Binning

1 Binning Conceptual Model

The proposed binning conceptual model is comprised of pass and fail soft bin groups, counters, device specs, zero or more soft-to-hardware bin maps, bin setting mechanisms, bin based events, and notions of a null bin and bin arbitration.

The motivation behind these elements and the structure imposed on them, besides the obvious classification of devices based on test results and collection of granular test data, is to enable writing easy to maintain code. Specifically, we exploit the relationship between device specifications and software bins so that editing (adding, deleting, enabling, disabling) device specifications and bins can alter the execution of a properly designed flow without having to edit the code describing that flow.

1.1 Top Level Container

This container has an id and contains general information and two groups of soft bins: pass bins and fail bins\(^1\). The conceptual model for each group is the same hence, one syntax should suffice for both.

The general information consists of a user-settable/readable property \textit{ContinueOnFail} which is used as the default on bins for which this property is not explicitly set.

1.2 Soft Bin Group

Each group contains one or more axes which in turn contain soft bins. If the group contains only one axis, the axis may be anonymous. If the group contains two or more axes\(^2\), each axis must have an identifier unique to the group. Each axis contains one or more soft bin definitions. Each soft bin definition identifier must be unique to the axis.

\begin{table}[h]
\begin{tabular}{|c|c|c|c|}
\hline
ContactOpens & ContactShorts & Functional & Timing \\
\hline
5 & 5 & 6 & 7 \\
\hline
\end{tabular}
\caption{Fail bin group with anonymous axis}
\end{table}

\begin{table}[h]
\begin{tabular}{|c|c|c|c|c|}
\hline
 & 3.00GHz & 2.93GHz & 2.66GHz & ClockSpeed \\
\hline
8Mb & 1 & 3 & 3 & \\
4Mb & 2 & 4 & 4 & \\
\hline
\end{tabular}
\caption{CacheSize}
\end{table}

\(^{1}\) Teradyne has type \textit{error} in addition to \textit{pass} and \textit{fail}. Handle errors via OnError entry point with no special bin category?

\(^{2}\) Explore the use of nested axes.
Table 2: Pass bin group with two labeled axes

Table 1 and Table 2 are representations of typical soft bin groups. Axis labels are shown in bold white on black background and soft bin names are shown in bold black on white. Table 1 is in effect a 1 x 4 array, i.e., 1 anonymous axis with 4 soft bin definitions. If there is a soft-to-hard bin map, each of the array elements shown in yellow must be mapped to a hardware bin. Hardware bin numbers imposed by an associated bin map are shown in green.

Table 2 is a 3 x 2 array, axes labeled ClockSpeed and CacheSize which have 3 and 2 soft bins respectively. Again, if there is a soft-to-hard bin map, each of the array elements shown in yellow must be mapped to a hardware bin.

The group has user-settable/readable property color of type String which serves as the default color for bins under that group, and a read-only property which returns the number of Axes in the group as an Unsigned.

1.3 Soft Bins

1.3.1 Null Bin

The null bin is used to define generalized actions. For example, a TestBase fail action for most production tests or flows derived from it, is to bin and stop, i.e., a single action that takes a bin argument: if the argument is null, it neither sets the bin nor stops, if it is a user-defined bin it sets the bin and then stops\(^3\).

\[^3\] Set TestBase fail bin data member to null and override the fail bin data member of the derived test or flow with a user-defined bin. Define stop action semantics, e.g., trigger an entry point where software bin arbitration can be done? Does it unwind the stack and carry out post actions?
### 1.3.2 User Defined Bins

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Const String</td>
<td>color</td>
<td>Hexadecimal RGB value or text, e.g., red. Used for print or display purposes. Default value is the group color.</td>
</tr>
<tr>
<td>Boolean</td>
<td>enable</td>
<td>Disabled bins are treated as though they didn’t exist at run-time. Bins are enabled by default.</td>
</tr>
<tr>
<td>Const String</td>
<td>general descriptor</td>
<td>May require several, e.g., character for a wafer map, short string for restricted real estate descriptor, and verbose descriptor.</td>
</tr>
<tr>
<td>Const enumerated/string/id</td>
<td>name</td>
<td>Allow for conversion to number or spec storage? See <em>user defined name</em> in 1450.0.</td>
</tr>
<tr>
<td>Const Integer</td>
<td>number</td>
<td>Bin number is optional. Default value is the index (starts at zero).</td>
</tr>
<tr>
<td>Const Boolean</td>
<td>pass/fail</td>
<td>Whether a bin is a pass or a fail bin is determined by the group in which it is defined</td>
</tr>
<tr>
<td>Mutable Unsigned</td>
<td>retest</td>
<td>Non-zero causes retest on fail up to N times(^4)</td>
</tr>
</tbody>
</table>

Table 3: User-settable soft bin properties

Table 3 shows only the bin properties that are programmed directly by the user via definition syntax. User-defined bins may be referred to by name or number and interrogated for additional information (see section 1.8 and Table 4).

