A Conversation with Richard K. Guy

Donald J. Albers and Gerald L. Alexanderson

As a young faculty member at Goldsmiths' College in London, Guy was told by a seasoned staff member, "Goldsmiths' is noted for its successes and suicides—which are you going to be?" A half century later the answer is clear—Richard K. Guy is a great success. He has published more than 200 papers and nine books, some running to several volumes and some translated into languages other than English. And more books are on the way. His writing is marked by clarity and wit. He is a very popular lecturer, who has an unerring sense of when to drop the unexpected pun on his listeners. His punning is usually accompanied by a sly smile and subtle twitching of his notable eyebrows.

Guy recalls his first day of kindergarten. Three-year old Richard told his parents, who were very eager to know how the day had gone, "It was all right, but the teacher doesn't know much. She asked me what shape the world was and all sort of things that I thought she would have known."

Guy is a collector of unsolved problems and has published two books devoted to them. He currently is working on three other books and several papers. His prodigious production is perhaps explained by the fact that he works both when awake and when asleep. He thinks, in fact, that most of his serious mathematics is done while sleeping!

In his spare moments he climbs mountains, camps in the snow and even on glaciers, and composes chess end games.

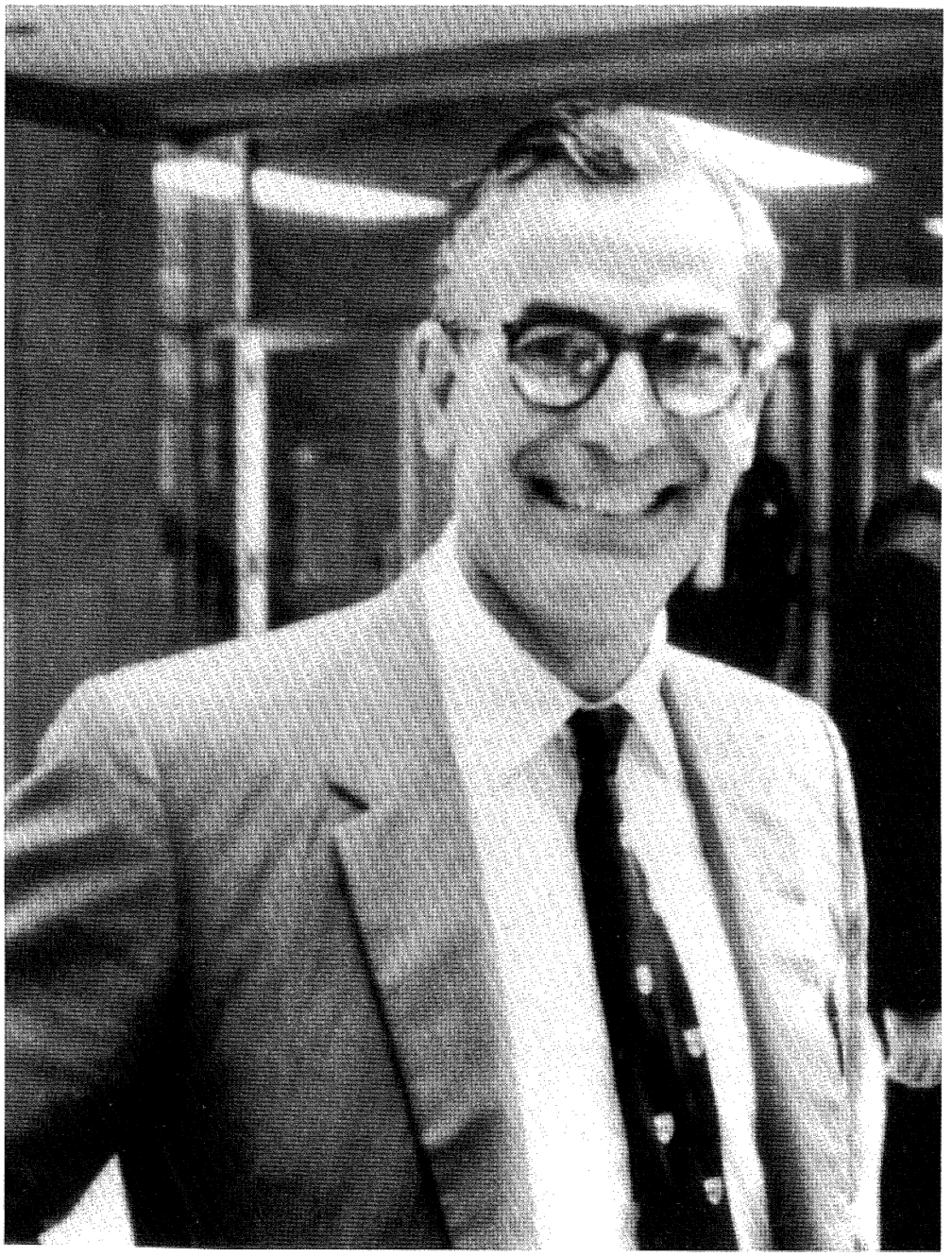
The following conversation took place in Menlo Park, California in the spring of 1988.

MP: You have covered a lot of the world in your professional career, but I understand that you started life in England.

Guy: Yes, I was born in Nuneaton, Warwickshire. But let me go back even further, 1912, when my father met my mother. She was the headmistress of a big girls' school in Acocks Green in the south of Birmingham. He was a young school teacher, eight and a half years her junior. He decided that he'd go out to the colonies, as I suppose they called them in those days. He went off in 1912 to teach in Perth Boys' School in Western Australia, the idea being that my mother would eventually join him and they would be married. In that case I would have been born Australian. But World War I started and my father, swept along by the wave of nationalism, joined up along with many colleagues. He was just in time to be at the fateful landing at Gallipoli, one of the few who survived. It must have had a very traumatic effect on him. He also served in France for a while and was wounded slightly. So he came home and married my mother. They never made the second attempt to emigrate. During the last five years of his life my father came out to stay with us in Calgary.

MP: Did your parents have any particular mathematical talent?

Guy: No, but they were general elementary school teachers in the old tradition so that they learnt and taught all subjects, including mathematics. I don't really



A happy Guy in Toronto, 1967.
(photo by Halmos)

Baby Richard

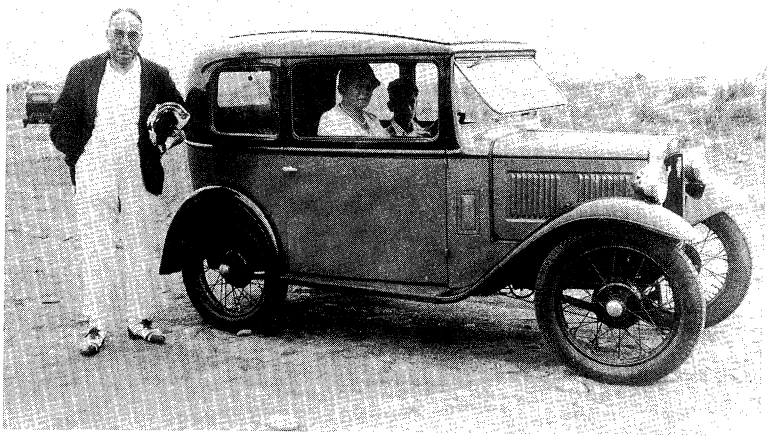
know what my mother's speciality was. She was just an expert on everything. My father claimed that English was his first subject, and he could certainly quote great chunks of Shakespeare. He also taught crafts, woodwork I think we would call it. He was very good at crafts. They were both very good craftspersons. You can't think of a craft—metal work or basket work or bookbinding or whatever—that they did not do, and with a very high standard. This was inhibiting for me because, although I knew how to do all these things in theory, as soon as I started to practice them, I would either give up or they would take over with "No, no, you should do it like this." My mother particularly was a great perfectionist.

