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Vedic Mathematics Techniques: Algebraic Foundations, Computational Efficiency and Pedagogical Relevance of Selected Sūtras

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Abstract

Background: "Vedic Mathematics", the system of sixteen sūtras and thirteen sub-sūtras published by Swami Bharati Krishna Tirtha in 1965, offers short mental methods for arithmetic and algebra. It is widely promoted in Indian schools and has attracted interest in digital multiplier design, but claims about it often outrun the evidence, and the algebra behind each method is seldom stated. **Methods:** This article selects five frequently used techniques — Ekādhikena Pūrveṇa, Nikhilam Navataścaramaṁ Daśataḥ, Ūrdhva-Tiryagbhyām, Ānurūpyeṇa and the duplex (Dvandva-yoga) method of squaring — and for each one states the rule, proves it algebraically, works examples and counts the elementary operations it requires compared with the standard column method. Their reported use in hardware multipliers and in the classroom is reviewed. **Results:** Every technique studied is a rearrangement of the distributive law or of the binomial expansion. Their advantage is not a reduction in single-digit multiplications in general, but a reduction in written partial products and carries, and, for special cases such as numbers near a base, a large reduction in effort. The vertical-and-crosswise pattern maps naturally to parallel hardware. **Conclusion:** The techniques are best presented as elegant algebraic shortcuts that build number sense and pattern recognition, with their scope and their modern rather than Vedic origin stated honestly.

Keywords: Vedic mathematics; Nikhilam sūtra; Ūrdhva-Tiryagbhyām; mental computation; multiplication algorithms; mathematics education; Vedic multiplier

1. Introduction

Fast and accurate arithmetic remains a foundation of mathematical competence, even in an age of calculators. Students who can compute fluently in their heads tend to estimate better, notice errors sooner and approach algebra with more confidence. Over the last three decades a set of methods known as "Vedic Mathematics" has become popular in India and abroad as a route to such fluency. The methods come from the book *Vedic Mathematics* by Jagadguru Swami Sri Bharati Krishna Tirthaji Maharaj, published posthumously in 1965 [1]. The book presents sixteen short aphorisms (sūtras) and thirteen corollaries (upasūtras), and shows how they yield one-line methods for multiplication, division, squaring, square roots, factorisation and the solution of equations.

The methods have been taken up in three distinct settings. In schools and coaching centres they are taught as speed-calculation techniques, and the National Education Policy 2020 encourages the inclusion of Indian knowledge systems in the curriculum [2]. In electronics, the Ūrdhva-Tiryagbhyām (vertically and crosswise) pattern has been used to design multipliers for digital signal processors and field-programmable gate arrays, with several studies reporting reduced delay [3–5]. In popular discourse, however, the methods are often described as ancient, as uniquely fast, or as replacing conventional mathematics — claims that historians and mathematicians have questioned [6,7].

A careful middle position is possible. The techniques are mathematically sound and frequently elegant, but each one works for a clear algebraic reason, and that reason is rarely stated in popular material. Without it, students learn tricks rather than mathematics, and teachers cannot judge when a method applies. The objectives of this article are therefore: (i) to state precisely five widely used techniques; (ii) to give an algebraic proof of each; (iii) to compare their computational effort with the standard methods; and (iv) to assess their value in hardware design and in teaching.

2. Background and Related Work

Tirthaji stated that the sūtras were reconstructed from the Atharvaveda, but the sūtras themselves do not appear in any known Vedic text, and the book's own editor, V.S. Agrawala, acknowledged that they are not found in the extant Pariśiṣṭas [1]. Dani [6] argued that the system is better understood as a twentieth-century creation than as Vedic heritage, while noting that its methods are correct. Genuine early Indian contributions to arithmetic — the decimal place-value system, zero as a number, and the algorithms of Āryabhaṭa, Brahmagupta and Bhāskara II — are a separate and well-documented body of work [7].

On the computational side, Tiwari et al. [3] proposed an Ūrdhva-Tiryagbhyām-based multiplier architecture and

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reported speed gains over array and Booth multipliers at small word lengths. Later studies implemented 8-, 16- and 32-bit Vedic multipliers on FPGAs and in CMOS, with results that depend strongly on word length and on the competing design [4,5]. In education, a number of small classroom studies in India report improved speed and attitude towards mathematics after short Vedic-mathematics interventions [8,9], although most lack control groups or long-term follow-up. Research on mental computation more generally shows that flexible strategy use, rather than any single algorithm, predicts arithmetic success [10].

