A Domain-specific Language for High-reliability Software used in the JUICE SWI Instrument – The hO Language Manual

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Abstract

$hO$ is a custom restricted dialect of Oberon, developed at the Max-Planck Institute for Solar System Research in Göttingen and used in the SWI flight software for the JUICE mission. $hO$ is applied to reduce the possibility of syntactically valid but incorrect code, provide better means of statically analyzing source code, is more readable than C and gives syntactic support for the software architecture used in the SWI instrument software. By using a higher-level, application-specific notation a whole range of possible errors is eliminated and source code size is reduced, while making the code itself easier to understand, review and analyze.

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1 Introduction

This document describes the $hO$ language, a dialect of Oberon\textsuperscript{26}, which is used as a replacement for C\textsuperscript{17} in the implementation of the SWI\textsuperscript{14} flight software for the JUICE\textsuperscript{8} mission.

The SWI flight software was initially planned to be implemented in C which is a de-facto standard for most software written for current and future ESA missions, as C is widely available and relatively well known. C is also directly supported by the main hardware platform\textsuperscript{10} that is used throughout the JUICE project in the form of the Gaisler BCC toolchain\textsuperscript{11} and debugging utilities.

For embedded systems in constrained environments, C is a common choice as an implementation language, but carries with it a considerable class of hazards regarding memory-safety and the handling of exceptional situations. C’s history as a systems programming language puts an emphasis on full control over hardware resources and maximum efficiency, but intentionally removes run-time checks and provides means to circumvent the type-system in various ways, for example by using type-casts and unions. In an environment where high-reliability and fault tolerance are at a premium, as is the case in space projects, the flexibility provided by C can be a liability, because error-checking and fault recovery are entirely the responsibility of the programmer. Moreover, only very low-level and general control structures are available which, when used, need careful attention to avoid out-of-bound errors, non-terminating iterations or unhandled cases when discriminating among a set of values. Additionally, unsafe pointer-handling makes it hard to ensure the absence of bugs and results in hard to read code, incurring additional time for reviews and more extensive levels of debugging\textsuperscript{23} \textsuperscript{2}.

Therefore we decided to use a custom, domain-specific language that is easier to parse – both for humans and tools – and that provides direct syntactic support for the architecture that we use in the SWI flight software. We briefly considered existing languages targeted for embedded high-reliability use:

Most obviously, Ada\textsuperscript{16} may be considered the prime choice for software development in this area, but a lack of programming experience in this language and the existing implementations and runtime-systems made us look for simpler and more lightweight solutions.

Another option would be Forth\textsuperscript{21}, which is already widely used in space applications, is very lightweight and extremely flexible. The problem here was that this would not have permitted us to use the Gaisler C toolchain and the greatly different philosophy of Forth would have required a complete redesign of the already existing prototypical C codebase that we used for
evaluating the architecture.

Finally, there are more recent, mostly academic attempts at designing languages for high-reliability software like Ivory\cite{Ivy}, but a lack of good documentation, a somewhat unstable implementation, and the very obscure syntax made us reject this option.

As both authors have experience in language design and implementation\cite{Muller} \cite{Koucky}, we decided to create a notation and translator of our own, tailored to the software architecture used in the SWI project.

We still use C as a target language, to avoid the intricacies of direct native code generation and take advantage of existing optimization technology. Moreover, using the vendor's toolchain takes advantage of workarounds for hardware bugs in the board that is used for testing the DPU software\cite{DPU}.

2 Architecture

As the architecture of the SWI flight software had considerable influence on the language design of hO, a short description of the structure of the application is given here.

The SWI application employs a cyclic executive\cite{Miller} \cite{Koucky} to schedule repeating and concurrent tasks. Functionality is separated into modules which are executed one after the other, repeatedly. Modules can be separated into the following groups:

a) Modules responsible for sub-units of the instrument (spectrometers, motors, oscillator).

b) Modules processing specific hardware (SpaceWire, SPI, GPIO, ADC/DAC).

c) Modules processing incoming telecommand- (TC) and outgoing telemetry packets (TM).

d) Modules performing checks of the overall status of the system as a whole and reporting the status to the on-board computer and ground (memory, safety checks, house keeping, watchdog).

e) Modules processing higher-level functionality, that is, sequences of operations specific to the instrument (scripts).

