 1922 in the city that today is called Cluj. It's the capital of Transylvania, Dracula country, which by the way, it is not. Dracula is an invention of Bram Stoker and the myth is not known in those parts of the world.

I was interested as a high school student in mathematics and physics. I was an enthusiast of relativity theory, modern physics. When I was 17 my dream was to understand the mathematics of that theory. And had the war not intervened, I would probably have become a physicist.

However, the war intervened. My town, Cluj, which belonged to Romania, was in 1940 attached, along with the whole of northern Transylvania, to Hungary. It became Kolozsvar. That's where I finished my high school studies in the Jewish gymnasium of the town, which was an excellent school because many of the school teachers were academic level persons who were not academics for the sole reason that they were Jews.

The war, which broke out in 1941, completely upset my plans. In Hungary there were anti-Semitic laws. As a Jew, I was not supposed to go, not allowed to go to university. I became a factory worker first in a foundry, then in a lathing shop. I was upset, as most of my fellows, most of my colleagues, by Hitler's and the Nazis horrific deeds. And I joined the underground communist movement, which at that time was the only force in that part of the country which resisted actively Nazism .

One may be surprised today in 2016, how can somebody choose Communism? But you must understand that in 1941, democracy was a highly compromised notion all over Europe, because Hitler easily conquered in several weeks all the European countries that were democratic. It seemed as if what he said about democracy being rotten, it seemed as if it were true in Europe. So again I joined that party which actively fought Nazism. I became a union member. I organized a partial strike. And my main activity was distributing a clandestine anti-war leaflet for which, for the distribution of which, I organized, I recruited 10 people.

I had to go soon underground. I lived with false papers for a year. I found myself a hiding place. At the end of August '44, for the first time it seemed that I might survive the war, I was arrested on the same day when the Allies entered Paris. I was taken to Budapest where I was tortured by the Hungarian gendarmerie. They would probably have killed me or broken me as they killed many others. I was very, very lucky. I managed to resist for three weeks and didn't give away anybody, but after three weeks fortunately, my ordeal ended because the Russians occupied my home town. So the gendarmerie in Budapest lost interest in me. Sent me over to trial. I got a sentence of 14 years, which now seems horrible: 14 years of forced labor; but at that time it was either life or death and the sentence meant life.

I spent several months in jail, after which we were put into a convoy to Germany by foot. I managed to escape from that convoy, together with a fellow inmate. We spent three months in the Hungarian countryside of early 1945, extremely adventurous. Adventures which I don't discuss now, but are described in my book.

Finally I was liberated, went home. At home I found that my family was killed. My hometown, Cluj, of about 110,000 people had 18,000 Jews. So every fifth, sixth person was a Jew. They were all deported and mostly killed. Out of 18,000, less than 2000 returned.

At home I enjoyed, at the beginning, great respect because I had resisted torture and not given away anybody. So I was soon recruited for the foreign ministry because I spoke several languages and I was sent to London as a diplomat. In 1948, I spent there a year. I was the youngest member of the diplomatic corps. When I returned, I was appointed Director of Economics in the Ministry of Foreign Affairs.

2. Economics in Communist Romania

EGON BALAS: I didn't mention that right after the war I enrolled as an economics student in my hometown. Without attending classes, I studied on my own, took exams, and in 1948 got a degree in economics.

IRV LUSTIG: And that was in your undergraduate degree.

EGON BALAS: That was my undergraduate degree, it was in economics. After my return from England, actually my conflicts with the regime started right there. I returned from England. I gave a report in the foreign office and I described the situation in England as I saw it. Namely, I said that what our newspapers are writing is not the actual situation in England. The English working class is not about to revolt and take power. Actually, it is a pretty good situation relative to working people in other European countries. And if there is any hope for the Communist Party in Romania to obtain its goals, then the policy has to be adjusted to reality. There was a huge scandal, but the thing was attributed to my youth. And so I still became director of that economic direction. I functioned there two, three years.

In 1952 the then leader of the Communist Party, a man called Gheorghiu-Dej, started a political campaign against his main opponent called Luca, who was the Minister of Finance, and involved in that Ana Pauker, the foreign minister and a third person, Teohari Georgescu. At first, he

publicly criticized them, then had them arrested. And my best friend, who was the leader of the Communist resistance in Transylvania during the war, was at that time Deputy Finance Minister, in other words, the right hand man of this Luca, who was the target of the right wing deviation. So he was arrested.

And soon after that I was eliminated. I was thrown out of the foreign ministry. There was a kind of a public execution, very much like the *auto-da-fé* of the Inquisition, where people had to speak up and attack the person accused. I was excluded, and a few weeks later, I was arrested. I spent 2 1/2 years in solitary confinement, not allowed to see anyone. Tortured under interrogation, under pressure, they wanted me-- they were preparing a show trial, similar to those that took place in other countries. In Hungary first, then in Czechoslovakia, they wanted one in Romania. I was supposed to be a witness against my friend. I refused.

So for 2 1/2 years my regime was the worst possible. Every week the interrogator repeated that all this could be changed if only I would collaborate. I could have more sleep. I could have a glass of milk per day. I could see sunshine and take a walk in the courtyard. For 2 and 1/2 years I was never taken out into the courtyard. I never had a glass of milk. I never had any of those goodies. I would probably have rotted there had it not happened that Stalin died. And when Stalin died, the pressure on the satellite countries to organize such show trials had ceased. And then in November '54, I and the others who were still alive, were freed.

So then I returned to my activity as an economist. I started teaching at the university. I started publishing. I wrote several economics papers. One revised the Marxist schemes of reproduction, modernized them. It was well received, except my very influential-- one of my very influential acquaintances called me and said "Congratulations on your article, but have you taken out a life insurance policy?" I didn't understand the question, and he said, "Well, our leading economists don't dare to change a comma in Marx and you are reformulating his equations?" That was his question.

I wrote-- I got a job then as a researcher in the economics institute of the academy.

