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Notes on this document

This document is posted for analysis by SPARK experts to determine the scope of changes needed in the document for compatibility with the latest published SPARK specification.

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# Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

In exceptional circumstances, when the joint technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art”, for example), it may decide to publish a Technical Report. A Technical Report is entirely informative in nature and shall be subject to review every five years in the same manner as an International Standard.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC TR 24772-6 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 22, *Programming languages, their environments and system software interfaces*.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

In exceptional circumstances, when the joint technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art”, for example), it may decide to publish a Technical Report. A Technical Report is entirely informative in nature and shall be subject to review every five years in the same manner as an International Standard.

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ISO/IEC TR 24772-3, was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 22, *Programming languages, their environments and system software interfaces*.

With the cancellation of TR 24772:2013, this document replaces ISO IEC TR 24772:2012 Annex G. The main changes between this document and the previous version are:

* This document has been brought up to date with respect to the most recent (June 2020) release of the SPARK Language Reference Manual.
* Recommendations to avoid vulnerabilities are ranked and the top 12 are placed in a table in clause 5, together with the vulnerabilities in clauses 6 that contain each recommendation.
* The following vulnerabilities that were documented in clause 8 of TR 24772:2013 are now addressed in this document in clause 6.
	+ [CGA] *Concurrency – Activation*
	+ [CGT] *Concurrency – Directed termination*
	+ [CGX] *Concurrent data access*
	+ [CGS] *Concurrency – Premature termination*
	+ [CGM] *Protocol lock errors is now Lock protocol errors*
	+ [CGY] *Inadequately secure communication of shared resource.*
* Clauses 6.2 *Terminology* is integrated into clause 3, and all subclauses in clause 6 are renumbered.
* The following vulnerabilities were removed:
	+ [XZI] *Sign extension error* was integrated into [XTR] *Type system*.
	+ [REU] *Termination strategy*, 6.39, is placed in clause 7 in Part 1, and hence is not documented for SPARK herein.
* The following vulnerabilities were renamed to track the changes made in Part 1:
	+ [HFC] *Pointer casting and pointer type changes* was renamed to *Pointer type conversion*;
	+ [JCW] *Operator precedence/Order of evaluation*, was renamed to *Operator precedence and associativity*;
	+ [XYL] *Memory leak* is renamed to *Memory leaks and heap fragmentation*;
	+ [XYP] *Hard coded password* is renamed *Hard coded credentials*;
* New vulnerabilities are added, to match the additions of Part 1:
	+ [YAN] *Deep vs shallow copying*;
	+ [BLP] *Violations of the Liskov substitution principle or the contract model*;
	+ [PPH] *Redispatching*;
	+ [BKK] *Polymorphic Variables*;
	+ [SHL] *Reliance on external format strings*;
* Guidance material for each vulnerability given in subclause 6.X.2 is reworded to be more explicit and directive.

Addition material has been added for some vulnerabilities to reflect addition knowledge gained since the publication of TR 24772:2

# Introduction

This Technical Report provides guidance for the programming language SPARK, so that application developers considering SPARK or using SPARK will be better able to avoid the programming constructs that lead to vulnerabilities in software written in the SPARK programming language and their attendant consequences. This guidance can also be used by developers to select source code evaluation tools that can discover and eliminate some constructs that could lead to vulnerabilities in their software. This report can also be used in comparison with companion Technical Reports and with the language-independent report, TR 24772–1, to select a programming language that provides the appropriate level of confidence that anticipated problems can be avoided.

This technical report part is intended to be used with TR 24772–1, which discusses programming language vulnerabilities in a language independent fashion. It is also intended to be used with TR 24772-2, Ada which discusses how the vulnerabilities introduced in TR 24772-1 are manifested in Ada, which is a superset of SPARK.

It should be noted that this Technical Report is inherently incomplete. It is not possible to provide a complete list of programming language vulnerabilities because new weaknesses are discovered continually. Any such report can only describe those that have been found, characterized, and determined to have sufficient probability and consequence.

**Information Technology — Programming Languages — Guidance to avoiding vulnerabilities in programming languages — Vulnerability descriptions for the programming language SPARK**

# 1. Scope

This Technical Report specifies software programming language vulnerabilities to be avoided in the development of systems where assured behaviour is required for security, safety, mission-critical and business-critical software. In general, this guidance is applicable to the software developed, reviewed, or maintained for any application.

Vulnerabilities described in this Technical Report document the way that the vulnerability described in the language-independent TR 24772–1 are manifested in SPARK.

This report is based on the publicly available “Community 2020” release of the SPARK, which is itself based on Ada 2012. Earlier versions of SPARK (those based on Ada83 through Ada2005), are *not* covered by this report.

# 2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 80000–2:2009, *Quantities and units* — *Part 2: Mathematical signs and symbols to be use in the natural sciences and technology*

ISO/IEC 2382–1:1993, *Information technology — Vocabulary — Part 1: Fundamental terms*

ISO/IEC TR 24772-1, *Information Technology – Programming Languages— Guidance to avoiding vulnerabilities in programming languages*

ISO/IEC 8652:2012, *Information Technology – Programming Languages—Ada*

# 3. Terms and definitions, symbols and conventions

## 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 2382, in TR 24772–1, in TR 24772–2, in 14882:2014 and the following apply. Other terms are defined where they appear in *italic* type.

See 2. Normative references, plus the references below. In the body of this annex, the following documents are referenced using the short abbreviation that introduces each document, optionally followed by a specific section number. For example “[SRM 5.2]” refers to section 5.2 of the SPARK Reference Manual.

[SRM] SPARK Reference Manual. AdaCore and Altran UK, Community 2020 Edition. Available from https[://](https://docs.adacore.com/live/wave/spark2014/html/spark2014_rm/index.html)docs.adacore.com/live/wave/spark2014/html/spark2014\_rm/index.html

# 4. Language concepts

The SPARK language is a subset of Ada, specifically designed for high-assurance systems. SPARK is designed to be amenable to various forms of static analysis that prevent or mitigate the vulnerabilities described in this TR.

Many terms and concepts applicable to Ada also apply to SPARK. See sections 3 and 4 of TR24772-2.

This section introduces concepts and terminology which are specific to SPARK and/or relate to the use of static analysis tools.

**Soundness**

This concept relates to the absence of false-negative results from a static analysis tool. A false negative is when a tool is posed the question “Does this program exhibit vulnerability X?” but incorrectly responds “no.” Such a tool is said to be *unsound* for vulnerability X. A sound tool effectively finds all the vulnerabilities of a particular class, whereas an unsound tool only finds some of them.

The provision of soundness in static analysis is problematic, mainly owing to the presence of unspecified and undefined features in programming languages. Claims of soundness made by tool vendors should be carefully evaluated to verify that they are reasonable for a particular language, compilers and target machines. Soundness claims are always underpinned by assumptions (for example, regarding the reliability of memory, the correctness of compiled code and so on) that should also be validated by users for their appropriateness.

Static analysis techniques can also be *sound in theory* – where the mathematical model for the language semantics and analysis techniques have been formally stated, proved, and reviewed – *but unsound in practice* owing to defects in the implementation of analysis tools. Again, users should seek evidence to support any soundness claim made by language designers and tool vendors. A language which is *unsound in theory* can never be sound in practice.

The single overriding design goal of SPARK is the provision of a static analysis framework which is sound in theory**,** and as sound in practice as is reasonably possible.

In the subsections below, we say that SPARK *prevents* a vulnerability if supported by a form of static analysis which is sound in theory. Otherwise, we say that SPARK *mitigates* a particular vulnerability.

**SPARK Analyzer**

We define a “SPARK Analyzer” to be a tool that implements the various forms of static analysis required by the SPARK language definition. Without a SPARK Analyzer, a program cannot reasonably be claimed to be SPARK at all, much in the same way as a compiler checks the static semantic rules of a standard programming language.

In SPARK, certain forms of analysis are said to be *mandatory*– they are required to be implemented and programs must pass these checks to be valid SPARK. Examples of mandatory analyses are the enforcement of the SPARK language subset, static semantic analysis (e.g. enhanced type checking) and information flow analysis.

