

Abstract Matrices in Symbolic Computation

Alan Sexton and Volker Sorge
School of Computer Science
University of Birmingham

aps@cs.bham.ac.uk, vxs@cs.bham.ac.uk

ABSTRACT

We introduce a new data type of abstract matrices that allows the description of underspecified matrices containing ellipses and their use as templates for classes of concrete matrices. We present a series of algorithms that fully analyses the structure of abstract matrices and their representation and supports subsequent instantiation to concrete matrices.

Categories and Subject Descriptors

I.1.1 [Symbolic and Algebraic Manipulation]: Expressions and Their Representation; I.1.2 [Symbolic and Algebraic Manipulation]: Algorithms—*Algebraic algorithms*

General Terms

Algorithms

Keywords

Underspecified Matrices, Constraints, Semantic Analysis

1. INTRODUCTION

In every day mathematical practice, matrices are often not fully specified, but rather are of indefinite dimension and contain abbreviations and underspecified parts such as ellipses (usually written as a series of dots indicating the omission of a number of terms). Thus the matrix

$$A = \begin{bmatrix} a_1 & b & \cdots & b \\ 0 & \ddots & \ddots & b \\ \vdots & \ddots & \ddots & b \\ 0 & \cdots & 0 & a_n \end{bmatrix} \quad (1)$$

can be considered as a template of the class of all square matrices of the above shape. The concrete instantiations for dimension n where $1 \leq n \leq 4$ are then:

$$[a_1] = \begin{bmatrix} a_1 & b \\ 0 & a_2 \end{bmatrix}, \quad \begin{bmatrix} a_1 & b & b \\ 0 & a_2 & b \\ 0 & 0 & a_3 \end{bmatrix}, \quad \begin{bmatrix} a_1 & b & b & b \\ 0 & a_2 & b & b \\ 0 & 0 & a_3 & b \\ 0 & 0 & 0 & a_4 \end{bmatrix}$$

While using underspecified matrices is routine, it has very limited automated support. For example, Maple [1, 3] provides functionality to specify matrices with some predefined

shapes, such as symmetric or hermitian. It also provides the facility to specify customised shapes via user defined functions. However, in all cases, the Maple support is only for fully specified matrices with fixed dimensions and no ellipses.

As a step towards rectifying this deficiency, we introduce a new data type, *Abstract Matrix*, that makes underspecified matrices first class objects in computer algebra. To support this data type, we present a series of algorithms that fully processes an input format for Abstract Matrices that is very similar to that which appears in mathematical texts, but adapted for automated systems, analyse its semantics and produce a structure that supports subsequent incremental refinement via the addition of extra constraints and eventual instantiation to a valid matching concrete matrix.

There are a number of subtleties in the interpretation of underspecified matrices. For example, some matrix expressions that appear in the literature have ellipses that are intended to instantiate into descending sequences of index values such as a_{-1}, a_{-2}, \dots . Another possibility is that for the instantiation $n = 1$ the dimension of matrix is not fixed to 1 but rather the main diagonal contains only the constant a_1 . If one wishes to accommodate those cases, then it is probably not reasonable to disallow the following possible, if unusual, instantiations of (1).

$$\begin{bmatrix} a_1 & b & b \\ 0 & a_2 & b \\ 0 & 0 & a_{-1} \end{bmatrix} \quad \begin{bmatrix} a_1 & b & b \\ 0 & a_1 & b \\ 0 & 0 & a_1 \end{bmatrix}$$

However, while mathematically there may be no problem with allowing any arbitrary integer sequence, it is extremely rare to find anything other than simple increments or decrements by one for matrix ellipse sequences in mathematical texts. For this reason, we impose the restriction that all such ellipses are restricted to such increments, decrements or may remain constant. Furthermore we assume that every ellipse is either vertical, horizontal, diagonal or anti-diagonal, and that, for the latter two cases, their vertical and horizontal lengths must be equal. Thus a matrix with a diagonal ellipse from its top left to its bottom right cells can be deduced to be square. Nevertheless, we can model truly rectangular matrices for our algorithms by specifying them as, for instance, in matrix (2) below.

$$\begin{bmatrix} a_{1,1} & \cdots & a_{1,m} \\ \vdots & \ddots & \vdots \\ a_{n,1} & \cdots & a_{n,m} \end{bmatrix} \quad (2) \quad \begin{bmatrix} a_1 & \cdots & \cdots & a_m \\ \vdots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \end{bmatrix} \quad (3)$$

For ease of computer analysis, and practical usability in Maple (in which we implemented our programs) we require our input to be a matrix structure where all cells must be filled. We employ a *dot term* \cdot for cells that would nor-

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Guillaume Favre



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