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# Symbolic Information in Computing Devices †

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## 1. Introduction

Intuitively, 0's and 1's on paper are different from their electronic counterparts on the computer. On paper, their representations are flat and motionless. On the computer, zeroes and ones travel at blinding speeds in 3-dimensional space. Regardless of the media, STEM research treats all zeroes and ones the same. The author considers this oversight not only a critical loss of information but a fundamental reason why the true limitations of mechanical computing remain unknown. He attributes this conflation of digital symbols in different media on two critical articles that go off in two different directions. They are: (1) Claude Shannon's theory of communications that introduces the bit as a unit of information (p. 380, [1]), and (2) Newell and Simon's Physical Symbol System Hypothesis (PSSH) that promotes AI by arguing that digital symbols create new expressions by symbolic manipulation [2]. The author believes that the mathematics in Shannon's article casts a long shadow over the Newell and Simon's hypothesis, in spite of the fact that their article addresses the key feature of 0's and 1's on the computer—they are interactive.

In his 1948 article, Shannon makes it clear that communication signals represent physical values. He identifies them as 'bits,' a portmanteau of Binary Digits. His description of them is quite similar to 0's and 1's printed on paper, flat and 2-dimensional. He goes on to point out that bits form larger units of information to represent symbols. In the 1960's, Newell and Simon argue that the physical symbols on a computer "operate on expressions to produce other expressions" (p. 116, [2]). They credit dynamic memory structures for making this possible. However, their description of symbolic manipulation is limited to a high-level discussion of programming languages like LISP. Regrettably, fifty years later this superficial understanding of symbolic manipulation remains unchanged [3].

To investigate the deep structure of physical symbols, the author turns to a newly discovered uniform pattern of data in the RDBMS. It is called the Aleph data relation [4]. Like Borges' namesake short story, the Aleph and its models of parent-child relations are a portal into the digital space of mechanical computation. In architectural terms, it is a design pattern. It is self-similar to the tree structure and, like a fractal, it has scaling symmetry. These features enable decision trees to emerge from relational data by recursive algorithms. From an engineering perspective, the Aleph is a data object that is analogous to objects in object-oriented programming languages. In a file or data stream, the spatial proximity of the parent to the child translates its physical symbols into an IF-THEN relationship. Child data always comes immediately after a parent. And finally, in terms of mathematical generalizations, the Aleph is an abstract object whose spatial embodiment of logical implication explains why a hardware address always implies its content.

Mark Burgin's named set theory [5], a form of pure mathematics, lays the groundwork for the Aleph's discovery. Applications of this mathematical theory resulted in an extensive system of nested models that represent tree structures. These models program relational data to self-reference their own data symbols. They transform relation data into menu data for "The Database Taxonomy" decision tree interface [6]. End-users navigate down its data topics to pinpoint information managed by the database. In effect, Burgin's models turn the database and its data content inside out. They also reduce its complexity and detail. Accordingly, they align two notoriously complex systems, Codd's relational model and the von Neumann machine, to unify their high-level components. This

system of models creates a cross-section of the database on a computer that penetrates deep down into the hardware details. One model highlights how the database system relies on logic gates for pattern matching on input and indirect addressing for output. Another model in the system shows how the same data symbol alternates between these two I/O operations. Subsequently, Burgin's models reveal how symbolic manipulation occurs at a deeper level of 0's and 1's. The author identifies this more in-depth view of digital symbols as meta-symbols: physical-values and constructed-types [6]. The paper focuses on the relationship between the Aleph data relation and its physical symbols to explore the deeper nature of zeroes and ones on the computer.

To study the relationship, the author draws on three cognitive tools. First, he relies extensively on Mark Burgin's theory of named sets because he believes, it brings about a radical simplification of ordered complexity (According to Warren Weaver, there are two types of complexity: ordered and chaotic). Second, he employs Herbert A. Simon's *The Science of the Artificial*, and its use of the interface metaphor (pp. 6–12, [7]), to analyze the exterior/interior views of artifacts that include mathematical expressions. And finally, he deploys the container metaphor used throughout database literature to bridge the widely accepted view of physical symbols, as values, with an overarching view of their addressability as the content of constructed 3-dimensional containers.

