Efficient textual representation of structure

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ABSTRACT
This paper attempts a more formal approach to the legibility of text-based programming languages, presenting, with proof, minimum possible ways of representing structure in text interleaved with information. This presumes that a minimalist approach is best for purposes of human readability, data storage and transmission, and machine evaluation.

Several proposals are given for improving the expression of interleaved hierarchical structure. For instance, a single colon can replace a pair of brackets, and bracket types do not need to be repeated in both opening and closing symbols or words. Historic and customary uses of punctuation symbols guided the chosen form and nature of the improvements.

KEYWORDS
programming language design, structured programming, human readability, syntax, notation, history, data compression, minimification

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1 INTRODUCTION
Information is almost always more useful when organized, and structure is key to that. Therefore efficient and clear representation of structure is of paramount importance. Structured programming languages are only one use of structure to organize one kind of information, source code, but they make such unprecedentedly elaborate use of structure that they have exposed deficiencies in our methods of expression.

The languages for programming and math developed in an evolutionary manner, with much borrowing from earlier work, and the reasons for various decisions became buried in custom and history. Studies on choices of characters and legibility have been patchy, with some questions overlooked because they were thought relatively unimportant. Pioneers of programming languages hurriedly made expedient adaptations of existing notations for similar problems. Most heavily borrowed was mathematical notation.

With many important questions needing settling with the creation of the first programming languages, issues of symbology were mostly passed over as unimportant and arbitrary. As Bob Bemer noted, “much documentation is lost, and it was characteristic of the times that nobody seemed to think character sets a very important feature of computers [12].” There are many studies on the readability and other properties of various fonts and color combinations, but when discussed in relation to source code, the term “readability” refers more to comprehensibility [21].

Punctuation is the class of symbol most closely associated with showy, interleaved structure. Positioning is the other major method used to indicate structure, and among the other intended purposes, “control characters” attempted to provide ways to position text. Currently, Python is the most popular programming language that relies on text positioning rather than punctuation to indicate structure. Visual programming goes further yet, replacing textual indicators of structure and flow with graphical ones.

The programming language wars are still hot today, with new languages emerging and gaining followers. One cause of the passionate debates is the tendency of language designers to resort to an evangelical approach to justify their choices of design elements for which they have little compelling technical reason. Sometimes the designers make overlarge and unsubstantiated claims [19]. For many programming languages, one of the defining features is the choice and usage of symbols. These choices are not modifiable by the programmers, so that if such changes are desired, a whole new programming language may need to be created, another factor in the very proliferation of programming languages that the ALGOL designers were hoping to avoid.

The ideas in this paper aim at the foundation, the symbolic representation of the structure. Structure is chosen as the crucial concept that must be addressed to improve representation. Minimalism is the chosen guide.

Too much minimalism is certainly possible, for instance by expecting people to work with information that has been minimized by data compression techniques which transform the data into a very compact but human unreadable form. The minimification techniques of removing unnecessary whitespace and shortening variable names is another example. The target of these minimization efforts is the representation of the structure of the source code, not the source code itself. Further, this is not about rewriting and rearranging to place information in more efficient structures, this is about making the representation more efficient regardless of the structure chosen. Punctuation has always been minimal, using smaller and less obtrusive symbols than those used to represent the letters of a language, and the syntax of structural elements follows that pattern.

Some more items to note are splits between textual representations used for source code, versus those used for markup, as in HTML, and data organization, as in XML and YAML. Within programming languages, there is the dot (or arrow) notation of Object Oriented Programming and the completely different notations for Structured Programming, such as the curly braces. Yet those splits...
seem artificial, as hierarchical structure is used in all. Many programming languages are needlessly poor at expressing data. Several of the improvements in C++11 and C++14 touch on this issue, allowing more flexible constructions of constants and initializations of arrays and objects. One intent of JSON is to bridge this divide.

Also, these are all interleaved formats, meaning the symbols that denote the structure are interleaved with the symbols of the data. Goals in data storage are minimal size, and fast access. An obvious and common method to achieve both is to exclude all complex structure from the data, using an external representation. The disadvantage is that they require some connection, often expressed in fixed sizes and padding, which can end up using more space than an interleaved method. Over the years, the attention paid to brevity has varied with the cost and availability of storage.

By 1963, the American Standard Code for Information Interchange (ASCII) was set to a fixed size of 7 bits, though at least two variable codes, Morse code (1844) and Huffman coding (1952) existed at the time.

One of the goals of XML was human readability. Minimalism was thought orthogonal or possibly even antithetical to the goal of human readability, and the resulting language ironically suffers from excessive verbosity that obscures essentials, rendering the result less human readable. XML and COBOL show that a negative attitude towards minimalism ("10. Terseness in XML markup is of minimal importance. [14]"), that regarding minimalism as unrelated or even an impediment to comprehension, is not correct. Minimalism is also central to Information Theory, in which it was demonstrated that the crude redundancy of repeating information over and over, is very wasteful and poor at preserving the fidelity of data against errors in the transmission. If repetition is a poor means of ensuring the fidelity of data, perhaps it is also a poor means of representing structure in ways easy for humans to read. Another demonstration of the limited usefulness of repetition is the FAT file system, which despite allocating room for a copy of the directories and file names, is actually one of the most fragile and easily corrupted file systems currently in use.

Of particular note is the C programming language. So many programming languages adopted the C syntax that they have been tagged with a moniker of their own, the "curly-brace" languages. Perhaps one of the reasons curly brace syntax eclipsed Pascal and ALGOL is the use of a single character each, rather than the words BEGIN and END, to delimit blocks. The designers of C did not restrict themselves to curly braces only, they also used square brackets, parentheses, and even angle brackets, for array indexing, lists of function parameters, and macros respectively. Why that choice of symbol assignment? Why not use parentheses for all, and rely on context or some other means to distinguish between a parameter list and a block of code? If there is any doubt that it is possible to use only parentheses, the LISP programming language is proof. Or, why not copy FORTRAN in the use of parentheses for array indices? One kind of answer is that in C these different kinds of brackets serve as sigils, to distinguish between identifiers for functions, arrays, and variables. But that only begs the question of why have sigils? And it still does not answer why any particular symbol was chosen for a particular use.