Some analyses are said to be *optional* – a user may choose to enable these additional analyses at their discretion. The most notable example of an optional analysis in SPARK is the generation and proof of verification conditions for user-defined contracts. Sometimes default SPARK proofs will be assisted by adding contracts such as type invariants, assertions, loop invariants and subprogram preconditions and postconditions. Optional analyses may provide greater depth of analysis, protection from additional vulnerabilities, and functional proofs of correctness.

**Failure modes for static analysis**

Unlike a language compiler, a user can always choose not to run a static analysis tool. Therefore, there are two modes of failure that apply to all vulnerabilities:

1. The user fails to apply the appropriate static analysis tool to their code.
2. The user fails to review or mis-interprets the output of static analysis.

In the discussion of specific vulnerabilities below, this report assumes that a user has sufficient expertise to apply a SPARK Analyzer and interpret the results correctly.

**Unsafe Programming**

In recognition of the occasional need to step outside the type system or to perform “risky” operations, SPARK provides clearly identified language features to do so. Examples include

* Using the generic Unchecked\_Conversion for unsafe type-conversions, and
* Hiding a unit from the SPARK verification system, by NOT providing the aspect “SPARK\_Mode” on a unit or on its body. This means that the unit body is written in Ada, but not SPARK. For such units, the advice of TR24772-2 applies.

The **pragma** Suppress allows an implementation to omit certain run-time checks, although the SPARK analyzer will continue to generate verification conditions to show the correctness of the operation.

**Access Types in SPARK**

Over and above the mechanisms inherited from Ada, SPARK requires additional protections from vulnerabilities associated with the use of access types and values.

Several vulnerabilities listed in Section 6 concern access types, so this section contains an introductory description of how access types are managed in SPARK, in order to avoid repetition of that material in section 6.

In SPARK, only simple “access-to-variable” and “access-to-constant” types are permitted which allocate memory from a single, global storage pool. User-defined storage pools are not permitted. “General” access types which can reference global memory or memory on the stack are not permitted.

An access value in SPARK can either be an “Owner” or an “Observer” of the designated memory. At any point in the execution of a SPARK program, any allocated area of memory can only have a single access value that owns it. Assignment of access values transfers ownership, leaving the original value unable to access the designated memory for reading or writing.

An “Observing” access value has read-only permission on a constant object, but several such observers are allowed to exist.

Any one area of allocated memory has exactly one owner, one or more observers, but not both.

Additionally, the ownership of an access value can be “borrowed” by a locally declared access value, with the ownership automatically returning to the original value at the end of the borrowing value’s scope. This “borrowing” allows for subprograms that traverse or modify linked and recursive data structures before returning ownership to an enclosing scope or calling subprogram.

A SPARK Analyzer is required to keep track of the ownership relationship between access values and allocated memory, and to enforce legality rules which are designed to prevent defects and vulnerabilities. See section 6 for further information on how these rules apply to the vulnerabilities identified by TR24772-1.

Full details of the ownership and legality rules for access types and values are in [SRM 3.10].

# 5. General guidance for SPARK

In addition to the generic programming rules from TR 24772-1 clause 5.4, additional rules from this section apply specifically to the SPARK programming language. The recommendations of this section are restatements of recommendations from clause 6, but represent ones stated frequently, or that are considered as particularly noteworthy by the authors. Clause 6 of this document contains the full set of recommendations, as well as explanations of the problems that led to the recommendations made.

|  |  |  |
| --- | --- | --- |
| **Index** | **Avoidance Mechanism** | **Reference** |
| 1 | Do not use features explicitly identified as unsafe, such as Unchecked\_Conversion, unless absolutely necessary and then with extreme caution. Apply the ‘Valid attribute on the value of a scalar object that results from a call to Unchecked\_Conversion. | 6.2 [IHN], 6.3 [STR], 6.11 [HFC], 6.14 [XYK], 6.33 [DCM], 6.53 [SKL], 6.56 [EWF] |
| 2 | Do not suppress the checks provided by the language unless the absence of the errors checked against has been verified by a SPARK Analyzer | 6.6 [FLC], 6.9 [XYZ], 6.33 [DCM], 6.52 [MXB], 6.56 [EWF] |
| 3 | Use a SPARK Analyzer to detect erroneous or undefined behaviors and to preclude the raising of implicit exceptions. | 6.6 [FLC], 6.18 [WXQ], 6.19 [YZS], 6.20 [YOW], 6.24 [SAM], 6.25 [KOA], 6.52 [MXB], 6.56 [EWF] |
| 4 | Include exception handlers for every task, so that their unexpected termination can be handled and possibly communicated to the execution environment. | 6.36 [OYB], 6.60 [CGT], 6.62 [CGS] |
| 5 | Specify pre- and postconditions on subprograms. | 6.32 [CSJ], 6.34 [OTR], 6.46 [TRJ] |
| 6 | Use user-defined types in preference to predefined types, including range and precision as needed. | 6.2 [IHN], 6.4 [PLF], 6.6 [FLC], 6.57 [FAB] |
| 7 | Exploit the type and subtype system to express constraints (pre- and post-conditions) on the values of parameters. | 6.46 [TRJ] |
| 8 | Specify subtype predicates and type invariants. | 6.44 [BKK], 6.46 [TRJ] |
| 9 | Whenever possible, the 'First, 'Last, and 'Range attributes should be used for loop termination. If the 'Length attribute must be used, then extra care should be taken to ensure that the length expression considers the starting index value for the array. | 6.29 [TEX], 6.30 [XZH] |
| 10 | Use SPARK's support for whole-array operations, such as for assignment and comparison, plus aggregates for whole-array initialization, to reduce the use of indexing. | 6.9 [XYZ], 6.10 [XYW], 6.30 [XZH] |
| 11 | For **case** statements and aggregates, do not use the **others** choice. | 6.5 [CCB], 6.27 [CLL] |
| 12 | Protect all data shared between tasks within a protected object or a suspension object, or mark the data Atomic. | 6.3 [STR], 6.56 [EWF], 6.61 [CGX] |

#### Table 5-1 Most relevant avoidance mechanisms to be used to prevent vulnerabilities

These vulnerability guidelines may be categorized into several functional groups.

* Items 1, 2, 3, and 4 are applicable to Exceptional and Erroneous Behaviours.
* Mitigation methods associated with Types, Subtypes, and Contracts include Items 5, 6, 7, and 8.
* Those techniques appropriate for Statements and Operations consist of Items 9, 10, and 11
* Finally, Items 12 is pertinent to Concurrency in applications.

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# 6. Specific Guidance for SPARK Vulnerabilities

## 6.1 General

This clause contains specific advice for SPARK about the possible presence of vulnerabilities as described in TR 24772-1 and provides specific guidance on how to avoid them in SPARK code. This section mirrors TR 24772-1 clause 6 in that the vulnerability “Type System [IHN]” is found in 6.2 of TR 24772–1, and SPARK specific guidance is found in clause 6.2 and subclauses in this TR.

## 6.2 Type System [IHN]

### 6.2.1 Applicability to language

SPARK’s type system is a simplification of Ada’s type system. Both explicit and implicit conversions are permitted in SPARK, as is instantiation and use of Unchecked\_Conversion [SB 1.3]. Developers can choose to use the underlying types such as full integers, floating point numbers, characters and strings instead of much more tightly specified data types and can use the less safe conversions. Even when using these less safe constructs, users can use the SPARK language precondition, postcondition, invariance mechanisms and the static provers to eliminate almost all of the vulnerabilities discussed in TR 24772-1 clause 6.2.

SPARK mitigates the vulnernabilities described in TR 24772-1 clause 6.2 through the use of its very strong typing system, as well as a strong contract model useful for developing formal proofs of correctness, and a strong proof tool to verification the type safety of the complete program.

 A design goal of SPARK is the provision of *static type safety,* meaning that programs can be shown to be free from all run-time type failures using entirely static analysis. If this optional analysis is achieved, a SPARK program should never raise an exception at run-time.

The SPARK analyzer generates verification conditions that are discharged by the verification tools. Failure to execute the verification tools does not prevent the compiler and linker from generating executables from legal programs, so developers are responsible for ensuring that executables are only produced for code that has also successfully completed data flow analysis and verification.