3. Methodology

Five techniques were selected because they are the ones most often taught and cited. For each, the procedure is stated in modern notation and proved from elementary algebra. Worked examples were verified by direct computation. To compare effort, the number of single-digit multiplications, the number of written partial products and the number of additions were counted for n-digit operands, following the convention used in the analysis of schoolbook multiplication [11]. The review of hardware and classroom studies is narrative, focusing on what each type of evidence can and cannot show.

4. Techniques and Their Algebraic Basis

4.1. Ekādhikena Pūrveṇa: Squaring Numbers Ending in 5

The sūtra means "by one more than the previous one". To square a number whose last digit is 5, multiply the preceding part by one more than itself and append 25. Thus 35^2: $3 \times 4 = 12$, giving 1225; and 85^2: $8 \times 9 = 72$, giving 7225.

Proof. Write the number as $10a + 5$. Then

$$(10a + 5)^2 = 100a^2 + 100a + 25 = 100 \cdot a(a + 1) + 25 \quad (1)$$

so the leading part is $a(a + 1)$ and the last two digits are 25. The same sūtra extends to products of two numbers whose tens digits are equal and whose units digits sum to 10, such as $47 \times 43 = (4 \times 5 \mid 7 \times 3) = 2021$, because $(10a + b)(10a + c) = 100a(a + 1) + bc$ when $b + c = 10$.

4.2. Nikhilam: Multiplication near a Base

The sūtra *Nikhilam Navataścaramaṁ Daśataḥ* means "all from nine and the last from ten"; it gives the complement of a number with respect to a power of ten. For numbers near a base $B = 10^k$, write each number as $B - d$, where d is its deficiency. Cross-subtract one deficiency from the other number to get the left part, and multiply the deficiencies to get the right part, which must have k digits. For 97×96 ($B = 100$): deficiencies 3 and 4; left part $97 - 4 = 93$; right part $3 \times 4 = 12$; answer 9312. For 998×997 ($B = 1000$): left part 995, right part $2 \times 3 = 006$, answer 995006.

Proof. With $x = B - d_1$ and $y = B - d_2$,

$$xy = B(B - d_1 - d_2) + d_1d_2 = B(x - d_2) + d_1d_2 \quad (2)$$

which is exactly the cross-subtraction followed by the product of deficiencies. For numbers above the base the deficiencies are negative, so the rule becomes cross-addition: $104 \times 107 = (104 + 7 \mid 4 \times 7) = 11128$. When d_1d_2 has more than k digits, the excess is carried to the left part.

4.3. Ūrdhva-Tiryagbhyām: General Multiplication

"Vertically and crosswise" is a general method for any two numbers. For two-digit numbers ab and cd, the digits of the product are, from left to right, $a \cdot c$, $a \cdot d + b \cdot c$ and $b \cdot d$, with carries propagated from the right. Thus 23×41 gives $2 \cdot 4 = 8$, $2 \cdot 1 + 3 \cdot 4 = 14$ and $3 \cdot 1 = 3$, that is $8 \mid 14 \mid 3 \rightarrow 943$. For three-digit numbers the pattern has five columns; for 123×456 the column sums are 4, 13, 28, 27 and 18, and carrying from the right gives 56088.

Proof. For numbers $x = \Sigma\, x_i 10^i$ and $y = \Sigma\, y_j 10^j$,

$$xy = \Sigma_k \left(\Sigma_{i+j=k}\, x_i y_j\right) 10^k \quad (3)$$

The inner sum is the k-th column of crosswise products. The method is therefore the convolution of the digit sequences, the same structure that underlies polynomial multiplication. Indeed the method multiplies polynomials directly: $(2x + 3)(4x + 1) = 8x^2 + 14x + 3$.

4.4. Ānurūpyeṇa: Working Bases

When numbers are near a sub-base such as 50 or 300, Nikhilam is applied with a convenient working base $W = mB$ and the left part is scaled. For 48×46 with $W = 50 = 100/2$: deficiencies 2 and 4, left part $48 - 4 = 44$, which is halved to 22, right part $2 \times 4 = 08$, answer 2208.

Proof. Replacing B by W in (2) gives $xy = W(x - d_2) + d_1d_2 = B \cdot (x - d_2)/2 + d_1d_2$ for $W = B/2$, which is the halving step. When the left part is odd, half of B is carried to the right part.

