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IN MEMORIAM: ERIC KAREL van DOUWEN (1946–1987)

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1. Some facts

Eric Karel van Douwen was born in Voorburg (The Netherlands) on 25 April 1946. He died of a heart attack on 28 July 1987, in his apartment in Athens (Ohio, USA). Eric obtained a masters degree in mathematics from the Delft Institute of Technology (Delft, The Netherlands) in January 1972 and a Ph.D. in Mathematics from the Vrije Universiteit (Amsterdam, The Netherlands) in March 1975. He initially enrolled in the university as a student in physics. Due to that he lost a few years.

Eric was a Ph.D. student in mathematics at the Delft Institute of Technology (Delft, The Netherlands) from January 1972 until March 1975. Then, at the invitation of D.J. Lutzer, he accepted the position of Visiting Assistant Professor at the University of Pittsburgh (Pittsburgh, PA, USA) from April 1975 until April 1976. He was then appointed by the Institute for Medicine and Mathematics (Athens, OH, USA) as a research fellow. He stayed in Athens from April 1976 until August 1982. After that he was a Van Vleck Assistant Professor of Mathematics at the University of Wisconsin (Madison, WI, USA), where he stayed until August 1985. He was then appointed Associate Professor of Mathematics at North Texas State University (Denton, TX, USA), where he spent the academic years 1985-86 and 1986-87. His last appointment was that of Associate Professor of Mathematics at Ohio University (Athens, OH, USA), where he should have started in the fall of last year. He was very pleased with this appointment.

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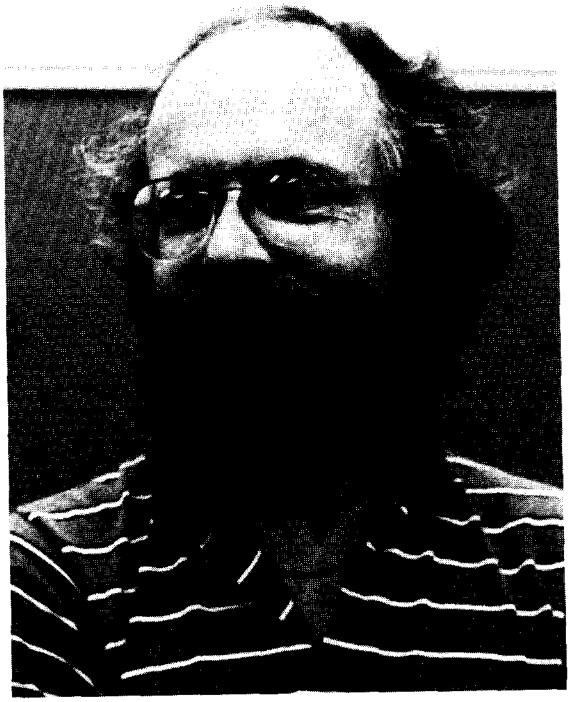

ERIC KAREL VAN DOUWEN (1946–1987)

Eric published over 70 research papers in journals all over the world. He was supported for many years by the National Science Foundation. In addition, he was a member of the Mathematical Association of America and of the Dutch Mathematical Society "Wiskundig Genootschap". Also, he was on the editorial board of the journal *Topology and its Applications.* He gave numerous invited talks at international conferences. Eric was a world figure in general topology, known in every corner of the earth where general topology is practiced. After a number of troubles, for example in obtaining his green card, it seemed he finally had come to a point where many of life's complexities were falling into place. The last days of his life were happy and relaxed. Eric died unfortunately at a time when it appeared he was on the threshold of his greatest accomplishments.

Eric started his mathematical career in Delft as a Ph.D. student under the supervision of J.M. Aarts. He was uncertain whether he should become an algebraist or a topologist. Someone in Delft told him that research prospects in topology were better than in algebra. That made him decide to become at topologist. Before he obtained his masters degree in mathematics, he published his first paper [vD 1], in which he used box products in order to answer a question due to J. van der Slot.[1] His doctoral dissertation, which was motivated by work of R.W. Heath and D.J. Lutzer [28], answered problems of C.R. Borges, R.W. Heath, D.J. Lutzer and E.A. Michael (see Section 2 for more details). Along the way, he also proved that the box product of countably many metrizable spaces need not be normal, [vD 7], and he wrote an intriguing paper about βX entitled "Martin's Axiom and pathological points in $\beta X/X$". Eric continued his studies under M.A. Maurice at the Vrije Universiteit in Amsterdam, where he got his Ph.D.