IRV LUSTIG: And this was in Romania.

EGON BALAS: In Romania still, in Bucharest. And in 1957-58 I wrote a book on Keynesian economics. To explain what this book was about, it's this. The Socialist countries, the Communist countries, the Stalinist countries viewed Western economists as lackeys of capitalism whose only role is to sing the praises of the capitalist system, and has nothing to do with science. In my book-- this was in the period after, if you remember, Khrushchev in 1956 gave his famous speech which unmasked the Stalinist regime's cruelties and inaugurated in Eastern Europe, in the Communist countries, a period of relative hesitancy about the strong line and some freedom of discussion. In Hungary and Poland this freedom of discussion was more serious. In Romania, it never materialized. But there was something in the atmosphere which suggested that one could dare to attack some dogma.

So I wrote this book in which I essentially said the following. All we say about the Western economists is that they are lackeys of capitalism. Now, Keynes certainly was an adept of the

capitalist system. But he not only praised the system, he wanted to cure it. The capitalist system had a major disease, there was this periodic crisis and he wanted to find the remedy. And we must admit that in order to cure the diseases of capitalism, he had to do some scientific research. And the results of that could also be used in a Socialist economy. This was the undertone of my book.

It was first greeted in the press as an original contribution. Three months later it was attacked as under Bourgeois influence, heretic, anti-Communist. It was forbidden, it was withdrawn from all libraries. And I was thrown out of the Institute of Research where I was working and excluded from the party. When I say excluded, you may be surprised, was I at that time still a party member? Well, the situation is that when I was released from prison, my party situation, which was essential to do any job in those times in Eastern Europe, was not clarified. When I went and asked what is my situation they said, "Well, you feel you are innocent because the Securitate-- this was the secret police-- was not able to prove anything against you, but you didn't help the party when you were in jail. You refused to cooperate." And my party membership was left floating.

So in early spring '59, I was excluded from the party. By that time, I also lost my faith in the Socialist, the Marxist doctrine. You must understand that it's not easy to abandon a belief which you acquired as a young man, which at that time seemed scientifically well-founded, and moreover, for which you fought and suffered and risked your life. So I, of course, experienced the anomalies in the situation. I saw that what we are living in is not the world that I fought for, that this is all a lie. However, for a long time I explained it through local conditions, that Romania didn't actually have a genuine proletarian revolution as Russia had. In Romania, Communism was an import good. And so I figured that in the Soviet Union it must be radically different, much better. Well, in 1956, I took the chance to visit the Soviet Union with my wife as a tourist, as a Romanian tourist, and that opened my eyes. The situation was indeed different in the Soviet Union than in Romania, except it wasn't better. It was much worse. Much, much worse. The living conditions were terrible. So that opened my eyes, so that by the time I experienced the Hungarian Revolution, I was with all my heart on their side and against the regime.

Suffice it to say that when I was thrown out of the Institute, along with an interdiction to publish anything in economics, I found myself in a crisis. This was 1959. I was 37 years old. No longer was I interested actually in economics. The kind of economics that I knew, Marxist economics, lost in my eyes all its value. So I felt like my professional career was broken and I had to do something completely new.

3. Back to Mathematics and Discovering Operations Research

And then I returned to my first love, which was mathematics. Wasn't easy. You know, mathematics training in Romanian high schools was pretty good. The Romanians copied the French model. So for instance, in my last two high school grades, I learned calculus. In the earlier grades I learned trigonometry and basic elements of algebra. So I revived those things. But I soon realized that it's not calculus that I need. I need something else.

How did I realize this? Well, I read the book -- in 1959, I read the book by Dorfman, Samuelson and Solow on Linear Programming and Economic Analysis. And that book caught my fantasy. I felt that this is something very important, very interesting, very new, and I could do it. I had the feeling that I could learn this. The mathematics that's needed for this, I don't have but I can-- So then I took books, I remember that linear algebra I studied from a Russian book by Khinchin. I read several math books. I read *Linear Programming*, what was available, which was the book by Charnes and Cooper, the short book.

IRV LUSTIG: In those books now, you were still in Romania at the time.

EGON BALAS: I was in Romania, in Bucharest.

IRV LUSTIG: And they were, and the books were published here in the United States in English and brought over?

EGON BALAS: No, no. Books, Western books were very, very hard to obtain. They were procured by the central library, but you didn't have access to them. So I had to pull strings. But I was pretty good at it, so I pulled all the strings and I got access to the book. But one thing is the following. Technical books, they didn't import from the West. So Dorfman, Samuelson and Solow, I managed to find. That was one of the books that they did buy. I was lucky that I found it. Most books they didn't. However, all those books were translated into Russian. This was Russian policy. And made cheaply available at low price. So I learned Russian. Not just for this, but this was one of the reasons. And for instance, algebra, I studied from a Russian book, Khinchin's book. Khinchin was a famous algebraist.

The Russians were very good in mathematics. That has its own explanation. You know Russia had a strong mathematical tradition. But besides that, under Communism, talented individuals who were looking for being able to do something which is not controlled by the party, had to look for branches like mathematics, physics, where the party didn't understand and couldn't control. Economics was not feasible. If you became an economist, you were considered a political person who was strictly controlled. You were -- you know, Khachian-- not Khachian—Kantorovich, Kantorovich, the Russian discoverer of linear programming. He was a mathematician. If he had been an economist, he would not have been allowed to do those things. He did those as mathematics, with some application to economics, which he hid under the rug. But it was mathematics. That's why he could do it.

So to come back to my evolution, I was helped in making this transition by a Romanian famous mathematician who was interested in introducing to Romania Operations Research. He learned about it and he thought that this is something practical and interesting.

IRV LUSTIG: And his name was?

EGON BALAS: Pardon me?

IRV LUSTIG: And his name?