Long-running tasks have to be split up manually to ensure a minimum latency between module executions, but the minimum latency for a complete execution cycle can be determined statically, and the system is fully deterministic: tasks are interrupted at well known and safe locations.
SWI does not use an operating system. The functional and performance requirements for the software are moderate and most hardware interfaces are SWI-specific. Therefore the additional complexity and size of an operating system is not justified. Moreover, having complete control of the system and being able to understand all parts of it in detail gives us the confidence that the number of errors in the final product is minimized.

Modules communicate by zero-copy message passing; each module has a public data area, accessible from other modules, and a private data area for internal use. A special structure named port holds a single message during the transmission from module A to module B. Once a message is processed, the port is emptied, the memory occupying the message is returned to the memory management subsystem and the port can receive a fresh message. Message buffers have a fixed size (just enough to hold the maximum telecommand/telemetry message packet size). Since nearly all messages are TC/TM packets or are derived from those, no copying is involved, as long as we ensure messages conform to the TC/TM layout. Internal messages for programmatic control of some parts of the system (scripting) use TC packets as messages, for example, and thus do not need special handling of packets that originated from ground control or from an internal source.

Memory from messages is dynamically allocated from a pool of fixed-size message blocks, which makes the memory management very simple and transparent. Unused memory is reclaimed as early as possible and messages can not be queued, avoiding the potential of ports filling up with unhandled messages and subsequent exhaustion of the available memory pool.

3 Language

hO is based on Oberon\textsuperscript{[26]}, a Pascal/Modula dialect developed by Niklaus Wirth. Oberon has the advantage of being syntactically simple and easy to understand, it has a simple runtime model and a minimal runtime system. hO further simplifies Oberon by removing support for strings, real numbers, procedure types, multi-dimensional arrays, derived record types, sets, WITH and most loop types. Dynamic memory management has been removed, with the exception of PORT types.

By choosing the simpler and stricter notation of Oberon instead of a C based syntax, many of the classic pitfalls in C programming are avoided. Specifically, of the 142 rules specified in the MISRA-C 2004 guidelines\textsuperscript{[20]}, a total of 116 rules are automatically enforced by the syntactic rules of the hO language and properties of the generated code and runtime system.

Similarly, only one out of the ten rules proposed with “The Power of
Ten”\cite{16} continues to play a role when switching from C to hO, while the other nine rules are obsolete. Moreover, while translating a fully functional prototype of the software from C to hO, the amount of source code did not increase, instead decreasing slightly from 3336 to 2853 LOC.

Extensions to Oberon that have been added to reflect the SWI software architecture are: syntax for state machines, a \texttt{PORT} type and built-in procedures for message passing, extensions for \textit{Design-by-Contract}\cite{19} and some low-level utilities for direct byte-level memory access. The \texttt{MODULE} construct has been modified to simplify the implementation of modules that are executed by the cyclic executive, which itself is implemented in C.

See appendix A for the language reference.

4 Runtime System

The runtime system, including memory management, low-level message passing, the cyclic executive scheduler, and an UART-driver for debugging output consists of roughly 400 lines of C. hO is translated to C and linked with the runtime system into an executable for final delivery to the processing unit of the instrument. Note that all memory accesses are indirect – exported and internal data of modules is held in a module-specific static data block, given to the module when it executes. That way module-data is position independent and may be moved in case memory should fail due to radiation damage. Moreover, all procedures are inlined, and no global variables are used. This ensures all code is agnostic of the physical location of procedures and variables on memory and can be moved at will.

Dynamic checks may result in error conditions that write debugging output to the serial interface at development time or result in error event telemetry and reboot (in case of fatal errors), when delivered in the flight model. To make sure that error event handling takes place, regardless of the state of the system, this mechanism has to circumvent the normal event and telemetry handling.

Message memory is managed in a simple list of free 4 kB blocks. There are basic operations for allocating a block (\texttt{NEW}) and releasing them back to the runtime system (\texttt{DISPOSE}). All blocks have the same size, and are passed from module to module, without copying. So, for example, the SpaceWire\cite{5} \cite{6} module retrieves a packet from the hardware interface, allocates and fills a block with the data and sends it to another module responsible for validating the packet. This module in turn will send the block further for more specific processing. Once the block/message/packet has been fully processed, it can be released and given back to the runtime system.
Direct access to the message contents is primitively only available on the byte-level. However, most telecommand/telemetry messages that SWI handles are structured records as defined by ESTEC[7]. A machine-generated library of accessor functions is used to take apart telecommands and construct telemetry packets, generated from the TC/TM (MIB) database that has to be provided as a component of the flight software.

