
SPARK 2014 LRM

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Altran and AdaCore

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INTRODUCTION

SPARK 2014 is a programming language and a set of verification tools designed to meet the needs of high-assurance software development. SPARK 2014 is based on Ada 2012, both subsetting the language to remove features that defy verification and also extending the system of contracts by defining new Ada aspects to support modular, formal verification.

The new aspects support abstraction and refinement and facilitate deep static analysis to be performed including information-flow analysis and formal verification of an implementation against a specification.

SPARK 2014 is a much larger and more flexible language than its predecessor SPARK 2005. The language can be configured to suit a number of application domains and standards, from server-class high-assurance systems to embedded, hard real-time, critical systems.

A major feature of SPARK 2014 is the support for a mixture of proof and other verification methods such as testing, which facilitates the use of unit proof in place of unit testing; an approach now formalized in DO-178C and the DO-333 formal methods supplement. Certain units may be formally proven and other units validated through testing.

The new aspects defined for SPARK 2014 all have equivalent pragmas which allows a SPARK 2014 program to be compiled by and executed by any Ada implementation; for instance an Ada 95 compiler provided the use of Ada 2005 and Ada 2012 implementation specific features are avoided. The SPARK 2014 attributes Update and Loop_Entry can be used only if the Ada implementation supports them. Additionally the attribute Old can be used in only a postcondition and not in a pragma.

The direct use of the new aspects requires an Ada 2012 compiler which supports them in a way consistent with the definition given here in the SPARK 2014 reference manual. The GNAT implementation is one such compiler.

1.1 Structure of Introduction

This introduction contains the following sections:

- Section *Lifecycle of this Document* describes how this document will evolve up to and beyond the first formal release of the SPARK 2014 language and toolset.
- Section *How to Read and Interpret this Manual* describes how to read and interpret this document.
- Section *Method of Description* describes the conventions used in presenting the definition of SPARK 2014.
- Section *Formal Analysis* gives a brief overview of the formal analysis to which SPARK 2014 programs are amenable.
- Section *Dynamic Semantics of SPARK 2014 Programs* gives details on the dynamic semantics of SPARK 2014.
- Section ~~provides an overview of the requirements presented in this document over and above the language definition rules of the sort that appear in the Ada 2012 Reference Manual (RM).~~

~~Section~~ *SPARK 2014 Strategic Requirements* defines the overall goals to be met by the SPARK 2014 language and toolset.

- Section *Explaining the Strategic Requirements* provides expanded detail on the main strategic requirements.
- Section ~~presents language-independent requirements that are common to a number of the language features described in this document.~~

~~Section~~ *Notes on the Current Draft* provides some brief detail on the current status and contents of this document.

1.2 Lifecycle of this Document

This document will be developed incrementally towards a number of milestones – this version of the document represents Milestone ~~2~~ 3 – culminating in Release 1 of the document that matches the first formal release of the toolset. Subsequent releases of the document will follow, associated with subsequent formal releases of the toolset. Hence, where inclusion of particular scope is deferred, it may be deferred to:

- A specified milestone, meaning that the feature will be included in the first formal release of the toolset.
- A release subsequent to Release 1, meaning that the feature will be implemented *after* the first formal release of the toolset.

Note that the content currently in scope for the current draft of this document will only be regarded as definitive when the Release 1 version of the document is ready, and so may be subject to change.

1.3 How to Read and Interpret this Manual

This RM (reference manual) is *not* a tutorial guide to SPARK 2014. It is intended as a reference guide for users and implementors of the language. In this context, “implementors” includes those producing both compilers and verification tools.

This manual is written in the style and language of the Ada 2012 RM, so knowledge of Ada 2012 is assumed. Chapters 2 through 13 mirror the structure of the Ada 2012 RM. Chapter 14 covers all the annexes of the Ada 2012 RM. Moreover, this manual should be interpreted as an extension of the Ada 2012 RM (that is, SPARK 2014 is fully defined by this document taken together with the Ada 2012 RM).

SPARK 2014 introduces a number of aspects. The language rules are written as if all the SPARK 2014 specific aspects are present but minimum requirements are placed on a tool which analyzes SPARK 2014 to be able to synthesize (from the source code) some of these aspects if they are not present. A tool may synthesize more aspects than the minimum required (see *Synthesis of SPARK 2014 Aspects*). An equivalent pragma is available for each of the new aspects but these are not covered explicitly in the language rules either.

Readers interested in how SPARK 2005 constructs and idioms map into SPARK 2014 should consult the appendix *SPARK 2005 to SPARK 2014 Mapping Specification*. ~~Note that this section does not cover all language features presented in this document—although it covers the main features—and will be updated for the Milestone 3 version of this document.~~

~~Update mapping specification section to cover all necessary language features. To be completed in the milestone 3 version of this document.~~

1.4 Method of Description

In expressing the aspects, pragmas, attributes and rules of SPARK 2014, the following chapters of this document follow the notational conventions of the Ada 2012 RM (section 1.1.4).

The following sections are given for each new language feature introduced for SPARK 2014, following the Ada 2012 RM (other than *Verification Rules*, which is specific to SPARK 2014):

1. Syntax: this section gives the format of ~~the any~~ SPARK 2014 ~~aspects and pragmas~~ specific syntax.
2. Legality Rules: these are rules that are enforced at compile time. A construct is legal if it obeys *all* of the Legality Rules.
3. Static Semantics: a definition of the compile-time effect of each construct.
4. Dynamic Semantics: a definition of the run-time effect of each construct.
5. Verification Rules: these rules define ~~the proof and flow analysis~~ checks to be performed on the language feature that relate to static analysis rather than simple legality rules.
6. Name Resolution Rules: There are very few SPARK 2014 specific name resolution rules. Where they exist they are placed under this heading.

~~All sections are always listed and if no content is required then the corresponding section will be marked *Not applicable*. A section might not be present if there are no rules specific to SPARK 2014 associated with the language feature.~~

When presenting rules, additional text may be provided in square brackets []. This text is redundant in terms of defining the rules themselves and simply provides explanatory detail.

In addition, examples of the use of the new features are given along with the language definition detail.

Todo

We need to increase the number of examples given. To be completed in the Milestone ~~3~~ 4 version of this document.

1.5 Formal Analysis

SPARK 2014 will be amenable to a range of formal analyses, including but not limited to the following static analysis techniques:

- Data-flow analysis, which considers the initialization of variables and the ~~direction of data flow into and out of subprograms~~ data dependencies of subprograms (which parameters and variables get read or written).
- Information-flow analysis, which also considers the coupling between the inputs and outputs of a subprogram (which input values of parameters and variables influence which output values). The term *flow analysis* is used to mean data-flow analysis and information-flow analysis taken together.
- Formal verification of robustness properties. In Ada terminology, this refers to the proof that certain predefined checks, such as the ones which could raise `Constraint_Error`, will never fail at run time and hence the corresponding exceptions will not be raised.
- Formal verification of functional properties, based on contracts expressed as preconditions, postconditions, type invariants and so on. The term *formal verification* is used to mean formal verification of robustness properties and formal verification of functional properties taken together.

Data and information-flow analysis is not valid and ~~may-might~~ not be possible if the legality rules of Ada 2012 and those presented in this document are not met. Similarly, a formal verification ~~may-might~~ not be possible if the legality rules are not met and may be unsound if data-flow errors are present.

Todo

Consider adding a glossary, defining terms such as flow analysis and formal verification. To be completed in the Milestone 4 version of this document.

1.5.1 Further Details on Formal Verification

Many Ada constructs have dynamic semantics which include a requirement that some error condition must or may¹ be checked, and some exception must or may¹ be raised, if the error is detected (see Ada 2012 RM 1.1.5(5-8)). For example, evaluating the name of an array component includes a check that each index value belongs to the corresponding index range of the array (see Ada 2012 RM 4.1.1(7)).

For every such run-time check a corresponding obligation to prove that the error condition cannot be true is introduced. In particular, this rule applies to the run-time checks associated with any assertion (see Ada 2012 RM (11.4.2)); the one exception to this rule is pragma Assume (see *Proof Pragmas*).

In addition, the generation of proof obligations is unaffected by the suppression of checks (e.g., via pragma Suppress) or the disabling of assertions (e.g., via pragma Assertion_Policy). In other words, suppressing or disabling a check does not prevent generation of its associated proof obligations.

All such generated proof obligations must be discharged before the formal program verification phase may be considered to be complete.

Note that formal verification of a program must take account of the machine on which that program is executed and the properties of the tools used to compile and build it. In such cases it must be possible to represent the dependencies as explicit inputs to the formal verification process.

1.6 Dynamic Semantics of SPARK 2014 Programs

Every valid SPARK 2014 program is also a valid Ada 2012 program. The ~~dynamic semantics of the two languages are defined to be identical, so that a valid SPARK 2014 dynamic semantics are the same as Ada 2012 with the exception of some new aspects, pragmas and attributes which have dynamic semantics. Additionally, the new dynamic semantics only affect assertion expressions so if assertion expressions are ignored then the dynamic semantics of an Ada 2012 program are the same as a~~ SPARK 2014 program ~~may be compiled and executed by means of an Ada compiler.~~

SPARK 2014 programs that have failed their static analysis checks can still be valid Ada 2012 programs. An incorrect SPARK 2014 program with, say, ~~inconsistent dataflow annotations~~ ~~flow analysis anomalies~~ or undischarged proof obligations can still be executed as long as the Ada compiler in question finds nothing objectionable. What one gives up in this case is the formal analysis of the program, such as proof of absence of run-time errors or the static ~~checking of dataflow dependencies~~ ~~checks performed by flow analysis such as the proof that all variables are initialized before use.~~

SPARK 2014 may make use of certain aspects, attributes and pragmas which are not defined in the Ada 2012 reference manual. Ada 2012 explicitly permits implementations to provide implementation-defined aspects, attributes and pragmas. If a SPARK 2014 program uses one of these aspects (e.g., Global), or attributes (e.g., Update) then it can only be compiled and executed by an implementation which supports the construct in a way consistent with the definition given here in the SPARK 2014 reference manual.

If the equivalent pragmas are used instead of the implementation-defined aspects and if the use of implementation-defined attributes is avoided, then a SPARK 2014 program may be compiled and executed by any Ada ~~2012~~ implementation (whether or not it recognizes the SPARK 2014 pragmas). Ada specifies that unrecognized pragmas are ignored: an Ada compiler that ignores the pragma is correctly implementing the dynamic semantics of SPARK 2014 and the SPARK 2014 tools will still be able to undertake all their static checks and proofs.

Todo

¹ In the case of some bounded errors a check and any resulting exception only *may* be required.

The pragmas equivalent to the new aspects need to be added to this document. [To be added in the Milestone 4 version of this document.](#)

The detailed SPARK 2014 language definition is given in Ada terminology and has two main components. The first defines extensions to Ada 2012 in terms of new aspects, pragmas and attributes to provide SPARK 2014 features such as global specifications for subprograms. The second defines a subset of Ada 2012 by excluding certain language features. The exclusions, the new aspects, pragmas, attributes and rules specify the largest SPARK 2014 language for which formal analyses are supported.

Code Policies may be applied which effectively reduce further the language subset which may be analyzed but may make analysis and proof easier, more precise and be suitable for some application areas (see).

Higher-level requirements are given in non-Ada specific terminology and have the following structure: Strategic requirements to be met by the

1.7 Main Program

[In SPARK 2005, a dedicated annotation was used to identify the main program. There is no corresponding aspect in SPARK 2014 and instead it is expected that any implementation of SPARK 2014 language and its associated toolset \(given in this chapter\).](#)

Requirements to provide particular language features.

For each such language feature, requirements are given to define how that feature should work in a way that is—as much as possible—language-independent. This means that language features may be understood independently of the low-level details needed to make them work.

Where relevant, a rationale will be given to explain why the requirement is levied. Further narrative detail is given on each of the strategic requirements.

Since this detail does not strictly belong in this document in future it will be extracted and included in a new requirements document.

For each language feature, higher-level requirements are given under the following headings: *Goals to be met by language feature*: this defines the broad need behind a given language feature, along with requirements on the capabilities that the feature needs to support.

Constraints: this defines any ways in which we need to restrict the nature of the language feature, typically to serve the needs of analysis or verification.

Consistency: here, we consider the other language features being implemented and consider what the relationship should be between this and those features.

Semantics: here we define what the language feature means and hence what it means for the program to be correct against any specification given using this feature.

The higher-level requirements are naturally given in language that is less precise than would be expected of rules in a language reference manual. Where greater precision is required, this will be given in the language definition rules themselves.

A number of requirements apply to multiple language features and they are given at the end of this chapter in section [will have its own mechanism to allow the tools to identify the main program \(albeit not within the language itself\).](#)

1.8 SPARK 2014 Strategic Requirements

The following requirements give the principal goals to be met by SPARK 2014. Some are expanded in subsequent sections within this chapter.

- The SPARK 2014 language subset shall embody the largest subset of Ada 2012 to which it is currently practical to apply automatic formal verification, in line with the goals below. However, future advances in verification research and computing power may allow for expansion of the language and the forms of verification available. See section *Principal Language Restrictions* for further details.
- The use of Ada 2012 preconditions, postconditions and other assertions dictates that SPARK 2014 shall have executable semantics for assertion expressions. Such expressions may be executed, proven or both. To avoid having to consider potential numeric overflows when defining an assertion expression SPARK 2014 mandates a mode whereby extended or infinite integer arithmetic is supported for assertion expressions. The way in which this mode is selected is tool dependent and shall be described in the user guide for the tool. If this mode is not active, proof obligations to demonstrate the absence of overflow in assertion expressions will be present.
- SPARK 2014 shall provide for mixing of verification evidence generated by formal analysis [for code written in the SPARK 2014 subset] and evidence generated by testing or other traditional means [for code written outside of the core SPARK 2014 language, including legacy Ada code, or code written in the SPARK 2014 subset for which verification evidence could not be generated]. See section *Combining Formal Verification and Testing* for further details.

~~SPARK-Note, however, that a core goal of is to provide a language expressive enough for the whole of a program to written in SPARK 2014 shall provide support for constructive, generative and retrospective analysis as follows (see section for further details): making it potentially entirely provable largely using automatic proof tools.~~

- SPARK 2014 shall support ~~constructive (modular) specification, constructive, modular development which allows contracts to be specified on the declaration of program units and allows analysis and verification of (partially) developed programs, to allow static analysis to be performed based on these contracts as early as possible in the development lifecycle. Hence, package and subprogram bodies need not be present for formal verification to proceed, even before the units are implemented. As units are implemented the implementation is verified against its specification given in its contract. The contracts are specified using SPARK 2014 specific aspects.~~
- ~~A SPARK 2014 shall complete by generation from the body code, where possible, incomplete contracts. For instance analysis tool is required to synthesize at least some of the SPARK 2014 specific aspects, used to specify the contract of a program unit, if a dependency relation is given on a subprogram but a subprogram nested within does not have a dependency relation, it should be generated by the tools. This may shorten development time and should simplify maintenance.~~

~~contract is not explicitly specified, for instance the *Global Aspect* and the *Depends Aspect* SPARK 2014 shall support retrospective analysis where useful forms of verification can be achieved with code that complies with the core SPARK 2014 restrictions, but otherwise does not have any contracts. Implicit contracts can be computed from the bodies of units, and then from the implementation of the unit if it exists. The minimum requirements are given in *Synthesis of SPARK 2014 Aspects* but a particular tool may provide more precise synthesis and the synthesis of more aspects. The synthesized aspect is used in the analysis of other units, and so on. Parts of the program which are not compliant with SPARK 2014 subset cannot be fully verified by the tools but may be represented by a the unit if the aspect is not explicitly specified. The synthesis of SPARK 2014 compatible contract at the unit level specific aspects facilitates different development strategies and the analysis of pre-existing code (see section *Synthesis of SPARK 2014 Aspects*).~~

- ~~Although a goal of SPARK 2014 is to provide a language that supports as many Ada 2012 features as practical, there is another goal which is to support good programming practice guidelines and coding standards applicable to certain domains or standards. This goal is met by *Code Policies* that shall be allowed that reduce the subset of Ada 2012 SPARK 2014 that may be used in line with specific goals such as domain needs or certification requirements (these are similar to *Profiles* but may be imposed at a finer granularity and the effect of a breach~~

~~may also be different). This.~~ The use of a code policy may also have the effect of simplifying proof or analysis. See section *Code Policies* for further details.

- SPARK 2014 shall allow the mixing of code written in the SPARK 2014 subset with code written in full Ada 2012. See section *In and Out of SPARK 2014* for further details.
- Many systems are not written in a single programming language. SPARK 2014 shall support the development, analysis and verification of programs which are only partly ~~within the in~~ SPARK 2014 ~~language~~, with other parts in another language, for instance, ~~full Ada or~~ C. SPARK 2014 ~~compatible contracts specific aspects manually specified~~ at unit level will form the boundary interface between the SPARK 2014 and other parts of the program. ~~Many systems are not written in a single programming language and when retrospectively analyzing pre-existing code it may well not all conform to the SPARK 2014 subset. No further detail is given in the current draft of this document on mixing SPARK 2014 code with non-Ada code.~~

Todo

Complete detail on mixing SPARK 2014 with non-Ada code. To be completed in the Milestone 4 version of this document.

- SPARK 2014 shall support entities which do not affect the functionality of a program but may be used in the test and verification of a program. See section *Ghost Functions*.
- SPARK 2014 shall provide counterparts of all language features and analysis modes provided in SPARK 83/95/2005, unless it has been identified that customers do not find them useful.
- ~~Support~~ Enhanced support for specifying and verifying properties of secure systems shall be ~~improved~~ provided (over what is available in SPARK ~~2005.~~ 2005). ~~[SPARK The features to provide this enhanced support are not yet fully defined and will not be implemented until after release 1 of the SPARK 2014 shall support the analysis of volatile variables, typically external inputs or outputs. See section tools.] for further details.~~
- SPARK 2014 shall support ~~provision of “formal analysis” as defined by DO-333, which states “an analysis method can only be regarded as formal analysis if its determination of property is sound. Sound analysis means that the method never asserts a property to be true when it is not true.” Language features that defy sound analysis will be eliminated or their use constrained to meet this goal~~ the analysis of external communication channels, which might be volatile variables, typically either an input or an output. See section *External State* for further details. ~~Note that the current draft of this document does not necessarily define all restrictions necessary to guarantee soundness.~~
- The language shall offer an unambiguous semantics. In Ada terminology, this means that all erroneous and unspecified behavior shall be eliminated either by direct exclusion or by adding rules which indirectly guarantee that some implementation-dependent choice, other than the fundamental data types and constants, cannot effect the externally-visible behavior of the program. For example, Ada does not specify the order in which actual parameters are evaluated as part of a subprogram call. As a result of the SPARK rules which prevent the evaluation of an expression from having side effects, two implementations might choose different parameter evaluation orders for a given call but this difference won't have any observable effect. [This means implementation-defined and partially-specified features may be outside of SPARK 2014 by definition, though their use could be allowed and a warning or error generated for the user. See section *In and Out of SPARK 2014* for further details.] *Note that the current draft of this document does not necessarily define all restrictions necessary to guarantee an unambiguous semantics.*
- SPARK 2014 shall support provision of “formal analysis” as defined by DO-333, which states “an analysis method can only be regarded as formal analysis if its determination of a property is sound. Sound analysis means that the method never asserts a property to be true when it is not true.” A language with unambiguous semantics is required to achieve this and additionally any other language feature that for which sound analysis is difficult or impractical will be eliminated or its use constrained to meet this goal. See section *Principal*

Language Restrictions for further details. Note that the current draft of this document does not necessarily define all restrictions necessary to guarantee soundness.

Todo

Ensure that all strategic requirements have been implemented. To be completed in the Milestone 4 version of this document.

Todo

Where Ada 2012 language features are designated as not in SPARK 2014 in subsequent chapters of this document, add tracing back to the strategic requirement that motivates that designation. To be completed in the Milestone 4 version of this document.

1.9 Explaining the Strategic Requirements

The following sections provide expanded detail on the main strategic requirements.

1.9.1 Principal Language Restrictions

To facilitate formal analyses and verification, SPARK 2014 enforces a number of global restrictions to Ada 2012. While these are covered in more detail in the remaining chapters of this document, the most notable restrictions are:

- The use of access types and allocators is not permitted.
- All expressions (including function calls) are free of side-effects.
- Aliasing of names is not permitted in general but the renaming of entities is permitted as there is a static relation ship between the two names. In analysis all names introduced by a renaming declaration are replaced by the name of the renamed entity. This replacement is applied recursively when there are multiple renames of an entity.
- The goto statement is not permitted.
- The use of controlled types is not currently permitted.
- Tasking is not currently permitted (it is intended that this will be included in Release 2 of the SPARK 2014 language and tools).
- Raising and handling of exceptions is not ~~permitted~~currently permitted (exceptions can be included in a program but proof must be used to show that they cannot be raised).

1.9.2 Combining Formal Verification and Testing

There are common reasons for combining formal verification on some part of a codebase and testing on the rest of the codebase:

1. Formal verification is only applicable to a part of the codebase. For example, it might not be possible to apply the necessary formal verification to Ada code that is not in SPARK 2014.
2. Formal verification only gives strong enough results on a part of the codebase. This might be because the desired properties cannot be expressed formally, or because proof of these desired properties cannot be sufficiently automated.

3. Formal verification ~~is~~ might be only cost-effective on a part of the codebase. (And it may be more cost-effective than testing on this part of the codebase.)

Since the combination of formal verification and testing cannot guarantee the same level of assurance as when formal verification alone is used, the goal when combining formal verification and testing is to reach a level of confidence at least as good as the level reached by testing alone.

Mixing of formal verification and testing requires consideration of at least the following three issues.

Demarcating the Boundary between Formally Verified and Tested Code

Contracts on subprograms provide a natural boundary for this combination. If a subprogram is proved to respect its contract, it should be possible to call it from a tested subprogram. Conversely, formal verification of a subprogram (including absence of run-time errors and contract checking) depends on called subprograms respecting their own contracts, whether these are verified by formal verification or testing.

In cases where the code to be tested is not SPARK 2014, then additional information may be provided in the code – possibly at the boundary – to indicate this (see section *In and Out of SPARK 2014* for further details).

Checks to be Performed at the Boundary

When a tested subprogram T calls a proved subprogram P, then the precondition of P must hold. Assurance that this is true is generated by executing the assertion that P's precondition holds during the testing of T.

Similarly, when a proved subprogram P calls a tested subprogram T, formal verification will have shown that the precondition of T holds. Hence, testing of T must show that the postcondition of T holds by executing the corresponding assertion. This is a necessary but not necessarily sufficient condition. Dynamically, there is no check that the subprogram has not updated entities not included in the postcondition.

In general, formal verification works by imposing requirements on the callers of proved code, and these requirements should be shown to hold even when formal verification and testing are combined. Any toolset that proposes a combination of formal verification and testing for SPARK 2014 should provide a detailed process for doing so, including any necessary additional testing of proof assumptions.

Restrictions that Apply to the Tested Code

There are two two sources of restriction that apply to the tested code:

1. The need to validate a partial proof that relies on code that is not itself proven but is only tested.
2. The need to validate the assumptions on which a proof is based when proven code is combined with tested code.

The specific details of the restrictions to be applied to tested code – which will typically be non-SPARK 2014 – code will be given in a subsequent draft of this document.

No further detail is given in the current draft of this document on Combining Formal Verification and Testing, or on providing what it needs. Further detail will be provided at least in part under TN LC10-020.

Todo

Add detail on restrictions to be applied to tested code, making clear that the burden is on the user to get this right, and not getting it right can invalidate the assumptions on which proof is based. To be completed in the Milestone 4 version of this document.

Todo

Complete detail on combining formal verification and testing. To be completed in the Milestone 4 version of this document.

1.9.3 Code Policies

The restrictions imposed on the subset of Ada that could be used in writing SPARK 2005 programs were not simply derived from what was or is amenable to formal verification. In particular, those restrictions stemmed partly from good programming practice guidelines and the need to impose certain restrictions when working in certain domains or against certain safety standards. Hence, we want to allow such restrictions to be applied by users in a systematic and tool-checked way despite the goal that SPARK 2014 embodies the largest subset of Ada 2012 that is practical to formally verify.

Since SPARK 2014 will allow use of as large a subset of Ada 2012 as possible, this allows for the definition of multiple *Code Policies* that allow different language subsets to be used as opposed to the single subset given by SPARK 2005. Each of these code policies can be targeted to meeting a specific user need, and where a user has multiple needs then multiple policies may be enforced. Needs could be driven by:

- Application domains - for example, server-class information systems,
- Standards - for example, DO-178C Level A,
- Technical requirements - for example, systems requiring software that is compatible with a “zero footprint” run-time library.

As an example, a user developing an air traffic control system against DO-178C might impose two code policies, one for the domain of interest and one for the standard of interest.

~~Since it should be possible to apply these policies at multiple levels of granularity—for example at a package level rather than at a library level—and since it need not be the case that violation of one of these policies leads to a compilation error, then the existing Ada mechanisms of pragma Restriction These capabilities will be handled outside of the language since the need is not specific to SPARK, and has already been resolved either by Ada 2012 (pragma Restrictions and pragma Profile are not suitable. Hence, pragma Code will be introduced as a counterpart to pragma Profile and pragma Guideline will be introduced as a counterpart to pragma Restriction, meaning that a Code is a grouping of Guidelines.~~

~~It is intended that code policies can be customised or new policies specified from a collection of guidelines.~~

~~No further detail is given in the current draft of this document on Code Policies.), or GNAT (pragma Restriction Warnings) or by coding standard checkers (e.g. gnatcheck).~~

Todo

Complete detail on Code Policies. To be completed in the Milestone 3.4 version of this document. Consider referencing the User's Guide for details of the various profiles.

1.9.4 Ghost Functions

Often extra entities, such as types, variables and functions may be required only for test and verification purposes. Such entities are termed *ghost* entities and their use should be restricted to places where they do not affect the functionality of the program. ~~In principle such entities could be completely removed from the program without any functional impact~~ Complete removal of ghost entities has no functional impact on the program.

SPARK 2014 currently supports ghost functions ~~which-but not ghost types or variables.~~ Ghost functions may be executable or non-executable. Non-executable ghost functions have no implementation and can be used for the pur-

poses of formal verification only. Such functions ~~have to be defined within an external proof tool to facilitate formal verification.~~

~~Any function, ghost or otherwise, may have its~~ may have their specification defined within an external proof tool ~~for formal verification purposes. The to facilitate formal verification. This~~ specification is outside of the SPARK 2014 language and toolset and therefore cannot be checked by ~~these~~ the tools. An unsound definition may lead to an unsound proof which is of no use. Ideally any definition will be checked for soundness by the external proof tools.

If ~~a function~~ the postcondition of a function, F, can be specified in SPARK 2014 ~~, then its specification can as F'Result = E, then the postcondition may~~ be recast as the expression of an ~~expression function without further implementation~~ expression_function_declaration as shown below:

```
function F (V : T) return T1 is (E);
```

The default postcondition of an expression function is F'Result = E making E both the implementation and the expression defining the postcondition of the function. This is useful, particularly for ghost functions, as the expression which acts as the postcondition might not give the most efficient implementation but if the function is a ghost function it may be sufficient.

Further Ghost entities are to be added in future drafts of this document.

~~Complete detail on Ghost Entities. To be completed in the Milestone 3 version of this document.~~ this might not matter.

1.9.5 Synthesis of SPARK 2014 Aspects

~~SPARK 2005 strongly favored the~~ SPARK 2014 supports a *constructive* analysis style where all program units ~~required contracts require contracts specified by SPARK 2014 specific aspects to be provided on their specifications. The contracts are needed to perform in-depth static analysis and formal verification. These contracts had declarations. Under this constructive analysis style, these contracts have~~ to be designed and added at an early stage to assist modular analysis and verification, and then maintained by the user as a program ~~evolved~~ evolves. When the body of a unit is implemented (or modified) it is checked that it conforms to its contract.

~~However, some of these contracts—if they are not explicitly provided—can be implicitly synthesized for a subprogram from its body (provided the contracts of any subprograms it calls are specified or have already been generated). The contracts can then be used in the analysis of calling subprograms and so on. In SPARK 2014 the contracts which may be synthesized from an implemented subprogram body are the global specification and~~ However, it is mandated that a SPARK 2014 analysis tool shall be able to synthesize a conservative approximation of at least a minimum of SPARK 2014 specific aspects from the source code of a unit.

Synthesis of SPARK 2014 aspects is fundamental to the analysis of pre-existing code where no SPARK 2014 specific aspects are provided.

The mandatory requirements of a SPARK 2014 analysis tool is that it shall be capable of synthesizing at least a basic, conservative Global Aspect, Depends Aspect, Refined_Global Aspect, Refined_Depends Aspect, Abstract_State Aspect, Refined_State Aspect and Initializes Aspect from either the implementation code or from other SPARK 2014 aspects as follows:

- if subprogram has no Depends aspect but has a Global aspect, an approximation of the Depends aspect is obtained by constructing a dependency_relation by assuming that all of the global_items that have a mode_selector of Output or In_Out are outputs, those that have a mode_selector of Input or In_Out are inputs of the dependency_relation and that each output is dependent on every input. This is a conservative approximation;
- if a subprogram has a Depends aspect but no Global aspect then the dependency_relation. It may be possible to generate some of Global aspect is determined by taking each input of the package contracts also once the package body and its private dependents have been implemented. dependency_relation which is not also an output and adding this to the Global aspect with a mode_selector of Input. Each output of the dependency_relation which is not also an input is added to the Global aspect with

a `mode_selector` of `Output`. Finally, any other input and output of the `dependency_relation` which has not been added to the `Global` aspect is added with a `mode_selector` of `In_Out`;

Unlike the-

- if neither a `Global` or `Depends` aspect is present, then first the globals of a subprogram are determined from an analysis of the entire program code. This is achieved in some tool dependent way. The globals of each subprogram determined from this analysis is used to synthesize the `Global` aspects and then from these the `Depends` aspects are synthesized as described above;
- if an `Abstract_State` is specified on a package and a `Refined_State` aspect is specified in its body, then `Refined_Global` and `Refined_Depends` aspects shall be synthesized in the same way as described above. From the `Refined_Global`, `Refined_Depends` and `Refined_State` aspects the abstract `Global` and `Depends` aspects used in flow analysis, the SPARK shall be synthesized if they are not present.
- if no abstract state aspect is specified on a package but it contains hidden state, then each variable that makes up the hidden state has a `Abstract_State` synthesized to represent it. At least a crude approximation of a single state abstraction for every variable shall be provided. A `Refined_State` aspect shall be synthesized which shows the constituents of each state.
- If no `Initializes` aspect is specified for a package but it declares persistent variables which are initialized then an `Initializes` aspect shall be synthesized stating the visible variables that are initialized and the state abstractions representing the hidden variables that are initialized.

The syntheses described above do not include all of the SPARK 2014 tools will not attempt to automatically synthesize for a given subprogram body the other aspects (i. e. `Pre` and `Post`), which define the subprogram's contract for the purpose of formal verification aspects and nor do the syntheses cover all facets of the aspects. In complex programs where extra or more precise aspects are required they might have to be specified manually.

An analysis tool may provide the synthesis of more aspects and more precise synthesis of the mandatory ones.

There are three main `Some` use cases where generation of contracts are required the synthesis of aspects is likely to be required are:

- Code has been developed as SPARK 2014 but in order to reduce costs not all the `contracts-aspects` are included on all subprograms by the developer. This is regarded as *generative analysis*, where the code was written with the intention that it would be analyzed.
- Code is in maintenance phase, it may or may not have complete `contracts` might or might not have all of the SPARK 2014 specific aspects. If the `contracts` are complete, the generated `contracts` aspects are present, the synthesized aspects may be compared with the given `contracts` explicit ones and auto correction used to update the `contracts` aspects if the changes are acceptable. If the `contracts` are incomplete there are aspects missing they are automatically generated-synthesized for analysis purposes. This is also regarded as *generative analysis*.
- Legacy code is analyzed which has no or incomplete `contracts`.

Hence, as well as still fully supporting the constructive development mode, SPARK 2014 is designed to facilitate the generation of contracts, which supports retrospective analysis.

Note that in the case where legacy specific aspects This is regarded as *retrospective analysis*, where code is being analyzed there may be that was not originally written with analysis in mind. Legacy code will typically have a mix of SPARK 2014 and non-SPARK 2014 code (and so there is an interaction with the detail presented in section *In and Out of SPARK 2014*). This leads to two additional process steps that may-might be necessary:

- An automatic identification of what code is in SPARK 2014 and what is not.
- An annotation `Manual definition` of the boundary between the SPARK 2014 and non-SPARK 2014 code with suitable SPARK 2014 compatible contracts. If this is not done then the analysis would have to assume some suitably conservative contract.

Note that when language features are presented and defined in the remainder of this document, it is assumed that analysis and verification is being performed constructively and no explicit detail is given on generative

~~or retrospective analysis.~~

~~No further detail is given in the current draft of this document on Constructive, Generative and Retrospective analysis and Verification.~~

~~Add detail on how retrospective analysis will work when we have a mix of~~ by explicitly specifying accurate and truthful contracts using SPARK 2014 ~~and specific aspects on the declarations of non-SPARK 2014.~~
~~To be completed in the Milestone 3 version of this document.~~ 2014 program units.

~~Complete detail on constructive, generative and retrospective analysis and verification. To be completed in the Milestone 3 version of this document.~~

1.9.6 In and Out of SPARK 2014

There are various reasons why it may be necessary to combine SPARK 2014 and non-SPARK 2014 in the same program, such as (though not limited to):

- Use of language features that are not amenable to formal verification (and hence where formal verification will be mixed with testing).
- Use of libraries that are not written in SPARK 2014.
- Need to analyze legacy code that was not developed as SPARK 2014.

Hence, it must be possible within the language to indicate what parts are (intended to be) in and what parts are (intended to be) out, of SPARK 2014.

The default is to assume all of the program text is in SPARK 2014, although this could be overridden. A new aspect SPARK_Mode is provided, which may be applied to a unit declaration or a unit body, to indicate when a unit declaration or just its body is not in SPARK and should not be analyzed. If just the body is not in SPARK 2014 a SPARK 2014 compatible contract may be supplied on the declaration which facilitates the analysis of units which use the declaration. The tools cannot check that the the given contract is met by the body as it is not analyzed. The burden falls on the user to ensure that the contract represents the behavior of the body as seen by the SPARK 2014 parts of the program and – if this is not the case – the assumptions on which the analysis of the SPARK 2014 code relies may be invalidated.

In general a definition may be in SPARK 2014 but its completion need not be.

A finer grain of mixing SPARK 2014 and Ada code is also possible by justifying certain warnings and errors. Warnings may be justified at a project, library unit, unit, and individual warning level. Errors may be justifiable at the individual error level or be unsuppressible errors.

Examples of this are:

- A ~~construct appearing in a unit may declaration occurring immediately within a unit might~~ not be in, or ~~may might~~ depend on features not in, the SPARK 2014 subset. The ~~construct may declaration might~~ generate a warning or an error which may be justifiable. This does not necessarily render the whole of the ~~unit as program unit~~ not in SPARK 2014. If the ~~construct declaration~~ generates a warning, or if the error is justified, then the unit is considered to be in SPARK 2014 except for the errant ~~construct declaration~~.
- It is the ~~use of a construct not in SPARK 2014~~ use of the entity declared by the errant declaration, for instance a call of a subprogram or the denoting of an object in an expression (generally within the statements of a body) that ~~potentially moves the code outside of the SPARK 2014 subset. An unsuppressible error will be generated in such a case and the body containing the code will result in an unsuppressible error. The body of a unit causing the unsuppressible (or declaration if this is the cause)~~ will need to be marked as not in SPARK 2014 to prevent its future analysis.

Hence, SPARK 2014 and non-SPARK 2014 code may mix at a fine level of granularity. The following combinations may be typical:

- Package specification in SPARK 2014. Package body entirely not in SPARK 2014.

- Visible part of package specification in SPARK 2014. Private part and body not in SPARK 2014.
- Package specification in SPARK 2014. Package body almost entirely in SPARK 2014, with a small number of subprogram bodies not in SPARK 2014.
- Package specification in SPARK 2014, with all bodies imported from another language.
- Package specification contains a mixture of declarations which are in SPARK 2014 and not in SPARK 2014. A client of the package may be in SPARK 2014 if it only references SPARK 2014 declarations; the presence of non-SPARK 2014 constructs in a referenced package specification does not by itself mean that a client is not in SPARK 2014.

Such patterns are intended to allow for mixed-language programming, mixed-verification using different analysis tools, and mixed-verification between formal verification and more traditional testing. A condition for safely combining the results of formal verification with other verification results is that formal verification tools explicitly list the assumptions that were made to produce their results. The proof of a property may depend on the assumption of other user-specified properties (for example, preconditions and postconditions) or implicit assumptions associated with the foundation and hypothesis on which the formal verification relies (for example, initialization of inputs and outputs, or non-aliasing between parameters). When a complete program is formally verified, these assumptions are discharged by the proof tools, based on the global guarantees provided by the strict adherence to a given language subset. No such guarantees are available when only part of a program is formally verified. Thus, combining these results with other verification results depends on the verification of global and local assumptions made during formal verification.

~~No further detail is given in the current draft of this document on mixing code that is in and out of SPARK 2014. Although there are a number of places where a statement is given on what is in or out of SPARK 2014, that information is not yet complete and nothing further is given on how it should be used. Full details on the SPARK_Mode aspect are given in the SPARK Toolset User's Guide (reference TBD).~~

Todo

We need to consider what might need to be levied on the non-SPARK 2014 code in order for flow analysis on the SPARK 2014 code to be carried out. To be completed in the Milestone 4 version of this document.

Todo

Complete detail on mixing code that is in and out of SPARK 2014. In particular, where subheadings such as Legality Rules or Static Semantics are used to classify the language rules given for new language features, any rules given to restrict the Ada subset being used need to be classified in some way (for example, as Subset Rules) and so given under a corresponding heading. In addition, the inconsistency between the headings used for statements and exceptions needs to be addressed. To be completed in the Milestone 4 version of this document.

1.9.7 External State

A variable or a state abstraction ~~(see-) may be designated~~ may be specified as external state to indicate that it represents an external communication channel, for instance, to a device or another subsystem. An external variable may be specified as volatile. A volatile ~~variable or state abstraction state~~ need not have the same value between two reads without an intervening update. Similarly an update of a volatile variable ~~(or state abstraction) may~~ might not have any effect on the internal operation of a program, its only effects are external to the program. These properties require special treatment of volatile variables during flow analysis and formal verification.

~~In formal verification a series of reads and updates of a volatile variable or state abstraction may be modeled by a sequence or a trace.~~

~~In both flow analysis and formal verification~~ SPARK 2014 follows the Ada convention that a read of a volatile variable has a possible side effect of updating the variable. SPARK 2014 extends this notion to cover updates of a volatile

variable such that an update of a volatile variable also has a side effect of reading the variable. SPARK 2014 further extends these principles to apply to state abstractions also.

The following detail relates to higher-level requirements but applies to multiple language features. Hence, it is given in a single place to ease readability.

The following terms are used in the presentation of the higher-level requirements; each is intended to have a definition consistent with that when used in language definition rules. *Hidden state*: state declared within a package but that is not directly accessible by users of that package.

Inputs and outputs of a subprogram: the set of data items that may be read or written either directly or indirectly on a call to that subprogram.

Global data of a subprogram: the inputs and outputs of a subprogram minus the formal parameters.

Entire variable: a variable that is not a subcomponent of a larger containing variable.

Entity: the semantic object that represents a given declaration.

Requirement: When specifying properties of a subprogram, it shall be possible to refer to (an abstraction of) hidden state without knowing the details of that hidden state.

Rationale: allows modular verification and also allows the management of complexity.

Requirement: It shall be possible to manage hierarchies of data abstraction i.e. it shall be possible to manage a hierarchical organization of hidden state.

Rationale: to allow modular verification and the management of complexity in the presence of programs that have a hierarchical representation of data.

Requirement: Variable names in a global specification of a subprogram are distinct from the formal parameter names of the subprogram.

