Uniform type system for the modern general-purpose programing language

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Abstract

The paper presents an overview of the type system which supports the convergence of procedural, object-oriented, functional, and concurrent programming paradigms relying on static type checking with smart type inference support and the ability to ensure dynamic type safety as well.

Keywords

Object, type, unit, class, module, interface, conformance, compatibility, type conversions, setters, reference and value objects, immutability.

CCS → Software and its engineering → Software notations and tools → General programming languages → Language types → Multi-paradigm programming languages

1. INTRODUCTION

The type system sets the basis for the reliable programming language and allows programmers to effectively express software design solutions using the power of the particular programming language raising the productivity of the software development process.

The modern tendency of convergence of different programming paradigms (merging procedural programming, structured programming, object-oriented programming, functional programming, and concurrent programming) forces the type system to support this.

So, in this paper, a highly condensed overview of the type system is presented and a programming language called SLang will be used for illustration of concepts. Necessary syntax constructions will be presented using simple notation based on the following convention. Where [term] means optional, {term} may be repeated zero or more times, term1 | term2 is the selection of term1 or term2, **bold font** is used to highlight keyword or special symbols.

Next is to define the notion of type as an important characteristic of every object during execution time (runtime). The type fixes the number of operations and their properties (signatures) as well as the size of memory required to store the object (number and types of object attributes). So, a type is an abstraction used to describe the structure and behavior of objects.

Authors rely on concepts that are well-known by a broad audience of programmers and terms like class or variable will be used without formal definitions. Some definitions will be given right now to simplify the understanding of examples. The unit is a named set of members. Where a member can be a routine or an attribute. Routines stand for actions while attributes stand for data. If a routine returns some value as a result of its execution we call it a function otherwise a procedure. If an attribute can change its value during the program execution we call it a variable attribute (or simply variable) otherwise we call it a constant attribute (or simply constant or immutable attribute). Unit is very similar to class and the difference is that the unit incorporates characteristics of classes and modules (Term module is used like it was introduced in Ada (package), Modula-2 (module) – a generally available collection of data and routines with initialization) in one concept and the foundation for types. So, the most important type is the unit-based type and that is why let's review units first.

2. UNITS

Any unit is a named collection of attributes or members. Such definition sets away routines but if to consider routines as constant attributes of routine type initialized with the routine signature and body then this definition becomes consistent. Besides unit has other characteristics related to inheritance and usage and they will be explored below. Every unit defines a type and the name of the unit will be used as a type name. Such type is a unit-based type. The formal definition of the unit is

UnitDeclaration:

[**final**] [**ref**|**val**|**concurrent**|**abstract**|**extend**]

unit Identifier [AliasName] [FormalGenerics]

    [InheritDirective] [UseDirective]

{

    MemberSelection |

    InheritedMemberOverriding |

    InitProcedureInheritance |

    ConstObjectsDeclaration |

    MemberDeclaration

}

[InvariantBlock]

end

Unit is a central component and has a lot of elements. For the purpose of the article (type system), only ConstObjectsDeclaration and MemberDeclaration will be reviewed as well as unit header specifiers.

These specifiers fix some characteristics of the unit and objects which can be built based on this unit-based type.

- As a unit may inherit members from other units **final** specifier prevents further inheritance from this unit. Implying there will be no descendants for this unit.
- **ref** | **val** – they specify the default form of objects which will be created using this unit as a type. The example below explains the difference.

```
val unit Integer /* by default we
like all objects of type Integer
to be values not references to
the integer number */
      … skipped
end // Integer
```

```
i: Integer is 5 /* 'i' is a value
object */
ir: ref Integer is 5 /* 'ir' is a
reference object*/
```

If no object kind specifier is provided then the default kind of object is a reference one. And using **ref** | **val** while declaring an attribute, it is possible in a flexible manner to control the kind of object being declared and created. This can be applied to any unit not only to Integer as in the example above. This is important to note that the unit-base type itself is not related to the form of objects of this type.