4.5. Dvandva-Yoga: Squaring by Duplex

The duplex D of a digit string is defined as a^2 for one digit, $2ab$ for two digits, $2ac + b^2$ for three digits, and so on. The square of a number is formed by writing the duplexes of successively longer left-anchored and then right-anchored substrings. For 34^2: $D(3) = 9$, $D(34) = 24$, $D(4) = 16$, giving $9 \mid 24 \mid 16 \rightarrow 1156$.

Proof. Squaring is the special case $x = y$ of (3), in which each crosswise product x_ix_j with $i \neq j$ occurs twice. The duplex simply groups these pairs, reducing the number of distinct multiplications from n^2 to $n(n + 1)/2$.

5. Computational Comparison

Table 1 compares the techniques with the standard column method for n-digit operands. The comparison counts operations a person performs; it ignores the cost of memorising the method.

Table 1. Approximate effort for n-digit operands.

Method	Single-digit mult.	Partial products written	Applicability
Column method	n^2	n rows	General
Ūrdhva-Tiryagbhyām	n^2	1 row	General

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Method	Single-digit mult.	Partial products written	Applicability
Nikhilam	$\approx k^2$ (deficiency digits)	1 row	Near a base
Ekādhikena	1 (for 2 digits)	1 row	Ends in 5
Duplex squaring	n(n+1)/2	1 row	Squares only

k, number of digits in the deficiency; for numbers close to the base, $k \ll n$.

Three observations follow. First, the general vertical-and-crosswise method does not reduce the number of single-digit multiplications; its gain is in writing a single line instead of n partial-product rows, at the cost of holding running column sums in memory. Second, the special-purpose methods give large savings only within their domain: Nikhilam multiplies 998 × 997 with one single-digit product instead of nine. Third, squaring by duplex roughly halves the multiplications for large n, a saving that is also exploited in computer arithmetic. Asymptotically faster algorithms such as Karatsuba's $O(n^{1.585})$ method [11] are of a different nature and are not anticipated by the sūtras.

In hardware, the value of Ūrdhva-Tiryagbhyām lies in parallelism: all column sums in (3) can be generated simultaneously and reduced by adder trees. This is the same structure as an array multiplier, and the reported gains in the literature come mainly from the way partial products are partitioned and summed for particular word lengths [3–5]. Claims that a Vedic multiplier is universally faster should therefore be treated with care.

6. Discussion

The algebraic analysis supports a balanced view. Each technique is a correct application of the distributive law, the binomial theorem or digit convolution, and each produces answers faster than the column method in its natural domain. For learners, the methods have a particular strength: they make the structure of place value visible. A student who understands why 97 × 96 equals 93 hundreds plus 12 has learned something about numbers that is not obvious from the column algorithm. When taught alongside their proofs, the sūtras can therefore serve as a bridge from arithmetic to algebra, as the polynomial example in Section 4.3 shows.

The same analysis also sets limits. Choosing the right method requires recognising special forms, which itself takes practice; for random multi-digit numbers the general method saves writing, not thinking. The classroom studies reviewed are encouraging but mostly small and uncontrolled, and the gains they report are consistent with any well-taught, practice-intensive intervention. Rigorous evaluations with control groups, delayed post-tests and measures of conceptual understanding are needed before strong claims are made [8–10].

Historical accuracy also matters in teaching. Presenting the sūtras as Vedic risks confusing students about the real and substantial history of Indian mathematics. It is more accurate, and no less inspiring, to present them as a twentieth-century Indian scholar's creative systematisation of arithmetic shortcuts, and to teach the genuine classical contributions alongside them [6,7].

The present study is limited to five techniques and to analytical comparison. Future work should conduct controlled classroom experiments in Madhya Pradesh schools, measure time and error rates for each technique across operand types, and benchmark Vedic and conventional multipliers on the same FPGA platform.

7. Conclusions

The five Vedic-mathematics techniques examined here — Ekādhikena Pūrveṇa, Nikhilam, Ūrdhva-Tiryagbhyām, Ānurūpyeṇa and duplex squaring — each rest on a short algebraic identity, proved in this article. They reduce written work and, for special operands, the number of multiplications, and the crosswise pattern suits parallel hardware. Their main educational value lies in revealing number structure and connecting arithmetic to algebra. Presented with their proofs, their scope and an accurate account of their origin, they are a worthwhile enrichment of the mathematics curriculum.

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