## 2. Burgin's Mathematical Theory

Burgin's named set theory applies the rigor and precision of mathematics to the study of names. Research in this area goes back to Frege's distinction between reference and meaning. To adapt this idea for structures today, Burgin adds a third component, a connection between a reference and its meaning. He calls this triadic structure the fundamental triad (p. 40, [5]).

This formal study of names centers on structures, in general, and on mathematical structures, in particular. All mathematical structures conform to a well-defined triplet expression. When a mathematician discovers something new, he or she intuitively treat this triplet as a reference according to Frege. Drawing on the fundamental triad, Burgin makes the connection between this triplet and its mathematical name explicit. With this new understanding in place, the analysis of any combination of names, references and their meanings in mathematics is possible. Accordingly, Burgin has undertaken a decades-long investigation of mathematical structures to study their patterns for new levels of abstraction.

For example, Burgin notes a prevalence of chaining patterns in the mathematical structures of advanced algebraic systems (pp. 445–412, [5]). In this study of physical symbols, named set theory predicts that similar chaining patterns exist in other highly abstract systems, such as the relational data model. The B-Z chain presented at the end of the next section confirms his conjecture.

## 3. The Aleph Data Relation

This mathematical investigation of physical symbols begins with the discovery of Aleph data relation. It is based on implementing Burgin's *algorithmic* named set (p. 42, [5]). This theoretical structure consists of an algorithm, an input set, and an output set. In notation, $\boldsymbol{A = (X, A, Y)}$ where $\boldsymbol{A}$ is an algorithm, $\boldsymbol{X}$ is an input set, and $\boldsymbol{Y}$ is an output set. In the database, the implementation of the algorithm named set allows the author to study the mapping between input and out attributes at the data level. He calls this mathematical structure, listed below, a binary attribute relation or BAR,

$$(A_{input}, \mathit{rules}, B_{output}),$$

where $A_{input}$ and $B_{output}$ are attributes in table $R$, and the *rules* are a wff SQL SELECT statement.

The author calls this SQL SELECT a BAR query. Its details, listed below, explicate how data condition $v$, a *known* input data, self-references $A_{input}$'s domain to fetch *unknown* output from $B_{output}$. The algebra in this expression allows output data $t$ to include one or more values, regardless of the database application.The Aleph takes shape outside of the query interface by the mapping input $v$ to its output $t$. In effect, it is a mechanically constructed parent/child data relation.

$$(\text{SELECT } B_{output} \text{ FROM R WHERE } A_{input} = v) \rightarrow t$$

where $v \ni A_{input}$; $t \subset B_{output}$; and $((A_{input} \subset R) \wedge (B_{output} \subset R))$.

The overall simplicity of BAR query creates an opportunity to view the deeper structure of physical symbols. Its straightforward layout highlights a division of labor between input and output. By viewing these channels as containers, we can create a conceptual metaphor that allows us to telescope down to the hardware and bounce back up with output data. For instance, with *input* = *v*, data signal *v* flows down to logic gates in the CPU to conduct pattern matching on $A_{input}$ components in the current dataset. When *v* is equivalent to a component value, the database selects the record for the new dataset. On output, data *t* rises upward from the newly selected dataset in line with address locations assigned to $B_{output}$'s record components. Thus, the computer relies on both the value of each data symbol as well as on its attribute container.

In the next Burgin model, the B-Z chain aggregates the Aleph to generate menu data for a decision tree. The recursive algorithm that generates this tree structure can be found in [4]. In the database, the B-Z chain models a data network. Each link in the chain depicts a BAR that models the Aleph. The B-Z chain aggregates each Aleph data relation by overlapping and by self-referencing the next link. At the data level, output from one link represents input for the next link in the chain,

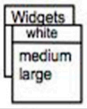
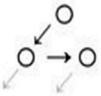
$$(A, A)\ (A, B)\ (B, C).$$

In a complex chain, the data flow includes keyed attributes in adjacent links that connect one table to another. At the data level, it reveals a second Aleph hidden between two related tables.