MP: Although your parents were both school teachers, they discouraged you from a school teaching career. You were the first of how many children?

Guy: I was the first of one. That's it: an awful, spoiled only child. Of course there are enormous advantages and disadvantages to being an only child, but it also means you grow up to be a rather selfish person and you aren't always able to accommodate to other people around you later. You get very possessive and don't want people invading your territory.

My mother had an incredibly strong personality. She was one of those infuriating people who are always right, even when they're clearly wrong. My father just

abdicated all responsibility, even in financial matters. I think he would have been irresponsible as far as money is concerned. School teachers were very poorly paid, but my mother was a financial wizard as well as everything else. She managed so that we had a very good standard of living for those days. Teachers in Britain took a ten percent cut in salary during the depression, and salaries were small enough before that. So she managed extremely well. We were even able to run a motor car from the year 1924. She used to buy a baby Austin car, sell it at a loss of about £15 at the end of two years and buy a new one. So we always had a car, which was very unusual in our social stratum.



Young Richard with his father and mother in the family car. c. 1925

The First Rule of Good Health

MP: Pleasant?

Guy: She was too demanding of high standards in everything to be pleasant, but she did have a good sense of humor and was far from being unpleasant. I'm incredibly proud and glad to have had her as my mother. I was lucky with parents. The first of good health rules is to choose your parents carefully. And I made an extremely good choice. Also they both had very good principles: they were always impeccably honest, straightforward, and outspoken against anything that was not for the common good. Mother was a great leader in the Women's Institutes, for example. She founded several Women's Institutes in Warwickshire, where I grew up.

MP: What were Women's Institutes?

Guy: They were really to cultivate the traditional image of women and could be formed only in villages, in small communities. They taught housekeeping and country arts, but they also taught crafts. They would have meetings and someone

The Guy family at Rhonegletscher in 1949. L to R, Mike, Anne, Peter, Louise, and Richard.

would demonstrate how to cut out a pattern for a dress, for example. I can remember helping my mother make the diagrams that she would hold up to show the women how to take measurements.

MP: Why did you choose something as purely theoretical as mathematics?

Guy: I didn't choose mathematics. It was chosen for me.

MP: By whom?

Guy: That's a long story. I was obviously fairly bright as a child, and showed some signs of being a prodigy at about three in that I learnt tables and did mental calculations well beyond my years. During school I certainly disliked history, geography, English, and most languages. I think I would have been good at languages. When I went to Warwick School, which was where I got the main part of my education, I was in fact at the top in French. But I'd had a year of French and most of my peers hadn't, so it was not too difficult to be at the top. My interest was killed off by having for three or four years in succession a master who was very unsympathetic.

The subjects I was really interested in were mathematics, physics and chemistry. When you get to the sixth form in the British system, which is where you start specializing, you settle down to three subjects. Then it was clear that those were

my three subjects. At that time if you'd asked me which was my true subject (I was very young—I was only thirteen when I went into the sixth form, which is two to three years younger than usual), I would have said chemistry. I was very keen on chemistry. But the chemistry teacher was a gentleman in the old English sense of the word. I think he had a private income. He didn't need to teach at all; he just did it out of love of the subject. So he had a very detached attitude, saying, "Here is my subject. If you care to sit at my feet and listen, you are very welcome." And that was fine with me. I would have gone on lapping it up; however, the mathematics teacher was a real go-getter and livewire, and if he saw anyone around who showed any aptitude at all he grabbed him and said, "Now, come on, you're going to do mathematics." He grabbed me and said that I was to do mathematics. That was Cyril T. Lear Caton, Lear because I think he was related to Edward Lear. He was a very interesting person. He was only about five feet tall—his wife was even shorter, I think. He was a very notable math teacher, and these were the days in Britain when all the senior math teachers in the so-called public schools, the grammar schools, were first class honors people from the two older universities. He went off to be headmaster at Alcester Grammar School after a while. After he left we got Kenneth Lansdell Wardle, who not too long ago retired from Birmingham University. Again he was a very good mathematician. I learned all sorts of things, such as Lagrange multipliers. I could solve any differential equation that you could solve with the usual methods. Quaternions I knew about, and therefore vectors in particular—wooden vectors, as I like to call them.

MP: Wooden vectors?

Chess, Bridge, and Snooker

Guy: Well, 3-D vectors, the kind I still tend to be fascinated with because you really can see them. Much of my career I've spent teaching engineers. I enjoy this very much because you can see the mathematics working in the ordinary three-dimensional space that we think we live in. It helps you to keep your feet on the ground. Anyway Wardle then took over for about three years. So when it came to decide on a career, obviously I'd just go on doing mathematics. When I went up to Cambridge, I went to Caius College, which was where Wardle himself had been. At the end of my time there I still didn't know what I was going to do. In those days one or two people went into the actuarial profession, and one or two people stayed on to do research mathematics. I got only a second class degree because I spent most of my undergraduate life playing chess or bridge or snooker. So the only thing I could do was to go into school teaching. My parents had both strongly advised against their profession, because it was so underpaid, but there was nothing else. In those days one of the deadly sins was to be unemployed. Your curriculum vitae had to show continuous employment, and if you'd ever been out of work no one would give you a job. I made only a few ineffectual attempts to get a job. Another difficulty in those days was that you had to have had experience. How anybody without experience manages to get experience is always a bit of a difficulty and still remains so to this day! I didn't succeed in getting a job, and in order to avoid this terrible hiatus, I went to Birmingham University and took a teaching diploma, really to fill in and give myself another year in which to make a more serious attack on landing a job, which I eventually did.

I went to Stockport Grammar School which boasted amongst its former pupils, W. L. Edge, the geometer, who died recently, and Horace Lamb who wrote the classic book on hydrodynamics. So I had landed at a place with a very good mathematical environment. But within a year or so I got overtaken by World War II. When I came back, apart from having gained a wanderlust as a result of travelling during the war, it became obvious to me that although the school was very good from the mathematical point of view, if I really wanted to advance my career, I couldn't do it by staying there. Eventually, if you stay, you become the senior mathematics master, but there were two excellent teachers of mathematics who had been at the school already for twenty years, and it was clear that they were going to be there for the next twenty. I was just going to be teaching middle school mathematics, and enjoyable as that was the first few times around I could see that it was going to be increasingly boring.So I decided I'd better try to move on. I applied to Goldsmiths' College, a part of London University, but a teachers' training college. From the academic point of view I don't think anybody regarded it as being on the same level as other colleges of the University.