### 6.2.2 Guidance to language users

* Follow the guidance of TR 24772-1 clause 6.2.2.
* Use the SPARK analysis and proof tools to verify the absence of runtime errors.
* Create or use tooling that prevent the compilation and linking of SPARK executables until the data flow and verification has completed successfully.

## 6.3 Bit Representations [STR]

### 6.3.1 Applicability to language

SPARK mitigates the vulnerability as described in ISO/IEC TR 24772-1 clause 6.3 by providing a semantics which is independent of the underlying representation chosen by a compiler for a particular target machine. Representation clauses are permitted, but these do not affect the semantics as seen by a static analysis tool [SB 1.3].

### 6.3.2 Guidance to language users

* Explicitly document any reliance on bit ordering or usage using SPARK’s representation clauses.
* Where bit ordering can change either between the development host and the target, or between interfaced targets, provide compatible types with derived types that document each system’s mapping and explicitly convert between them. For example:

type Reversible\_Integer is new integer;

type Big\_E\_Integer is new Reversible\_Integer;

for Big\_E\_Integer’Bit\_Order use High\_Order\_First;

type Little\_E\_Integer is new Reversible\_Integer;

for Little\_E\_Integer’Bit\_Order use Low\_Order\_First;

BI : Big\_E\_Integer := <Some\_Value>;

LI : Little\_E\_Integer := Little\_E\_Integer(BI);

* Localize and document the code associated with explicit manipulation of bits and bit fields.
* Use SPARK’s static analysis tools and proof tools to verify the correct usage and conversion between types.

## 6.4 Floating-point Arithmetic [PLF]

### 6.4.1 Applicability to language

The vulnerability as described in ISO/IEC TR 24772-1 clause 6.4 aplies to the SPARK programming language. SPARK specifies adherence to the IEEE Floating Point Standards (ISO/IEC/IEEE-60559-2011, IEEE-854-1987).

###

### 6.4.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.4.5 of TR 24772-1.
* Rather than using predefined types, such as Float and Long\_Float, whose precision may vary according to the target system, declare floating-point types that specify the required precision (for example, **digits** 10). Additionally, specifying ranges of a floating point type enables constraint checks which prevents the propagation of infinities and NaNs.
* Avoid comparing floating-point values for equality. Instead, use comparisons that account for the approximate results of computations. Consult a numeric analyst when appropriate.
* Make use of static arithmetic expressions and static constant declarations when possible, since static expressions in SPARK are computed at compile time with exact precision.
* Use mathematical models and SPARK’s proof tools to verify the correctness of mathematical calculations in floating point. This may necessitate recasting algorithms to make them amenable to such proofs.
* Avoid direct manipulation of bit fields of floating-point values, since such operations are generally target-specific and error-prone. Instead, make use of the predefined floating-point attributes (such as 'Exponent).

## 6.5 Enumerator Issues[CCB]

### 6.5.1 Applicability to language

The vulnerability as described in ISO/IEC TR 24772-1 clause 6.5 applies (is mitigated?) to the SPARK programming language. Enumeration representation specification may be used to specify non-default representations of an enumeration type, for example when interfacing with external systems. All of the values in the enumeration type must be defined in the enumeration representation specification. The numeric values of the representation must preserve the original order. For example:

**type** IO\_Types **is** (Null\_Op, Open, Close, Read, Write, Sync);

**for** IO\_Types **use** (Null\_Op => 0, Open => 1, Close => 2,

Read => 4, Write => 8, Sync => 16);

An array may be indexed by such a type. SPARK does not prescribe the implementation model for arrays indexed by an enumeration type with non-contiguous values. Two options exist: Either the array is represented “with holes” and indexed by the values of the enumeration type, or the array is represented contiguously and indexed by the position of the enumeration value rather than the value itself. In the former case, the vulnerability described in TR 24772-1 subclause 6.5 exists only if unsafe programming is applied to access the array or its components outside the protection of the type system. Within the type system, the semantics are well defined and safe. The vulnerability of unexpected but well-defined program behaviour upon extending an enumeration type exists in SPARK. In particular, subranges or **others** choices in aggregates and case statements are susceptible to unintentionally capturing newly added enumeration values.

### 6.5.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.5.5 of TR 24772-1. In particular, use SPARK’s analysis and proof tools to diagnose inappropriate use of enumeration types or values.
* For **case** statements and aggregates, do not use the **others** choice.
* For **case** statements and aggregates, mistrust subranges as choices after enumeration literals have been added anywhere but the beginning or the end of the enumeration type definition

## 6.6 Conversion Errors [FLC]

### 6.6.1 Applicability to language

SPARK is designed to be amenable to static verification of the absence of predefined exceptions, and in particular all cases covered by this vulnerability [SB 11]. All numeric conversions (both explicit and implicit) give rise to verification conditions that are discharged using SPARK’s automated theorem-prover. Except for the unsafe generic function Unchecked\_Conversion, conversion between non-numeric types can only happen

* if one type is a derivation of the other,
* if both types are subtypes of a common parent, or
* if all components of the source and target types are either numeric types or related types and conversion is done component-by-component.

In each of these cases, SPARK will generate the respective verification conditions to be discharged by the toolchain or by the user.

If Unchecked\_Conversion is used, SPARK will assume that the conversion is correct and will generate TRUE conditions for the conversion and for ‘Valid applied to the conversion. Unchecked conversions are highly dependent on the layout of the source and targets of the conversion as well as values contained and do not fit the SPARK model analysis. Therefore, static correctness of unchecked conversions must be verified by other means, such as by ???

### 6.6.2 Guidance to language users

* Use SPARK’s analysis and proof tools to statically verify the absence of errors in the use of conversions.
* Create contract models and SPARK proof tools to verify the correct functional use of conversions.
* If Unchecked\_Conversion is used, apply ‘Valid to the result of the conversion before attempting to use the result with both a TRUE path and a FALSE path, and then use assertions to verify that the failure path operates correctly.

Note: SPARK assumes that the result is valid and will ignore the false path in its generation of automatic proofs. Use other analysis methods to verify the correctness of the conversion(s) or create extremely simple code for the FALSE path that sets an error condition and exits.

## 6.7 String Termination [CJM]

The vulnerability as described in ISO/IEC TR 24772-1 clause 6.7 is not applicable to SPARK as strings are not delimited by a termination character. SPARK programs that interface to languages that use null-terminated strings and manipulate such strings directly should apply the vulnerability mitigations recommended for that language.

## 6.8 Buffer Boundary Violation [HCB]

With the exception of unsafe programming (see 4 Language concepts), the vulnerability as described in ISO/IEC TR 24772-1 clause 6. is not applicable to SPARK (see 6.9 Unchecked Array Indexing [XYZ] and 6.10 Unchecked Array Copying [XYW]).

## 6.9 Unchecked Array Indexing [XYZ]

### 6.9.1 Applicability to language

The vulnerability as described in ISO/IEC TR 24772-1 clause 6.9 is mitigated by SPARK static analysis tools, which verify the absence of boundary violations through techniques such as theorem proving or abstract interpretation [SB 11].

SPARK programs that have been subject to this level of analysis can be compiled with run-time checks suppressed, supported by a body of evidence that such checks could never fail, and thus removing the possibility of erroneous execution.

### 6.9.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.9.5 of TR 24772-1.
* Use SPARK’s support for whole-array operations, such as for assignment and comparison, plus aggregates for whole-array initialization, to reduce the use of indexing.
* Use SPARK’s verification tools and contracts to verify the functional correctness of the code.

## 6.10 Unchecked Array Copying [XYW]

With the exception of unsafe programming, the vulnerability as described in ISO/IEC TR 24772-1 clause 6.10 does not apply to SPARK. Array assignments in SPARK are only permitted between objects that have statically matching bounds. Hence all violations are detected by the SPARK analysis tools. SPARK programs that have been subject to this level of analysis can be compiled with run-time checks suppressed, supported by a body of evidence that such checks could never fail, and thus removing the possibility of erroneous execution.

## 6.11 Pointer Type Conversions [HFC]

With the exception of unsafe programming techniques, this vulnerability does not apply to SPARK, because SPARK forbids type conversion of access values.