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Const Unsigned</td>
<td>index</td>
<td>The index into the Axis, i.e., array of bins.</td>
</tr>
<tr>
<td>Const Unsigned</td>
<td>counter</td>
<td>The number of times a bin has been set. See section 1.6 and Figure 6</td>
</tr>
<tr>
<td>Const Boolean</td>
<td>is_set</td>
<td>True if the bin is set. See Figure 6.</td>
</tr>
</tbody>
</table>

Table 4: Read-only soft bin properties

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\(^4\) If the program stops and retest is non-zero, retest is decremented and an OnRetest event is generated. If retest is zero on stop, the program stops and restores retest’s original value.
1.4 Hard Bins

Same as user-defined soft bins (see Table 3 and Table 4) if required. Question: are hard bin definitions required or is an integer representing a hard bin sufficient? 

1.5 Bin Setting and Arbitration

Bins are automatically unset by the OnStart event handler. When a bin is set, it remains set until the next OnStart event. Bins may be set only in the context of FlowNode, Test, and/or Flow (post?) actions via one of the mechanisms described in Table 5.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Parameters</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin</td>
<td>1. bin name, number, or variable</td>
<td>Set bin and continue.</td>
</tr>
<tr>
<td>SetBinStop6</td>
<td>1. bin name, number, or variable</td>
<td>Continue if parameter 1 is the null bin, otherwise set bin and based on parameter 2 either stop (generates OnFinish event) or continue.</td>
</tr>
<tr>
<td>SetBinRetest</td>
<td>1. bin name, number, or variable</td>
<td>Same as SetBinStop with additional retest actions.</td>
</tr>
<tr>
<td></td>
<td>2. Boolean ContinueOnFail</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Unsigned Integer retest</td>
<td></td>
</tr>
</tbody>
</table>

Retest schemes:

a. If the program stops and retest is non-zero, retest is decremented and an OnRetest event is generated. If retest is zero on stop, the program stops and restores retest’s original value.

b. make retest Boolean and use an unsigned Integer data element (in the softbin group container?) to control the maximum number of reprobes.

c. provide bin independent retest syntax.

Table 5: Soft Bin Setting Mechanisms

Looking back on the Table 2 example, independent tests may reach different conclusions regarding device speed, e.g., an at-speed functional test passes the device at 2.93GHz whereas a timing test determines that the device meets its 3.00GHz spec. For various

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5 That integer is in the Map statement in the BinMap block.
6 Stop, a related mechanism, has nothing to do with binning.
purposes, hardware binning being among them, one of the two bins, presumably the lesser 2.93GHz bin is chosen to act upon.

An Axis is an object that returns, e.g., the highest index bin that is set when queried.

If, in the Table 2 example, the at-speed functional test fails and a timing test still determines that the device meets its 3.00GHz spec, then the fail bin should be acted upon.

If multiple fail bins are set the lowest (highest) index bin is acted upon.

Alternatively or additionally, the syntax can provide means for interpreting any combination of pass and fail bins that have been set.

1.6 Counters

1.6.1 Soft Bin Counters

Proposed: there is a counter group for each object in the binning hierarchy beginning with the top level. Each counter in the group is initialized/re-initialized by a different event (see Table 6 for a list of supported events) and automatically incremented when a bin is set. The counters are chained such that incrementing a group at the lowest level, increments every group above it. The entire structure is repeated for each site.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OnLoad</td>
</tr>
<tr>
<td>2</td>
<td>OnLotStart</td>
</tr>
<tr>
<td>3</td>
<td>OnWaferStart</td>
</tr>
<tr>
<td>4</td>
<td>OnRetest</td>
</tr>
<tr>
<td>5</td>
<td>OnStart</td>
</tr>
</tbody>
</table>

Table 6: Counter group consists of one counter for each of these events

The Table 1 / Table 2 example is used to describe the counters mechanism. Assuming single site, there are 75 counters in this example, one group per each of the fifteen objects in the hierarchy shown in Table 7 times five counters per group, one counter per event shown in Table 6.

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7 The language provides read-only access to these counters.
As the events in Table 6 occur, each of the corresponding counters in the 15 groups of Table 7 is initialized.