5 The Compiler

The hO compiler is implemented in Scheme[24] and parses our Oberon dialect, performs type-checking and generates ANSI C99. The compiler is implemented in a straightforward manner, using the Silex[3] lexer generator and a custom PEG[9] parser. The type-checker implements a straightforward static typing scheme and performs some additional checks that we considered worthwhile. For documentation purposes the compiler also provides generating a dot diagram depicting message-flow between modules, using the graphviz[13] tool, and generating support files for mapping runtime error information to source code locations.

To allow circular module references, the compiler can be run in a restricted mode that just generates interface information for each module, instead of fully validating inter-module data access.

6 Properties of the generated C code

The use of hO eliminates many sources of undefined behaviour in C, among these are:

1. NULL-pointer references
2. Pointer-arithmetic
3. Numeric overflow of signed integers, provided the necessary compiler flags are given when compiling the generated C code
4. Right-shifts of signed integers always produce an unsigned result
5. Division/modulo by zero is detected and caught at runtime
6. Uninitialized variables
The code generated by hoc uses GNU extensions, namely local (inline) functions and statement expressions. It is recommended to compile the C code with the `-fno-strict-aliasing -fwrapv -std=gnu99` compiler options to ensure correct semantics at runtime.

Appendix A – hO Language Reference

If not indicated differently, the lexical syntax of hO is the same as in Oberon. Comments are written as

\[ (* \ldots *) \]

and can not be nested.

hO is case-sensitive, builtin keywords may alternatively be given in lowercase.

Toplevel forms

Modules

The application is structured into modules, where each module contains some toplevel code, executed periodically, and a private and optionally public set of global variables. Modules may be instantiated multiple times, for example, to provide implementations for two redundant hardware interfaces or for multiple variants of the same functionality. In SWI we have a second redundant SpaceWire interface and both the spectrometer and autocorrelator exist in 2 versions.

A module must return to its caller, or the system will grind to a halt, but since there are no syntactic constructs to perform unbounded loops or mutually recursive procedures, such a situation is not possible.

A module is defined using the syntax

\[
\text{MODULE name;}
\text{VAR exported*: u32, listener*: port;}
\text{secret, unknown: u32;}
\text{BEGIN}
\text{...}
\text{END name.}
\]

Here, exported and listener are externally visible, secret and unknown are internal. The variables declared are visible in the scope of the module.
and retain their contents over every cyclic execution. To access the exported variables of another module the `name.listener` syntax can be used, provided the module `name` was imported into the current scope using the `IMPORT` form.

Module variables are always initialized to 0 (zero) or, in the case of “port” objects, to empty ports.

Modules that exist in multiple instances (currently at most 2) are defined like this:

```
MODULE spw*;
...
```

The `spw` module above will exist in two variants (spw0 and spw1) in the final image. Note that though they do share source code, at runtime they share neither code nor data.

To access the public variables of another module, use the `IMPORT` statement:

```
IMPORT some_module;
```

If a module provides several instances, then access to the variables of a particular instance, or of the instance corresponding to the instance of the current module can be specified as follows:

```
IMPORT mod0 := mod[0]; (* only access instance 0 *)
IMPORT mod := mod[*]; (* import corresponding instance *)
```

`mod` variables can be accessed now using `dot` notation, as in

```
SEND(msg, mod.port);
```

**Message passing**

Modules communicate by sending messages. A message is a raw u8 array of at most 4096 bytes. Any variable of type `port` can hold at most one message or is empty. Sending a message from one port to another port moves the data array: sending a message from an empty port or to a blocked port does nothing, otherwise the target port holds the message and the source port is empty.

Uninitialized ports are empty
Type-, constant and procedure definitions

Types and constants are defined as in Oberon:

```
TYPE point = RECORD x, y: s32 END;
CONST zero = 0;
```

Builtin types exist for basic numeric types: u8, u16, u32, s8, s16, s32 and boolean.

Procedure and function definitions are also similar to Oberon, with the exception of unspecified ARRAY arguments – in hO all arrays must have a fixed, statically known length. Procedures are always inlined, so should be kept at a reasonable size.

Procedures may be declared at the start of a module to define internal procedures, not visible in other modules. These internal procedures have full access to the public and private module variables.

Procedures may modify their argument variables for arguments declared with VAR (as in Oberon.)

