

# *S*-Motzkin paths with catastrophes and air pockets (very early version)

Helmut Prodinger<sup>1,\*</sup>

<sup>1</sup>Helmut Prodinger, Department of Mathematical Sciences, Stellenbosch University, 7602 Stellenbosch, South Africa, and NTHuCS (National Institute for Theoretical and Computational Sciences), South Africa

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## Abstract

So called *S*-Motzkin paths are combined the concepts ‘catastrophes’ and ‘air pockets’. The enumeration is done by properly set up bivariate generating functions which can be extended using the kernel method.

**Keywords:** *S*-Motzkin path; catastrophe; kernel method; air pocket.

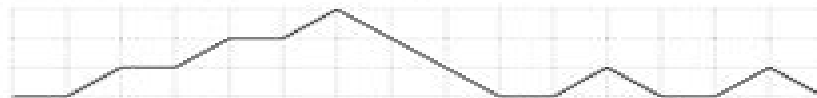
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## 1. Introduction

Dyck paths consist of up-steps  $(1, 1)$  and down-steps  $(1, -1)$ , start at the origin and do not go below the  $x$ -axis; they appear in many texts, we just give one major reference, [12]. Typically, the path returns to the  $x$ -axis at the end, but we also consider the scenario of open paths, where the paths end at level  $j$ , say. A popular variation of Dyck paths are Motzkin paths: the difference is just that now a horizontal step  $(1, 0)$  is also allowed.

In this paper, we concentrate on *S*-Motzkin paths, which is a subfamily of all Motzkin paths: all three steps (up, level, down) must appear  $n$  times, and, ignoring the down-steps, the sequence is  $(1, 0)(1, 1)(1, 0)(1, 1)(1, 0)(1, 1) \dots (1, 0)(1, 1)$ . The follow figure shows how these paths are recognized: The two layers enforce that the flat and up steps are interlaced. Only paths that end in the origin are *S*-Motzkin but we consider all paths wherever they end.

Here is an example of such an *S*-Motzkin path with 15 steps:



Now we present a graph (automaton) to recognize exactly the *S*-Motzkin paths:



Figure 1: Graph to recognize *S*-Motzkin paths; they start and end at the special state (origin).

This subfamily of Motzkin paths originated from a question in a student competition; see [10] and [7] for history and analysis. In the following we will combine this family with catastrophes and air pockets, both originating in papers by Jean-Luc Baril and his team [5], [3]; the older paper by Banderier and Wallner [2] might be called the standard reference for lattice paths with catastrophes. The very recent papers [4,5] contain some bijective aspects. Our own paper [9] investigates the situation in the context of skew Dyck paths.

Dyck (and other lattice) paths with catastrophes are characterized by additional steps (‘catastrophes’) that bring the path back to the  $x$ -axis in just one step from any level  $j \geq 2$ . For *S*-Motzkin paths the definition is similar, and the graphical description in Figure 2 is easiest to understand; the catastrophes are drawn in special colors.

In the last section, *S*-Motzkin paths with air pockets will be discussed. Briefly, down steps of any length are now allowed, but no two down steps may follow each other.

\*Corresponding author (hprodinger@sun.ac.za)

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Diophantine approximation and basis reduction 7 Fundamental concepts and results on polyhedra linear inequalities and

linear programming 8 The structure of polyhedra 9 Polarity and blocking and anti blocking polyhedra 10 Sizes and the theoretical complexity of linear inequalities and linear programming 11 The simplex method 12 Primal dual elimination and relaxation methods 13 Khachiyan's method for linear programming 14 The ellipsoid method for polyhedra more generally 15 Further polynomiality results in linear programming 16 Introduction to integer linear programming 17 Estimates in integer linear programming 18 The complexity of integer linear programming 19 Totally unimodular matrices fundamental properties and examples 20 Recognizing total unimodularity 21 Further theory related to total unimodularity 22 Integral polyhedra and total dual integrality 23 Cutting planes 24 Further methods in integer linear programming Historical and further notes on integer linear programming References Notation index Author index Subject index      [Selected Papers of Norman Levinson](#) J.A. Nohel, D.H. Sattinger, Gian-Carlo Rota, 1997-12-18 The deep and original ideas of Norman Levinson have had a lasting impact on fields as diverse as differential integral equations harmonic complex stochastic analysis and analytic number theory during more than half a century Yet the extent of his contributions has not always been fully recognized in the mathematics community For example the horseshoe mapping constructed by Stephen Smale in 1960 played a central role in the development of the modern theory of dynamical systems and chaos The horseshoe map was directly stimulated by Levinson's research on forced periodic oscillations of the Van der Pol oscillator and specifically by his seminal work initiated by Cartwright and Littlewood In other topics Levinson provided the foundation for a rigorous theory of singularly perturbed differential equations He also made fundamental contributions to inverse scattering theory by showing the connection between scattering data and spectral data thus relating the famous Gel'fand Levitan method to the inverse scattering problem for the Schrodinger equation He was the first to analyze and make explicit use of wave functions now widely known as the Jost functions Near the end of his life Levinson returned to research in analytic number theory and made profound progress on the resolution of the Riemann Hypothesis Levinson's papers are typically tightly crafted and masterpieces of brevity and clarity It is our hope that the publication of these selected papers will bring his mathematical ideas to the attention of the larger mathematical community      [Lectures On Convex Sets \(Second Edition\)](#) Valeriu Soltan, 2019-11-28 The book provides a self contained and systematic treatment of algebraic and topological properties of convex sets in the  $n$  dimensional Euclidean space It benefits advanced undergraduate and graduate students with various majors in mathematics optimization and operations research It may be adapted as a primary book or an additional text for any course in convex geometry or convex analysis aimed at non geometers It can be a source for independent study and a reference book for researchers in academia The second edition essentially extends and revises the original book Every chapter is rewritten with many new theorems examples problems and bibliographical references included It contains three new chapters and 100 additional problems with solutions      **NBS-INA, the Institute for Numerical Analysis, UCLA 1947-1954** Magnus Rudolph Hestenes, 1991      [Mathematics Related to Physics](#) Raoul Bott, 1994 Volume 4      *Mathematics*

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