<table>
<thead>
<tr>
<th></th>
<th>Top Level</th>
<th>Soft Bin Groups</th>
<th>Axes</th>
<th>Bins</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Pass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>ClockSpeed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>3.00GHz</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>2.93GHz</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>2.66GHz</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>CacheSize</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>8Mb</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>4Mb</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Anonymous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td>ContactOpens</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td>ContactShorts</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td>Functional</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>Timing</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: a counter group per row per site

When a bin is set, the corresponding counter hierarchy is incremented. For example, a timing test sets the 2.93GHz bin, incrementing the 2.93GHz counter group (Table 7, row 5), the ClockSpeed counter group (Table 7, row 3), the Pass counter group (Table 7, row 2), and the Top Level counter group (Table 7, row 1).

Support bin yield alarms (too high, too low).

### 1.6.2 Hard Bin Counters

Same as soft bin counters, i.e., is there any reason for the conceptual model to be different?

### 1.6.3 Counter Based Events

These are events triggered by counter contents or calculations involving counter contents and handled by *EntryPoints*, e.g., scrubbing and/or re-probing for up to three consecutive
contact test failures, characterizing every Nth good device, or stopping and raising an alarm when device yield drops below a certain point..

1.7 User-defined Device Specifications
Proposed: for software maintenance purposes it is useful to allow one or more sets of user-defined device specs per axis. The intent is to be able to write tests that can iterate simultaneously over axis bins and their corresponding specs. To be used for this purpose, each named specification must be able to hold a one or more values (min, max, or min and max) per bin.

In our example, one set of device specifications may be used for ac timing tests for a micro-processor. A single timing test can then iterate over each spec, e.g., data setup time, iterate over the timing values associated with the 3.00GHz, 2.93GHz, and 2.66GHz portions of that spec and bin the device accordingly.

Adding another spec, e.g., data hold time, then becomes a matter of adding in effect, a named variable with three values (assuming minimums only), one for each bin under ClockSpeed. Adding another ClockSpeed becomes a matter of adding a bin and a corresponding value to each of the specs associated with the ClockSpeed axis. Disabling one or more ClockSpeed bins can be implemented as a simple Boolean function.

1.8 Data Access
Proposed: access is provided for both stored and processed data, e.g., the contents of a counter (stored) and the dominant bin if more than one is set (processed).

Stored data may be accessed via the object hierarchy using, e.g., a dot syntax: a.b.c where data element c is contained by object b which is contained by object a. If b is an array then c of the first element of b may be accessed by, e.g., a.b[0].c (consider associative arrays for binning, i.e., the index may be other than numeric).

Processed data may be accessed via the object hierarchy using, e.g., a dot syntax: a.b.c() where function c is a member of object b which is contained by object a.

Appropriate member functions need to be defined for each object type.

2 Soft to Hard Bin Maps
Proposed: we provide the capability to define zero or more named maps and a mechanism for selecting the currently active map. Each map has no less than one entry for each cell in the array of enabled software bins formed by the bin axes, and no more than one entry

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8 STIL.0 Spec and Category syntax may be applicable here: Spec per Axis, Category per Bin.
9 The dominant bin is used for soft to hard bin mapping, for example.
for each cell in the array of enabled and disabled software bins\textsuperscript{10}. For single axis bin definitions, that means one entry per software bin. For multi-axis arrays, that means one entry for each combination of software bins. Each entry maps a software bin array cell to a hardware bin, specified as an unsigned Integer.

Assuming all bins are enabled, the example used in this document requires one entry for each fail-bin in the anonymous one dimensional array, and one entry for each of the combinations of ClockSpeed/CacheSize axis bins, i.e., 3 x 2 equals 6 entries.

\section{Binning Syntax}

\subsection{Definitions}

\begin{verbatim}
softbin_property =
  <
    Color = String; |   // Hex RGB or name
    Enable = Boolean; |
    Number = Integer; |   // 2 bins with same number OK
    Retest = Unsigned; |   // Hold off on semantics
    Terse = String;  |
    Verbose = String; |
    WafermapChar = Character;
  >
softbin_definition =
  Bin SOFTBIN_NAME;    |   // Sets property Name
  Bin SOFTBIN_NAME { softbin_property* }
\end{verbatim}