Contracts

hO supports a basic Design-by-Contract facility to run dynamic checks at runtime. A contract is a boolean function, optionally with arguments. Contracts must be defined at toplevel and can not be local to a module.

```
CONTRACT ensure_positive(x: s32)
BEGIN
  return x > 0
END;
```

Contracts may not use VAR arguments.

To use a contract, use the REQUIRE, PROVIDE and INVARIANT statements at the start of a statement sequence, that is, at the start of a module-, procedure, conditional or loop body:

```
LOCAL counter := 0;
REPEAT 10 TIMES
  REQUIRE ensure_positive(counter), other_contract;
  ...
END;
```

Contracts used by REQUIRE are checked at the start of the respective statement sequence, contracts used by PROVIDE at the end and contracts used by INVARIANT are checked both at the start and at the end of a sequence, respectively.
Include Files

The contents of external files can be included using the INCLUDE form:

    INCLUDE "some_file.ho";

An include-file is included at most once. Including the same file subsequently has no effect.

Statements

The following statements are allowed:

Conditionals

    IF expression THEN ... [ELSIF ...] [ELSE ...] END
    CASE expression OF const1: ... | const2: ... [ELSE ...] END

    IF is the usual conditional statement. CASE provides an n-way comparison with optional default (ELSE) clause. Multiple constants and constant ranges can be used in CASE clauses, as in Oberon. If no case applies, then execution continues normally after the CASE construct. At the end of a clause, execution continues after the CASE statement.

Loops

There is only a single loop statement available, a counted loop with an optional condition:

    [WHILE expression] REPEAT constant TIMES ... END

    The loop counter must be constant to ensure termination. The expression is evaluated before each loop iteration. A dedicated loop variable is not provided, but can be defined and updated manually. Note that regardless of the value of the guard expression, the loop will terminate after the indicated number of iterations.

State machines

Built-in support for state machines is provided. You can declare states using the STATE form:

    STATE init, process, idle;
STATE defines each declared state as a constant of type s32, starting with 0 (so an uninitialized state variable implicitly holds the first state.) The SELECT statement dispatches between states, and NEXT switches to another state:

```
SELECT current OF state1: ... | state2: ... END
```

current must be an assignable value or type u32. NEXT assigns a new state to the state variable given:

```
NEXT process;
```

There is no “fall-through” in state clauses: at the end of the statement-sequence in a state, execution commences after the SELECT statement.

Note that NEXT does not perform a transfer of control to a different state clause, but to the end of the select statement instead. On the next execution of the select statement, the state variable given in the SELECT statement will have the new value assigned to it in the previous iteration.

NEXT is not allowed to exit a looping construct. If no clause of the SELECT form applies to the current state, execution continues after the SELECT form as normal.

Other statements

hO supports the usual procedure calls, assignments and RETURN statements as in Oberon. Local variables may be declared at any point using

```
LOCAL var := 0;
```

The scope of the variable extends to the current block, that is, to the next outer END token. Local variables must be initialized and may optionally be declared to have a particular type, if the type of the initialization expression is insufficient:

```
LOCAL unsigned := 0: u32;
```

So called external variables allow accessing direct memory locations:

```
EXTERNAL uart_reg := 80000100h: VOLATILE POINTER TO u32
```

Should a locally defined variable shadow an existing variable in an outer scope, then the compiler will issue a warning.
Expressions

The usual arithmetic and comparison operators of Oberon are provided in hO as well. Since hO does not support floating-point arithmetic, \(/\) and DIV are equivalent. Consult the EBNF grammar later in this section for information about operator precedence.

Builtin types, constants, operators and procedures

Types

- s8, s16, s32, u8, u16, u32
  Numerical base types.

- boolean
  The boolean type.

- port
  The type of a structure that can hold messages.

- [VOLATILE] POINTER TO type
  A pointer type, optionally declared volatile, to disallow assumption made by the compiler about the value of memory locations, when the memory location might be updated asynchronously, for example.

Constants

- MODULE_ID: u32
  A constant holding the numeric ID of the current module.

- INSTANCE: u32
  A constant holding the instance-ID of the current module, if this module has several instances (currently 0 or 1).

- TRUE, FALSE: boolean
  The canonical true and false values.

Operators

- AND OR NOT
  Boolean operators. Note that AND and OR are short-circuiting as in C.

- \(/\ \backslash\ \//\ \text{ }\text{ }\text{ }\text{ }>\text{ }\text{ }\text{ }\text{ }\text{ }<\text{ }\text{ }\text{ }\text{ }\text{ }\sim\)
  Binary logic operators (and, or, xor, not).
Perform unsigned left or right shift of $x$ by $y$ bits.