Cricket Anyone?
Guy, front row left, was part of the Staff Cricket Team of Goldsmith's College in 1949.

MP: I notice that you had a first class honors on the tripos.

Guy: Well that was Part I. That's put down just to impress people. I only got a second in Part II, which is called Senior Optime and also sounds quite impressive (first class is called Wrangler).

Master's Degrees For Five Guineas

MP: But then in '41 you took the M.A. at Cambridge.

Guy: Well, again, that was completely phony. Let me put it in the best possible way that I can. The mathematical education at Cambridge was so superb that

getting an ordinary bachelor's degree there was equivalent to getting a master's degree anywhere else. So for the price of five guineas and a decent interval of time (three years) you automatically got a master's degree.

MP: Does that mean you applied for a master's degree?

Guy: Yes, you have to know the Cambridge system. The masters become voting members of the university. After you acquire a certain amount of seniority you're allowed to take part in the political process. It's not really an academic matter; it's a university political thing.

Guy as a member of the Royal Air Force in 1942.

MP: Did this require any additional time at Cambridge?

Guy: No. Only the length of time to write out the cheque and make the application.

MP: What's the theory behind that system?

Guy: You'd have to ask a university historian. It probably dates from the time when everybody got a bachelor's. You just went on residing there. If you had been there long enough you were sufficiently senior to be admitted to the brotherhood. You were elevated to a kind of peerage and allowed to take part in the discussion of college and university business.

MP: Had you solved any interesting problems at this time?

Guy: Your title, *Mathematical People*, did reassure me when I agreed to be interviewed. I was glad that the word mathematician doesn't appear in it, because I don't regard myself as a mathematician.

MP: You don't? A person who's published nearly 200 papers!

Guy: Again, you can fool some of the people all of the time, and all of the people some of the time. And you publish or perish; this is the way you survive. I have published virtually nothing in the way of theorems. If I sent you a list of publications you would find that there are few things which you might call research papers. Otherwise it's all padding. When I came to this continent, I found that you had to have a publications list, so I started dragging things together. O.K. My first theorem is a very nice one. If you look in an early issue of the *Mathematical Gazette*, roughly the British equivalent of the *Monthly*, you'll find "A Single Scale Nomogram." I merely made the observation that a cubic equation with no x^2 term has zero for the sum of its roots. If you draw a cubic curve, $y = x^3 + ax + b$ and put a straight line $y = mx + c$ across it, the sum of the x-coordinates of the intersections is zero. If the curve is symmetrical about the origin ($b = 0$) and you change the sign of x on the negative half, then one coordinate is equal to the sum or difference of the other two. Combine this with the principle of the slide rule, which simply adds one chunk to another. For example, if the chunks are logs, you have multiplication and division. Anything you can do with a slide rule you can do with any single scale nomogram. That was my first theorem, I suppose.

Harry Golenbeck, editor, *The British Chess Magazine*, making a move against Guy in a simultaneous display at Goldsmith's College in 1949.

MP: You said with some passion a minute ago that you're *not* a mathematician. If you're not a mathematician, then what are you?

Guy: An amateur, I mean I'm not a *professional* mathematician. I'm an amateur in the more genuine sense of the word in that I love mathematics and I would like everybody in the world to like mathematics.

MP: Why should they?

Guy: Well, because it has become a very important part of our lives, yet the great majority of people obviously have a fear and hatred of mathematics. This is a great shame. It's almost like going back to very superstitious times when many people were bedeviled by the idea that there were evil spirits lurking behind every tree, and lived in fear and trembling. I think the modern equivalent is people living in fear of mathematics when it can be such an enjoyable thing, and such a useful thing. My desire has been to pursue mathematics, mainly in the selfish way of just enjoying it on my own, but also wanting to pass this enjoyment on to other people, particularly as I get older and feel that at least I owe something for the terrific privilege that I've had of being able to live, all the time doing what I wanted to do. Most people have to earn their living doing things they don't like doing, and I've always been amazed that people would pay me to do what I would be doing anyway. Now I want to repay people by trying to sell mathematics to as many other people as I can.

MP: You say you're an amateur, but I don't know if you want to stick by this statement that you're not a mathematician. How about your collaborators—Berlekamp, Conway, Erdös? Are they mathematicians?

Guy: Certainly they are. And in fact this rather supports my remark that I'm not a mathematician. I appear to be hanging on to the coattails of some of these more obviously genuine mathematicians. I love mathematics so much, and I love anybody who can do it well, so I just like to hang on and try to copy them as best I can, even though I'm not really in their league.

MP: Do you seek them out?

Guy: Well, you would have to take them individually to get an answer to that question. I've had the advantage of age over most of them. I've noticed that young people are much more respectful of age than they were say one generation ago. Two or three generations ago you had to be respectful of your seniors or else. But then somewhere about the fifties, perhaps even earlier, youth got very rebellious against age. I notice nowadays that young people don't seem to mind the generation gap. They're willing to listen and talk to older people.

Conway was still a young graduate student when I met him through my son Mike, who is two or three years his junior. So if Conway didn't have respect for me as a mathematician, he at least had some respect on account of my age. Also I think that my son had sold him on some of the things that I'm interested in, particularly game theory. Mike Guy was interested in games because what one would call my second theorem, I suppose, was the discovery of the periodicity of what are now known as nim-values, what we called $\mathscr{G}$-values in the paper with

Guy played Archbishop Cramer in "A Rose Without a Thorn" in Delhi in 1964. (Nehru shook hands after the performance.)

Cedric Smith. So when I met him, Conway had already been a bit brainwashed by Mike in the areas of game theory, graph theory, the beginnings of combinatorics and so on. The real reason Conway would bother with me at all is that he had enormous respect for Mike Guy. Mike is a genuine mathematician, although you'll find only about one paper of his in the literature because he doesn't bother to publish. In Conway's writings, scattered about, you'll find references to him. In "Monstrous Moonshine" Mike Guy appears early on in the paper. And Conway's paper on the Archimedean solids in four dimensions was really a piece of joint work with Mike. Conway has enormous respect for Mike's abilities and therefore a certain respect, perhaps vicariously, for the parent that produced Mike Guy.

The Benefits of "Hmmm, Yes"

I think Conway liked to use me, also, for what John Leech calls a blind ear. You know how very useful it is when you're just on the verge of getting some mathematical idea, to have someone who will listen. Our daughter used to use my wife in this way. My wife doesn't know any mathematics at all, but when my daughter would be wrestling with some topological problem she'd come downstairs from where she was studying. Louise would be in the kitchen, baking a cake or something, and my daughter would start expounding away. Louise would say, "Hmm, yes." If you've just got somebody there listening, you're clarifying your own ideas. I think Conway used to do this with me and found it useful to have someone say, "Hmm, yes," every now and again. Anyway for one reason or another, a very unlikely pair of people got together. Also I knew him in the early days when he was completely unable to write anything down. He was pouring out ideas all the time, so I would scribble them down and say, "Look, you've got a lovely paper. Here it is." I can't say I wrote his papers for him—that's certainly not true—but I

often gave him a draft which would then provide sufficient stimulus for him to put the thing down the way it really should have been written out in the first place.