2 HISTORY

For answers, one must dig into the history of computation and mathematics. In the case of C, the chain of preceding languages is roughly B, BCPL (Basic CPL), CPL (Combined Programming Language), and finally ALGOL (Algorithmic Language). The paper on ALGOL 58 [6] says of the choice to use square brackets to delimit array indices, only that "subscripted variables" (the term used in ALGOL for what today we call an array variable, or simply an array), "designate quantities which are components of multidimensional arrays" and that "The complete list of subscripts is enclosed in the subscript brackets [ ]." But why did they pick square brackets? FORTRAN, the oldest programming language to achieve wide acceptance, uses parentheses, not square brackets.

For that matter, why use any bracket at all? No one says. It seems likely that they would rather have used actual subscripted text, just like in mathematical notation, but early computers could not do it. Square brackets was a notational device to indicate subscription without actually presenting the text so. Apart from computer limitations, a big problem with subscripting is that the notation doesn’t nest well, at 3 or more levels becoming too small for the human eye to read. One can surmise from the use of the term "subscript" that this was another borrowing, from linear algebra in which a matrix is denoted with square brackets. And indeed the original name of ALGOL 58, is International Algebraic Language. The only deviation in the use of square brackets for array indexes from ALGOL to C was BCPL, which among the many simplifications of CPL it introduced, attempted to repurpose square brackets for code blocks, using only pointer arithmetic to access array elements [8].

ASCII codified the glyphs used for nearly all programming languages. A notable exception is APL, which makes use of mathematical symbols, mainly from Set Theory and Vector calculus, that were not put in ASCII [7]. Unlike EBCDIC, ASCII at least organized the alphabet into a contiguous block. But the exact set of punctuation symbols is unclear, ranging from all symbols that are not letters, numbers, and control characters, to only those used to clarify the structure and meaning of sentences and text. There are no formal, ordered, centuries old lists of punctuation symbols.

The ASCII ordering and choice of punctuation is derived from the QWERTY keyboard layout, which dates to the late 19th century. The notion that QWERTY was deliberately arranged to slow typists down is a popular but wrong myth [23]. Morse Code and many other factors were considered, and over the years small changes have been made to accommodate new uses. For instance, "shift-2" is the double quote mark on many older keyboards, but today is '@' on most keyboards.

We could go further back, and ask why mathematical notation uses parentheses for functions, and square brackets for matrices. Why is $y = f(x)$ the customary, canonical expression for a function, and why in particular the use of parentheses to bracket the independent variable $x$? In A History of Mathematical Notations [3], Cajori credits Euler (1707-1783) with the first use of parentheses to bracket the variable of a function, in a 1734 paper. That paper is E44 [1] in the numbering scheme created to refer to Euler’s works. However, examining E44 and several others of Euler’s papers, one finds no such use of parentheses, and the exact phrase and formula
Traditionally, data has been organized into fixed size elements so that no symbols need be reserved for explicit denotation of structure. This is exemplified by the relational database model. No longer are interleaving structural data storage, which was introduced in the 1960s before the advent of computers, the expedient method used is to have a small fixed size field to aid the human eye. Where one-size-fits-all is inadequate, the expedient method used is to have a small fixed size field to hold a value for the size of a variable length field. Packet networking is an example of this organization of data. The roughly analogous method in writing is the technique of employing any of a variety of superscripted symbols such as an asterisk, *, or a dagger, †, to indicate there is a footnote.

XML and HTML are the most well known of these markup languages, and like programming languages, their history is also evolutionary. Both trace back to Standard Generalized Markup Language (SGML) which was standardized in 1986, predating the World Wide Web. Like so many other decisions in languages, the creators of the Web seized upon SGML out of expediency. SGML in turn descends from GML, an IBM effort to manage technical documentation and data, based upon ideas first articulated circa 1966 [16].

But as many have complained over the years, these markup languages have undesirable features, and among the biggest is extreme verbosity. The rules they force upon users, to come closer to the goal of “human readability”, often have the opposite effect. On the scales of minimalism, XML and relatives are extremely poor because their representations are highly redundant. Not only must brackets be balanced in “proper” HTML and XML, but the matching tags must repeat the tag name. Why did the designers do it? Ironically, those rules have done much to add clutter and thereby reduce the human readability that was their intended goal. YAML (YAML Ain’t Markup Language) was motivated in part by recognition that XML is burdened with design constraints that have little purpose in data serialization [17]. Lightweight markup languages such as Markdown are an acknowledgment that the human readability of HTML could be better.

Most popular programming languages are poor at expressing structure. Here are some examples to illustrate this. A list of the first 10 chemical elements can be encoded in a JavaScript array like this:

```
const CE = ['?', 'H', 'He', 'Li', 'Be', 'B', 'C', 'N', 'O', 'F', 'Ne'];
```

A simple trick yields a much cleaner representation:

```
const CE = '? H He Li Be B C N O F Ne''.split(' ');
```

But this is the very sort of trick that makes programming needlessly difficult for professional programmers unfamiliar with the arcana of a particular language.

One problem is that the default, unquoted meaning of an alphabetic sequence is to treat it as the name of a variable. The double quote mark changes the mode, but that mode has no support for structural elements, so only a simple string can be encoded. The programmer is forced to change modes over and over, entering string mode to give a short string, leaving string mode to impart a tiny amount of structure, then entering string mode again to give the next string. Or the programmer can use a clever trick such as the split function, or create a function to parse a string into a complicated object, or even employ a library such as YAML.

Another example, of a family tree, in Python:

```
class tn: # tn means "tree node"
def __init__(self, name, child=None):
    if child == None: self.c = []
    else: self.c = child
```

Cajori quoted is not present. Euler uses parentheses to group parts of equations, but not to separate function names and variables. Euler’s notation is \( y = f(x) \), and it is up to the reader to understand that \( x \) and \( y \) are variables, and \( f \) is a function.

Note also the choice of the letter \( f \) because it is the first letter of the word “function”, a custom followed in many places, such as the decision in FORTRAN to use the first letter of a variable name to indicate integer (name begins with ‘I’ for integer, through ‘Z’) or floating point (name begins with ‘A’ through ‘H’). This desire to match functionality to the first letter of an appropriate term was taken to extremes, so that more than one early game employed a lucky placement of keys on the QWERTY keyboard, ‘W’, ‘E’, ‘S’, plus ‘S’, to refer to west, east, south, and north respectively.