$+ - * / \text{DIV} \mod$

Numerical operators. Arithmetic between arguments of differing numeric type are allowed. \text{DIV} is currently an alias for $/$.

$= \# > < \geq \leq$

Comparison operators for arguments of numeric type.

\text{SIZE}(\text{type})

Returns the size in bytes of the memory occupied by \text{type}.

Expressions of boolean or comparison operators that produce a constant result will produce a warning as this may indicate a programming error.

Operator precedence is as follows, listed from highest precedence to lowest, sequent binary operators are evaluated from left to right:

1. Selection operators (., [] ^)
2. Subexpression (())
3. Unary operators (unary + - NOT ~ and \text{SIZE})
4. Multiplicative operators (* / \text{DIV} \mod \text{AND} \text{AND} /)\)
5. Shift operators (\text{>>} \text{<<})
6. Additive operators (binary + - and \text{OR} \text{OR} \text{\textbackslash} \text{\textbackslash} \text{\textgreater} \text{\textless})
7. Comparison operators (= \# \leq \geq \rightarrow \leftarrow \textless \textgreater)

Procedures

\text{CLONE}(\text{oldport}, \text{newport})

Clones the message stored by \text{oldport} and puts a copy into \text{newport}, both of which must be port objects. \text{oldport} may be empty.

\text{DEC}(\text{var})
\text{INC}(\text{var})

Increase or decrease the numeric value in location \text{var}.

\text{DISPOSE}(\text{port})

Free the memory used by the message in \text{port}. If the \text{port} is empty, do nothing.
EXTEND(port, n)
Increase or decreases the used size of the message in port by n. n may be negative.

LOG(string)
LOG(string, x)
Writes debugging output to the serial interface, optionally with a numeric argument.

NEW(port, size)
Allocates a buffer of the given size for holding a message and stores it in port. The message is uninitialized and contains random data.

SEND(fromport, toport)
Moves a message from port to port. If the receiver port is non-empty, this operation is a no-op. If the receiver port is empty, the sender port will be emptied.

Functions

ADR(var): POINTER TO type
Returns a pointer to the location given by var.

COUNT(port): s32
Returns the size of the message stored in port, in bytes.

DATA(port): ARRAY blocksize OF u8
Returns the data array holding the data of any message in port.

MAX(x, y): s32
MIN(x, y): s32
The minimum and maximum functions.

PENDING(port): boolean
Returns true if port holds a message.