- The next is **concurrent**, it allows us to specify that objects of this unit will be processed (executed) by a processing element that is different from the one which is used for all objects which are not marked as concurrent. The processing element is a general term for a physical processor, thread, process, remote server, or whatever computing machine. We do not specify exactly how execution be done we just specify that execution will be done concurrently. The mapping between the concurrent unit and actual physical executors is to be done outside of the programming language and it is not described here.

```
concurrent unit Philosopher
      /* There are 5 of them
      eating spaghetti …*/
end
```

- If we like to ensure that there will be no objects created for the unit, it is to be marked as **abstract**. Of course, if there are some abstract routines within the body of the unit it is not possible to create an object of this unit type. So, it is not mandatory to mark such units as abstract as the compiler knows this, but if one likes to prevent objects creation for some units with having all routines as non-abstract then marking the unit abstract will allow to make it. Example

```
abstract unit AnArray [G]
```

- And the last specifier is **extend**, it allows to extend already compiled unit with new members. Source #1 has

```
unit A
      foo do … end
end
```

Source #2 has

```
extend unit A
```

```
goo do … end
end
```

Source #3 has

```
a is new A
a.foo
a.goo
```

So, the second call to routine goo is valid if and only if the A unit extension was provided. Or in other words sources #1, #2, and #3 will be compiled separately, but a compilation of Source #2 relies on the interface from Source #1, and a compilation of #Source 3 relies on interfaces of #1 and #2 sources.

It is essential to note that `final` will not work together with `abstract` as it is out of sense to create a unit when it is not possible to create objects of this unit and unit descendants are prohibited as well.

- Aliasing. And now let's explore what can be put after the unit name. Some programmers do not like Integer they prefer int or INTEGER, so for such purpose one may specify another alias name (AliasName) which can be used as the unit name

```
val unit Integer alias Int
```

As we follow the style guideline that unit names should start with the capital letter.

Aliasing does not create a new type. It just gives an additional name – alias to the unit name which was already defined. It allows us to create unique names, allows us to use short names instead of long ones for those who are lazy to type. So, alias directive can be put at the global level of the source like in this example

```
alias StandardInputOutput as IO
IO.print ("Hello world!\n")
```

But the name `StandardInputOutput` still stays as a valid name of the unit. So, unit-based types name by `StandardInputOutput` and `IO` refer to the same type.

- Next (FormalGenerics) is the optional parametrization of the unit with some unit-based type, or value, or routine. For such kind of parametrization, the term genericity is used. The notation uses square brackets not <> as in some programming languages. Array access uses () as it is semantically identical to the function call.

```
abstract unit AnArray [G]
```

where G is the name of the type which is to be provided to get particular instantiation of the unit-based type.

```
abstract unit OneDimentionalArray [G extend Any init ()]
```

G can be constrained meaning that any type which will be used for instantiation is to be conformant to the type specified as a constraint. In the case of the example above it should be a descendant of Any. And if it is necessary to create objects of the formal generic type we need to know which initialization procedure (constructor) to be used – in this example requirement for the instantiating type is to have an initialization procedure without arguments.

```
unit Array [G extend Any init (), N: Integer] extend OneDimentionalArray [G]
```

Here we have two generic parameters and the second one is the constant of the type which is specified.

- Next is InheritDirective which specifies from which units this unit will inherit members. Keyword extend is used as it is used in popular programming languages. Inheritance is a separate big topic and a dedicated paper will be devoted to it. Here it is essential just to mention that inheritance is multiple and does not use the subobject concept. Every unit member is inherited on its own. The keyword `extend` (which is well-known by many programmers) is used to highlight the set of parent (base) units. The example above in the section on generics shows that unit Array inherits all members from the unit OneDimentionalArray.