By 1837, in a major work on Number Theory which is regarded as also an important paper on the modern definition of a function, Dirichlet (1805-1859) used parentheses around the independent variable \( x \). But why did mathematicians pick those symbols, that format? They too engaged in expedience, adopting the idea of parentheses from still earlier scholars. Mathematical notation has a long evolutionary history, and while fascinating, the main point here is that many choices of symbols and syntax were made long before any possible use in programming languages was conceived. While 1837 is also the year that Babbage proposed the Analytical Engine, arguably the first computer, functioning computation machinery would not be built until many years later. Therefore symbols and syntax certainly could not have been chosen based on experiences in computer programming.

That was about as far as the early pioneers went in exploring questions of how best to symbolize code and data. None of the terms and areas of study, not semiotics, symbolism, linguistics, grammar, lexicology, punctuation, readability, typography, legibility, notation, expressiveness, or rubrication, quite address these questions. Studies of notation and syntax get the closest, but even there syntax is confined to issues of context.

Most programming languages use a hierarchical structure to organize code. Possibly the earliest and simplest formally specified language for expressing hierarchy is Dyck Language. Object Oriented Programming and Functional Programming did not abandon this fundamental organization, they only added to it. Declarative programming, as represented in Prolog and SQL, at first glance seems not to need much structure. A point of confusion is order vs hierarchy. Declarative programming needs structure, but not order and not necessarily hierarchy. Hierarchic structure, of programs and data, can be more efficiently represented with several changes.

The advent of markup languages revived interest in hierarchical data storage, which was introduced in the 1960s, before the relational database model. No longer were interleaving structural symbols just for programs, they were harnessed to organize data. Traditionally, data has been organized into fixed size elements so that no symbols need be reserved for explicit denotation of structure, and, even more importantly, so that random access is quick, taking \( O(1) \) time to retrieve any one element. This is also true of the pre-computer era, which used tables extensively, carefully lining up columns to aid the human eye. Where one-size-fits-all is inadequate, the expedient method used is to have a small fixed size field...
which is perhaps most obvious in LISP, and for which it has been criticized in the "backronym" of Lots of Idiotic Spurious Parentheses. Often, brackets cluster, as several structures all start or end simultaneously. They can add to the visual clutter without adding to the ease of comprehension.

There are many solutions to this problem, among them operator precedence, and postfix notation, also known as Reverse Polish notation, first conceived in 1924[4]. A limitation of these Polish notations is that to make brackets unnecessary, the number of operands must be fixed, an inflexibility that is insufficiently general for the structures used in programming.

A popular short cut is use of context and knowledge about the permitted or sensible content of subtrees. For instance, in HTML the paragraph indicator, `<p>`, cannot be nested. This is often used to omit the matching closing bracket, `</p>`, when the next structure is another paragraph, or something else that cannot be inside a paragraph, such as a header. Such omissions are not officially sanctioned in HTML, but are so popular that web browsers had to support them anyway. Obvious problems with this approach are that knowledge of every exception to the rules for indicating the nesting may be very large, and may change.

The approach taken in Perl 6 is to allow all kinds of shortcuts that do not greatly complicate the parser. Compared to Perl 5, some brackets are no longer required. In particular, the parentheses of the if and for statements are optional [18]. Effectively, this change is a recognition that if and for are enough by themselves to indicate structure, that they are in fact now part of the set of symbols used to denote structure.

One could employ 2 sets of brackets, perhaps (`) and `[]`, in a scheme in which a closing bracket closes its matching opening bracket, and all the open brackets of the other kind in between. For example, `[a [b]] becomes `[a (b), [d [e [f]]] becomes `d [e f]. This idea can work in the other direction. `[[g] h] becomes `[g h]. It even works in both directions at once, with `((j)(k)) becoming `[j](k]. However, the best this idea can do for `((m)) is `[m].

An issue is that 2 more symbols are needed. We can employ only one more symbol, eliminating only one of the excess opening or closing brackets, and still clean up most of clutter. Call a 3 symbol system that eliminates excess closing brackets a "closing 3", and a 3 symbol system that eliminates excess opening brackets an "opening 3". Using colon, `:`, for this 3rd symbol in a closing 3 system, because that approximately matches the traditional use of the colon in natural languages, changes `(a : b)` into `(a : b).

For a slightly larger example, consider this Ackermann function, as defined in the classic textbook Structure and Interpretation of Computer Programs, exercise 1.8 [10]:

```
(define (A x y)
  (cond ((= y 0) 0)
        ((= x 0) (* 2 y))
        ((= y 1) 2)
        (else (A (+ x 1) (A x 0)))))
```

Employing a closing 3 system as suggested above, gives this:

```
(define (A x y)
  (:cond ((= y 0) 0)
        ((= x 0) (* 2 y))
        ((= y 1) 2)
        (else :A (+ x 1)
              :A (+ x y 1))))
```

6 colons have replaced 6 opening brackets. The 6 matching closing brackets have been removed. Indeed, there is never a need for multiple adjacent closing brackets, as proven next.

**Theorem 3.1.** Given a sequence $S$ of arbitrary symbols over an alphabet $\mathcal{A}$ in which 2 symbols, an “opening” and a “closing” symbol, are reserved to denote hierarchy in a format that interleaves data and structure, and $S$ is properly balanced, the hierarchy can always be represented in a system with 3 reserved symbols in which there are no runs (sequences of length 2 or greater) of the closing symbol.

**Proof.** WLOG, let `'(` and `)``, the parentheses, represent the opening and closing symbols in both systems, and let `:`, the colon,
represent the 3rd symbol in the 3 symbol system. To allow elimination of all runs of 2 or more closing symbols, assign ‘:’ the same meaning as ‘(’, the opening of a subtree, except that the matching closing symbol for ‘:’ is an already necessary ‘)’ that matches an existing ‘)’ which precedes the ‘:’.

Then, instances of the sequence “( s1 ( s2 ))” in which s1 and s2 are arbitrary sequences which may include balanced occurrences of ‘(’ and ‘)’ and ‘:’, may be replaced with “( s1 : s2 )”.