With Elwyn Berlekamp, again, it was perhaps more the respect for age than anything else, but the respect came out of game theory again. I first met Berlekamp in 1966 at the Chapel Hill Combinatorics Conference. He was rather pleased with himself, as he deserved to be because he's extremely bright. He had just solved the children's game of Dots-and-Boxes. And an important tool in this was the Guy–Smith paper I mentioned earlier. He'd used this as part of the quite complicated theory that we regard as being one of the most satisfactory chapters in *Winning Ways*. The general public would find it rather heavy going, but to a mathematician I think it's a good chapter. Berlekamp said, "More people should know about the Guy–Smith paper. It's a very important one." He said we should write a book on games. I said, "Yes, that's fine with me." I thought about it a bit and said, "Well, I know someone who could help us a great deal with this." So I wrote to Conway. Once a year I would go back to Cambridge for a few weeks and we'd sit down and Conway would spout away and I would scribble down things. So a draft of a chapter would be produced.

MP: By you.

Guy: Well, you often see these papers produced by great mathematicians, that just say notes were prepared by some graduate student. Much of Conway's writing has originated in this way. I would write things down as he dictated them and try to write out a fair copy. The next time I'd see him I'd show it to him and he'd say, "No, no, you've got this all wrong."

MP: The gestation period for *Winning Ways* was fairly long.

Guy: It was started in '66 and published in '82, 16 years. But we were not working continuously. We are three very different personalities and I think my

Louise and Richard on Heart Mountain.
Steven Bryan Grantham

main role was keeping Berlekamp and Conway both together and apart. A lot of the work was done in our house in Calgary. Louise has been an enormous help to mathematics and to a large number of mathematicians, including some rather queer ones, whom she has given hospitality to at one time or another. Occasionally Conway and Berlekamp would almost come to blows. It's very interesting that they can work together because the lay mathematician would guess that Conway and Berlekamp were very different kinds of mathematician. Once Conway wrote a letter of reference for Berlekamp for the chair of mathematics or electrical engineering or whatever it is that he holds now in Berkeley. Conway just dictated it to me. He said how well he had worked with Berlekamp because Berlekamp had these great intuitive ideas. His own analytical abilities could cash in on them. Now I think most people would guess that Conway was the intuitive one, with brilliant ideas, and that Berlekamp was more the steady plodder. But he isn't. Having worked with them both I know that Conway is not a plodder but he works fantastically hard and methodically and pounds away at something until he gets there. Berlekamp gets quite bright ideas, suddenly. He just states theorems and they're true. He doesn't stop to prove them. Conway's much more cautious. He says, "Wait a minute. How do you prove this?" And Berlekamp says, "Well, you know, it's quite easy." Often there were wrangles that would go on and on and it would turn out that there were holes in Berlekamp's ideas. But they could always be mended, so that it was a very interesting collaboration. The book *Winning Ways* is a collection of essays. The ideas came from Berlekamp and Conway, but they were mainly written by me, almost entirely from Conway's dictation, either of his original ideas or of the ideas written out by Berlekamp in what was for us a not very acceptable style of writing—not acceptable because Berlekamp tended to a rather formal mathematical style which we certainly didn't want for *Winning Ways*. We wanted it to be a popular book. Conway would get hold of Berlekamp's rather long and ponderous essays on various topics and tear them apart and say, "Let's invent some names." We would delight in doing this, lots of plays on words. We would try to outdo one another in producing the most outrageous puns.

MP: You did very well.

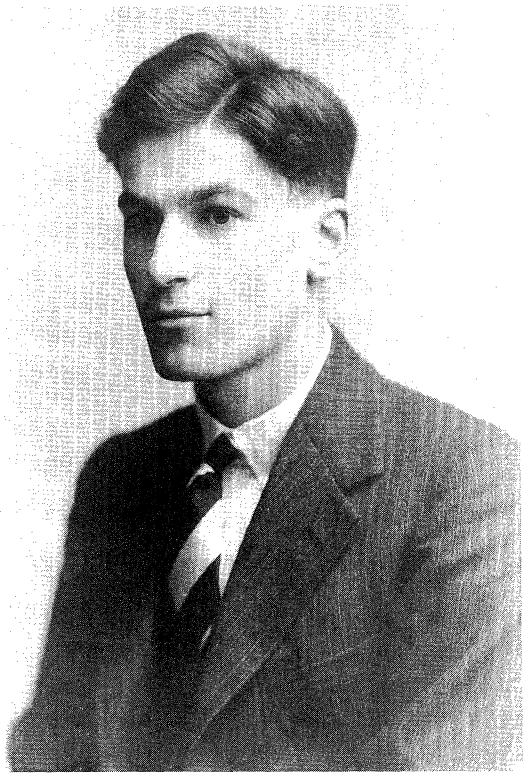
Guy: I remember one occasion when the two of us visited Bell Labs when Berlekamp was still there. Every now and again Conway and I would be working away together and something would set us off. I can remember at least two occasions when Berlekamp almost lost his temper. He wanted to get on with the work and we were making puns back and forth or going off into some complete irrelevance, nothing to do with the mathematics. It was like slapstick comedy. But it was wasting time as far as he was concerned.

MP: Yes, but it was a very effective collaboration.

Guy: Oh yes.

MP: You've worked in a variety of fields: number theory, combinatorics, graph theory, geometry, and game theory.

Guy: Jack of all trades and master of none.



R.K.G. in 1938.

MP: At the same time you've had some very distinguished coauthors, of course, a whole string of them. Did you pick the coauthors for their fields or the fields for the people you could work with?

Guy: Well, my own interests have been in combinatorics, game theory, and number theory. I seize hold of people who are in those fields. Erdös collaborates with everybody. It's hardly fair to say anything positive or negative about someone because he has written a paper with Erdös. It's such an enormous crew and includes some of the world's best mathematicians, but it also includes young hopefuls who have only written one paper in their lives because Erdös stimulated them. Erdös is another person who had a big effect on me. I first met him at the Davenport seminar in 1949. I can't claim that he had very much influence on me then, but when he came to Singapore in 1960, he stayed with me and gave me two or three of his problems. I made some progress in each of them. This gave me encouragement and I began to think of myself as possibly being something of a research mathematician, which I hadn't done before.

Dickson—Better Than Shakespeare

MP: In a conversation with Erdös some years ago—actually it was in *Mathematical People*—he said that he no longer works much in number theory because all the problems that are left are much too hard. Do you think that is valid?

The Guy boys at Cambridge. L to R: Kenneth, Peter, R.K.G., Andrew, and Mike.