2. Eric's mathematical work[2]

We now turn our attention to a discussion of Eric's work. He accomplished quite a lot during his career. While Eric may be remembered for his work in compactifications, in fact, his work covered a wide area including Boolean algebras and topological groups. We have organized our discussion of his research into several natural areas, and we begin by looking at the topics in his dissertation (not all of which was published).

Extenders

Let X be a topological space. As usual, $C^*(X)$ denotes the vector space of bounded continuous real valued functions on X. If A is a subspace of X then a function $\Psi : C^*(A) \to C^*(X)$ is called an *extender* if for each $f \in C^*(A)$, $\Psi(f)$ extends f. In addition, Ψ is called linear if $\Psi(\lambda f + \mu g) = \lambda\Psi(f) + \mu\Psi(g)$ for all

[1] He told me that the first thing he tried worked, something that would happen quite often during his career.

[2] I have included in smaller type several personal anecdotes about Eric.

$f, g \in C^*(A)$ and $\lambda, \mu \in \mathbb{R}$. A space X is said to have property D_c^*, where c is a real number greater than or equal to 1, if for every nonempty closed subspace A of X there is a linear extender $\Psi: C^*(A) \to C^*(X)$ with norm not exceeding c. The Dugundji Extension Theorem [15] implies that every metrizable space has property D_1^*. C.R. Borges [5] proved a result from which it follows that every stratifiable space has property D_1^*. Since every stratifiable space is a σ-space, [27], E.A. Michael asked whether every paracompact σ-space has property D_1^* (in fact, Michael asked more).

Again, let X be a topological space. It will be convenient to let τX denote the topology of X. A space X is said to be a K_n-space if for every subspace A of X there is a function $\kappa: \tau A \to \tau X$ such that

(1) $A \cap \kappa(U) = U$ (i.e. κ extends the open sets of A to open sets of X),

(2) if $\{U_i\}_{i=0}^n$ is a family of $n+1$ pairwise disjoint open subsets of A then $\bigcap_{i=0}^n \kappa(U_i) = \emptyset$.

In his dissertation [vD 5], Eric proved that a space with property D_c^* is a K_n-space, where n is the smallest integer $> \frac{1}{2}(c-1)$. In addition, he gave an example of a first countable cosmic (=continuous image of a separable metrizable space) space H_∞ which is not a K_n-space for any n. Hence H_∞ does not have property D_c^* for any c and consequently answers Michael's question in the negative. These results (and others) were also published in [vD 6].

In Pittsburgh, in cooperation with R. Pol, D.J. Lutzer and T.C. Przymusiński, Eric continued to work on "extension" properties, see [vD 13] and [vD 17].

Box products

Around the time Eric wrote his dissertation in [vD 5] he also solved a basic problem about box products. Stone [32] asked whether the box product of countably many metrizable spaces is normal and Rudin [51] showed that under CH this is true if the factors of the box product under consideration are locally compact (see also [35]). In [vD 7], which is probably Eric's most famous paper, he proved that the box product of countably many metrizable spaces need not be normal, even if all factors but one are compact. In later years he never stopped thinking about box products, see [vD 12] and [vD 38] (for recent information on box products see Williams [58]). Eric used his nonnormal box product theorem to answer a question analysts had asked M.E. Rudin. Let $\mathscr{C}$ be the set of continuous functions from $\mathbb{R}$ into $\mathbb{R}$. Topologize $\mathscr{C}$ by declaring that $\mathscr{U} \subseteq \mathscr{C}$ is open if and only if $\bigcup \mathscr{U}$ is open in $\mathbb{R}^2$. Eric proved that $\mathscr{C}$ with this topology is not normal by constructing a closed copy of his nonnormal box product in $\mathscr{C}$. Unfortunately, Eric never published his result (see [vD u 80]).