Moisil was his name, Moisil. He was the most famous Romanian scientist at the time. A very open-minded person. I met him when I was still at the Economics Institute. He came there to discuss this, how could we -- and at that time, of course, I was the one from the Institute who talked to him, along with some others. But he liked me and he thought that we could work together on that.

So when this catastrophe happened to me, when I was thrown out --- a few weeks after that -- I gave him a phone call. And I said this is what happened to me. I was thrown out of the institute. I was excluded from the party. My acquaintances tried to avoid me. Do you still want to have anything to do with me? And he said what happened to me, what's happened to you, is highly regrettable. I didn't change my opinion that operations research should be introduced in Romania. And I still think that you're the right person to do that. So good luck with finding a job and give me a phone call when you have one.

What help did I need? Well, there was one computer in Romania at the time at the Institute of Atomic Physics. And he controlled access to that. So I needed contact with a computer programmer -- you know, in Romania there were two or three computer programmers at that time.

But he put me in contact with one of his doctoral students, Peter Hammer. At that time he was called Ivanescu because he married a Romanian girl called Ivanescu. He himself was Jewish, and Ivanescu was a better name in Romania to be tolerated then Hammer.

So together with Hammer, we started. The academician whom I mentioned, Moisil, suggested that we do something which is applicable so that we can show early results, so that this new research field is accepted. And we did that. We sought out a transportation problem, namely the distribution of fire wood, which was the main home heating fuel at that time in Romania. The transportation and distribution of that wood and other kinds of wood products. We managed to solve that large transportation problem -- linear program-- at first without computers, with a group of students. The iterations were done and repeated. Every iteration was repeated twice.

IRV LUSTIG: All by hand.

EGON BALAS: By hand, by hand. By a team of eight students. And that's the way we solved the problem first. And it was a nationwide transportation plan which showed 8% savings over the plan actually used, which was a bomb in the press. So we were-- this gave us sort of help to work. And then we did also theoretical work still with Peter Hammer. We published a version of the generalized transportation problem. We solved the parametric transportation problem. And these publications came out, we sent them to the west and so on.

Now my step into integer programming came about in 1962. I was working at the designing institute of the timber industry. Romania is a country which has a third of its surface covered by forests. So the timber industry was an important one, very important economic branch. This was a huge institute, which designed all the new factories and all the forestry undertakings that happened in the country. It had more than 1,000 employees, of whom about 500-- 600 engineers

and the rest auxiliary personnel. I was hired there through a competition for the role of engineer who evaluates the projects for new plants. OK? That was my function.

And in the meantime, I worked on linear programming, had the Institute form a small group of linear programming, and we came across a problem that had to be solved. Namely, optimal management of a forest plot, optimal harvesting plan. It was a forest plot divided in lots. The lots were more or less homogeneous containing forests with trees roughly of the same kind and same age. And there were constraints which said that at most, 40% or 50% of this plot can be cut in the next five years. How do you choose them? It was an optimization problem. And since in the cutting of the wood, the main expense is salaries, which is linear in quantity, and the value is linear, I formulated that as a linear program.

Except there was one problem. One of the main cost items was the building of a road network. In order to take out the wood, you had to build the roads. But the road network was not--its cost was not linear. Because if you wanted to cut wood from a given parcel in the middle of this entire region, you needed a road to it. You needed to connect it to a neighboring one, those neighboring parcels needed to connect to some other neighbor and ultimately you had to connect to the main road. And these were all yes or no decisions. Connect to this, to that or to the third one, and so on.

So I formulated it as a zero one programming problem. This was 1962. At that time, Gomory's algorithm already existed, but was not available in Romania and not programmable and couldn't solve problems of the size we had. At the time --this was a 40 variable problem--Gomory's algorithm, as he himself says in different places, in the first two years couldn't solve anything beyond a few variables because there were numerical difficulties with it.

Branch and Bound had already been invented 1960. This was, I am writing 1962, but there was no code available. My algorithm, the Additive Algorithm I called it, because it involved only addition, subtraction and examination of the consequences. It was something very similar to what today is called constraint propagation. It's done in constraint programming. So it was a precursor of that later constraint propagation, but it could solve that problem of mine of 40 variables.

So it was kind of a sensation. I presented it first in Bucharest, then I got this professor who was supporting our work, to send it to a French colleague. He had studied in France and had connections there. And it appeared in the *Comptes Rendus de l'Academie des Sciences*, the French Academy's publication as a short note of a few pages. And I sent a detailed article with proofs to *Operations Research*. That's where it finally appeared two years later in 1965. The associate editor who handled it, Bill Cooper, later brought me to Carnegie Mellon and became a good friend.

It was a very adventurous thing how I managed to send it to the Mathematical Programming Symposium in London in 1964. I sent 50 copies, which were distributed there. I couldn't go, of course, because I wasn't allowed to travel. So this was my start in integer programming, but I think I gave a pretty long answer to your simple question. Maybe you want to ask now further questions.

IRV LUSTIG: So it's a wonderful story of the transition from your early life into discovering the Dorfman book about linear programming, and then getting to solve an integer program without much access to what was happening in the west at the time in operations research and optimization. Even though you were aware of Gomory's work. Did you end up having any formal training from it like a graduate degree or something like that?

EGON BALAS: Not in Romania. I tried to enroll into a doctoral program. I was rejected as politically inimical, so it was not possible. I tried several times. Moisil tried to help me, but it was not possible. So I got my degrees when I emigrated.

4. Attempts at Emigration from Romania

EGON BALAS: The story I told was incomplete in many respects, but among other features which I must add, because without those, the thing cannot be understood: around 1960 I decided that I had enough of it and want to try to emigrate. Now this was a difficult thing, but it was not impossible. The Romanian regime, in spite of being a rigid, Communist regime, was in a certain way, corrupt. It sold people. Jews were allowed to leave for a certain amount of money. They could be bailed out from abroad. The cost for a family was about $10,000.

IRV LUSTIG: In 1960 dollars.