Rationale: A variable cannot be both a formal parameter and a global variable simultaneously.

Requirement: Names used in the new flow analysis specifications shall refer to entire variables. Within a subprogram body flow analysis will operate at an individual subcomponent level for objects of a record type.

Rationale: For the flow analysis model at the inter-subprogram level, updating part of a variable is regarded as updating all of it. Within a subprogram body the subcomponents of a record type object are tracked individually.

Requirement: Where distinct names are referenced within a given flow analysis specification, then those names shall refer to distinct entities.

Rationale: to support flow analysis and to aid clarity of the interface definition.

using the Input Only and Output Only options in the declaration of a state abstraction (see section *External State*)
Requirement: When specifying program behavior in terms of a relation or a set, it shall be possible to explicitly provide a null relation or an empty set.

Rationale: to explicitly identify programs that—for example—do not reference global data. This is especially needed in the presence of retrospective analysis, where absence of a specification cannot mean presence of a null specification.

Requirement: It shall be possible to designate both visible and hidden state items that are Volatile and for each to give a mode of either in or out.

Rationale: to model programs that refer to external state, since that state is modeled differently to internal state.

Requirement: When specifying subprogram behavior other than via proof statements—such as global data—it shall be necessary to provide a complete specification.

Rationale: To allow provision of at least the same functionality and error detection as SPARK 2005 and to allow modular analysis. This is also necessary for security analysis.

1.10 Notes on the Current Draft

~~This document is a draft that covers all language-independent requirements for the main language features, provides syntax where possible and otherwise provides the detailed rules necessary to support implementation of basic flow analysis. Where detail is not relevant to meeting these needs then it has typically been removed, though a “ToDo” will indicate that there is material still to be provided.~~ The aim of this draft of the document is to fully define the main features of the SPARK 2014 language. Subsequent updates for release 1 of the tools are only expected to fix problems arising during implementation of the tools and correct any errors in the document.

~~Note this means there are certain of the strategic requirements that are currently not decomposed into language definition detail. Where this is the case, it will have been explicitly indicated in this chapter~~ There are two areas of the language where there is on-going significant discussion and so are likely to change. These areas are “Externals” and “Refined_Pre and Refined_Post”.

LEXICAL ELEMENTS

SPARK 2014 supports the full Ada 2012 language with respect to lexical elements. Users may choose to apply restrictions to simplify the use of wide character sets and strings.

2.1 Character Set

No extensions or restrictions.

2.2 Lexical Elements, Separators, and Delimiters

No extensions or restrictions.

2.3 Identifiers

No extensions or restrictions.

2.4 Numeric Literals

No extensions or restrictions.

2.5 Character Literals

No extensions or restrictions.

2.6 String Literals

No extensions or restrictions.

2.7 Comments

No extensions or restrictions.

2.8 Pragmas

SPARK 2014 introduces a number of new pragmas that facilitate program verification. These are described in the relevant sections of this document.

2.9 Reserved Words

No extensions or restrictions.

DECLARATIONS AND TYPES

SPARK 2014 does not add any declarations or types to Ada 2012, but it restricts their usage.

3.1 Declarations

The view of an entity is in SPARK 2014 if and only if the corresponding declaration is in SPARK 2014. When clear from the context, we say *entity* instead of using the more formal term *view of an entity*.

~~Certain type and subtype declarations can specify a default value to be given to declared objects of the (sub)type. There are several syntactic names and schemes for defining the default value: the of discriminants and record components; Default~~
A type is said to *define full default initialization* if it is

- a scalar type with a specified Default_Value aspect of scalar types and Default; or
- an array-of-scalar type with a specified Default_Component_Value aspect for an array-of-scalar subtype. These are collectively known as *default initialization*; or
- an array type whose element type defines default initialization; or
- a record type or type extension each of whose component_declarations either includes a default_expression or has a type which defines full default initialization and, in the case of a type extension, is an extension of a type which defines full default initialization.

[The discriminants of a discriminated type play no role in determining whether the type defines full default initialization.]

3.2 Types and Subtypes

The view of an entity introduced by a `private_type_declaration` is in SPARK 2014 if the types of any visible discriminants are in SPARK 2014, even if the entity declared by the corresponding `full_type_declaration` is not in SPARK 2014.

For a type or subtype to be in SPARK 2014, all predicate specifications that apply to the (sub)type must be in SPARK 2014. Notwithstanding any rule to the contrary, a (sub)type is never in SPARK 2014 if its applicable predicate is not in SPARK 2014.

Subtypes that are not preelaborable are not subject to flow analysis. [Users may write programs using such subtypes and those programs can be subject to formal verification. However, flow analysis will ignore the use of such a subtype and will instead raise a warning to indicate that its use has not been analysed.]

Todo

Lift restriction that non-prelaborable subtypes are not subject to flow analysis. To be completed in a post-Release 1 version of this document.

3.2.1 Classification of Operations

No restrictions or extensions.

3.2.2 Subtype Predicates

The Static_Predicate aspect is in SPARK 2014. The Dynamic_Predicate aspect is not in SPARK 2014.

[Eventually SPARK 2014 may include uses of the Dynamic_Predicate aspect, subject to the restriction that the predicate expression cannot take any variables as inputs. This is needed to ensure that if a value belonged to a subtype in the past, then the value will still belong to the subtype in the future. Predicates for composite types might also be restricted to disallow dependencies on non-discriminant components (but allow dependencies on discriminants and array bounds) in order to avoid cases where modifying a subcomponent can violate the subtype predicate of an enclosing object.]

Todo

~~It is intended to support subtype predicates. Analysis is required to determine if any subset rules need to be applied and also regarding any extra proof rules that might need to be applied~~Add the Dynamic_Predicate aspect to SPARK 2014. To be completed in a post-Release 1 version of this document.

3.3 Objects and Named Numbers

The entity declared by an `object_declaration` is in SPARK 2014 if its declaration does not contain the reserved word **aliased**, its type is in SPARK 2014, and its *initialization_expression*, if any, is in SPARK 2014.

3.3.1 Object Declarations

No extensions or restrictions.

3.3.2 Number Declarations

Constants that are not prelaborable are not subject to flow analysis. [Users may write programs using such constants and those programs can be subject to formal verification. However, flow analysis will ignore the use of such a constant and will instead raise a warning to indicate that its use has not been analysed.]

Todo

Lift restriction that non-prelaborable constants are not subject to flow analysis. To be completed in a post-Release 1 version of this document.

3.4 Derived Types and Classes

An entity declared by a `derived_type` declaration is in SPARK 2014 if its parent type is in SPARK 2014, and if the declaration contains an `interface_list` or a `record_part` these must also contain entities that are in SPARK 2014.

3.5 Scalar Types

~~A scalar type declaration is in SPARK 2014 unless it has a default initialization that is not in SPARK 2014. No extensions or restrictions.~~

3.6 Array Types

An entity declared by a `array_type_definition` is in SPARK 2014 if its components are in SPARK 2014 and default initialization is in SPARK 2014.

3.7 Discriminants

A `discriminant_specification` is in SPARK 2014 if ~~it is not an access type and its default initialization, if any, is in SPARK 2014~~ its type is discrete and it does not occur as part of a derived type declaration whose parent type is discriminated. [In other words, inherited discriminants shall not be hidden.]

3.8 Record Types

~~An entity declared by a is in SPARK 2014 if all of its components are in SPARK 2014 and if a component has a default initialization then all of the components must have~~ does not permit partial default initialization of record objects. More specifically, if at least one non-discriminant component (either explicitly declared or inherited) of a record type or type extension either is of a type which defines default initialization or is declared by a `component_declaration` which includes a `Default_Value`, then the record type or type extension shall define full default initialization.

[The enforcement of this rule requires looking at the `full_type_declaration` of a `private_type_declaration` to determine whether the private type has a default initialization. A ~~default initialization, if present must also be~~ future version of SPARK 2014 may introduce extra features to avoid having to do this.]

3.9 Tagged Types and Type Extensions

~~Use of the 'Class attribute is not permitted~~ in SPARK 2014.

[This restriction may be relaxed at some point in the future. As a consequence of this restriction, dispatching calls are not currently in SPARK 2014 ~~does not permit partial default initialization of record objects~~ but are planned for a future release.]

Todo

~~Add 'Class attribute to SPARK 2014. To be completed in a post-Release 1 version of this document.~~

3.9.1 Type Extensions

A type extension declared within a subprogram body, block statement, or generic body which does not also enclose the declaration of each of its ancestor types is not in SPARK 2014.

3.9.2 Dispatching Operations of Tagged Types

No extensions or restrictions.

3.9.3 Abstract Types and Subprograms

No extensions or restrictions~~currently identified, though see ToDo.~~

3.9.4 Interface Types

Use of `interface_type_definition` is not permitted in SPARK 2014.

Todo

~~RCC comment: This will need to describe any global restrictions on tagged types (if any) and any additional Restrictions that we may feel users need. Include interface types in SPARK 2014.~~ To be completed in ~~the Milestone 4~~ a post-Release 1 version of this document.

3.10 Access Types

Access types allow the creation of aliased data structures and objects, which notably complicate the specification and verification of a program's behavior. Therefore, all forms of access type declaration are excluded from SPARK 2014.

The attribute `Access` is not in SPARK 2014.

Finally, as they are based on access discriminants, user-defined references and user-defined indexing are not in SPARK 2014.

3.11 Declarative Parts

No extensions or restrictions.

NAMES AND EXPRESSIONS

The term *assertion expression* denotes an expression that appears inside an assertion, which can be a pragma Assert, a precondition or postcondition, a type invariant or (subtype) predicate, or other assertions introduced in SPARK 2014.

4.1 Names

A name that denotes an entity is in SPARK 2014 if and only if the entity is in SPARK 2014. Neither `explicit_dereference` nor `implicit_dereference` are in SPARK 2014.

4.1.1 Indexed Components

No extensions or restrictions.

4.1.2 Slices

No extensions or restrictions.

4.1.3 Selected Components

Some constructs which would unconditionally raise an exception at ~~run-time~~ run time in Ada are rejected as illegal in SPARK 2014 if this property can be determined prior to formal program verification.

In particular, if the prefix of a record component selection is known statically to be constrained so that the selected component is not present, then the component selection (which, in Ada, would raise `Constraint_Error` if it were to be evaluated) is illegal.

4.1.4 Attributes

The `attribute_designator` `Access` is not allowed in SPARK 2014.

Todo

Are there any other language defined attributes which will not be supported? To be completed in the Milestone ~~3~~ 4 version of this document.

Todo

What do we do about Gnat defined attributes, a useful one is: For a prefix X that denotes an object, the GNAT-defined attribute `X'ValidScalars` is defined in SPARK 2014. This Boolean-valued attribute is equal to the conjunction of the `Valid` attributes of all of the scalar parts of X.

[If X has no volatile parts, `X'ValidScalars` implies that each scalar subcomponent of X has a value belonging to its subtype. Unlike the Ada-defined `Valid` attribute, the `ValidScalars` attribute is defined for all objects, not just scalar objects.]

Perhaps we should list which ones are supported in an appendix? Or should they be part of the main language definition?

It would be possible to use such attributes in assertion expressions but not generally in Ada code in a non-Gnat compiler.

To be completed in the Milestone 3.4 version of this document. Note that as language-defined attributes form Appendix K of the Ada RM, any GNAT-defined attributes supported in SPARK 2014 will be presented in an appendix.

4.1.5 User-Defined References

User-defined references are not allowed in SPARK 2014 and so the aspect `Implicit_Dereference` is not in SPARK 2014.

4.1.6 User-Defined Indexing

User-defined indexing is not allowed in SPARK 2014 and so the aspects `Constant_Indexing` and `Variable_Indexing` are not in SPARK 2014.

4.2 Literals

The literal `null` representing an access `type-value` is not allowed in SPARK 2014.

4.3 Aggregates

Legality Rules

The box symbol, `<>`, may only be used in an aggregate if the type ~~of the (s) of the corresponding component(s) to which it pertains has a default initialization. This restriction is covered in more detail in the following subsections.~~

~~**Verification Rules** A may only use the option if the type denoted by each component has a define full default initialization.~~

~~No extensions or restrictions.~~

~~**Verification Rules** [The symbol may only be used after an **others** symbol in a if the component type of the array has a default initialization.~~

~~box symbol cannot be used in an aggregate to produce an uninitialized scalar value or a composite value having an uninitialized scalar value as a subcomponent.] The symbol may only be used in a of a if the component type of the array has a default initialization.~~

4.3.1 Update Expressions

Todo

Detail on Update Expressions needs to be put into the standard format. To be completed in the Milestone 3.4 version of this document.

The `Update` attribute provides a way of overwriting specified components of a copy of a given composite value. For a prefix `X` that denotes an object of a nonlimited record type or record extension `T`, the attribute

```
X'Update ( record_component_association_list )
```

is defined and yields a value of type `T`. The `record_component_association_list` shall have one or more `record_component_associations`, each of which shall have a non-**others** `component_choice_list` and an expression.

Each `selector_name` of each `record_component_name` shall denote a distinct non discriminant component of `T`. Each `record_component_association`'s associated components shall all be of the same type. The expected type and applicable index constraint of the expression is defined as for a `record_component_association` occurring within a record aggregate.

In all cases (i.e., whether `T` is a record type, a record extension type, or an array type - see below), evaluation of `X'Update` begins with the creation of an anonymous object of type `T` which is initialized to the value of `X` in the same way as for an occurrence of `X'Old` (except that the object is constrained by its initial value but not constant). Next, components of this object are updated as described below. The attribute reference then denotes a constant view of this updated object. The master and accessibility level of this object are defined as for the anonymous object of an aggregate. The assignments to components of the result object described below are assignment operations and include performance of any checks associated with evaluation of the target component name or with implicit conversion of the source value to the component subtype.

If `T` is a record type or record extension then the component updating referenced above proceeds as follows. For each component for which an expression is provided, the expression value is assigned to the corresponding component of the result object. The order in which the components are updated is unspecified.

For a prefix `X` that denotes an object of a nonlimited one dimensional array type `T`, the attribute

```
X'Update ( array_component_association {, array_component_association} )
```

is defined and yields a value of type `T`.

Each `array_component_association` of the attribute reference shall have one or more `array_component_associations`, each of which shall have an expression. The expected type and applicable index constraint of the expression is defined as for an `array_component_association` occurring within an array aggregate of type `T`. The expected type for each `discrete_choice` is the index type of `T`. The reserved word **others** shall not occur as a `discrete_choice` of an `array_component_association` of the attribute reference.

For a prefix `X` that denotes an object of a nonlimited multidimensional array type `T`, the attribute

```
X'Update ( multidimensional_array_component_association
           {, multidimensional_array_component_association} )
```

is defined with associated syntax

```
multidimensional_array_component_association ::=
  index_expression_list_list => expression
index_expression_list_list ::=
  index_expression_list { | index_expression_list }
index_expression_list ::=
  ( expression {, expression} )
```

and yields an object of type T.

The expected type and applicable index constraint of the expression of a `multidimensional_array_component_association` are defined as for the expression of an `array_component_association` occurring within an array aggregate of type T. The length of each `index_expression_list` shall equal the dimensionality of T. The expected type for each expression in an `index_expression_list` is the corresponding index type of T.

If T is a one-dimensional array type then the component updating referenced above proceeds as follows. The discrete choices and array component expressions are evaluated. Each array component expression is evaluated once for each associated component, as for an array aggregate. For each such associated component of the result object, the expression value is assigned to the component. Evaluations and updates are performed in the order in which the `array_component_associations` are given; within a single `array_component_association`, in the order of the `discrete_choice_list`; and within the range of a single `discrete_choice`, in ascending order.

If T is a multidimensional type then the component updating referenced above proceeds as follows. For each `multidimensional_array_component_association` (in the order in which they are given) and for each `index_expression_list` (in the order in which they are given), the index values of the `index_expression_list` and the expression are evaluated (in unspecified order) and the expression value is assigned to the component of the result object indexed by the given index values. Each array component expression is evaluated once for each associated `index_expression_list`.

Note: the Update attribute for an array object allows multiple assignments to the same component, as in either

```
Some_Array'Update (1 .. 10 => True, 5 => False)
```

or

```
Some_Array'Update (Param_1'Range => True, Param_2'Range => False)
-- ok even if the two ranges overlap
```

This is different from the Update attribute of a record

```
Some_Record'Update
(Field_1 => ... ,
 Field_2 => ... ,
 Field_1 => ... ); -- illegal; components not distinct
```

for which the order of component updates is unspecified.

4.4 Expressions

An expression is said to be *side-effect free* if the evaluation of the expression does not update any object. The evaluation of an expression free from side-effects only retrieves [or computes](#) a value.

An expression is in SPARK 2014 only if its type is in SPARK 2014 and the expression is side-effect free.

An expression (or range) in SPARK 2014 occurring in certain contexts (listed below) shall not have a variable input. This means that such an expression shall not read a variable, nor shall it call a function which (directly or indirectly) reads a variable. These contexts include:

- [a constraint](#);
- [the default](#) expression [of a discriminant](#) specification [or component](#) declaration;
- [a Dynamic](#) Predicate [aspect specification](#);
- [an indexing expresssion of an indexed](#) component [or the discrete](#) range [of a slice in an object renaming declaration which renames part of that index or slice](#).

[An expression in one of these contexts may read a constant which is initialized with the value of a variable.]

[The `Dynamic_Predicate` rule is redundant because no use of the `Dynamic_Predicate` is currently in SPARK 2014. This rule is added in anticipation of the possible relaxation of that restriction.]

4.5 Operators and Expression Evaluation

~~No extensions or restrictions~~ Ada grants implementations the freedom to reassociate a sequence of predefined operators of the same precedence level even if this changes the behavior of the program with respect to intermediate overflow (see Ada 2012 RM 4.5). SPARK 2014 assumes that an implementation does not take advantage of this permission; in particular, a proof of the absence of intermediate overflow in this situation may depend on this assumption.

[The GNAT Ada 2012 compiler does not take advantage of this permission. The GNAT compiler also provides an option for rejecting constructs to which this permission would apply. Explicit parenthesization can always be used to force a particular association in this situation.]

4.6 Type Conversions

No extensions or restrictions.

4.7 Qualified Expressions

No extensions or restrictions.

4.8 Allocators

The use of allocators is not allowed in SPARK 2014.

4.9 Static Expressions and Static Subtypes

No extensions or restrictions.

STATEMENTS

SPARK 2014 restricts the use of some statements, and adds a number of pragmas which are used for verification, particularly involving loop statements.

5.1 Simple and Compound Statements - Sequences of Statements

SPARK 2014 restricts statements that complicate verification, and excludes statements related to tasking and synchronization.

Extended Legality Rules

1. A `simple_statement` shall not be a `goto_statement`, an `entry_call_statement`, a `requeue_statement`, a `delay_statement`, an `abort_statement`, or a `code_statement`.
2. A `compound_statement` shall not be an `accept_statement` or a `select_statement`.

A statement is only in SPARK 2014 if all the constructs used in the statement are in SPARK 2014.

[A future release of SPARK 2014 is planned to support the Ravenscar multi-tasking profile and then some of the tasking statements such as `entry_call_statement`, and `delay_statement` will be permitted.]

5.2 Assignment Statements

No extensions or restrictions.

5.3 If Statements

No extensions or restrictions.

5.4 Case Statements

No extensions or restrictions.

5.5 Loop Statements

5.5.1 User-Defined Iterator Types

SPARK 2014 currently does not support the implementation of user-defined iterator types.

~~SPARK 2014 does not permit the use of variable iterators.~~

Todo

Need to consider further the support for iterators and whether the application of constant iterators could be supported.

~~To be completed in Milestone.4 version of this document.~~

~~Goals to be met by language features:~~ **Requirement:** ~~SPARK 2014 shall include feature/s to support proof of loop termination.~~

Rationale: ~~To aid detection of a serious programming error.~~

Requirement:

5.5.2 Generalized Loop Iteration

SPARK 2014 ~~shall include feature/s to support proof of partial correctness of code containing loops.~~

Rationale: ~~To support proof.~~

Requirement: ~~Within a loop, it shall be possible to refer to the value of a given variable on entry to that loop~~ currently does not support generalized loop iteration.

Rationale: ~~To support proof.~~

~~Constraints, Consistency, Semantics, General requirements: Not applicable~~

5.5.3 Loop Invariants, Variants and Entry Values

Two loop-related pragmas, ~~and~~ Loop_Invariant and Loop_Variant, and a loop-related attribute, Loop_Entry are defined. The pragma ~~is similar to pragma except for its proof semantics.~~ Pragma_Loop_Invariant is used to specify the essential non-varying properties of a loop Pragma_Loop_Variant is intended for use in ensuring termination. The Loop_Entry attribute is used to refer to the value that an expression had upon entry to a given loop in much the same way that the `Old` attribute in a subprogram postcondition can be used to refer to the value an expression had upon entry to the subprogram.

Syntax

```
loop_variant_parameters ::= loop_variant_item {, loop_variant_item}
loop_variant_item       ::= change_direction => discrete_expression
change_direction        ::= Increases | Decreases
```

Static Semantics

1. Pragma_Loop_Invariant is like a pragma Assert except it also acts as a cut point in formal verification. A cut point means that a prover is free to forget all information about modified variables that has been established within the loop. Only the given Boolean expression is carried forward..
2. Pragma_Loop_Variant is used to demonstrate that a loop will terminate by specifying expressions that will increase or decrease as the loop is executed.

Legality Rules

1. Loop_Invariant is just like pragma Assert with respect to syntax of its Boolean actual parameter, name resolution, legality rules ~~and~~ dynamic semantics, ~~and-assertion-policy, except for an legality rule except for extra legality rules~~ given below.
2. Loop_Variant has an expected actual parameter which is a specialization of an Ada expression. ~~In all other respects Otherwise~~, it has the same ~~syntax, name resolution, legality rules, and assertion-policy~~ name resolution and legality rules as pragma Assert, except for extra legality rules given below.

~~Loop has different dynamic semantics as detailed below:-~~

3. The following constructs are said to be restricted to loops:

- A Loop_Invariant pragma;

Syntax

- ~~Pragma A Loop_Variant expects a list of parameters which are a specialization of an Ada expression as follows:-~~ pragma;
- A block_statement whose sequence_of_statements or declarative_part immediately includes a construct which is restricted to loops.

~~To be completed in the Milestone-3 version of this document.~~

4. A construct which is restricted to loops shall occur immediately within either:

- the sequence_of_statements of a loop_statement; or
- the sequence_of_statements or declarative_part of a block_statement.

~~Provide detail on pragmas-~~

~~[Roughly speaking, a Loop_Invariant and-or Loop_Variant, and-attribute Loop. To be completed in the Milestone-pragmas shall only occur immediately within a loop statement except that intervening block statements are ignored for purposes of this rule.]~~

5. The expression of a loop_variant_item shall be of any discrete type.

Dynamic Semantics

1. Other than the above legality rules, pragma Loop_Invariant is equivalent to pragma Assert. Pragma Loop_Invariant is an assertion (as defined in Ada RM 11.4.2(1.1/3) ~~version of this document.~~) and is governed by the Loop_Invariant assertion aspect [and may be used in an Assertion_Policy pragma].

~~No extensions or restrictions.~~

2. The elaboration of an Checked Loop_Variant pragma begins by evaluating the discrete_expressions in textual order. For the first elaboration of the pragma within a given execution of the enclosing loop statement, no further action is taken. For subsequent elaborations of the pragma, one or more of these expression results are each compared to their corresponding result from the previous iteration as follows: comparisons are performed in textual order either until unequal values are found or until values for all expressions have been compared. In either case, the last pair of values to be compared is then checked as follows: if the change_direction for the associated loop_variant_item is Increases (respectively, Decreases) then a check is performed that the expression value obtained during the current iteration is greater (respectively, less) than the value obtained during the preceding iteration. The exception Assertions.Assertion_Error is raised if this check fails. All comparisons and checks are performed using predefined operations. Pragma Loop_Variant is an assertion (as defined in Ada RM 11.4.2(1.1/3)) and is governed by the Loop_Variant assertion aspect [and may be used in an Assertion_Policy pragma].

~~No extensions or restrictions.~~

~~The goto statement is not permitted in SPARK 2014.~~

Examples

The following example illustrates some pragmas of this section

~~This section discusses the pragmas Assert and Assume~~

```
procedure P is
  type Total is range 1 .. 100;
  subtype T is Total range 1 .. 10;
  I : T := 1;
  R : Total := 100;
begin
  while I < 10 loop
    pragma Loop_Invariant (R >= 100 - 10 * I);
    pragma Loop_Variant (Increases => I,
                        Decreases => R);

    R := R - I;
    I := I + 1;
  end loop;
end P;
```

Note that in this example, the loop variant is unnecessarily complex, stating that I increases is enough to prove termination of this simple loop.

Attribute Loop_Entry

Static Semantics

- ~~1. **Goals to be met by language feature:** For a prefix X that denotes an object of a nonlimited type, the following attribute is defined:~~

~~:: X'Loop_Entry [(loop_name)]~~

- ~~1. **Requirement:** It shall be possible for users to explicitly state assumptions within the text of a subprogram to support the formal verification of that subprogram~~The value of X'Loop_Entry [(loop_name)] is the value of X on entry to the loop that is denoted by loop_name. If the optional loop_name parameter is not provided, the closest enclosing loop is the default.

~~**Rationale:**~~**Legality Rules** This allows facts about the domain to be used in a proof in a clean and explicit way

- ~~1. A Loop_Entry attribute_reference *applies to a loop_statement in the same way that an exit_statement does* (see Ada RM 5.7). For every rule about exit_statements in the Name Resolution Rules and Legality Rules sections of Ada RM 5.7, a corresponding rule applies to Loop_Entry attribute_references.~~
- ~~2. In many cases, the language rules pertaining to the Loop_Entry attribute match those pertaining to the Old attribute (see Ada LRM 6.1.1), except with “Loop_Entry” substituted for “Old”. These include:~~
 - ~~• **Requirement:** It shall be possible for users to assert at a given point within a subprogram the minimum set of facts required to complete formal verification of that subprogram~~prefix name resolution rules (including expected type definition)
 - nominal subtype definition
 - accessibility level definition
 - run-time tag-value determination (in the case where X is tagged)
 - interactions with abstract types
 - interactions with anonymous access types

- forbidden attribute uses in the prefix of the `attribute_reference`.

Rationale: ~~This allows an explicit statement of what is necessary to complete formal verification and also assists the efficiency of that verification.~~

The following rules are not included in the above list; corresponding rules are instead stated explicitly below:

- the requirement that an Old `attribute_reference` shall only occur in a postcondition expression;
 - the rule disallowing a use of an entity declared within the postcondition expression;
 - the rule that a potentially unevaluated Old `attribute_reference` shall statically denote an entity;
 - the prefix of the `attribute_reference` shall not contain a Loop_Entry `attribute_reference`.
3. ~~Constraints, Consistency, Semantics, General requirements:~~ A Loop_Entry `attribute_reference` shall occur within a Loop_Variant or Loop_Invariant pragma.
 4. The prefix of a Loop_Entry `attribute_reference` shall not contain a use of an entity declared within the `loop_statement` but not within the prefix itself.

[This rule is to allow the use of I in the following example:

```
loop
  pragma Assert
    ((Var > Some_Function (Param => (for all I in T => F (I))))'Loop_Entry);
```

In this example the value of the inequality “>” that would have been evaluated on entry to the loop is obtained even if the value of Var has since changed].

5. The prefix of a Loop_Entry `attribute_reference` shall statically denote an entity, or shall denote an `object_renaming_declaration` if
 - ~~Not applicable~~ the `attribute_reference` is potentially unevaluated; or
 - the `attribute_reference` does not apply to the innermost enclosing `loop_statement`.

[This rule follows the corresponding Ada RM rule for ‘Old The prefix of an Old `attribute_reference` that is potentially unevaluated shall statically denote an entity and have the same rationale. If the following was allowed:

```
procedure P (X : in out String; Idx : Positive) is
begin
  Outer :
    loop
      if Idx in X'Range then
        loop
          pragma Loop_Invariant (X(Idx) > X(Idx)'Loop_Entry(Outer));
```

this would introduce an exception in the case where Idx is not in X'Range.]

Dynamic Semantics

1. For each X'Loop_Entry other than one occurring within an Ignored assertion expression, a constant is implicitly declared at the beginning of the associated loop statement. The constant is of the type of X and is initialized to the result of evaluating X (as an expression) at the point of the constant declaration. The value of X'Loop_Entry is the value of this constant; the type of X'Loop_Entry is the type of X. These implicit constant declarations occur in an arbitrary order.
2. The previous paragraph notwithstanding, the implicit constant declaration is not elaborated if the `loop_statement` has an `iteration_scheme` whose evaluation yields the result that the `sequence_of_statements` of the `loop_statement` will not be executed (loosely speaking, if the loop completes after zero iterations).

[Note: This means that the constant is not elaborated unless the loop body will execute (or at least begin execution) at least once. For example, a while loop

```
while <condition> do
  sequence_of_statements; -- contains Loop_Entry uses
end loop;
```

may be thought of as being transformed into

```
if <condition> then
  declare
    ... implicitly declared Loop_Entry constants
  begin
    loop
      sequence_of_statements;
      exit when not <condition>;
    end loop;
  end;
end if;
```

The rule also prevents the following example from raising Constraint_Error:

```
declare
  procedure P (X : in out String) is
  begin
    for I in X'Range loop
      pragma Loop_Invariant (X(X'First)'Loop_Entry >= X(I));
      ...; -- modify X
    end loop;
  end P;
  Length_Is_Zero : String := "";
begin
  P (Length_Is_Zero);
end;]
```

5.6 Block Statements

No extensions or restrictions.

5.7 Exit Statements

No extensions or restrictions.

5.8 Goto Statements

The goto statement is not permitted in SPARK 2014.

5.9 Proof Pragmas

This section discusses the pragmas Assert_And_Cut and Assume.

Two SPARK 2014 pragmas are defined, `Assert_And_Cut` and `Assume`. Each has a single Boolean parameter and may be used wherever pragma `Assert` is allowed.

A Boolean expression which is an actual parameter of pragma `Assume` can be assumed to be True for the remainder of the subprogram. ~~No~~ If the `Assertion_Policy` is `Check` for pragma `Assume` and the Boolean expression does not evaluate to True, the exception `Assertions.Assertion_Error` will be raised. However, in proof, no verification of the expression is performed and in general it cannot. It has to be used with caution and is used to state axioms.

Static Semantics

1. Pragma `Assert_And_Cut` ~~and `Loopare` similar to an `Assert` statement except they also act as a cut point is the same as a pragma `Assert` except it also acts as a cut point~~ in formal verification. ~~A~~ The cut point means that a prover is free to forget all information about modified variables that has been established from the statement list before the cut point. Only the given Boolean expression is carried forward.

~~Assert, Assume and Loopare~~

2. Pragma `Assume` is the same as ~~pragma `Assert` with respect to Syntax, Name Resolution, Legality Rules, Dynamic Semantics, and assertion policy. Apart from the legality rule that restricts the use of `Loop` to a loop (see a pragma `Assert` except that there is no proof obligation to prove the truth of the Boolean expression that is its actual parameter. [Pragma `Assume` indicates to proof tools that the expression can be assumed to be True]).~~

~~(TJJ-21-Feb-2013) `Loop` is partially covered in two separate sections when we re-instate and complete the loop invariant, variant, loop entry value text we should rationalize the placement of the description of loop invariant to one section.~~

Verification Legality Rules

1. ~~Pragma `Pragmas` `Assert_And_Cut` and `Loop` have similar rules to pragma `Assert` and follow from the usual rule that any runtime check in this case, the check is that the evaluation of the assertion expression yields True introduces a corresponding proof obligation. The difference is that these two pragmas introduce cut points: which indicate to a prover that it may, after proving the truth of the assertion, dispose of certain other conclusions that may have been inferred at that point~~ Assume have the same syntax for their Boolean actual parameter, name resolution rules and dynamic semantics as pragma `Assert`.

Verification Rules

1. The verification rules for pragma `Assume` are significantly different to that pragma `Assert`. [It would be difficult to overstate the importance of the difference.] Even though the dynamic semantics of pragma `Assume` and pragma `Assert` are identical, pragma `Assume` does not introduce a corresponding proof obligation. Instead the prover is given permission to assume the truth of the assertion, even though this has not been proven. [A single incorrect `Assume` pragma can invalidate an arbitrarily large number of proofs - the responsibility for ensuring correctness rests entirely upon the user.]

Examples The following example illustrates some pragmas of this section-

~~Note that in this example, the loop variant is unnecessarily complex, stating that increases is enough to prove termination of this simple loop.~~

SUBPROGRAMS

6.1 Subprogram Declarations

We distinguish the *declaration view* introduced by a `subprogram_declaration` from the *implementation view* introduced by a `subprogram_body` or an `expression_function_declaration`. For subprograms that are not declared by a `subprogram_declaration`, the `subprogram_body` or `expression_function_declaration` also introduces a declaration view which may be in SPARK 2014 even if the implementation view is not.

Rules are imposed in SPARK 2014 to ensure that the execution of a function call does not modify any variables declared outside of the function. It follows as a consequence of these rules that the evaluation of any SPARK 2014 expression is side-effect free.

We also introduce the notion of a *global item*, which is a name that denotes a global ~~variable-object~~ or a state abstraction (see *Abstraction of State*). Global items are presented in Global aspects (see *Global Aspect*).

An *entire object* is an object which is not a subcomponent of a larger containing object. More specifically, an *entire object* is an object declared by an ~~object~~`object_declaration` (as opposed to, for example, a slice or the result object of a function call) or a formal parameter of a subprogram. ~~An entire variable is an an entire object which is a variable.~~

Static Semantics

1. The ~~final~~exit value of a global item or parameter of a subprogram is its value immediately following the successful call of the subprogram.
2. The ~~initial~~entry value of a global item or parameter of a subprogram is its value at the call of the subprogram.
3. An *output* of a subprogram is a global item or parameter whose final value may be updated by a call to the subprogram. The result of a function is also an output.
4. An *input* of a subprogram is a global item or parameter whose initial value may be used in determining the ~~final~~exit value of an output of the subprogram.

As a special case, a global item or parameter is also ~~considered~~ an input if it is ~~deemed to have no observable effect on any output of the subprogram but is only used in determining a null value. Such a null value can only be specified using a an explicit~~ mentioned in a `null_dependency_clause` in the Depends aspect of the subprogram (see *Depends Aspect*).

Verification Rules

1. A function declaration shall not have a `parameter_specification` with a mode of **out** or **in out**. This rule also applies to a ~~subprogram~~`subprogram_body` for a function for which no explicit declaration is given.

~~In the future we may be able to permit access and aliased formal parameter specs. Target: Release 2 of SPARK 2014 language and toolset or later.~~

~~What do we do regarding null-exclusion parameters? To be completed in the Milestone 3 version of this document.~~

~~What do we do regarding function access results and function null-exclusion results? To be completed in the Milestone 3 version of this document.~~

6.1.1 Preconditions and Postconditions

As indicated by the `aspect_specification` being part of a `subprogram_declaration`, a subprogram is in SPARK 2014 only if its specific contract expressions (introduced by `Pre` and `Post`) ~~and class-wide contract expressions (introduced by `Pre'Class` and `Post'Class`)~~, if any, are in SPARK 2014.

~~For an `expression_function_declaration`, `F`, without an explicit `Postcondition`, the expression, `E`, implementing the function acts as its `Postcondition`, that is the default postcondition is `F'Result = E`.~~

~~Think about `Pre'Class` and `Post'Class`. To be completed in the Milestone 3 version of this document.~~
~~In general the expression, `E`, of a postcondition of a function may be used as the expression of an `expression_function_declaration` instead making `E` both the implementation of the function and the expression of its [default] postcondition.~~

6.1.2 Subprogram Contracts

In order to extend Ada's support for specification of subprogram contracts (e.g., the `Pre`, ~~`Post`, `Pre'Class` and `Post'Class` aspects~~ and `Post`) by providing more precise and/or concise contracts, the SPARK 2014 aspects, `Global`, `Depends`, and `Contract_Cases` are defined.

Legality Rules

1. The `Global`, `Depends` and `Contract_Cases` aspects may be specified for a subprogram with an `aspect_specification`. More specifically, these aspects are allowed in the same contexts as a `Pre` or `Post` aspect.

See section *Contract Cases* for further detail on `Contract_Case` aspects, section *Global Aspect* for further detail on `Global` aspects and section *Depends Aspect* for further detail on `Depends` aspects.

6.1.3 Contract Cases

~~Goals to be met by language feature: **Requirement:** It shall be possible to specify pre- and post-conditions in a concise way in the case that subprogram behaviour is specified in terms of what behaviour should be in each of a series of mutually-independent cases.~~

~~**Rationale:** To provide a more structured way of specifying subprogram behaviour.~~

~~Constraints, Consistency, Semantics, General requirements: Not applicable~~

The `Contract_Cases` aspect provides a structured way of defining a subprogram contract using mutually exclusive subcontract cases. The final case in the `Contract_Case` aspect may be the keyword **others** which means that, in a specific call to the subprogram, if all the `conditions` are `False` this `contract_case` is taken. If an **others** `contract_case` is not specified, then in a specific call of the subprogram exactly one of the guarding `conditions` should be `True`.

A `Contract_Cases` aspect may be used in conjunction with the language-defined aspects `Pre` and `Post` in which case the precondition specified by the `Pre` aspect is augmented with a check that exactly one of the `conditions` of the `contract_case_list` is satisfied and the postcondition specified by the `Post` aspect is conjoined with conditional expressions representing each of the `contract_cases`. For example:

```

procedure P (...)
  with Pre  => General_Precondition,
       Post => General_Postcondition,
       Contract_Cases => (A1 => B1,
                          A2 => B2,
                          ...
                          An => Bn);

```

is short hand for

```

procedure P (...)
  with Pre  => General_Precondition
           and then Exactly_One_Of (A1,A2...An),
       Post => General_Postcondition
           and then (if A1'Old then B1)
           and then (if A2'Old then B2)
           and then ...
           and then (if An'Old then Bn);

```

where

A1 .. An are Boolean expressions involving the initial-entry values of formal parameters and global variables-objects and

B1 .. Bn are Boolean expressions that may also use the final-exit values of formal parameters, global variables-objects and results.

Exactly_One_Of (A1,A2...An) evaluates to True if exactly one of its inputs evaluates to True and all other of its inputs evaluate to False.

The Contract_Cases aspect is specified with an aspect_specification where the aspect_mark is Contract_Cases and the aspect_definition must follow the grammar of contract_case_list given below.

Syntax

```

contract_case_list ::= (contract_case {, contract_case})
contract_case      ::= condition => consequence
                    | others => consequence

```

where

```
consequence ::= Boolean_expression
```

Legality Rules

1. A Contract_Cases aspect may have at most one **others** contract_case and if it exists it must be the last one in the contract_case_list.
2. A consequence expression is considered to be a postcondition expression for purposes of determining the legality of Old or Result attribute_references.

Static Semantics

1. A Contract_Cases aspect is an assertion (as defined in RM 11.4.2(1.1/3)); its assertion expressions are as described below. Contract_Cases may be specified as an assertion_aspect_mark in an Assertion_Policy pragma.

Dynamic Semantics

1. Upon a call of a subprogram or-entry which is subject to an enabled Contract_Cases aspect, Contract_Cases checks are performed as follows:

- Immediately after the specific precondition expression is evaluated and checked (or, if that check is disabled, at the point where the check would have been performed if it were enabled), all of the `conditions` of the `contract_case_list` are evaluated in textual order. A check is performed that exactly one (if no **others** `contract_case` is provided) or at most one (if an **others** `contract_case` is provided) of these `conditions` evaluates to True; `Assertions.Assertion_Error` is raised if this check fails.
- Immediately after the specific postcondition expression is evaluated and checked (or, if that check is disabled, at the point where the check would have been performed if it were enabled), exactly one of the `consequences` is evaluated. The consequence to be evaluated is the one corresponding to the one `condition` whose evaluation yielded True (if such a `condition` exists), or to the **others** `contract_case` (if every `condition`'s evaluation yielded False). A check is performed that the evaluation of the selected consequence evaluates to True; `Assertions.Assertion_Error` is raised if this check fails.

