

VDMJ Annotations Guide

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1. Overview

Annotations were introduced in VDMJ version 4.2.1 as a means to allow a specifier to affect the tool's behaviour without affecting the meaning of the specification. The idea is very similar to the notion of annotations in Java, which can be used to affect the Java compiler, but do not alter the runtime behaviour of a program.

VDMJ provides some standard annotations, but the intent is that specifiers can create new annotations and add them to the VDMJ system easily.

2. Syntax

Annotations are added to a specification as regular comments, either block comments or one-line comments. This is so that other VDM tools will not be affected by the addition of annotations, and emphasises the idea that annotations do not alter the meaning of a specification.

An annotation must be present at the start of a comment, and has the following syntax:

```
'@', identifier, [ '(', expression list, ')' ]
```

So for example, an operation in a VDM++ class could be annotated as follows:

```
class A
operations
  -- @Override
  public add: nat * nat ==> nat
  add(a, b) == ...
```

Or the value of variables can be traced during execution as follows:

```
functions
  add: nat * nat +> nat
  add(a, b) ==
    /* @Trace(a, b) */ a + b;
```

3. Location

Annotations are located next to another syntactic category, even if they do not affect the behaviour or meaning of that construct. In the examples above, the `@Override` annotation applies to the definition of the add operation, and the `@Trace` annotation applies to the expression `a+b`.

Specific annotations may limit where they can be applied (for example, `@Override` only makes sense for operations and functions in VDM++ specifications), but in general annotations can be applied to the following:

- To classes or modules.
- To definitions within a class or module.
- To expressions within a definition.
- To statements within an operation body.

In each case, the annotation must appear in a comment, by itself, before the construct concerned. Multiple annotations can be applied to the same construct, and may be interleaved with other textual comments, but each annotation must appear in its own comment.

4. Tool Effects

Annotations can be used to affect the following aspects of VDMJ's operation:

- The parser (for example) to enable or disable new language features.
- The type checker (for example) to check for overrides or suppress warnings
- The interpreter (for example) to trace the execution path or variables' values
- The PO generator to (for example) skip obligations for an area of specification.

Note that none of these examples affect the meaning of the specification, only the operation of the tool. Although it would be possible to create an annotation to affect a specification's behaviour, this is strongly discouraged.

5. Loading and Checking

A global Settings boolean field called "annotations" is set by an `"-annotations"` command line argument. This field can be checked by any annotation processing (and skipped if not set). It is currently only used by the interpreter.

Annotations are processed as follows by the parser:

- All comments that precede class/modules, definitions, expressions and statements are collected by the lexical analyser and added to the corresponding AST node by the parser.
- The parser checks the comments in an annotated node, looking for those that start with `@<identifier>`, optionally followed by an expression list in brackets. If there are any parse errors at this stage, the comment is assumed to merely resemble an annotation and is silently ignored.
- Each annotation that parses correctly is then used to attempt to load a Java class called `AST<Name>Annotation` from a configurable classpath. If the class cannot be found, the comment containing the annotation is silently assumed to coincidentally contain something that is a valid annotation syntax, but which is not actually an annotation - like using

@NickBattle to refer to a person by their Twitter handle.

- For the annotation classes that load successfully, the parser instantiates each annotation, and calls a "before" method, passing the SyntaxReader that is currently processing the specification. This allows the annotation to affect the parse of the syntactic element that follows the annotation.
- The parser parses the element following the comments.
- The parser calls an "after" method on the annotations after the parse of the element, passing the SyntaxReader and the parsed AST node, to allow the annotation to affect the result of the parse or undo any changes it made to the SyntaxReader.
- The parse then continues as normal.

Note that so far there has been no checking of the annotation itself, other than its syntax. If VDMJ correctly parses an entire specification, it next performs type checking. This is done by converting the tree of AST objects into an equivalent tree of TC objects. This includes annotations that are attached to AST nodes - AST<Name>Annotation objects are converted to TC<Name>Annotation objects, loaded from the same classpath, which contain code to type check the annotation itself as well as code which may affect the type check of the annotated element.