SEND(fromport, toport): boolean
As the SEND procedure, but returns a boolean, indicating whether the message was actually sent.
EBNF Grammar

```
compilation-unit ::= { toplevel ";" } .
toplevel ::= typedef | module | function | contract | include | constdef .
include ::= "INCLUDE" string .
constdef ::= "CONST" { id "=" constant ";" } .
typedef ::= "TYPE" { id "=" type ";" } .
function ::= "PROCEDURE" id "(" param { "," param } ")" [ ";" type ]
             "BEGIN" statements "END" .
contract ::= "CONTRACT" id "(" param { "," param } ")" ]
             "BEGIN" statements "END" .
param ::= [ "VAR" ] id { "=" id } ";" type .
statement ::= if | loop | return | pcall | variable | external |
             | typedef | import | select | log | next | case | assign | ";" .
statements ::= { check ";" } statement { ";" statements } .
log ::= "LOG" "(" string [ "=" expr ")" .
check ::= "REQUIRE" assert { "=" assert } |
         "PROVIDE" assert { "=" assert } |
         "INVARIANT" assert { "=" assert } .
assert ::= pcall | id .
variable ::= "LOCAL" id "=" expr [ ";" type ]
             { ";" id "=" expr [ ";" type ] } .
external ::= "EXTERNAL" id "=" constant ";" type
             { ";" id "=" constant ";" type } .
constdef ::= "STATE" id { ";" id } .
import ::= "IMPORT" importspec { ";" importspec } .
importspec ::= id [ ";=" id [ "[" ( "*" | constant ) ""] ] ] .
select ::= "SELECT" lvalue "OF" state { ";" state } "END" .
state ::= range ";" statements .
range ::= range-element { ";" range-element } .
range-element ::= constant [ ... constant ] .
next ::= "NEXT" constant .
loop ::= [ "WHILE" expr ] "REPEAT" constant "TIMES" statements "END" .
case ::= "CASE" expr "OF" state { ";" | state } [ "ELSE" statements ] "END" .
assign ::= designator "=" expr .
return ::= "RETURN" [ expr ] .
if ::= [ "IF" expr "THEN" statements ] [ "ELSIF" statements ]
             [ "ELSE" statements ] "END" .
pcall ::= id "(" expr { "," | expr } ")" .
expr ::= sum [ ( "=" | "+" | "#" | "<-" | "->" | "<" | ">" ) sum ] .
sum ::= term { ( "+" | "-" | "OR" | "+/" | "><" ) term } .
```
term ::= product [ ( "<<" | ">>" ) product ] .  
product ::= unary { ( "*" | "/" | "DIV" | "MOD" | "AND" | "\" ) unary } .  
unary ::= [ "*" | "-" | "~" | "NOT" ] factor | "SIZE" "(" type ")" .  
factor ::= designator | number | "(" expr ")" | boolean .  
boolean ::= "TRUE" | "FALSE" .  
designator ::= ( id | pcall ) { "." id | "[" expr "]" | "~" } .  
module ::= "MODULE" id [ "*" ] ";" [ modulevars ] [ modulefunctions ]  
BEGIN statements "END" id ";" .  
modulevars ::= "VAR" vardef { ";" vardef } .  
modulefunctions ::= function { ";" function } .  
vardef ::= id [ "*" ] { ".", id [ "*" ] } ";:" type .  
type ::= simpletype | structtype | ptrtype | arraytype .  
ptrtype ::= [ "VOLATILE" ] "POINTER" "TO" type .  
structtype ::= "RECORD" field { ";" field } "END" .  
field ::= id { ".", id } ":" type .  
arraytype ::= "ARRAY" constant "OF" type .  
simpletype ::= id .  
constant ::= expr const .  
id ::= (letter|"_"){letter|"_"}digit.  
string ::= "{character}"" .  
number ::= digit{digit}{hexdigit}"h" | '{character}' .

Appendix B – Compiler Usage

If correctly installed, the hO→C translator can be invoked by entering the hoc command, passing the name of a hO source file and zero or more of the following command line options:

-h
  Show a short message listing the available options

-I directory
  Specifies an additional include directory to be added to the search path for files accessed via the INCLUDE form.

-d
  Generate dependency rules for make(1), writing them to the standard output channel.

17
-f
Generate a message flow diagram suitable for the dot(1) tool, writing it to the standard output channel.

-o filename
Specify an alternative output filename. The default is to use the name of the source file, but with the ‘.c’ extension.

-g
Only generate an interface file, named after the source filename, but with the ‘.hi’ extension.

-k
Keep intermediate files from the parsing, processing and type-checking stages.

Appendix C – Dynamic runtime checks

The following conditions are dynamically checked at runtime, unless being explicitly disabled by compiling the C files generated by hoc with the -DNDEBUG option:

Empty port access
Accessing the DATA of an empty port.

Division/modulo by zero
Using /, DIV or MOD with a second argument that is zero.

Invalid shift
Using << or >> with a second argument that is negative or equal or higher than the word size of the used processor architecture.

Array bounds
Accessing an array with an index that is negative or exceeds the size of the array.

Appendix D – Proposed coding style

The following is a description of the coding style that we use in the JUICE SWI project. We recommend to follow this style when using hO.
1. A line of code should contain at most a single statement. If the statement is a complete control structure like `IF/THEN` and the body contains a single statements that fits into the line, then the conditional may occupy the complete line.

2. `THEN` and `OF` should terminate a line, possibly with a trailing semicolon `;`.

3. `ELSE` and `END` should always be on a separate line.

4. Define local or external variables as near to their first use as possible.

5. Declare local variables to a specific type to avoid expression ambiguity.

6. Avoid complex expressions that exceed a single line.

7. Indent `CASE` and `SELECT` cases consistently.

8. Separate `VAR` blocks and module bodies by an empty line.

9. Surround binary expression- and assignment operators with a single space on both sides.

10. Separate toplevel entities (function- and module definitions, also comment blocks) by at least one empty line. Otherwise avoid empty lines in source code.

11. Avoid unnecessary comments unless they convey something important or critical to the understanding of the code.

12. Don’t use source lines that exceed 100 columns.

13. Write keywords in lowercase.

14. Avoid TAB characters as there is no standard width of a TAB and source code may look differently depending on client settings.

15. Whatever you do in following or deviating from this coding style, be consistent.
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21