Guy: Yes, it is, I think. Number theory is at least 4000 years old, because we know the Sumerians must have been doing number theory to write down tables of what we now call Pythagorean triples and approximations to the square root of 2 and things which are clearly mathematics and not astrology or astronomy or anything else. So number theory is the oldest branch of mathematics, and quite a lot of people have put in a lot of thought. If you want to get into an area, then number theory is perhaps the field where it is hardest to get up to the frontiers of knowledge. Combinatorics is an extremely young subject and it has in common with number theory an immediate appeal to amateurs such as myself in that it's very easy to understand the problems. But it may be of varying difficulty to solve them. I was always interested in number theory, ever since I was a small child. When I was a youth I'd bought Dickson's *History of the Theory of Numbers*.

MP: How old were you?

Guy: Well, seventeen perhaps. I walked into a book shop: an ordinary book shop but it had a copy of Dickson's *History* and I was fascinated, although it was about six guineas, which was a fantastic price in those days for me. I wasn't earning anything, so I must have talked my parents into giving me the money. But it was better than getting the whole works of Shakespeare and heaven knows what else.

MP: Let's go back to the field of combinatorics for a moment. Unhappily, it seems to me, that although we've had absolutely first class work in the last ten, fifteen, twenty years in combinatorics with the work of Lovász, Szemerédi, and so on, there is yet to be a Fields Medal awarded in this area. It seems that the subject is not recognized within the mathematical community at large. The mathematical establishment seems to be dominated by algebraic topologists, algebraic geometers, and such.

Guy: There's not much to say. You've already said it. There are fashions in these things and combinatorics has not yet been very fashionable. Of course, you can go

back and point to a lot of Euler's work, and some of Gauss's, and many people, like Cayley and Sylvester. A lot of what they did was combinatorics. Even Hardy, Ramanujan, and, I'm sure, Frobenius worked on combinatorial problems. There are plenty of good names. You can say, "Well, that's really a combinatorial theorem." But combinatorics hasn't on the one hand formed itself into a coherent body of knowledge, and on the other hand it hasn't caught the attention of the serious mathematicians.

MP: Yes, I suppose the algebraic geometers and the topologists would look to their fields and say, "Well it has this enormous structure." This may not be true of combinatorics.

Guy: I think this is the trouble. Many people regard combinatorics, probably quite correctly, as being just a bag of more or less unrelated facts, and a bag of particular tricks for solving particular problems. You can pick out a number of themes that do carry over into various problems, but, as you say, it's difficult to see a real structure there.

MP: It isn't a lack of depth.

Guy: Pólya's theorem (the Redfield–Pólya–deBruijn–Read theorem) and Ramsey theory are really very deep, and of enormous significance. You can do a great deal with them.

MP: I want to get back to Erdös for a minute. I know your Erdös number is considerably less than one.

Guy: How do you get an Erdös number of less than one? Do you divide by the number of joint papers?

MP: That's exactly right. So what is your current Erdös number?

Guy: I had a letter from the Hungarian Academy the other day. Somebody there is trying to put together a list of all of Erdös's papers. So they wrote and said, "We notice the following paper or papers joint with Erdös. Could you check the bibliographic details and tell us of any other papers that you know about?" So I did make a list. But there were only four papers with Erdös. So I have Erdös number 1/4.

A Distinction in Art

MP: You often illustrate your manuscripts. As a child were you interested in art?

Guy: Yes, as I've already said, my parents were school teachers and every summer they went away to a summer school for teachers, refresher courses of many kinds which tended in the main to be moderately light-hearted. Many were in art and crafts at which both my parents were superb performers. When I was very small I used to go and play on the sands with my bucket and spade. When I came to be a youth, I enrolled in an art course, or a so-called art course. But I can't in any way claim to be an artist. When I was at school, I took a subject which

Guy with Teoh Gim Hock working with polyhedra in Singapore in 1952.

went by the rather grandiose title of "Engineering" but in fact was half metalwork, and half machine-drawing. We drew stress diagrams, which was very useful to me because it was really mathematics and statics. I did machine drawing and developed a certain amount of facility. I won't claim to be in the Escher class. Escher was in the first instance not so much an artist, although I'm running him down considerably in suggesting that, but he was an incredibly meticulous designer. He was a very careful draftsman in the more technical sense. You see the same thing in Salvador Dali's early work. Not only do you get the strange visions and surrealism of Dali, but you also get this terrific technical ability. So that even in the early days when Dali was a complete shocker, as far as most people were concerned, a large number of people had to be respectful of his technical ability. I had acquired a certain amount of technical ability as I went to these art courses and I learned lettering. That's a skill that has been very useful and that I passed on to my daughter and to my granddaughter. It was something that I was fascinated with—designing of fonts and typefaces and posters. I took a teaching diploma at Birmingham University. I needed some nontechnical subjects, so I took Art. I got a distinction in Art then because it was very easy to turn out this mechanical kind of thing. You didn't have to be an artist in any sense or show any originality. You just had to show some sense of taste and a certain amount of ability and technical skill. I've always had that and it's always been very useful to me.

How to Write a Preface

MP: I want to turn to the preface of *Winning Ways*.

Guy: Yes, guess which of the three of us wrote it. I always thought that everyone would guess that it's Conway.

MP: Oh no, I guessed it was you.

Guy: You're quite right.

MP: Let me read a little bit here to you. "Does a book need a preface? What more, after fifteen years of toil, do three talented authors have to add? We can reassure the bookstore browser, yes, this is just the book you want. We can direct you if you want to know quickly what's in the book to the last page of this preliminary material. This in turn directs you to pages 1, 255, 427, and 695. We can supply the reviewer faced with the task of ploughing through nearly a thousand information-packed pages with some pithy criticisms by indicating the horns of the polylemma the book finds itself on. It is not an encyclopedia. It is encyclopedic, but there are still too many games missing for it to claim to be complete.... So just don't stand back and admire it, work of art though it is. It is not a graduate text since it's too expensive and contains far more than any graduate student can be expected to learn. But it does carry you to the frontiers of research in combinatorial game theory and...many unsolved problems." That's an absolutely delightful preface.

Guy: So much so that I know at least two reviewers who just copied that paragraph. Eventually after working all these years, Berlekamp more or less worships the ground that Conway and I write on. He has really learnt style. We even taught him how to spell. He has an enormous respect for what Conway and I have managed to put together after buffooning around. Conway more or less said, "Anything that you write will be O.K. with me." In any case, I tried to write the preface as though Conway was writing it. By that time I'd assimilated his style.

Mathematics, Games, and Geometry

MP: I am afraid that at this point we have gotten away from the chronology of your career, which has taken you to a couple of rather exotic places.