Verification Rules

1. Each `condition` in a `Contract_Cases` aspect has to be proven to be mutually exclusive, that is only one condition can be True with any set of inputs conformant with the formal parameters and satisfying the specific precondition.
2. At the point of call a check that a single `condition` of the `Contract_Cases` aspect is True has to be proven, or if no condition is True then the `Contract_Cases` aspect must have an **others** `contract_case`.
3. For every `contract_case`, when its `condition` is True, or the **others** `contract_case` when none of the conditions are True, the implementation of the body of the subprogram must be proven to satisfy the consequence of the `contract_case`.

Todo

(TJJ 29/11/12) Do we need this verification rule? Could it be captured as part of the general statement about proof?
[To be completed in milestone 4 version of this document.](#)

6.1.4 Global Aspect

~~Goals to be met by language feature:~~ **Requirement:** It shall be possible to specify the list of global data read and updated when the subprogram is called. Note that the data read can include data used in proof contexts, including assertions.

~~**Rationale:** to allow provision of at least the same functionality as SPARK 2005 and to allow modular analysis~~ [A Global aspect of a subprogram lists the global items whose values are used or affected by a call of the subprogram.](#)

~~**Requirement:** It shall be possible to specify the mode (input, output or both) for each global data item.~~

~~**Rationale:** This matches the presentation of formal parameters, and the information is used by both flow analysis and proof~~ [The Global aspect may only be specified for the initial declaration of a subprogram \(which may be a declaration, a body or a body stub\). The implementation of a subprogram body must be consistent with the subprogram's Global aspect.](#)

[Note that a Refined_Global aspect may be applied to a subprogram body when using state abstraction; see section Refined_Global Aspect](#) **Requirement:** It shall be possible to identify globals that are used only in proof contexts [for further details.](#)

~~**Rationale:** since the list of global data items constrains the data that can be read and updated when the subprogram is called, then the global data list needs to cover data items that are read in proof contexts.~~ [The Global aspect is introduced by an aspect_specification where the aspect_mark is Global and the aspect_definition must follow the grammar of global_specification](#)

Syntax


```

global_specification      ::= (moded_global_list {, moded_global_list})
                           | global_list
                           | null_global_specification
moded_global_list         ::= mode_selector => global_list
global_list               ::= global_item
                           | (global_item {, global_item})
mode_selector             ::= Input | Output | In_Out | Proof_In
global_item               ::= name
null_global_specification ::= null

```

Static Semantics

1. ~~Constraints:—No further Global-specific requirements needed~~ A global_specification that is a global_list is shorthand for a moded_global_list with the mode_selector Input.
2. ~~Consistency~~ A global_item is referenced by a subprogram if:
 - ~~Requirement: The mode associated with a formal parameter~~ It denotes an input or an output of the subprogram, or;
 - ~~of an enclosing subprogram~~ Its entry value is used to determine the value of an assertion expression within the subprogram, or;
 - ~~or volatile variable in a global data list shall be consistent with the mode associated with it at the point of its declaration.~~

~~Rationale: this provides an early basic consistency check~~ Its entry value is used to determine the value of an assertion expression within another subprogram that is called either directly or indirectly by this subprogram.
3. ~~Semantics: Requirement: A global data item with an input mode is read on at least one executable path~~ A null_global_specification indicates that the subprogram does not reference any global_item directly or indirectly.

~~Rationale: by definition.~~

Name Resolution Rules

1. ~~Requirement: A global data item with an output mode is written on at least one executable path~~ A global_item shall denote an entire object or a state abstraction. [This is a name resolution rule because a global_item can unambiguously denote a state abstraction even if a function having the same fully qualified name is also present].

~~Rationale: by definition.~~

Legality Rules

1. ~~Requirement: A global data item with an output mode but no input mode is written on all executable paths.~~

~~Rationale: to ensure that data items with output mode are always initialized on completion of a call to the subprogram~~ For a subprogram that has a global_specification, an entire object that is outside the subprogram, can only be referenced within if it is a global_item in the global_specification.
2. ~~Requirement: A global data item that is only read in a proof context shall not have an input or output mode.~~

~~Rationale: the effect of reading data items in a proof context is fundamentally different from the reading of data items outside of a proof context, since the former does not contribute to information flow relations.~~

A global_item shall not denote a constant object other than a formal parameter [General requirements: of an enclosing subprogram] See also section of mode in. [This restriction may be relaxed in some way at some point in the future.] :-

~~A Global aspect~~

3. The Global aspect may only be specified for the initial declaration of a subprogram ~~lists the global items whose values are used or affected by a call of the subprogram (which may be a declaration, a body or a body stub).~~

~~The Global aspect is introduced by an where the is Global and the must follow the grammar of~~

Syntax ::= null

Legality Rules

4. A `global_item` shall ~~denote an entire variable or not denote~~ a state abstraction ~~; this rule is a name resolution rule.~~

~~(SB) This rule may eventually be relaxed to allow references to non-static constants, whose refinement is visible [(a state abstraction cannot be named within its enclosing package's body other than in its refinement)].~~

5. Each `mode_selector` shall occur at most once in a single Global aspect.
6. A function subprogram ~~may shall~~ not have a `mode_selector` of ~~or~~ `Output` or `In_Out` in its Global aspect.
7. The `global_items` in the same a single Global aspect specification shall denote distinct ~~objects or state abstractions/entities.~~
8. A `global_item` occurring in a Global aspect specification of a subprogram ~~aspect specification~~ shall not denote a formal parameter of the subprogram.

Static Semantics ~~A that is a is considered to be a with the Input.~~

9. ~~A If a subprogram is~~ referenced by a subprogram if: It is an input or an output of the subprogram, or;

~~Its initial value is used to determine the value of an assertion expression within the subprogram, or;~~

~~Its initial value is used to determine the value of an assertion expression within another subprogram that is called either directly or indirectly by this subprogram.~~

~~A indicates that the subprogram does not reference any nested within another and if the global_specification of the outer subprogram has an entity denoted by a global_item directly or indirectly with a mode_specification of Input, then a global_item of the global_specification of the inner subprogram shall not denote the same entity with a mode_selector of In_Out or Output.~~

Dynamic Semantics

There are no dynamic semantics associated with a Global aspect as it is used purely for static analysis purposes and is not executed.

Verification Rules

~~There are no verification rules associated with~~

1. A `global_item` shall occur in a Global aspect of a subprogram ~~declaration. The rules given in the Subprogram Bodies section under Global aspects are checked when a subprogram body is analyzed.~~

Examples

if and only if it denotes an entity that is referenced by the subprogram.

2. ~~Goals to be met by language feature~~ Each entity denoted by a `global_item` in a `global_specification` of a subprogram that is an input or output of the subprogram shall satisfy the following mode specification rules [which are checked during analysis of the subprogram body]:

- **Requirement:** It shall be possible to specify the dependency relation—that is, which outputs are dependent on which inputs—that is met by a given subprogram.

Rationale: To allow provision of at least the same functionality as SPARK 2005 and to allow modular analysis, a `global_item` that denotes an input but not an output has a `mode_selector` of `Input`;

- **Requirement:** It shall be possible to refer to both global data and formal parameters in the dependency relation.

Rationale: The inputs and outputs are given by both the global data and the formal parameters. a `global_item` that denotes an output but not an input and is always fully initialized as a result of any successful execution of a call of the subprogram has a `mode_selector` of `Output`;

- **Requirement:** It shall be possible to assume an implicit dependency relation on functions and so an explicit statement shall not be required.

Rationale: this is typical usage and saves effort otherwise the `global_item` denotes both an input and an output, is has a `mode_selector` of `In_Out`.

Constraints: No further Depends-specific requirements needed.

Semantics: For purposes of determining whether an output of a subprogram shall have a `mode_selector` of `Output` or `In_Out`, reads of array bounds, discriminants, or tags of any part of the output are ignored. Similarly, for purposes of determining whether an entity is “fully initialized as a result of any successful execution of the call”, only nondiscriminant parts are considered. **Requirement:** That (X, Y) is in the dependency relation for a given subprogram (i.e. X depends on Y) means that X is This implies that given an output of the subprogram such that the initial value of the input Y is used to set the final value of X on at least one executable path.

Rationale: by definition.

Consistency: **Requirement:** The dependency relation defines an alternative view of the inputs and outputs of the subprogram and that view must be equivalent to the list of global data items and formal parameters and their modes (ignoring data items used only in proof contexts).

Rationale: this provides a useful early consistency check.

a discriminated type that is not known to be constrained (“known to be constrained” is defined in Ada RM 3.3), the discriminants of the output might or might not be updated by the call.] **General requirements:**

1. **See also section** An entity that is denoted by a `global_item` which is referenced by a subprogram but is neither an input nor an output but is only referenced directly, or indirectly in assertion expressions has a `mode_selector` of `Proof_In`.

Examples

```
with Global => null; -- Indicates that the subprogram does not reference
                    -- any global items.
with Global => V;    -- Indicates that V is an input of the subprogram.
with Global => (X, Y, Z); -- X, Y and Z are inputs of the subprogram.
with Global => (Input  => V); -- Indicates that V is an input of the subprogram.
with Global => (Input  => (X, Y, Z)); -- X, Y and Z are inputs of the subprogram.
with Global => (Output  => (A, B, C)); -- A, B and C are outputs of
                    -- the subprogram.
with Global => (In_Out  => (D, E, F)); -- D, E and F are both inputs and
                    -- outputs of the subprogram
with Global => (Proof_In => (G, H));  -- G and H are only used in
                    -- assertion expressions within
                    -- the subprogram

with Global => (Input    => (X, Y, Z),
               Output   => (A, B, C),
               In_Out   => (P, Q, R),
               Proof_In => (T, U));
-- A global aspect with all types of global specification
```

6.1.5 Depends Aspect

A Depends aspect defines a *dependency relation* for a subprogram which may be given in the `aspect_specification` of the subprogram. The dependency relation is used in information flow analysis.

~~Depends aspects are simple specifications.~~

A Depends aspect for a subprogram specifies for each output every input on which it depends. The meaning of ~~X depends on Y~~ X depends on Y in this context is that the ~~final-exit~~ value of output, X, on the completion of the subprogram is at least partly determined from the ~~initial-entry~~ value of input, Y, and is written ~~X=>Y~~ X=>Y. As in UML, the entity at the tail of the arrow depends on the entity at the head of the arrow.

If an output does not depend on any input this is indicated using a **null**, e.g., ~~X=>~~ X=> **null**. An output may be self-dependent but not dependent on any other input. The shorthand notation denoting self-dependence is useful here, ~~X=>+ null~~.

The functional behavior of a subprogram is not specified by the Depends aspect but, unlike a postcondition, the Depends aspect has to be complete in the sense that every input and output of the subprogram must appear in the Depends aspect.

The Depends aspect may only be specified for the initial declaration of a subprogram (which may be a declaration, a body or a body stub). The implementation of a subprogram body must be consistent with the subprogram's Depends Aspect.

Note that a Refined_Depends aspect may be applied to a subprogram body when using state abstraction; see section Refined_Depends Aspect for further details.

The Depends aspect is introduced by an `aspect_specification` where the `aspect_mark` is Depends and the `aspect_definition` must follow the grammar of `dependency_relation` given below.

Syntax

```

dependency_relation    ::= null
                        | (dependency_clause {, dependency_clause})
dependency_clause      ::= output_list =>[+] input_list
                        | null_dependency_clause
null_dependency_clause ::= null => input_list
output_list             ::= output
                        | (output {, output})
input_list              ::= input
                        | (input {, input})
                        | null
input                  ::= name
output                 ::= name | function_result

```

where

`function_result` is a function Result attribute_reference.

Legality-Name Resolution Rules

1. ~~Every An input and-or output of a dependency_relation of a Depends aspect shall denote an entire variable shall denote only an entire object or a state abstraction; this rule.~~ [This is a name resolution rule because an input or output can unambiguously denote a state abstraction even if a function having the same fully qualified name is also present.]

(SB) This rule may eventually be relaxed to allow references to non-static constants as inputs.

Legality Rules

1. The Depends aspect shall only be specified for the initial declaration of a subprogram (which may be a declaration, a body or a body stub).

2. An input ~~must have a mode of in~~ or ~~in-out~~ and an output ~~must have an mode of of~~ a dependency_relation shall not denote a state abstraction whose refinement is visible [a state abstraction cannot be named within its enclosing package's body other than in its refinement].
3. The explicit input set of a subprogram is the set of formal parameters of the subprogram of mode in and in-out along with the entities denoted by global_items of the Global aspect of the subprogram with a mode_selector of Input and In_Out.
4. The input set of a subprogram is the explicit input set of the subprogram augmented with those formal parameters of mode in-out- having discriminants, array bounds, or a tag which can be read and whose values are not implied by the subtype of the parameter. More specifically, it includes formal parameters of mode out which are of an unconstrained array subtype, an unconstrained discriminated subtype, a tagged type, or a type having a subcomponent of an unconstrained discriminated subtype. [Note: As a consequence an entity which is both an and an shall have a mode of in-out. Tagged types are mentioned in this rule in anticipation of a later version of SPARK 2014 in which the current restriction on uses of the 'Class attribute is relaxed; currently there is no way to read or otherwise depend on the underlying tag of an out mode formal parameter of a tagged type.]
5. The output set of a subprogram is the set of formal parameters of the subprogram of mode in out and out along with the entities denoted by global_items of the Global aspect of the subprogram with a mode_selector of In_Out and Output and (for a function) the function_result.
6. The entity denoted by each input of a dependency_relation of a subprogram shall be a member of the input set of the subprogram.
7. Every member of the explicit input set of a subprogram shall be denoted by at least one input of the dependency_relation of the subprogram.
8. The entity denoted by each output of a dependency_relation of a subprogram shall be a member of the output set of the subprogram.
9. Every member of the output set of a subprogram shall be denoted by exactly one output in the dependency_relation of the subprogram.
10. For the purposes of determining the legality of a Result attribute_reference, a dependency_relation is considered to be a postcondition of the function to which the enclosing aspect_specification applies.
11. ~~There In a dependency_relation there~~ can be at most one dependency_clause which is a ~~null symbol-null_dependency_clause~~ and if it exists it must be the ~~of-the-last~~ dependency_clause in the dependency_relation. ~~An which is in an of a null may not appear in another of the same.~~
12. ~~The entity denoted by an in an shall not be denoted by any other in that or any other.~~
The An entity denoted by an input which is in an input_list of a null output_list shall not be denoted by any other an input in that another input_list of the same dependency_relation.
13. ~~Every of the subprogram shall appear in exactly one.~~
Every of the subprogram shall appear in at least one The inputs in a single input_list shall denote distinct entities.
14. A null_dependency_clause shall not have an input_list of null.

Static Semantics

1. ~~The grammar terms and have the meaning given to input and output given in.~~

~~A has the meaning that the final value of every in the is dependent on the initial value of every in the.~~

A dependency_clause with a "+" symbol in the syntax `output_list =>+ input_list` means that each output in the `output_list` has a *self-dependency*, that is, it is dependent on itself. [The text (A, B, C) =>+ Z is shorthand for (A => (A, Z), B => (B, Z), C => (C, Z)).]

2. A `dependency_clause` of the form `A =>+ A` has the same meaning as `A => A`. [The reason for this rule is to allow the short hand: $((A, B) \Rightarrow (A, C))$ which is equivalent to $(A \Rightarrow (A, C), B \Rightarrow (A, B, C))$.]
3. A `dependency_clause` with a `null` `input_list` means that the final value of the entity denoted by each output in the `output_list` does not depend on any member of the input set of the subprogram (other than itself, if the `output_list =>+ null` self-dependency syntax is used).
4. ~~A represents a sink for each in the.~~ The inputs in the `input_list` ~~have no discernible effect from an information flow analysis viewpoint. The purpose of a null_dependency_clause is to facilitate the abstraction and calling of subprograms whose implementation is not in SPARK 2014.~~ may be read by the subprogram but play no role in determining the values of any outputs of the subprogram.
5. A `Depends` aspect of a subprogram with a `null` `dependency_relation` indicates that the subprogram has no inputs or outputs. [From an information flow analysis viewpoint it is a null operation (a no-op).]
6. ~~A function which does not have~~ A function without an explicit `Depends` aspect specification is assumed to have the `dependency_relation` that its result is dependent on all of its inputs. ~~Generally a~~ Generally an explicit `Depends` aspect is not required for functions.]
7. [A subprogram which has an explicit `Depends` aspect specification and lacks an explicit `Global` aspect specification is assumed to have the [unique] `Global` aspect specification that is consistent with the subprogram's `Depends` aspect.]
8. [A subprogram which has an explicit `Global` aspect specification but lacks an explicit `Depends` aspect specification and, as yet, has no implementation of its body is assumed to have the conservative `dependency_relation` that each member of the output set is dependent on every member of the input set.]

~~Add rules relating to volatile state. To be completed in the Milestone 3 version of this document.~~

Dynamic Semantics

There are no dynamic semantics associated with a `Depends` aspect as it is used purely for static analysis purposes and is not executed.

Verification Rules

~~There are no verification rules associated with a~~

1. Each entity denoted by an output given in the `Depends` aspect of a subprogram ~~declaration. The rules given in the Subprogram Bodies section under Depends aspects are checked when a subprogram body is analyzed~~ must be an output in the implementation of the subprogram body and the output must depend on all, but only, the entities denoted by the inputs given in the input_list associated with the output.
2. Each output of the implementation of the subprogram body is denoted by an output in the Depends aspect of the subprogram.

~~Consider whether to capture the rules from SPARK 2005 about flow=auto mode in this document or whether it is purely a tool issue (in SPARK 2005, in flow=auto mode if a subprogram is missing a dependency relation then the flow analysis assumes all outputs)~~
3. [Each input of the implementation of a subprogram body is denoted by an input of the Depends aspect of the subprogram ~~are derived from all of its inputs).~~]

Examples

```

procedure P (X, Y, Z in : Integer; Result : out Boolean)
  with Depends => (Result => (X, Y, Z));
-- The exit value of Result depends on the entry values of X, Y and Z

procedure Q (X, Y, Z in : Integer; A, B, C, D, E : out Integer)
  with Depends => ((A, B) => (X, Y),

```

```

        C      => (X, Z),
        D      => Y,
        E      => null);
-- The exit values of A and B depend on the entry values of X and Y.
-- The exit value of C depends on the entry values of X and Z.
-- The exit value of D depends on the entry value of Y.
-- The exit value of E does not depend on any input value.

procedure R (X, Y, Z : in Integer; A, B, C, D : in out Integer)
  with Depends => ((A, B) =>+ (A, X, Y),
                  C      =>+ Z,
                  D      =>+ null);
-- The "+" sign attached to the arrow indicates self-dependency, that is
-- the exit value of A depends on the entry value of A as well as the
-- entry values of X and Y.
-- Similarly, the exit value of B depends on the entry value of B
-- as well as the entry values of A, X and Y.
-- The exit value of C depends on the entry value of C and Z.
-- The exit value of D depends only on the entry value of D.

procedure S
  with Global  => (Input  => (X, Y, Z),
                  In_Out => (A, B, C, D)),
  Depends => ((A, B) =>+ (A, X, Y, Z),
              C      =>+ Y,
              D      =>+ null);
-- Here globals are used rather than parameters and global items may appear
-- in the Depends aspect as well as formal parameters.

function F (X, Y : Integer) return Integer
  with Global  => G,
  Depends => (F'Result => (G, X),
             null      => Y);
-- Depends aspects are only needed for special cases like here where the
-- parameter Y has no discernible effect on the result of the function.

```

6.1.6 Ghost Functions

Ghost functions are intended for use in discharging proof obligations and in making it easier to express assertions about a program. The essential property of ghost functions is that they have no effect on the dynamic behavior of a valid SPARK program other than, depending on the assertion policy, the execution of known to be true assertion expressions. More specifically, if one were to take a valid SPARK program and remove all ghost function declarations from it and all assertions containing references to those functions, then the resulting program might no longer be a valid SPARK program (e.g., it might no longer be possible to discharge all the program's proof obligations) but its dynamic semantics (when viewed as an Ada program) should be unaffected by this transformation other than evaluating fewer known to be true assertion expressions.

The rules below are given in general terms in relation to “ghost entities” since in future it is intended that ghost types and ghost variables will be allowed. Currently, however, only ghost functions are allowed and so an additional legality rule is provided that allows only functions to be explicitly declared as a ghost (though entities declared within a ghost function are regarded implicitly as ghost entities). When the full scope of ghost entities is allowed, the rules given in this section may be moved to other sections as appropriate, since they will refer to more than just subprograms.

Todo

Add ghost types and ghost variables to SPARK 2014. To be completed in a post-Release 1 version of this document.

Static Semantics

1. ~~Goals to be met by language feature:~~ SPARK 2014 defines the convention_identifier Ghost. An entity (e.g., a subprogram or an object) whose Convention aspect is specified to have the value Ghost is said to be a ghost entity (e.g., a ghost function or a ghost variable).
2. ~~**Requirement:** It shall be possible to specify functions which are used for testing and verification only. Their presence should have no effect on the functionality of program execution which terminates normally (without exception).~~

~~**Rationale:** In principle such functions could be removed from the code (possibly automatically by the compiler) on completion of testing and verification and have no effect on the functionality of the program. The Convention aspect of an entity declared inside of a ghost entity (e.g., within the body of a ghost function) is defined to be Ghost.~~

3. ~~**Requirement:** It shall be possible to specify functions which are used for formal verification only which have no implementation. The Link_Name aspect of an imported ghost entity is defined to be a name that cannot be resolved in the external environment.~~

~~**Rationale:** A function used for formal verification purposes may be difficult (or impossible) to specify or implement in SPARK 2014. A function without an implementation will be defined, for proof purposes, in an external proof tool.~~

Legality Rules

1. Only functions can be explicitly declared with the Convention aspect Ghost. [This means that the scope of the following rules is restricted to functions, even though they are stated in more general terms.]
2. ~~Constraints:~~ A ghost entity shall only be referenced:
 - ~~In order to be removed they can only be applied in places where it can be ascertained that they will not be called during normal execution of the program (that is with test and verification constructs disabled) from within an assertion expression; or~~
 - ~~A function without an implementation cannot be called during execution of a program within or as part of the declaration or completion of a ghost entity (e.g., from within the body of a ghost function); or~~
 - within a statement which does not contain (and is not itself) either an assignment statement targeting a non-ghost variable or a procedure call which passes a non-ghost variable as an out or in out mode actual parameter.
3. ~~Consistency:~~ Within a ghost procedure, the view of any non-ghost variable is a constant view. Within a ghost procedure, a volatile object shall not be read. [In a ghost procedure we do not want to allow assignments to non-ghosts either via assignment statements or procedure calls.]

~~Not applicable~~

4. A ghost entity shall not be referenced from within the expression of a predicate specification of a non-ghost subtype [because such predicates participate in determining the outcome of a membership test].
5. ~~Semantics:~~ All subcomponents of a ghost object shall be initialized by the elaboration of the declaration of the object.

~~Not applicable.~~

Todo

Make worst-case assumptions about private types for this rule, or blast through privacy? To be completed in milestone 4 version of this document.

6. ~~General requirements:~~ A ghost instantiation shall not be an instantiation of a non-ghost generic package. [This is a conservative rule until we have more precise rules about the side effects of elaborating an instance of a generic package. We will need the general rule that the elaboration of a ghost declaration of any kind cannot modify non-ghost state.]
7. ~~See also section~~ The Link_Name or External_Name aspects of an imported ghost entity shall not be specified. A Convention aspect specification for an entity declared inside of a ghost entity shall be confirming [(in other words, the specified Convention shall be Ghost)].

~~In SPARK 2014 a function may be denoted as being a Ghost function using the boolean Ghost. This shows an intent that this function should only be called directly, or indirectly from within assertion expressions excluding predicate subtypes. In Ada subtype predicates are executed irrespective of the assertion policy.~~

Legality Rules

8. ~~A function with a Ghost in the of its declaration may only be called from within an assertion expression, excluding subtype predicates, or from within another ghost function~~ tagged types are disallowed. [This is because just the existence of a ghost tagged type (even if it is never referenced) changes the behavior of Ada.Tags operations. Note overriding is not a problem because Convention participates in conformance checks (so ghost can't override non-ghost and vice versa).]
9. The Convention aspect of an External entity shall not be Ghost.

~~Static Semantics [There are no static semantics associated with Ghost aspects. We are ignoring interactions between ghostliness and freezing. Adding a ghost variable, for example, could change the freezing point of a non-ghost type. It appears that this is ok; that is, this does not violate the ghosts-have-no-effect-on-program-behavior rule.]~~

Todo

Can a ghost variable be a constituent of a non-ghost state abstraction, or would this somehow allow unwanted dependencies? If not, then we presumably need to allow ghost state abstractions or else it would be illegal for a library level package body to declare a ghost variable. To be completed in a post-Release 1 version of this document.

Todo

Do we want an implicit Ghost convention for an entity declared within a statement whose execution depends on a ghost value? To be completed in a post-Release 1 version of this document.

Dynamic Semantics

1. ~~There are no dynamic semantics associated with Ghost aspects.~~ The effects of specifying a convention of Ghost on the runtime representation, calling conventions, and other such dynamic properties of an entity are the same as if a convention of Ada had been specified.

[If it is intended that a ghost entity should not have any runtime representation (e.g., if the entity is used only in discharging proof obligations and is not referenced (directly or indirectly) in any enabled (e.g., via an Assertion_Policy pragma) assertions), then the Import aspect of the entity may be specified to be True.]

Verification Rules

1. ~~There are no verification rules associated with Ghost aspects.~~
Examples A non-ghost output shall not depend on a ghost input.
2. A ghost entity shall not be referenced

- within a call to a procedure which has a non-ghost output; or

~~SPARK 2014 permits the use of non-executable ghost functions that have no body and are used in formal specification and verification only. A non-executable ghost function is introduced by declaring a ghost function with an Import in its declaration.~~

- within a control flow expression (e.g., the condition of an if statement, the selecting expression of a case statement, the bounds of a for loop) of a compound statement which contains such a procedure call. [The case of a non-ghost-updating assignment statement is handled by a legality rule; this rule is needed to prevent a call to a procedure which updates a non-ghost via an up-level reference, as opposed to updating a parameter.]

~~If a call is made, directly or indirectly, to this function other than in an assertion expression which is not a subtype predicate, or if the assertion policy Ignore is not selected, an error will be reported when an attempt is made to build and execute the program. [This rule is intended to ensure an update of a non-ghost entity shall not have a control flow dependency on a ghost entity.]~~

~~It is expected that the definition of a non-executable ghost function will be provided within an external proof tool.~~

~~There are no additional legality rules, static or dynamic semantics or verification rules associated with non-executable ghost functions~~

3. A ghost procedure shall not have a non-ghost output.

Examples

```
function A_Ghost_Expr_Function (Lo, Hi : Natural) return Natural is
  (if Lo > Integer'Last - Hi then Lo else ((Lo + Hi) / 2))
with Pre      => Lo <= Hi,
  Post       => A_Ghost_Function'Result in Lo .. Hi,
  Convention => Ghost;

function A_Ghost_Function (Lo, Hi : Natural) return Natural
with Pre      => Lo <= Hi,
  Post       => A_Ghost_Function'Result in Lo .. Hi,
  Convention => Ghost;
-- The body of the function is declared elsewhere.

function A_Nonexecutable_Ghost_Function (Lo, Hi : Natural) return Natural
with Pre      => Lo <= Hi,
  Post       => A_Ghost_Function'Result in Lo .. Hi,
  Convention => Ghost,
  Import;
-- The body of the function is not declared elsewhere.
```

6.2 Formal Parameter Modes

No extensions or restrictions.

Todo

The modes of a subprogram in Ada are not as strict as S2005 and there is a difference in interpretation of the modes as viewed by flow analysis. For instance in Ada a formal parameter of mode out of a composite type need only be partially updated, but in flow analysis this would have mode in out. Similarly an Ada formal parameter may have mode in out but not be an input. In flow analysis it would be regarded as an input and give arise-rise to flow errors.

In deciding whether a parameter is only partially updated, discriminants (including discriminants of subcomponents) are ignored. For example, given an *out* mode parameter of a type with defaulted discriminants, a subprogram might or might not modify those discriminants (if it does, there will of course be an associated proof obligation to show that the parameter's 'Constrained attribute is False in that path).

Perhaps we need an aspect to describe the strict view of a parameter if it is different ~~to~~ from the specified Ada mode of the formal parameter? To be completed in ~~the Milestone 3~~ a post-Release 1 version of this document.

6.3 Subprogram Bodies

6.3.1 Conformance Rules

No extensions or restrictions.

6.3.2 Inline Expansion of Subprograms

No extensions or restrictions.

~~If a subprogram does not have a separate declaration then the Global aspect is applied to the declaration of its body or body stub. The implementation of a subprogram body must be consistent with its Global Aspect.~~

~~Note that a Refined Global aspect may be applied to a subprogram body when using state abstraction; see section for further details.~~

~~**Syntax** No extra syntax is associated with Global aspects on subprogram bodies.~~

~~**Legality Rules** No extra legality rules are associated with Global aspects on subprogram bodies.~~

~~**Static Semantics** No extra static semantics are associated with Global aspects on subprogram bodies.~~

~~**Dynamic Semantics** No extra dynamic semantics are associated with Global aspects on subprogram bodies.~~

~~**Verification Rules** A “global” shall occur in a Global aspect of a subprogram if and only if it denotes an entity that is referenced by the subprogram.~~

~~Each entity denoted by a in a Global aspect of a subprogram that is an input or output of the subprogram shall satisfy the following mode specification rules which are checked during analysis of the subprogram body: a that denotes an input but not an output is mode **in** and has a of Input;~~

~~a that denotes an output but not an input is always fully initialized on every call of the subprogram, is mode **out** and has a of Output;~~

~~otherwise the denotes both an input and an output, is mode **in-out** and has a of In.~~

~~An entity that is denoted by a which is referenced by a subprogram but is neither an input nor an output but is only referenced directly, or indirectly in assertion expressions has a of Proof.~~

~~Consider how implicitly generated proof obligations associated with runtime checks should be viewed in relation to Proof. To be addressed in the Milestone 4 version of this document.~~

~~If a subprogram does not have a separate declaration then the Depends aspect is applied to the declaration of its body or body stub. The implementation of a subprogram body must be consistent with its Depends Aspect.~~

~~Note that a Refined Depends aspect may be applied to a subprogram body when using state abstraction; see section for further details.~~

~~**Syntax** No extra syntax is associated with Depends aspects on subprogram bodies.~~

~~**Legality Rules** No extra legality rules are associated with Depends aspects on subprogram bodies.~~

~~**Static Semantics** No extra static semantics are associated with Depends aspects on subprogram bodies.~~

~~**Dynamic Semantics** No extra dynamic semantics are associated with Depends aspects on subprogram bodies.~~

~~**Verification Rules** Each given in the Depends aspect must be an in the implementation of the subprogram body and the must depend on all, but only, the given in the associated with the.~~

~~Each of the implementation of the subprogram body is present as an output in the Depends aspect.~~

~~Each of the Depends aspect is an of the implementation of the subprogram body.~~

6.4 Subprogram Calls

A call is in SPARK 2014 only if it resolves statically to a subprogram whose declaration view is in SPARK 2014 ~~(whether the call is dispatching or not).~~ 2014.

6.4.1 Parameter Associations

No extensions or restrictions.

6.4.2 Anti-Aliasing

An alias is a name which refers to the same object as another name. The presence of aliasing is inconsistent with the underlying flow analysis and proof models used by the tools which assume that different names represent different entities. In general, it is not possible or is difficult to deduce that two names refer to the same object and problems arise when one of the names is used to update the object.

A common place for aliasing to be introduced is through the actual parameters and between actual parameters and global variables in a procedure call. Extra verification rules are given that avoid the possibility of aliasing through actual parameters and global variables. A function is not allowed to have side-effects and cannot update an actual parameter or global variable. Therefore, function calls cannot introduce aliasing and are excluded from the anti-aliasing rules given below for procedure calls.

~~Goals to be met by language feature: Not applicable.~~

~~Constraints: **Requirement:** An entity that may be updated on a call to a subprogram may not be referred to by distinct names within that subprogram.~~

~~**Rationale:** Flow analysis specifications are presented and analyzed in terms of names rather than the entities to which those names refer.~~

~~Semantics: Not applicable.~~

~~Consistency: Not applicable.~~

~~General requirements: Not applicable.~~

Syntax

No extra syntax is associated with anti-aliasing.

Legality Rules

No extra legality rules are associated with anti-aliasing.

Static Semantics

~~No extra static semantics are associated with~~

1. Objects are assumed to have overlapping locations if it cannot be established statically that they do not. [This definition of overlapping is necessary since these anti-aliasing checks will initially be implemented by flow analysis; in a future tool release it is intended that these checks will be implemented by the proof engine and so the static checking may be suppressed.]

Dynamic Semantics

No extra dynamic semantics are associated with anti-aliasing.

Verification Rules

1. ~~In SPARK 2014, a~~ A procedure call shall not pass actual parameters which denote objects with overlapping locations, when at least one of the corresponding formal parameters is of mode **out** or **in out**, unless the other corresponding formal parameter is of mode **in** and is of a by-copy type.
2. ~~In SPARK 2014, a~~ A procedure call shall not pass an actual parameter, whose corresponding formal parameter is mode **out** or **in out**, that denotes an object which overlaps with any `global_item` referenced by the subprogram.
3. ~~In SPARK 2014, a~~ A procedure call shall not pass an actual parameter which denotes an object which overlaps a `global_item` of mode **out** or **in out** of the subprogram, unless the corresponding formal parameter is of mode **in** and by-copy.
4. Where one of these rules prohibits the occurrence of an object V or any of its subcomponents as an actual parameter, the following constructs are also prohibited in this context:
 - A type conversion whose operand is a prohibited construct;
 - A call to an instance of `Unchecked_Conversion` whose operand is a prohibited construct;
 - A qualified expression whose operand is a prohibited construct;
 - A prohibited construct enclosed in parentheses.

6.5 Return Statements

No extensions or restrictions.

6.5.1 Nonreturning Procedures

Syntax

There is no additional syntax associated with nonreturning procedures in SPARK 2014.

Legality Rules

1. For a call to a nonreturning procedure to be in SPARK 2014, it must be immediately enclosed by an if statement which encloses no other statement.

Static Semantics

There are no additional static semantics associated with nonreturning procedures in SPARK 2014.

Dynamic Semantics

There are no additional dynamic semantics associated with nonreturning procedures in SPARK 2014.

Verification Rules

1. A call to a nonreturning procedure introduces an obligation to prove that the statement will not be executed, much like the proof obligation associated with

```
pragma Assert (False);
```

[In other words, the proof obligations introduced for a call to a nonreturning procedure are the same as those introduced for a runtime check which fails unconditionally. See also section *Exceptions*, where a similar restriction is imposed on `raise_statements`.]

6.6 Overloading of Operators

No extensions or restrictions.

6.7 Null Procedures

No extensions or restrictions.

6.8 Expression Functions

`Contract_Cases`, `Global` and `Depends` aspects may be applied to an expression function as for any other function declaration if it does not have a separate declaration. If it has a separate declaration then the aspects are applied to that. It may have refined aspects applied (see *State Refinement*).

PACKAGES

~~A compile-time constant is a static expression or an expression involving only static expressions for example an aggregate of static expressions.~~

~~In SPARK 2014 a declaration or statement occurring immediately within the package shall only read—whether directly or indirectly—values derived only from compile-time constants.~~

~~Among other things this restriction avoids the need to have dependency relations applied to packages.~~

Verification Rules

1. ~~Each occurring in the visible or private part~~ In SPARK 2014 the elaboration of a package shall ~~not read~~ only update, directly or indirectly, ~~any value which is not entirely derived from compile-time constants~~ variables declared immediately within the package.

7.1 Package Specifications and Declarations

7.1.1 Abstraction of State

The variables declared ~~immediately~~ within a package ~~Q, its embedded packages and its private descendants constitute the state of Q,~~ but not within a subprogram body or block which does not also enclose the given package constitute ~~the persistent state~~ the persistent state of the package. A package's persistent state is divided into ~~visible state~~ visible state and ~~hidden state~~ hidden state. If a declaration that is part of a package's persistent state is visible outside of the package, then it is a constituent of the package's visible state; otherwise it is a constituent of the package's hidden state.

~~The variable declarations are only visible to clients of Q if they are declared in the visible part of Q. The declarations of all other variables are hidden from a client of Q. Though the variables are may be hidden they still form part (or all) of the state of Q and this hidden state persistent state of the package and the hidden state cannot be ignored for static analyses flow analysis and proof. State abstraction is the means by which this hidden state is managed for static analyses flow analysis and proof. A state abstraction represents one or more declarations which are part of the hidden state of a package.~~

SPARK 2014 extends the concept of state abstraction to provide hierarchical data abstraction whereby the ~~hidden state of a package Q may be refined over a tree of private descendants or embedded packages of Q~~ state abstraction declared in a package may contain the persistent state of other packages given certain restrictions described in *Abstract_State*, *Package Hierarchy* and *Part_Of*. This provides data refinement similar to the refinement available to types whereby a record may contain fields which are themselves records.

~~Volatile state is a volatile variable or a volatile state abstraction~~

Static Semantics

1. The visible state of a package P consists of:

- any variables declared immediately within the visible part of package P; and
- the state abstractions declared by the Abstract_State aspect specification (if any) of package P; and
- the visible state of any packages declared immediately within the visible part of package P.

~~The abstract state aspect provides a way to designate a named abstract state as being volatile, usually representing an external input or output. A volatile variable is designated as volatile using a Volatile aspect possibly with a further designation of whether it is~~

2. The hidden state of a package P consists of:

- any variables declared immediately in the private part or body of P; and
- the state declared in the visible part of any packages declared immediately within the private part or body of P.

7.1.2 External State

External state is a state abstraction or variable representing something external to a program. For instance, an input or an output device, or a communication channel to another subsystem such as another SPARK 2014 program.

~~The read or update of a volatile variable or state abstraction~~ External state may be specified as *output only* or *input only*. The update of output only external state is considered to be both a read and an update of the entity. In read by some external reader of the state and so the update is not ineffective even though the program itself cannot read the updated state. Input only external state is considered to be updated by some external writer and so successive reads of the input only external state may not give the same value even though the program itself cannot update the state. In other words the update of output only and the read of input only external state both have a side effect.

Output only and input only external states are treated specially in Global and Depends aspects this means that volatile entities will be regarded as being both an input and an output and this fact may be stated explicitly in those aspects, for example by using the mode in the Global aspect. However if a variable or abstract state is explicitly designated as being a Volatile Input or a VolatileOutput, an abbreviated form of the Global and Depends aspect is permitted which gives a more intuitive view of the globals and the dependency relation, as described below and cannot be denoted as actual parameters or be `global_items` of a function as they would introduce side-effects.

~~If the variable or~~ External state that is not specified as output only or input only behaves as normal (non-volatile) state and may be read or updated by the program and has no special treatment for Global and Depends aspects.

SPARK 2014 aspects are defined for specifying a variable as an input only or an output only [Ada aspects Volatile, Import and Export are used for specifying whether a variable is external] see *Input_Only and Output_Only Aspects*. When a state abstraction is designated as Volatile Input, then it may only appear as an Input in the Global aspect. There is an implicit declaration that it is also an Output. In a Depends aspect it need not appear as an output as an implicit self dependency of the entity will be declared declared by an Abstract_State aspect (see *Abstract_State Aspect*) it may be specified as external, in which case it may be also specified as either input only or output only.

~~If the variable or state abstraction is designated as Volatile Output, then it may only appear as an Output in the Global aspect. There is an implicit declaration that it is also an Input. In a Depends aspect it need not appear as an input as an implicit self dependency of the entity will be declared.~~

Static Semantics

Static semantics are given individually for external variables and external state abstractions.

~~A volatile variable or volatile state abstraction cannot be mentioned directly in an assertion expression as the reading of a volatile may affect its value~~

Legality Rules

1. External state which is specified as input only shall not be denoted in a Global aspect with a `mode_selector` of `In_Out` or `Output`. [Nor shall it be denoted as an `output` of a Depends aspect.]