## 6.12 Pointer Arithmetic [RVG]

With the exception of unsafe programming techniques, this vulnerability does not apply to SPARK, because SPARK does not allow pointer arithmetic.

## 6.13 NULL Pointer Dereference [XYH]

### 6.13.1 Applicability to the language

A SPARK Analyzer is required to prevent this vulnerability through static analysis to ensure that a null value can never be dereferenced. This is considered a mandatory analysis in SPARK.

### 6.13.2 Guidance to language users

* Use a SPARK Analyzer to prove that a null value can never be dereferenced.
* Use non-null access types where possible.
* For code written in Ada (but not in SPARK), use Ada’s runtime checks and exception handling facilities to mitigate this vulnerability.

## 6.14 Dangling Reference to Heap [XYK]

With the exception of unsafe programming techniques, this vulnerability does not apply to SPARK, because a SPARK Analyzer is required to implement analyses that prevent this vulnerability. In particular:

* SPARK’s ownership model for access values, and transfer of that ownership on assignments, mean that dangling access values cannot be used or returned from a subprogram.
* The unique, single owner of an allocated memory area must be deallocated before going out of scope. Failure to do so will be reported as a memory leak.

## 6.15 Arithmetic Wrap-around Error [FIF]

### 6.15.1 Applicability to language

With the exception of unsafe programming (see [4 Language concepts](#_4_Language_concepts)), the vulnerability as described in ISO/IEC TR 24772-1 clause 6.15 is not applicable to SPARK as wrap-around arithmetic is limited to modular types. Arithmetic operations on such types use modulo arithmetic, and thus no such operation can create an invalid value of the type.

For non-modular arithmetic, the predefined exception Constraint\_Error is raised whenever a wrap-around occurs but implementations are allowed to refrain from doing so when a correct final value is obtained.

### 6.15.2 Guidance to language users

* Use the SPARK static analysis tools to show that exceptions cannot be raised by values exceeding their specified limits.
* Develop contracts and use SPARK analysis and prover to verify that the program meets the specified contracts.

## 6.16 Using Shift Operations for Multiplication and Division [PIK]

With the exception of unsafe programming (see [4 Language concepts](#_4_Language_concepts)), the vulnerability as described in ISO/IEC TR 24772-1 clause 6.16 does not apply to SPARK as shift operations are limited to the modular types declared in the standard package Interfaces, which are not signed entities.

## 6.17 Choice of Clear Names [NAI]

### 6.17.1 Applicability to language

There are two possible issues: the use of the identical name for different purposes (overloading) and the use of similar names for different purposes.

This vulnerability does not address overloading, which is covered in 6.20 *Identifier Name Reuse [YOW]*.

The risk of confusion by the use of similar names might occur through:

* Mixed casing. This is not an issue since SPARK treats upper-case and lower-case letters in names as identical. Confusion for the programmer may arise through an attempt to use Item and ITEM as distinct identifiers with different meanings, but the language system and strong type checking will verify appropriate and correct usage.
* Underscores and periods. SPARK permits single underscores in identifiers and they are significant. Thus, BigDog and Big\_Dog are different identifiers and the language system and strong type checking will ensure appropriate and correct usage. Multiple underscores (which might be confused with a single underscore) leading underscores and trailing underscores are forbidden.
* Periods in SPARK denote substructures and hence are meaningful.
* Singular/plural forms. SPARK permits the use of identifiers which differ solely in this manner such as Item and Items. The programmer may create plural and singular forms to identify single items or collections, and the language system and strong type checking will ensure appropriate and correct usage.
* International character sets. SPARK strictly conforms to the appropriate International Standard for character sets.
* Identifier length. All characters in an identifier in SPARK are significant and an identifier cannot be split over the end of a line. The only restriction on the length of an identifier is that enforced by the line length and this is guaranteed by the language standard to be no less than 200.

SPARK permits the use of names such as X, XX, and XXX (which might all be declared as integers) and a programmer could easily, by mistake, write XX where X (or XXX) was intended. SPARK does not attempt to catch such errors unless the developer:

1. Declares such similar names to have different types in which case the type system will guarantee safe usage; or
2. Creates contracts that define the functional behaviour of the code module and uses the analysis and proof tools to verify correct usage.

### 6.17.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.17.5 of TR 24772-1.
* Avoid the use of similar names to denote different objects of the same type.
* Adopt a project convention for dealing with similar names.

## 6.18 Dead Store [WXQ]

SPARK prevents this vulnerability through automatic static information flow analysis, which detects dead stores. Additionally, SPARK requires variables that are used for output to the environment, where multiple writes to a variable without intervening reads could be confused as dead store, to be specifically identified. In this case, the information flow analysis for such variables is modified since it is known that consecutive writes to such variables might not constitute a dead store.

## 6.19 Unused Variable [YZS]

### 6.19.1 Applicability to language

SPARK is designed to permit sound static analysis of the following cases for information flow analysis:

* Variables which are declared but not used at all.
* Variables which are assigned to, but the resulting value is not used in any way that affects an output of the enclosing subprogram. This is called an “ineffective assignment” in SPARK

### 6.19.2 Guidance to language users

* Mark variables that are written by a subprogram but read elsewhere with the aspect Volatile or Volatile\_Components.
* Follow the guidance of SPARK flow analysis with respect to unused variables.

## 6.20 Identifier Name Reuse [YOW]

### 6.20.1 Applicability to language

SPARK permits local scope, and names within nested scopes, including declarative items in **for** loops. Local names can hide identical names declared in an outer scope. As such it is susceptible to the vulnerability described in TR 24772-1 clause 6.20 [YOW]. For subprograms and other overloaded entities, the problem is reduced by the fact that hiding also takes the signatures of the entities into account. Entities with different signatures, therefore, do not hide each other.

Name collisions with keywords cannot happen in SPARK since keywords are reserved.

The mechanism of failure identified in subclause 6.20.3 of TR 24772-1 regarding the declaration of non-unique identifiers in the same scope cannot occur in SPARK because all characters in an identifier are significant.

### 6.20.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.20.5 of TR 24772-1.
* Use *expanded names* whenever confusion may arise*.*
* Use compiler diagnostics to detect declarations in inner scopes that hide declarations in outer scopes

## 6.21 Namespace Issues [BJL]

The vulnerability as described in ISO/IEC TR 24772-1 clause 6.21. is not applicable to SPARK, since the language does not attempt to disambiguate conflicting names imported from different packages. Use of a name with conflicting imported declarations causes a compile time error. The programmer can disambiguate the name usage by using a expanded name that identifies the exporting package.

## 6.22 Initialization of Variables [LAV]

SPARK prevents this vulnerability through mandatory static information flow analysis.

### *Question – does spark flow analysis failures halt the compilation process?*

## 6.23 Operator Precedence and Associativity [JCW]

### 6.23.1 Applicability to language

Since this vulnerability is about "incorrect beliefs" of programmers, there is no way to establish a limit to how far incorrect beliefs can go. However, SPARK is less susceptible to that vulnerability than many other languages, since

* There are six levels of precedence, and associativity is close to common expectations. For example, an expression like A = B or C = D will be parsed as expected, as (A = B) or (C = D).
* Mixed logical operators are not allowed without parentheses, for example, "A or B or C" is valid, as well as "A and B and C", but "A and B or C" is not; the user must write "(A and B) or C" or "A and (B or C)".
* Assignment is not an operator.

### 6.23.2 Guidance to language users

* Follow the guidance provided in TR 24772-1 clause 6.23.5
* Use parentheses whenever arithmetic operators, logical operators, mixed logical operators such as “and” and “and then” and shift operators are mixed in an expression.
* Create contracts that specify the expressions in mathematical terms and verify using the SPARK static analysis tools.

## 6.24 Side-effects and Order of Evaluation of Operands [SAM]

This vulnerability is prevented by SPARK since it provides a number of mitigations to prevent erroneous behaviour from side effects or order of evaluation:

* There are no operators that have direct side effects on their operands using the language-defined operations, especially not the increment and decrement operation.
* SPARK does not permit multiple assignments in a single expression or statement.
* SPARK functions are side-effect free.