Čech–Stone compactifications

In Delft, Eric became also interested in Čech–Stone compactifications, which would turn out to be his major field of interest. He distributed among his friends a handwritten manuscript [vD u 77] entitled "Martin's Axiom and pathological points in $\beta X\backslash X$". In that paper, which he never published, he outlined his view of βX. Reading this paper again for the preparation of this article it struck me that most of the themes that came up later in his work about Čech–Stone compactifications are present in [vD u 77]. Prior to Eric, mathematicians had mostly studied βX for general X, or for discrete X. Eric however liked to study the spaces βX for concrete X, such as the natural numbers $\mathbb{N}$, the rationals $\mathbb{Q}$, the real line $\mathbb{R}$, or the Sorgenfrey line S. He tried to give what he called "honest" proofs that the Čech–Stone remainders of these spaces are not topologically homogeneous. This was motivated by Frolík's Theorem [23] that $\beta X\backslash X$ is not homogeneous if X is nonpseudocompact. The proof of Frolík's Theorem is based on a cardinality argument and does not show "why" $\beta X\backslash X$ is not homogeneous because it does not yield two points which are topologically distinct for some obvious reason. A point $p\in\beta X$ is called a *remote point* of X if $p\notin \mathrm{cl}_{\beta X}D$ for any nowhere dense subset D of X. A space X is *extremally disconnected* at the point x if for all disjoint open subsets U and V in X, $x\notin U^-\cap V^-$. So a space X is extremally disconnected if and only if X is extremally disconnected at every point. In his unpublished paper [vD u 77], Eric proved that Martin's Axiom (abbreviated MA) implies that each nonpseudocompact space of countable π-weight has $2^{\mathfrak{c}}$ remote points. Moreover he showed that for nowhere locally compact X, $\beta X\backslash X$ is extremally disconnected at each remote point. Since it is easy to see that for $Y\in\{\mathbb{Q}, S\}$, $\beta Y\backslash Y$ is not extremally disconnected, these two results together imply that $\beta Y\backslash Y$ is not homogeneous under MA *because* it is extremally disconnected at some but not at all points. This is what Eric meant by an "honest" nonhomogeneity proof. Of course Eric was not satisfied by his proof because he needed MA.

A space X is called a *Parovičenko* space if

(1) X is a compact zero-dimensional space of weight $\mathfrak{c}$ without isolated points,

(2) every two disjoint open F_σ's in X have disjoint closures, and

(3) every nonempty G_δ in X has nonempty interior.

Parovičenko [45] proved that under the Continuum Hypothesis (abbreviated CH), up to homeomorphism, $\beta\mathbb{N}\backslash\mathbb{N}$ is the only Parovičenko space (see [20] for a recent topological proof of Parovičenko's Theorem). In [vD u 77] Eric proved that CH was necessary in this result because he constructed a Parovičenko space which is not homeomorphic to $\beta\mathbb{N}\backslash\mathbb{N}$ under MA+$\neg$CH. Again he was not satisfied. His result left open the obvious question whether Parovičenko's characterization of $\beta\mathbb{N}\backslash\mathbb{N}$ implies CH. So Eric did not publish his paper. Parovičenko's characterization of $\beta\mathbb{N}\backslash\mathbb{N}$ was shown to be equivalent to CH in [vD 22]. For related results, see [vD 25], [vD 45] and [vD 72].

> I met Eric for the first time at the end of 1974 when I had just begun as a graduate student in topology at the Vrije Universiteit in Amsterdam. Someone had told Eric that I was interested in compactifications so he came to me with a copy of [vD u 77] asking me whether I was able to prove his results on remote points without MA.

For years Eric tried very hard to prove the existence of remote points without MA;

here the first thing he tried did not work. And finally he succeeded! By a very clever argument he showed that every nonpseudocompact space with countable π-weight has $2^{\mathfrak{c}}$ remote points in ZFC, [vD 51] (independently, this result was also obtained by Chae and Smith [7]). He published a preliminary announcement of his result in the Bulletin of the American Mathematical Society, [vD 20]. So he had finally obtained "honest" proofs of the nonhomogeneity of the spaces $\beta\mathbb{Q}\backslash\mathbb{Q}$ and $\beta S\backslash S$. His results motivated the question whether every nonpseudocompact space has remote points. That that is not the case was demonstrated in [vD 60]. Since then, Dow [11, 12] and Dow and Peters [13] extended Eric's results in various directions; in addition, Dow has also constructed many other spaces that have no remote points [10]. Also, Eric's work on remote points motivated Dow to prove the result now called "Dow's lemma", [11], which has become an important tool in consistency proofs. The basic application of Dow's Lemma is that if one adds enough Cohen reals and a space is still normal then it must already have been collectionwise normal, see e.g. [14].