2. External state which is specified as output only shall not be denoted in a Global aspect with a `mode_selector` of `Input` or `Input_Out`. [Nor shall not be denoted as an input of a `Depends` aspect.]
3. A `global_item` of a function shall not denote input only or output only external state.

~~More details on volatile variables and definition of~~

4. An actual parameter in a complete model. At the very least, if `V` is a Volatile Input variable should not have the following assertion provable: `T1 := V; T2 := V; pragma Assert (T1 = T2);` To be completed in the Milestone 3 version of this document. function call shall not denote output only or input only external state.
5. Since output only external state shall never be read by the program and input only external state may never be updated by the program neither of these sorts of external state shall be denoted by a name of an `initialization_item` of an `Initializes` aspect (see *Initializes Aspect*).

~~Need to describe the conditions under which a volatile variable can be a parameter of a subprogram. To be completed in the Milestone 3 version of this document.~~

7.1.3 Input_Only and Output_Only Aspects

A variable which represents a communication channel with an external entity, for instance a transducer, subsystem, or program is considered an *external variable*. A variable is external if it is Volatile or is declared with an Ada `Address`, `Import`, or `Export` specification (either using an aspect or a pragma).

~~Consider more than just simple Volatile Inputs and Outputs; Latched outputs, Involatiles, etc. To be completed in the Milestone 4 version of this document. If a variable is volatile it has to be specified as an input only or an output only external state. The Boolean aspects `Input_Only` and `Output_Only` are used for this specification.~~

Static Semantics

1. A variable which is Volatile or has one of the Ada aspects `Import` or `Export`, or the Ada aspect `Address` specified in its declaration is an external variable.

Legality Rules

1. ~~Goals to be met by language feature:~~ The declaration of Volatile variable shall have exactly one of an `Input_Only` or `Output_Only` aspect specified as `True`. A variable with a `True Input_Only` specification is an *external input*; a variable with a `True Output_Only` specification is an *external output*. [The rule that a volatile variable shall be either an input or an output only may be relaxed in a future version of SPARK.]
2. ~~**Requirement:** It shall be possible to provide an abstracted view of hidden state that can be referred to in specifications of program behavior.~~ A variable which is not Volatile shall not have an `Input_Only` or `Output_Only` aspect specified as `True`.

~~**Rationale:** this allows modular analysis, since modular analysis is performed before all package bodies are available and so before all hidden state is known. Abstraction also allows the management of complexity~~

3. The Boolean expression of the aspect definitions of the `Input_Only` or `Output_Only` aspects shall be static.
4. ~~**Constraints**~~ Contrary to the general SPARK 2014 rule that expression evaluation cannot have side effects, a read of an external input is considered to have side effects. To reconcile this discrepancy, a name denoting an external input shall only occur in the following contexts:
 - ~~No further abstract state specific requirements.~~ as the [right hand side] expression of an assignment statement; or
 - as the expression of an initialization expression of an object declaration that is not specified as volatile; or
 - ~~**Consistency:**~~ as an actual parameter in a call to an instance of `Unchecked_Conversion` whose result is renamed [in an object renaming declaration]; or

- ~~No further abstract state specific requirements~~ as an actual parameter in a procedure call of which the corresponding formal parameter is mode **in** and is of a non-scalar volatile type.

[This rule means that an external input cannot be updated directly by the program.]

5. **Semantics** A name denoting an external output shall only occur in the following contexts:

- ~~No further abstract state specific requirements~~ as the name on the left-hand side of an assignment statement;
or
- as an actual parameter in a procedure call of which the mode of the corresponding formal parameter is **out** and is of a non-scalar volatile type.

[~~General requirements~~: This rule means that an external output cannot be directly read by the program.]

6. See ~~also section~~ section on volatile variables for rules concerning their use in SPARK 2014 (*Shared Variable Control* (Annex C.6)).

Dynamic Semantics

There are no dynamic semantics associated with these aspects.

Verification Rules

There are no extra verification rules.

Examples

```
with System.Storage_Units;
package Input_Port
is
  Sensor : Integer
    with Volatile,
         Input_Only,
         Address => System.Storage_Units.To_Address (16#ACECAFE#);
end Input_Port;
```

```
with System.Storage_Units;
package Multiple_Ports
is
  type Volatile_Type is record
    I : Integer
  end record with Volatile;

  -- Read_Port may only be called with an actual parameter for Port
  -- which is an external input only
  procedure Read_Port (Port : in Volatile_Type; Value : out Integer)
    with Depends => (Value => Port); -- Port is an external input only

  -- Write_Port may only be called with an actual parameter for Port
  -- which is an external output only
  procedure Write_Port (Port : out Volatile_Type; Value : in Integer)
    with Depends => (Port => Value); -- Port is external output only

  -- The following declarations are all external input only variables
  V_In_1 : Volatile_Type
    with Input_Only,
         Address => System.Storage_Units.To_Address (16#A1CAFE#);
```

```

V_In_2 : Integer
  with Volatile,
    Input_Only,
    Address => System.Storage_Units.To_Address (16#ABCCAFE#);

-- The following declarations are all external output only variables
V_Out_1 : Volatile_Type
  with Output_Only,
    Address => System.Storage_Units.To_Address (16#BBCCAFE#);

V_Out_2 : Integer
  with Volatile,
    Output_Only,
    Address => System.Storage_Units.To_Address (16#ADACAFE#);

-- The following is a declaration of a non-volatile external variable
V_Non_Volatile : Integer
  with Address => System.Storage_Units.To_Address (16#BEECAFE#);

end Multiple_Ports;

```

Todo

Add support for more complex models of external state. To be completed in a post-Release 1 version of this document.

7.1.4 Abstract_State Aspect

State abstraction provides a mechanism for naming, in a package's visible part, state (typically a collection of variables) that will be declared within the package's body, ~~packages nested within these, or within private descendants of the package's body (its hidden state)~~. For example, a package declares a visible procedure and we wish to specify the set of global variables that the procedure reads and writes as part of the specification of the subprogram. ~~Those variables. The variables declared in the package body~~ cannot be named directly in the package specification. Instead, we introduce a state abstraction which is visible in the package specification and later, when the package body is declared, we specify the set of variables that *constitute* or *implement* ~~that the~~ state abstraction. ~~If~~

If immediately within a package body ~~contains~~, for example, a nested ~~package~~ package is declared, then a state abstraction of the inner package may also be part of the implementation of the given state abstraction of the outer package.

The hidden state of a package may be represented by one or more state abstractions, with each pair of state abstractions representing disjoint sets of hidden variables.

If a subprogram P with a Global aspect is declared in the visible part of a package and P reads or updates any of the hidden state of the package then ~~P must include in its Global aspect the abstract state names with the correct mode that represent the hidden state referenced~~ the state abstractions shall be denoted by P. If P has a Depends aspect then the ~~abstract state names must appear~~ state abstractions shall be denoted as inputs and outputs of P, as appropriate, in the dependency_relation of the Depends aspect.

~~The Abstract State~~ SPARK 2014 facilitates the specification of a hierarchy of state abstractions by allowing a single state abstraction to contain visible declarations of package declarations nested immediately within the body of a package, private child or private sibling units and descendants thereof. Each visible state abstraction or variable of a private child or descendant thereof has to be specified as being *part of* a state abstraction of a unit which is more visible than itself.

The Abstract_State aspect is introduced by an aspect_specification where the aspect_mark is Abstract_State and the aspect_definition ~~must~~ shall follow the grammar of abstract_state_list given below.

Syntax

```

abstract_state_list      ::= null
                           | state_name_with_options
                           | (state_name_with_options { , state_name_with_options } )
state_name_with_options ::= state_name
                           | ( state_name with option_list )
option_list              ::= option { , option }
option                   ::= simple_option
                           | name_value_option
simple_option             ::= External
                           | Input_Only
                           | Output_Only
name_value_option        ::= Part_Of => abstract_state
state_name               ::= defining_identifier
abstract_state           ::= name

```

Legality Rules

1. ~~The of a shall be Volatile, Input, or Output.~~

~~There shall be at most one occurrence of the Volatile, Input and Output in a single~~ An option shall not be repeated within a single option_list.

2. ~~If a includes Volatile, then it shall also include exactly~~ External is specified in an option_list then at most one of Input or Output.

~~If a includes either Input or Output, then it shall also include Volatile.~~

~~The of a shall be Integrity_Only or Output_Only options~~ shall be specified in the option_list. The Input_Only and Output_Only options shall not be specified in an option_list without an External option.

3. ~~If a includes Integrity then it an~~ option_list contains one or more name_value_option items then they shall be the final property-options in the list. [This eliminates the possibility of a positional association following a named association in the property list.]

4. ~~A package or generic~~ package_declaration or generic_package_declaration shall have a completion [(require a body)] if it contains a non-null AbstractState_State aspect specification.

~~Static Semantics The visible state and state abstractions of a package P consist of: any variables declared immediately within the visible part of P; and~~

~~any state abstractions declared by the AbstractState aspect specification (if any) of package P; and~~

~~the visible state and state abstractions of any packages declared immediately within the visible part of P if a package declaration has a non-null Abstract_State aspect but in Ada a body is not required, a pragma Elaborate_Body shall be stated within the package declaration to make it required in Ada.~~

5. ~~The hidden state of a package P consists of: any variables declared immediately within the private part or body of P;~~

~~the state abstractions of any packages declared immediately within the visible part of P; and~~

~~the visible state and state abstractions of any packages declared immediately within the private part or body of P; and of any private child units of P or of their public descendants.~~

A subprogram declaration that overloads a state abstraction has an implicit Global aspect denoting the state abstraction with a mode_selector of Input. An explicit Global aspect may be specified which replaces the

implicit one.

~~(SB) These definitions may eventually be expanded to include non-static constants, not just variables.~~

Static Semantics

1. Each `state_name` occurring in an `Abstract_State` aspect specification for a given package `P` introduces an implicit declaration of a ~~*state abstraction*~~ state abstraction entity. This implicit declaration occurs at the beginning of the visible part of `P`. This implicit declaration shall have a completion and is overloadable.

Note: (SB) Making these implicit declarations overloadable allows declaring a subprogram with the same fully qualified name as a state abstraction; to make this scenario work, rules of the form "... shall denote a state abstraction" need to be name resolution rules, not just legality rules.

2. [A state abstraction shall only be named in contexts where this is explicitly permitted (e.g., as part of a ~~*Globals*~~ Global aspect specification), but this is not a name resolution rule. Thus, the declaration of a state abstraction has the same visibility as any other declaration. A state abstraction is not an object; it does not have a type. The completion of a state abstraction declared in a package ~~*aspect*~~ aspect `aspect_specification` can only be provided as part of a `Refined_State` ~~*aspect_specification*~~ aspect_specification within the body of the package.]
3. A **null** `abstract_state_list` specifies that a package contains no hidden state.
4. ~~The specification is checked when the package is analyzed.~~ An External state abstraction is one declared with an `option_list` that includes the External option (see *External State*).
5. ~~A *volatile* state abstraction is one declared with a property list that includes the Volatile property, and either Input or Output.~~ state abstraction which is declared with an `option_list` that includes a `Part_Of` `name_value_option` indicates that it is a constituent (see *State Refinement*) exclusively of the state abstraction denoted by the `abstract_state` of the `name_value_option` (see *Abstract_State*, *Package Hierarchy* and *Part_Of*).

~~Verification Rules~~ Dynamic Semantics

There are no ~~Verification Rules~~ dynamic semantics associated with the `AbstractState_State` aspect.

~~Dynamic Semantics~~ Verification Rules

There are no ~~Dynamic Semantics~~ verification rules associated with the `AbstractState_State` aspect.

Examples

```
package Q
  with Abstract_State => State
  is
    function Is_Ready return Boolean
      with Global => State;

    procedure Init
      with Global => (Output => State),
      Post => Is_Ready;

    procedure Op_1 (V : Integer)
      with Global => (In_Out => State),
      Pre => Is_Ready,
      Post => Is_Ready;
end Q;
```

-- Declaration of abstract state named State
-- representing internal state of Q.

-- Function checking some property of the State.
-- State may be used in a global aspect.

-- Procedure to initialize the internal state of Q
-- State may be used in a global aspect.

-- Another procedure providing some operation on S

```
package X
  with Abstract_State => (A, B, (C with External, Input_Only))
    -- Three abstract state names are declared A, B & C.
    -- A and B are internal abstract states
    -- C is specified as external state which is input only.
is
  ...
end X;

package Mileage
  with Abstract_State => (Trip, -- number of miles so far on this trip
    -- (can be reset to 0).
    Total) -- total mileage of vehicle since last factory-reset.
is
  function Trip return Natural; -- Has an implicit Global => Trip.
  function Total return Natural; -- Has an implicit Global => Total.

  procedure Zero_Trip
    with Global => (Output => Trip), -- In the Global and Depends aspects
      Depends => (Trip => null), -- Trip denotes the state abstraction.
      Post => Trip = 0; -- In the Post condition Trip denotes
        -- the function.

  procedure Inc
    with Global => (In_Out => (Trip, Total)),
      Depends => ((Trip, Total) =>+ null),
      Post => Trip = Trip'Old + 1 and Total = Total'Old + 1;

  -- Trip and Old in the Post conditions denote functions but these
  -- represent the state abstractions in Global and Depends specifications.

end Mileage;
```

~~Further semantic detail regarding Volatile state and integrity levels needs to be added, in particular in relation to specifying these properties for variables which are declared directly within the visible part~~

7.1.5 Initializes Aspect

~~The Initializes aspect specifies the visible variables and state abstractions of a package specification. To be completed in the Milestone 3 version of this document.~~

~~Goals to be met by language feature: **Requirement:** Flow analysis requires the knowledge of whether each variable has been initialized. It should be possible to determine this from the specification of a unit.~~

~~**Rationale:** Variables and state abstractions may be initialized within a package body as well as a package specification. It follows not all initializations are visible from the specification. An Initializes aspect is applied to a package specification to indicate which variables and state abstractions are initialized by the package. This facilitates modular analysis.~~

~~Constraints: No further Initializes-specific requirements.~~

~~Consistency: No further Initializes-specific requirements.~~

~~Semantics: **Requirement:** The set of data items listed in an Initializes aspect shall be fully initialized during elaboration of this package.~~

~~**Rationale:** To ensure that listed data items are always initialized before use.~~

that are initialized by the elaboration of the package. In SPARK 2014 a package shall only initialize variables declared immediately within the package.

~~General requirements: See also section~~ If the initialization of a variable or state abstraction, V , during the elaboration of a package, P , is dependent on the value of a visible variable or state abstraction from another package, then this entity shall be denoted in the input list associated with V in the Initializes aspect of P .

The Initializes aspect is introduced by an aspect_specification where the aspect_mark is Initializes and the aspect_definition ~~must~~ shall follow the grammar of initialization_spec given below.

Syntax

~~Provide language definition for Initializes aspect. To be completed in the Milestone 3 version of this document.~~

```
initialization_spec ::= initialization_list
                    | null

initialization_list ::= initialization_item
                    | ( initialization_item { , initialization_item } )

initialization_item ::= name [ => input_list]
```

Legality Rules

- ~~Goals to be met by language feature:~~ An Initializes aspect shall only appear in the aspect_specification of a package_specification.
- Requirement:** It shall be possible to formally specify the result of performing package elaboration.

Rationale: This specification behaves as a postcondition for the result of package elaboration and so establishes the “pre-condition” that holds at the point of beginning execution of the program proper. Giving an explicit postcondition supports modular analysis.

The Initializes aspect shall follow the Abstract_State aspect if one is present.

- ~~Constraints:~~ The name of each initialization_item in the Initializes aspect definition for a package shall denote a state abstraction of the package or an entire variable declared immediately within the visible part of the package.
- ~~No further Initial Condition specific requirements~~ Each name in the input_list shall denote an entire variable or a state abstraction but shall not denote an entity declared in the package with the aspect_specification containing the Initializes aspect.
- ~~Consistency:~~ Each entity in a single input_list shall be distinct.

Static Semantics

- ~~No further Initial Condition specific requirements.~~

The Initializes aspect of a package has visibility of the declarations occurring immediately within the visible part of the package.

- ~~Semantics:~~ The Initializes aspect of a package specification asserts which state abstractions and visible variables of the package are initialized by the elaboration of the package, both its specification and body, and any units which have state abstractions or variable declarations that are part (constituents) of a state abstraction declared by the package. [A package with a null initialization_list, or no Initializes aspect does not initialize any of its state abstractions or variables.]
- Requirement:** The predicate given by the Initial Condition aspect should evaluate to True at the point at which elaboration of the package, its embedded packages and its private descendants has completed. If an initialization_item has an input_list then the names in the list denote entities which are used in determining the initial value of the state abstraction or variable denoted by the name of the initialization_item but are not constituents of the state abstraction.

~~Rationale: By definition.~~

Dynamic Semantics

There are no dynamic semantics associated with the Initializes aspect.

Verification Rules

1. ~~General requirements:~~ If the Initializes aspect is specified for a package, then after the body (which may be implicit if the package has no explicit body) has completed its elaboration, every (entire) variable and state abstraction denoted by a name in the Initializes aspect shall be initialized. A state abstraction is said to be initialized if all of its constituents are initialized. An entire variable is initialized if all of its components are initialized. Other parts of the visible state of the package shall not be initialized.
2. ~~See also section~~ If an initialization_item has an input_list then the entities denoted in the input list shall be used in determining the initialized value of the entity denoted by the name of the initialization_item.

~~The InitialCondition~~

Examples

```
package Q
  with Abstract_State => State,    -- Declaration of abstract state name State
       Initializes    => State      -- Indicates that State will be initialized
                                   -- during the elaboration of Q.
is
  ...
end Q;

package Y
  with Abstract_State => (A, B, (C with External, Input_Only)),
       -- Three abstract state names are declared A, B & C.
       Initializes    => A
       -- A is initialized during the elaboration of Y.
       -- C is specified as external input only state
       -- B is not initialized.
is
  ...
end Y;

package Z
  with Abstract_State => A,
       Initializes    => null
       -- Package Z has an abstract state name A declared but the
       -- elaboration of Z and its private descendants do not
       -- perform any initialization during elaboration.
is
  ...
end Z;
```

7.1.6 Initial_Condition Aspect

The Initial_Condition aspect is introduced by an aspect_specification where the aspect_mark is “Initial_Condition” and the aspect_definition must be an shall be a Boolean expression.

~~Provide language definition for InitialCondition aspect~~

Legality Rules

1. An Initial_Condition aspect shall only be placed in an aspect_specification of a package_specification. ~~To be completed in the Milestone 3 version of this document.~~
2. The Initial_Condition aspect shall follow the Abstract_State aspect and Initializes aspect if they are present.
3. Each variable or state abstraction denoted in an Initial_Condition aspect of a package Q which is declared immediately within the visible part of Q shall be initialized during the elaboration of Q and be denoted by a name of an initialization_item of the Initializes aspect of Q.

~~Verification Rules~~ Static Semantics

1. ~~Each declaration of the of a shall not read, directly or indirectly, any value which is not entirely derived from compile-time constants.~~ An Initial_Condition aspect is a sort of postcondition for the elaboration of both the specification and body of a package. If present on a package, then its Boolean_expression defines properties (a predicate) of the state of the package which can be assumed to be true immediately following the elaboration of the package. [The expression of the Initial_Condition cannot denote a state abstraction. This means that to express properties of hidden state, functions declared in the visible part acting on the state abstractions of the package must be used.]

Dynamic Semantics

1. ~~Each statement of a of a shall not read, directly or indirectly, a value which is not entirely derived entirely from compile-time constants.~~ With respect to dynamic semantics, specifying a given expression as the Initial_Condition aspect of a package is equivalent to specifying that expression as the argument of an Assert pragma occurring at the end of the (possibly implicit) statement list of the (possibly implicit) body of the package. [This equivalence includes all interactions with pragma Assertion_Policy. This equivalence does not extend to matters of static semantics, such as name resolution.] An Initial_Condition expression does not cause freezing until the point where it is evaluated [, at which point everything that it might freeze has already been frozen].

Verification Rules

1. [The Initial_Condition aspect gives a proof obligation to show that the implementation of the package_specification and its body satisfy the predicate given in the Initial_Condition aspect.]

Examples

```
package Q
  with Abstract_State    => State,    -- Declaration of abstract state name State
    Initializes         => State,    -- State will be initialized during elaboration
    Initial_Condition => Is_Ready    -- Predicate stating the logical state after
                                   -- initialization.
is
  function Is_Ready return Boolean
    with Global => State;
end Q;

package X
  with Abstract_State    => A,        -- Declares an abstract state named A
    Initializes         => (A, B),  -- A and visible variable B are initialized
                                   -- during package initialization.
    Initial_Condition => A_Is_Ready and B = 0
                                   -- The logical conditions that hold
                                   -- after package elaboration.
is
  ...
  B : Integer;
```

```

function A_Is_Ready return Boolean
  with Global => A;
end X;

```

7.2 Package Bodies

7.2.1 State Refinement

A `state_name` declared by an `AbstractState_State` aspect in the specification of a package `Q` is an abstraction of the non-visible variables declared in the private part, body, or private descendants of `Q`, which together form the hidden state, of `Q`. In the body of `Q` shall denote an abstraction representing all or part of its hidden state. The declaration must be completed in the package body by a `Refined_State` aspect. The `Refined_State` aspect defines a refinement for each `state_name` has to be refined by showing which. The refinement shall denote the variables and subordinate abstract states are state abstractions represented by the `state_name` (its constituents). A `Refined_State` aspect in the body of `Q` is used for this purpose and these are known as its *constituents*.

Constituents of each `state_name` have to be initialized consistently with that of their representative `state_name` as determined by its denotation or absence in the `Initializes` aspect of the package.

In the body A subprogram may have an *abstract view* and a *refined view*. The abstract view is a subprogram declaration in the visible part of a package the constituents of the refined, the refined view, has to be used rather than the abstract view of the. `RefinedGlobal`, `depends`, `pre` and `post` where a subprogram may refer to private types and state abstractions whose details are not visible. A refined view of a subprogram is the body or body stub of the subprogram in the package body whose visible part declares its abstract view.

In a refined view a subprogram has visibility of the full type declarations of any private types declared by the enclosing package and visibility of the refinements of state abstractions declared by the package. `Refined_Global`, `Refined_Depends`, `Refined_Pre` and `Refined_Post` aspects are provided to express the refined view contracts of a refined view of a subprogram.

In the refined view the constituents of each have to be initialized consistently with their appearance or omission from the `Package Depends` or `Initializes` aspect of the package

7.2.2 Refined_State Aspect

The `Refined_State` aspect is introduced by an aspect specification where the `aspect_mark` is `Refined_State` and the aspect definition shall follow the grammar of `refinement_list` given below.

Where it is possible to specify subprogram behavior using a language feature that refers to abstract state, it should be possible to define a corresponding-

Syntax

```

refinement_list  ::= refinement_clause
                  | ( refinement_clause { , refinement_clause } )
refinement_clause ::= state_name => constituent_list
constituent_list ::= null
                  | constituent
                  | ( constituent { , constituent } )

```

where

```

constituent ::= refinedobject version of the language feature that refers to the decomposition of
that abstract state. name | state_name

```

The rationale for this is as follows:-

Name Resolution Rules

1. ~~The semantics of properties defined in terms of abstract state can only be precisely defined in terms of the corresponding concrete state, though nested abstraction is also necessary to manage hierarchies of data.~~ A Refined_State aspect of a package_body has visibility extended to the declarative_part of the body.

Legality Rules

1. ~~There may be multiple possible refinements for a given abstract specification and so the user should be able to specify what they actually want.~~ A Refined_State aspect shall only appear in the aspect_specification of a package_body. [The use of package_body rather than package body allows this aspect to be specified for generic package bodies.]
2. ~~This is necessary to support development via stepwise refinement.~~ If a package_specification has a non-null Abstract_State aspect its body shall have a Refined_State aspect.
3. ~~Goals to be met by language feature:~~ If a package_specification does not have an Abstract_State aspect, then the corresponding package_body shall not have a Refined_State aspect.
4. **Requirement:** ~~For each state abstraction, it shall be possible to define the set of hidden state items that implement or refine that abstract state (where the hidden state items can either be concrete state or further state abstractions).~~ Each constituent shall be either a variable or a state abstraction.

Rationale: see section-

5. An object which is a constituent shall be an entire object.

6. **Constraints:** **Requirement:** ~~Each item of hidden state must map to exactly one state abstraction.~~

Rationale: all hidden state must be covered since otherwise specifications referring to abstract state may be incomplete; each item of that hidden state must map to exactly one abstraction to give a clean and easily understandable abstraction, and for the purposes of simplicity of analysis A constituent shall denote an entity of the hidden state of a package or an entity which has a Part_Of option or aspect associated with its declaration.

7. **Requirement:** ~~Each item of abstract state covered by the package shall be mapped to at least one item of hidden state (either concrete state or a further state abstraction).~~

Rationale: the semantics of properties defined in terms of abstract state can only be precisely defined in terms of the corresponding concrete state Each abstract_state_name declared in the package specification shall be denoted as the state_name of a refinement_clause in the Refined_State aspect of the body of the package.

8. **Requirement:** ~~Each item of hidden state should appear in at least one global data list within the package body.~~

Rationale: If this is not the case, then there is at least one hidden state item that is not used by any subprogram.

Every entity of the hidden state of a package shall be denoted as a constituent of exactly one abstract_state_name in the Refined_State aspect of the package and shall not be denoted more than once. [Consistency: These constituents are either variables declared in the private part or body of the package, or the declarations from the visible part of nested packages declared immediately therein.] No further Refinedstate-specific requirements needed.

9. **Semantics:** The legality rules related to a Refined_State aspect given in Abstract_State, Package Hierarchy and Part_Of ~~No further Refinedstate-specific requirements needed~~ also apply.

Static Semantics

1. ~~General requirements:~~ A Refined_State aspect of a package_body completes the declaration of the state abstractions occurring in the corresponding package_specification and defines the objects and each

subordinate state abstraction that are the constituents of the *abstract* state names declared in the package specification.

2. ~~See also section A null~~ constituent_list indicates that the named abstract state has no constituents. The state abstraction does not represent any actual state at all. [This feature may be useful to minimize changes to Global and Depends aspects if it is believed that a package may have some extra state in the future, or if hidden state is removed.] ~~–~~

~~The consistency rules will be updated as the models for volatile variables and integrity levels are defined. To be completed in the Milestone 3 version of this document.~~

~~Consider whether it should be possible to refine null abstract state onto hidden state. *Rationale: this would allow the modeling of programs that—for example—use caches to improve performance.* To be completed in the Milestone 3 version of this document.~~

Dynamic Semantics

There are no dynamic semantics associated with Refined_State aspect.

~~Consider whether it should be possible to refine abstract onto hidden state without any restrictions, although the refinement would be checked and potential issues flagged up to the user.~~

Verification Rules

There are no verification rules associated with Refined_State aspect.

Rationale: ~~there are a number of different possible models of mapping abstract to concrete state—especially when volatile state is being used—and it might be useful to provide greater flexibility to the user. In addition, if a facility is provided to allow users to step outside of the language when refining depends, for example, then it may be necessary to relax the abstraction model as well as relaxing the language feature of direct relevance.*~~

Examples

-- Here, we present a package Q that declares two abstract states:

```
package Q
  with Abstract_State => (A, B),
    Initializes      => (A, B)
```

is

```
...
end Q;
```

-- The package body refines

-- A onto three concrete variables declared in the package body

-- B onto the abstract state of a nested package

```
package body Q
  with Refined_State => (A => (F, G, H),
    B => R.State)
```

is

```
F, G, H : Integer := 0; -- all initialized as required
```

```
package R
```

```
  with Abstract_State => State,
```

```
    Initializes      => State -- initialized as required
```

is

```
...
end R;
```

```
...
end Q;
```

~~To be completed in the Milestone 3 version of this document.~~

7.2.3 Abstract_State, Package Hierarchy and Part_Of

Each item of state declared in the visible part of a private library unit (and any descendants thereof) must be connected, directly or indirectly, to an *encapsulating* state abstraction of some public library unit. This is done using the Part_Of option or aspect associated with each declaration of the visible state of the private unit.

~~The Refined_State aspect is introduced by an where the is “Refined~~ The unit declaring the encapsulating state abstraction identified by the Part_Of option or aspect needs not be its parent, but it must be a unit whose body has visibility of the private library unit, while being *more visible* than the original unit. Furthermore, the unit declaring the encapsulating state abstraction must denote the corresponding item of visible state in its Refined_State ” ~~and the must follow the grammar of given below~~ aspect to indicate that it includes this part of the visible state of the private unit. That is, the two specifications, one in the private unit, and one in the body of the (typically) public unit, must match one another.

Syntax Hidden state declared in the private part of a unit also requires a Part_Of option or aspect, but it must be connected to an encapsulating state abstraction of the same unit.

~~where~~ The option or aspect Part_Of is used to specify the encapsulating state abstraction of the (typically) public unit with which a private unit’s visible state item is associated.

~~variable~~ To support multi-level hierarchies of private units, a private unit may connect its visible state to the state abstraction of another private unit, so long as eventually the state gets connected to the state abstraction of a public unit through a chain of connections. However, as indicated above, the unit through which the state is *exposed* must be *more visible*.

If a private library unit has visible state, this state might be read or updated as a side effect of calling a visible operation of a public library unit. This visible state may be referenced, either separately or as part of the state abstraction of some other public library unit. The following scenario gives rise to aliasing between the state abstraction and its constituents:

- a state abstraction is visible; and

~~Provide language definition for Refinedaspeect. To be completed in the Milestone 3 version of this document.~~

- an object (or another state abstraction) is visible which is a constituent of the state abstraction; and
- it is not apparent that the object (or other state) is a constituent of the state abstraction - there are effectively two entities representing part or all of the state abstraction.

~~We need to consider the interactions between package hierarchy and abstract state . Do we need to have rules restricting access between parent and child packages? Can we ensure abstract state encapsulation? To be completed in the Milestone 3 version of this document.~~

To resolve such aliasing, rules are imposed to ensure such a scenario can never occur. In particular, it is always known what state abstraction a constituent is part of and a state abstraction always knows all of its constituents.

~~Provide Verification Rules for Initializes aspect in the presence of state abstraction. To be completed in the Milestone 3 version of this document.~~

Static Semantics

1. A *Part_Of indicator* is a Part_Of option of a state abstraction declaration in an Abstract_State aspect, a Part_Of aspect applied to a variable declaration or a Part_Of aspect applied to a generic package instantiation. The Part_Of indicator shall denote the encapsulating state abstraction of which the declaration is a constituent.
2. A unit is *more visible* than another if it has less private ancestors.

~~The subject of refined-Global, Depends, Pre and Post aspects is still under discussion (and their need questioned) and so the subsections covering these aspects is subject to change. To be resolved and completed by Milestone 3 version of this document.~~

Legality Rules

1. ~~Goals to be met by language feature~~ Every private unit and each of its descendants, that have visible state shall for each declaration in the visible state:
 - **Requirement:** Where a global data list referring to abstract state has been specified for a subprogram, it shall be possible to provide a refined global data list that takes account of the refinement of that abstract state—connect the declaration to an encapsulating state abstraction by associating a Part_Of indicator with the declaration; and
 - **Rationale:** see section—
 - ~~name~~ an encapsulating state abstraction in its Part_Of indicator if and only if the unit declaring the state abstraction is strictly more visible than the unit containing the declaration.

[Each state abstraction which has a Part_Of indicator, the unit in which it is declared and its encapsulating state is noted by any tool analyzing SPARK 2014.]
2. **Constraints** Each item of hidden state declared in the private part of a unit shall have a Part_Of indicator associated with the declaration which shall denote an encapsulating state abstraction of the same unit.
3. No other declarations shall have a Part_Of indicator.
4. The body of a unit whose specification declares a state abstraction named as an encapsulating state abstraction of a Part_Of indicator shall:
 - ~~No further Refined~~Global-specific requirements needed have a with_clause naming each unit, excluding itself, containing such a Part_Of indicator; and
 - in its Refined_State aspect, denote each declaration associated with such a Part_Of indicator as a constituent exclusively of the encapsulating state abstraction.

[The state abstractions with a Part_Of indicator, the unit in which they have been declared and their encapsulating state have been noted as described previously and these records are used to check this rule.]
5. **Consistency:** If both a state abstraction and one or more of its constituents are visible in a private package specification or in the package specification of a non-private descendant of a private package, then either the state abstraction or its constituents may be denoted but not within the same Global aspect or Depends aspect. The denotation must also be consistent between the Global and Depends aspects of a subprogram.
6. ~~Let *Abstract* be the abstraction function defined by state refinement (such that *Abstract* is the identity function when applied to visible state). Let *G* be the global data list and *RG* be the refined global data list. Then: In a public package specification entities that are Part_Of an encapsulating state abstraction shall not be denoted; such entities may be represented by denoting their encapsulating state abstraction which is not Part_Of a more visible state abstraction. [This rule is applied recursively, if an entity is Part_Of a state abstraction which itself a Part_Of another encapsulating state abstraction, then it must be represented by the encapsulating state abstraction]. The exclusion to this rule is that for private parts of a package given below.~~
7. **Requirement:** If *X* appears in *RG* but not all constituents of *Abstract(X)* appear in *RG* then *Abstract(X)* must appear in *G* with at least input mode. In the private part of a package a state abstraction declared by the package shall not be denoted other than for specifying it as the encapsulating state in the Part_Of indicator. The state abstraction's constituents declared in the private part shall be denoted.

Rationale: In this case, *Abstract(X)* is not fully initialized by the subprogram and the relevant components must be initialized prior to calling the—
8. In the body of a package, a state abstraction whose refinement is visible shall not be denoted except as an encapsulating state in a Part_Of indicator. Only its constituents may be denoted.
9. Within a package body where a state abstraction is visible, its refinement is not visible, but one or more of its constituents are visible, then the following rules apply:

- either the state abstraction or its constituents may be denoted but not within the same Global aspect or Depends aspect. The denotation must also be consistent between the Global and Depends aspects of a subprogram.
- **Requirement:** If Y appears in G , then at least one X such that $Abstract(X) = Y$ must appear in RG . A state abstraction denoted in a Global or Depends aspect is not refined into its constituents in a Refined_Global or Refined_Depends aspect [because the refinement of the state abstraction is not visible].

Rationale: By definition of abstraction—

Verification Rules

1. **Requirement: Refinement of modes** In a package body of a public child when a state abstraction is visible, its refinement is not but one or more of its constituents are visible then if a subprogram declared in the visible part of the package, directly or indirectly:
 - If the mode of X in RG indicates it is **not** used in a proof context, then that mode must be reads a constituent of a mode of $Abstract(X)$ in G . state abstraction then, this shall be regarded as a read of the most visible encapsulating state abstraction of the constituent and shall be represented by this encapsulating state in the Global and Depends aspects of the subprogram; or
 - If the mode of X in RG indicates it is used in a proof context and $Abstract(X)$ does not have another mode according to the above rules, then the mode of $Abstract(X)$ shall indicate it is only used in proof contexts updates a constituent of a state abstraction then, this shall be regarded as an update of the most visible encapsulation state abstraction of the constituent and shall be represented by this encapsulating state with a mode_selector of In_Out in the Global aspect of the subprogram and as both an input and an output in the Depends aspect of the subprogram. [The reason for this is that it is not known whether the entire state abstraction is updated or only some of its constituents.] This rule does not apply when the most visible encapsulating state abstraction is External Input_Only or Output_Only. In this case the state abstraction shall have a mode_selector of Input for Input_Only states and Output for Output_Only states. Similarly in the Depends aspect Input_Only states shall be denoted only as inputs and Output_Only states shall be denoted only as outputs.

Rationale: Examples In general, modes should be preserved by refinement. However, if one refinement constituent of a state abstraction has an input and/or output mode, then it is no longer of interest whether another constituent is only used in a proof context—

```
package P
  -- P has no state abstraction
  is
  ...
end P;

-- P.Pub is the public package that declares the state abstraction
package P.Pub -- public unit
  with Abstract_State => (R, S)
  is
  ...
end P.Pub;

-- State abstractions of P.Priv, A and B, plus
-- the concrete variable X, are split up among
-- two state abstractions within P.Pub, R and S

private package P.Priv -- private unit
  with Abstract_State => ((A with Part_Of => P.Pub.R),
    (B with Part_Of => P.Pub.S))
  is
```

```

    X : T -- visible variable which is part of state abstraction P.Pub.R.
      with Part_Of => P.Pub.R;
end P.Priv;

with P.Priv; -- P.Priv has to be with'd because its state is part of the
              -- refined state.
package body P.Pub
  with Refined_State => (R => (P.Priv.A, P.Priv.X, Y),
                        S => (P.Priv.B, Z))
is
  Y : T2; -- hidden state
  Z : T3; -- hidden state
  ...
end P.Pub;

package Outer
  with Abstract_State => (A1, A2)
is
  procedure Init_A1
    with Global  => (Output => A1),
         Depends => (A1 => null);

  procedure Init_A2
    with Global  => (Output => A2),
         Depends => (A2 => null);

private
  -- A variable declared in the private part must have a Part_Of aspect
  Hidden_State : Integer
    with Part_Of => A2;

  package Inner
    with Abstract_state => (B1 with Part_Of => Outer.A1)
      -- State abstraction declared in the private
      -- part must have a Part_Of option
      -- A1 cannot be denoted in the private part.
  is
    procedure Init_B1
      with Global  => (Output => B1),
           Depends => (B1 => null);

    procedure Init_A2
      -- A2 cannot be denoted in the private part but
      -- Outer.Hidden_State, which is Part_Of A2, may be denoted.
      with Global  => (Output => Outer.Hidden_State),
           Depends => (Outer.Hidden_State => null);

  end Inner;
end Outer;

package body Outer
  with Refined_State => (A1 => Inner.B1,
                        A2 => Hidden_State)
```



```

-- Outer.A1 and Outer.A2 cannot be denoted in the
-- body of Outer because their refinements are visible.
is
package body Inner
  with Refined_State => (B1 => null) -- Oh, there isn't any state after all
is
  procedure Init_B1
    with Refined_Global  => null, -- Refined_Global and Refined_Depends of a null re
      Refined_Depends => null
  is
  begin
    null;
  end Init_B1;

  procedure Init_A2
    -- Refined_Global and Refined_Depends aspects not required
    -- because there is no refinement of Outer.Hidden_State.
  is
  begin
    Outer.Hidden_State := 0;
  end Init_A2;

end Inner;

procedure Init_A1
  with Refined_Global  => (Output => B1),
      Refined_Depends => (B1 => null)
is
begin
  Inner.Init_B1;
end Init_A1;

procedure Init_A2
  with Refined_Global  => (Output => Hidden_State),
      Refined_Depends => (Hidden_State => null)
is
begin
  Inner.Init_A2;
end Init_A2;

end Outer;

package Q
  with Abstract_State => (Q1, Q2)
is
  -- Q1 and Q2 may be denoted here
  procedure Init_Q1
    with Global  => (Output => Q1),
      Depends => (Q1 => null);

  procedure Init_Q2
    with Global  => (Output => Q2),
      Depends => (Q2 => null);

```

```
private
  -- Q1 and Q2 may only be denoted as the encapsulating state abstraction
  Hidden_State : Integer
    with Part_Of => Q2;
end Q;

private package Q.Child
  with Abstract_State => (C1 with Part_Of => Q.Q1)
is
  -- Only constituents of Q1 and Q2 may be denoted here
  procedure Init_Q1
    with Global    => (Output => C1),
         Depends  => (C1 => null);

    procedure Init_Q2
      with Global    => (Output => Q.Hidden_State),
           Depends  => (Q.Hidden_State => null);
end Q.Child;

with Q;
package body Q.Child
  with Refined_State => (C1 => Actual_State)
is
  -- C1 shall not be denoted here - only Actual_State
  -- but Q.Hidden_State may be denoted.
  Actual_State : Integer;

  procedure Init_Q1
    with Refined_Global    => (Output => Actual_State),
         Refined_Depends  => (Actual_State => null)
  is
  begin
    Actual_State := 0;
  end Init_Q1;

  procedure Init_Q2
  is
  begin
    Q.Hidden_State := 0;
  end Init_Q2;

end Q.Child;

with Q.Child;
package body Q
  with Refined_State => (Q1 => Q.Child.C1,
                        Q2 => Hidden_State)
is
  -- Q1 and Q2 shall not be denoted here but the constituents
  -- Q.Child.C1 and Hidden_State may be.

  procedure Init_Q1
    with Refined_Global    => (Output => Q.Child.C1),
         Refined_Depends  => (Q.Child.C1 => null)
```

```

is
begin
  Q.Child.Init_Q1;
end Init_Q1;

procedure Init_Q2
  with Refined_Global => (Output => Hidden_State),
       Refined_Depends => (Hidden_State => null)
is
begin
  Q.Child.Init_Q2;
end Init_Q2;

end Q;

```

7.2.4 Initialization Issues

Every state abstraction specified as being initialized in the `Initializes` aspect of a package has to have all of its constituents initialized. This may be achieved by initialization within the package, by assumed pre-initialization (in the case of external state) or, for constituents which reside in another package, initialization by their declaring package.