The replacement symbols are sufficient to represent all the relationships. The symbols still indicate that s1 is the parent of s2, preserve all relationships s1 and s2 have with all other sequences before and after because none of them need change and no additional context is needed, and preserve all relationships contained within and between s1 and s2 also because none of them change, nor add any contextual dependencies.

This replacement can be applied repeatedly, to reduce any number of adjacent closing brackets to 1 closing bracket. Each replacement preserves the property of balance for all remaining parenthesees, as exactly one pair of matched parentheses is replaced with a single colon.

The corollary that no runs of the opening bracket are needed in an opening 3 system, is obvious.

A pushdown automaton can easily transform from an opening 3 to a 2, or from a 2 to a closing 3, if the data is processed in reverse order. Of course, a pushdown automaton can easily reverse a string. In practice, the C++ style of comment delimited by 2 slashes takes more work to detect from back to front. Nor can the start of a C style comment be simply determined working from back to front, because ‘/\*’ can be within a comment.

A natural question is why not use a 4 symbol system, as originally outlined above with the 2 sets of bracket symbols, and eliminate all runs of opening and closing brackets? Simply put, the additional savings is not significant, as can be seen in that it is no help at all on the examples of ((m)) and ((n)).

As to why, it is not possible to employ any finite set of symbols to represent infinitely many numbers with just 1 symbol each, no matter what form the representation takes. If the representation takes the form of n opening brackets followed by n closing brackets, all of one kind of bracket can be collapsed, because n is preserved in the other. If both are collapsed, then n must be represented some other way. That is why the idea of using 2 sets of brackets does not work to reduce all runs of opening and of closing brackets to 1.

Thus we see that the idea of replacing each run of closing brackets with a single closing bracket is really the removal of a redundancy, the redundancy of specifying the depth twice, first with opening brackets, then with an equal number of closing brackets. That redundancy is no longer available to remove once one kind of bracket has been reduced.

The 3 symbol system need not be exclusive, can mix with 2 symbol usage as in (a (b : c)). In practice, in coding it will likely be preferable to use the 3rd symbol only for subtrees that are known in advance to be the terminal child. For other uses, such as mification of JavaScript or JSON, may want to use the 3rd symbol everywhere possible.

Removing the redundancies of the 2 symbol system can be of some value in data compression. Since the amount of information encoded is the same, an ideal data compression algorithm should produce the same size compressed output whether a 2 or a 3 symbol system is used. In practice, the output sizes vary, sometimes better for the 3 symbol system, and sometimes worse. To better test whether the more efficient representation helps with data compression, can try a much larger example. Biologists have organized millions of species into a Tree of Life [28], using Newick format [11], an interleaved hierarchical format. Tests upon grafted_solution.tre from version 9.1, the file with the highest percentage of interleaved structural symbols relative to data, containing 100,734 parenthesees in 721,324 characters total, show an “opening 3” system does reduce size even after compression.

| compression | system                  | original 2 symbol | opening 3  |
|-------------|-------------------------|-------------------|------------|
| none        | 721,324                 | 690,077           |            |
| gzip        | 250,142                 | 241,169           |            |
| bzip2       | 218,717                 | 213,341           |            |
| xz          | 211,812                 | 203,724           |            |

A final note about whether to prefer an opening 3 or a closing 3 system. The closing 3 is the better fit with our customs. For instance, in curly brace languages, the name of an array is given before the index of the desired element. It is arr[39] not [39]arr. It is the same with function names and parameters– the name comes first.

4 UNIVERSAL BRACKET

A sequence such as ”[x(y)z]” in which 2 different sets of brackets are interwoven, is almost always an error, not valid in any mainstream language. An analogous sequence in HTML could be “<p>x</p><p>y</p>”, which is not valid, even though its meaning can in this case make sense. The HTML specification calls this “misenest”. This invalidity is used in an ad hoc fashion to reduce some of HTML’s redundancy. A common case is the closing of an outer structure that implies an inner structure must also close, as in this example: “<tr><td>x</td></tr>". Some omissions require knowledge that some structure is not allowed. For instance, “<p><p>x<p><p>y</p></p></p>” is not valid because the ‘p’ element (p for paragraph) can’t be the direct child of another ‘p’ element. Therefore “<p>x<p>y</p>” always implies a closing tag preceding the 2nd opening tag: “<p>x</p><p>y</p>”. This usage is acknowledged in HTML5, but still recommended against: “…the closing tag is considered optional. Never rely on this. It might produce unexpected results and/or errors if you forget the end tag.” [25]

A combination opening and closing tag in one, called a “self-closing” tag, is meant for an empty element, and has been in XML from the start [14]. As of version 5, HTML has adopted a variation of this idea. The XML self-closing tag requires a slash character immediately before the closing angle bracket. In HTML5, 15 element types were singled out as making sense only as empty (void), and HTML does not use or permit the penultimate slash character in those tags.

Another solution to some of HTML’s verbosity is to omit the name from the end tags, using only “<”/”, which works fine since misnesting is not allowed or often sensible anyway. SGML has
this feature in its SHORTTAG constructs, calling it the empty end tag. But HTML does not allow it. This idea of a universal closing bracket or, alternatively, a universal opening bracket, can be employed in any language containing 2 or more sets of bracket symbols and in which interweaving is invalid. It eliminates misnesting, as interweaving is no longer possible. And it reduces the alphabet size.

If we choose the square bracket for the universal closing symbol, then a sequence such as "(x[y]z)" could become "(x[y]z]", and the closing parenthesis symbol would be unused, and could be repurposed. (Note that this change does not reduce the number of closing brackets, there are still 2 in the example. It reduces the required size of the alphabet.)

There can still be a need for other closing characters, such as an "unindent" invisible control character. The universal closing bracket could still be used for that, but would want it to be invisible in that case.

Converting back and forth between a representation that uses closing brackets that match the opening brackets, and a representation that uses only a universal closing bracket is easily done with a pushdown automaton. The type of the node is preserved in the choice of opening bracket, and having the type repeated with a matching closing bracket is merely redundant.