Since Eric's method of proving nonhomogeneity of Čech-Stone remainders works "only" for nowhere locally compact spaces, the question remained what could be done for $\beta\mathbb{N}\backslash\mathbb{N}$ and $\beta\mathbb{R}\backslash\mathbb{R}$. Kunen [36] proved the existence of so-called weak P-points in $\beta\mathbb{N}\backslash\mathbb{N}$ and $\beta\mathbb{R}\backslash\mathbb{R}$, which immediately gives "honest" proofs of the nonhomogeneity of these spaces (and many others). A little earlier than Kunen, Eric also obtained an "honest" proof of the nonhomogeneity of $\beta\mathbb{R}\backslash\mathbb{R}$, [vD 18].

At the time of the fifth Prague Topological Symposium (August 1976), Eric had already become a well-known topologist. On their way to Prague, several mathematicians visited Amsterdam, many of whom stayed in Eric's house in Delft. I remember Bill Fleissner, Gary Gruenhage, Dave Lutzer, Mike Wage, Mike Reed and Frank Tall. They all came to The Netherlands at the urging of Eric.

Pixley-Roy spaces

Let X be a space and let $\mathscr{F}(X)$ denote the collection of all nonempty finite subsets of X. For $F\in\mathscr{F}(X)$ and open $U\subseteq X$, define

$$[F, U]=\{G\in\mathscr{F}(X): F\subseteq G\subseteq U\}.$$

The collection of $[F, U]$'s is a base for a topology on $\mathscr{F}(X)$, which is called the *Pixley-Roy topology*, and $\mathscr{F}(X)$ with this topology is denoted by $\mathscr{F}[X]$. This topology (for the special case $X=\mathbb{R}$) was introduced in [46] by Pixley and Roy: they proved that $\mathscr{F}[\mathbb{R}]$ is an example of a nonseparable countable chain condition (=ccc) Moore space. In [vD 19], Eric studied some of the basic properties of the Pixley-Roy topology. His paper became influential very quickly. There was a time it seemed that everybody was doing Pixley-Roy topology. Let us give a few highlights. Eric, in cooperation with Weiss and Tall, [vD 15], used the Pixley-Roy topology for the construction of a very interesting L-space, i.e. a hereditarily Lindelöf space which is not separable. Bell [3] used it to present the first example of a σ-compact first countable ccc nonseparable space (this is delicate since it is consistent that every compact ccc first countable space is separable [30]). Bennett, Fleissner and Lutzer

[4] studied the metrizability of $\mathscr{F}[X]$ and Rudin [52] characterized those subsets X of $\mathbb{R}$ having the property that $\mathscr{F}[X]$ is normal. Hajnal and Juhász [25] studied the countable chain condition property in $\mathscr{F}[X]$ and Wage [57] proved that $\mathscr{F}[\mathbb{R}]$ is homogeneous, which answered one of Eric's problems.

I met Eric again during the fifth Winterschool on Abstract Analysis and Topology in Štefanová, Czechoslovakia, in January 1977. During that conference, Zdeněk Frolík organized a soccer game: "Czechoslovakia" against "The Rest of the World". Since "The Rest of the World" was a minority, the Czechs loaned us the person whom they thought was their worst player: Jan Pelant. Jan, however, made the first goal in the match against Czechoslovakia. Eric was one of the best players on the team of "The Rest of the World", which surprised me.

Examples

It is well-known that every space of weight $\mathfrak{c}$ can be embedded in a separable space. Ott [44] proved that every metrizable space of weight $\mathfrak{c}$ can be embedded in a separable Moore space and raised the question whether each Moore space of weight $\mathfrak{c}$ can be embedded in a separable Moore space. While investigating this question, Reed [49] asked whether every first countable space can be embedded in a separable first countable space. These are very natural questions. Eric was very interested in questions of this nature during his stay in Pittsburgh. In [vD 43] by an interesting technique, he and Przymusiński solved them by showing that they cannot be answered in ZFC. They also used their technique in [vD 28] to present the following examples:

(1) A first countable Lindelöf space all compactifications of which contain $\beta\mathbb{N}$.
(2) A countable space with one non-isolated point all compactifications of which contain $\beta\mathbb{N}$.