Guy: Unfortunately most of the changes in my life have been made for purely negative reasons. I've already told you that I moved from Stockport Grammar School to London, and not because of anything I disliked about the school. It was a lovely situation. I used to help with the coaching of cricket and rugger. I enjoyed teaching young people. I started a chess club there. In fact, let me interrupt myself to say something which I think is important. It may throw some light on the curious working of what I'll call my mind. When I first started teaching at Stockport Grammar School, I was given a Form, that is, a class of say 28 boys. You're sort of moral tutor for this Form, in addition to being a mathematics teacher. Mine was Form 1, the year before they started doing four years of algebra and geometry, leading to what used to be called School Certificate, and is now O-level. The only mathematics they did was arithmetic: fractions, decimals, percentages, and so on, for the sixth year in succession. Most of them already knew the stuff backwards and we had six periods a week because we worked Monday through Saturday. I felt that I would get terribly bored even if they wouldn't. So I declared that we would in fact have four periods a week of arithmetic, and the two other periods would be called Games and Geometry. "Geometry" consisted mostly of geometrical constructions and manufacture of polyhedra, and "Games" was mostly chess. We also used to play Battleships that would introduce coordinates and a certain amount of strategy. But I was already interested in chess endings. I would demonstrate to

them how certain of the more combinatorial aspects of the endings went: for example, if you are left with rook and king against king you mate the king. There are similar endings of that kind which are done mechanically. If you really want to be a competent chess player these things should be among your tools. So I taught these in a fairly formal fashion. When I came back to the school after the war, the chess club was functioning every night and they had to press nearly all the staff in the school into supervising it. There is a boy who had just left the school and was already third in the British championship, Alan Phillips. It was very much like what they were doing in Russia. You taught chess in the schools and produced an enormous body of very good chess players.

The geometry was also rather fascinating. I can tell you a nice Mordell story arising out of this. I said, "For homework this week make any polyhedron. Make a pyramid or something." There were a couple of kids who came with an icosahedron and a dodecahedron which I certainly hadn't expected. I was hoping to lead up to those, of course, but we'd done only cubes and tetrahedra. They came with them welded in metal. So I said, "Well that's very, very good, but where did you get the mathematical expertise and the metal working expertise to produce these? Who helped you with them?" And they said, "Oh, our father has a big collection of polyhedra." And I said, "Oh yes, what does your father do?" They said, "He's professor of zoology at Manchester University." It was Herbert Graham Cannon; he was quite a famous figure. And so I got an invitation to tea one Sunday and got to see Cannon's quite notable collection of polyhedra. He just had it as a hobby. So I got to talking and of course he was in the same Common Room as Mordell. I knew of Mordell, of course. In fact I'd written and asked him some of the stupid questions that I often get asked myself these days and, quite reasonably, he hadn't bothered to answer.

Mordell was one of many mathematicians who were interested in climbing. Cannon told me this lovely story about Mordell, how he'd arrived back on Monday morning in the Common Room and proudly announced to the general multitude, "Well, twenty-four hours ago I was climbing." This went over like a lead balloon. Except for the English professor, who looked up from his *Times* and asked, "Trees?" Louis tended to look a bit anthropoid.

Singapore

Anyway, I left Stockport because I couldn't see any future as far as advancing my career there was concerned. Then when I got to Goldsmiths'—and this was a very exciting place to be—I worked much too hard. I spent a lot of time on chess endings, a lot on graduate mathematics, a lot on the job, and far too little on my family. I was teaching 22 periods a week and many of the lectures were pretty much university level courses. It was a small place with about five hundred students, but they used to run two rugger teams, two soccer teams, two field hockey teams, and put on plays and do everything that you can think of that students used to do, an incredible amount of activity. It was a fascinating place to be, but the academic powers that be suddenly decreed that the general degree, the ordinary degree, was not a suitably distinguished thing for the University of London to offer. Now they couldn't do very much about the unique position that the University was in. Throughout the colonies and many other parts of the world there were thousands and thousands of people every year who took London degrees externally. Papers were shipped out to them. They wrote the papers, got

Officer Training Field Day at Warwick School.

examined, people in India and Malaya and almost every other place in the world which either didn't have very many universities or had very poor ones. They managed to acquire this certificate of merit. I suppose in a way it was a substitute for the Open University in the early days. It was an incredibly useful service. So the University Senate couldn't get rid of that, but what they could do was say to Goldsmiths', which was an *internal* London college, "You're not going to teach this stuff any more." With the big guns they had it looked inevitable that we would lose our degree work. And fascinated as I was with the teaching of mathematics, my main interest was in mathematics itself. And there were about half a dozen colleagues in English and other subjects who took off at the same time. We decided, "It's time for the rats to desert the sinking ship." We applied for jobs. As I said, Goldsmiths' now is an extremely reputable place, especially in mathematics, but it looked then as though it might not be. So we took off and it happened that the first place that offered me a job was the University of Malaya in Singapore.

MP: That's a long way from England.

Guy: Yes, but there was the need to survive. I didn't want to go back to school teaching, and to go to anything less than a college didn't seem right to me. The regular universities in Britain could get all the people they wanted in those days, so there was little hope of getting a job there. Going to the colonies was really the only way to get the kind of job I wanted. By this time I had a wife and three children and I dragged them protesting to Singapore. It's a very curious thing, because when I first met Louise, she was the one who wanted to travel. But as soon as we got married, the nesting instinct came into play and she wanted to make a home for the children. I'd gone off to the war and travelled about and got terrific wanderlust. Anyhow off we went to Singapore. I wouldn't change that for the world. We had an excellent department there, although it was very hard to get people. It was really only a man and boy operation. Well it was two men and a boy because we did have Oppenheim, now Sir Alexander Oppenheim, whom I visited

just recently and who's well into his 80's now. We also had Jack Cooke, who was professor of applied mathematics. They were both very reputable mathematicians.

I must tell you a story. Bobby Ho, who was in the Geography Department in Singapore, said to me one day, "Come round to dinner; I want you to meet a friend of mine who's a mathematician." They had both been at King's College, London. The friend was Eric Milner, who had been supervised in a master's degree by Coulson.

The Road to Calgary

MP: Charles Alfred Coulson? Who was later professor of chemistry in Oxford and very prominent in the movement to unite the churches?

Guy: Yes, that's the one. Evidently—this is probably an apocryphal story—at a drunken party someone said, "You mathematicians are useless: you couldn't get a job in the real world." As a result someone stuck a pin in *The Times* and said to Eric, "I bet you can't get this job," selecting a job at random. The job was with the Straits Trading Company, a tin-mining operation in Malaya. At the time that Eric came out, this was a pretty dicey business, because of the bandits or terrorists, the Japanese Liberation Army. The day after I met Eric I went to Oppenheim's office and said, "Hey, there's a mathematician lying around loose here in Singapore. Let's grab him." So we did. Well, he's fairly eminent now, a fellow of the Royal Society of Canada, and invited speaker at some of the International Congresses. Later on when I was Head of the Department I also managed to recruit Peter Lancaster, now another Fellow of the Royal Society of Canada. And both he and Milner are with me now, but for opposite reasons. I'm in Calgary because Peter Lancaster went there first and Milner is there because I went there. We had excellent people in Singapore and although we were isolated, we did get people like Heilbronn, Coulson, Eilenberg, Erdös, and the Lehmers to visit. An important turning point in my life was the Lehmers' visiting Singapore early in '59 and telling me about the Boulder conference, to which I went. I made contact with dozens of number theorists. It was the beginning of a long friendship with Selfridge. It was the first time I had met Leo Moser. That was another turning point: Leo was one of the various reasons I went to Alberta. I had heard of Alberta, through Leo, but I'd never heard of the Calgary Stampede. I hope that Leo would be suitably flattered that he was more important than the Calgary Stampede. I had met Leo by correspondence but there I met him in the flesh. We immediately clicked. Leo had this deadpan Buster Keaton sense of humor which many people didn't understand at all. They just thought he was being rude or at least uninteresting. But Leo and I hit it off very much the way John Selfridge and I hit it off.