Type checking then proceeds as follows:

- When the TC tree is created, AST<Name>Annotation objects from the parse are converted to TC<Name>Annotation objects.
- When the type checker starts, it calls a static `doInit` method in all loaded TC annotations. This allows them to reset or set up any persistent data that they require.
- Before the type check of an annotated element, the type checker calls the "before" method of annotations attached to the node, passing the TC node of the element and the Environment list.
- The type check of the annotated element then proceeds as normal.
- After the type check, the "after" method of the annotations is called, passing the TC node and Environment as before, but also passing the `TCType` of the checked node.

The annotation typically uses the "before" method to type check itself (if necessary) and check anything it needs to check about the annotated TC node. For example, the `@Trace` annotation checks that its arguments are simple variable identifiers that are in scope; and the `@Override` annotation checks that there are no arguments, that the dialect is VDM++, that the definition annotated is an operation or function and that there is a superclass that has a definition which is being overridden by the annotated element.

After the type checking phase, if there are no errors, VDMJ will normally create a tree for the interpreter: TC classes are converted to IN classes, and this includes annotations. Annotations which apply to classes/modules and definitions do not affect the interpreter, but those that apply to statements and expressions do (since these elements are "executed").

Execution proceeds as follows:

- When the IN tree is created, TC<Name>Annotation objects are converted to IN<Name>Annotation objects.
- When the interpreter is initialised, it calls a static `doInit` method in all loaded IN annotations. This allows them to reset or set up any persistent data that they require.
- When an annotated `INStatement` or `INExpression` is executed, the evaluation first calls the "before" method of the annotations, passing the statement or expression and the runtime Context stack.

- The statement or expression is then evaluated as normal.
- The evaluation then calls an "after" method on the annotations, passing the statement or expression, the runtime Context and the Value from the execution. The annotation cannot affect the return value.
- Finally the return value is returned as usual and the overall evaluation proceeds as normal.

The before and after methods allow annotations that affect the interpreter to either intervene before the annotated element is evaluated or to look at the result after its execution (or both).

If PO generation is required, the TC tree is used to generate a tree of PO objects, including PO<Name>Annotation classes. Proof obligation generation then proceeds as follows:

- When the PO tree is created, TC<Name>Annotation objects are converted to PO<Name>Annotation objects.
- When PO generation starts, it calls a static `doInit` method in all loaded PO annotations. This allows them to reset or set up any persistent data that they require.
- Before any annotated definition, statement or expression is processed by the PO generator, the "before" method of the annotations is called, being passed the `POContextStack` and the PO node concerned.
- PO generation of the PO node then proceeds as normal.
- After the PO generation, the "after" method of the annotations is called, passing the `POContextStack`, the PO node and the `ProofObligationList` generated by the node. This list can be modified by the "after" method - for example, the `@NoPOG` annotation clears it.

Note that the same annotation (that is, one `@Name` comment in the source) can affect all four areas of VDMJ operation, though to do so it needs to define code in the AST, TC, IN and PO trees. If an annotation affects the type checker, but not (say) the interpreter, the TC-IN mapping for the annotation should map TC<Name>Annotation to `INNullAnnotation`, which does nothing. The same principle applies to other unused analysis mappings; all annotations must define `AST<Name>Annotation`.

6. Standard Annotations

VDMJ is provided with some standard annotations. They perform the following processing:

6.1. @Override

This is very similar to the Java `@Override` annotation, which is used to verify that a Java method overrides a superclass method, raising an error if not. In VDMJ, the override applies to operations or functions in a VDM++ class.

The typecheck of the annotation (in the `TCOverrideAnnotation` "before" methods) verifies that the dialect is VDM++, that the annotation has no arguments, and that it is applied to either an operation or a function definition. Lastly, if there is no "inherited" method that this definition overrides, an error is raised.

```
Error 3363: Definition does not @Override superclass in 'A' (test.vpp) at line 3:9
```

The annotation has no effect on the interpreter or the PO generator.

