The Whiley Language Specification

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Types

4.1 Overview

Discuss syntactic versus semantic types. Also, need to consider constrained types as well as type patterns.

```
Type ::=
       |  TermType
       |  UnionType
       |  IntersectionType
```

```
TermType ::=
           |  PrimitiveType
           |  TupleType
           |  RecordType
           |  ReferenceType
           |  NominalType
           |  CollectionType
           |  NegationType
           |  FunctionType
           |  MethodType
```

4.2 Primitives

```
PrimitiveType ::=
                |  AnyType
                |  VoidType
                |  NullType
                |  BoolType
                |  ByteType
                |  CharType
                |  IntType
                |  RealType
```

4.2.1 Any Type

```
AnyType ::= any
```

Description. The type **`any`** represents the type whose variables may hold any possible value.

Examples.

Semantics.

Notes. The **`any`** type is top in the type lattice. That is, it is the supertype of all other types.

4.2.2 Void Type

```
VoidType ::= void
```

Description. The **`void`** type represents the type whose variables cannot exist! That is, they cannot hold any possible value. Void is used to represent the return type of a function which does not return anything. However, it is also used to represent the element type of an empty list of set.

Examples.

Semantics.

Notes. The void type is a subtype of everything; that is, it is bottom in the type lattice.

4.2.3 Null Type

```
NullType ::= null
```

Description. The null type is a special type which should be used to show the absence of something. It is distinct from void, since variables can hold the special **`null`**¿ value (where as there is no special ”**`void`**” value).

Examples.

Semantics.

Notes. With all of the problems surrounding **`null`** and `NullPointerException`s in languages like Java and C, it may seem that this type should be avoided. However, it remains a very useful abstraction to have around and, in Whiley, it is treated in a completely safe manner (unlike e.g. Java).

4.2.4 Bool Type

```
BoolType ::= bool
```

Description. Represents the set of boolean values (i.e. `true` and `false`).

Examples.

Semantics.

Notes.

4.2.5 Byte Type

```
ByteType ::= byte
```

Description. Represents a sequence of 8 bits.

Examples.

Semantics.

Notes. Unlike for many languages, there is no representation associated with a byte. For example, to extract an integer value from a byte, it must be explicitly decoded according to some representation (e.g. two's compliment) using an auxillary function (e.g. `Byte.toInt()`).

4.2.6 Char Type

```
CharType ::= char
```

Description. Represents a unicode character.

Examples.

Semantics.

Notes.

4.2.7 Int Type

```
IntType ::= int
```

Description. Represents the set of (unbound) integer values.

Examples.

Semantics.

Notes. Since integer types in Whiley are unbounded, there is no equivalent to Java's `MIN_VALUE` and `MAX_VALUE` for **`int`** types.

4.2.8 Real Type

```
RealType ::= [real]
```

Description. Represents the set of (unbound) rational numbers.

Examples.

Semantics.

Notes.

4.3 Tuple Types

```
TupleType ::= [(] Type ( [,] Type )+ [)]
```

Description. A tuple type describes a compound type made up of two or more subcomponents. It is similar to a record, except that fields are effectively anonymous.

Examples.

Semantics.

Notes.

4.4 Record Types

```
RecordType ::= [{] Type Ident ( [,] Type Ident )* [ [,] [...] ] [}]
```

Description. A record is made up of a number of fields, each of which has a unique name. Each field has a corresponding type. One can think of a record as a special kind of "fixed" map (i.e. where we know exactly which entries we have).

Examples.

Semantics.

Notes. Syntax for functions? Open versus closed records?

4.5 Reference Types

```
ReferenceType ::= & Type
```

Description. Represents a reference to an object in Whiley.

Examples.

Semantics.

Notes.

4.6 Nominal Types

```
NominalType ::= Ident
```

Description. The existential type represents the an unknown type, defined at a given position.

Examples.

Semantics.

Notes.

4.7 Collection Types

4.7.1 Set Type

```
SetType ::= { Type }
```

Description. A set type describes set values whose elements are subtypes of the element type. For example, `{1,2,3}` is an instance of set type `{int}`; however, `{1.345}` is not.

Examples.

Semantics.

Notes.

4.7.2 Map Type

```
MapType ::= { Type => Type }
```

Description. A map represents a one-many mapping from variables of one type to variables of another type. For example, the map type `{int=>real}` represents a map from integers to real values. A valid instance of this type might be `{1=>1.2,2=>3.0}`.

Examples.

Semantics.

Notes.