## 6.25 Likely Incorrect Expression [KOA]

### 6.25.1 Applicability to language

An instance of this vulnerability consists of two syntactically similar constructs such that the inadvertent substitution of one for the other may result in a program which is accepted by the compiler but does not reflect the intent of the author.

The examples given in subclause 6.25 of TR 24772-1 are not problems in SPARK because of the strong typing and because an assignment is not an expression in SPARK.

In SPARK, a type-conversion and a qualified expression are syntactically similar, differing only in the presence or absence of a single character:

 Type\_Name (Expression) -- a type-conversion

vs.

 Type\_Name'(Expression) -- a qualified expression

Typically, the inadvertent substitution of one for the other results in either a semantically incorrect program which is rejected by the compiler or in a program which behaves in the same way as if the intended construct had been written. In the case of a constrained array subtype, the two constructs differ in their treatment of sliding (conversion of an array value with bounds 100 .. 103 to a subtype with bounds 200 .. 203 will succeed; qualification will fail a run-time check).

Potential task-based difficulties in Ada are avoided in SPARK because SPARK only supports the Ravenscar Tasking Profile which removes order of access ambiguities.

Problems arising from a failure to use short-circuit Boolean forms are less frequent in SPARK programs because access types, which are the largest driver of the need for short-circuit Boolean forms, are forbidden.

### 6.25.2 Guidance to language users

* If a possible need for short-circuit Booleans is identified, construct contracts that fully express the logic required, for example

AI – Steve – construct a better example.

if I < N and completed(X[I}) then . . . -- should have been “and then”

 -- May be necessary if N is not static

 assert (i<N and completed[i]); -- incorrect since call to completed

 -- for i>=N legal

 assert (completed(X[i] => I<N))-- correct assertion

end if;

## 6.26 Dead and Deactivated Code [XYQ]

### 6.26.1 Applicability to language

SPARK provides static analysis to detect dead and deactivated code.

EXPAND.

### 6.26.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.26.5 of TR 24772-1.
* Use implementation-specific mechanisms, if provided, to support the elimination of dead code. In some cases, use pragmas such as Restrictions, Suppress, or Discard\_Names to inform the compiler that some code whose generation would normally be required for certain constructs would be dead because of properties of the overall system, and that therefore the code need not be generated. For example:

**package** Pkg **is**

**type** Enum **is** (Aaa, Bbb, Ccc);

**pragma** Discard\_Names( Enum );

**end** Pkg;

If Pkg.Enum'Image and related attributes (e.g., Value, Wide\_Image) of the type Enum are never used, and if the implementation normally builds a table of the enumeration literals, then the **pragma** allows the elimination of the table.

## 6.27 Switch Statements and Static Analysis [CLL]

### 6.27.1 Applicability to language

With the exception of unsafe programming (see [4 Language concepts](#_4_Language_concepts)) and the use of default cases, this vulnerability is mitigated by SPARK, which ensures at compile time that a case statement provides exactly one alternative for each value of the expression's subtype.

The **others** clause may be used as the last choice of a case statement to capture any remaining values of the case expression type that are not covered by the preceding case choices. If the value of the expression is outside of the range of this subtype (e.g., due to an uninitialized variable), then the resulting behaviour is well-defined (Constraint\_Error is raised). Control does not flow from one alternative to the next. Upon reaching the end of an alternative, control is transferred to the end of the **case** statement.

The remaining vulnerability is that unexpected values can be captured by the **others** clause or a subrange as case choice. The introduction of additional values may have been intended to have their own case alternatives but instead fall into the others category. Another example is the inclusion of additional values internal to a range (usually done by adding an enumeration value to an enumeration type but not at the first or last of that type), and some case statements choices hide the addition in a range of choices.

### 6.27.2 Guidance to language users

* For **case** statements and aggregates, avoid the use of the **others** choice.
* For **case** statements and aggregates, mistrust subranges as choices after enumeration literals have been added anywhere but the beginning or the end of the enumeration type definition.15F[[1]](#footnote-1)
* When adding enumeration values to an enumeration type, review all of the places where if statements or case choices are used to ensure that the position of the added value does not create logic errors.

## 6.28 Demarcation of Control Flow [EOJ]

This vulnerability does not apply to SPARK, since SPARK enforces a clear demarcation of all branching control flows, if statements, case statements, loops, and blocks.

## 6.29 Loop Control Variables [TEX]

### 6.29.1 Applicability to language

With the exception of unsafe programming (see [4 Language concepts](#_4_Language_concepts)), this vulnerability is not applicable to SPARK, which defines a **for … loop** where the number of iterations is controlled by a loop control variable (called a loop parameter). This value has a constant view and cannot be updated within the sequence of statements of the body of the loop.

For “while” loops and “repeat … until” loops, loop control logic is defined by the programmer who bears complete responsibility for correctly updating loop control conditions on every path within the loop body. SPARK assertions, loop invrince expressions, and static analysis can be used to prove that only correct and safe operations happen in the loop construct.

EXAMPLE:

### 6.27.2 Guidance to language users

???

## 6.30 Off-by-one Error [XZH]

### 6.30.1 Applicability to language

The vulnerability as documented in ISO/IEC TR 24772-1 applies to SPARK since SPARK permits the use of cardinal numbers for indexing arrays and loops. SPARK does, however, provide alternative syntax which, if used, dramatically reduce the occurrence of such errors.

#### Confusion between the need for < and <= or > and >= in a test.

A SPARK **for loop** does not require the programmer to specify a conditional test for loop termination. Instead, the starting and ending value of the loop can be specified (in terms of using a subrange expression to define the object being iterated over or using ‘First and ‘Last to eliminate this source of off-by-one errors. SPARK also provides special **for loop** structures that iterate through an entire array or container. These avoid the need to specify any bounds for the iteration.

A **while loop,** however, lets the programmer specify the loop termination expression, which could be susceptible to an off-by-one error. Any off-by-one error that gives rise to the potential for a buffer-overflow, range violation, or any other construct that could give rise to a predefined exception, will be detected by static analysis in SPARK

#### Confusion as to the index range of an algorithm.

Although there are language defined attributes to symbolically reference the start and end values for a loop iteration, the language does allow the use of explicit values and loop termination tests. Off-by-one errors can result in these circumstances.

Care should be taken when using the 'Length attribute in the loop termination expression. The expression should generally be relative to the 'First value.

SPARK’s strong typing eliminates the potential for buffer overflow associated with this vulnerability. In addition, SPARK’s static analysis will detect erroneous uses of loops that do not properly cover a range.

If the error is not statically caught at compile time, then a run-time check generates an exception if an attempt is made to access an element outside the bounds of an array.

SPARK does not use sentinel values to terminate arrays (such as strings). Therefore, the vulnerability documented in TR 24772-1 clause 6.30 related to space required for implicit sentinel values does not apply to SPARK.

### 6.30.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.30.5 of TR 24772-1.
* Whenever possible, use a for loop instead of a **while loop**.
* Whenever possible, use the form of iteration that takes the name of the array or container and nothing more.
* When indices are necessary, use the 'first, 'last, and 'range attributes for loop termination, e.g. **for** I **in** My\_Array'**range** **loop**….
* If the 'length attribute must be used, ensure that the index computation considers the starting index value for the array.
* Use the SPARK analysis and proof tools on all code as off-by-one errors often manifest as proof failures. ***This needs an example****.*

## 6.31 Structured Programming [EWD]

### 6.31.1 Applicability to language

SPARK programs can exhibit many of the vulnerabilities noted in Subclause 6.31 of TR 24772-1: leaving a **loop** at an arbitrary point, and multiple exit points from subprograms. SPARK forbids non-local jumps or to have multiple entries to subprograms.

SPARK provides mitigations for these issues through the use of loop invariance and loop termination contracts.

### 6.31.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.31.5 of TR 24772-1.
* Create SPARK contracts to verify that code written conforms to the its functional specification.