\medskip

\textbf{Figure 1: Soft bin definition}

\textsuperscript{10} In other words, disabled bin cell entries are optional.
If the bracketed \texttt{Map} statement in Figure 3 specifies multiple bins, comma is used as a separator, e.g.:

\begin{verbatim}
\end{verbatim}

or, since the two bin descriptors are unique in the context of the \texttt{BinDefs} block being mapped:

\begin{verbatim}
Map [ "3.00GHz", "8Mb" ] 1;
\end{verbatim}

The bracketed \texttt{Map} statement requires that all bin descriptors refer to the same group, i.e., either \texttt{Pass} or \texttt{Fail}, and that each bin listed comes from a different axis in that group. Each \texttt{Map} statement should contain a unique combination of bins. The totality of \texttt{Map} statements should cover all combinations. For the example used in this document, that requires $3 \times 2 = 6$ \texttt{Map} statements to map all \texttt{Pass} bins.
Changes from P1450-4-D18-SyntaxSummary11-28-2007.pdf:

- Removed Integer option in “\texttt{Bin SOFTBIN\_NAME (Integer)};“ because:
  - in the context of \textit{Axis} it is unclear what the relationship between that Integer and the index of a \textit{Bin} is.
    - a gap in the number sequence and duplicate integers pose problems with iterating over \textit{Bins} if that Integer is the index.

- Table 3
  - Added individual soft bin properties as per Table 3. This captures the intent of the Integer above using a different syntax.
  - Added keyword Map to each line under \textit{BinMap} to conform with 1450.0 general STIL statement form: \texttt{Keyword (OPTIONAL\_TOKENS)*};
  - Required at least one soft bin in brackets for 2\textsuperscript{nd} statement under \textit{BinMap}.
  - Substituted white-space for -> in statements inside the \textit{BinMap} to mimic 1450.1 \textit{NameMaps} syntax (that syntax puts the use of keyword Map in question):

```stil
NameMaps VECTOR\_ASSOCIATIONS {
  Signals {
    "A" "top\_test.PI[0]";
    "B1" "top\_test.PI[1]";
    "C1" "top\_test.PI[2]";
    "D11" "top\_test.PI[3]";
  }
  SignalGroups {
    _PI "top\_test.PI";
    _PO "top\_test.PO";
  }
  Variable { _PATCOUNT "PATTERN"; }
}
```

3.2 Usage and Data Access

3.2.1 Group Property Access Syntax

```
group\_property = <
  Color | // String (hexadecimal RGB or name, e.g., red
  isAnyBinSet | // Boolean
  NrOfAxes | // Signed
>```

Figure 4: Group Property Access
3.2.2 Axis Property Access Syntax

```plaintext
axis_property =
   <
      highestSetBin | // Unsigned(Integer in case no bin is set ?)
      lowestSetBin  | // Unsigned(Integer in case no bin is set ?)
      NrOfBins      | // Unsigned
      Name          // String
   >
group = < Pass|Fail >