Do you know Leo's story about this publisher saying, "Well, when's this book of yours going to be published?" And Leo said, "Oh, I don't know, probably posthumously." The publisher said, "Well, make it soon."

The Numbers Racket

The Boulder conference was a three-week summer institute in number theory, which is quite a long time, particularly if you get to know someone immediately. A small group of us ended up going around together. Leo Moser, John Selfridge, Raymond Ayoub, and I found ourselves in Trader Vic's in Denver, having a drink.

The waitress came up to take our order—she could easily tell we were from out of town—so she asked, "What do you people do?" Right off Leo Moser said, "We're in the numbers racket."

I used to play a lot of bridge and someone wanted to make up a four—so I found myself sitting opposite Leo Moser. This was early on in the conference and I had only just met Leo. He said to me, "Do you know the Smith convention?" I said, "Yes." So we sat down and started playing and after a little while, Leo looked over his hand and said "I've only got twelve cards." I said, "Well, I've got fourteen," and we threw the hand in. We were not playing for money.

Then there was an interval of around twelve years—it must have been about 1970—and I was staying with Ted and Peggy Youngs in Santa Cruz over Christmas. Some friends of theirs—he was evidently a very well-known film director—were there and it was again suggested that we have a game of bridge. I had to admit that I knew the rules. I sat down opposite this film director and our opponents were Ted Youngs and his son. The film director said, "Do you play the Smith convention?" I said, "Yes." So we pulled this stunt again. I never saw Youngs get so angry. He became apoplectic. I did know that he had a heart problem and I got worried that we might have precipitated something. There was a terrific uproar. Eventually it resulted in this film director and his wife leaving the house and I felt absolutely terrible being part of the sequence of events. But I was reassured that every time this film director came to their house—and they were very old friends—they managed to get sufficiently drunk that they found something to have some fantastic disagreement over. Every time the evening broke up in this way. There was nothing unusual about it at all. So there were two times in my life that I have been able to use the Smith convention. There are, of course, two responses. If one says that he has twelve cards, it means that he has an indifferent hand. So you can respond that you have fourteen, meaning that you too have an indifferent hand. But if you have a good hand, you can say, "I have thirteen; you'd better count again."

As a postscript to this, Patrick Browne, my present head of department, told me that he and Eric Milner were playing a tournament in Calgary, against some university students, when one of the students said, "I've only got 12 cards." Quick as a flash, Eric Milner preempted with "I've got 13, you'd better count again." He and Patrick made a small slam!

MP: Between Singapore and Calgary you spent some time in India. What prompted the move to New Delhi?

Guy: I was reading *The Mathematical Gazette* and to my surprise there was an advertisement in it for a job. In those days, job advertisements didn't appear in *The Mathematical Gazette*. The advertisement was for someone to start up a mathematics department in the new Indian Institute of Technology in Delhi, although it barely mentioned the name. I don't think it had yet been approved by the Indian government. I thought, "Well, this looks interesting." So I applied. I just wrote a letter saying, "I've just seen this. It's ages old and I presume you've filled the post by now, but if you are still interested I can send you a more formal application." Back comes a letter by return post, "Yes, please apply immediately." So, I sent it in. Back came a reply again. "Can you be interviewed?" In fact I'd arranged to go on a holiday up in the jungle, and an aborigine arrived with a message in a cleft stick saying, "Could you be in Kuala Lumpur in forty-eight hours' time for an interview?" Anyhow, they were in a mad hurry to get someone. In the event the

Indian government failed to approve this for a heck of a long time so I didn't actually go to India for quite a while after that. I signed a five-year contract, but I did only about three and a half years in Delhi, because although it was a very fascinating and interesting country, the director there had a chip on his shoulder about the British Raj [the time when India was under British rule]. He only knew one word and that was "no." He had excellent people. He'd got really good British people as heads of departments. Engineering in India at that time was the prestigious profession. In most countries it's medicine, but in India it was engineering. So we got the best students from all over India. And we got the best Indian staff. We had help from the British taxpayer who paid our salaries, and help from British industry which supplied the equipment. We really had everything going for us. It was an excellent place and it had terrific momentum, but we had this director who kept saying "no" to every idea we had, even if it wouldn't cost money. He just had to be in charge. So several of us didn't finish our terms.

Anyway I was looking for a job again, when Louise wrote to Edna, Peter Lancaster's wife. He had left Singapore in 1962 and had in fact called on us in Delhi on his way to Calgary. Louise wrote to Edna saying, "Richard's pretty frustrated here." So I got a letter back, "Why not come to Calgary?" So I said, "Why not?" I applied to Calgary and said, "I'll come for one year." That was in 1965.

MP: Quite a shift in climate.

Guy: It certainly was. But that's fine because I was getting into my late forties by then and as you get older climates matter more. The Delhi climate is particularly bad. The temperature in Singapore never gets up to blood heat. It's never much below either. But I think once the temperature gets above blood heat there's nothing you can do about it. That's my criterion for rejecting a climate. If it gets warm you can perhaps run a bath of water and lie in it and hope. If it gets cold, you can run around, or burn the furniture and keep warm. But you can't keep cool.

Endgames and Unsolved Problems

MP: Spoken like an Englishman. At what point did you start getting interested in all these unsolved problems, with which your name is now associated?

Guy: I think I was always interested, and I kept looking at problems, mainly supplied by Erdös and others. Leo Moser was a great source of unsolved problems. When I found I couldn't solve the problems myself, the only thing to do was to pass them on to other people. Since I can't do the mathematics myself, I encourage other people to try to do it. In the early days when I first moved to London, when I went to Goldsmiths' College, I found myself within easy cycling distance of Thomas Rayner Dawson, the famous chess problemist. Although Dawson was not particularly interested in endgames, he ran the Endgames section of the *British Chess Magazine*, in addition to the problems section. Because I had been composing endgames and had made a bit of a name for myself, he suggested that I take over the Endgames section. He gave me a little section of his card index which referred to endgames and I eventually built up a very nice endgame library which I passed on to my successor. Dawson was an amateur mathematician—he has half a dozen papers in *The Mathematical Gazette*—he was a rubber chemist by

profession, although he had retired by that time. We used to love to discuss problems. They often turned out to be combinatorial: for example, Dawson wrote on polyominoes long before Sol Golomb did, but he didn't call them polyominoes.