**PROVIDE EXAMPLES OF LOOP PROOFS**

 **- see** <http://docs.adacore.com/spark2014-docs/html/ug/en/tutorial.html>

 <http://docs.adacore.com/spark2014-docs/html/ug/gnatprove_by_example/loop.html>

## 6.32 Passing Parameters and Return Values [CSJ]

This vulnerability is not applicable to SPARK since SPARK functions cannot have side effects, and since procedure and entry parameters must always be declared as **in**, **out**, or **in out** and access types are forbidden, eliminating the possible use of indirection in parameters.

## 6.33 Dangling References to Stack Frames [DCM]

Access types (pointers) are forbidden in SPARK, hence this vulnerability does not apply to SPARK.

*Rework – not true anymore.*

## 6.34 Subprogram Signature Mismatch [OTR]

### 6.34.1 Applicability to language

Except for the case of calls to/from subprograms where the other side is a foreign language, or the case where a SPARK generic subprogram or subprogram of a generic package contains formal parameters with default expressions, this vulnerability does not apply.

The first case, interlanguage calls, is addressed in 6.46.

In the second case, actual parameters are constructed for the missing formal parameters via the default expression, hence all subprogram expressions will exist and there will be no stack corruption.

At compilation time, the parameter association is checked to ensure that the type of each actual parameter matches the type of the corresponding formal parameter. In addition, the formal parameter specification may include default expressions for a parameter. Hence, a procedure call may be constructed with some actual parameters missing. In this case, if there is a default expression for the missing parameter, then the call will be compiled without any errors. If no default expression exists for missing parameters, then a compilation error is generated.

### 6.34.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.34.5 of TR 24772-1.

## 6.35 Recursion [GDL]

### 6.35.1 Applicability to language

SPARK permits recursion. The exception Storage\_Error is raised when the recurring execution results in insufficient storage. This will result in program termination unless an exception handler is placed outside the SPARK portion of the program.

### 6.35.2 Guidance to language users

* Apply the guidance described in TR 24772-1 clause 6.35.5.
* Use contracts and assertions in conjunction with the SPARK proof tools to guarantee that each recursive call is a reduction from the previous call, and to verify that all recursive calls are bounded.
* Consider applying the restriction No\_Recursion or No\_Reentrancy to eliminate this vulnerability.

## 6.36 Ignored Error Status and Unhandled Exceptions [OYB]

### 6.36.1 Applicability to language

SPARK permits the declaration of exceptions, and the execution of the **raise** statement. SPARK does not permit exception handlers, which means that all SPARK programs must be verified to be free of all predefined and user defined exceptions. Note however, that exception handlers can be declared in parts of the program explicitly excluded from the SPARK analyzer, for example in the main subprogram to handle exceptions generated by hardware faults and to handle program closeout or restart.

The ‘Valid attribute can be used to check the result of Unchecked\_Conversion and to handle resulting error conditions by explicit code such as if-then-else. The SPARK verification tools, however, will assume that ‘Valid is always true.

### 6.36.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.36.5 of TR 24772-1.
* Use the SPARK flow static analysis to verify the absence of runtime errors.
* Create and statically verify contracts to verify that error situations that can lead to exceptions do not occur.
* Use the result of the 'Valid attribute to check for the validity of values delivered to an SPARK program from an external device or from Unchecked\_Conversion prior to use and explicitly handle both TRUE and FALSE cases.
* Consider placing a top-level exception handler in the main program (external to SPARK) and in each task so that notification of failure can be given.

## 6.37 Type-breaking Reinterpretation of Data [AMV]

### 6.37.1 Applicability to language

SPARK permits the instantiation and use of Unchecked\_Conversion as in Ada. The result of a call to Unchecked\_Conversion cannot be assumed to be valid. The ‘valid construct can be used inside an if statement with verified paths to handle the case of valid conversion or of invalid conversion. In this case, the SPARK proof tools assume that the conversion is always valid and will not generate proof conditions for code in the invalid case path.

Language rules prevent the changing of a discriminate of a variable unless the whole object is written, so reinterpreting an objects components is not possible. Record extensions require that the extension components be written or read by subprograms with visibility to the extensions, hence those elements will be correctly interpreted.

### 6.37.2 Guidance to language users

* Follow the guidelines of TR 24772-1 clause 6.38.5.
* Consider applying the restrictions No\_Use\_Of\_Pragma(Unchecked\_Union),
No\_Use\_Of\_Aspect(Unchecked\_Union), and No\_Unchecked\_Conversion to ensure this vulnerability cannot arise.
* Use ‘Valid on the result of unavoidable unchecked programming, provide alternatives for successful and unsuccessful results, and place explicit assertions inside the else (‘Valid = FALSE) to force the analysis tool to generate static checks.

## 6.38 Deep vs. Shallow Copying [YAN]

This vulnerability does not apply to SPARK since the use of access types is not permitted and owned access types cannot be copied.

## 6.39 Memory Leak and Heap Fragmentation [XYL]

This vulnerability does not apply to SPARK since the use of access types is forbidden.

## 6.40 Templates and Generics [SYM]

With the exception of unsafe programming (see [4 Language concepts](#_4_Language_concepts)), this vulnerability is not applicable to SPARK since its generics model is based on imposing a contract on the structure and operations of the types that can be used for instantiation. Also, explicit instantiation of the generic is required for each particular type and SPARK generates static checks for each instantiation of the generic.

Therefore, the compiler is able to check the generic body for programming errors, independently of actual instantiations. At each actual instantiation, the compiler will also check that the instantiated type meets all the requirements of the generic contract.

SPARK also does not allow for ‘special case’ generics for a particular type, therefore behaviour is consistent for all instantiations.

## 6.41 Inheritance [RIP]

### 6.41.1 Applicability to language

The vulnerability documented in TR 24772-1 subclause 6.41 applies to SPARK.

SPARK permits a restricted form of multiple inheritance, where only one of the multiple ancestors (the parent) may implement operations. All other ancestors (interfaces) can only specify the operations’ signature, and whether the operation must be overridden, or can simply do nothing if never explicitly defined. Therefore, SPARK does not suffer from multiple-inheritance related vulnerabilities.

SPARK has no preference rules to resolve ambiguities of calls on primitive operations of tagged types and thus reports the ambiguity for the programmer to disambiguate. Hence the related vulnerability documented in TR 24772-1 subclause 6.41 does not apply.

## 6.41.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.41.5 of TR 24772-1.
* Use the overriding indicators on potentially inherited subprograms to ensure that the intended set of operations are overridden, thus preventing the accidental redefinition or failure to redefine an operation of the parent.
* Specify Pre’Class and Post’Class aspects when a primitive operation is initially defined, to indicate the properties of inputs that any overridings must accept, and the properties of outputs that any overridings must produce.

## 6.42 Violations of the Liskov Substitution Principle or the Contract Model [BLP]

This vulnerability does not apply to SPARK, since SPARK generates static checks that the Liskov Substitution Principle is followed across the hierarchy and discharged using the SPARK prover.

INCONSISTENT ARGUMENT?

## 6.43 Redispatching [PPH]

This vulnerability does not apply to SPARK, since SPARK generates static checks that redispatching is correct and appropriate, and the static checks are discharged using the SPARK prover.

INCONSISTENT ARGUMENT?

YANNICK – PLEASE DISCUSS WITH ERHARD.

## 6.44 Polymorphic variables [BKK]

Except for unsafe programming (see [4 Language concepts](#_4_Language_concepts)), the vulnerabilities related to unsafe casts do not apply to SPARK. For downcasts, SPARK generates static checks that each downcasts is correct and appropriate, and the static checks are discharged using the SPARK prover.

INCONSISTENT ARGUMENT?

WHAT ABOUT THE VULNERABILITIES OF UPCASTS? ARE YOU ENSURING THAT THE PARENT OPERATIONS ARE ALWAYS CALLED?

## 6.45 Extra Intrinsics [LRM]

The vulnerability does not apply to SPARK, because all subprograms, whether intrinsic or not, belong to the same name space. This means that all subprograms must be explicitly declared, and the same name resolution rules apply to all of them, whether they are predefined or user-defined. If two or more subprograms with the same name and signature are visible (that is to say nameable) at the same place in a program, then a call using that name will be rejected as ambiguous by the compiler, and the programmer must specify (for example, by means of an expanded name) which subprogram is meant.