Having established that a universal bracket symbol is workable, several more questions naturally arise. Does it make code easier to understand, more human readable? Many have expressed the sentiment that requiring a closing tag to repeat the type given in the opening tag helps prevent human mistakes, and is therefore good. The issue is confused by the practice of entirely omitting tags in specific situation. With a means of representing structure that is not so tiresomely redundant, these ugly short cuts can be made unnecessary.

5 TYPES FOR NODES

Often the representational capability of a hierarchical structure is enhanced by adding some means of representing different kinds of children. An example is the "red–black tree" in which tree nodes have been assigned an additional property, a color. This can be and is often done independently of the structure, by means of an additional data item. Another very popular method is sigils in the form of different kinds of brackets. ASCII has 3 sets of symbols meant solely for brackets: the parenthesis, square bracket, and curly braces. One more set, the angle brackets, doubles as the mathematical symbols "greater than" and "less than", and for that reason was used gingerly. Further sets can be contrived, for instance 'n' and '/', and for that matter of course any two arbitrary characters could be chosen to serve as brackets. The obvious complaint is that 4 sets is far too few. Even if a dozen plus from Unicode are added, it still isn’t enough.

In any case, programming language designers used all the ASCII symbols meant for brackets early on. The curly brace languages employ curly braces to denote blocks of code, square brackets to denote array indices, and parentheses for parameter lists. The dual purpose symbols for angle brackets did not go unused as brackets, being employed in the C preprocessor, and later in the markup languages SGML, XML, and HTML.

These SGML markup languages expanded the number of bracket types infinitely, by allowing multiple character brackets. Although that solves the problems caused by finite quantities of different bracket symbols, the means and requirements chosen add greatly to the verbosity, a common criticism often expressed in abuse of the rules rather than in words. It is possible that the desire for a visual match between the opening and closing bracket led to the SGML requirement that both the opening and closing brackets contain copies of the string employed to give them a type, despite the obvious redundancy.

An efficient way is to designate one of the bracket sets as "typed", the start of a multicharacter bracket. That allows the other brackets to remain bare to be used same as traditionally used in programming languages, and still allows infinite bracket types. Which symbol is best employed, and where should it be positioned? Between bracket and name, or after the name? Or, should it be a combined symbol, a bracket that indicates a name is to follow, since there is more than one kind of bracket available? Possibly the most efficient use of existing symbols is to keep parentheses as is, bare, and designate the square bracket or curly brace as the indicator for a child structure with a type, with the name to follow, similar to HTML.

Another method is to reserve a symbol to indicate a type name only, no structure. "$" is often used similarly.

Whichever method is chosen to indicate the start of a type name, how is the name to be ended? The name could be just like variable names in programming languages, with only letters and numbers (and the underscore character) allowed in the name so that any other symbol, such as the space character, automatically ends the name. The method of using a special symbol, as done with the closing angle bracket of HTML, is also workable.

But the designers of HTML did not let tag names be only names. They crammed additional structured information into "attributes". An example is "<ul class="vsl" id="item1"> content </ul>". This information could have been in the same system, for instance something like "<ul> <attr class = "vsl" id = "item1" > content </attr> </ul>", or even "<ul> <attr> <nm class = "vms" > vs1 </nm> <nm id = "item1" > val </nm> </attr> content </ul>". The only purposes this alternate subsystem really serves is visual distinction and less verbosity, though it’s claimed to maintain the distinction between data and metadata. HTML has evolved towards lighter use of attributes, moving much formatting information from the tags to CSS, where it is also less redundant.

6 REPRESENTING SIBLINGS AND COUSINS

The list is well known and has a long history. Each item in a list can be considered a sibling of each other item. Traditionally, each item is on its own line, or is separated by a comma. LISP means "List Processor", and is built around the idea of making lists the fundamental building block with which to organize both data and code. Comma Separated Values (CSV) notation [20] is a simple data format based on one list with items separated by, of course, commas. One of the most notorious departures from the use of commas is multidimensional arrays in C, in which the syntax to access an element at index \(x; y\) is not \(x; y\), it is \(xy\).
The idea of separating items in a list with a single symbol (or word) seems simple, but turns out to have several surprisingly tricky issues.

Consider how to represent a list in a language that does not have any symbol analogous to the comma. Dyck Language interleaved with data. How is the sibling relationship expressed? (First, note the convention is to place the parent before the child, as in \( p(c) \), although the opposite, \((c)p\) is just as expressive.) One way is to wrap brackets around each individual data item. Then the number of brackets needed to represent a relationship must be increased by 1 for all depths, so that \((a)(b)\) means \(a\) and \(b\) are siblings, and \(((c))(d))\) means \(c\) and \(d\) are 1st cousins. A 2x2 array would be \((p(q))(r(s))\). Although it works, it is far more verbose. Additionally it spoils the abbreviation of allowing siblings to be separated by a child, as in \(a(e)b\), which must instead be \((a(e))\)(b).

So, a better way is to always separate siblings with a child, using a null child if the older sibling has no children, as in \(a(\_b)\). Then a 2x2 array can be represented with \((p(q)(r))(s))\). Expanding to cousins is still a problem. With the addition of the comma as a sibling separator, \((p(q))(r)(s))\) becomes \((p,q)(r,s)\). The sequence still has a \(,\) which the comma does not help reduce. An obvious extension is to introduce another symbol, say semicolon, to separate 1st cousins. Then the sequence can become \(p,q;r,s\).

What to do for 2nd cousins? Just add brackets to the semicolon, as in \(;(\_)?\) or employ yet another symbol to replace \(\_\). There are several different more precise meanings this could have. With many symbols should be so employed? The ASCII committee settled on 4, ASCII characters 28 through 31, though 8 were proposed [12]. They were called Information Separators [9]. We can do better than that.

There are several issues with having 2 or more Information Separators that merit careful consideration.

First, consider the sequence \(p(q;r)s\). \(\_q\) and \(\_r\) are siblings to each other, and descendants of \(p\), and \(s\) is 1st cousin to \(q\) and \(r\). There are several different more precise meanings this could have. The semicolon can be given higher precedence than the brackets, that is, all three of \(\_q\), \(\_r\), and \(s\) are children of \(p\). In that case, this particular sequence is invalid, because \(\_q\) and \(\_r\) are siblings, and \(s\) cannot be children of \(p\) and 1st cousins to each other. All children of the same parent must be siblings.