6.2. @Trace

The @Trace annotation is intended to trace the flow of control in the interpreter, either to note that a particular point in the execution has been reached, or to log the values of variables at that location.

The typechecker checks (in the TCTraceAnnotation "before" methods) that the annotation is applied to a statement or an expression only. The check also makes sure that any arguments supplied are simple variable names and refer to variables that are in scope.

When the interpreter is running, the INTraceAnnotation "before" method either just prints out the current location to stderr, or it prints the location and "<name> = <value>" for each argument (ie. each variable name traced). For example, the specification in section 2 produces the following:

```
> p add(1,2)
Trace: in 'A' (test.vdm) at line 9:13, A'a = 1
Trace: in 'A' (test.vdm) at line 9:13, A'b = 2
= 3
Executed in 0.007 secs.
```

The annotation has no effect on the execution values or the PO generator.

6.3. @NoPOG

The @NoPOG annotation is intended to suppress PO generator over a region of the specification. It can be applied to a definition, a statement or an expression.

The typechecker (the TCNoPOGAnnotation "before" methods) just checks that the annotation has no arguments passed.

```
Error 3361: @NoPOG has no arguments in 'A' (test.vdm) at line 9:13
```

The PO generator (the POnoPOGAnnotation "after" methods) clear the list of proof obligations generated for the annotated element (definition, statement or expression).

The annotation has no effect on the interpreter.

7. Writing New Annotations

Adding new annotations is a matter of doing the following:

- Write a new AST<Name>Annotation class that extends ASTAnnotation. Annotations that don't affect the parse do not have to implement any methods; there are "before" and "after" methods that will be called during the parse, if required (see above).
- Write TC, IN and/or PO<Name>Annotation classes that extend TCAnnotation etc. and add the checking and functionality that you require.
- Create the mapping file lines that map the new classes for AST-TC, TC-IN and TC-PO. For example to add two new annotations called @Notice and @Classic, produce an ast-tc.mappings file like this:

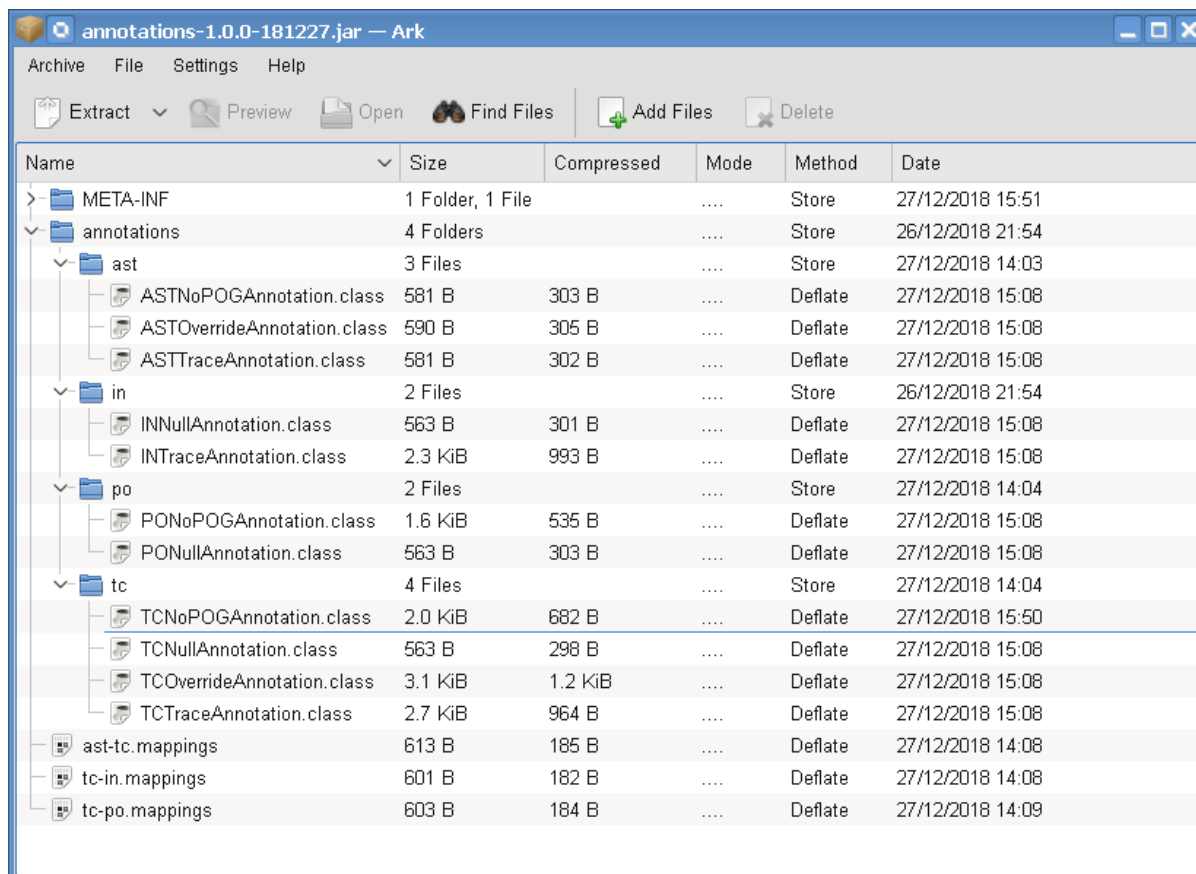
```
package annotations.ast to annotations.tc;
map ASTNoticeAnnotation(name, args) to TCNoticeAnnotation(name, args);
map ASTClassicAnnotation(name, args) to TCClassicAnnotation(name, args);
```