Verification Rules

1. **Semantics** For each state abstraction denoted by the name of an `initialization_item` of an `Initializes` aspect of a package, all the constituents of the state abstraction must be initialized by:

- ~~As per Global aspect.~~
initialization within the package; or
- ~~General requirements:~~ assumed pre-initialization (in the case of external states); or
- ~~See also section~~ for constituents which reside in another unit [and have a `Part_Of` indicator associated with their declaration] by their declaring package. [It follows that such constituents will appear in the initialization clause of the declaring unit unless they are external states.] ~~—~~

~~The consistency rules will be updated as the model for volatile variables is defined. To be completed in the Milestone 3 version of this document.~~

~~If it ends up being possible to refine null abstract state, then refinements of such state could appear in refined globals statements, though they would need to have mode in-out. To be completed in the Milestone 3 version of this document.~~

7.2.5 Refined_Global Aspect

A subprogram declared in the visible part of a package may have a ~~RefinedGlobal~~ `Refined_Global` aspect applied to its body or body stub. ~~The RefinedGlobal aspect defines the global items~~ A `Refined_Global` aspect of a subprogram defines a refinement of the `Global` Aspect of the subprogram in terms of the of a of the package rather than the; that is, the `Refined_Global` aspect repeats the `Global` aspect of the subprogram except that references to state abstractions whose refinements are visible at the point of the subprogram_body are replaced with references to [some or all of the] constituents of those abstractions.

The ~~RefinedGlobal~~ `Refined_Global` aspect is introduced by an `aspect_specification` where the `aspect_mark` is ~~“Refined_Global”~~ and the `aspect_definition` ~~must~~ shall follow the grammar of `global_specification` in *Global Aspect*.

Static Semantics

The static semantics are equivalent to those given for the Global aspect in *Global Aspect*.

~~Provide language definition for~~

Legality Rules

1. ~~A Refined_Global aspect~~ ~~–To be completed in the Milestone 3 version of this document.–~~

~~shall be specified on a body_stub (if one is present) or subprogram body if and only if it has a declaration in the visible part of an enclosing package, the declaration has a Global aspect which denotes a state abstraction declared by the package and the refinement of the state abstraction is visible.~~

2. ~~Goals to be met by language feature~~ A Refined_Global aspect specification shall *refine* the subprogram's Global aspect as follows:

- **Requirement:** ~~Where a dependency relation referring to abstract state has been given, it shall be possible to specify a refined dependency relation that takes account of the refinement of that abstract state.~~ For each global_item in the Global aspect which denotes a state abstraction whose non-null refinement is visible at the point of the Refined_Global aspect specification, the Refined_Global specification shall include one or more global_items which denote constituents of that state abstraction.

Rationale: ~~see section~~

- For each global_item in the Global aspect which denotes a state abstraction whose null refinement is visible at the point of the Refined_Global aspect specification, the Refined_Global specification shall be omitted, or if required by the syntax of a global_specification replaced by a null in the Refined_Global aspect.
 - **Constraints:** For each global_item in the Global aspect which does not denote such a state abstraction, the Refined_Global specification shall include exactly one global_item which denotes the same entity as the global_item in the Global aspect.
 - No ~~further Refineddepends-specific requirements needed~~ other global_items shall be included in the Refined_Global aspect specification.
3. **Consistency:** Global_items in a Refined_Global aspect_specification shall denote distinct entities.
 4. **Requirement:** The refined dependency relation defines an alternative view of the inputs and outputs of the subprogram and that view must be equivalent to the refined list of global data items and formal parameters and their modes (ignoring data items used only in proof contexts).

Rationale: ~~this provides a useful early consistency check~~ The mode of each global_item in a Refined_Global aspect shall match that of the corresponding global_item in the Global aspect unless: the mode_selector specified in the Global aspect is In_Out; the corresponding global_item of Global aspect shall denote a state abstraction whose refinement is visible; and the global_item in the Refined_Global aspect is a constituent of the state abstraction.

~~Let *Abstract* be the abstraction function defined by state refinement (such that *Abstract* is the identity function when applied to visible state). Let *D* be a dependency relation and *RD* be the corresponding refined dependency relation. Then~~ For this special case when the mode_selector is In_Out, the Refined_Global aspect may denote individual constituents of the state abstraction as Input, Output, or In_Out (given that the constituent itself may have any of these mode_selectors) so long as one or more of the following conditions are satisfied:

- **Requirement:** If (X, Y) is in *RD* –i.e. *X* depends on *Y*– then $(Abstract(X), Abstract(Y))$ is in *D*.

Rationale: ~~dependencies must be preserved after abstraction.~~ at least one of the constituents has a mode_selector of In_Out; or

- **Requirement:** If (X, Y) is in RD and there is A such that $Abstract(A) = Abstract(X)$ but there is no B such that (A, B) is in RD , then $(Abstract(X), Abstract(X))$ is in D .

Rationale: In this case, $Abstract(X)$ is not fully initialized by the subprogram and the relevant components must be initialized prior to calling the subprogram. There is at least one of each of a constituent with a mode_selector of Input and of Output; or

- **Requirement:** If (S, T) is in D then there shall exist (V, W) in RD such that $Abstract(V) = S$ and $Abstract(W) = T$.

Rationale: By definition of abstraction the Refined_Global aspect does not denote all of the constituents of the state abstraction but denotes at least one constituent that has a mode_selector of Output.

[Semantics: This rule ensures that a state abstraction with the mode_selector In_Out cannot be refined onto a set of constituents that are Output or Input only. The last condition satisfies this requirement because not all of the constituents are updated, some are preserved, that is the state abstraction has a self-dependency.]

5. **As per Depends aspect:** If the Global aspect specification references a state abstraction with a mode_selector of Output, whose refinement is visible, then every constituent of that state abstraction shall be referenced in the Refined_Global aspect specification.
6. **General requirements:** The legality rules for Global Aspect See also section and External states described in Refined External States also apply.

Dynamic Semantics

There are no dynamic semantics associated with a Refined_Global aspect.

The consistency rules will be updated as the model for volatile variables is defined. To be completed in the Milestone 3 version of this document.

Verification Rules

1. If a subprogram has a Refined_Global aspect it is used in the analysis of the subprogram body rather than its Global aspect.
2. The verification rules given for Global Aspect also apply.

If it is possible to refine null abstract state, then refinements of such state could appear in refined depends statements, but wouldn't map to anything in the depends relation itself and would need to have mode in/out in the refined depends. To be completed in the Milestone 3 version of this document.

7.2.6 Refined_Depends Aspect

A subprogram declared in the visible part of a package may have a Refined_Depends aspect applied to its body or body stub. The Refined_Depends aspect of a subprogram defines a refinement of the Depends aspect defines the of the subprogram in terms of the of a of the package rather than the; that is, the Refined_Depends aspect repeats the Depends aspect of the subprogram except that references to state abstractions, whose refinements are visible at the point of the subprogram body, are replaced with references to [some or all of the] constituents of those abstractions.

The Refined_Depends aspect is introduced by an aspect_specification where the aspect_mark is "Refined_Depends" and the aspect_definition must shall follow the grammar of dependency_relation in Depends Aspect.

Static Semantics

The static semantics are equivalent to those given for the Depends aspect in Depends Aspect.

Provide language definition for

Legality Rules

1. A Refined_Depends aspect ~~—To be completed in the Milestone 3 version of this document—~~

shall be specified on a body_stub (if one is present) or subprogram body if and only if it has a declaration in the visible part of an enclosing package and the declaration has a Depends aspect which denotes a state abstraction declared by the package and the refinement of the state abstraction is visible.

2. ~~Goals to be met by language feature~~ A Refined_Depends aspect specification is, in effect, a copy of the corresponding Depends aspect specification except that any references in the Depends aspect to a state abstraction, whose refinement is visible at the point of the Refined_Depends specification, are replaced with references to zero or more direct or indirect constituents of that state abstraction. A Refined_Depends aspect is defined by creating a new dependency_relation from the original given in the Depends aspect as follows:

- **Requirement:** ~~Where a precondition has been provided for a subprogram declaration, it shall be possible to state a refined precondition that refers to concrete rather than abstract state and/or concrete rather than abstract type detail.~~ A partially refined dependency relation is created by first copying, from the Depends aspect, each output that is not state abstraction whose refinement is visible at the point of the Refined_Depends aspect, along with its input_list, to the partially refined dependency relation as an output denoting the same entity with an input_list denoting the same entities as the original. [The order of the outputs and the order of inputs within the input_list is insignificant.]

Rationale: ~~See section~~

- ~~The partially refined dependency relation is then extended by replacing each output in the Depends aspect that is a state abstraction, whose refinement is visible at the point of the Refined_Depends, by zero or more outputs in the partially refined dependency relation. It shall be zero only for a null refinement, otherwise all of the outputs shall denote a constituent of the state abstraction.~~

If the output in the Depends_Aspect denotes a state abstraction which is not also an input, then all of the constituents [for a non-null refinement] of the state abstraction shall be denoted as outputs of the partially refined dependency relation.

These rules may, for each output in the Depends aspect, introduce more than one output in the partially refined dependency relation. Each of these outputs has an input_list that has zero or more of the inputs from the input_list of the original output. The union of these inputs shall denote the same inputs that appear in the input_list of the original output.

- **Constraints:** ~~If the Depends aspect has a null_dependency_clause, then the partially refined dependency relation has a null_dependency_clause added with an input_list denoting the same inputs as the original.~~
 - ~~No further Refinedprecondition-specific requirements needed.~~ The partially refined dependency relation is completed by replacing the inputs which are state abstractions, whose refinements are visible at the point of the Refined_Depends aspect, by zero or more inputs. It shall be zero only for a null refinement, otherwise each of the inputs shall denote a constituent of the state abstraction. The completed dependency relation is the dependency_relation of the Refined_Depends aspect.
3. **Consistency:** These rules result in omitting each state abstraction whose null refinement is visible at the point of the Refined_Depends. If and only if required by the syntax, the state abstraction shall be replaced by a null symbol rather than being omitted.
 4. **Requirement:** ~~The refined precondition of the subprogram must be implied by the precondition. No other outputs or inputs shall be included in the Refined_Depends aspect specification. Outputs in the Refined_Depends aspect specification shall denote distinct entities. Inputs in an input_list shall denote distinct entities.~~
- Rationale:** ~~standard definition of proof refinement~~
5. [The above rules may be viewed from the perspective of checking the consistency of a Refined_Depends aspect with its corresponding Depends aspect. In this view, each input in the Refined_Depends aspect that is a

constituent of a state abstraction, whose refinement is visible at the point of the Refined_Depends aspect, is replaced by its representative state abstraction with duplicate inputs removed.

Each output in the Refined_Depends aspect, which is a constituent of the same state abstraction whose refinement is visible at the point of the Refined_Depends aspect, is merged along with its input_list into a single dependency_clause whose output denotes the state abstraction and input_list is the union of all of the inputs from the original input_lists.]

6. ~~Semantics: The rules for Depends Aspect As per the semantics of the Precondition aspect also apply.~~

Dynamic Semantics

There are no dynamic semantics associated with a Refined_Depends aspect as it is used purely for static analysis purposes and is not executed.

Verification Rules

1. ~~General requirements: If a subprogram has a Refined_Depends aspect it is used in the analysis of the subprogram body rather than its Depends Aspect.~~
2. ~~See also section The verification rules given for Depends Aspect also apply.~~

7.2.7 Refined Precondition Aspect

A subprogram declared in the visible part of a package may have a Refined Precondition aspect applied to its body or body stub. The Refined Precondition may be used to restate a precondition given on the declaration of a subprogram in terms of the full view of a private type or the constituents of a refined state_name.

The Refined Precondition aspect is introduced by an aspect_specification where the aspect_mark is “Re-fined_Pre” and the aspect_definition ~~must~~ shall be a Boolean expression.

~~Provide language definition for Refinedaspect. To be completed in the Milestone 3 version of this document.~~

Legality Rules

1. ~~Goals to be met by language feature: **Requirement:** Where a post-condition has been provided for a subprogramdeclaration, it shall be possible to state a refined post-condition that refers to concrete rather than abstract state and/or concrete rather than abstract type detail. A Refined_Pre aspect may appear only on a body_stub (if one is present) or the body (if no stub is present) of subprogram if the subprogram is declared in the visible part of a package, its abstract view. If the subprogram declaration in the visible part has no explicit precondition, a precondition of True is assumed for its abstract view.~~

~~**Rationale:** See section~~

2. ~~At the point of call of a subprogram, both its precondition and the expression of its Refined_Post aspect shall evaluate to True.~~

~~Constraints:-~~

3. ~~No further Refined post-condition specific requirements needed~~ The same legality rules apply to a Refined Precondition as for a precondition.

Static Semantics

1. ~~Consistency: **Requirement:** The post-condition of A Refined Precondition of a subprogram defines a refinement of the precondition of the subprogram must be implied by the refined post-condition.~~

~~**Rationale:** standard definition of proof refinement.~~

2. ~~Semantics: The static semantics are otherwise as for a precondition.~~

Dynamic Semantics

1. ~~As per the semantics of the Post-condition aspect~~ When a subprogram with a Refined Precondition is called; first the precondition is evaluated as defined in the Ada RM. If the precondition evaluates to True, then the Refined Precondition is evaluated. If either precondition or Refined Precondition do not evaluate to True an exception is raised.

Verification Rules

1. ~~General requirements: See also section~~ The precondition of the abstract view of the subprogram shall imply its Refined Precondition.

7.2.8 Refined Postcondition Aspect

A subprogram declared in the visible part of a package may have a Refined Postcondition aspect applied to its body or body stub. The Refined Postcondition may be used to restate a postcondition given on the declaration of a subprogram in terms the full view of a private type or the constituents of a refined state_name.

The Refined ~~Precondition~~ Postcondition aspect is introduced by an aspect_specification where the aspect_mark is “Refined_Post” and the aspect_definition ~~must~~ shall be a Boolean expression.

~~Provide language definition for-~~

Legality Rules

1. A Refined_Post aspect ~~.- To be completed in the Milestone 3 version of this document.~~ may only appear on a body_stub (if one is present) or the body (if no stub is present) of a subprogram which is declared in the visible part of a package, its abstract view. If the subprogram declaration in the visible part has no explicit postcondition, a postcondition of True is assumed for the abstract view.
2. The same legality rules apply to a Refined Postcondition as for a postcondition.

Static Semantics

1. A Refined Postcondition of a subprogram defines a refinement of the postcondition of the subprogram.
2. Logically, the Refined Postcondition of a subprogram must imply its postcondition. This means that it is perfectly logical for the declaration not to have a postcondition (which in its absence defaults to True) but for the body or body stub to have a Refined Postcondition.
3. The default Refined_Post for an expression function, F, is F'Result = expression, where expression is the expression defining the body of the function.
4. The static semantics are otherwise as for a postcondition.

Dynamic Semantics

1. When a subprogram with a Refined Postcondition is called; first the subprogram is evaluated. The Refined Postcondition is evaluated immediately before the evaluation of the postcondition or, if there is no postcondition, immediately before the point at which a postcondition would have been evaluated. If the Refined Postcondition evaluates to True then the postcondition is evaluated as described in the Ada RM. If either the Refined Postcondition or the postcondition do not evaluate to True then the exception Assertions.Assertion_Error is raised.

Verification Rules

1. The precondition of a subprogram declaration with the Refined Precondition of its body or body stub and its Refined Postcondition together imply the postcondition of the declaration, that is:
(Precondition and Refined Precondition and Refined Postcondition) -> Postcondition

Todo

refined contract_cases. To be completed in ~~the Milestone 3~~ a post-Release 1 version of this document.

7.2.9 Refined External States

External state which is a state abstraction requires a refinement as does any state abstraction. There are rules which govern refinement of a state abstraction on to external states which are given in this section.

Legality Rules

1. A state abstraction that is not specified as External shall not have constituents which are External states.
2. An External, Input_Only state abstraction shall have only constituents that are External, Input_Only states.
3. An External, Output_Only state abstraction shall have only constituents that are External, Output_Only states.
4. A state abstraction that is specified as just External state, referred to as a *plain External state* may have constituents of any sort of External state and, or, non External states.
5. A subprogram declaration that has a Global aspect denoting a plain External state abstraction with a mode_selector other than In_Out, and the refinement of the state abstraction is visible at the point of the Refined_Global aspect, shall not denote a Volatile constituent of the state abstraction, in its Refined_Global aspect.
6. All other rules for Refined_State, Refined_Global and Refined_Depends aspect also apply.

Examples

```
package Externals
  with Abstract_State => ((Combined_Inputs with External, Input_Only),
                        (Displays with External, Output_Only),
                        (Complex_Device with External)),
  Initializes => Complex_Device
is
  procedure Read (Combined_Value : out Integer)
    with Global => Combined_Inputs, -- Combined_Inputs is an Input_Only
                                     -- External state; it can only be an
                                     -- Input in Global and Depends aspects.
    Depends => (Combined_Value => Combined_Inputs);

  procedure Display (D_Main, D_Secondary : in String)
    with Global => (Output => Displays), -- Displays is an Output_Only
                                     -- External state; it can only be an
                                     -- Output in Global and Depends
                                     -- aspects.
    Depends => (Displays => (D_Main, D_Secondary));

  function Last_Value_Sent return Integer
    with Global => Complex_Device; -- Complex_Device is a Plain External
                                     -- state. It can be an Input and
                                     -- be a global to a function provided
                                     -- the Refined_Global aspect only
                                     -- refers to non-volatile or non-external
                                     -- constituents.

  procedure Output_Value (Value : in Integer)
    with Global => (In_Out => Complex_Device),
```

```
        Depends => (Complex_Device => (Complex_Device, Value));
-- If the refined Global Aspect refers to constituents which
-- are volatile then the mode_selector for Complex_Device must
-- be In_Out and it is both an input and an output.
-- The subprogram must be a procedure.

end Externals;

private package Externals.Temperature
  with Abstract_State => (State with External, Input_Only,
                          Part_Of => Externals.Combined_Inputs)
is
  ...
end Externals.Temperature;

private package Externals.Pressure
  with Abstract_State => (State with External, Input_Only,
                          Part_Of => Externals.Combined_Inputs)
is
  ...
end Externals.Pressure;

private package Externals.Main_Display
  with Abstract_State => (State with External, Output_Only,
                          Part_Of => Externals.Displays)
is
  ...
end Externals.Main_Display;

private package Externals.Secondary_Display
  with Abstract_State => (State with External, Output_Only,
                          Part_Of => Externals.Displays)
is
  ...
end Externals.Secondary_Display;

with Externals.Temperature,
      Externals.Pressure,
      Externals.Main_Display,
      Externals.Secondary_Display;
package body Externals
  with Refined_State => (Combined_Inputs => (Externals.Temperature,
                                              Externals.Pressure),
                        -- Input_Only external state so both Temperature and
                        -- Pressure must be Input_Only.

                        Displays => (Externals.Main_Display,
                                     Externals.Secondary_Display),
                        -- Output_Only external state so both Main_Display and
                        -- Secondary_Display must be Output_Only.

                        Complex_Device => (Saved_Value,
                                           Out_Reg,
```

```

                                In_Reg))
                                -- Complex_Device is a Plain External and may be
                                -- mapped to any sort of constituent.
is
  Saved_Value : Integer := 0;  -- Initialized as required.

  Out_Reg : Integer
    with Volatile,
         Output_Only,
         Address => System.Storage_Units.To_Address (16#ACECAFE#);

  In_Reg : Integer
    with Volatile,
         Input_Only,
         Address => System.Storage_Units.To_Address (16#A11CAFE#);

  function Last_Value_Sent return Integer
    with Refined_Global => Saved_Value -- Refined_Global aspect only
                                         -- refers to non external state
                                         -- as an Input.
  is
  begin
    return Saved_Value;
  end Last_Value_Sent;

  procedure Output_Value (Value : in Integer)
    with Refined_Global => (Input  => In_Reg,
                           Output => Out_Reg,
                           In_Out  => Saved_Value),
    -- Refined_Global aspect refers to both volatile
    -- state and non external state.

    Refined_Depends => ((Out_Reg,
                        Saved_Value) => (Saved_Value,
                                         Value),
                       null => In_Reg)
  is
    Ready : constant Integer := 42;
    Status : Integer;
  begin
    if Saved_Value /= Value then
      loop
        Status := In_Reg;  -- In_Reg is Input_Only external state
                           -- and may appear on RHS of assignment
                           -- but not in a condition.

        exit when Status = Ready;
      end loop;

      Out_Reg := Value;  -- Out_Reg is an Output_Only external
                        -- state. Its value cannot be read.
      Saved_Value := Value;
    end if;
  end Output_Value;

```

...
end Externals;

7.3 Private Types and Private Extensions

The partial view of a private type or private extension may be in SPARK 2014 even if its full view is not in SPARK 2014. The usual rule applies here, so a private type without discriminants is in SPARK 2014, while a private type with discriminants is in SPARK 2014 only if its discriminants are in SPARK 2014.

7.3.1 Private Operations

No extensions or restrictions.

7.3.2 Type Invariants

Syntax ~~There is no additional syntax associated with type invariants.~~ The aspect_specification Type_Invariant is not permitted in SPARK 2014. [Type invariants are not currently supported in SPARK 2014 but are intended to be introduced in a future release.]

Legality Rules ~~There are no additional legality rules associated with type invariants.~~

Todo

Static Semantics ~~There are no additional static semantics associated with type invariants.~~ Add support for type invariants in SPARK 2014. To be completed in a post-Release 1 version of this document.

7.4 Deferred Constants

The view of an entity introduced by a deferred_constant_declaration is in SPARK 2014, even if the initialization_expression in the corresponding completion is not in SPARK 2014.

7.5 Limited Types

No extensions or restrictions.

7.6 Assignment and Finalization

Controlled types are not permitted in SPARK 2014.

7.7 Elaboration Issues

SPARK 2014 imposes a set of restrictions which ensure that a call to a subprogram cannot occur before the body of the subprogram has been elaborated. The success of the runtime elaboration check associated with a call is guaranteed by these restrictions and so the proof obligation associated with such a check is trivially discharged. Similar restrictions are imposed to prevent the reading of uninitialized library-level variables during library unit elaboration, and to prevent instantiation of a generic before its body has been elaborated. Finally, restrictions are imposed in order to ensure that the `Initial_Condition` (and `Initializes` aspect) of a library level package can be meaningfully used.

Dynamic Semantics ~~There are no additional dynamic semantics associated with type invariants~~ These restrictions are described in this section. Because all of these elaboration-related issues are treated similarly, they are discussed together in one section.

Note that throughout this section an implicit call (e.g., one associated with default initialization of an object or with a defaulted parameter in a call) is treated in the same way as an explicit call, and an explicit call which is unevaluated at the point where it (textually) occurs is ignored at that point (but is not ignored later at a point where it is evaluated). This is similar to the treatment of expression evaluation in Ada's freezing rules. This same principle applies to the rules about reading global variables discussed later in this section.

~~Verification Rules~~ Static Semantics

1. ~~The Ada 2012 RM lists places at which an invariant check is performed. In SPARK 2014, we add the following places in order to guarantee that an instance of a type always respects its invariant at the point at which it is passed as an input parameter:~~ A call which occurs within the same compilation_unit as the subprogram_body of the callee is said to be an *intra-compilation_unit call*.
2. ~~Before a call on any subprogram or entry that :~~ A construct (specifically, a call to a subprogram or a read or write of a variable) which occurs in elaboration code for a library level package is said to be *executable during elaboration*. If a subprogram call is executable during elaboration and the callee's body occurs in the same compilation_unit as the call, then any constructs occurring within that body are also executable during elaboration. [If a construct is executable during elaboration, this means that it could be executed during the elaboration of the enclosing library unit and is subject to certain restrictions described below.]

Legality Rules

1. SPARK 2014 requires that an intra-compilation_unit call which is executable during elaboration shall occur after a certain point in the unit (described below) where the subprogram's completion is known to have been elaborated. The portion of the unit following this point and extending to the start of the completion of the subprogram is defined to be the *early call region* for the subprogram. An intra-compilation_unit call which is ~~explicitly declared within the immediate scope of type T (or by executable during elaboration and which occurs~~ (statically) before the start of the completion of the callee shall occur within the early call region of the callee.
2. The start of the early call region is obtained by starting at the subprogram's completion (typically a subprogram_body) and then traversing the preceding constructs in reverse elaboration order until a non-preelaborable statement/declarative_item/pragma is encountered. The early call region starts immediately after this non-preelaborable construct (or at the beginning of the enclosing block (or library unit package spec or body) if no such non-preelaborable construct is found).

[The idea here is that once elaboration reaches the start of the early call region, there will be no further expression evaluation or statement execution (and, in particular, no further calls) before the subprogram_body has been elaborated because all elaborable constructs that will be elaborated in that interval will be preelaborable. Hence, any calls that occur statically after this point cannot occur dynamically before the elaboration of the subprogram body.]

[These rules allow this example

```
package Pkg is
  ...
  procedure P;
```

```

    procedure Q;
    X : Integer := Some_Function_Call; -- not preelaborable
    procedure P is ... if Blap then Q; end if; ... end P;
    procedure Q is ... if Blaq then P; end if; ... end Q;
begin
    P;
end;

```

even though the call to Q precedes the body of Q. The early call region for either P or Q begins immediately after the declaration of X. Note that because the call to P is executable during elaboration, so is the call to Q.

[TBD: it would be possible to relax this rule by defining a less-restrictive notion of preelaborability which allows, for example,

```

    type Rec is record F1, F2 : Integer; end record;
    X : constant Rec := (123, 456); -- not preelaborable

```

while still disallowing the things that need to be disallowed and then defining the above rules in terms of this new notion instead of preelaborability. The only disadvantage of this is the added complexity of defining this new notion.]

3. For purposes of the above rules, a subprogram completed by a renaming-as-body is treated as though it were a wrapper which calls the renamed subprogram (as described in Ada RM 8.5.4(7.1/1)). [The notional “call” occurring in this wrapper is then subject to the above rules, like any other call.]
4. If an instance of a generic ~~unit, and the generic is declared within the immediate scope of type T~~, and occurs in the same compilation_unit as the body of the generic, the body must precede the instance. [If this rule were only needed in order to avoid elaboration check failures, a similar rule to the rule for calls could be defined. This stricter rule is used in order to avoid having to cope with use-before-definition, as in

```

generic
package G is
    ...
end G;

procedure Proc is
    package I is new G; -- expansion of I includes references to X
begin ... ; end;

X : Integer;

package body G is
    ... <uses of X> ...
end G;

```

This stricter rule applies even if the declaration of the instantiation is not “executable during elaboration”].

5. ~~is visible outside the immediate scope of type T or overrides an operation that is visible outside the immediate scope of T, and~~ In the case of a dispatching call, the subprogram_body mentioned in the above rules is that (if any) of the statically denoted callee.
6. ~~has one or more in-out or in parameters with a part of type T~~ The first freezing point of a tagged type shall occur within the early call region of each of its overriding primitive operations.

[This rule is needed to prevent a dispatching call before the body of the (dynamic, not static) callee has been elaborated. The idea here is that after the freezing point it would be possible to declare an object of the type and then use it as a controlling operand in a dispatching call to a primitive operation of an ancestor type. No analysis is performed to identify scenarios where this is not the case, so conservative rules are adopted.]

[Ada ensures that the freezing point of a tagged type will always occur after both the completion of the type and the declarations of each of its primitive subprograms; the freezing point of any type will occur before the declaration of any objects of the type or the evaluation of any expressions of the type. This is typically all that one needs to know about freezing points in order to understand how the above rule applies to a particular example.]

7. For purposes of defining the early call region, the spec and body of a library unit package which has an `Elaborate_Body` pragma are treated as if they both belonged to some enclosing declaration list with the body immediately following the specification. This means that the early call region in which a call is permitted can span the specification/body boundary. This is important for tagged type declarations.

[This example is in SPARK 2014, but would not be without the `Elaborate_Body` pragma (because of the tagged type rule).

```
with Other_Pkg;
package Pkg is
  pragma Elaborate_Body;
  type T is new Other_Pkg.Some_Tagged_Type with null record;
  overriding procedure Op (X : T);
  -- freezing point of T is here
end;

package body Pkg is
  ... ; -- only preelaborable constructs here
  procedure Op (X : T) is ... ;
end Pkg;
```

~~the check is performed on each such part of type T~~ An elaboration check failure would be possible if a call to `Op` (simple or via a dispatching call to an ancestor) were attempted between the elaboration of the spec and body of `Pkg`. The `Elaborate_Body` pragma prevents this from occurring. A library unit package spec which declares a tagged type will typically require an `Elaborate_Body` pragma.]

8. For the inter-compilation unit case, SPARK 2014 enforces the following static elaboration order rule:
 - If a unit has elaboration code that can directly or indirectly make a call to a subprogram in a with'd unit, or instantiate a generic package in a with'd unit, then if the with'd unit does not have pragma `Pure` or `Preelaborate`, then the client should have a pragma `Elaborate_All` for the with'd unit. For generic subprogram instantiations, the rule can be relaxed to require only a pragma `Elaborate`. ~~[Note that these checks are only performed statically, and this does not create an obligation to extend the run-time checks performed in relation to type invariants]~~ This rule is the same as the GNAT static elaboration order rule as given in the GNAT Pro User's Guide.]

For each call that is executable during elaboration for a given library unit package spec or body, there are two cases: it is (statically) a call to a subprogram whose body is in the current compilation unit, or it is not. In the latter case, we require an `Elaborate_All` pragma as described above (the pragma must be given explicitly; it is not supplied implicitly).

[Corner case notes: These rules correctly prohibit the following example:

```
package P is
  function F return Boolean;
  Flag : Boolean := F; -- would fail elab check
end;
```

~~The support for type invariants needs to be considered further and will be completed for Milestone 3 version of this document.~~ following dispatching-call-during-elaboration example would be problematic if the `Elaborate_Body` pragma were not required; with the pragma, the problem is solved because the elaboration order constraints are unsatisfiable:

~~The view of an entity introduced by a is in SPARK 2014, even if the initialization in the corresponding completion is not in SPARK 2014.~~

```
package Pkg1 is
  type T1 is abstract tagged null record;
  function Op (X1 : T1) return Boolean is abstract;
end Pkg1;

with Pkg1;
package Pkg2 is
  pragma Elaborate_Body;
  type T2 is new Pkg1.T1 with null record;
  function Op (X2 : T2) return Boolean;
end Pkg2;

with Pkg1, Pkg2;
package Pkg3 is
  X : Pkg2.T2;
  Flag : Boolean := Pkg1.Op (Pkg1.T1'Class (X));
  -- dispatching call during elaboration fails check
  -- Note 'Class is not currently permitted.
end Pkg3;

with Pkg3;
package body Pkg2 is
  function Op (X2 : T2) return Boolean is
  begin return True; end;
end Pkg2;
```

~~No extensions or restrictions.~~

9. For an instantiation of a generic which does not occur in the same compilation unit as the generic body, the rules are as described in the GNAT RM passage quoted above.

~~Controlled types are not permitted in SPARK 2014.~~

7.7.1 Use of Initial_Condition and Initializes Aspects

To ensure the correct semantics of the Initializes and Initial_Condition aspects, when applied to library units, language restrictions (described below) are imposed in SPARK 2014 which have the following consequences:

- During the elaboration of a library unit package (spec or body), library-level variables declared outside of that package cannot be modified and library-level variables declared outside of that package can only be read if
 - the variable (or its state abstraction) is mentioned in the Initializes aspect of its enclosing package; and
 - an Elaborate (not necessarily an Elaborate_All) pragma ensures that the body of that package has been elaborated.
- From the end of the elaboration of a library package's body to the invocation of the main program (i.e., during subsequent library unit elaboration), variables declared in the package (and constituents of state abstractions declared in the package) remain unchanged. The Initial_Condition aspect is an assertion which is checked at the end of the elaboration of a package body (but occurs textually in the package spec). The initial condition of a library level package will remain true from this point until the invocation of the main subprogram (because none of the inputs used in computing the condition can change during this interval). This means that a package's initial condition can be assumed to be true both upon entry to the main subprogram itself and during elaboration of any other unit which applies an Elaborate pragma to the library unit in question (note: an Initial_Condition which

depends on no variable inputs can also be assumed to be true throughout the execution of the main subprogram).

- If a package's Initializes aspect mentions a state abstraction whose refinement includes constituents declared outside of that package, then the elaboration of bodies of the enclosing packages of those constituents will precede the elaboration of the body of the package declaring the abstraction. The idea here is that all constituents of a state abstraction whose initialization has been promised are in fact initialized by the end of the elaboration of the body of the abstraction's unit - we don't have to wait for the elaboration of other units (e.g., private children) which contribute to the abstraction.

Verification Rules

1. If a read of a variable (or state abstraction, in the case of a call to a subprogram which takes an abstraction as an input) declared in another library unit is executable during elaboration (as defined above), then the compilation unit containing the read shall apply an Elaborate (not necessarily Elaborate_All) pragma to the unit declaring the variable or state abstraction. The variable or state abstraction shall be specified as being initialized in the Initializes aspect of the declaring package. [This is needed to ensure that the variable has been initialized at the time of the read.]
2. The elaboration of a package's specification and body shall not write to a variable (or state abstraction, in the case of a call to a procedure which takes an abstraction as in output) declared outside of the package. The implicit write associated with a read of an external input only state is permitted. [This rule applies to all packages: library level or not, instantiations or not.] The inputs and outputs of a package's elaboration (including the elaboration of any private descendants of a library unit package) shall be as described in the Initializes aspect of the package.

Legality Rules

1. A package body shall include Elaborate pragmas for all of the other library units [(typically private children)] which provide constituents for state abstraction refinements occurring in the given package body. [This rule could be relaxed to apply only to constituents of an abstraction which is mentioned in an Initializes aspect.]

VISIBILITY RULES

8.1 Declarative Region

No extensions or restrictions.

8.2 Scope of Declarations

No extensions or restrictions.

8.3 Visibility

No extensions or restrictions.

8.4 Use Clauses

Use clauses are always in SPARK 2014, even if the unit mentioned is not completely in SPARK 2014.

8.5 Renaming Declarations

~~No extensions or restrictions.~~

8.5.1 Object Renaming Declarations

An `object_renaming_declaration` for an entire object or a component of a record introduces a static alias of the renamed object. As the alias is static, in SPARK 2014 analysis it is replaced by the renamed object. This scheme works over multiple levels of renaming.

In an `object_renaming_declaration` which renames the result of a function the name of the declaration denotes a read only variable which is assigned the value of the function result from the elaboration of the `object_renaming_declaration`. This read only variable is used in SPARK 2014 analysis.

8.5.2 Exception Renaming Declarations

No extensions or restrictions.

~~Describe model of renaming for array indexing and slices. To be completed in the Milestone 3 version of~~

8.5.3 Package Renaming Declarations

No extensions or restrictions.

8.5.4 Subprogram Renaming Declarations

Syntax

There is no additional syntax associated with subprogram renaming declarations in SPARK 2014.

Legality Rules

1. The aspect_specification on a subprogram_renaming_declaration shall not include any of the SPARK 2014-defined aspects introduced in this document. [This restriction may be relaxed in the future.]

Static Semantics

There are no additional static semantics associated with subprogram renaming declarations in SPARK 2014.

Dynamic Semantics

There are no additional dynamic semantics associated with subprogram renaming declarations in SPARK 2014.

Verification Rules

There are no additional verification rules associated with subprogram renaming declarations in SPARK 2014.

[Note that, from the point of view of both static and dynamic verification, a *renaming-as-body* is treated as a one-line subprogram that “calls through” to the renamed unit.]

8.5.5 Generic Renaming Declarations

No extensions or restrictions.

8.6 The Context of Overload Resolution

No extensions or restrictions.

TASKS AND SYNCHRONIZATION

Concurrent programs require the use of different specification and verification techniques from sequential programs. For this reason, tasks, protected units and objects, and synchronization features are currently excluded from SPARK 2014 but are targeted to be included in Release 2 of the SPARK 2014 language and toolset. 2014.

Todo

RCC: The above text implies that SPARK 2014 does not support Ada.Calendar, which is specified in RM 9.6. SPARK 2005 supports and prefers Ada.Real_Time and models the passage of time as an external “in” mode protected own variable. Should we use the same approach in SPARK 2014? Discussion under TN [LB07-024]. To be completed in the Milestone 3.4 version of this document.

Todo

Add Tasking. ~~Target: release 2 of SPARK 2014 language and toolset~~To be completed in a post-Release 1 version of this document.

PROGRAM STRUCTURE AND COMPILEATION ISSUES

High-Level Requirements Goals to be met by language feature: **Requirement:** The ability to analyze incomplete programs.

Rationale: In order to support incremental development and analysis. To facilitate the use of flow analysis and formal verification as early as possible in the software life-cycle.

Constraints, Consistency, Semantics, General requirements: Interface specifications have to be provided for all modules. In analysis the module is represented by its interface specification.

Language Definition

SPARK 2014 supports constructive, modular analysis. This means that analysis may be performed before a program is complete based on unit interfaces. For instance, to analyze a subprogram which calls another all that is required is a specification of the called subprogram including, at least, its `global_specification` and if formal verification of the calling program is to be performed, then the Pre and Postcondition of the called subprogram needs to be provided. The body of the called subprogram does not need to be implemented to analyze the caller. The body of the called subprogram is checked to be conformant with its specification when its implementation code is available and analyzed.

The separate compilation of Ada `compilation_units` is consistent with SPARK 2014 modular analysis except where noted in the following subsections but, particularly with respect to incomplete programs, analysis does not involve the execution of the program.

10.1 Separate Compilation

A program unit cannot be a task unit, a protected unit or a protected entry.

10.1.1 Compilation Units

No restrictions or extensions.

10.1.2 Context Clauses - With Clauses

Goals to be met by language feature: **Requirement:** State abstractions and visible variable declarations shall be visible in the limited view of a package.

Rationale: ~~This allows the flow analysis specifications of a package P1 to refer to the state of P2 in the case that P1 only has a limited view of P2.~~

~~Constraints, Consistency, Semantics, General requirements: Not applicable.~~

State abstractions are visible in the limited view of packages in SPARK 2014. The notion of an *abstract view* of a variable declaration is also introduced, and the limited view of a package includes the abstract view of any variables declared in the visible part of that package. The only allowed uses of an abstract view of a variable are where the use of a state abstraction would be allowed (for example, in a Global ~~aspect specification~~ `aspect_specification`).

Syntax

There is no additional syntax associated with limited package views in SPARK 2014.

Legality Rules

1. A name denoting the abstract view of a variable shall occur only:
 - as a `global_item` in a Global ~~or Refined~~ `Global` aspect specification; or
 - as an input or output in a Depends ~~or Refined~~ `Depends` aspect specification.

Static Semantics

1. Any state abstractions declared within a given package are present in the limited view of the package. [This means that, for example, a Global ~~aspect specification~~ `aspect_specification` for a subprogram declared in a library unit package ~~P1~~ `P1` could refer to a state abstraction declared in a package ~~P2 if P1~~ `P2 if P1` ~~P2 if P1~~ `P2 if P1` has a limited with of ~~P2~~ `P2`.]
2. For every variable object declared by an `object_declaration` ~~occurring~~ `occurring` immediately within the visible part of a given package, the limited view of the package contains an *abstract view* of the object.
3. The abstract view of a volatile variable is ~~volatile~~ `external`.