(String) group [Integer] .axis_property
```

Figure 5: Axis Property Access

3.2.3 Bin Property Access Syntax
For example, the expression\(^{11}\):
\[\text{Pass[ClockSpeed["3.00GHz"].Index}\]

yields 0, the index of bin ”3.00GHz”, whereas:
\[\text{bindefs.Pass[ClockSpeed[0].Name}\]

yields the bin name string ”3.00GHz”\(^{12}\), assuming an instance of type BinDefs named bindefs exists.

\(^{11}\) This form requires that the program knows the in-use instance, e.g., bindefs.
\(^{12}\) The returned string does not include quotes, regardless of whether they were used in the bin name or not unless String provides a mechanism for getting an unquoted version.
Expression:
\[
\text{bindefs.Pass.ClockSpeed["3.00GHz"].counter.OnLoad}
\]
yields an Integer representing the number of times bin "3.00GHz" has been set since
the test program was loaded.

### 3.2.4 Binning Syntax

Binning code is restricted to specific blocks\(^{13}\). For tests and flows, that is in the
PostAction, PassAction, and FailAction blocks. For flow-nodes, that is in the PostAction
and exit-port action blocks.

Statements SetBin, Stop, and SetBinStop are provided because they represent
commonly used actions provided by most testers and are easily parsed by both human
and machine, e.g., it is easier to find SetBinStop occurrences than the equivalent **If**
statement syntax provided below.

\[
\text{bin_identifier =}
\begin{align*}
\text{<} \\
\text{Bin = Bin;}
\text{Index = Unsigned;}
\text{Name = User_defined_name;}
\text{Number = Integer;}
\text{>} \\
\setbin (Bin); \\
\setbin \{ \text{bin_identifier} \} \\
\setbinstop (Bin); \\
\setbinstop \{ \text{(bin_identifier)} \} \\
\text{Stop;}
\end{align*}
\]

**Figure 7: Binning**

The SetBin statement sets the bin only, i.e., does not stop. Of the two Stop statement
forms, the first is unconditional, the second only stops if ContinueOnFail is False.
SetBinStop semantics are equivalent to the following\(^{14}\):

\[
\text{If FailBin != NoBin}
\begin{align*}
\{ \text{SetBin; If ContinueOnFail == False Stop; } \}
\end{align*}
\]

\(^{13}\) Re-evaluate with respect to Skip action, i.e., maybe PreAction binning should be allowed.

\(^{14}\) Lots of assumptions about syntax which is incompletely defined in syntax document.
3.2.5 NoBin Properties

NoBin is a special bin defined by the standard. It has no user-settable properties. Figure 8 shows the values returned when NoBin properties are interrogated. Refer to Figure 6 for the definition of counter_reset_event.

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>String &quot;grey&quot;</td>
</tr>
<tr>
<td>ContinueOnFail</td>
<td>Boolean True</td>
</tr>
<tr>
<td>counter_counter_reset_event</td>
<td>Unsigned, default = 0, incremented when set</td>
</tr>
<tr>
<td>Enabled</td>
<td>Boolean True</td>
</tr>
<tr>
<td>Index</td>
<td>Unsigned MaxUnsigned|Infinity</td>
</tr>
<tr>
<td>IsFailBin</td>
<td>Boolean False</td>
</tr>
<tr>
<td>isSet_counter_reset_event</td>
<td>Boolean, default = False, becomes True when set</td>
</tr>
<tr>
<td>Name</td>
<td>String &quot;NoBin&quot;</td>
</tr>
<tr>
<td>Number</td>
<td>Integer MaxUnsigned|Infinity</td>
</tr>
<tr>
<td>retest_(current|Original)</td>
<td>Unsigned 0|0</td>
</tr>
<tr>
<td>Terse</td>
<td>String &quot;&quot; (empty)</td>
</tr>
<tr>
<td>Verbose</td>
<td>String &quot;&quot; (empty)</td>
</tr>
<tr>
<td>WafermapChar</td>
<td>Character ' ' (space)</td>
</tr>
</tbody>
</table>

Figure 8: NoBin Properties

Issues:

- Do we allow Bin assignment, i.e., Bin::operator=(const Bin\&), ref Index, Number
- MaxUnsigned or Infinity are currently not keywords. What are the merits of each, assuming Infinity could be used across types, e.g., Integer, Real, Seconds, etc

3.2.6 Re-probe Syntax

Issue: define format easily mapped to multiple targets. Is there such a thing? Delay to phase II?

3.3 Examples

4 Spill-over Issues

Some issues arising in the context of binning spill over into other areas of the language and/or vice versa, begging for some co-ordination to minimize unnecessary proliferation of rules and concepts. These are merely alluded to here, expecting resolution in the greater context:
a. Initialization: when defining an object such as a variable, it is useful to be able to specify the event that initializes/re-initializes it, e.g., one counter may be re-initialized by event OnWaferStart, another by event OnLoad, etc.
b. Object member functions: it is useful to specify member functions for integral objects, e.g., string.length(), array.dim(), array.dim(0).length(), etc.
c. Do we want to allow string to number-with-units conversion?
d. Do we provide syntax to allow the user to trigger an EntryPoint event, e.g., trigger OnStart or OnRetest for retest? Support more standard or user-defined events, e.g., low bin yield alarms? Delayed until phase II.
e. IO syntax, e.g., cin, cout, cerr, clog, stringstream, file IO, formatting, etc. Delayed until phase II.
f. Prior to optional property access syntax, the in-use BinDefs must be known (currently described in TestProgram block which comes last).
g. A context sensitive keyword for the null bin is required, e.g., NullBin or NoBin. Settled on NoBin.
h. Need OnRetest event/EntryPoint (initializes retest.current along with OnLoad). Done.

In order to adequately describe binning behavior or syntax, some clarification regarding the semantics and/or syntax associated with existing language elements is necessary. Clarification is needed for the:

a. semantics regarding OnStart and OnSiteStart EntryPoints: OnSiteStart has been dropped.
b. use of dot 0 Spec/Category syntax, i.e., how do we access, e.g., Meas under Spec tmode_spec, or Max under variable tplh under Category tmode under Spec tmode_spec? Do we need a Meas for every Category (device in different state may have different measurement result for the same Spec)?
c. dot 4 provided basic test definitions: syntax requirements may change depending on what pre-defined test elements exist in dot 4, e.g., if all we provide is a functional test then in order to be define an DC or AC parametric test, syntax that permits the iterative alteration of a specific level or timing edge is required. If dot 4 provides basic tests to perform linear and binary searches that syntax may take on a different character. Run-time efficiency may be affected by our choices.
d. definition of dimensioned array variables.
e. Does String provide a mechanism for getting unquoted version?

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