Another interpretation is to allow a single opening bracket to separate a variable number of generations instead of always one generation. Then, since grandchildren of \(p\) can be 1st cousins to one another, all 3 of \(\_q\), \(\_r\), and \(s\) must be grandchildren of \(p\). But this idea has the big disadvantage of adding context dependency to the grammar. Whether \(q\) is a child or a grandchild of \(p\) cannot be known until all the characters between the opening and closing brackets are scanned. If a semicolon is found on the same level as \(q\), then \(q\) is a grandchild of \(p\). If there are even deeper separators, \(q\) is a great grandchild or even more distant descendant of \(p\). If none are found, then \(q\) is a child of \(p\).

Best is to consider the semicolon as a combined open and close bracket, \(,\), having the same precedence as any other bracket. In that case, \(,s\) is not a descendant of \(p\), \(s\) is a nephew of \(p\). That meaning does not add context. This does have more invalid strings, for instance the simple sequence \(r;s\) is invalid because the brackets are balanced.

Second, consider how to combine separators with colons. The colon is a bracket, and should have the same precedence. Then a sequence such as \((p;q;r)\) means \(p\) is parent to \(q\), and not parent or sibling to \(r\). \(p\) is uncle to \(q\), \(q\) is 1st cousin to \(r\), and \(r\)'s parent is null. Perhaps the easiest way to see this is to reverse the colon transform to get \((p(q;r))\), then reverse the separator transform to get \((p(q;r))(s))\). If \(p\) and \(r\) are supposed to be siblings, and \(q\) a child of \(p\), the correct way to represent that is not to use semicolon or colon, it is \((p(q)r)\).

The 2 transforms, colon and separator, are mostly complementary, but in some cases can compete to reduce the same redundancies. The following table shows the results of transforming each of the 14 Dyck words of length 8 (replacing \([\]) with a comma rather than a semicolon, for greater visual clarity.)

| Dyck word | colon | separator | both |
|-----------|-------|-----------|------|
| 1         | [[:]] | [[]]      | [[:]]|
| 2         | [[[|]]] | [[[:]]] | [[]] |
| 3         | [[:|]] | [[:]]    | [[]] |
| 4         | [[[|]]] | [[][:]] | [[:]]|
| 5         | [[[:]]] | [[][:]] | [[:]]|
| 6         | [[[|]]] | [[][:]] | [[:]]|
| 7         | [[[:]]] | [[][:]] | [[:]]|
| 8         | [[[|]]] | [[][:]] | [[:]]|
| 9         | [[[:]]] | [[][:]] | [[:]]|
| 10        | [[[|]]] | [[][:]] | [[:]]|
| 11        | [[[:]]] | [[][:]] | [[:]]|
| 12        | [[[|]]] | [[][:]] | [[:]]|
| 13        | [[[:]]] | [[][:]] | [[:]]|
| 14        | [[[|]]] | [[][:]] | [[:]]|

The last column shows the result of applying the semicolon transform, followed by the colon transform. Applied second, the transform to colon can be blind to the presence of any separators, and be correct and achieve maximum reduction. A separator acts as a bridge, so that a colon can start a list, a natural looking use, rather than opening the last item of a list.

If the separator transform is second, then to achieve maximum reduction, as well as a correct transformation, it has to be done with awareness of colons. A colon may be opening the last item in a list, and it can be moved to the head. \([[:]]\) can become \([[:]]\) by replacing \([:]\); which is an open close pair of brackets, with a separator, and then, replacing the opening bracket of the previous item in the list with a colon. This can be repeated until the colon has migrated to the front of the list. If the separator transform is done blindly on a sequence with colons, it can be incorrect. \([[:]]\) is \([[:]]\) but then replacing \([[:]]\) with a separator gives \([[:]]\), which is not correct. Correct is \([[:]]\). Undoing \([[:]]\) shows that sequence is actually \([[:]]\), a list of 2 items.

Applying both transforms to the Ackermann function given earlier replaces a total of 11 bracket pairs with either a single separator (the comma was used in this example) or a single colon:

\[
\begin{align*}
\text{define} & : A \times y, \\
\text{cond} & : (= y 0) 0, \\
& (= x 0, * 2 y), \\
& (= y 1) 2, \\
\text{else} & : A : x 1, \\
& A x : y 1)
\end{align*}
\]
Third, what of types? Should the separated items be the same types? The traditional meaning of a comma is as a separator only, of untyped data.

Or, should text adjacent to a comma be interpreted as a type name? A way to resolve that question is to provide another means to add a type if desired, and let separators remain separators only. For example, as mentioned in the section on types, the ‘$’ character could be used to indicate an alphanumeric sequence is a type name. Deeper separators would need a list of types, or restrictions on elements for which they can specify a new type, and while notations for that can of course be invented, there is little point when opening brackets can accomplish that with reasonable efficiency and without any additional rules.

Fourth, there are different potential meanings for runs of a separator symbol. 2 adjacent semicolons could mean that there is an empty element in the middle, like for(); in C. Or, it could mean that the separation between the data elements on either side is deeper, that is, they are 2nd cousins instead of 1st cousins. What should 2 semicolons mean, , , or ( , )? The former is the more widely used meaning. The latter is accomplished by the limited method of having more Information Separator symbols, which cannot neatly handle great depths. It seems useful to have clear and concise ways to express either meaning. One way to do this is to have 2 Information Separators, one for siblings and one for cousins. The wrinkle is that repetition of these symbols would have the 2 different meanings, $n$ of the sibling separator can mean there are $n$ 1 siblings who have been omitted from the list, while $n$ of the cousin separator can mean the cousins are $n$th cousins, being 1st cousins only when $n = 1$. This approach, combined with an efficient way to express quantities, discussed next, can express both meanings.

However, another way is not to use the system for expressing quantities, and then assign different meanings to those quantities, but to use typing. A semicolon could be followed by an integer to indicate the depth of the divide, eg. “;3” means the adjacent elements are 3rd cousins. Then a run of $n$ semicolons can mean that there are $n$ 1st cousins in the middle, same as a run of $n$ commas means $n$ 1 middle siblings. This makes it slightly harder to support typed separators, but of course it can still be done. That point is moot if sticking with the traditional meaning of separators being typeless.