- Now it is the time to deal with the UseDirective. As usage is based on the concept of a module as a container of functionality, a couple of words on the difference between classes and modules. And the key difference between them is that based on the class one may create an unlimited number of objects while for the module there will be just one object created and properly initialized. And modules are created and initialized without explicit programming language construction while object creation is a special statement or expression. So, it implies that a unit may be used as a module if and only if it has no initialization procedure or at least one initialization procedure with no arguments. The example below highlights that

```
alias StandardInputOutput as IO
IO.print ("Hello world!\n")
/* IO is the name of the module which is created ad initialized at some moment of the program execution (2 options are possible - to create all module objects at the program start or the first access to the module members) */
io is new IO.init (IO.TextMode)
/* io is an object which is initialized with the creation of a new object of type IO */
io1 is new IO.init (IO.GraphicalMode)
/* Unlimited number of objects can be created and initialized */
```

```
io.print ("Hello world!\n")
```

In this example, IO is a global module which is available across all components of the program, but if we like to have a module dedicated to the unit hierarchy (current unit and all its descendants (derived units)) then we can specify it using UseDirective like this

```
unit A use B
	/* So, inside of A all calls of
the form B.foo () are calls to the
functionality fo the module B */
end
```

If access to the global unit B is required then it is possible to give a local name for the B which is used as a module for A unit hierarchy like this

```
unit A use B as BB
	/* So, inside of A all calls of
the form B.foo () are calls to the
functionality of the global module B,
and calls like BB.foo() are calls to
the local module*/
end
```

And next is the MemberDeclaration section of the unit declaration

2.1 UNIT MEMBERS

There are 3 kinds of unit members – unit routines (procedures or function), unit attributes (data fields), and unit initialization procedures. By default, all unit members are visible for unit descendants and clients and this visibility implies an ability to call routines and read the attributes while clients are not able to change the value of attributes and override routines. Of course, there should be a mechanism to change the visibility of the particular unit member or a group of members. One may limit visibility in the following ways

```
unit A
	rtn1 do end
	/*Procedure 'rtn1' is visible for
all descendants and clients*/
	{} rtn2: T do end
	/*Function 'rtn2' is visible for
all descendants only*/
	{this} rtn3 do end
	/*Routine 'rtn3' is visible only
for the current unit A */
	{B, C} rtn4 do end
	/*Routine 'rtn4' is visible for
all descendants and clients B and C
only */
	{}: /* Group of members with the
same visibility */
		attr1: T1
		var attr2: T2
	end
end
```

One may notice that the second attribute is marked with **var** specifier while the first one has nothing. By default, all attributes are in fact constants with initialization. So adding var, it will be possible to change the value of this attribute and its content at any time during program execution. The concept of constantness (immutability) will be explored later but now let's review initialization procedures.

2.2 UNIT INITIALIZATION PROCEDURES

And when an object is being created there should be a way to put it into a consistent stage which fully matches its invariant. That is why we need an initialization procedure (constructor or creation procedure in other programming languages) as the only task it has is to initialize all attributes of the unit. The straightforward choice for the name was "init" and as the name of the initialization procedure is known it can be skipped when a new object is being created, as well the empty parenthesis if init has not arguments. So, here is a reduced example of the initialization procedure of unit Boolean

```
val unit Boolean
	init do
		data := 0xb
	end
	{} var data:
		Bit
	[Platform.BooleanBitsCount]
end // Boolean
```

Variable attribute 'data' that is not visible to the clients of Boolean is initialized with zero, interpreted as false. So, here is implicit magic (no defaults) – all units including basic ones explicitly define initial values for all their attributes.

```
	b is new Boolean
```

This means that object b will be created with the value false. This is a short cut for the declaration like this

```
	b: Boolean is new Boolean.init()
```

Of course, a unit may have several init procedures and the programmer is to select the one which is required for the particular case.

```
unit A
	init (a1: T1; a2: T2) do end
	{} init (a: A) do end
	foo do
		a is new A(this)
		/* 'a' is a local attribute
		of routine foo, created
		with help of new and
		initialized with the second
		init procedure which is
		available only for this
		unit and its descendants */
```

```
    end
    end
    a1 is new A.init (new T1, new T2)
    a2 is new A (new T1, new T2)
    /* As init name is known it can
be skipped. Here (outside of unit A)
only one initialization procedure for
objects of unit A is visible and must
be used for the creation of objects*/
```

As the initialization procedure turns freshly created objects into the consistent stage it is the right time to observe invariants that describe an object consistent state.