Dawson showed me a problem of his, which we now call "Dawson's Chess." I managed to analyze this and in doing so rediscovered what we now know to be the Sprague–Grundy theory. I was taking a course in number theory from Estermann in University College. I showed him the analysis and asked him if it was significant. He said, "I don't know, but I can tell you who does," and sent me over to the Galton Lab to find Cedric Smith.

Now Cedric Smith turned out to have been an exact contemporary of mine in Cambridge, though we didn't meet there. He is one quarter of Blanche Descartes. They were all undergraduates at Trinity College. B was Bill Tutte, originally a

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Grundy's Game is played with heaps of beans: two players alternately choose a heap and partition it into two *unequal* heaps, so that the game ends when all heaps are of size one or two: the last player is the winner.

Dawson's Chess is perhaps most easily explained as a bowling game, played with rows of pins. The two players alternately knock down any pin, together with its immediate neighbors, if any, so that a move may separate a row into two shorter rows. Again, the player who knocks down the last pin wins.

These two games are examples of impartial games, in which the options are the same for each player, regardless of whose turn it is to move. The last-player-winning versions of such games are covered by the **Sprague-Grundy theory** which states that (any position in) any impartial game is equivalent to a heap of beans in the game of Nim. The number of beans in the heap is called the **nim-value** of the position. **Nim** is played with heaps of beans—a move is to select a heap and remove any positive number of beans from it. The elegant theory of Nim was given by C. L. Bouton around the turn of the century.

The **nim-sequence** for a game played with heaps is the sequence of nim-values of heaps of $0, 1, 2, \ldots$ beans. For Nim itself this is obviously $01234567\ldots$. For Dawson's Chess it begins $0112031103322405223301 1\ldots$ and eventually becomes periodic with period 34. Grundy's Game starts $0001021021021321324304 30\ldots$; Mike Guy has calculated ten million nim-values without finding any periodicity.

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chemist, who developed his expertise in graph theory at that time. L was Leonard Brooks, who became an income tax inspector, but has remained an amateur graph theorist: all graph theorists know Brooks's theorem. A was Arthur Stone, the Syracuse topologist, and C was Cedric. Now they didn't like BLAC, so they changed it to Blanche, and M. Filet de Carte Blanche was born (filet for networks, in which they were interested). Later, as sex change operations became popular, he became Blanche Descartes.

Cedric was quite excited about my rediscovery of Grundy's theory (we didn't know about Sprague then). Grundy had (apart from "Grundy's Game", whose analysis still defeats us) only a few trivial examples where he could apply the theory, whereas I had an infinite family, based on Dawson's Chess, and Kayles, another game I analyzed. (In Rouse Ball's *Mathematical Recreations and Essays*, there used to be a very significant diagram, due to Michael Goldberg, analyzing Kayles as far as 20 skittles: Goldberg was unlucky not to have discovered the complete analysis and the S–G theory.) This resulted in the Guy-Smith paper, which Berlekamp was to find useful later on.

Brooks's theorem is concerned with coloring the vertices of a graph. If the maximum valence of a graph is n, then the vertices of the graph may be colored with n colors with no edge having the same color at each end, *except* in two cases: if $n = 2$ and the graph contains an odd cycle; or if $n > 2$ and the graph contains $n + 1$ vertices each of which is joined to the other n.

MP: Who got you interested in chess?

Guy: It's hard to say, because neither of my parents played chess, but when I got to boarding school I just picked it up. So I started playing at a moderately early age, nothing prodigious, but I played fairly steadily while I was in school, and we did have a school chess team that played semi-serious chess. I used to play for the university but not on the top boards. I suppose I'd always had a combinatorial turn of mind. The endgame, which is capable of exact analysis, appealed to me very much and I used to love to get hold of books on the endgame. In fact I once planned a large three volume book on endgames.

Doing Mathematics While Sleeping

MP: How do you work as a mathematician?

Guy: If I do any mathematics at all I think I do it in my sleep.

MP: Do you think a lot of mathematicians work that way?

Guy: I do. Yes. The human brain is a remarkable thing and we are a long way from understanding how it works. For most mathematical problems, immediate thought and pencil and paper—the usual things one associates with solving mathematical problems—are just totally inadequate. You need to understand the problem, make a few symbols on paper and look at them, and draw a few sausages on the paper. Most of us, as opposed to Erdös who would probably give an answer to a problem almost immediately, would then probably have to go off to bed and, if we're lucky, when we wake up in the morning, we would already have some insight into the problem. On those rare occasions when I have such insight, I quite often don't know that I have it, but when I come to work on the problem again, to put pencil to paper, somehow the ideas just seem to click together and the thing goes through. It is clear to me that my brain must have gone on, in an almost combinatorial way, checking the cases or doing an enormous number of fairly trivial arithmetical computations. It seems to know the way to go. I first noticed this with chess endgames, which are indeed finite combinatorial problems. The first indication that I was interested in combinatorics—I didn't know I had the interest and I didn't even know there was such a subject as combinatorics—was that I used to compose chess endgames. I would sit up late into the night trying to analyze a position. Eventually I would sink into slumber and wake up in the morning to realize that if I had only moved the pawns over one file the whole thing would have gone through clearly. My brain must have been checking over this finite but moderately large number of possibilities during the night. I think a lot of mathematicians must work that way.

MP: Have you talked to any other mathematicians about that?

Guy: No. But in Hadamard's book on invention in the mathematical field, he quotes some examples there where it is fairly clear that people do that kind of thing. There was someone earlier this week who was talking about Serre. He said that if you ask Serre a question he either gives you the answer immediately or, if he hesitates, and you push him in any way, he will say, "How can I think about the question when I don't know the answer?" I thought that was a lovely remark. At a much lower level, one should think, "What shape should the answer be?" Then your mind can start checking whether you're right and how to find some logical sequence to get you where you want to go.

MP: Do you think number theorists are different from other mathematicians? Do they think of themselves as different?

Guy: That's a very difficult question. I think I have to answer that somewhat obliquely. Insofar as I am not a number theorist and I do have some other interests, I would have to claim that they are not different. But insofar as I am a number theorist, I would have to say that we are in a class by ourselves.

For those who would like to investigate further some of the problems and games referred to in the interview, Professor Guy has provided the following set of references:

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Homo investigatio

We are what we are: each one of us, even the peasant, even the most modest artisan, is a researcher, has always been that.

Primo Levi, *The Mirror Maker*, Schocken Books, 1989, p. 175

The best way to learn something

..."What really is the point of trying to teach anything to anybody?

This question seemed to provoke a murmur of sympathetic approval from up and down the table.

Richard continued, "What I mean is that if you really want to understand something, the best way is to try and explain it to someone else. That forces you to sort it out in your own mind. And the more slow and dim-witted your pupil, the more you have to break things down into more and more simple ideas. And that's really the essence of programming. By the time you've sorted out a complicated idea into little steps that even a stupid machine can deal with, you've certainly learned something about it yourself. The teacher usually learns more than the pupil. Isn't that true?"

Douglas Adams, *Dirk Gently's Holistic Detective Agency*, Pocket Books, 1987