EGON BALAS: In 1960 dollars. And the Germans were sold to the West German Republic. So Jews and Germans were emigrating selectively, if they found the way. So I had a second uncle, a distant relative, distant by blood relation, but very close in spirit to me, well, he was a real friend. And he left Romania, he was much older than me. He left Romania in the late 50s or early 60s. And I wrote to him and asked him to try to raise money to bail us out. And I also was able to send him by various routes, some money from Romania. OK? So he tried and he deposited the amount of money. There was a merchant in London who was doing this business. He would come periodically to Bucharest. So he'd try to get me out. When he was in Bucharest I phoned him at his hotel. He told me that I am on his list, that he tried and he was refused. They didn't allow me. He didn't understand why. I knew why. Because of my past.

So that failed. And this was in '59-60. So it was a desperate situation, but I felt that I have nothing to lose. My life is at stake, I must get out. So I registered officially a request for immigration. My friends all thought that I'm a fool. They'll never let me leave with my past, with the witness I can be against the regime, this is nonsense.

But I was sort of a risk-taker. It was a desperate situation. I felt that my life here has come to an impasse and I risked it. So I was rejected. I applied again. I was rejected. It went like that for several years. At one point we tried to go on vacation to Yugoslavia. Do you remember Yugoslavia had a Communist regime, but dissidents from-- Tito was Yugoslav. And we heard, we learned that if you are on vacation in Yugoslavia, it was neighboring to Romania, if you are on vacation in Yugoslavia you could cross the border there and come to the west. So several people escaped that way.

So as soon as I heard that, I applied for going on vacation to Yugoslavia. As the outcome of that, I was called to the passport office by a telephone call. And at the passport office, they took me to a special room and I faced people of the Securitate, the secret police.

They said, "Well, you want to go to Yugoslavia. Why do you want to Yugoslavia? Obviously, you want to defect." I said "No, no. We want to vacation, it's the seaside."

"Well, we have the Black Sea here." I said, "Yeah, we were at the Black Sea seven times, eight times, and we also would like to see another sea."

To make it short they said, "We can help you to go if you work for us." So they wanted to recruit me, go to Yugoslavia, escape, and then become a Romanian spy. Now this was an offer not easy to reject, because you know...

So I simply said that "It's interesting, but this is a new profession. And I like my current profession."

"Oh, you don't want to help us."

I said, "I didn't say that. I want to help you. I can optimize your plans for this, for that." I described what I did for the forestry. "I could do the same thing for you. I'm willing to help. But this sort of involves learning a new profession."

"So then you won't go to Yugoslavia."

I won't go to Yugoslavia. And that was the end of it.

Well, in the meantime, after the initial success and publications, I managed to get from this designing institute, I managed to get to a scientific institute, Institute of Mathematical Statistics in Bucharest, where I was the head of a section for a year, which was pretty successful. We had two very talented young guys doing mathematical programming work. We got some publications.

But then in '65, the last time when I renewed my application for immigration, I was publicly rejected. The president of the academy ordered the institute to fire me. And I was without a job. And then I said to myself that this is now the opportunity to make a desperate effort because in the Communist countries, in the Communist countries the basic propaganda tenet is that we don't have unemployment. Everybody here is employed. And they tried to do that. And so I then wrote, within three weeks, I wrote nine memoranda to the prime minister, to this, that, Minister of the Interior, every person who possibly could have a say in immigration, arguing that I am unemployed, I am not useful to anybody, I have no relatives here, all my relatives live abroad. (All my relatives was this single uncle, but I said all my relatives live abroad). And I ask you to revise this decision and let me go.

And it so happened, that the leader of the committee was a very well-known economist who once, 25 years earlier, had asked me to help him out with a lecture. He didn't know me. He was a

friend of my friend who was that Deputy Finance Minister, who I mentioned was later arrested. And he complained to him that he has a lecture at the party Center Committee's Institute next morning about the economic, world economic situation, and he has to go see the party leader. He got an appointment and doesn't know what to do. And my friend told him, well, I can help you. I have a good friend who will give a lecture in your place and I guarantee that will be a good lecture. And so I gave a lecture for him and he was very satisfied. After that, I had no more contact with him. This happened 25 years earlier. Now I wrote him a letter and I described my situation and asked for his help. I have no way of knowing even today whether he was the one who helped or others.

I made everything, I moved everything, you wouldn't believe it. I asked for an interview with the head of the secret police. Me, who was in his jail. I asked for the Head. The secretary said he's busy, he cannot. I insisted. Then after a few days she called back and she said that he has no time, but his deputy will see me. And I said no. I have something important to communicate to him and I can only do that personally. And she insisted that I talk to the deputy and I said no. Either he wants to hear what I have to say or not. They believed, probably, that I want to offer myself as a spy. He received me. He received me in his office. I went to the office. There was nobody waiting. I was the only person. I was ushered in. I told him why I came for. I told him that it's true that I was a Romanian diplomat, but that was 20 some years ago. There are no secrets from that time that I know. And that I insist that he lift this interdiction of me leaving the country.

And it's fantastic, it's unbelievable, that the head of secret police suddenly became defensive. He told me "No, no, no, it's not us. We don't have anything against it." This is what he said. "We don't have anything against you leaving. It's not us."

Well, I said, so this was it. And I made other visits and I moved everything that is possible. And after a few months we got the permission to leave. So this is how we came to the West.

5. Entering the West

IRV LUSTIG: So then when you left, where did you go when you came into, so you came to the US? Or were you in Western Europe?