- Put the new classes and the necessary mapping files on the classpath when VDMJ is

executed. This is easily done by putting them in a jar file, with the mapping file(s) at the top level. Use the property `vdmj.annotations` to set the classpath for the annotation classes, unless you use the standard `annotations.ast` package for them.

- Add `@Name` comments to your specification :-)

Note that VDMJ is issued with `@Override`, `@Trace` and `@NoPOG` annotations in a separate "annotations" jar. This contains the classes and mapping file extracts required for the standard annotations. The source (in GitHub) may be a useful resource for producing new annotations. The layout of the jar is as follows:



Name	Size	Compressed	Mode	Method	Date
META-INF	1 Folder, 1 File		...	Store	27/12/2018 15:51
annotations	4 Folders		...	Store	26/12/2018 21:54
ast	3 Files		...	Store	27/12/2018 14:03
ASTNoPOGAnnotation.class	581 B	303 B	...	Deflate	27/12/2018 15:08
ASTOverrideAnnotation.class	590 B	305 B	...	Deflate	27/12/2018 15:08
ASTTraceAnnotation.class	581 B	302 B	...	Deflate	27/12/2018 15:08
in	2 Files		...	Store	26/12/2018 21:54
INNullAnnotation.class	563 B	301 B	...	Deflate	27/12/2018 15:08
INTraceAnnotation.class	2.3 KiB	993 B	...	Deflate	27/12/2018 15:08
po	2 Files		...	Store	27/12/2018 14:04
PONoPOGAnnotation.class	1.6 KiB	535 B	...	Deflate	27/12/2018 15:08
PONNullAnnotation.class	563 B	303 B	...	Deflate	27/12/2018 15:08
tc	4 Files		...	Store	27/12/2018 14:04
TCNoPOGAnnotation.class	2.0 KiB	682 B	...	Deflate	27/12/2018 15:50
TCNullAnnotation.class	563 B	298 B	...	Deflate	27/12/2018 15:08
TCOverrideAnnotation.class	3.1 KiB	1.2 KiB	...	Deflate	27/12/2018 15:08
TCTraceAnnotation.class	2.7 KiB	964 B	...	Deflate	27/12/2018 15:08
ast-tc.mappings	613 B	185 B	...	Deflate	27/12/2018 14:08
tc-in.mappings	601 B	182 B	...	Deflate	27/12/2018 14:08
tc-po.mappings	603 B	184 B	...	Deflate	27/12/2018 14:09