These examples prove the existence of a first countable space with no first countable compactification, a countable space all compactifications of which have cardinality $2^{\mathfrak{c}}$, and a scattered space with no scattered compactification. Such examples already existed in the literature but the Van Douwen–Przymusiński examples are much simpler and are constructed in a unified way. In [vD 32], in cooperation with Wage, Eric constructed several other "impossible" examples during his stay in Pittsburgh.

In the Netherlands, some of my friends quite often challenge me to explain what I am doing. At such occasions I speak with great enthusiasm about my teaching at the Vrije Universiteit. Some of my friends however don't buy that. At a party in my house, one of my closest friends again challenged me. As usual, I started to talk about the wonderful students that exist everywhere. However, that did not satisfy my audience at all. Eric, as a real big brother, took over and explained to my friend why the Hilbert cube is homogeneous. After Eric's lecture, my friend had to take a few extra drinks, but was finally convinced of the fact that the work Eric and I were doing was very serious.

Ostaszewski's technique

Ostaszewski [43] introduced what is now sometimes called the "adding limit points technique". The essential idea of this technique is that one constructs a topology on a set by transfinite induction assigning limit points to a carefully selected family of subsets of that set. If one does that with enough care, astonishing examples can be obtained, Ostaszewski [43], Juhász, Kunen and Rudin [31]. Prior to Eric, the technique had been used only to produce consistent examples. The original Ostaszewski example required ◆ and the examples in [31] were constructed under CH. In [vD u 79], which again was never published, Eric combined and refined the ideas in [43] and [31] yielding a technique that can be used to construct "honest" examples (=not requiring anything beyond ZFC), see e.g. [vD 10]. Eric's technique was again very influential. It was used by Przymusiński [48] to construct among other things (in ZFC!) a Lindelöf space X whose square X^2 is normal but not Lindelöf and by Broverman [6] and Mysior [41] to construct an easy example of a zero-dimensional realcompact space that is not $\mathbb{N}$-compact. See also Charalambous [8], Przymusiński [47] and Hart [26] for applications of Eric's technique in dimension theory and in the theory of fully normal spaces, respectively.

Eric had a very special sense of humour that I liked, but some others did not. At one of the Spring Topology Conferences that I attended, a mathematician, say α, constantly asked Eric questions of the following type: "Eric, is every β space also δ?". That was the wrong approach. He should have asked whether Eric knew of an example of a space having β but not δ. Eric got tired of his questions that he could answer with simple counterexamples all the time. Once more α approached Eric and said: "Eric, can I ask you a question". "YES", Eric replied, "but the answer is NO".

Cardinal functions and cardinal numbers

Eric was very much interested in cardinal functions. His most famous cardinal inequality, established in [vD 21], is the following:

If X is a homogeneous space then $|X| \leqslant 2^{\pi(X)}$.

Here $|X|$ means the cardinality of X and $\pi(X)$ denotes its π-weight (see [30] for more information about cardinal functions). A simple proof of this inequality was later given by Frankiewicz [21]. Eric quickly applied his result to Čech–Stone remainders by observing (among others) that since $\beta\mathbb{Q}\backslash\mathbb{Q}$ has countable π-weight, it cannot be homogeneous because its cardinality is $2^{\mathfrak{c}}$ (in fact he proved much more, namely that no power of $\beta\mathbb{Q}\backslash\mathbb{Q}$ or $\beta\mathbb{N}\backslash\mathbb{N}$ is homogeneous).

It is well known that every compact metrizable space is a continuous image of the homogeneous Cantor discontinuum. Kunen asked whether every compact space is a continuous image of some homogeneous compact space. Uspenskiĭ [54] proved that for every space X there is a space Y such that $X \times Y$ is homogeneous; in addition, Morotov [40] has shown that for the familiar $\sin(1/x)$ continuum X there does not exist a compact space Y such that $X \times Y$ is homogeneous (see also Arhangel'skiĭ [2]). Kunen's question however is still unanswered. An obvious candidate for a counterexample is $\beta\mathbb{N}$. As a partial answer, Eric proved in [vD 21] (among others) that if X is compact and has weight $\mathfrak{c}$ and can be mapped onto $\beta\mathbb{N}$