A minor matter is that separators have an inherent off-by-one issue. A comma separated list usually contains one fewer commas than data items. Often, specifications allow a meaningless trailing comma to be present, for the convenience of programmers.

A big reason to support efficient representation of a cousin relationship and even reserve symbols especially for it rather than rely on brackets is that it is a natural way to map multidimensional arrays to a hierarchical structure. Another reason is that people are familiar with and like separators.

Though we can’t collapse arbitrary quantities to single symbols, we can however do better than using $n$ symbols to represent $n$, by employing the same principle used in the Arabic numbering system that replaced unary numbering systems such as the Roman one and hash marks. All this is well known, as is that a binary numbering system has the minimum number of symbols needed to represent quantities of $n$ with $\log n$ symbols.

Can we do even better than $\log n$, represent any arbitrary quantity of size $n$ with even fewer symbols? No. For this question, the Pigeonhole principle applies. As in data compression, to be able to represent some quantities of amount $n$ with fewer than $\log n$ symbols (from a finite set of symbols), other quantities must be represented with more than $\log n$ symbols. When the amounts are averaged over all quantities $n$, the size is $\log n$, or greater.

Numbering systems can be employed to represent structure. Rather than come up with more and more symbols to represent greater and greater quantities, as the ASCII committee did with their 4 separator symbols, can employ 2 symbols in a binary code.

Obviously any one symbol which may be repeated can be made one member of a set of 2 symbols to be used in a binary encoding. But if there are many symbols which may be repeated, finding enough symbols becomes a problem.

Since quantities are so useful, and unused symbols so precious, a better idea is to reserve 2 symbols for a binary code for quantities only, for any other symbol that may be repeated. For example, instead of using 2 kinds of open bracket symbol in a binary code as in something like [([ ] to represent 9 open brackets, have 1001( mean 9 open brackets, 1101* mean 13 asterisks, and so on.

Still better is to use an escape character and a decimal representation. The backslash can be used for this, as the only backslash escape sequence that uses a number is $0 \backslash$, to mean the NULL character, ASCII 0. Then 9 open brackets can be represented with $9\backslash$. One desirable additional symbol to allow is the minus sign, for negative quantities. If only integers are allowed, then there is no need to overload the meaning of an escaped period for a decimal point character.

This sort of representation is the well known idea of run-length encoding (RLE) [5]. RLE is simple and easy, even relatively easy for a person to understand without computer aid.

Of course there is the minor problem that the numeric symbols themselves cannot be the object of a RLE escape sequence. There are several easy ways to resolve that issue. Easiest is to simply not support repetition of the digit characters, forcing the use of the traditional method if repetition of a digit is wanted. Perhaps next easiest is to employ a terminal symbol. To keep the representation one character shorter, the terminal symbol can be optional, used only if needed to remove ambiguity.

But RLE is very limited in what it can express. That keeps it dirt simple and easy to read, but perhaps more expressiveness is desirable, for such uses as repeating patterns, not only single characters. One simple example of such a sequence is the CR/LF pair. With a trivial amount of additional syntax, it is possible to efficiently encode repeating patterns. A further use is as a repetition of an escape. Suppose one has a string consisting of many, perhaps over half, of characters that must be escaped. One traditional method is to inflate by up to double the quantity of characters by preceding each special character with an escape character. That

7 EFFICIENT REPRESENTATION OF ARBITRARY QUANTITIES

Infinitely many numbers cannot be represented with single symbols from a finite set of symbols.
can get difficult for a programmer to read, as seen in Perl’s regular expressions. A quantity that can be applied to indicate how many characters are to be escaped can supersede the traditional escape character method. This notion is fairly obvious and has been proposed on a number of occasions, for instance by Rivest in his draft for S-expressions [15], for what he called “Verbatim representation”, and with Hollerith constants in FORTRAN 66 [13]. Perl’s regular expressions has a similar mechanism.

While it is trivial to extend run length encoding to handle repeating patterns, there are still many other highly redundant strings that this extended RLE cannot encode, yet are simple to describe. The question is how far to go, how much complexity is really using patterns, there are still many other highly redundant strings readable? Perhaps an efficient way to represent “)”(“()”(“ and larger combinations is also desirable? To encode such things, more is required. A simple idea is to support the encoding of lists of quantities, a vector, rather than a single quantity. The escape character can be employed as a separator. Then what is needed is agreement on the meanings to assign to the multiple quantities. For example, to encode 5 repetitions of a string of length 4, “abcd”, should it be “n5:abcd” or “n5:4abcd” or something else?

But if a vector of quantities is such a good idea, why not a tree of quantities? Takes only 2 symbols to represent the structure of a tree. However, the additional complexity is almost certainly too much to remain human readable, and there’s the question of what uses could we make of a tree of quantities?

One use for a vector of quantities is for the sizes of the dimensions of a multidimensional array. Such a usage creeps into the domain of external representation of structure. The interleaving can be reduced to a single character used as a separator, or removed entirely. For instance, a 2x3 array with variable sized elements could be notated as n2:n3:n? 1a, 1b, 1c, 2a, 2b, 2c, using the same separator symbol every time, with the division between 1c and 2a known to be deeper than the rest only because that info was given in the vector of quantities. Or that 2x3 array with fixed sized elements could be notated as n2n3n2 1a1b1c2a2b2c.

If means to represent something analogous to a Hollerith constant are provided, some probably will use it for very complicated objects. Just serialize the data, and use the total length of the resulting string as the size. Supporting runs of the same symbol, and blocks of data analogous to Hollerith constants, provides enough for further elaboration if desired, while keeping the notation simpler.

We get away with unary representations, because we stick to small and simple structures. If we seldom count higher than 3 or 5, and almost never higher than 10, tally marks work fine. A check of the Firefox source code reveals that only a few programs reached a nesting depth of 15, with most never exceeding 10, so RLE for opening brackets and colons, and quantities to indicate the depths of separators are not going to remove much clutter. But perhaps flatter structuring has been chosen to avoid the clutter that would result from deeper nestings. And block escapes are still a viable use of quantities.