Dynamic Semantics

There are no additional dynamic semantics associated with limited package views in SPARK 2014.

Verification Rules

There are no verification rules associated with limited package views in SPARK 2014.

Note: (SB) No need to allow such a name in other contexts where a name denoting a state abstraction could be legal. In particular, in an `Initializes` aspect spec or in any of the various refinement aspect specifications. `Initializes` aspect specs do not refer to variables in other packages. Refinements occur in bodies and bodies don't need limited withs.

Note: (SB) Is the rule about volatility needed? I think this is needed in order to prevent a function's Global specification from mentioning an abstract view of a volatile variable, but I'm not sure because I don't understand what prevents a function's Global specification from mentioning the "concrete" view of a volatile variable. This problem is briefly mentioned at the beginning of the peculiarly numbered subsection 7.2 (package bodies) of section 7.2.4 (volatile variables).

With clauses are always in SPARK 2014, even if the unit mentioned is not completely in SPARK 2014.

10.1.3 Subunits of Compilation Units

No restrictions or extensions.

10.1.4 The Compilation Process

The analysis process in SPARK 2014 is similar to the compilation process in Ada except that the `compilation_units` are analyzed, that is flow analysis and formal verification is performed, rather than compiled.

10.1.5 Pragmas and Program Units

No restrictions or extensions.

10.1.6 Environment-Level Visibility Rules

No restrictions or extensions.

10.2 Program Execution

SPARK 2014 analyses do not involve program execution. However, SPARK 2014 programs are executable including those new language defined aspects and pragmas where they have dynamic semantics given.

10.2.1 Elaboration Control

No extensions or restrictions.

EXCEPTIONS

~~Goals to be met by language feature: Not applicable.~~

~~Constraints: **Requirement:** Most explicit uses of exceptions are excluded from SPARK 2014 as described below. Exceptions can be raised implicitly (for example, by the failure of a language-defined check), but only in the case of a program with an undischarged (or incorrectly discharged, perhaps via an incorrect Assume pragma) proof obligation. Explicit raising of exceptions is dealt with similarly.~~

~~**Rationale:** Raising and handling of exceptions allow forms of control flow that complicate both specification and verification of a program's behavior.~~

~~Consistency: Not applicable.~~

~~Semantics: Not applicable.~~

~~General requirements: Not applicable.~~

Syntax

There is no additional syntax associated with exceptions in SPARK 2014.

Legality Rules

1. Exception handlers are not in SPARK 2014. [Exception declarations (including exception renamings) are in SPARK 2014. Raise statements are in SPARK 2014, but must (as described below) be provably never executed.]
2. Raise expressions are not in SPARK 2014; for a raise statement to be in SPARK 2014, it must be immediately enclosed by an if statement which encloses no other statement. [It is intended that these two rules will be relaxed at some point in the future (this is why raise expressions are mentioned in the Verification Rules section below).]

Static Semantics

There are no additional static semantics associated with exceptions in SPARK 2014.

Dynamic Semantics

There are no additional dynamic semantics associated with exceptions in SPARK 2014.

Verification Rules

1. A `raise_statement` introduces an obligation to prove that the statement will not be executed, much like the proof obligation associated with

```
pragma Assert (False);
```

[In other words, the proof obligations introduced for a raise statement are the same as those introduced for a runtime check which fails unconditionally. A raise expression (see Ada AI12-0022 for details) introduces a similar obligation to prove that the expression will not be evaluated.]

2. The pragmas `Assertion_Policy`, `Suppress`, and `Unsuppress` are allowed in SPARK 2014, but have no effect on the generation of proof obligations. [For example, an array index value must be shown to be in bounds regardless of whether `Index_Check` is suppressed at the point of the array indexing.]

GENERIC UNITS

~~Generic units are not classified as being SPARK. Any generic unit is in SPARK 2014 or non-SPARK, regardless of whether it contains constructs that are not normally in SPARK 2014. Only their instantiations are~~ [Information flow analysis is not performed on a generic unit; a generic unit generates no proof obligations].

An instantiation of a generic is or is not in SPARK 2014 depending on whether the instance declaration and the instance body (described in section 12.3 of the Ada reference manual) are in SPARK 2014 [(i.e., when considered as a package (or, in the case of an instance of a generic subprogram, as a subprogram))].

[For example, a generic which takes a formal limited private type would be in SPARK 2014. An instantiation which passes in a task type as the actual type would not be in SPARK 2014; another instantiation of the same generic which passes in, for example, `Standard.Integer`, might be in SPARK 2014.]

[Ada has a rule that legality rules are not enforced in an instance body. No such rule applies to the restrictions defining which Ada constructs are in SPARK 2014. For example, a `goto` statement in an instance body would cause the instantiation to not be in SPARK 2014.]

[Consider the problem of correctly specifying the Global and Depends aspects of a subprogram declared within an instance body which contains a call to a generic formal subprogram (more strictly speaking, to the corresponding actual subprogram of the instantiation in question). These aspects are simply copied from the corresponding aspect specification in the generic, so this implies that we have to “get them right” in the generic (where “right” means “right for all instantiations”). One way to do this is to assume that a generic formal subprogram references no globals (or, more generally, references any fixed set of globals) and to only instantiate the generic with actual subprograms that meet this requirement. Other solutions involving “generative mode” (where flow-related aspect specifications are omitted in the source and generated implicitly by the tools) may also be available, but are outside of the scope of this document.]

[At some point in the future, a more sophisticated treatment of generics may be defined, allowing a generic to be “proven” and eliminating the need separately verify the correctness of each instantiation. That is not today’s approach.]

[TBD: discuss LSP-ish rules for globals, similar to the compatibility rules for Global/Depends aspects of a subprogram which overrides a dispatching operation. OK, for example, if a subprogram reads fewer inputs than it said it would.]

Todo

~~Constructive modular analysis of generies (including prove once, use many times). Will require significant restrictions and extra aspects to implement~~ Update SPARK 2014 to allow prove once/use many approach to generics. To be completed in a post-Release 1 version of this document.

REPRESENTATION ISSUES

Todo

Provide full detail on Representation Issues. To be completed in a post-Release 1 version of this document.

Todo

This statement was originally in this chapter “Pragma or aspect Unchecked_Union is not in SPARK 2014” this needs to be recorded in the list of unsupported aspects and pragmas. To be completed in the Milestone 4 version of this document.

~~The~~

13.1 Operational and Representation Aspects

No restrictions or additions.

13.2 Packed Types

No restrictions or additions.

13.3 Operational and Representation Attributes

No restrictions or additions.

13.4 Enumeration Representation Clauses

No restrictions or additions.

13.5 Record Layout

13.6 Change of Representation

No restrictions or additions.

13.7 The Package System

The use of the operators defined for type Address are not permitted in SPARK 2014 ~~toolset must be able to analyse programs containing representation clauses and unchecked conversions. Further detail on this will be provided in a subsequent draft~~ except for use within representation clauses.

13.8 Machine Code Insertions

Machine code insertions are not in SPARK 2014.

13.9 Unchecked Type Conversions

An instantiation of an Unchecked_Conversion may have Refined_Pre and Refined_Post aspects specified.

Todo

Provide a detailed semantics for Refined_Pre and Refined_Post aspects on Unchecked_Conversion. To be completed in a post-Release 1 version of this document.

13.9.1 Data Validity

[Currently SPARK 2014 does not check for data validity as it analyses code, though this may be changed in a future release. It is therefore up to users to ensure that data read from external sources is valid.]

Todo

~~Provide detail on Representation Issues~~ Need to put some words in here to describe the precautions that may be taken to avoid invalid data. To be completed in the Milestone 4 version of this document.

Todo

Introduce checks for data validity into the proof model as necessary. To be completed in a post-Release 1 version of this document.

13.10 Unchecked Access Value Creation

As access types are not supported in SPARK 2014, neither is this attribute.

13.11 Storage Management

These features are related to access types and not in SPARK 2014.

13.12 Pragma Restrictions and Pragma Profile

Restrictions and Profiles will be available with SPARK 2014 to provide profiles suitable for different application environments.

13.13 Streams

Stream types and operations are not in SPARK 2014.

13.14 Freezing Rules

No restrictions or additions.

SHARED VARIABLE CONTROL (ANNEX C.6)

The following restrictions are applied to the declaration of volatile types and objects in SPARK 2014:

Legality Rules

1. A volatile representation aspect may only be applied to an object_declaration or a full_type_declaration.
2. A component of a non-volatile type declaration shall not be volatile.
[This may require determining whether a private type is volatile.]
[The above two rules may be relaxed in a future version.]
3. A discriminant shall not be of a volatile type.
4. Neither a discriminated type nor an object of such a type shall be volatile.
5. Neither a tagged type nor an object of such a type shall be volatile.
6. A volatile variable shall not be declared within the body of a function, directly or indirectly.

THE STANDARD LIBRARIES

This chapter ~~will describe~~ describes how SPARK 2014 treats the Ada predefined language environment and standard libraries, corresponding to appendices A through H of the Ada RM. The goal is that SPARK 2014 programs are able to use as much as possible of the the Ada predefined language environment and standard libraries.

Todo

Provide detail on Standard Libraries. To be completed in a post-Release 1 version of this document. This targeting applies to all Todos in this chapter.

Todo

In particular, it is intended that predefined container generics suitable for use in SPARK 2014 will be provided. These will have specifications as similar as possible to those of Ada's bounded containers (i.e., `Ada.Containers.Bounded_*`), but with constructs removed or modified as needed in order to maintain the language invariants that SPARK 2014 relies upon in providing formal program verification.

15.1 Predefined Language Environment

15.1.1 The Package Standard

SPARK 2014 supports all of the types, subtypes and operators declared in package Standard. The predefined exceptions are considered to be declared in Standard, but their use is constrained by other language restrictions.

15.1.2 The Package Ada

Todo

~~Provide detail on Standard Libraries. To be completed in the Milestone 4 version of this document~~Should we say here which packages are supported in SPARK 2014 or which ones aren't supported? How much of the standard library will be available, and in which run-time profiles?

15.2 Interface to Other Languages

This section describes features for mixed-language programming in SPARK 2014, covering facilities offered by Ada's Annex B.

Todo

How much to say here? S95 supports a subset of Interfaces, and a very small subset of Interfaces.C but that's about it.

Todo

What is status of supported for pragma Unchecked_Union in GNATProve at present?

15.3 Systems Programming

tbd.

15.4 Real-Time Systems

This section describes features for real-time programming in SPARK 2014, covering facilities offered by Ada's Annex D.

Todo

RCC: Need to think about Ada.Real_Time. It's important for all S95 customers, to get at monotonic clock, even if not using RavenSPARK. It does depend on support for external variables, though, since Ada.Real_Time.Clock is most definitely Volatile. TN [LB07-024] raised to discuss this.

15.5 Distributed Systems

TBD.

15.6 Information Systems

TBD.

15.7 Numerics

This section describes features for numerical programming in SPARK 2014, covering facilities offered by Ada's Annex G.

Todo

How much here can be supported? Most S95 customers want Ada.Numerics.Generic_Elementary_Functions plus its predefined instantiation for Float, Long_Float and so on. How far should we go?

15.8 High Integrity Systems

SPARK 2014 fully supports the requirements of Ada's Annex H.

SPARK 2005 TO SPARK 2014 MAPPING SPECIFICATION

This appendix defines the mapping between SPARK 2005 and SPARK 2014. It is intended as both a completeness check for the SPARK 2014 language design, and as a guide for projects upgrading from SPARK 2005 to SPARK 2014.

A.1 Subprogram patterns

A.1.1 Global and Derives

This example demonstrates how global variables can be accessed through procedures/functions and presents how the SPARK 2005 *derives* annotation maps over to *depends* in SPARK 2014. The example consists of one procedure (*Swap*) and one function (*Add*). *Swap* accesses two global variables and swaps their contents while *Add* returns their sum.

Specification in SPARK 2005:

```
package Swap_Add_05
--# own X, Y: Integer;
is

    procedure Swap;
    --# global in out X, Y;
    --# derives X from Y &
    --#           Y from X;

    function Add return Integer;
    --# global in X, Y;

end Swap_Add_05;
```

Specification in SPARK 2014:

```
package Swap_Add_14
    with Abstract_State => (X, Y)
is
    procedure Swap
        with Global   => (In_Out => (X, Y)),
             Depends => (X => Y,    -- to be read as "X depends on Y"
                        Y => X); -- to be read as "Y depends on X"
```

```
function Add return Integer
  with Global => (Input => (X, Y));
end Swap_Add_14;
```

A.1.2 Pre/Post/Return contracts

This example demonstrates how the *Pre/Post/Return* contracts are restructured and how they map from SPARK 2005 to SPARK 2014. Procedure *Swap* and function *Add* perform the same task as in the previous example, but they have been augmented by post annotations. Two additional functions (*Max* and *Divide*) and one additional procedure (*Swap_Array_Elements*) have also been included in this example in order to demonstrate further features. *Max* returns the maximum of the two globals. *Divide* returns the division of the two globals after having ensured that the divisor is not equal to zero. The *Swap_Array_Elements* procedure swaps the contents of two elements of an array. For the same reasons as in the previous example, the bodies are not included.

Specification in SPARK 2005:

```
package Swap_Add_Max_05
--# own X, Y: Integer;
is

  subtype Index      is Integer range 1..100;
  type   Array_Type is array (Index) of Integer;

  procedure Swap;
  --# global in out X, Y;
  --# derives X from Y &
  --#           Y from X;
  --# post X = Y~ and Y = X~;

  function Add return Integer;
  --# global in X, Y;
  --# return X + Y;

  function Max return Integer;
  --# global in X, Y;
  --# return Z => (X >= Y -> Z = X) and
  --#           (Y > X -> Z = Y);

  function Divide return Float;
  --# global in X, Y;
  --# pre Y /= 0;
  --# return Float(X / Y);

  procedure Swap_Array_Elements(A: in out Array_Type);
  --# global in X, Y;
  --# derives A from A, X, Y;
  --# pre X in Index and Y in Index;
  --# post A = A~[X => A~(Y); Y => A~(X)];

end Swap_Add_Max_05;
```

Specification in SPARK 2014:

```
package Swap_Add_Max_14
  with Abstract_State => (X, Y)
```

```

is
  subtype Index      is Integer range 1..100;
  type   Array_Type is array (Index) of Integer;

  procedure Swap
    with Global => (In_Out => (X, Y)),
    Depends => (X => Y,
               Y => X),
    Post      => (X = Y'Old and Y = X'Old);

  function Add return Integer
    with Global => (Input => (X, Y)),
    Post      => Add'Result = X + Y;

  function Max return Integer
    with Global => (Input => (X, Y)),
    Post      => (if X >= Y then Max'Result = X
                  else Max'Result = Y);

  function Divide return Float
    with Global => (Input => (X, Y)),
    Pre       => Y /= 0,
    Post      => Divide'Result = Float(X / Y);

  procedure Swap_Array_Elements(A: in out Array_Type)
    with Global => (Input => (X, Y)),
    Depends => (A => (A, X, Y)),
    Pre     => X in Index and Y in Index,
    Post    => A = A'Old'Update (X => A'Old (Y), Y => A'Old (X));
end Swap_Add_Max_14;

```

A.1.3 Attributes of unconstrained out parameter in precondition

The following example illustrates the fact that the attributes of an unconstrained formal array parameter of mode “out” are permitted to appear in a precondition. The flow analyser also needs to be smart about this, since it knows the X'First and X'Last are well-defined in the body, even though the content of X is not.

Specification in SPARK 2005:

```

package P
is
  type A is array (Positive range <>) of Integer;

  -- Shows that X'First and X'Last _can_ be used in
  -- precondition here, even though X is mode "out"...
  procedure Init (X : out A);
  --# derives X from ;
  --# pre X'First <= 2 and
  --#     X'Last  >= 20;
  --# post for all I in Positive range X'Range => (X (I) = 0);

end P;

```

Body in SPARK 2005:

```
package body P is

  procedure Init (X : out A) is
  begin
    --# accept F, 23, X, "OK" &
    --# F, 602, X, X, "OK";
    for I in Positive range X'Range loop
      X (I) := 0;
      --# assert for all J in Positive range X'First .. I => (X (J) = 0);
    end loop;
  end Init;

end P;
```

Specification in SPARK 2014:

```
package P
is
  type A is array (Positive range <>) of Integer;

  -- Shows that X'First, X'Last and X'Length _can_ be used
  -- in precondition here, even though X is mode "out"...
  procedure Init (X : out A)
    with Depends => (X => null),
         Pre      => X'First <= 2 and X'Last >= 20,
         Post     => (for all I in X'Range => (X (I) = 0));

end P;
```

Todo

~~Note that the details of false alarm management are still TBD and so there is currently no equivalent of the accept annotation in the SPARK 2005 body.~~ Depending on the outcome of M423-014, either pragma Annotate or pragma Warning will be utilized to accept warnings/errors in SPARK 2014. To be completed in the Milestone 3.4 version of this document.

Body in SPARK 2014:

```
package body P is

  procedure Init (X : out A) is
  begin
    -- SPARK 2005 example uses accept annotation here:
    -- corresponding syntax is TBD.
    for I in Positive range X'Range loop
      X (I) := 0;
      pragma Loop_Invariant (for all J in X'First .. I => (X (J) = 0));
    end loop;
  end Init;

end P;
```

A.1.4 Nesting of subprograms, including more refinement

This example demonstrates how procedures and functions can be nested within other procedures and functions. Furthermore, it illustrates how global variables refinement can be performed.

Specification in SPARK 2005:

```
package Nesting_Refinement_05
--# own State;
--# initializes State;
is
  procedure Operate_On_State;
  --# global in out State;
end Nesting_Refinement_05;
```

Body in SPARK 2005:

```
package body Nesting_Refinement_05
--# own State is X, Y;      -- Refined State
is
  X, Y: Integer;

  procedure Operate_On_State
  --# global in out X;      -- Refined Global
  --#          out Y;
  is
    Z: Integer;

    procedure Add_Z_To_X
    --# global in out X;
    --#          in    Z;
    is
    begin
      X := X + Z;
    end Add_Z_To_X;

    procedure Overwrite_Y_With_Z
    --# global    out Y;
    --#          in    Z;
    is
    begin
      Y := Z;
    end Overwrite_Y_With_Z;
  begin
    Z := 5;
    Add_Z_To_X;
    Overwrite_Y_With_Z;
  end Operate_On_State;

  begin -- Promised to initialize State
    -- (which consists of X and Y)
    X := 10;
    Y := 20;
  end Nesting_Refinement_05;
```

Specification in SPARK 2014:

```
package Nesting_Refinement_14
  with Abstract_State => State,
       Initializes    => State
is
  procedure Operate_On_State
    with Global => (In_Out => State);
end Nesting_Refinement_14;
```

Body in SPARK 2014:

```
package body Nesting_Refinement_14
  -- State is refined onto two concrete variables X and Y
  with Refined_State => (State => (X, Y))
is
  X, Y: Integer;

  procedure Operate_On_State
    with Refined_Global => (In_Out => X,
                           Output => Y)
  is
    Z: Integer;

    procedure Add_Z_To_X
      with Global => (In_Out => X,
                    Input  => Z)
    is
      begin
        X := X + Z;
      end Add_Z_To_X;

    procedure Overwrite_Y_With_Z
      with Global => (Output => Y,
                    Input  => Z)
    is
      begin
        Y := Z;
      end Overwrite_Y_With_Z;

    begin
      Z := 5;
      Add_Z_To_X;
      Overwrite_Y_With_Z;
    end Operate_On_State;

  begin -- Promised to initialize State
    -- (which consists of X and Y)
    X := 10;
    Y := 20;
  end Nesting_Refinement_14;
```

A.2 Package patterns

A.2.1 Abstract Data Types (ADTs)

Visible type

The following example adds no mapping information. The SPARK 2005 and SPARK 2014 versions of the code are identical. Only the specification of the SPARK 2005 code will be presented. The reason why this code is being provided is to allow for a comparison between a package that is purely public and an equivalent one that also has private elements.

Specification in SPARK 2005:

```
package Stacks_05 is
  Stack_Size : constant := 100;
  type Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range is Pointer_Range range 1 .. Stack_Size;
  type Vector is array(Index_Range) of Integer;

  type Stack is
    record
      Stack_Vector : Vector;
      Stack_Pointer : Pointer_Range;
    end record;

  function Is_Empty(S : Stack) return Boolean;
  function Is_Full(S : Stack) return Boolean;

  procedure Clear(S : out Stack);
  procedure Push(S : in out Stack; X : in Integer);
  procedure Pop(S : in out Stack; X : out Integer);
end Stacks_05;
```

Private type

Similarly to the previous example, this one does not contain any annotations either. Due to this, the SPARK 2005 and SPARK 2014 versions are exactly the same. Only the specification of the 2005 version shall be presented.

Specification in SPARK 2005:

```
package Stacks_05 is

  type Stack is private;

  function Is_Empty(S : Stack) return Boolean;
  function Is_Full(S : Stack) return Boolean;

  procedure Clear(S : out Stack);
  procedure Push(S : in out Stack; X : in Integer);
  procedure Pop(S : in out Stack; X : out Integer);

private
  Stack_Size : constant := 100;
  type Pointer_Range is range 0 .. Stack_Size;
```

```
subtype Index_Range is Pointer_Range range 1 .. Stack_Size;
type Vector is array(Index_Range) of Integer;

type Stack is
  record
    Stack_Vector : Vector;
    Stack_Pointer : Pointer_Range;
  end record;
end Stacks_05;
```

Private type with refined pre/post contracts in the body

This example demonstrates how *pre* and *post* conditions, that lie in the specification of a package, can be refined in the package's body. Contracts that need not be refined, do not have to be repeated in the body of a package. In this particular example, the body of the SPARK 2005 might seem to be needlessly repeating contracts. However, this is not true since the contracts that are being repeated are indirectly being refined through the refinement of the *Is_Empty* and *Is_Full* functions.

Specification in SPARK 2005:

```
package Stacks_05
is

  type Stack is private;

  function Is_Empty(S : Stack) return Boolean;
  function Is_Full(S : Stack) return Boolean;

  procedure Clear(S : in out Stack);
  --# post Is_Empty(S);
  procedure Push(S : in out Stack; X : in Integer);
  --# pre  not Is_Full(S);
  --# post not Is_Empty(S);
  procedure Pop(S : in out Stack; X : out Integer);
  --# pre  not Is_Empty(S);
  --# post not Is_Full(S);

private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range     is Pointer_Range range 1 .. Stack_Size;
  type      Vector        is array(Index_Range) of Integer;

  type Stack is
    record
      Stack_Vector : Vector;
      Stack_Pointer : Pointer_Range;
    end record;
end Stacks_05;
```

Body in SPARK 2005:

```
package body Stacks_05 is

  function Is_Empty (S : Stack) return Boolean
```



```

--# return S.Stack_Pointer = 0;
is
begin
    return S.Stack_Pointer = 0;
end Is_Empty;

function Is_Full (S : Stack) return Boolean
--# return S.Stack_Pointer = Stack_Size;
is
begin
    return S.Stack_Pointer = Stack_Size;
end Is_Full;

procedure Clear (S : in out Stack)
--# post Is_Empty(S);
is
begin
    S.Stack_Pointer := 0;
end Clear;

procedure Push (S : in out Stack; X : in Integer)
--# pre  not Is_Full(S);
--# post not Is_Empty(S) and
--#      S.Stack_Pointer = S~.Stack_Pointer + 1 and
--#      S.Stack_Vector = S~.Stack_Vector[S.Stack_Pointer => X];
is
begin
    S.Stack_Pointer := S.Stack_Pointer + 1;
    S.Stack_Vector (S.Stack_Pointer) := X;
end Push;

procedure Pop (S : in out Stack; X : out Integer)
--# pre  not Is_Empty(S);
--# post not Is_Full(S) and
--#      X = S.Stack_Vector(S~.Stack_Pointer) and
--#      S.Stack_Pointer = S~.Stack_Pointer - 1 and
--#      S.Stack_Vector = S~.Stack_Vector;
is
begin
    X := S.Stack_Vector (S.Stack_Pointer);
    S.Stack_Pointer := S.Stack_Pointer - 1;
end Pop;
end Stacks_05;

```

Specification in SPARK 2014:

```

package Stacks_14
is

    type Stack is private;

    function Is_Empty(S : Stack) return Boolean;
    function Is_Full(S : Stack) return Boolean;

    procedure Clear(S : in out Stack)

```

```
    with Post => Is_Empty(S);
  procedure Push(S : in out Stack; X : in Integer)
    with Pre  => not Is_Full(S),
         Post => not Is_Empty(S);
  procedure Pop(S : in out Stack; X : out Integer)
    with Pre  => not Is_Empty(S),
         Post => not Is_Full(S);

private
  Stack_Size : constant := 100;
  type       Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range      is Pointer_Range range 1 .. Stack_Size;
  type       Vector        is array(Index_Range) of Integer;

  type Stack is
    record
      Stack_Vector : Vector;
      Stack_Pointer : Pointer_Range;
    end record;
end Stacks_14;
```

Body in SPARK 2014:

```
package body Stacks_14 is
  function Is_Empty(S : Stack) return Boolean
    with Refined_Post => Is_Empty'Result = (S.Stack_Pointer = 0)
  is
  begin
    return S.Stack_Pointer = 0;
  end Is_Empty;

  function Is_Full(S : Stack) return Boolean
    with Refined_Post => Is_Full'Result = (S.Stack_Pointer = Stack_Size)
  is
  begin
    return S.Stack_Pointer = Stack_Size;
  end Is_Full;

  procedure Clear(S : in out Stack)
    with Refined_Post => Is_Empty(S)
  is
  begin
    S.Stack_Pointer := 0;
  end Clear;

  procedure Push(S : in out Stack; X : in Integer)
    with Refined_Pre  => S.Stack_Pointer /= Stack_Size,
         Refined_Post => (S.Stack_Pointer = S'Old.Stack_Pointer + 1 and
                        S.Stack_Vector = S'Old.Stack_Vector'Update(S.Stack_Pointer => X))
  is
  begin
    S.Stack_Pointer := S.Stack_Pointer + 1;
    S.Stack_Vector(S.Stack_Pointer) := X;
  end Push;
```

```

procedure Pop(S : in out Stack; X : out Integer)
  with Refined_Pre => S.Stack_Pointer /= 0,
       Refined_Post => (X = S.Stack_Vector(S'Old.Stack_Pointer) and
                        S.Stack_Pointer = S'Old.Stack_Pointer - 1 and
                        S.Stack_Vector = S'Old.Stack_Vector)
is
begin
  X := S.Stack_Vector(S.Stack_Pointer);
  S.Stack_Pointer := S.Stack_Pointer - 1;
end Pop;
end Stacks_14;

```

Public child extends non-tagged parent ADT

The following example covers the main differences between a child package and an arbitrary package, namely:

- The private part of a child package can access the private part of its parent.
- The body of a child package can access the private part of its parent.
- The child does not need a with clause for its parent.

A private type and private constant are declared in the parent. The former is accessed in the body of the child, while the latter is accessed in the private part of the child.

Specifications of both parent and child in SPARK 2005:

```

package Pairs_05 is

  type Pair is private;

  -- Sums the component values of a Pair.
  function Sum (Value : in Pair) return Integer;

private

  type Pair is
    record
      Value_One : Integer;
      Value_Two : Integer;
    end record;

  Inc_Value : constant Integer := 1;

end Pairs_05;
--#inherit Pairs_05;

package Pairs_05.Additional_05
is

  -- Additional operation to add to the ADT, which
  -- increments each value in the Pair.
  procedure Increment (Value: in out Pairs_05.Pair);
  --# derives Value from Value;

private

```

```
-- Variable declared to illustrate access to private part of
-- parent from private part of child.
Own_Inc_Value : constant Integer := Pairs_05.Inc_Value;
```

```
end Pairs_05.Additional_05;
```

Bodies of both parent and child in SPARK 2005:

```
package body Pairs_05
is

    function Sum (Value : in Pair) return Integer
    is
    begin
        return Value.Value_One + Value.Value_Two;
    end Sum;

end Pairs_05;

package body Pairs_05.Additional_05
is

    procedure Increment (Value: in out Pairs_05.Pair) is
    begin
        -- Access to private part of parent from body of public child.
        Value.Value_One := Value.Value_One + Own_Inc_Value;
        Value.Value_Two := Value.Value_Two + Own_Inc_Value;
    end Increment;

end Pairs_05.Additional_05;
```

Specifications of both parent and child in SPARK 2014:

```
package Pairs_14 is

    -- No change to parent.

    type Pair is private;

    -- Sums the component values of a Pair.
    function Sum (Value : in Pair) return Integer;

private

    type Pair is
        record
            Value_One : Integer;
            Value_Two : Integer;
        end record;

    Inc_Value : constant Integer := 1;

end Pairs_14;

package Pairs_14.Additional_14
is
```

```

-- Additional operation to add to the ADT, which
-- increments each value in the Pair.
procedure Increment (Value: in out Pairs_14.Pair);
  with Depends => (Value => Value);

private

  -- Variable declared to illustrate access to private part of
  -- parent from private part of child.
  Own_Inc_Value : constant Integer := Pairs_14.Inc_Value;

end Pairs_14.Additional_14;
```

Bodies of both parent and child in SPARK 2014:

As per SPARK 2005.

Tagged type in root ADT package

The following example illustrates the use of a tagged type in an ADT package.

Specification in SPARK 2005:

```

package Stacks_05 is

  type Stack is tagged private;

  function Is_Empty(S : Stack) return Boolean;
  function Is_Full(S : Stack) return Boolean;

  procedure Clear(S : out Stack);
  --# derives S from ;

  procedure Push(S : in out Stack; X : in Integer);
  --# derives S from *, X;

  procedure Pop(S : in out Stack; X : out Integer);
  --# derives S, X from S;

private
  Stack_Size : constant := 100;
  type Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range is Pointer_Range range 1 .. Stack_Size;
  type Vector is array(Index_Range) of Integer;
  type Stack is tagged
    record
      Stack_Vector : Vector;
      Stack_Pointer : Pointer_Range;
    end record;
end Stacks_05;
```

Body in SPARK 2005:

N/A

Specification in SPARK 2014:

```
package Stacks_14 is

  type Stack is tagged private;

  function Is_Empty(S : Stack) return Boolean;
  function Is_Full(S : Stack) return Boolean;

  procedure Clear(S : out Stack)
    with Depends => (S => null);

  procedure Push(S : in out Stack; X : in Integer)
    with Depends => (S =>+ X);
  -- The =>+ symbolizes that any variable on the left side of =>+,
  -- depends on all variables that are on the right side of =>+
  -- plus itself. For example (X, Y) =>+ Z would mean that
  -- X depends on X, Z and Y depends on Y, Z.

  procedure Pop(S : in out Stack; X : out Integer)
    with Depends => ((S,X) => S);

private
  Stack_Size : constant := 100;
  type Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range is Pointer_Range range 1 .. Stack_Size;
  type Vector is array(Index_Range) of Integer;

  type Stack is tagged
    record
      Stack_Vector : Vector;
      Stack_Pointer : Pointer_Range;
    end record;
end Stacks_14;
```

Body in SPARK 2014:

N/A

Extension of tagged type in child package ADT

The following example illustrates the extension of a tagged type in a child package.

Specification in SPARK 2005:

```
--# inherit Stacks_05;
package Stacks_05.Monitored_05 is

  type Monitored_Stack is new Stacks_05.Stack with private;

  overriding
  procedure Clear(S : out Monitored_Stack);
  --# derives S from ;

  overriding
  procedure Push(S : in out Monitored_Stack; X : in Integer);
  --# derives S from S, X;
```

```

function Top_Identity(S : Monitored_Stack) return Integer;
function Next_Identity(S : Monitored_Stack) return Integer;

private

type Monitored_Stack is new Stacks_05.Stack with
  record
    Monitor_Vector : Stacks_05.Vector;
    Next_Identity_Value : Integer;
  end record;

end Stacks_05.Monitored_05;

```

Body in SPARK 2005:

```

package body Stacks_05.Monitored_05 is
  subtype Index_Range is Stacks_05.Index_Range;

  overriding
  procedure Clear(S : out Monitored_Stack) is
  begin
    S.Stack_Pointer := 0;
    S.Stack_Vector := Stacks_05.Vector'(Index_Range => 0);
    S.Next_Identity_Value := 1;
    S.Monitor_Vector := Stacks_05.Vector'(Index_Range => 0);
  end Clear;

  overriding
  procedure Push(S : in out Monitored_Stack; X : in Integer) is
  begin
    Stacks_05.Push(Stacks_05.Stack(S), X);
    S.Monitor_Vector(S.Stack_Pointer) := S.Next_Identity_Value;
    S.Next_Identity_Value := S.Next_Identity_Value + 1;
  end Push;

  function Top_Identity(S : Monitored_Stack) return Integer is
    Result : Integer;
  begin
    if Is_Empty(S) then
      Result := 0;
    else
      Result := S.Monitor_Vector(S.Stack_Pointer);
    end if;
    return Result;
  end Top_Identity;

  function Next_Identity(S : Monitored_Stack) return Integer is
  begin
    return S.Next_Identity_Value;
  end Next_Identity;

end Stacks_05.Monitored_05;

```

Specification in SPARK 2014:

```
package Stacks_14.Monitored_14 is

  type Monitored_Stack is new Stacks_14.Stack with private;

  overriding
  procedure Clear(S : out Monitored_Stack)
    with Depends => (S => null);

  overriding
  procedure Push(S : in out Monitored_Stack; X : in Integer)
    with Depends => (S =>+ X);

  function Top_Identity(S : Monitored_Stack) return Integer;
  function Next_Identity(S : Monitored_Stack) return Integer;

private

  type Monitored_Stack is new Stacks_14.Stack with
    record
      Monitor_Vector : Stacks_14.Vector;
      Next_Identity_Value : Integer;
    end record;

end Stacks_14.Monitored_14;
```

Body in SPARK 2014:

As per SPARK 2005.

Private/Public child visibility

The following example demonstrates visibility rules that apply between public children, private children and their parent in SPARK 2005. More specifically, it shows that:

- Private children are able to see their private siblings but not their public siblings.
- Public children are able to see their public siblings but not their private siblings.
- All children have access to their parent but the parent can only access private children.

Applying the SPARK tools on the following files will produce certain errors. This was intentionally done in order to illustrate both legal and illegal access attempts.

~~The SPARK 2014 version of the code is not provided since the restrictions that are to be shares Ada2012's visibility rules. No restrictions have been applied in terms of package visibility are yet to be determined. To be completed in the Milestone 3 version of this document.~~ visibility and thus no SPARK 2014 code is provided in this section.

Specification of parent in SPARK 2005:

```
package Parent_05
is
  function F return Integer;
end Parent_05;
```

Specification of private child A in SPARK 2005:

```
--#inherit Parent_05; -- OK
private package Parent_05.Private_Child_A_05
is
```



```
end Parent_05.Private_Child_A_05;
```

Specification of private child B in SPARK 2005:

```
--#inherit Parent_05.Private_Child_A_05, -- OK
--#      Parent_05.Public_Child_A_05; -- error, public sibling
private package Parent_05.Private_Child_B_05
is
end Parent_05.Private_Child_B_05;
```

Specification of public child A in SPARK 2005:

```
--#inherit Parent_05, -- OK
--#      Parent_05.Private_Child_A_05; -- error, private sibling
package Parent_05.Public_Child_A_05
is
  pragma Elaborate_Body (Public_Child_A_05);
end Parent_05.Public_Child_A_05;
```

Specification of public child B in SPARK 2005:

```
--#inherit Parent_05.Public_Child_A_05; -- OK
package Parent_05.Public_Child_B_05
is
end Parent_05.Public_Child_B_05;
```

Body of parent in SPARK 2005:

```
with Parent_05.Private_Child_A_05, -- OK
     Parent_05.Public_Child_A_05; -- error, public children not visible
package body Parent_05
is
  function F return Integer is separate;
end Parent_05;
```

Body of public child A in SPARK 2005:

```
package body Parent_05.Public_Child_A_05
is
  procedure Proc(I : in out Integer)
  --#derives I from I;
  is
  begin
    I := I + Parent_05.F; -- OK
  end Proc;
end Parent_05.Public_Child_A_05;
```

A.2.2 Abstract State Machines (ASMs)

Visible, concrete state

Initialized by declaration

The example that follows presents a way of initializing a concrete state (a state that cannot be refined) at the point of the declaration of the variables that compose it. This can only be done in SPARK 2005. In SPARK 2014 state abstractions cannot share names with variables and consequently cannot be implicitly refined.

Specification in SPARK 2005:

```
package Stack_05
--# own S, Pointer;      -- concrete state
--# initializes S, Pointer;
is
  procedure Push(X : in Integer);
    --# global in out S, Pointer;

    procedure Pop(X : out Integer);
      --# global in S; in out Pointer;
    end Pop;
  end Push;
end Stack_05;
```

Body in SPARK 2005:

```
package body Stack_05
is
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector       is array(Index_Range) of Integer;

  S : Vector := Vector'(Index_Range => 0);  -- Initialization of S
  Pointer : Pointer_Range := 0;             -- Initialization of Pointer

  procedure Push(X : in Integer)
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;

end Stack_05;
```

Specification in SPARK 2014:

```
package Stack_14
  with Abstract_State => (S_State, Pointer_State),
       Initializes    => (S_State, Pointer_State)
is
  procedure Push(X : in Integer)
    with Global => (In_Out => (S_State, Pointer_State));

  procedure Pop(X : out Integer)
    with Global => (Input  => S_State,
                  In_Out => Pointer_State);
end Stack_14;
```

Body in SPARK 2014:

~~As per SPARK 2005:-~~

```

package body Stack_14
  with Refined_State => (S_State      => S,
                        Pointer_State => Pointer)
is
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector       is array(Index_Range) of Integer;

  S : Vector := Vector'(Index_Range => 0);  -- Initialization of S
  Pointer : Pointer_Range := 0;             -- Initialization of Pointer

  procedure Push(X : in Integer)
    with Refined_Global => (In_Out => (S, Pointer))
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    with Refined_Global => (Input  => S,
                          In_Out => Pointer)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;

end Stack_14;

```

Initialized by elaboration

The following example presents how a package's concrete state can be initialized at the statements section of the body. The specifications of both SPARK 2005 and SPARK 2014 are not presented since they are identical to the specifications of the previous example.

Body in SPARK 2005:

```

package body Stack_05
is
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector       is array(Index_Range) of Integer;

  S : Vector;
  Pointer : Pointer_Range;

  procedure Push(X : in Integer)
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

```

```

    end Push;

    procedure Pop(X : out Integer)
    is
    begin
        X := S(Pointer);
        Pointer := Pointer - 1;
    end Pop;

begin -- initialization
    Pointer := 0;
    S := Vector'(Index_Range => 0);
end Stack_05;

```

Body in SPARK 2014:

As per SPARK 2005.

Private, concrete state

The following example demonstrates how variables, that need to be hidden from the users of a package, can be placed on the package's private section. The ~~bodies-of-the-packages-have~~ SPARK 2005 body has not been included since ~~they contain no annotation~~ it does not contain any annotations.

Specification in SPARK 2005:

```

package Stack_05
--# own S, Pointer;
is
    procedure Push(X : in Integer);
    --# global in out S, Pointer;

    procedure Pop(X : out Integer);
    --# global in      S;
    --#               in out Pointer;
private
    Stack_Size : constant := 100;
    type      Pointer_Range is range 0 .. Stack_Size;
    subtype Index_Range     is Pointer_Range range 1..Stack_Size;
    type      Vector        is array(Index_Range) of Integer;

    S : Vector;
    Pointer : Pointer_Range;
end Stack_05;

```

Specification in SPARK 2014:

```

package Stack_14
    with Abstract_State => (S_State, Pointer_State)
is
    procedure Push(X : in Integer)
        with Global => (In_Out => (S_State, Pointer_State));

    procedure Pop(X : out Integer)
        with Global => (Input  => S_State,
                       In_Out => Pointer_State);

```

```

private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector       is array(Index_Range) of Integer;

  S : Vector
    with Part_Of => S_State;
  Pointer : Pointer_Range
    with Part_Of => Pointer_State;
end Stack_14;

```

Body in SPARK 2014:

```

package body Stack_14
  with Refined_State => (S_State      => S,
                        Pointer_State => Pointer)
is
  procedure Push(X : in Integer)
    with Refined_Global => (In_Out => (S, Pointer))
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    with Refined_Global => (Input  => S,
                          In_Out => Pointer)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;
end Stack_14;

```

Private, abstract state, refining onto concrete states in body

Initialized by procedure call

In this example, the abstract state declared at the specification is refined at the body. Procedure *Init* can be invoked by users of the package, in order to initialize the state.