## 6.46 Argument Passing to Library Functions [TRJ]

### Applicability to language

The general vulnerability that parameters might have values that are precluded by preconditions of the called routine applies to SPARK.

To the extent that the preclusion of values can be expressed as part of the type system of SPARK, the preconditions are checked by the compiler or the analyzer statically or can be checked by dynamic checks and thus are no longer vulnerabilities. For example, any range constraint on values of a parameter can be expressed in SPARK by means of type or subtype declarations. Type violations are detected at compile time; subtype violations cause run-time exceptions. For that situation, preconditions, postconditions, type invariants, and subtype predicates can be specified explicitly to express more complex restrictions to be observed by callers. These can be recognized by other static analysis tools as part of program verification.

### 6.46.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.46.5 of TR 24772-1.
* Exploit the type and subtype system of SPARK to express restrictions on the values of parameters and results.
* Specify explicit preconditions and postconditions for subprograms wherever practical.
* Specify subtype predicates and type invariants for subtypes and private types when appropriate.
* Execute the SPARK analysis tools and use successful completion as a gate for completing program build.

## 6.47 Inter-language Calling [DJS]

### 6.47.1 Applicability to language

The vulnerability applies to SPARK, however SPARK provides mechanisms to interface with common languages, such as C, C++, Fortran and COBOL, so that vulnerabilities associated with interfacing with these languages can be mitigated.

### 6.47.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.47.5 of TR 24772-1.
* Use the inter-language methods and syntax specified by SPARK and ISO/IEC 8652 [15] when the routines to be called are written in languages that ISO/IEC 8652 [15] specifies an interface with.
* Use interfaces to the C programming language where the other language system(s) are not covered by ISO/IEC 8652, but the other language systems have interfacing to C.
* Make explicit checks on all return values from foreign system code artifacts, for example by using the 'Valid attribute or by performing explicit tests to ensure that values returned by inter-language calls conform to the expected representation and semantics of the SPARK application.

Note the caveat on how SPARK handles ‘Valid, see 6.6 Conversions.

## Dynamically-linked Code and Self-modifying Code [NYY]

With the exception of unsafe programming (see 4 Language concepts), this vulnerability is not applicable to SPARK, which supports neither dynamic linking nor self-modifying code. The latter is possible only by exploiting other vulnerabilities of the language in the most malicious ways and even then, it is still difficult to achieve.

## 6.49 Library Signature [NSQ]

### 6.49.1 Applicability to language

The vulnerability are described in ISO/IEC TR 24772-1 exists in SPARK, which provides mechanisms to explicitly interface to modules written in other languages. **Pragma**s Import, Export and Convention permit the name of the external unit and the interfacing convention to be specified.

### Even with the use of pragma Import, pragma Export and pragma Convention the vulnerabilities stated in subclause 6.49 of TR 24772-1 are possible. Names and number of parameters change under maintenance; calling conventions change as compilers are updated or replaced, and languages for which SPARK does not specify a calling convention may be used.

### 6.49.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.49.5 of TR 24772-1.

## 6.50 Unanticipated Exceptions from Library Routines [HJW]

### 6.50.1 Applicability to language

SPARK permits the declaration and raising of exceptions, but does not support exception handlers, so any exception raised will cause either the task that was subject to the exception to silently terminate, or the main program to terminate. Since SPARK is a subset of Ada, it is possible to hide the main body of a task or the main subprogram from SPARK and place an exception handler there to perform appropriate notifications or last wishes.

### 6.50.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.50.5 of TR 24772-1.
* Ensure that the interfaces with libraries written in other languages are compatible in the naming and generation of exceptions.
* Consider failure strategies and consider placing exception handlers at the top level of all tasks and the main subprogram.

Note: Since exception declarations are external to SPARK, wrapping the main subprogram with another subprogram that exclusively calls the main SPARK subprogram and handles and exception minimizes the amount of non-SPARK code. Similarly, for tasks, placing the task code in a subprogram that never exits and making the task body contain only the call to that subprogram and the exception handlers minimizes the amount of non-SPARK code.

* Document any exceptions that may be raised by any Ada units being used as library routines.

## 6.51 Pre-processor Directives [NMP]

This vulnerability is not applicable to SPARK, which does not have a pre-processor.

## 6.52 Suppression of Language-defined Run-time Checking [MXB]

### 6.52.1 Applicability to language

The vulnerability exists in SPARK since **pragma** Suppress permits explicit suppression of language-defined checks on a unit-by-unit basis or on partitions or programs as a whole. (The language-defined default, however, is to perform the runtime checks that prevent the runtime vulnerabilities.) **Pragma** Suppress can suppress all language-defined checks or 12 individual categories of checks (see subclause 11.5 of ISO/IEC 8652 [15]). Note, however, that SPARK creates verification conditions to be discharged, even if suppression is used.

### 6.52.2 Guidance to Language Users

Follow the mitigation mechanisms of ISO/IEC TR 24772-1 subclause 6.52.5.

##

## 6.53 Provision of Inherently Unsafe Operations [SKL]

### 6.53.1 Applicability to language

In recognition of the occasional need to step outside the type system or to perform “risky” operations, SPARK provides clearly identified language features to do so. Examples include the generic Unchecked\_Conversion for unsafe type-conversions and mechanisms to implement unit bodies outside of SPARK (in Ada).

For Unchecked\_Conversion, the declaring unit needs to specify the respective generic unit in its context clause, thus identifying potentially unsafe units.

To permit programming some portions of the program in Ada, instead of SPARK, SPARK only provides restrictions and analysis on packages and subprograms (or their bodies) that have the apsect “SPARK\_Mode” in the declaration. It is permissible to have the specification in SPARK\_Mode and the body not. This provides for callers or users of the unit to have the call checked even if the body is not SPARK.

### 6.53.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.53.5 of TR 24772-1. In particular, use the SPARK static analysis tools to identify inherently unsafe operations.
* Avoid the use of unsafe programming practices.
* Use the **pragma** Restrictions to prevent the inadvertent use of unsafe language constructs.
* Carefully scrutinize any code that refers to a program unit explicitly designated to provide unchecked operations.
* Use non-SPARK units sparingly and ensure that a thorough analysis is performed on the code since the SPARK verification tools will not be used.

## 6.54 Obscure Language Features [BRS]

### 6.54.1 Applicability of language

SPARK provides facilities for a wide range of application areas. Because some areas are specialized, it is likely that a programmer not versed in a special area might misuse features for that area. For example, the use of tasking features for concurrent programming requires knowledge of this domain.

### 6.54.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.54.5 of TR 24772-1.
* Use the **pragma** Restrictions to prevent the use of obscure features of the language.
* *Similarly, avoid features in a Specialized Needs Annex of ISO/IEC 8652 unless the application area concerned is well-understood. ???*
* Use the language-defined restriction No\_Dependence to prevent the use of specified pre-defined or user-defined libraries.

## 6.55 Unspecified Behaviour [BQF]

### 6.55.1 Applicability of language

In SPARK, there are two main categories of unspecified behaviour, one having to do with unspecified aspects of normal run-time behaviour, and one having to do with *bounded errors*, errors that may not be detected at run-time but for which there is a limited number of possible run-time effects.

For Bounded\_Error, SPARK detects and issues diagnostic messages for all occurrences.

For the normal behaviour category, there is one aspects of run-time behaviour that might be unspecified; the order in which certain actions are performed at run-time. SPARK assumes left-to-right association of operators at the same level of precedence, so is susceptible to implementations that group operations in different orders. SPARK analyzers can detect such usage when tuned with implementation behaviour information.

### 6.55.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.55.5 of TR 24772-1.

## 6.56 Undefined Behaviour [EWF]

From Ada. Can this be reduced? Some removals (e.g. discussion of access types or address-to-access conversions).

### 6.56.1 Applicability to language

In SPARK, undefined behaviour is called *erroneous execution*, and can arise from certain errors that are not required to be detected by the implementation, and whose effects are not in general predictable.