2.3 UNIT INVARIANTS

Unit invariant is a set of predicates that state when objects of this unit type and its descendants be consistent. It is a requirement to objects consistency – that is why the keyword '**require**' is being used to highlight that. See example:

```
abstract unit Numeric
    one: as this abstract
    zero: as this abstract
    /* Declarations of * and + are
skipped */
require
    this = this * one
    zero = this * zero
    this = this + zero
end // Numeric
```

So, every numeric object of a type which is a descendant of Numeric should implement concepts of one (1) and zero (0) and should be consistent with the invariant stated in Numeric. So, if some operation is applied to an object of some type then after completing the operation the unit invariant is to be checked to ensure that object is still in the consistent state and ready again to perform new operations.

2.4 UNIT SETTERS AND GETTERS

As all visible unit attributes are directly accessible for clients and descendants – their names are effective getters. No need for extra efforts. For setters, it is rather convenient to use syntax like a.b := expression instead of a.b.set_b(expression), but semantically they have the same meaning – we need to call some procedure which will set the value of some unit attribute to a proper state. So, the straightforward approach is to use := as the name of the setter and associate it with the attribute declaration.

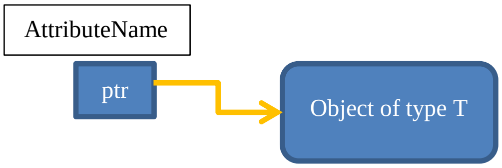
```
unit A
    var attr1: T1 := alias setAttr1
(other: T2) /* variable attr1 has a
setter with an argument of type T2 and
this setter has an additional name
setAttr1 */
    do
        //some algorithm which sets
attr based on other
    end
    attr2: T1 := (other: T1) do end
/* Compile time error, as attr2 is
immutable, it is nor marked as var! */
end
a is new A
a.attr1 := new T2
a.setAttr1 (new T2)
/* Both last 2 statements do the same –
they set attribute of a to the same
value */
```

2.5 IMMUTABILITY

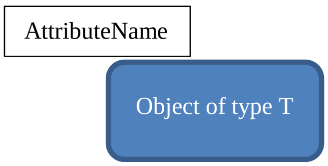
As `a: Type` is a declaration of the constant attribute, a similar scheme is applied for routine arguments. It implies that it is not possible to assign new values to formal arguments. Other implications of the constantness status of an attribute that it is not possible to change the state of an object. It implies that any call to routines which change such state are statically detected by the compiler and a proper error message is generated. So, if an attribute is marked as **var** attribute – assignment to this attribute and any correct routine call will be a valid action. If no mark in place or attribute is marked as **rigid**, then the attribute can only be initialized once, and then it will keep its value. In the case of **rigid**, the whole object tree accessible from this object is immutable. So, rigid implies deep constantness of an attribute while no mark means shallow constantness.

As data attributes can be of two kinds – reference and value, the semantic of the assignment statement is a bit different. There are 4 possible cases

```
    ref1 := ref2 /* Copy 'ref2' into
'ref1'. After the assignment, they both
point to the same object. */
    val1 := val2 /* Field by field
copy of the object named 'val2' into
the corresponding fields of the object
named 'val1'*/
    ref := val /* Clone the object
named 'val' and reference to this clone
is put into 'ref' */
    val := ref /* Field by field
copy all fields of the object pointed
by 'ref' into the corresponding fields
in the object named 'val' */
```




```
AttributeName: ref T
```




```
AttributeName: val T
```