EGON BALAS: We were, of course, decided on coming to the US, but the first station was Italy. So we stopped in Italy. We spent there half a year waiting for the US visa. In Italy I called the Director of the International Computing Institute, which existed at that time in a suburb of Rome called EUR. And this director was Claude Berge, the graph theorist. I didn't know him, he didn't know me, but he was the chairman of a conference that summer, the previous. This happens in July 1966, and at the end of May, he was the president of a conference to which I had sent a paper, knowing that I won't be able to participate. But I sent a paper. So I called him and I was hoping that he would recognize my name as I sent him a paper. And I said on the phone, I am so-and-so from Bucharest and I submitted a paper. And he interrupted me. Oh, he said, "Balas? You don't have to tell me who you are. I just returned from Lake Tahoe from a conference where there were four papers presented on your additive algorithm." So this was my entry. I call the paper on the additive algorithm, my entry ticket to the profession. And he immediately, in the

first, he said come and see me. I went to see him. In the first 10 minutes of our conversation, he offered me a fellowship for six months to work part-time. It was exactly what I needed.

IRV LUSTIG: A fellowship in Italy at the--

EGON BALAS: In Rome, at that institute. And that's where I worked. Now I went to the American consulate and I applied for immigration. The consul was very impressed with this technical bent. She-- it was she -- said that she would recommend our admission on the basis of, there was an article for people useful for the US economy. And that was the article.

And I said to her, "Very nice, but did you read my bio?" She said, "Of course." And I said, "Well, I was a member of the Communist Party." And she said that, "Yes, we know that and you will be listed as an involuntary Communist. Because we have two categories. Voluntary, those who help the regime, and involuntarily is the other. We know that there are pressures". I thought about it, and I said to her that "I am sorry, but that's not the case. I was not involuntarily. Actually, I was voluntary. And when I became a Communist, I am not ashamed of it. I became a fighter in the anti-Nazi resistance and I don't renege that."

And she tried to convince me. She said that "Involuntarily is just a bureaucratic category. There are two categories, pro-regime or involuntary, and we put you in the latter." I said "No. There must have been other dissidents." And I told her that one of the main reasons why I decided to leave the Communist world, I don't, I can't, and I don't want to live in a lie. And so I don't want to start my new life with a lie. There must have been other dissidents like me before.

And she said "Then it will take much longer and I cannot guarantee you the positive outcome".

And I said “So be it.” And it lasted -- at first she said it would be two or three months -- well, it lasted nine months. And so when the sixth month came to an end, we had to move. I got an invitation to join the University of Toronto and we moved to Toronto. And I spent the period between January and March at the University of Toronto, and finally in March, the immigration visa came.

6. Visit to Stanford and Joining Carnegie Mellon

IRV LUSTIG: So at which point now then, so that was the immigration then into the US, and you went where?

EGON BALAS: So, while I was still in Italy I sent my vita to several places. And I got answers. And I got a letter from Dantzig, Stanford, inviting me there for a semester. And I got a letter from Cyert, Carnegie Mellon, inviting me there. And I got other letters.

So I accepted the Stanford letter and the Carnegie Mellon letter: the Stanford letter for the summer, June to September, May to September; and the Carnegie Mellon letter for the year starting in September.

So when we immigrated, our first station was Stanford in Dantzig's group, and that was very, very useful to me. I learned a lot there. I slept little. I worked hard. You know, my mathematics was very thin. I knew everything that you needed to know for linear programming, but nothing beyond that. And so there were huge holes in my mathematical education. I was completely self-educated. I never attended courses. So I had to fill these holes, and I learned a lot in Stanford during those six months. Then I joined Carnegie Mellon, which treated me wonderfully. It let me teach what I wanted to teach.

IRV LUSTIG: So when you joined Carnegie Mellon, you joined as a faculty member.

EGON BALAS: Yes.

IRV LUSTIG: And they didn't have issues that you didn't have a doctorate?

EGON BALAS: Well, I couldn't tell you everything. In the meantime, I did acquire the doctorate. So when I emigrated, when I was still in Rome, in Italy, I went to a conference in Florence where I met a mathematical economist, Belgian, Walbroek, who agreed to take me on as a doctoral student. He knew my work, this additive algorithm, the thing-- and I gave him an outline of the thesis that I would write. And he said that upon his return he will, and he finally put together a doctoral committee and accepted me as doctoral student. And I was supposed to go back a year later. I had to -- I made three visits to Brussels within a year. I took exams there and finally got a Ph.D. However, he told me in the middle of the procedure, that he is, on paper, an econometrician. And his chair is in econometrics, so the diploma will be in economics.

But I also felt that I want confirmation of my mathematical qualifications. So while still in Rome, I visited in Paris, Fortet, the professor who arranged for the publication of my paper in the bulletin of the Academie. And he agreed to take me on as a doctoral student and gave me in '68 a doctorate in mathematics, called Docteur de l'Universite. This is the title, Doctor of the University.

IRV LUSTIG: And that's then from an institute in France.

EGON BALAS: In France. So the Economics degree is from Belgium and the Mathematics degree is from France.

IRV LUSTIG: I see.

EGON BALAS: And so Carnegie Mellon treated me wonderfully. Again, they let me not only teach what I wanted, but do mostly research, build an operations research group. They allowed me to hire people. I hired talented people. One of them, the best one of them was Bob Jeroslow, who was a mathematician, a logician. And I attracted him to integer programming. He left logic and came to integer programming, made very important contributions.

To put it briefly I am still very, very grateful to Carnegie Mellon for this initial, enormous help, and all the later years when I was treated well.

7. Disjunctive Cuts Become Lift-and-Project Cuts

IRV LUSTIG: So at Carnegie Mellon, I know you've had a distinguished career in integer programming. One of the things that I think people in the field know about your work in disjunctive programming and disjunctive cuts. Do you want to say how you came into that area?

EGON BALAS: My original contribution was an enumerative method, the additive algorithm. It's a type of Branch and Bound. And it was very successful for a few years. It could solve problems. But I realized already at that time its limitations.

Integer programming can be approached in two ways, either by breaking up the feasible set into more and more subsets and studying them separately, which is what Branch and Bound does. Or by trying to describe or approximate the convex hull of integer points. And this is where theoretical contributions were required and came about. For several decades, research in integer programming focused on cutting plane theory, which is a convexification procedure essentially.