Specification in SPARK 2005:

```

package Stack_05
--# own State;
is
  procedure Push(X : in Integer);
  --# global in out State;

  procedure Pop(X : out Integer);
  --# global in out State;

```

```
    procedure Init;
    --# global      out State;
private
    Stack_Size : constant := 100;
    type      Pointer_Range is range 0 .. Stack_Size;
    subtype Index_Range     is Pointer_Range range 1..Stack_Size;
    type      Vector        is array(Index_Range) of Integer;

    type Stack_Type is
        record
            S : Vector;
            Pointer : Pointer_Range;
        end record;
end Stack_05;
```

Body in SPARK 2005:

```
package body Stack_05
--# own State is Stack;
is
    Stack : Stack_Type;

    procedure Push(X : in Integer)
    --# global in out Stack;
    is
    begin
        Stack.Pointer := Stack.Pointer + 1;
        Stack.S(Stack.Pointer) := X;
    end Push;

    procedure Pop(X : out Integer)
    --# global in out Stack;
    is
    begin
        X := Stack.S(Stack.Pointer);
        Stack.Pointer := Stack.Pointer - 1;
    end Pop;

    procedure Init
    --# global      out Stack;
    is
    begin
        Stack.Pointer := 0;
        Stack.S := Vector'(Index_Range => 0);
    end Init;
end Stack_05;
```

Specification in SPARK 2014:

```
package Stack_14
with Abstract_State => State
is
    procedure Push(X : in Integer)
        with Global => (In_Out => State);

    procedure Pop(X : out Integer)
```

```

    with Global => (In_Out => State);

    procedure Init
      with Global => (Output => State);
    private
      Stack_Size : constant := 100;
      type      Pointer_Range is range 0 .. Stack_Size;
      subtype Index_Range    is Pointer_Range range 1..Stack_Size;
      type      Vector       is array(Index_Range) of Integer;

      type Stack_Type is
        record
          S : Vector;
          Pointer : Pointer_Range;
        end record;
    end Stack_14;

```

Body in SPARK 2014:

```

package body Stack_14
  with Refined_State => (State => Stack)
is
  Stack : Stack_Type;

  procedure Push(X : in Integer)
    with Refined_Global => (In_Out => Stack)
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    with Refined_Global => (In_Out => Stack)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;

  procedure Init
    with Refined_Global => (Output => Stack)
  is
  begin
    Stack.Pointer := 0;
    Stack.S := Vector'(Index_Range => 0);
  end Init;
end Stack_14;

```

Initialized by elaboration of declaration

The example that follows introduces an abstract state at the specification and refines it at the body. The constituents of the abstract state are initialized at declaration.

Specification in SPARK 2005:

```
package Stack_05
--# own State;
--# initializes State;
is
  procedure Push(X : in Integer);
  --# global in out State;

  procedure Pop(X : out Integer);
  --# global in out State;
private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector        is array(Index_Range) of Integer;

  type Stack_Type is
    record
      S : Vector;
      Pointer : Pointer_Range;
    end record;
end Stack_05;
```

Body in SPARK 2005:

```
package body Stack_05
--# own State is Stack; -- refinement of state
is
  Stack : Stack_Type := Stack_Type'(Pointer => 0, S => Vector'(Index_Range => 0));
  -- initialization by elaboration of declaration

  procedure Push(X : in Integer)
  --# global in out Stack;
  is
  begin
    Stack.Pointer := Stack.Pointer + 1;
    Stack.S(Stack.Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
  --# global in out Stack;
  is
  begin
    X := Stack.S(Stack.Pointer);
    Stack.Pointer := Stack.Pointer - 1;
  end Pop;
end Stack_05;
```

Specification in SPARK 2014:

```
package Stack_14
  with Abstract_State => State,
  Initializes      => State
is
  procedure Push(X : in Integer)
    with Global => (In_Out => State);
```



```

    procedure Pop(X : out Integer)
      with Global => (In_Out => State);
private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector        is array(Index_Range) of Integer;

  type Stack_Type is
    record
      S : Vector;
      Pointer : Pointer_Range;
    end record;
end Stack_14;

```

Body in SPARK 2014:

```

package body Stack_14
  with Refined_State => (State => Stack) -- refinement of state
is
  Stack : Stack_Type := Stack_Type'(Pointer => 0, S => Vector'(Index_Range => 0));
  -- initialization by elaboration of declaration

  procedure Push(X : in Integer)
    with Refined_Global => (In_Out => Stack)
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    with Refined_Global => (In_Out => Stack)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;
end Stack_14;

```

Initialized by package body statements

This example introduces an abstract state at the specification and refines it at the body. The constituents of the abstract state are initialized at the statements part of the body. The specifications of the SPARK 2005 and SPARK 2014 versions of the code are as in the previous example and have thus not been included.

Body in SPARK 2005:

```

package body Stack_05
  --# own State is Stack; -- refinement of state
is
  Stack : Stack_Type;

  procedure Push(X : in Integer)
    --# global in out Stack;

```

```
is
begin
  Stack.Pointer := Stack.Pointer + 1;
  Stack.S(Stack.Pointer) := X;
end Push;

procedure Pop(X : out Integer)
--# global in out Stack;
is
begin
  X := Stack.S(Stack.Pointer);
  Stack.Pointer := Stack.Pointer - 1;
end Pop;
begin -- initialized by package body statements
  Stack.Pointer := 0;
  Stack.S := Vector'(Index_Range => 0);
end Stack_05;
```

Body in SPARK 2014:

```
package body Stack_14
with Refined_State => (State => Stack) -- refinement of state
is
  Stack: Stack_Type;

  procedure Push(X : in Integer)
with Refined_Global => (In_Out => Stack)
is
begin
  Pointer := Pointer + 1;
  S(Pointer) := X;
end Push;

  procedure Pop(X : out Integer)
with Refined_Global => (In_Out => Stack)
is
begin
  X := S(Pointer);
  Pointer := Pointer - 1;
end Pop;
begin -- initialized by package body statements
  Stack.Pointer := 0;
  Stack.S := Vector'(Index_Range => 0);
end Stack_14;
```

Initialized by mixture of declaration and statements

This example introduces an abstract state at the specification and refines it at the body. Some of the constituents of the abstract state are initialized during their declaration and the rest at the statements part of the body.

Specification in SPARK 2005:

```
package Stack_05
--# own Stack;
--# initializes Stack;
```

```

is
  procedure Push(X : in Integer);
    --# global in out Stack;

  procedure Pop(X : out Integer);
    --# global in out Stack;
private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector        is array(Index_Range) of Integer;
end Stack_05;

```

Body in SPARK 2005:

```

package body Stack_05
--# own Stack is S, Pointer; -- state refinement
is
  S : Vector;
  Pointer : Pointer_Range := 0;
  -- initialization by elaboration of declaration

  procedure Push(X : in Integer)
    --# global in out S, Pointer;
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    --# global in      S;
    --#                in out Pointer;
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;
begin -- initialization by body statements
  S := Vector'(Index_Range => 0);
end Stack_05;

```

Specification in SPARK 2014:

```

package Stack_14
  with Abstract_State => Stack,
       Initializes    => Stack
is
  procedure Push(X : in Integer)
    with Global => (In_Out => Stack);

  procedure Pop(X : out Integer)
    with Global => (In_Out => Stack);
private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;

```

```
    subtype Index_Range    is Pointer_Range range 1..Stack_Size;
    type    Vector          is array(Index_Range) of Integer;
end Stack_14;
```

Body in SPARK 2014:

```
package body Stack_14
with Refined_State => (Stack => (S, Pointer)) -- state refinement
is
  S : Vector; -- left uninitialized
  Pointer : Pointer_Range := 0;
  -- initialization by elaboration of declaration

  procedure Push(X : in Integer)
    with Refined_Global => (In_Out => (S, Pointer))
  is
  begin
    Pointer := Pointer + 1;
    S(Pointer) := X;
  end Push;

  procedure Pop(X : out Integer)
    with Refined_Global => (Input  => S,
                          In_Out => Pointer)
  is
  begin
    X := S(Pointer);
    Pointer := Pointer - 1;
  end Pop;
begin -- partial initialization by body statements
  S := Vector'(Index_Range => 0);
end Stack_14;
```

Initial condition

This example introduces a new SPARK 2014 feature that did not exist in SPARK 2005. On top of declaring an abstract state and promising to initialize it, we also illustrate certain conditions that will be valid after initialization. The body is not being provided since it does not add any further insight.

Specification in SPARK 2014:

```
package stack_14
with Abstract_State    => State,
  Initializes          => State,
  Initial_Condition => Is_Empty -- Stating that Is_Empty holds
                                -- after initialization
is
  function Is_Empty return Boolean
    with Global => State;

  function Is_Full return Boolean
    with Global => State;

  function Top return Integer
    with Global => State,
```

```

        Pre      => not Is_Empty;

    procedure Push (X: in Integer)
        with Global => (In_Out => State),
        Pre      => not Is_Full,
        Post     => Top = X;

    procedure Pop (X: out Integer)
        with Global => (In_Out => State),
        Pre      => not Is_Empty;
end stack_14;

```

Private, abstract state, refining onto concrete state of private child

The following example shows a parent package `Power` that contains a `State` own variable. This own variable is refined onto concrete state contained within the two private children `Source_A` and `Source_B`.

Specification of Parent in SPARK 2005:

```

-- Use of child packages to encapsulate state
package Power_05
--# own State;
is
    procedure Read_Power(Level : out Integer);
    --# global State;
    --# derives Level from State;
end Power_05;

```

Body of Parent in SPARK 2005:

```

with Power_05.Source_A_05, Power_05.Source_B_05;

package body Power_05
--# own State is Power_05.Source_A_05.State,
--#           Power_05.Source_B_05.State;
is
    procedure Read_Power(Level : out Integer)
    --# global Source_A_05.State, Source_B_05.State;
    --# derives
    --#     Level
    --#     from
    --#         Source_A_05.State,
    --#         Source_B_05.State;
    is
        Level_A : Integer;
        Level_B : Integer;
    begin
        Source_A_05.Read (Level_A);
        Source_B_05.Read (Level_B);
        Level := Level_A + Level_B;
    end Read_Power;

end Power_05;

```

Specifications of Private Children in SPARK 2005:

```
--# inherit Power_05;
private package Power_05.Source_A_05
--# own State;
is
  procedure Read (Level : out Integer);
  --# global State;
  --# derives Level from State;
end Power_05.Source_A_05;

--# inherit Power_05;
private package Power_05.Source_B_05
--# own State;
is
  procedure Read (Level : out Integer);
  --# global State;
  --# derives Level from State;
end Power_05.Source_B_05;
```

Bodies of Private Children in SPARK 2005:

```
package body Power_05.Source_A_05
is
  State : Integer;

  procedure Read (Level : out Integer)
  is
  begin
    Level := State;
  end Read;
end Power_05.Source_A_05;

package body Power_05.Source_B_05
is
  State : Integer;

  procedure Read (Level : out Integer)
  is
  begin
    Level := State;
  end Read;
end Power_05.Source_B_05;
```

Specification of Parent in SPARK 2014:

```
-- Use of child packages to encapsulate state
package Power_14
  with Abstract_State => State
is
  procedure Read_Power (Level : out Integer)
    with Global => State,
    Depends => (Level => State);
end Power_14;
```

Body of Parent in SPARK 2014:

```
with Power_14.Source_A_14, Power_14.Source_B_14;

package body Power_14
```

```

    with Refined_State => (State => (Power_14.Source_A_14.State,
                                     Power_14.Source_B_14.State))
is

procedure Read_Power(Level : out Integer)
  with Refined_Global  => (Source_A_14.State, Source_B_14.State),
       Refined_Depends => (Level => (Source_A_14.State,
                                     Source_B_14.State))
is
  Level_A : Integer;
  Level_B : Integer;
begin
  Source_A_14.Read (Level_A);
  Source_B_14.Read (Level_B);
  Level := Level_A + Level_B;
end Read_Power;

end Power_14;

```

Specifications of Private Children in SPARK 2014:

```

private package Power_14.Source_A_14
  with Abstract_State => (State with Part_Of => Power_14.State)
is
  procedure Read (Level : out Integer)
    with Global => State,
         Depends => (Level => State);
end Power_14.Source_A_14;

private package Power_14.Source_B_14
  with Abstract_State => (State with Part_Of => Power_14.State)
is
  procedure Read (Level : out Integer)
    with Global => State,
         Depends => (Level => State);
end Power_14.Source_B_14;

```

Bodies of Private Children in SPARK 2014:

~~As per SPARK 2005-~~

```

package body Power_14.Source_A_14
  with Refined_State => (State => S)
is
  S : Integer;

  procedure Read (Level : out Integer)
    with Refined_Global  => S,
         Refined_Depends => (Level => S)
  is
    begin
      Level := S;
    end Read;
end Power_14.Source_A_14;

package body Power_14.Source_B_14
  with Refined_State => (State => S);

```

```
is
  S : Integer;

  procedure Read (Level : out Integer)
    with Refined_Global => S,
         Refined_Depends => (Level => S)
  is
    begin
      Level := S;
    end Read;
end Power_14.Source_B_14;
```

Private, abstract state, refining onto concrete state of embedded package

This example is based around the packages from section [Private, abstract state, refining onto concrete state of private child](#), with the private child packages converted into embedded packages.

Specification in SPARK 2005:

```
-- Use of embedded packages to encapsulate state
package Power_05
--# own State;
is
  procedure Read_Power(Level : out Integer);
  --# global State;
  --# derives Level from State;
end Power_05;
```

Body in SPARK 2005:

```
package body Power_05
--# own State is Source_A.State,
--#           Source_B.State;
is

  -- Embedded package spec for Source_A
  package Source_A
  --# own State;
  is
    procedure Read (Level : out Integer);
    --# global State;
    --# derives Level from State;
  end Source_A;

  -- Embedded package spec for Source_B.
  package Source_B
  --# own State;
  is
    procedure Read (Level : out Integer);
    --# global State;
    --# derives Level from State;
  end Source_B;

  -- Embedded package body for Source_A
  package body Source_A
```



```

is
  State : Integer;

  procedure Read (Level : out Integer)
  is
  begin
    Level := State;
  end Read;
end Source_A;

-- Embedded package body for Source_B
package body Source_B
is
  State : Integer;

  procedure Read (Level : out Integer)
  is
  begin
    Level := State;
  end Read;

end Source_B;

procedure Read_Power(Level : out Integer)
--# global Source_A.State, Source_B.State;
--# derives
--#   Level
--#   from
--#       Source_A.State,
--#       Source_B.State;
is
  Level_A : Integer;
  Level_B : Integer;
begin
  Source_A.Read (Level_A);
  Source_B.Read (Level_B);
  Level := Level_A + Level_B;
end Read_Power;

end Power_05;

```

Specification in SPARK 2014:

```

-- Use of embedded packages to encapsulate state
package Power_14
  with Abstract_State => State
is
  procedure Read_Power(Level : out Integer)
    with Global  => State,
         Depends => (Level => State);
end Power_14;

```

Body in SPARK 2014:

```

package body Power_14
  with Refined_State => (State => (Source_A.State, Source_B.State))

```

```
is

-- Embedded package spec for Source_A
package Source_A
  with Abstract_State => State
is
  procedure Read (Level : out Integer)
    with Global  => State,
         Depends => (Level => State);
end Source_A;

-- Embedded package spec for Source_B.
package Source_B
  with
    Abstract_State => State
is
  procedure Read (Level : out Integer)
    with Global  => State,
         Depends => (Level => State);
end Source_B;

-- Embedded package body for Source_A
package body Source_A
  with Refined_State => (State => S)
is
  S : Integer;

  procedure Read (Level : out Integer)
    with Refined_Global  => S,
         Refined_Depends => (Level => S)
  is
  begin
    Level := S;
  end Read;
end Source_A;

-- Embedded package body for Source_B
package body Source_B
  with Refined_State => (State => S)
is
  S : Integer;

  procedure Read (Level : out Integer)
    with Refined_Global  => S,
         Refined_Depends => (Level => S)
  is
  begin
    Level := S;
  end Read;

end Source_B;

procedure Read_Power(Level : out Integer)
  with Refined_Global  => (Source_A.State, Source_B.State),
```

```

        Refined_Depends => (Level => (Source_A.State, Source_B.State))
    is
        Level_A : Integer;
        Level_B : Integer;
    begin
        Source_A. Read (Level_A);
        Source_B.Read (Level_B);
        Level := Level_A + Level_B;
    end Read_Power;

end Power_14;

```

Private, abstract state, refining onto mixture of the above

This example is based around the packages from sections [Private, abstract state, refining onto concrete state of private child](#) and [Private, abstract state, refining onto concrete state of embedded package](#). Source_A is an embedded package, while Source_B is a private child. In order to avoid repetition, the code of this example is not being presented. ~~However, it is available under the “codeasm”.~~

A.2.3 External Variables

Basic Input and Output Device Drivers

The following example shows a main program - Copy - that reads all available data from a given input port, stores it internally during the reading process in a stack and then outputs all the data read to an output port. The specification of the stack package are not being presented since they are identical to previous examples.

Specification of main program in SPARK 2005:

```

with Input_Port_05, Output_Port_05, Stacks_05;
--# inherit Input_Port_05, Output_Port_05, Stacks_05;
--# main_program;
procedure Copy_05
--# global in      Input_Port_05.Input_State;
--#               out      Output_Port_05.Output_State;
--# derives Output_Port_05.Output_State from Input_Port_05.Input_State;
is
    The_Stack    : Stacks_05.Stack;
    Value         : Integer;
    Done          : Boolean;
    Final_Value   : constant Integer := 999;
begin
    Stacks_05.Clear(The_Stack);
    loop
        Input_Port_05.Read_From_Port(Value);
        Stacks_05.Push(The_Stack, Value);
        Done := Value = Final_Value;
        exit when Done;
    end loop;
    loop
        Stacks_05.Pop(The_Stack, Value);
        Output_Port_05.Write_To_Port(Value);
        exit when Stacks_05.Is_Empty(The_Stack);
    end loop;
end Copy_05;

```

```
    end loop;  
end Copy_05;
```

Specification of input port in SPARK 2005:

```
package Input_Port_05  
  --# own in Input_State;  
is  
  procedure Read_From_Port (Input_Value : out Integer);  
  --# global in Input_State;  
  --# derives Input_Value from Input_State;  
  
end Input_Port_05;
```

Body of input port in SPARK 2005:

```
package body Input_Port_05  
is  
  
  Input_State : Integer;  
  for Input_State'Address use 16#CAFE#;  
  pragma Volatile (Input_State);  
  
  procedure Read_From_Port (Input_Value : out Integer)  
  is  
  begin  
    Input_Value := Input_State;  
  end Read_From_Port;  
  
end Input_Port_05;
```

Specification of output port in SPARK 2005:

```
package Output_Port_05  
  --# own out Output_State;  
is  
  procedure Write_To_Port (Output_Value : in Integer);  
  --# global out Output_State;  
  --# derives Output_State from Output_Value;  
end Output_Port_05;
```

Body of output port in SPARK 2005:

```
package body Output_Port_05  
is  
  
  Output_State : Integer;  
  for Output_State'Address use 16#CAFE#;  
  pragma Volatile (Output_State);  
  
  procedure Write_To_Port (Output_Value : in Integer)  
  is  
  begin  
    Output_State := Output_Value;  
  end Write_To_Port;  
  
end Output_Port_05;
```

Note that the syntax for identifying the main program in SPARK 2014 is still TBD. To be completed in the Milestone 3 version of this document.

Specification of main program in SPARK 2014:

```
with Input_Port_14, Output_Port_14, Stacks_14;
-- Approach for identifying main program is TBD.
procedure Copy_14
  with Global => (Input => Input_Port_14.Input_State,
                  Output => Output_Port_14.Output_State),
  Depends => (Output_Port_14.Output_State => Input_Port_14.Input_State)
is
  The_Stack    : Stacks_14.Stack;
  Value         : Integer;
  Done          : Boolean;
  Final_Value   : constant Integer := 999;
begin
  Stacks_14.Clear(The_Stack);
  loop
    Input_Port_14.Read_From_Port(Value);
    Stacks_14.Push(The_Stack, Value);
    Done := Value = Final_Value;
    exit when Done;
  end loop;
  loop
    Stacks_14.Pop(The_Stack, Value);
    Output_Port_14.Write_To_Port(Value);
    exit when Stacks_14.Is_Empty(The_Stack);
  end loop;
end Copy_14;
```

Specification of input port in SPARK 2014:

```
package Input_Port_14
  with Abstract_State => (Input_State with External, Input_Only)
is
  procedure Read_From_Port(Input_Value : out Integer)
    with Global => (Input => Input_State),
    Depends => (Input_Value => Input_State);
end Input_Port_14;
```

Specification of output port in SPARK 2014:

```
package Output_Port_14
  with Abstract_State => (Output_State with External, Output_Only)
is
  procedure Write_To_Port(Output_Value : in Integer)
    with Global => (Output => Output_State),
    Depends => (Output_State => Output_Value);
end Output_Port_14;
```

Body of input port in SPARK 2014:

This is as per SPARK 2005, but uses aspects instead of representation clauses and pragmas.

```
package body Input_Port_14
  with Refined_State => (Input_State => Input_S)
is
```

```
Input_S : Integer
  with Address => 16#CAFE#,
  Volatile;

procedure Read_From_Port (Input_Value : out Integer)
  with Refined_Global => (Input => Input_S),
  Refined_Depends => (Input_Value => Input_S)
is
begin
  Input_Value := Input_S;
end Read_From_Port;
end Input_Port_14;
```

Body of output port in SPARK 2014:

This is as per SPARK 2005, but uses aspects instead of representation clauses and pragmas.

```
package body Output_Port_14
  with Refined_State => (Output_State => Output_S)
is
  Output_S : Integer
    with Address => 16#CAFE#,
    Volatile;

  procedure Write_To_Port (Output_Value : in Integer)
    with Refined_Global => (Output => Output_S),
    Refined_Depends => (Output_S => Output_Value)
  is
  begin
    Output_S := Output_Value;
  end Write_To_Port;
end Output_Port_14;
```

Input driver using ‘Append and ‘Tail contracts

This example uses the Input_Port package from section [Basic Input and Output Device Drivers](#) and adds a contract using the ‘Tail attribute. The example also use the Always_Valid attribute in order to allow proof to succeed (otherwise, there is no guarantee in the proof context that the value read from the port is of the correct type).

Todo

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. Note that this also applies to the use of the Always annotation. There will not be an equivalent of ‘Append and ‘Tail in SPARK 2014. However, we will be able to achieve the same functionality using generics. To be completed in the Milestone 3.4 version of this document.

Specification in SPARK 2005:

```
package Input_Port
  --# own in Inputs : Integer;
is
  procedure Read_From_Port (Input_Value : out Integer);
  --# global in Inputs;
  --# derives Input_Value from Inputs;
  --# post Input_Value = Inputs~ and Inputs = Inputs' Tail (Inputs~);
```

```
end Input_Port;
```

Body in SPARK 2005:

```
package body Input_Port
is

  Inputs : Integer;
  for Inputs'Address use 16#CAFE#;
  --# assert Inputs'Always_Valid;
  pragma Volatile (Inputs);

  procedure Read_From_Port (Input_Value : out Integer)
  is
  begin
    Input_Value := Inputs;
  end Read_From_Port;

end Input_Port;
```

Output driver using 'Append and 'Tail contracts

This example uses the Output package from section [Basic Input and Output Device Drivers](#) and adds a contract using the 'Append attribute.

Todo

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. There will not be an equivalent of 'Append and 'Tail in SPARK 2014. However, we will be able to achieve the same functionality using generics. To be completed in the Milestone [3-4](#) version of this document.

Specification in SPARK 2005:

```
package Output_Port
--# own out Outputs : Integer;
is
  procedure Write_To_Port (Output_Value : in Integer);
  --# global out Outputs;
  --# derives Outputs from Output_Value;
  --# post Outputs = Outputs'Append (Outputs~, Output_Value);
end Output_Port;
```

Body in SPARK 2005:

```
package body Output_Port
is

  Outputs : Integer;
  for Outputs'Address use 16#CAFE#;
  pragma Volatile (Outputs);

  procedure Write_To_Port (Output_Value : in Integer)
  is
  begin
    Outputs := Output_Value;
```

```
    end Write_To_Port;

    end Output_Port;
```

Refinement of external state - voting input switch

The following example presents an abstract view of the reading of 3 individual switches and the voting performed on the values read.

Abstract Switch specification in SPARK 2005:

```
package Switch
--# own in State;
is

    type Reading is (on, off, unknown);

    function ReadValue return Reading;
    --# global in State;

end Switch;
```

Component Switch specifications in SPARK 2005:

```
--# inherit Switch;
private package Switch.Val1
--# own in State;
is
    function Read return Switch.Reading;
    --# global in State;

end Switch.Val1;

--# inherit Switch;
private package Switch.Val2
--# own in State;
is
    function Read return Switch.Reading;
    --# global in State;

end Switch.Val2;

--# inherit Switch;
private package Switch.Val3
--# own in State;
is
    function Read return Switch.Reading;
    --# global in State;

end Switch.Val3;
```

Switch body in SPARK 2005:

```
with Switch.Val1;
with Switch.Val2;
with Switch.Val3;
package body Switch
```



```

--# own State is in Switch.Val1.State,
--#           in Switch.Val2.State,
--#           in Switch.Val3.State;
is

subtype Value is Integer range -1 .. 1;
subtype Score is Integer range -3 .. 3;
type ConvertToValueArray is array (Reading) of Value;
type ConvertToReadingArray is array (Score) of Reading;

ConvertToValue : constant ConvertToValueArray := ConvertToValueArray' (on => 1,
                                                                    unknown => 0,
                                                                    off => -1);

ConvertToReading : constant ConvertToReadingArray :=
    ConvertToReadingArray' (-3 .. -2 => off,
                           -1 .. 1 => unknown,
                           2 .. 3 => on);

function ReadValue return Reading
--# global in Val1.State;
--#           in Val2.State;
--#           in Val3.State;
is
    A, B, C : Reading;
begin
    A := Val1.Read;
    B := Val2.Read;
    C := Val3.Read;
    return ConvertToReading (ConvertToValue (A) +
        ConvertToValue (B) + ConvertToValue (C));
end ReadValue;

end Switch;

```

Abstract Switch specification in SPARK 2014:

```

package Switch
    with Abstract_State => (State with External, Input_Only)
is
    type Reading is (on, off, unknown);

    function ReadValue return Reading
        with Global => (Input => State);
end Switch;

```

Component Switch specifications in SPARK 2014:

```

private package Switch.Val1
    with Abstract_State => (State with External, Input_Only,
                          Part_Of => Switch.State)
is
    function Read return Switch.Reading
        with Global => (Input => State);
end Switch.Val1;

private package Switch.Val2

```

```
    with Abstract_State => (State with External, Input_Only,
                             Part_Of => Switch.State)
is
  function Read return Switch.Reading
    with Global => (Input => State);
end Switch.Val2;

private package Switch.Val3
  with Abstract_State => (State with External, Input_Only,
                           Part_Of => Switch.State)
is
  function Read return Switch.Reading
    with Global => (Input => State);
end Switch.Val3;
```

Switch body in SPARK 2014:

```
with Switch.Val1;
with Switch.Val2;
with Switch.Val3;
package body Switch
  -- State is refined onto three states, each of which has properties Volatile and Input
  with Refined_State => (State => (Switch.Val1.State,
                                   Switch.Val2.State,
                                   Switch.Val2.State))
is

  subtype Value is Integer range -1 .. 1;
  subtype Score is Integer range -3 .. 3;
  type ConvertToValueArray is array (Reading) of Value;
  type ConvertToReadingArray is array (Score) of Reading;

  ConvertToValue : constant ConvertToValueArray := ConvertToValueArray' (on => 1,
                                                                           unknown => 0,
                                                                           off => -1);

  ConvertToReading : constant ConvertToReadingArray :=
    ConvertToReadingArray' (-3 .. -2 => off,
                           -1 .. 1 => unknown,
                           2 .. 3 => on);

  function ReadValue return Reading
    with Refined_Global => (Input => (Val1.State, Val2.State, Val3.State))
  is
    A, B, C : Reading;
  begin
    A := Val1.Read;
    B := Val2.Read;
    C := Val3.Read;
    return ConvertToReading (ConvertToValue (A) +
                             ConvertToValue (B) + ConvertToValue (C));
  end ReadValue;

end Switch;
```

Complex I/O Device

The following example illustrates a more complex I/O device: the device is fundamentally an output device but an acknowledgement has to be read from it. In addition, a local register stores the last value written to avoid writes that would just re-send the same value. The own variable is then refined into a normal variable, an input external variable and an output external variable.

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.

Specification in SPARK 2005:

```
package Device
--# own State;
--# initializes State;
is
  procedure Write (X : in Integer);
  --# global in out State;
  --# derives State from State, X;
end Device;
```

Body in SPARK 2005:

```
package body Device
--# own State is      OldX,
--#                  in   StatusPort,
--#                  out Register;
-- refinement on to mix of external and ordinary variables
is
  OldX : Integer := 0; -- only component that needs initialization
  StatusPort : Integer;
  pragma Volatile (StatusPort);
  -- address clause would be added here

  Register : Integer;
  pragma Volatile (Register);
  -- address clause would be added here

  procedure WriteReg (X : in Integer)
  --# global out Register;
  --# derives Register from X;
  is
  begin
    Register := X;
  end WriteReg;

  procedure ReadAck (OK : out Boolean)
  --# global in StatusPort;
  --# derives OK from StatusPort;
  is
    RawValue : Integer;
  begin
    RawValue := StatusPort; -- only assignment allowed here
    OK := RawValue = 16#FFFF_FFFF#;
  end ReadAck;
```

```
procedure Write (X : in Integer)
--# global in out OldX;
--#          out Register;
--#          in   StatusPort;
--# derives OldX, Register from OldX, X &
--#          null          from StatusPort;
is
  OK : Boolean;
begin
  if X /= OldX then
    OldX := X;
    WriteReg (X);
    loop
      ReadAck (OK);
      exit when OK;
    end loop;
  end if;
end Write;
end Device;
```

Specification in SPARK 2014:

```
package Device
  with Abstract_State => State,
        Initializes   => State
is
  procedure Write (X : in Integer)
    with Global   => (In_Out => State),
        Depends => (State =>+ X);
end Device;
```

Body in SPARK 2014:

```
package body Device
  with Refined_State => (State => (OldX,
                                   StatusPort,
                                   Register))
  -- refinement on to mix of external and ordinary variables
is
  OldX : Integer := 0; -- only component that needs initialization
  StatusPort : Integer
    with Volatile,
        Input_Only;
  -- address clause would be added here

  Register : Integer
    with Volatile,
        Output_Only;
  -- address clause would be added here

  procedure WriteReg (X : in Integer)
    with Refined_Global   => (Output => Register),
        Refined_Depends => (Register => X)
  is
  begin
    Register := X;
```

```

end WriteReg;

procedure ReadAck (OK : out Boolean)
  with Refined_Global => (Input => StatusPort),
       Refined_Depends => (OK => StatusPort)
is
  RawValue : Integer;
begin
  RawValue := StatusPort; -- only assignment allowed here
  OK := RawValue = 16#FFFF_FFFF#;
end ReadAck;

procedure Write (X : in Integer)
  with Refined_Global => (Input => StatusPort,
                        Output => Register,
                        In_Out => OldX),
       Refined_Depends => ((OldX,
                          Register) => (OldX,
                                      X),
                          null => StatusPort)
is
  OK : Boolean;
begin
  if X /= OldX then
    OldX := X;
    WriteReg (X);
    loop
      ReadAck (OK);
      exit when OK;
    end loop;
  end if;
end Write;
end Device;

```

Increasing values in input stream

The following example illustrates an input port from which values are read. According to its postcondition, procedure `Increases` checks whether the first values read from the sequence are in ascending order. This example shows that postconditions can refer to multiple individual elements of the input stream.

Todo

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. There will not be an equivalent of 'Append and 'Tail in SPARK 2014. However, we will be able to achieve the same functionality using generics. To be completed in the Milestone 3-4 version of this document.

Specification in SPARK 2005:

```

package Inc
--# own in Sensor;
is
  pragma Elaborate_Body (Inc);
end Inc;

```

Body in SPARK 2005:

```
package body Inc
--# own Sensor is in S;
is
  S : Integer;
  for S'Address use 16#DEADBEEF#;
  pragma Volatile (S);

  procedure Read (V      : out Integer;
                  Valid : out Boolean)
  --# global in S;
  --# post (Valid -> V = S~) and
  --#      (S = S'Tail (S~));
  is
    Tmp : Integer;
  begin
    Tmp := S;
    if Tmp'Valid then
      V := Tmp;
      Valid := True;
      --# check S = S'Tail (S~);
    else
      V := 0;
      Valid := False;
    end if;
  end Read;

  procedure Increases (Result : out Boolean;
                      Valid   : out Boolean)
  --# global in S;
  --# post Valid -> (Result <-> S'Tail (S~) > S~);
  is
    A, B : Integer;
  begin
    Result := False;
    Read (A, Valid);
    if Valid then
      Read (B, Valid);
      if Valid then
        Result := B > A;
      end if;
    end if;
  end Increases;

end Inc;
```

A.2.4 Package Inheritance

Contracts with remote state

The following example illustrates indirect access to the state of one package by another via an intermediary. `Raw_Data` stores some data, which has preprocessing performed on it by `Processing` and on which `Calculate` performs some

further processing (although the corresponding bodies are not given, `Read_Calculated_Value` in `Calculate` calls through to `Read_Processed_Data` in `Processing`, which calls through to `Read` in `Raw_Data`).

Specifications in SPARK 2005:

```
package Raw_Data
--# own State;
is

    --# function Data_Is_Valid (Value : Integer) return Boolean;

    procedure Read (Value : out Integer);
    --# global in State;
    --# derives Value from State;
    --# post Data_Is_Valid (Value);

end Raw_Data;

with Raw_Data;
--# inherit Raw_Data;
package Processing
--# own State;
is

    procedure Read_Processed_Data (Value : out Integer);
    --# global in State, Raw_Data.State;
    --# derives Value from State, Raw_Data.State;
    --# post Raw_Data.Data_Is_Valid (Value);

end Processing;

with Processing;
--# inherit Processing, Raw_Data;
package Calculate
is

    procedure Read_Calculated_Value (Value : out Integer);
    --# global in Processing.State, Raw_Data.State;
    --# derives Value from Processing.State, Raw_Data.State;
    --# post Raw_Data.Data_Is_Valid (Value);

end Calculate;
```

Specifications in SPARK 2014:

```
package Raw_Data
    with Abstract_State => State
is

    function Data_Is_Valid (Value : Integer) return Boolean
        with Convention => Ghost;

    procedure Read (Value : out Integer)
        with Global    => (Input => State),
             Depends  => (Value => State),
             Post      => Data_Is_Valid (Value);
```

```
end Raw_Data;

with Raw_Data;
package Processing
  with Abstract_State => State
is

  procedure Read_Processed_Data (Value : out Integer)
    with Global   => (Input => (State, Raw_Data.State)),
         Depends => (Value => (State, Raw_Data.State)),
         Post     => Raw_Data.Data_Is_Valid (Value);

end Processing;

with Processing;
package Calculate
is

  procedure Read_Calculated_Value (Value : out Integer)
    with Global   => (Input => (Processing.State, Raw_Data.State)),
         Depends => (Value => (Processing.State, Raw_Data.State)),
         Post     => Raw_Data.Data_Is_Valid (Value);

end Calculate;
```

Package nested inside package

See section [Private, abstract state, refining onto concrete state of embedded package](#).

Package nested inside subprogram

This example is a modified version of that given in section [Refinement of external state - voting input switch](#). It illustrates the use of a package nested within a subprogram.

Abstract Switch specification in SPARK 2005:

```
package Switch
--# own in State;
is

  type Reading is (on, off, unknown);

  function ReadValue return Reading;
  --# global in State;

end Switch;
```

Component Switch specifications in SPARK 2005:

As in [Refinement of external state - voting input switch](#)

Switch body in SPARK 2005:

```
with Switch.Val1;
with Switch.Val2;
with Switch.Val3;
package body Switch
```



```

--# own State is in Switch.Val1.State,
--#           in Switch.Val2.State,
--#           in Switch.Val3.State;
is

subtype Value is Integer range -1 .. 1;
subtype Score is Integer range -3 .. 3;

function ReadValue return Reading
--# global in Val1.State;
--#           in Val2.State;
--#           in Val3.State;
is
  A, B, C : Reading;

  -- Embedded package to provide the capability to synthesize three inputs
  -- into one.
  --# inherit Switch;
  package Conversion
  is

    function Convert_To_Reading
      (Val_A : Switch.Reading;
       Val_B : Switch.Reading;
       Val_C : Switch.Reading) return Switch.Reading;

  end Conversion;

  package body Conversion
  is

    type ConvertToValueArray is array (Switch.Reading) of Switch.Value;
    type ConvertToReadingArray is array (Switch.Score) of Switch.Reading;
    ConvertToValue : constant ConvertToValueArray := ConvertToValueArray' (Switch.unknown,
                                                                              Switch.off =>
                                                                              Switch.on);

    ConvertToReading : constant ConvertToReadingArray :=
      ConvertToReadingArray' (-3 .. -2 => Switch.off,
                              -1 .. 1  => Switch.unknown,
                              2 .. 3   => Switch.on);

    function Convert_To_Reading
      (Val_A : Switch.Reading;
       Val_B : Switch.Reading;
       Val_C : Switch.Reading) return Switch.Reading
    is
      begin

        return ConvertToReading (ConvertToValue (Val_A) +
                                  ConvertToValue (Val_B) + ConvertToValue (Val_C));
      end Convert_To_Reading;

```

```
        end Conversion;

    begin
        A := Val1.Read;
        B := Val2.Read;
        C := Val3.Read;
        return Conversion.Convert_To_Reading
            (Val_A => A,
             Val_B => B,
             Val_C => C);
    end ReadValue;

end Switch;
```

Abstract Switch specification in SPARK 2014:

```
package Switch
  with Abstract_State => (State with External, Input_Only)
is
  type Reading is (on, off, unknown);

  function ReadValue return Reading
    with Global => (Input => State);
end Switch;
```

Component Switch specification in SPARK 2014:

As in [Refinement of external state - voting input switch](#)

Switch body in SPARK 2014:

```
with Switch.Val1;
with Switch.Val2;
with Switch.Val3;
package body Switch
  -- State is refined onto three states, each of which has properties
  -- Volatile and Input.
  with Refined_State => (State => (Switch.Val1.State,
                                   Switch.Val2.State,
                                   Switch.Val3.State))
is
  subtype Value is Integer range -1 .. 1;
  subtype Score is Integer range -3 .. 3;

  function ReadValue return Reading
    with Refined_Global => (Input => (Val1.State, Val2.State, Val3.State))
  is
    A, B, C : Reading;

    -- Embedded package to provide the capability to synthesize three inputs
    -- into one.
    package Conversion
    is
      function Convert_To_Reading
        (Val_A : Switch.Reading;
         Val_B : Switch.Reading;
         Val_C : Switch.Reading) return Switch.Reading;
```

```

end Conversion;

package body Conversion
is
  type ConvertToValueArray is array (Switch.Reading) of Switch.Value;
  type ConvertToReadingArray is array (Switch.Score) of Switch.Reading;
  ConvertToValue : constant ConvertToValueArray := ConvertToValueArray' (Switch.
                                                                    Switch.unknown
                                                                    Switch.off =>

  ConvertToReading : constant ConvertToReadingArray :=
                                                                    ConvertToReadingArray' (-3 .. -2 => Switch.off,
                                                                    -1 .. 1  => Switch.unknown,
                                                                    2  .. 3  => Switch.on);

  function Convert_To_Reading
    (Val_A : Switch.Reading;
     Val_B : Switch.Reading;
     Val_C : Switch.Reading) return Switch.Reading
  is
  begin
    return ConvertToReading (ConvertToValue (Val_A) +
                             ConvertToValue (Val_B) + ConvertToValue (Val_C));
  end Convert_To_Reading;

end Conversion;
begin -- begin statement of ReadValue function
  A := Val1.Read;
  B := Val2.Read;
  C := Val3.Read;
  return Conversion.Convert_To_Reading
    (Val_A => A,
     Val_B => B,
     Val_C => C);
end ReadValue;
end Switch;

```

Circular dependence and elaboration order

This example demonstrates how the Examiner locates and disallows circular dependence and elaboration relations.