So, once again the type itself is agnostic to the kind of objects which will be created. So, `ref` and `val` objects of the same type can be easily assigned to each other (boxing unboxing is done by the compiler automatically). The example below illustrates this.

```
unit A
	var attr: Type := (other: Type) do
		/* As this attribute has an
		assignment procedure (setter), it can be assigned with := form. This setter changes the internal state of any object of type A */
		attr := other
	end
	foo (arg: Type) do
		arg.attr := Type /*Compile
		time error as arg is a constant object!*/
	end
	goo (var arg: Type) do
		arg.attr := Type /*OK!As we
		explicitly stated that arg is variable (mutable) */
	end
end // A
// One more illustration how var works in the context of ref and val objects
i is 6 // Type of 'i' is deduced by compiler based on type of 6 - val Integer
ir: ref Integer is 6 /* 'ir' has got explicit type and 6 will be cloned into ref Integer */
var j is 5
var jr: ref Integer is 5
i++ // Compile time error as it is immutable
j++ // OK!
ir++ // Compile time error as it is immutable
jr++ // OK!
```

So, `ref` and `val` kinds of objects are completely unrelated to the immutability status of objects and both mechanisms give the full control over objects' semantic. Now we have described how to define immutable attributes but how can we properly define constants like numbers, characters, string, and value constants of any type. This leads to the constant objects section.

3. CONSTANT OBJECTS

3.1 BACKBONE - TWO FUNDAMENTAL CONSTANTS.

When we start learning computer science, we start with 2 simple idioms – 0 and 1 (zero and one). Generalizing we may state that we have 2 signs circle and bar and start defining everything in the digital world combining these signs into sequences and giving a different interpretation of such chains. Binary digit (bit) was selected as a term to represent this. So, in fact, we have defined some unit Bit which has 2 constant objects of type Bit: Bit.0b0 and Bit.0b1. Notation can be different – for example Bit.0 and Bit.1 or Bit.0b and Bit.1b but to stay with the most widely used C-style languages we will proceed with the form Bit.0b0 and Bit.0b1. An example with the part of the source code of unit Bit illustrates how these constants are defined.

```
val unit Bit
	const /* two constants of type Bit */
		0b0, 0b1
		/* As unit Bit has no init
		procedure 0b0 and 0b1 are just two different objects and 0b0 and 0b1 are their names and values at the same time*/
	end
	/* function & is fully defined in the souce code*/
	pure & alias and
	(other: as this): as this =>
		if this = 0b0 do 0b0
```

```
            elsif other = 0b0 do 0b0
            else 0b1
end // Bit
```

3.2 BASIC UNITS – BASIC TYPES.

Using the same approach all basic types are being introduced. As one more example, we will use some fragments of units Integer and Integer [BitsNumber: Integer]. It illustrates one more concept of unit names overloading which works well within our type system.

```
val unit Integer extend Integer
      [Platform.IntegerBitsCount]

      /* That is a general Integer
which uses the platform desctiption
constnt the number of bits in integer
for setup */

      … skipped

end

val unit Integer [BitsNumber: Integer]

      /*So, we can instantiate this
type like Integer[4] or Integer [16]
when we need particular types of a
particular size in bits */

      extend Numeric, Enumeration

      /* Integer[BitsNumber] inherits
from Numeric and Enumeration – any
integer is a number and enumeration at
the same time */

      minInteger is - (2 ^ (BitsNumber
      - 1))

      maxInteger is 2 ^ (BitsNumber -
      1) - 1

      const /* That is ordered set
      defined as range of all Integer
      constant values (objects) */

            minInteger .. maxInteger

      end

      … skipped

      init do

            data := new Bit
                  [BitsNumber]

      end

      {} data: Bit [BitsNumber]

require // unit invariant

   BitsNumber > 0 /* Number of bits in
Integer must be greater than zero! *.

end
```

For types like String and Bit [N] regular expressions are beign used to defined all possible constants of these types.

3.3 GENERAL CASE.

- Every unit may define all known constant objects or specify the rule how all constants will be generated. Block **`const end`** is aimed to do that.
- Integer.1 is a valid constant object of type Integer.
- To skip unit name prefix apply **`use const`** – import all constants into the place where one needs them.