then X is not homogeneous. He continued to be interested in questions such as Kunen's. He observed that he did not know many examples of homogeneous compacta. Of course there are many homogeneous compact metrizable spaces, and products thereof, and compact topological groups, but these spaces are all ccc. There are examples of homogeneous compacta that have cellularity $\mathfrak{c}$ (Maurice [38]). But, as Eric observed, no homogeneous compacta of cellularity greater than $\mathfrak{c}$ are known. This astonished Eric and on several occasions he raised the question of whether such spaces exist (Istvan Juhász proposes to call this "Van Douwen's problem"). Eric was an excellent source of open problems of this sort. His questions were always natural and concrete and seemed so obvious: why did not anybody think of this before? In [vD u 77] he constructed an example of nowhere locally compact space having no connected compactification, and this led him to pose the problem whether the Sorgenfrey line, one of his favorite spaces, has a connected compactification. This turned out not to be the case (Emeryk and Kulpa [16]).

In [vD 47] he obtained results somewhat in the same spirit as his cardinal inequality for homogeneous spaces. He proved that if X is a pseudocompact homogeneous space the cardinality of which has countable cofinality then the density of X is smaller than its cardinality, in symbols:

If X is homogeneous, pseudocompact and $\mathrm{cf}(|X|)=\omega$ then $d(X)<|X|$.

An F-space is a space in which every cozero-set is C^*-embedded. These spaces come up naturally in the theory of Čech–Stone compactifications, so Eric was very interested in them. In [vD 50] he wrote a paper about cardinal functions in compact F-spaces. Among other things, he proved that if X is a compact F-space then

(1) $|X|=|X|^{\omega}$,
(2) $\chi(X)$ has uncountable cofinality, and
(3) $w(X)=w(X)^{\omega}$

(here $\chi(X)$ denotes the character of X). Recently he also completed a carefully written survey about cardinal functions on compact zero-dimensional spaces that will be published in the Handbook of Boolean Algebras, [vD 66]. I think that his most famous and most useful paper about cardinal functions and cardinal numbers is his paper in the Handbook of Set Theoretic Topology [vD 62]. In that paper he finally published results and ideas he had for years. Let $\mathcal{P}(\omega)$ and ω^{ω} denote the power set of ω $(=\{0,1,2,\ldots\})$ and the set of functions from ω into ω, respectively. Eric, motivated by work of Rothberger [50] and Hechler [29], studied six cardinals associated with ω, namely $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{d}$, $\mathfrak{p}$, $\mathfrak{s}$ and $\mathfrak{t}$, each of which is the minimum cardinality of a special subfamily of $\mathcal{P}(\omega)$ or ω^{ω}, and discussed their relationships and roles in topology. Each of these cardinals lies between ω_1 and $\mathfrak{c}$. It turns out that certain topological results hold if and only if one of these cardinals equals ω_1. For example, $\mathfrak{b}=\omega_1$ if and only if the Michael line has an uncountable Lindelöf subspace. Also, if one of these cardinals equals $\mathfrak{c}$, nice counterexamples can be constructed. For example, Eric noticed that $\mathfrak{c}=\omega_1$ in Vaughan's example [55] could be weakened to $\mathfrak{b}=\mathfrak{c}$ and thus if $\mathfrak{b}=\mathfrak{c}$ then there is a family of $2^{\mathfrak{c}}$ first countable countably compact (hence sequentially compact) locally compact spaces whose product is not countably compact; this is relevant since the product of at most $\mathfrak{t}$ sequentially compact spaces is always countably compact. For more information about these results and references see [vD 62] and Fremlin [22].

As mentioned earlier, Eric was sometimes dissatisfied with results assuming MA. He wanted a proof in ZFC or a companion proof showing that some extra axiom is needed. Unfortunately, the latter often requires constructing a special model of set theory. Discussing several of these constructions with Fleissner, Eric noticed a common theme. These ideas led to the *Definable Forcing Axiom* (abbreviated: DFA): "In a definable ccc poset P, there is a set $\{G_\alpha : \alpha < \omega_1\}$ of filters on P such that every dense set meets all but countably many G_α's". In many cases where MA + $\neg$CH says that "ω_1 is as small as countable", DFA says that "ω_1 is as large as $\mathfrak{c}$". For details, see [vD 75].