## 4. The Aleph's Upward Ascent

The Aleph data relation exists naturally throughout the database. In the decision tree interface, it is a design pattern that ascends from the database table upward to data topics displayed in its GUI. To investigate this upward ascent, the author constructed the conceptual model in Table 1 below to identify its transition points.

**Table 1.** The Aleph's Upward Ascent

| Burgin's Models | Digital Constructions | Interface Perspective | Aleph's Graphic Representation | Physical Symbols |
|---|---|---|---|---|
| (COLOR, COLOR) (COLOR, SIZE) (SIZE, ID) | Database Taxonomy Interface | Exterior HCI view |   | (white (medium, large)) |
| | k2h | Interior HCI view |  | (white (medium, large)) |
| (COLOR, COLOR) (COLOR, SIZE) (SIZE, ID) | OHDS | menu data file |  | (white (medium, large)) |
| SELECT COLOR FROM WIDGETS WHERE COLOR = 'white' | SQL | Exterior SELECT interface view | white → medium, large | (white (medium, large)) |
| | | Interior SELECT interface view: inside Widgets table |   | (white (medium, large)) |

In Table 1 above, the ascent of relational data from the table to the decision tree passes through four states:

(1) At the bottom row, we start off with data in the database table.
(2) Moving up one row from the bottom, we construct the Aleph data relation outside of the query interface.
(3) In the third row of Table 1, the B-Z chain depict nested Aleph data objects in menu data files.
(4) And finally, in the top two rows, the decision tree displays the Aleph data relation.

In these four states, the decision tree HCI and the SQL SELECT represent two different type of interfaces. In keeping with Simon's study of interfaces, the table depicts the exterior and interior views of each one. The transition from one view to other is particularly noteworthy with the SELECT interface because here Simon's and Burgin's theoretical approaches overlap. The SELECT's exterior is a *black box* process. In Burgin's theory, it is an *algorithmic* named set consisting of input and output (p. 42, [5]). According to both theories, its interior view is a *white box* process. The *Aleph's Graphic Representation, in column four*, shows how the SELECT on physical symbols operates in a set-theoretic manner that demonstrates the enduring power of Codd's set metaphor.

In Table 1, the analysis of the role of physical symbols goes bottom-up. It also starts with *Burgin's Models* in column one and proceeds in a left-to-right direction, row by row. All of *Burgin's models* implicitly represent the Aleph in terms of physical symbols. These models serve as blueprints for the *Digital Constructions* in column two that transport the Aleph data object through digital space. Before the Aleph, the database table contains only application data. With Burgin's SELECT statement, the Aleph emerges as a figure rising from this background data. In the next table row, the B-Z chain predicts the open hierarchical data structure (OHDS). It also highlights the format for storing nested Aleph objects in files and memory. When the decision tree displays these menu data files, the B-Z chain is general enough to predict yet, another abstract structure, the k2H hyper-graph that describes nested Aleph objects.

While Burgin's models are general predictors, the *Aleph's Graphic Representation* in column three depicts this object in a more detailed fashion. Consequently, each depiction in this column is different because each one reflects its digital setting and/or state. In column five, however, a more profound pattern of information unfolds. When each graphic representation is modeled by its *Physical Symbols* and—according to their hierarchical containment—a uniform models emerges. This model highlights the invariant layout of its physical symbols that indicates that these 0's and 1's are held together by a deeper, underlying mathematical bond that transcends time and space.

## 5. Physical Symbols and Meta-Symbols

In Table 1, a mathematical connection holds all of the Aleph models together. The author believes this relationship is grounded in the logical structure of physical symbols. In column five, the invariant pattern of models makes this point clear. Therefore, the author reasons that all 0's and 1's on the computer possess a deeper logical pattern that is precise and uniform.