8 REPRESENTING STRUCTURE WITH POSITIONING

The only ASCII control characters still really useful are the 2 for indicating a new line of text. Next most used is tab, which has ambiguous meaning and is easily and often replaced with spaces, except in a few special cases such as Makefiles. The rest of the ASCII control characters are very seldom seen, and when present, modern applications may simply ignore their meanings [27]. Of the 132,231 text files in the Firefox 50 source code, just 121 have ASCII control characters other than the 3 most common: LF, tab, and CR. A mere 5 files use ANSI escape sequences, which start with the Escape character (ctrl-[, ASCII 27), and that only to set text colors.

ASCII’s minimal means of positioning text is sufficient but not efficient or neat. One of the worst inefficiencies is the very repetitive use of spaces to indent lines of text. Some ANSI escape sequences address this issue, but not well. The VT100 series text terminals became popular in large part because they adopted and extended the ANSI escape sequences. Yet they have not been much used outside of terminal control. They did not grow beyond that niche to become common within text files. Colored text is the ANSI escape sequence most used, yet it is rare. One of the most common uses of colored text, highlighting of source code, does not use ANSI at all, even though editing may still be done in a terminal that supports ANSI. Rather, text editors parse the source code being edited to compute which colors to assign, updating in real time as the user makes changes. HTML and CSS can specify colors directly, and are not limited to a tiny 16 color palette. That and word processor options have become the way to set text and other colors in documents. ASCII and ANSI must use a fixed width font to position text accurately, and consequently, source code is almost always viewed in such fonts.

What sort of positioning information would be most useful? Means of clear, easy, and minimal description of position that best supports useful structures should be leading contenders. Indentation is the most popular way to express hierarchy through position alone. It is so common that even though curly brace languages do not use indentation, coders are exhorted to use “proper indentation” anyway, so that their source code is more readable. Perhaps the most prominent and distinctive feature of the Python programming language is the use of pure positioning to indicate code structure. Another major use is the alignment of columns, usually for tables. The ASCII tab character does not do either of these well.

Superscripting and subscripting can be considered a kind of positioning. It has a major limitation in that it does not scale. Each successively deeper nesting requires progressively smaller text, which soon becomes too small to read.

A proposal is to reassign 4 ASCII control characters for indentation. 3 of them can be increase indent (push), revert indent (pop), and boost indent, analogous to the 2 brackets and colon in a closing 3 system. These characters can be invisible and have a width of zero, not directly affecting the position of text. They only change the level of indentation. The 4th character can mean forward to the next indentation, replacing the leading spaces on all indented lines of text. It could also mean advance to the next line, but that
would be less flexible, wouldn’t support situations in which text such as a line number is wanted before the indentation.

These characters do not specify the size of an indentation, only the number of levels. This would allow individual users to set the indentation size themselves without affecting others. It could also make variable width fonts usable, as the problem of what unit to use to specify indentation sizes is entirely avoided. It does add one item to the state a text editor or viewer must maintain: a stack of indentation levels.

Indentation characters could ease editing of source code. There would be no more need to shift blocks of code several spaces right or left by changing the number of leading spaces on each line, whether by manually adding or deleting each space, or by using some smart editor function such as that assigned to the tab key in EMACs.

For the columns of tables, need better tab functionality. It would be desirable not to rely on the use of a monospace font to recreate the intended horizontal alignments. A limitation to dump is any sort of tiny maximum distance of 8 spaces. Further, it should be independent of any indentation setting. The C1 set of control characters contains several intended for tabular positioning, but they do not do enough. One problem is that the state they set up is global. Another is that they still implicitly depend upon a fixed font, using the cursor position for fixing the location of tab stops. It is basically a copy of the ideas and means used in the most advanced typewriters, with all their limitations.

The means HTML provides for laying out tables is fairly comprehensive and flexible, and proven over many years of use. If better handling of tables is desired in plain text, copying HTML’s handling and a subset of capabilities concerning tables into control character functionality seems a good approach. Lightweight markup languages such as Markdown [26] and Bulletin Board Code (bbcode) [22], arose to satisfy the desire to be able to create lists and tables in text based forums more easily than with HTML. This shows that many users like text editing to have such capabilities.

9 CONCLUSION

This paper proposed several changes in standard textual notations to eliminate redundancy that may be hampering the human readability of structured documents such as source code. Proving that human readability is improved was not attempted. Instead, the paper surmises that some kinds of redundancy merely add clutter, showed where and how redundancy lurks, and proposed ways to eliminate it. Good answers to Lots of Idiotic Spurious Parentheses have been desired for a long time, and perhaps until now have not been satisfactory.

Notation that scales and adds expressiveness, and allows much more brevity without sacrificing clarity, is especially preferred. Punctuation with long histories in natural languages, especially English, was tapped as a guide, in part because those uses are familiar to people literate in those languages.

The first proposed change was to add a 3rd kind of bracket symbol roughly equivalent to the meaning of the colon in English, so that a parent–child relationship represented as “\((p : c)\)” is instead represented as “\((p ; c)\)”. Proof was given that this 3 symbol system can collapse all runs of 2 or more closing brackets to a single closing bracket.

The idea of a universal closing bracket was presented. “\(fa (b [c] d) e\)g” can be represented as “\(fa (b [c] d) e\)\'”， reducing the number of different symbols required, as ‘\(\)’ and ‘\(\)’ are no longer needed.

More use of separators was proposed to replace sequences of closing brackets followed by opening brackets. “\(((a) (b) (c) (d))\)” can be represented with “\((a; b; c; d)\)”.

Ways of adding types to the structure were discussed. Positioning was recognized as an important way of denoting structure. It is observed that means of expressing position have been neglected. Markup languages limit themselves to data, and are not much used for writing of other structured information such as source code. Moreover, by using visible text to express position, and requiring translation with special tools such as a web browser, they fail at the goal of using position alone to express structure. The means provided in ASCII work only with monospace fonts, and require much wasteful redundancy. Repurposing some of the unused control characters to better support indentation and tabular structure was proposed.

Together, these changes reduced the number and quantity of symbols needed. They improved the amount of data compression obtained by general purpose data compression programs. They reduced the size of the source code. Whether the goal of greater human readability was also achieved was not studied, but it was surmised that removing redundancies in the notation does help with readability.

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