Boolean algebras

Eric was very much interested in Boolean algebras. Together with Monk and Rubin he wrote a paper about open problems in Boolean algebras, [vD 44]. His paper [vD 50] on cardinal functions on compact F-spaces gives also information about cardinal functions on Boolean algebras. See also [vD 66]. In [vD 45] he and Van Mill constructed a (consistent) example of a weakly countably complete Boolean algebra that is not a homomorphic image of a countably complete Boolean algebra. He also constructed a very clever example of a (consistent) Boolean algebra of cardinality ω_1 whose automorphism group is countably infinite [vD 36]. Anderson [1] proved a result from which it follows that the automorphism group of the denumerable free Boolean algebra is algebraically simple. This motivated the authors of [vD 44] to ask whether the automorphism group of every homogeneous Boolean algebra is algebraically simple. This question was answered (consistently) in the negative by Koppelberg [33] and independently by Eric [vD 81]. He proved that in Shelah's model where all homeomorphisms of $\beta\mathbb{N}\backslash\mathbb{N}$ are induced by a permutation of $\mathbb{N}$ (mod finite), the autohomeomorphism group of $\beta\mathbb{N}\backslash\mathbb{N}$ is not algebraically simple. In Boolean algebraic language, the automorphism group of $\mathcal{P}(\mathbb{N})/\text{fin}$ is not algebraically simple (it is possible to prove that under CH, this group is simple).

In [vD 44] the authors asked whether every Boolean algebra with a homogeneous Stone space is homogeneous. In topological language this becomes: does every homogeneous zero-dimensional compact space have the property that all of its nonempty clopen (=open and closed) subsets are homeomorphic? This is a very natural question and it is not obvious at all how to attack it. Eric solved it by a fascinating approach in [vD 61], which is the paper he was most proud of. He presented an example of a compact zero-dimensional homogeneous space X which has a Borel measure μ having (among others) the property that two clopen subsets of X are homeomorphic if and only if they have the same measure. In fact, up to a multiplicative constant, μ is unique with respect to this property. The space X is a compactification of a very special subgroup of the circle group $\boldsymbol{T}$ which made Eric become interested in the structure of homogeneous zero-dimensional subsets of $\mathbb{R}$. He asked the following question: does every homogeneous zero-dimensional separable metrizable space admit the structure of a topological group? This was again a typical van Douwen question: why did not anybody think of this question before? He answered the problem himself by constructing a homogeneous zero-dimensional separable metrizable space $\mathfrak{S}$, which is not a topological group, and which is (topologically) characterized by the following properties:

(1) $\mathfrak{S}$ is the union of a countable subspace and a topologically complete subspace,

(2) $\mathfrak{S}$ is nowhere countable and nowhere topologically complete.

It is interesting to mention that one apparently needs the characterization of $\mathfrak{S}$ in order to prove that it is homogeneous. Indeed, since every nonempty clopen subspace of $\mathfrak{S}$ clearly has the properties that characterize $\mathfrak{S}$, every nonempty clopen subspace of $\mathfrak{S}$ is homeomorphic to $\mathfrak{S}$. Then homogeneity follows immediately by observing that $\mathfrak{S}$ is zero-dimensional and first countable. Eric never published this result because its proof did not satisfy him: it was too involved (a proof of the topological characterization of $\mathfrak{S}$ was published in [18] and that $\mathfrak{S}$ is not a topological group can be deduced from [39, Theorem 2.1]). Van Engelen [17] recently presented topological characterizations of *all* homogeneous Borel subsets of $\mathbb{R}$ and proved that there are "only" $\aleph_1$ of them. In addition, Van Engelen, Miller and Steel [19] proved that no Borel subset of $\mathbb{R}$ is topologically *rigid* (i.e. has no autohomeomorphisms other than the identity), which answered another typical Van Douwen problem. Eric also asked whether there exists an example of a homogeneous zero-dimensional separable metrizable space with the fixed point property for homeomorphisms. This problem is still unsolved as far as I know.