So I soon started looking at cutting planes and already in 1971, I came across a family of cutting planes -- different, radically different, from what was known until then as the Gomory cuts-- which I called intersection cuts, which are basically derived from the optimal solution of the linear programming relaxation using the cone associated, the polyhedral cone associated with that optimal solution, and intersecting the extreme rays of that cone with some convex set whose interior does not contain integer points, but contains the linear programming optimum. This was the so-called intersection cut.

Now the intersection cut idea leads directly to disjunctive cuts. Namely, saying that your solution cannot belong to the interior of a polyhedron is the same thing as saying that your solution must satisfy the reverse of one of the inequalities describing the polyhedron, and that's a disjunction. This is how the idea came to me. It seems at first that these are two equivalent things. It's just a different way of looking at it. So what's the big deal about it? Well, the big deal is, that if you look at it in this new way as a disjunction, then you immediately discover that this disjunction remains valid if you add to each term those common inequalities, to all of them. But then you have a union of polyhedra. You know, initially you just had a union of half spaces. But now you have a union of polyhedra. And a union of polyhedra, of course, is non-convex. The dividing line -- at that time, complexity theory was not yet around. Complexity theory came about couple of years later, not much later. But it was clear to me that with the lack of convexity, we ran into a stumbling block. Linear programming, which came about in 1947, was relatively easily generalized to convex programming called, in my view erroneously, at that time, nonlinear programming. It should have been called nonlinear convex programming because it can only solve convex problems. And the barrier seemed to be convexity. Integer programming is not convex and you couldn't solve it. At that time you couldn't solve it at all. So here there was a situation where you could turn this non-convex set into something that is not yet convex, but it is a union of convex sets. So I looked closely at that union and it turned out that it can be convexified. In what sense? In the sense that it can be, its convex hull can be described in a higher dimensional space whose dimension, however, grows only linearly with the number of polyhedra. So you got here a handle on non-convexity. This is, I think, a crucial step in traversing this gap between the convex and the non-convex worlds.

This is how I came across disjunctive programming. At the beginning it was not well received because we had no implementation, no efficient algorithm. It was just a basic result, an idea, an interesting idea but it was not popular.

However, 15 years later when we essentially offered the same kind of cuts except accompanied with an algorithm implemented and successful, and we called it Lift and Project Cuts, then it conquered the scene. And it became, of course, it became what it became.

IRV LUSTIG: Right, and now it's part of the standard software packages.

EGON BALAS: Now it's part of the standard offering and it's the general formula for any cut. Of course, at the beginning it had the drawback that you had to solve this higher dimensional linear program. Not very much higher, but still higher. Two, three times the original. But a few years later we discovered-- when I say we, together with a doctoral student of mine, Perregaard-- we discovered the close relationship that exists between these Lift and Project cuts when derived from a split disjunction, and the original linear program. So we were able to establish a precise correspondence between feasible bases of the higher dimensional linear program and feasible or infeasible bases of the original linear program; which allowed us to generate the Lift and Project Cuts from the original linear program without actually formulating this higher dimensional linear program. In other words, mimicking the simplex pivots in the higher dimensional space on the original space.

How is this possible? It is possible because that higher dimensional construction works with the data of the original problem. So they are all present in the original LP, except they are differently placed, displayed and repeated many times in the higher dimensional formulation. So this was possible--this ability to perform the Lift and Project pivots in the original simplex tableau by computing the reduced costs of the higher dimensional LP from the data of the original LP and making the pivots in the original LP. This led to the practical applicability of this type of cuts.

And it was implemented first in Xpress by Perregaard. Then later in CPLEX by Tramantoni. But these are commercial codes; in between Bonami implemented it on COIN-OR and it's publicly available and we ran a large numerical computational experiment which showed the advantages and the power of the procedure.

8. Job Shop Scheduling

IRV LUSTIG: So it's really interesting to hear how you came to integer programming in Romania working on a forest problem. And back then thinking about enumerations of zeros and ones and now we're having a discussion about the convexification of non-convex regions and how on your own, over the time, you had to learn the math to be able to get to that state.

I think there was something else you also shared with me prior to our interview today. You mentioned that first application in forestry, which was in there. I think there's been some other applications that have inspired your work.

EGON BALAS: Many.

IRV LUSTIG: Would you care to share a couple of your favorites?

EGON BALAS: Sure, sure, many. From the late 60s I became interested in scheduling problems, machine scheduling, job shop scheduling. It occurred to me that in job shop scheduling problems, the key are the machines through which the jobs have to pass. If you knew for each machine in what order it has to take the jobs for the schedule to be optimal--meaning of minimum length-- if you knew, if those sequences were set on the machine, on each machine, then this problem would boil down to a well-known project scheduling problem, PERT, which was well-known, and which you can solve fast by the shortest or longest path technique. So it occurred to me that on every machine, solving the--finding the optimal sequence, is a traveling salesman problem. Why? Because I first stated it – initially -- as a disjunctive cut problem--not cut -- disjunctive set problem. For every pair of operations you have a pair of arcs, pair of oppositely directed, either this precedes that or the other way.

IRV LUSTIG: A goes before B or B goes before A.

EGON BALAS: Right. And if you put that down for every pair, you get what I call a disjunctive clique. Now finding the minimum route through this disjunctive clique can be reformulated as a directed traveling salesman problem. OK? So you have here a problem with these disjunctive cliques. And I thought at that time, traveling salesman problems could not be solved efficiently--I mean they are NP-complete, but you could find efficient heuristics.

And I proposed a scheduling problem in the early 80s. The idea goes back to '69, but it came to fruition in the 80s when I had a doctoral student, Joe Adams, who came from the military establishment. He had a military rank. Together, we developed a heuristic, which I called the Shifting Bottleneck Procedure. What does the name tell you? In any job shop scheduling problem, in practice, there always develops a bottleneck. And the bottleneck is at one of the machines. The machine which is most overcharged, if you want. My method would heuristically solve this traveling salesman problem quickly for each machine, run the schedule and find the bottleneck, the machine that is the bottleneck. You then return to it and improve the schedule on that machine. Run it again, there is another bottleneck at another machine. This is the shifting bottleneck idea. Now this, today, is successfully used. Did you ever look at the, for instance, the book by Pinedo on scheduling?