However, today's understanding of physical symbols is limited to a single dimension: each bit or string of bits only represent numeric values. In database research, these values are widely recognized as the source for linking tables together (p. 21, [8]). Recent discoveries in physics add support to the physicality of symbols on the computer [9]. But the author believes that this single dimension of digital symbols is not a complete or balanced view. He contends that these symbols represent a more detailed system that has a precise order in a mathematical sense.

And so, the author argues that physical symbols on a computer are composed of deeper, sources of information. They include mechanical sources of information that shed light on how the computer system manipulates its digital symbols. He believes that the logical relationship between its signals and symbols is bi-conditional. The system treats both on a casual, mechanical basis. For any possible signal, the system always determines the same symbol. The same holds true when converting from symbols to signals. But the speed of these transformations makes direct observation of this mechanical phenomena virtually impossible. Therefore we can investigate these details by applying

pure mathematics, such as Burgin's named set theory, to model these systems and to draw inferences from their abstractions. Subsequently, the author relies on the integrity of this mathematical system to establish new, credible levels of abstraction that permit us to observe these details as sources of new information.

Based on the predictive power of Burgin's system of models, and on the mathematical certainty of mechanical computing, the author contends that all physical symbols on the computer are composed of two meta-symbols: (1) physical-values and (2) constructed-types. The author believes that these two aspects of digital symbols enable computer systems to treat its 0's and 1's, in a linguistic fashion, as types and tokens.

The physical-value of each symbol enables the computer to treat all strings of 0's or 1's as a "type". This meta-symbol allows the system to differentiate one form of signal/symbol from another by using logic gates for pattern matching.

In contrast, a symbol's constructed-type allows the computer to treat each token as the content of a container. Some of these containers are constructed by hand, like table attributes, while others emerge at runtime, such as dynamic addressing. Both types of containers scale up and down the computer system in a hierarchical fashion that is unbounded. At the bottom of this virtual system, the hardware surface serves as a container for all containers. Each virtual address establishes a container, one that differentiates one bit from every other bit on the machine. And so, this simple address/content relationship makes each string of 0's and 1's unique. It also underscores the logical power of indirect addressing: a *known* address always implies knowledge of its content, even when its actual value is *unknown*.

At higher levels of the system, a constructed-type could be a table attribute in a database, a database table, or even the database itself. With these nested containers, one can easily see how a database differentiates "NY" the *CITY* from "NY" the *STATE* as two different "NY" tokens based on their attribute membership or constructed-types.

## 6. Discussion

The ability of mathematics to distal new details by abstraction is crucial to the discovery of new information. The paper presents a system of mathematical models based on Mark Burgin's named set theory. These models penetrate deep into the logical structure of physical symbols on the computer to reveal new information about their properties. These models not only uncover a hidden parent/child data pattern in the database called the Aleph they also show how decision trees can emerge from these patterns. With this scientific evidence, and with the certainty of mechanical computing, the author proposes a theory about digital symbols on the computer. This theory holds that digital symbols consist of two meta-symbols: (1) physical values; and (2) constructed-types. It also holds that mechanical computing employs these two properties to manipulate symbols and to differentiate one symbol from another, even when two such symbols are visibly identical. The author argues that these meta-symbols enable computing systems to manage their digital content in a linguistic fashion that differentiates types from tokens. He believes this new understanding is a balanced view of physical symbols that unifies Shannon's understanding of their numeric values with PSSH's focus on their dynamic structures and addressing.

To develop this theory of physical symbols, the author considers Marshall McLuhan's advice to study the media of digital computation. The aim here is to undercover the nature of its dimensions. Next, he intends to use mathematical modeling to investigate symbol grounding on these machines. The objective of this research is not only to survey and chart the logical boundaries of physical symbols but to differentiate them from the purely abstract symbols in the mind's eye. To make this distinction, the author intends to revisit the philosophic issues raised by Ernst Cassirer and his student Susan Langer regarding the difference between signals and symbols. He also plans to investigate how symbolic content emerges from an artifact compared to its emergence in natural phenomena as explained by [10].

**Conflicts of Interest:** The authors declare no conflict of interest.

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