Topological groups

It is well known that there exist two countably compact spaces whose product is not countably compact, in fact not even pseudocompact [42, 53]. It is natural to ask whether topological groups with the same properties can exist. However, by a theorem of Comfort and Ross [9], any product of pseudocompact topological groups is pseudocompact (see [56] for a somewhat simpler proof of this result). This left open the question, due to Comfort, whether the product of countably compact topological groups is countably compact. Around the time Eric wrote his paper [vD 61], he became very interested in topological groups. Since compact topological groups are dyadic, [37], they are ccc and contain a nontrivial convergent sequence. One can deduce the countable chain condition part of this statement easily from the existence of Haar measure on a compact group. However, the simple fact that every compact group contains a nontrivial convergent sequence does not seem to have a simple proof and this intrigued Eric tremendously. Hajnal and Juhász [24] proved that under CH there exists a countably compact hereditarily separable, hereditarily normal, countably compact subgroup of $2^{\mathfrak{c}}$ without nontrivial convergent sequences: such an example cannot be constructed in ZFC alone. This shows that countably compact groups differ substantially from compact groups (at least consistently). By an ingenious construction, Eric proved in [vD 46] the existence of a countably compact topological group without nontrivial convergent sequences from MA. Since MA is strictly weaker than CH, his result can be seen as a generalization of the Hajnal–Juhász example. Unfortunately (or: interestingly, depending on your taste), Eric also showed that his construction needed MA in an essential way. He was not done yet: he proved that if E is an infinite countably compact topological Boolean (=each point has order at most 2) group without nontrivial convergent sequences then E contains two countably compact subgroups E_0 and E_1 whose product $E_0 \times E_1$ is not countably compact. So under MA this yields a solution to Comfort's problem. In an addendum Eric stated that he was able to construct from MA one single countably compact topological group whose square is not countably compact. Unfortunately, this interesting strengthening was never published. By applying Eric's method to the Hajnal–Juhász example one obtains (under CH) two countably compact hereditarily separable and hereditarily normal topological groups E_0 and E_1 whose product $E_0 \times E_1$ is not countably compact. In particular, this yields under CH the existence of two countably compact normal spaces whose product is not countably compact. In [vD 71] Eric obtained such examples under MA. The last paper Eric wrote also dealt with groups [vD 76]. He proved the remarkable result that if X is countable and homogeneous and if G is a countable group then G can be endowed with a left-invariant topology τ such that $\langle G, \tau\rangle$ is homeomorphic to X.

3. Some further remarks

As is clear from the above, Eric was a very influential mathematician. He was widely known as a source of interesting problems. In the recently published *Handbook of Set Theoretic Topology* [34], he was the most quoted mathematician. He commented frequently on the work of others, pointing out errors, simplifications, etc. Due to that he was thanked in numerous papers for helpful comments. Eric was also an outstanding referee.

Eric's life was general topology. He loved his field and was very proud of it. His papers were models for other authors in their organization and in their presentation of intuition. He rewrote them many times and was never fully satisfied with the final draft.

Although Eric adapted quite well to the American way of life, in his heart he was a European. He never gave up his Dutch citizenship and was always extremely interested in hearing what was going on mathematically in the Netherlands. He was without any doubt one of the best-known Dutch mathematicians of his time.

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[vD u 80] Nonnormality and paracompactness of some spaces of real functions.
[vD u 81] The automorphism group of $\mathscr{P}(\omega)/\text{fin}$ need not be simple.
[vD u 82] An easier superrigid countable T_1-space.
[vD u 83] Not locally not locally not locally not locally connected spaces.
[vD u 84] The product of a Fréchet space and a metrizable space.
[vD u 85] Ordinary products and line products.
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[vD u 87] Continuous constructions.
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[vD u 89] Spaces of subuniform ultrafilters in spaces of uniform ultrafilters (with A. Bešlagić).
[vD u 90] Countable torsion free groups.
[vD u 91] Barely separable extremally disconnected compacta.
[vD u 92] Čech–Stone remainders avoiding countable cofinality.
[vD u 93] Rigid zerodimensional dyadic spaces.
[vD u 94] Maximal topologies, with an application to ω^*.
[vD u 95] Chains of orbit closures in βG.
[vD u 96] Minimal invariant sets in βG.
[vD u 97] Another silly attempt to construct increasing chains of orbit closures in βG.
[vD u 98] Closed images of σ-discrete metrizable spaces.
[vD u 99] The number of isomorphism classes of spreads.
[vD u 100] Measures invariant under actions of F_2.

[3] It seems that Eric intended to publish most of these papers. We plan to publish all of them posthumously.