4.7.3 List Type

```
ListType ::= [ Type ]
```

Description. A list type describes list values whose elements are subtypes of the element type. For example, `[1,2,3]` is an instance of list type `[int]`; however, `[1.345]` is not.

Examples.

Semantics.

Notes.

4.8 Function Types

```
FunctionType ::= function ( [ Type ( , Type )* ] ) => Type
```

Description.

Examples.

Semantics.

Notes.

4.9 Method Types

```
MethodType ::= method ( [ Type ( , Type )* ] ) => Type
```

Description.

Examples.

Semantics.

Notes.

4.10 Union Types

$$\texttt{UnionType} ::= \texttt{IntersectionType} \left(\boxed{\texttt{|}}\ \texttt{IntersectionType} \right)^{+}$$

Description. A union type represents a type whose variables may hold values from any of its "bounds". For example, the union type `null|int` indicates a variable can either hold an integer value, or `null`.

Examples.

Semantics.

Notes. There must be at least two bounds for a union type to make sense.

4.11 Intersection Types

$$\texttt{IntersectionType} ::= \texttt{TermType} \left(\boxed{\texttt{\&}}\ \texttt{TermType} \right)^{+}$$

Description.

Examples.

Semantics.

Notes.

4.12 Negation Types

$$\text{NegationType} ::= \boxed{!}\ \texttt{Type}$$

Description. A negation type represents a type which accepts values *not* in a given type.

Examples.

Semantics.

Notes.

4.13 Abstract Types

4.13.1 Recursive Types

4.13.2 Effective Tuples

4.13.3 Effective Records

4.13.4 Effective Collections

4.14 Subtyping Algorithms

Discussion of soundness and completeness.

$$
\begin{array}{rcll}
\text{Expr} & ::= & Cond\ [\ (\ \boxed{\texttt{\&\&}} \mid \boxed{\texttt{||}}\ )\ Expr\ ] & \textit{// Expressions} \\
\text{Cond} & ::= & Append\ [\ Cop\ Expr\ ] & \textit{// Condition Expressions} \\
\text{Append} & ::= & Range\ [\ \boxed{\texttt{++}}\ Expr\ ] & \textit{// Append Expressions} \\
\text{Range} & ::= & AddSub\ [\ \boxed{\texttt{..}}\ Expr\ ] & \textit{// Range Expressions} \\
\text{AddSub} & ::= & MulDiv\ [\ (\ \boxed{\texttt{+}} \mid \boxed{\texttt{-}}\ )\ Expr\ ] & \textit{// Additive Expressions} \\
\text{MulDiv} & ::= & Index\ [\ (\ \boxed{\texttt{*}} \mid \boxed{\texttt{/}} \mid \boxed{\texttt{\%}}\ )\ Expr\ ] & \textit{// Multiplicative Expressions} \\
\text{Index} & ::= & ??? & \textit{// Index Expressions}
\end{array}
$$

Figure 5.1: Syntax for Binary Expressions

Chapter 5

Expressions

5.1 Binary Expressions

$$
\begin{array}{lcll}
\text{Term} & ::= & \textit{// Terms} & \\
& | & Constant & \textit{// Constant expressions} \\
& | & Identifier & \textit{// Identifier expressions} \\
& | & Expr_1 \; (\boxed{\texttt{,}} \; Expr_i \;)^{+} & \textit{// Tuple expressions} \\
& | & \boxed{\texttt{(}} \; Expr \; \boxed{\texttt{)}} & \textit{// Bracketed expressions} \\
& | & \boxed{\texttt{|}} \; Expr \; \boxed{\texttt{|}} & \textit{// Size expressions} \\
& | & Identifier \; \boxed{\texttt{(}} \; [\; Expr_1 \; (\boxed{\texttt{,}} \; Expr_i \;)^{+} \;] \; \boxed{\texttt{)}} & \textit{// Invocation expressions} \\
& | & (\boxed{\texttt{-}} \mid \boxed{\texttt{!}} \mid \boxed{\texttt{\textasciitilde}} \mid \boxed{\texttt{\&}} \mid \boxed{\star}) \; Expr & \textit{// Unary expressions} \\
& | & \boxed{\texttt{new}} \; Expr & \textit{// Allocation expressions} \\
& | & \boxed{\{} \; [\; Expr_1 \; (\boxed{\texttt{,}} \; Expr_i \;)^{*} \;] \; \boxed{\}} & \textit{// Set expressions} \\
& | & \boxed{\{} \; [\; Expr_1 \; \boxed{\texttt{=>}} \; Expr'_1 \; (\boxed{\texttt{,}} \; Expr_i \; \boxed{\texttt{=>}} \; Expr'_i \;)^{*} \;] \; \boxed{\}} & \textit{// Map expressions} \\
& | & \boxed{\texttt{[}} \; [\; Expr_1 \; (\boxed{\texttt{,}} \; Expr_i \;)^{*} \;] \; \boxed{\texttt{]}} & \textit{// List expressions} \\
& | & \boxed{\{} \; [\; n_1 \boxed{\texttt{:}} \; Expr_1 \; (\boxed{\texttt{,}} \; n_i \; \boxed{\texttt{:}} \; Expr_i \;)^{*} \;] \; \boxed{\}} & \textit{// Record expressions}
\end{array}
$$