IRV LUSTIG: I'm familiar with it, yes.

EGON BALAS: You are familiar. Well, he has it in his scheme, this plays a central role. And it has many, many other uses. So this is the shifting bottleneck.

Later I added to it a new feature quite recently, in 2000, with a much, much improved heuristic to solve these traveling salesman problems, these small traveling salesman problems (small, depending on how large this thing is) using another, this type of practical discovery, which I have to describe separately. This came about -- this I will discuss later, because this comes in 2000. And first I want to tell you about some things that I did earlier. My main excursion into the practical application area was also in this realm of scheduling.

9. Steel Rolling Mill Scheduling

I developed in the mid 80s a very successful rolling mill scheduling algorithm. A steel rolling mill takes hot slabs eight, nine yards long, red hot slabs as they come from the furnace and processes these slabs into sheets by flattening them between two rolls, two sets of rolls, long, a mile long. This is a rolling mill. And I developed with a doctoral student of mine, Martin, a scheduling system for rolling mill operations where the problem comes from the fact that you have to choose the slabs for next day's schedule according to certain criteria--if that could be done in isolation it would be a knapsack problem-- and then you have to schedule optimally the sequence in which the slabs are processed, which would be a traveling salesman problem if it could be done independently.

But the two are interrelated for the following reason. For the sequence to be successful, the order in which the items are processed is crucial. Let me explain. If you first process a slab of a given width--not the slab -- the sheet, the required sheet has a given width-- the edge of that sheet leaves a line, a scratch on the rolls. Because the rolls are also of steel. A harder steel, but steel. So there is a trace there. If the next sheet is wider, then that leaves a line on the next sheet. It's not garbage, it's still usable, but it's an inferior quality, of inferior quality. So it's no good, for instance, for automobile bodies. It can be used for other things. So you have to avoid that.

Well, this seems simple. You order them according to decreasing width. You start with the widest, next widest. Yes, you could do that, if this were the only condition, but this is just one of many. Another condition is that you should not have jumps in the thickness. Because if one slab is followed by a slab that differs in thickness by more than a quarter of an inch, then you have to stop and readjust the machine, which took three minutes on average. So both the quality of the product and the efficiency of the procedure crucially depend on the sequence.

Now, for the sequence to meet these conditions, you have to have the slab inventory that you chose have certain qualities. For instance, if slabs of a certain dimension are missing from the items that you have chosen, then you cannot meet the condition.

So the two problems, the so-called knapsack problem and the TSP, cannot be solved separately, because that schedule has to combine both -- it's a joint problem. For this I devised a heuristic -- it's not an exact method -- developed a code, founded a company called Axioma. Sorry.

IRV LUSTIG: Didn't think it was Axioma.

EGON BALAS: Algorithmica. OK, it starts with A. And I forgot because I gave up the company several years ago. So I had Algorithmica as a company from about 1985 to 1997 or 1998. We did this and we called the software Roll-A-Round. Why? Because in the scheduler's jargon, the daily schedule is a round. So you roll a round. And we had this introduced at LTV Steel. Actually, that's where I got the idea from, how I came across this problem. A former master student of Carnegie Mellon who was working in the Operations Research group at LTV Steel called me one day. Professor, I came across a problem which seems to be an integer program. Do you want to look at it? Yes. So they came, this is how it started.

They introduced it. It was successful. They used it day in, day out, for more than 10 years until they went bankrupt. They went bankrupt, not because of my software package, but in spite of it. Anyway, however, this was a great success. At the time, the Japanese were reputed as the best steel makers and believe it or not -- this lasted only six, seven years--but at that time every American steel manufacturing company had a Japanese advisor. It's hard to believe, but that was the situation. I tried to sell the software to other steel-making companies and a typical discussion would go like this. I would call them. I would say that we have this thing. It's applied at LTV Steel. They can send people to inspect there how it functions. LTV Steel agreed to receive them.

And they would listen, be interested, in the end they would say, we have to consult with our Japanese advisor. So the Japanese themselves became interested. In 1988 when I went to the International Symposium in Tokyo, three months before that I contacted Japanese steelmakers and told them that I am coming and I would like to--and they invited me to give a lecture on this software package to a group of steelmakers.

It was a fantastic experience. I sent them my brochure, a four pages brochure on Roll-A-Round. They said that eight steel companies would be represented and there would be 32 people attending the meeting. I figured if they say 32, probably there will be about 15--16. I judged from my local experience. I arrived and went to the lecture room. There were 32 people. I counted. Each one had in front of him a copy of my brochure with the Japanese translation at its side. I started talking and I realized that they all had read the brochure. It was fantastic. It was a two-hour meeting with 50--60 questions, which we had to finish because the room was needed for something else.

As a follow-up, Sumitomo started a correspondence with me, which lasted for several months and they sent a team of three people to spend three weeks at Carnegie Mellon with 15 test problems, which had their characteristics, to see what changes they wanted in this one. Suffice it to say, to make the story short, in the end they bought the product. Which was a great success for me because the Japanese were leaders in steel.

Another-- so this, by the way, always happened that way: that the practical applications also led to theoretical breakthroughs. This led me to a new model. You see, the model that we used here was not just a simple traveling salesman problem, but a generalization of the traveling salesman problem, where the salesman has to visit only some of the cities. But the cities that he visits pay him a premium. The goal is to minimize the total cost of the trip with a lower bound on the premium that he has to bring in. So I called this the prize collecting traveling salesman problem. It's become a well known model, which has a literature of its own. And led me later in later years, to give a new characterization of the cycle polytope of a directed graph,based on, starting from, those results and applying them, generalizing them, to the directed cycle polytope.