Specification of package P_05 in SPARK 2005:

```

--# inherit Q_05;
package P_05
--# own P_State;
--# initializes P_State;
is
  procedure Init(S : out Integer);
end P_05;

```

Specification of package Q_05 in SPARK 2005:

```

--# inherit P_05;
package Q_05

```

```
--# own Q_State;  
--# initializes Q_State;  
is  
  procedure Init(S : out Integer);  
end Q_05;
```

Body of package P_05 in SPARK 2005:

```
with Q_05;  
package body P_05  
is  
  P_State : Integer;  
  
  procedure Init(S : out Integer)  
  is  
  begin  
    S := 5;  
  end Init;  
begin  
  Q_05.Init(P_State);  
end P_05;
```

Body of package Q_05 in SPARK 2005:

```
with P_05;  
package body Q_05  
is  
  Q_State : Integer;  
  
  procedure Init(S : out Integer)  
  is  
  begin  
    S := 10;  
  end Init;  
begin  
  P_05.Init(Q_State);  
end Q_05;
```

Specification of package P_14 in SPARK 2014:

```
package P_14  
  with Abstract_State => P_State,  
       Initializes    => P_State  
is  
  procedure Init(S : out Integer);  
end P_14;
```

Specification of package Q_14 in SPARK 2014:

```
package Q_14  
  with Abstract_State => Q_State,  
       Initializes    => Q_State  
is  
  procedure Init(S : out Integer);  
end Q_14;
```

Body of package P_14 in SPARK 2014:

```
with Q_14;
```

```

package body P_14
  with Refined_State => (P_State => P_S)
is
  P_S : Integer;

  procedure Init(S : out Integer)
  is
  begin
    S := 5;
  end Init;
begin
  Q_14.Init(P_S);
end P_14;

```

Body of package Q_14 in SPARK 2014:

```

with P_14;
package body Q_14
  with Refined_State => (Q_State => Q_S)
is
  Q_S : Integer;

  procedure Init(S : out Integer)
  is
  begin
    S := 10;
  end Init;
begin
  P_14.Init(Q_S);
end Q_14;

```

A.3 Bodies and Proof

A.3.1 Assert, Assume, Check contracts

Assert (in loop) contract

The following example demonstrates how the *assert* annotation can be used inside a loop. At each run of the loop the list of existing hypotheses is cleared and the statements that are within the *assert* annotation are added as the new hypotheses. The SPARK 2014 equivalent of *assert*, while within a loop, is *pragma Loop_Invariant*.

Specification in SPARK 2005:

```

package Assert_Loop_05
is
  subtype Index is Integer range 1 .. 10;
  type A_Type is Array (Index) of Integer;

  function Value_present (A: A_Type; X : Integer) return Boolean;
  --# return for some M in Index => (A (M) = X);
end Assert_Loop_05;

```

Body in SPARK 2005:

```

package body Assert_Loop_05

```

```
is
  function Value_Present (A: A_Type; X : Integer) return Boolean
  is
    I : Index := Index'First;
  begin
    while A (I) /= X and I < Index'Last loop
      --# assert I < Index'Last and
      --#      (for all M in Index range Index'First .. I => (A (M) /= X));
      I := I + 1;
    end loop;
    return A (I) = X;
  end Value_Present;
end Assert_Loop_05;
```

Specification in SPARK 2014:

```
package Assert_Loop_14
is
  subtype Index is Integer range 1 .. 10;
  type A_Type is Array (Index) of Integer;

  function Value_present (A: A_Type; X : Integer) return Boolean
    with Post => (for some M in Index => (A(M) = X));
end Assert_Loop_14;
```

Body in SPARK 2014:

```
package body Assert_Loop_14
is
  function Value_Present (A: A_Type; X : Integer) return Boolean
  is
    I : Index := Index'First;
  begin
    while A (I) /= X and I < Index'Last loop
      pragma Loop_Invariant (I < Index'Last and
        (for all M in Index range Index'First .. I => (A(M) /= X)));
      I := I + 1;
    end loop;
    return A (I) = X;
  end Value_Present;
end Assert_Loop_14;
```

Assert (no loop) contract

While not in a loop, the SPARK 2005 *assert* annotation maps to *pragma Assert_And_Cut* in SPARK 2014. These statements clear the list of hypotheses and add the statements that are within them as the new hypotheses.

Assume contract

The following example illustrates use of an Assume annotation (in this case, the Assume annotation is effectively being used to implement the Always_Valid attribute).

Specification for Assume annotation in SPARK 2005:

```
package Input_Port
  --# own in Inputs;
```

```

is
  procedure Read_From_Port (Input_Value : out Integer);
    --# global in Inputs;
    --# derives Input_Value from Inputs;

end Input_Port;

```

Body for Assume annotation in SPARK 2005:

```

package body Input_Port
is

  Inputs : Integer;
  for Inputs'Address use 16#CAFE#;
  pragma Volatile (Inputs);

  procedure Read_From_Port (Input_Value : out Integer)
  is
  begin
    --# assume Inputs in Integer;
    Input_Value := Inputs;
  end Read_From_Port;

end Input_Port;

```

Specification for Assume annotation in SPARK 2014:

```

package Input_Port
  with Abstract_State => (State_Inputs with External, Input_Only)
is
  procedure Read_From_Port (Input_Value : out Integer)
    with Global    => (Input => State_Inputs),
         Depends => (Input_Value => State_Inputs);
end Input_Port;

```

Body for Assume annotation in SPARK 2014:

```

package body Input_Port
  with Refined_State => (State_Inputs => Inputs)
is
  Inputs : Integer;
  for Inputs'Address use 16#CAFE#;
  pragma Volatile (Inputs);

  procedure Read_From_Port (Input_Value : out Integer)
    with Refined_Global  => (Input => Inputs),
         Refined_Depends => (Input_Value => Inputs)
  is
  begin
    pragma Assume (Inputs in Integer);
    Input_Value := Inputs;
  end Read_From_Port;
end Input_Port;

```

Check contract

The SPARK 2005 *check* annotation is replaced by *pragma assert* in SPARK 2014. This annotation adds a new hypothesis to the list of existing hypotheses. The code is not presented but can be found under “code\check_contract”.

A.3.2 Assert used to control path explosion

This example will be added in future, based on the Tutorial 5, Exercise 1 example from the advanced SPARK course.

A.4 Other Contracts and Annotations

A.4.1 Declare annotation

Todo

The declare annotation SPARK is used to control the generation of proof rules for composite objects. It is not clear that this will be required in SPARK 2014, so this section will be updated or removed in future. To be completed in the Milestone 4 version of this document.

A.4.2 Always_Valid assertion

See section [Input driver using ‘Append and ‘Tail contracts](#) for use of an assertion involving the Always_Valid attribute.

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.

A.4.3 Rule declaration annotation

See section [Proof types and proof functions](#).

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.

A.4.4 Proof types and proof functions

The following example gives pre- and postconditions on operations that act upon the concrete representation of an abstract own variable. This means that proof functions and proof types are needed to state those pre- and postconditions. In addition, it gives an example of the use of a rule declaration annotation - in the body of procedure Initialize - to introduce a rule related to the components of a constant record value.

Todo

Note that the SPARK 2014 version of the rule declaration annotation has not yet been defined [[M520-006](#)] - note that it ~~may~~ might not even be needed, though this is to be determined - and so there is no equivalent included in the SPARK 2014 code. To be completed in the Milestone 4 version of this document.

Specification in SPARK 2005:


```

package Stack
--# own State : Abstract_Stack;
is

  -- Proof functions to indicate whether or not the Stack is empty
  -- and whether or not it is full.
  --# type Abstract_Stack is abstract;
  --# function Is_Empty(Input : Abstract_Stack) return Boolean;
  --# function Is_Full(Input : Abstract_Stack) return Boolean;

  -- Proof function to give the number of elements on the stack.
  --# function Count(Input : Abstract_Stack) return Natural;

  -- Post-condition indicates that the stack will be
  -- non-empty after pushing an item on to it, while the pre-condition
  -- requires it is not full when we push a value onto it.
  procedure Push(X : in Integer);
  --# global in out State;
  --# pre  not Is_Full(State);
  --# post not Is_Empty(State);

  -- Procedure that swaps the first two elements in a stack.
  procedure Swap2;
  --# global in out State;
  --# pre  Count(State) >= 2;
  --# post Count(State) =  Count(State~);

  -- Initializes the Stack.
  procedure Initialize;
  --# global out State;
  --# post Is_Empty (State);

  -- Other operations not included as not needed for
  -- this example.

private
  Stack_Size : constant := 100;
  type      Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range    is Pointer_Range range 1..Stack_Size;
  type      Vector        is array(Index_Range) of Integer;

  type Stack_Type is
    record
      S : Vector;
      Pointer : Pointer_Range;
    end record;

  Initial_Stack : constant Stack_Type :=
    Stack_Type'(S      => Vector'(others => 0),
                Pointer => 0);

end Stack;

```

Body in SPARK 2005:

```
package body Stack
--# own State is My_Stack;
is
  My_Stack : Stack_Type;

  procedure Push(X : in Integer)
  --# global in out My_Stack;
  --# pre My_Stack.Pointer < Pointer_Range'Last;
  --# post My_Stack.Pointer /= 0;
  is
  begin
    My_Stack.Pointer := My_Stack.Pointer + 1;
    My_Stack.S(My_Stack.Pointer) := X;
  end Push;

  procedure Swap2
  --# global in out My_Stack;
  --# pre My_Stack.Pointer >= 2;
  --# post My_Stack.Pointer = My_Stack~.Pointer;
  is
    Temp : Integer;
  begin
    Temp := My_Stack.S (1);
    My_Stack.S (1) := My_Stack.S (2);
    My_Stack.S (2) := Temp;
  end Swap2;

  procedure Initialize
  --# global out My_Stack;
  --# post My_Stack.Pointer = 0;
  is
    --# for Initial_Stack declare Rule;
  begin
    My_Stack := Initial_Stack;
  end Initialize;

end Stack;
```

Specification in SPARK 2014

```
package Stack
  with Abstract_State => State
is
  -- We have to turn the proof functions into actual functions
  function Is_Empty return Boolean
    with Global      => (Input => State),
         Convention => Ghost;

  function Is_Full return Boolean
    with Global      => (Input => State),
         Convention => Ghost;

  function Count return Natural
    with Global      => (Input => State),
         Convention => Ghost;
```

```

-- Post-condition indicates that the stack will be
-- non-empty after pushing an item on to it, while the pre-condition
-- requires it is not full when we push a value onto it.
procedure Push(X : in Integer)
  with Global => (In_Out => State),
       Pre    => not Is_Full,
       Post   => not Is_Empty;

-- Procedure that swaps the first two elements in a stack.
procedure Swap2
  with Global => (In_Out => State),
       Pre    => Count >= 2,
       Post   => Count = Count'Old;

-- Initializes the Stack.
procedure Initialize
  with Global => (Output => State),
       Post   => Is_Empty;

private
  Stack_Size : constant := 100;
  type Pointer_Range is range 0 .. Stack_Size;
  subtype Index_Range is Pointer_Range range 1 .. Stack_Size;
  type Vector is array(Index_Range) of Integer;

  type Stack_Type is
    record
      S : Vector;
      Pointer : Pointer_Range;
    end record;

  Initial_Stack : constant Stack_Type :=
    Stack_Type'(S => Vector'(others => 0),
                Pointer => 0);
end Stack;

Body in SPARK 2014:

package body Stack
  with Refined_State => (State => My_Stack)
is
  My_Stack : Stack_Type;

  function Is_Empty return Boolean
    with Refined_Global => (Input => My_Stack),
         Refined_Post   => Is_Empty'Result = (My_Stack.Pointer = 0)
  is
  begin
    return My_Stack.Pointer = 0;
  end Is_Empty;

  function Is_Full return Boolean
    with Refined_Global => (Input => My_Stack),
         Refined_Post   => Is_Full'Result = (My_Stack.Pointer = Pointer_Range'Last)
  is
  begin
    return My_Stack.Pointer = Pointer_Range'Last;
  end Is_Full;
end package body Stack;

```

```
is
begin
  return My_Stack.Pointer = Pointer_Range'Last;
end Is_Full;

function Count return Natural
with Refined_Global => (Input => My_Stack),
     Refined_Post   => Count'Result = My_Stack.Pointer
is
begin
  return My_Stack.Pointer;
end Count;

procedure Push(X : in Integer)
with Refined_Global => (In_Out => My_Stack),
     Refined_Pre     => My_Stack.Pointer /= Pointer_Range'Last,
     Refined_Post    => My_Stack.Pointer /= 0
is
begin
  My_Stack.Pointer := My_Stack.Pointer + 1;
  My_Stack.S(My_Stack.Pointer) := X;
end Push;

procedure Swap2
with Refined_Global => (In_Out => My_Stack),
     Refined_Pre     => My_Stack.Pointer >= 2,
     Refined_Post    => My_Stack.Pointer = My_Stack'Old.Pointer
is
  Temp : Integer;
begin
  Temp := My_Stack.S (1);
  My_Stack.S (1) := My_Stack.S (2);
  My_Stack.S (2) := Temp;
end Swap2;

procedure Initialize
with Refined_Global => (Output => My_Stack),
     Refined_Post    => My_Stack.Pointer = 0
is
begin
  My_Stack := Initial_Stack;
end Initialize;
end Stack;
```

A.4.5 Main_Program annotation

See the main program annotation used in section [Basic Input and Output Device Drivers](#).

A.4.6 RavenSPARK patterns

The Ravenscar profile for tasking is not yet supported in SPARK 2014. Mapping examples will be added here in future.

RESTRICTIONS AND PROFILES

A list of restrictions by section and their effect:

2.1 Character Set

1. No_Wide_Characters

This GNAT-defined restriction may be applied to restrict the use of Wide and Wide_Wide character and string types in SPARK 2014.

6.1 Subprogram Declarations

1. No_Default_Subprogram_Parameters

Prohibits the use of default subprogram parameters, that is, a parameter_specification cannot have a default_expression.

Todo

access and aliased parameter specs, null exclusion parameters. Function access results function null exclusion results. To be completed in the Milestone 4 version of this document.

Note: RCC. Should we forbid these thing outright, or just ignore them and/or mark the corresponding declarations as “not SPARK”? Assign: ???

6.1.4 Mode Refinement

1. Moded_Variables_Are_Entire

Asserts that a moded_item cannot be a subcomponent name.

2. No_Conditional_Modes

Prohibits the use of a conditional_mode in a mode_specification.

3. No_Default_Modes_On_Procedures

A style restriction that disallows a default_mode_specification within a procedure mode_refinement. An explicit Input => must be given. A function mode_refinement may have a default_mode_specification.

6.1.5 Global Aspects

Todo

In the following restriction, is this the assumption of no Global aspect implies Global => null sensible or should we always insist on Global => null?? I hope not!! RCC comment: see discussion under LA11-017 started by RCC on 26/10. To be completed in the Milestone 4 version of this document.

1. Global_Aspects_Required

Enforces the use of a global_aspect on every subprogram which accesses a global variable. When this restriction is in force a subprogram which does not have an explicit global_aspect is considered to have a have have one of Global => null.

2. Global_Aspects_On_Procedure_Declarations

A less stringent restriction which requires a global_aspect on all procedure declarations that access a global variable. A global_aspect is optional on a subprogram body that does not have a separate declaration. An implicit global aspect is calculated from the body of each subprogram body which does not have an explicit global_aspect.

Note: RCC. I have changed “virtual” to “implicit” here since the latter is used to mean the same thing later on and seems more consistent.

6.1.7 Dependency Aspects

1. Procedures_Require_Dependency_Aspects

Mandates that all procedures must have a dependency_aspect. Functions may have a dependency_aspect but they are not required.

2. Procedure_Declarations_Require_Dependency_Aspects

A less stringent restriction which only requires a dependency_aspect to be applied to a procedure declaration. A dependency_aspect is optional on a subprogram body that does not have a separate declaration. An implicit dependency aspect is calculated from the body of each subprogram body which does not have an explicit dependency_aspect.

3. No_Conditional_Dependencies

Prohibits the use of a conditional_dependency in any dependency_relation.

4. Dependencies_Are_Entire

Prohibits the use of subcomponents in dependency_relations.

6.2 Formal Parameter Modes

1. Strict_Modes

- A formal parameter (see Ada RM 6.1) of a subprogram of mode **in** or **in out** (an import) must be read on at least one execution path through the body of the subprogram and its initial value used in determining the value of at least one of export or the special **null** export symbol.
- A formal parameter of a subprogram of mode **in out** must be updated directly or indirectly on at least one executable path within the subprogram body.
- A formal parameter of a subprogram of mode **out** must be updated directly or indirectly on every executable path through the subprogram body.

This restriction has to be checked by flow analysis.

6.3 Subprogram Bodies

1. End_Designators_Required

Mandates that the final end of every subprogram body, package declaration and package body has a designator which repeats the defining designator of the unit.

Note: RCC. Is End_Designators_Required really ever going to be used? It was only required in S95 to facilitate the implementation of the hide anno really. This feels more like a rule for GNATCheck that users might choose to employ, but I don't think it makes any difference to verifiability, so no business of SPARK 2014?

6.3.2 Global Aspects

1. No_Scope_Holes

A subprogram, P, shall not declare an entity of the same name as a moded_item or the name of the object of which the moded_item is a subcomponent in its global_aspect within a loop_statement or block_statement whose nearest enclosing program unit is P.

Note: RCC. Is No_Scope_Holes really necessary for proof or any other form of verification?

6.4.2 Anti-Aliasing

1. Array_Elements_Assumed_To_Overlap

Enforces the assumption that array elements are always considered to be overlapping and so, for example, V.A(I).P and V.A(J).Q are considered as overlapping. This restriction can be enforced simply whereas the more general rule that array subcomponents are only considered to be overlapping when they have common indices requires formal proof in general.

Note: RCC. Strongly agree that we need this for rel1, since it gets us back to the simple aliasing rules of S95, without having to resort to proof.

7.1 Packages

1. End_Designators_Required

See the same restriction in section 6.3.

2. Package_Aspects_Required

Enforces the restrictions Abstract_State_Aspects_Required, Initializes_Aspects_Required and Refined_State_Aspects_Required.

7.1.2 Abstract State Aspect

1. Abstract_State_Aspects_Required

Applies to an entire package including any embedded packages and its private child packages and enforces the restriction that a package which has hidden state must have an abstract_state_aspect. If this restriction is in force the absence of an abstract_state_name implies Abstract_State => null.

7.1.3 Initializes Aspect

1. Initializes_Aspects_Required

If any of the state components of a package, including variables declared in its visible part are initialized during the elaboration of the package, then the initializes state components must appear in an initializes_aspect. If this restriction is in force the absence of an initializes_aspect implies Initializes => null.

2. Package_Elaboration_Initializes_Local_State_Only

Applies to an entire package including any embedded packages and its private child packages and enforces the restriction that the package may only initialize state declared locally to the package during its elaboration. That is, only the *variables* declared immediately within the package.

3. Package_Elaboration_Initializes_Local_And_Parent_State_Only

A package may only initialize a *variable* declared *locally* to the package, a visible *variable* of its parent or indirectly a *state_name* of its parent.

4. Package_Elaboration_Order_Independence

Enforces the rule that elaboration of a package Q may only initialize a *variable* using a *static expression* or using subprograms and *variables local* to Q. Ultimately all the initialization values must be derived from *static expressions*. If this restriction is in force then the predicate of an *initial_condition_aspect* of a package may only refer to state initialized by Q.

7.1.4 Initial Condition Aspect

1. Initialize_Package_Local_State_Only

See the same restriction in section 7.1.3.

2. Package_Elaboration_Order_Independence

See the same restriction in section 7.1.3.

7.2.2 Refined State Aspect

1. Refined_State_Aspects_Required

If a package has an *abstract_state_aspect* then a corresponding “*refined_state_aspect*” is required.

2. Null_State_Refinement_Prohibited

The *abstract_state_name* **null** cannot be used in a *state_refinement_aspect*.

3. Strict_Volatile_State_Refinement

A constituent of a *Volatile* *abstract_state_name* must be *Volatile* and be of the same mode.

END OF FILE

TO-DO SUMMARY

Todo

~~It is intended to support subtype predicates. Analysis is required to determine if any subset rules need to be applied and also regarding any extra proof rules that might need to be applied.~~ Lift restriction that non-prelaborable subtypes are not subject to flow analysis. To be completed in a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/declarations-and-types.rst, line 42:50.)

Todo

~~RCC comment: This will need to describe any global restrictions on tagged types (if any) and any additional Restrictions that we may feel users need.~~ Add the Dynamic Predicate aspect to SPARK 2014. To be completed in the Milestone 4 a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/declarations-and-types.rst, line 95:74.)

Todo

~~Constructive modular analysis of generics (including prove once, use many times). Will require significant restrictions and extra aspects to implement.~~ Lift restriction that non-prelaborable constants are not subject to flow analysis. To be completed in a post-Release 1 version of this document.

(The original entry is located in /home/pavlos/Documents/Versioning_systems/Git/spark2014/docs/lrm/source/declarations-and-types.rst line 99.)

Todo

Add 'Class attribute to SPARK 2014. To be completed in the Milestone 4 a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Documents/LatexVersioning_systems/OldGit/Oldspark2014/docs/lrm/source/declarations-and-types.rst, line 156.)

Todo

Include interface types in SPARK 2014. To be completed in a post-Release 1 version of this document.

(The *original entry* is located in [/home/pavlos/Documents/Versioning_systems/Git/spark2014/docs/lrm/source/generic-unitsdeclarations](#) line ~~9~~[184](#).)

Todo

Update ~~mapping specification section to cover all necessary language features~~[SPARK 2014 to allow prove once/use many approach to generics](#). To be completed in ~~the milestone 3~~[a post-Release 1](#) version of this document.

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~112~~[53](#).)

Todo

We need to increase the number of examples given. To be completed in the Milestone ~~3~~[4](#) version of this document.

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~149~~[156](#).)

Todo

Consider adding a glossary, defining terms such as flow analysis and formal verification. [To be completed in the Milestone 4 version of this document.](#)

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~183~~[193](#).)

Todo

The pragmas equivalent to the new aspects need to be added to this document. [To be added in the Milestone 4 version of this document.](#)

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~256~~[268](#).)

Todo

Complete detail on mixing SPARK 2014 with non-Ada code. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~402~~[355](#).)

Todo

Ensure that all strategic requirements have been implemented. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in [/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/intro](#) line ~~447~~[403](#).)

Todo

Where Ada 2012 language features are designated as not in SPARK 2014 in subsequent chapters of this document, add tracing back to the strategic requirement that motivates that designation. [To be completed in the Milestone 4 version of this document.](#)

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/intro line ~~451~~.407.)

Todo

Add detail on restrictions to be applied to tested code, making clear that the burden is on the user to get this right, and not getting it right can invalidate the assumptions on which proof is based. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/intro line ~~569~~.531.)

Todo

Complete detail on combining formal verification and testing. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/intro line ~~574~~.536.)

Todo

Complete detail on Code Policies. To be completed in the Milestone ~~3~~4 version of this document.

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/introduction.rst, line 624.)~~

~~Complete detail on Ghost Entities. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/introduction.rst, line 658.)~~

~~Add detail on how retrospective analysis will work when we have a mix of SPARK 2014 and non-SPARK 2014. To be completed in the Milestone 3 version of this document~~[Consider referencing the User's Guide for details of the various profiles.](#)

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/lrm/source/introduction line ~~725~~.)

~~Complete detail on constructive, generative and retrospective analysis and verification. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/docs/lrm/source/introduction.rst, line ~~729~~.576.)~~

Todo

We need to consider what might need to be levied on the non-SPARK 2014 code in order for flow analysis on the SPARK 2014 code to be carried out. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/intro line ~~824~~.807.)

Todo

Complete detail on mixing code that is in and out of SPARK 2014. In particular, where subheadings such as Legality Rules or Static Semantics are used to classify the language rules given for new language features, any rules given to restrict the Ada subset being used need to be classified in some way (for example, as Subset Rules) and so given under a corresponding heading. In addition, the inconsistency between the headings used for statements and exceptions needs to be addressed. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/intro.spec.rst, line ~~829~~.812.)

Todo

~~Note that the details of false alarm management are still TBD and so there is currently no equivalent of the accept annotation in the SPARK 2005 body. Depending on the outcome of M423-014, either pragma Annotate or pragma Warning will be utilized to accept warnings/errors in SPARK 2014.~~ To be completed in the Milestone ~~3~~4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/mapping.spec.rst, line 94.)

Todo

~~The SPARK 2014 version of the code is not provided since the restrictions that are to be applied in terms of package visibility are yet to be determined. There will not be an equivalent of ‘Append and ‘Tail in SPARK 2014. However, we will be able to achieve the same functionality using generics.~~ To be completed in the Milestone ~~3~~4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/mapping.spec.rst, line ~~332~~.-)

~~Note that the syntax for identifying the main program in SPARK 2014 is still TBD. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/mapping-spec.rst, line 751.)~~

~~Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. Note that this also applies to the use of the Always annotation. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/mapping-spec.rst, line 799.806.)~~

Todo

~~Note that the There will not be an equivalent of ‘Append and ‘Tail in SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. 2014. However, we will be able to achieve the same functionality using generics.~~ To be completed in the Milestone ~~3~~4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/mapping.spec.rst, line ~~824~~.831.)

Todo

~~Note that the There will not be an equivalent of ‘Append and ‘Tail in SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/mapping-spec.rst, line 912.)~~

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. 2014. However, we will be able to achieve the same functionality using generics. To be completed in the Milestone 3-4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/ma spec.rst, line 941-954.)

Todo

The declare annotation SPARK is used to control the generation of proof rules for composite objects. It is not clear that this will be required in SPARK 2014, so this section will be updated or removed in future. To be completed in the Milestone 4 version of this document.

(The ~~is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/mapping-spec.rst, line 1210.~~)

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/lrm/source/mapping line 1221.)

Note that the SPARK 2014 versions of this example are currently TBD, as the relevant syntax is not yet defined. To be completed in the Milestone 3 version of this document.

(The ~~is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014~~docs/lrm/source/mapping-spec.rst, line 1231-1223.)

Todo

Note that the SPARK 2014 version of the rule declaration annotation has not yet been defined [M520-006] - note that it ~~may~~might not even be needed, though this is to be determined - and so there is no equivalent included in the SPARK 2014 code. To be completed in the Milestone 4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/ma spec.rst, line 1247-1250.)

Todo

Are there any other language defined attributes which will not be supported? To be completed in the Milestone 3-4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/nar and-expressions.rst, line 45.)

Todo

What do we do about Gnat defined attributes, a useful one is: For a prefix X that denotes an object, the GNAT-defined attribute X'ValidScalars is defined in SPARK 2014. This Boolean-valued attribute is equal to the conjunction of the Valid attributes of all of the scalar parts of X.

[If X has no volatile parts, X'ValidScalars implies that each scalar subcomponent of X has a value belonging to its subtype. Unlike the Ada-defined Valid attribute, the ValidScalars attribute is defined for all objects, not just scalar objects.]

Perhaps we should list which ones are supported in an appendix? Or should they be part of the main language definition?

It would be possible to use such attributes in assertion expressions but not generally in Ada code in a non-Gnat compiler.

To be completed in the Milestone [3.4](#) version of this document. Note that as language-defined attributes form Appendix K of the Ada RM, any GNAT-defined attributes supported in SPARK 2014 will be presented in an appendix.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/nar~~and-expressions.rst, line 48.)

Todo

Detail on Update Expressions needs to be put into the standard format. To be completed in the Milestone [3.4](#) version of this document.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/nar~~and-expressions.rst, line ~~126;103~~.)

Todo

~~More details on volatile variables and definition of a complete model. At the very least, if V is a Volatile Input variable should not have the following assertion provable: T1 := V; T2 := V; pragma Assert (T1 = T2);~~ [Add support for more complex models of external state.](#) To be completed in ~~the Milestone 3~~ [a post-Release 1](#) version of this document.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/pac~~line ~~81;256~~.)

Todo

~~Need to describe the conditions under which a volatile variable can be a parameter of a subprogram~~ [refined contract](#) cases. To be completed in ~~the Milestone 3~~ [a post-Release 1](#) version of this document.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/pac~~line ~~89;1758~~.)

Todo

~~Consider more than just simple Volatile Inputs and Outputs; Latched outputs, Involatiles, etc.~~ [Add support for type invariants in SPARK 2014.](#) To be completed in ~~the Milestone 4~~ [a post-Release 1](#) version of this document.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/pac~~line ~~93;1964~~.)

Todo

~~Further semantic detail regarding Volatile state and integrity levels needs to be added, in particular in relation to specifying these properties for variables which are declared directly within the visible part of a package specification~~ [Provide full detail on Representation Issues.](#) To be completed in ~~the Milestone 3~~ [a post-Release 1](#) version of this document.

(The *original entry* is located in /home/pavlos/~~Desktop/LatexDocuments/OldVersioning~~_systems/~~OldGit~~/spark2014/~~docs/lrm/source/pac~~line ~~328;6~~.)

Todo

~~Provide language definition for Initializes aspect~~ This statement was originally in this chapter “Pragma or aspect `Unchecked_Union` is not in SPARK 2014” this needs to be recorded in the list of unsupported aspects and pragmas. To be completed in the Milestone 3.4 version of this document.

(The *original entry* is located in `/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae` line 394.9.)

Todo

Provide ~~language definition for Initial Condition aspect~~ a detailed semantics for `Refined_Pre` and `Refined_Post` aspects on `Unchecked_Conversion`. To be completed in the Milestone 3 a post-Release 1 version of this document.

(The *original entry* is located in `/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae` line 438.60.)

Todo

~~The consistency rules will be updated as the models for volatile variables and integrity levels are defined~~ Need to put some words in here to describe the precautions that may be taken to avoid invalid data. To be completed in the Milestone 3.4 version of this document.

(The *original entry* is located in `/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae` line 543.72.)

Todo

~~Consider whether it should be possible to refine null abstract state onto hidden state. Rationale: this would allow the modeling of programs that—for example—use caches to improve performance.~~ Introduce checks for data validity into the proof model as necessary. To be completed in the Milestone 3 a post-Release 1 version of this document.

(The *original entry* is located in `/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae` line 547.76.)

Todo

~~Consider whether it should be possible to refine abstract onto hidden state without any restrictions, although the refinement would be checked and potential issues flagged up to the user.~~

Rationale: there are a number of different possible models of mapping abstract to concrete state—especially when volatile state is being used—and it might be useful to provide greater flexibility to the user. In addition, if a facility is provided to allow users to step outside of the language when refining depends, for example, then it may be necessary to relax the abstraction model as well as relaxing the language feature of direct relevance.*

~~access and aliased parameter specs, null exclusion parameters. Function access results function null exclusion results.~~ To be completed in the Milestone 3.4 version of this document.

(The *original entry* is located in `/home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae` line 552.25.)

Todo

~~Provide language definition for Refined aspect.~~ In the following restriction, is this the assumption of no Global aspect implies `Global => null` sensible or should we always insist on `Global => null`?? I hope not!! RCC comment: see discussion under LA11-017 started by RCC on 26/10. To be completed in the Milestone 3.4 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 589:54.)

Todo

~~We need to consider the interactions between package hierarchy and abstract state. Do we need to have rules restricting access between parent and child packages? Can we ensure abstract state encapsulation? To be completed in the Milestone 3 version of this document~~Need to consider further the support for iterators and whether the application of constant iterators could be supported.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 596:54.)

Todo

~~Provide Verification Rules for Initializes aspect in the presence of state abstraction. (TJJ 29/11/12) Do we need this verification rule? Could it be captured as part of the general statement about proof? To be completed in the Milestone 3-milestone 4 version of this document.~~

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 605:225.)

Todo

~~The subject of refined Global, Depends, Pre and Post aspects is still under discussion (and their need questioned) and so the subsections covering these aspects is subject to change. To be resolved and completed by Milestone 3~~Add ghost types and ghost variables to SPARK 2014. To be completed in a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 614:772.)

Todo

~~The consistency rules will be updated as the model for volatile variables is defined. Make worst-case assumptions about private types for this rule, or blast through privacy? To be completed in the Milestone 3-milestone 4 version of this document.~~

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 674:819.)

Todo

~~If it ends up being possible to refine null abstract state, then refinements of such state could appear in refined globals statements, though they would need to have mode in-out~~Can a ghost variable be a constituent of a non-ghost state abstraction, or would this somehow allow unwanted dependencies? If not, then we presumably need to allow ghost state abstractions or else it would be illegal for a library level package body to declare a ghost variable. To be completed in ~~the Milestone 3~~a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/LatexDocuments/OldVersioning_systems/OldGit/spark2014/docs/lrm/source/pae line 678:848.)

Todo

~~Provide language definition for Refinedaspect. Do we want an implicit Ghost convention for an entity declared within a statement whose execution depends on a ghost value? To be completed in the Milestone 3 a post-Release 1 version of this document.~~

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/packages.rst, line 696.856.)

Todo

~~The consistency rules will be updated as the model for volatile variables is defined. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 759.)~~

~~If it is possible to refine null abstract state, then refinements of such state could appear in refined depends statements, but wouldn't map to anything in the depends relation itself and would need to modes of a subprogram in Ada are not as strict as S2005 and there is a difference in interpretation of the modes as viewed by flow analysis. For instance in Ada a formal parameter of mode out of a composite type need only be partially updated, but in flow analysis this would have mode in/out in the refined depends. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 763.)~~

~~Provide language definition for Refinedaspect. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 782.)~~

~~Provide language definition for Refinedaspect. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 831.)~~

~~Provide language definition for Refinedaspect. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 879.)~~

~~out. Similarly an Ada formal parameter may have mode in out but not be an input. In flow analysis it would be regarded as an input and give rise to flow errors.~~

~~refined contract~~ In deciding whether a parameter is only partially updated, discriminants (including discriminants of subcomponents) are ignored. For example, given an *out* mode parameter of a type with defaulted discriminants, a subprogram might or might not modify those discriminants (if it does, there will of course be an associated proof obligation to show that the parameter's 'Constrained attribute is False in that path).

~~Perhaps we need an aspect to describe the strict view of a parameter if it is different from the specified Ada mode of the formal parameter? To be completed in the Milestone 3 a post-Release 1 version of this document.~~

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/packages.rst, line 882.924.)

Todo

~~The support for type invariants needs to be considered further and will be completed for Milestone 3 version of this document.~~

~~(The RCC: The above text implies that SPARK 2014 does not support Ada.Calendar, which is specified in RM 9.6. SPARK 2005 supports and prefers Ada.Real_Time and models the passage of time as an external "in" mode protected own variable. Should we use the same approach in SPARK 2014? Discussion under TN [LB07-024] is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/packages.rst, line 942.)~~

~~Provide detail on Representation Issues. To be completed in the Milestone 4 version of this document.~~

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/Old/Git/spark2014/docs/lrm/source/rep line 10.)

Todo

~~Need to consider further the support for iterators and whether the application of constant iterators could be supported.~~ Add Tasking. To be completed in Milestone.4 a post-Release 1 version of this document.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/Old/Git/spark2014/docs/lrm/source/stat line 54.16.)

Todo

Provide detail on ~~pragmas Loop and Loop, and attribute Loop~~ Standard Libraries. To be completed in ~~the Milestone 3~~ a post-Release 1 version of this document. This targeting applies to all ToDos in this chapter.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/Old/Git/spark2014/docs/lrm/source/stat line 124.11.)

Todo

~~In the future we may be able to permit access and aliased formal parameter specs. Target: Release 2 of~~ particular, it is intended that predefined container generics suitable for use in SPARK 2014 ~~language and toolset or later.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/subprograms.rst, line 65.)~~

~~What do we do regarding null exclusion parameters? To be completed in the Milestone 3 version of this document will be provided. These will have specifications as similar as possible to those of Ada's bounded containers (i.e., Ada.Containers.Bounded_*), but with constructs removed or modified as needed in order to maintain the language invariants that SPARK 2014 relies upon in providing formal program verification.~~

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/Old/Git/spark2014/docs/lrm/source/sub line 69.)

~~What do we do regarding function access results and function null exclusion results? To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/subprograms.rst, line 73.15.)~~

Todo

~~Think about Pre'Class and Post'Class. To be completed in the Milestone 3 version of this document. Should we say here which packages are supported in SPARK 2014 or which ones aren't supported? How much of the standard library will be available, and in which run-time profiles?~~

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/Old/Git/spark2014/lrm/source/subprog line 87.)

~~Add rules relating to volatile state. To be completed in the Milestone 3 version of this document.~~

~~(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/docs/lrm/source/subprograms~~ the standard library ~~.rst, line 681.)~~

~~Consider whether to capture the rules from SPARK 2005 about flow=auto mode in this document or whether it is purely a tool issue (in SPARK 2005, in flow=auto mode if a subprogram is missing a dependency relation then the flow analysis assumes all outputs of the subprogram are derived from all of its inputs).~~

(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/subprograms.rst, line 705.36.)

Todo

The modes of a subprogram in Ada are not as strict as S2005 and there is a difference in interpretation of the modes as viewed by flow analysis. For instance in Ada a formal parameter of mode out of a composite type need only be partially updated, but in flow analysis this would have mode in out. Similarly an Ada formal parameter may have mode in out but not be an input. In flow analysis it would be regarded as an input and give arise to flow errors. Perhaps we need an aspect to describe the strict view of a parameter if it is different to the specified Ada mode of the formal parameter? To be completed in the Milestone 3 version of this document. How much to say here? S95 supports a subset of Interfaces, and a very small subset of Interfaces.C but that's about it.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/sub line 884.47.)

Todo

Consider how implicitly generated proof obligations associated with runtime checks should be viewed in relation to Proof. To be addressed in the Milestone 4 version of this document. What is status of supported for pragma Unchecked_Union in GNATProve at present?

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/sub line 969.50.)

Todo

RCC: ~~The above text implies that SPARK 2014 does not support Ada.Calendar, which is specified in RM 9.6. SPARK 2005 supports and prefers~~ Need to think about Ada.Real_Time. It's important for all S95 customers, to get at monotonic clock, even if not using RavenSPARK. It does depend on support for external variables, though, since Ada.Real_Time and models the passage of time as an external "in" mode protected own variable. Should we use the same approach in SPARK 2014? Discussion under Clock is most definitely Volatile. TN [LB07-024] . To be completed in the Milestone 3 version of this document raised to discuss this.

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/lrm/source/tasks-and line 11.)

Add Tasking. Target: release 2 of SPARK 2014 language and toolset.

(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/docs/lrm/source/tasks-and-synchronization the-standard-library.rst, line 17.)

Provide detail on Standard Libraries. To be completed in the Milestone 4 version of this document.

(The is located in /home/pavlos/Desktop/Latex/Old/Old/spark2014/lrm/source/the-standard-library.rst, line 19.63.)

Todo

~~Describe model of renaming for array indexing and slices. To be completed in the Milestone 3 version of this document.~~ How much here can be supported? Most S95 customers want Ada.Numerics.Generic_Elementary_Functions plus its predefined instantiation for Float, Long_Float and so on. How far should we go?

(The *original entry* is located in /home/pavlos/Desktop/Latex/Documents/Old/Versioning_systems/OldGit/spark2014/docs/lrm/source/vis line 43.84.)

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