Figure 5.2: Syntax for Term Expressions

$$
\begin{array}{lcll}
\text{Constant} & ::= & \textit{// Constants} & \\
& | & (\boxed{\texttt{0}} \mid \boxed{\texttt{1}})^{+} \; \boxed{\texttt{b}} & \textit{// Boolean constants} \\
& | & (\boxed{\texttt{0-9}})^{+} & \textit{// Integer constants} \\
& | & (\boxed{\texttt{0-9}})^{+} \; \boxed{\texttt{.}} \; (\boxed{\texttt{0-9}})^{+} & \textit{// Decimal constants} \\
& | & \boxed{\texttt{null}} & \textit{// Null constant}
\end{array}
$$

Figure 5.3: Syntax for Constant Expressions

$$
\text{Identifier} \quad ::= \quad (\boxed{\texttt{\_}} \mid \boxed{\texttt{a-z}} \mid \boxed{\texttt{A-Z}}) \; (\boxed{\texttt{\_}} \mid \boxed{\texttt{a-z}} \mid \boxed{\texttt{A-Z}} \mid \boxed{\texttt{0-9}})^{*} \quad \textit{// Identifiers}
$$

Figure 5.4: Syntax for Identifiers

Chapter 6

Statements

6.1 Assert Statement

```
AssertStmt  ::=  assert Expr
```

Description. Represents an *assert statement* of the form "**assert** e", where e is a boolean expression.

Examples. The following illustrates:

```
function abs(int x) => int:
    if x < 0:
        x = -x
    assert x >= 0
    return x
```

Notes. Assertions are either *statically checked* by the verifier, or turned into *runtime checks*.

6.2 Assignment Statement

```
AssignStmt  ::=  LVal = Expr
```

Description. Represents an *assignment statement* of the form `lhs = rhs`. Here, the `rhs` is any expression, whilst the `lhs` must be an `LVal` — that is, an expression permitted on the left-side of an assignment.

Examples. The following illustrates different possible assignment statements:

```
x = y          // variable assignment
x.f = y        // field assignment
x[i] = y       // list assignment
x[i].f = y     // compound assignment
```

The last assignment here illustrates that the left-hand side of an assignment can be arbitrarily complex, involving nested assignments into lists and records.

Semantics.

Notes.

6.3 Assume Statement

```
AssumeStmt  ::=  assume Expr
```

Description. Represents an *assume statement* of the form "`assume e`", where `e` is a boolean expression.

Examples. The following illustrates a simple function which uses an `assume` statement to meet its postcondition:

```
function abs(int x) => int:
    assume x >= 0
    return x
```

Notes. Assumptions are *assumed* by the verifier and, since this may be unsound, are always turned into *runtime checks*.

6.4 Return Statement

```
ReturnStmt  ::=  return [Expr]
```

Description. Represents a *return statement* with an optional expression is referred to as the *return value*.

Examples. The following illustrates a simple function which returns the increment of its parameter `x`:

```
function f(int x) => int:
    return x + 1
```

Here, we see a simple **`return`** statement which returns an **`int`** value.

Notes. The returned expression (if there is one) must begin on the same line as the return statement itself.

6.5 Throw Statement

```
ThrowStmt ::= throw Expr
```

Description.

Examples.

Notes.

6.6 Variable Declarations

```
VarDecl ::= Type Ident [ = Expr ]
```

Description. Represents a *variable declaration* which has an optional expression assignment referred to as an *initialiser*. If an initialiser is given, then this will be evaluated and assigned to the variable when the declaration is executed.

Examples. Some example variable declarations are:

```
int x
int y = 1
int z = x + y
```

Notes.

6.7 If/Else Statements

6.8 While Statements

6.9 Do/While Statements

6.10 For Statements

6.11 Switch Statements

6.12 Try/Catch Statements