There are various kinds of errors that can lead to erroneous execution, including:

* Changing a discriminant of a record (by assigning to the record as a whole) while there remain active references to subcomponents of the record that depend on the discriminant;
* Referring via a task id, or tag to an object, task, or type that no longer exists at the time of the reference;
* *Sharing an object between multiple tasks without adequate synchronization, see clause 6.63??*
* Suppressing a language-defined check that *is outside of the analysis capabilities of the SPARK analyser* and may be violated at run-time;
* Specifying the alignment of an object in an inappropriate way; *-- not possible in SPARK?*
* Using Unchecked\_Conversion, or calling an imported subprogram to create a value that has an *abnormal* representation.

Any occurrence of erroneous execution represents a failure situation, as the results are unpredictable, and may involve overwriting of memory, jumping to unintended locations within memory, and other uncontrolled events.

SPARK mitigates most of these cases, however, implementations that need to implement features that can lead to undefined behaviour often step outside of SPARK (by leaving “with SPARK\_Mode” off the unit declaration or the unit body declaration) and therefore correct behaviour must be shown by other means.

### 6.56.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.56.5 of TR 24772-1.
* Ensure that all data shared between tasks are either private within a protected object or marked Atomic;
* Use **pragma** Suppress only after the code has been completely analyzed by the SPARK analysis tools with no errors reported. The other errors that can lead to erroneous execution are less common, but clearly in any given Ada application, care must be taken when using features such as:
* Unchecked\_Conversion;
* The results of imported subprograms;
* Discriminant-changing assignments to global variables.
* Minimize the use of removing “with SPARK\_Mode” from unit or unit body declarations and devise alternate verification mechanisms for units that are not examined by the SPARK analyzer.

## 6.57 Implementation–defined Behaviour [FAB]

### 6.57.1 Applicability to language

There are a number of situations in SPARK where the language semantics are implementation defined, to allow the implementation to choose an efficient mechanism, or to match the capabilities of the target environment. Each of these situations is identified in Annex M of ISO/IEC 8652, and implementations are required to provide documentation associated with each item in Annex M to provide the programmer with guidance on the implementation choices.

A failure can occur in a SPARK application due to implementation-defined behaviour if the programmer presumed the implementation made one choice, when in fact it made a different choice that affected the results of the execution. In many cases, a compile-time message or a run-time exception will indicate the presence of such a problem. For example, the range of integers supported by a given compiler is implementation defined. However, if the programmer specifies a range for an integer type that exceeds that supported by the implementation, then a compile-time error will be indicated, and if at run time a computation exceeds the base range of an integer type, then Constraint\_Error is raised.

Failure due to implementation-defined behaviour is generally due to the programmer presuming a particular effect that is not matched by the choice made by the implementation. As indicated above, many such failures are indicated by compile-time error messages or run-time exceptions. However, there are cases where the implementation-defined behaviour might be silently misconstrued, such as if the implementation presumes Ada.Exceptions.Exception\_Information returns a string with a particular format, when in fact the implementation does not use the expected format. If a program is attempting to extract information from Exception\_Information for the purposes of logging propagated exceptions, then the log might end up with misleading or useless information if there is a mismatch between the programmer’s expectation and the actual implementation-defined format.

Many implementation-defined limits have associated constants declared in language-defined packages, generally package System. In particular, the maximum range of integers is given by System.Min\_Int .. System.Max\_Int, and other limits are indicated by constants such as System.Max\_Binary\_Modulus, System.Memory\_Size, System.Max\_Mantissa, and similar. Other implementation-defined limits are implicit in normal ‘First and ‘Last attributes of language-defined (sub) types, such as System.Priority'First and System.Priority'Last. Furthermore, the implementation-defined representation aspects of types and subtypes can be queried by language-defined attributes. Thus, code can be parameterized to adjust to implementation-defined properties without modifying the code.

### 6.57.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.57.5 of TR 24772-1.
* Be aware of the contents of Annex M of ISO/IEC 8652 [15] and avoid implementation-defined behaviour whenever possible.
* Make use of the constants and subtype attributes provided in package System and elsewhere to avoid exceeding implementation-defined limits.
* Minimize use of any predefined numeric types, as the ranges and precisions of these are all implementation defined. Instead, declare your own numeric types to match your particular application needs.
* When there are implementation-defined formats for strings, such as Exception\_Information, localize any necessary processing in packages with implementation-specific variants.

## 6.58 Deprecated Language Features [MEM]

This vulnerability does not apply to SPARK, since this is a new language syntax for SPARK. SPARK 2005 and earlier was different in its approach and tools used, hence there are no backward compatibility issues.

## 6.59 Concurrency – Activation [CGA]

This vulnerability does not apply to SPARK because SPARK’s concurrency is restricted to Ada’s Ravenscar Tasking Profile. Under this profile, all tasks are declared in library-level packages and are elaborated before the main program begins. Therefore, all resources required for task activation are allocated before the main program begins, and failure in activation will result in exceptions in the main program.

## 6.60 Concurrency – Directed termination [CGT]

This vulnerability does not apply to SPARK because SPARK concurrency is restricted to Ada’s Ravenscar Tasking Profile. Under this profile, all tasks are declared in library-level packages and are elaborated before the main program begins. In addition, the Ravenscar Tasking Profile prohibits the “abort” statement, and Ravenscar tasks never terminate before the main program ends, hence directed termination is not possible, the resources are not freed, and there is no risk of claiming a terminated task’s resources. Tasks may be effectively removed from consideration by reducing their priority to below that of the idle task, thereby preventing execution.

## 6.61 Concurrent Data Access [CGX]

### 6.61.1 Applicability to language

SPARK’s concurrency is restricted to Ada’s Ravenscar Tasking Profile. Under this profile and SPARK, tasks communicate exclusively using atomic shared data, suspension objects, a very limited form of protected objects. SPARK enforces these restrictions. Therefore, race conditions are eliminated.

### 6.61.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.61.5 of TR 24772-1.
* Use a single protected objects to access each collection of shared data, either by declaring the objects as part of the protected object or by showing statically that a single protected object access a shared object, or by declaring the shared object **atomic.**
* Use SPARK to statically determine that no unprotected data is used directly by more than one task.
* Use **pragma** Atomic and **pragma** Atomic\_Components to ensure that all updates to objects and components happen atomically.
* Use **pragma** Volatile and **pragma** Volatile\_Components to ensure that all tasks see updates to the associated objects or array components in the same order.

## 6.62 Concurrency – Premature Termination [CGS]

This vulnerability does not apply to SPARK because SPARK’s concurrency is restricted to Ada’s Ravenscar Tasking Profile. Under this profile, all tasks are declared in library-level packages and are elaborated before the main program begins. In addition, the Ravenscar Tasking Profile prohibits the “abort” statement, and Ravenscar tasks never terminate, hence premature termination is not possible, the resources are not freed and there is no risk of claiming a terminated task’s resources. Tasks may be effectively removed from consideration by reducing their priority to below that of the idle task, thereby preventing execution.

## 6.63 Protocol Lock Errors [CGM]

### 6.63.1 Applicability to language

SPARK is open to the errors identified in this vulnerability but supports a number of features that aid mitigation.

1. SPARK tasks are created befor the main subprogram begins execution, never terminate and cannot be aborted.
2. SPARK provides protected objects that provide single-threaded access to shared data contained in those objects as well as providing scheduling mechanism for a single task (at a time) to be suspended upon a ‘protected entry’

### 6.63.2 Guidance to language users

* Follow the mitigation mechanisms of subclause 6.63.5 of TR 24772-1.
* Make use of loosely coupled communication using protected objects.
* Stay within the constraints defined by the Ravenscar Tasking profile [15].
* Verify with static analysis that exceptions cannot be raised in protected calls.
* Guard against protocol failures by using timed communication, watchdog timers (programmed using timed events) or time-stamped data (using the clock facilities). Do not use unprotected shared data for synchronization between tasks

## 6.64 Uncontrolled Format String [SHL]

### This vulnerability does not apply to SPARK since the language does not contain subprograms that use format strings.

# 7. Language specific vulnerabilities for SPARK

[TBD]

# 8. Implications for standardization

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# Index

LHS (left-hand side), 22

1. This case is somewhat specialized but is important, since enumerations are the one case where subranges turn *bad* on the user. [↑](#footnote-ref-1)
2. The first edition should not be used or quoted in this work. [↑](#footnote-ref-2)