10. An Application in Bus Driver Scheduling

Now another discovery, which originates in a practical situation, happened in 1980 when I was for a year on sabbatical in Germany. I was working at the Mathematisches Institut in Koln. And it so happened that at the same time, Bill Pulleyblank from the University of Waterloo, was on sabbatical in Bonn. And Bonn and Koln are 20 kilometers apart. We got into contact and we did

jointly an interesting project, which started as follows. The Dutch Operations Research group of the National Railways contacted me. They found out that I'm in Germany. They would like to consult me on a project of theirs. Would I receive them? Of course.

They came to Koln. It turned out that they had a bus driver scheduling problem, which they had formulated and could not solve and could I help them. Well, my first question was, "You're the operations research group of the railway company, you say, what do you have to do with bus drivers?" They said "Holland is a small country and so we are the OR group of the National Railways, but we also help the bus company, municipal bus company." So this was for one of the cities. I don't remember whether it was Rotterdam or which one. The daily schedule of the bus drivers. And they formulated it as a set covering problem, which is the usual model for representing crew scheduling problems. It started in airline, with airline crews, but it applies equally well to train scheduling. My colleague and co-author, Fischetti, together with Paolo Toth, applied it to the Italian national railways and won a prize there.

But these people were doing it for bus scheduling. And they ended up with a set covering problem with 150,000 variables and couldn't solve it. I looked at the problem, and it turned out that there are morning schedules and there are afternoon schedules, which are relatively loosely connected. If you could separate them, then there would be only a few hundred morning schedules and a few hundred afternoon schedules. But when you take them together, you multiply 600 by 600, you get into the 100,000s. OK?

So I started looking at what connects them, why can't they be solved separately. Well, it's obvious that if a driver has a morning schedule which ends in a certain place, then you cannot assign to that same driver an afternoon schedule which starts in a very different place. So there are conditions. This is just one of the conditions. There are other conditions. And I figured that if we could capture this aspect on a graph, on a bipartite graph, where the nodes on one side are the possible morning schedules and on the other side the possible afternoon schedules, then you have to define compatibility between the morning nodes and the afternoon nodes. And this can be formulated as a problem of finding the optimal matchable sub-graph. You have a bipartite graph, and which are the sub-graphs which can be matched, for which you can find a perfect matching. That was the condition.

And this is the problem that we addressed with Pulleyblank. The perfectly matchable sub-graph of a bipartite graph. And we solved it. And this was path-breaking in many respects in the following sense. We formulated the inequalities which define this perfectly matchable sub-graph. They are inequalities on the nodes, involving the nodes. This is a small integer program. And I had the feeling that this integer program formulated the linear constraints of this integer program must have an integer solution without imposing integrality. But I couldn't prove it. We couldn't prove it. The constraint set didn't have that property. It’s called total unimodularity. It was not totally unimodular. So our main objective was to try to prove that this linear program has integer solutions without imposing integrality. We couldn't.

And then the idea occurred to us to reformulate the problem in the higher dimensional space of node variables and arc variables. Of course, it sounds foolish. Arcs are more than nodes. And

why would you introduce new variables? It turned out, when you formulated it in the higher dimensional space, it had the total unimodularity property. So that was our proof.

This was, now why do I say that this was crucial? It has a huge impact. This was the first so-called extended formulation. Now it's a common practice to do extended formulations with the objective of being able either to prove something or to solve something, or find some property which the original formulation doesn't have, but the higher formulation has it.

This result had an outgrowth. Four years later we managed to prove the same thing for general non-bipartite graphs, which was much more difficult. This was a purely mathematical problem, it didn't have this application to the set covering-- But it originated from that. It started there.

11. Legacy

IRV LUSTIG: So we have spent a lot of time here today hearing some great stories and your journey from Europe into mathematics and into integer programming and practical problems.

So I'd like to find, there so many things I could ask you to wrap up. But I guess I think I want to wrap up and ask you of all these different things from your journey that you had as a young man in Europe and dealing with, being a Communist, rejecting Communism, dealing with the regimes and the secret police in Romania to your journey to get out and immigrate to the West, getting into mathematics, discovering linear programming, integer programming and the different applications, what's the one thing that you would say we should remember Egon Balas for?

EGON BALAS: I don't know, I don't know. It's not for me to decide. I don't know.

IRV LUSTIG: Well, OK, then maybe I'll reword it as, what's the thing you're most proud of?

EGON BALAS: Well, I tell you. I am most proud of the fact that when I was 37 years old and down, my life, they planned, they intended to destroy my life. And to a large extent, they managed. Well, I managed to resist them. I managed to start a new life. I managed to acquire what became a wonderful profession and a wonderful second life. It's a second life.

When I wrote that book, when I decided to write that book, it happened on the 30th anniversary of our emigration. I realized that it's an anniversary. I sat back and I said to myself, I had two lives. Very, very different. The first life was a terrible obstacle course. Obstacle after obstacle, humiliation after humiliation, torture, prison, this, that. The second half doesn't seem to have anything in common with it. It's a sequence of success stories.

So what connects the two lives? This was my thought after 30 years. And I actually wrote this in my book, I think, either in the epilogue or in the preface that my life consists of two parts that seem orthogonal, to use the mathematical expression. And that's what the German reviewer picked up.

So I am most proud of the fact that I was able to overcome those. And maybe, maybe, just maybe, I cannot tell that, maybe those difficulties did play a role in my later successes. Because

research requires some obstinacy, some persistence, some willingness to not give up when it seems impossible to achieve. And maybe these character traits have something to do with that kind of "education", quote unquote, that I received.

IRV LUSTIG: Yes, I think so. And I think I know the math programming community and the operations research community are definitely grateful for the journey that you've had. And I want to thank you for your time today in telling your story. Both part one and part two of the life of Egon Balas.

EGON BALAS: Thank you very much.