As an example of constants import, we may consider unit Any which resides at the top of all units (like class Object in Java)

```
abstract unit Any use const Integer,
Real, Boolean, Character, String, Bit
[2 ** Integer.MaxInteger]

/* Import all constant objects from
basic units allows using these
constants without respective unit name
prefix.*/
```

And here is an example of weekdays which shows that constant objects replace enumeration types.

```
unit WeekDay

      const

            Monday, Tuesday, Wednesday,
            Thursday, Friday, Saturday,
            Sunday

      end

end

use const WeekDay /* Import all
constant into this script code */

foo (Monday) /* Call procedure foo with
the parameter Monday. Type safe call */


foo (day: WeekDay) do

   if day is /* That is an example of
pattern matching */

      Monday .. Friday: StandardIO.put
(“Workday – go to the office!\n”)

     Saturday, Sunday: StandardIO.put
(“WeekEnd – do what you like!\n”)

   end

end
```

And the last artificial example which shows the exact meaning of constant objects.

```
unit A /* Some unit A. It defines 3
constant objects and use all 3
initialization procedures for their
creation */

      const

            a1.init, a2.init (new T),
```

```
        a3.init (new T1, new T2)
    end
    init do end
    init (arg: T) do end
    init (arg1: T1; arg2: T2) do end
end
x is A.a1 // One more constant object
var y is A.a2 /* Compile-time error, as
it is illegal to assign constant to
variable */
```

4. TYPES

There are 8 kinds of types – unit-based type, anchored type, multi-type, detachable type, tuple type, range type, routine type, and unit type. Every type has an explicit description – type declaration. Some types also have names, some just declarations. So, we will review all 8 types in more details below

1. Unit-based type is the most commonly used kind of type. Every new unit declaration defines a new type. Such unit declaration explicitly defines all attributes and all routines of this unit – fixing the set of operations over objects of this type and size of objects of this type in memory. Units are a more general form of classes and modules. Units may inherit like classes and may be used like modules (provide a single object, supplier of functionality). Example

```
unit A // Start of the unit declaration
    var attribute: Type
    // Unit attribute
    routine do … end
    // Unit procedure
end // A
a: A /* 'a' is declared as having type
A */
```

2. Anchored type is the type, which is the same as another entity has. It works as an automatic overriding while inheriting and allows not to repeat the exact type name. Example

```
b: as a /* 'b' defined as having type
the same as 'a' has */
x: as this /* 'x' has the type similar
to the current unit*/
```

3. Multi-type states that objects of this type can be one of the types specified in the type declaration. So, the set of operations which can be applied to such objects is an intersection of operation from all types included in the multi-type declaration. So, it allows producing code, which works with objects of already compiled units with no need for inheritance. Example

```
c: A | B /* 'c' may be assigned with
objects of types A or B */
c := new A
c := new B
c.foo (expression) /* Both types A and
B must have a routine 'foo' with the
proper signature for the 'expression'
to be compatible with both signatures.
Exact definition of types compatibility
will be given later */
```

4. Detachable type in the form of "? UnitBasedType" allows us to declare attributes with no initial value and such attributes can be initialized later with objects of UnitBasedType or its descendants and dynamic type check has to be applied to deal with such objects (call member-routines or read member-attributes). Example

```
d: ?A /* 'd' is just defined as having
no value. So, 'd' cannot be used unless
its type is checked at runtime*/
if d is A do // A is type name here
      d.foo
end
/*Inside of the do block (then part) of
the if statement 'd' has the type of A
till the first assignment to 'd'*/
```

5. Tuple type defines a group of entities of potentially different types specified in the type declaration. The number of entities is part of the type declaration. It is possible to name these tuple fields with identifiers for access by name

```
e: (Integer, Real, String) is
      (5, 6.6, "Hello world!")
/* 'e' is defined as a group of values.
A tuple with 3 types in the specified
order is the type of 'e'*/
(x1, x2) is SolveSquareEquation (a, b,
c)
/* Type of object (x1, x2) is (Real,
Real) */
SolveSquareEquation (a, b, c: Real):
(r1: Real; r2: Real) do … end /*
function body skipped */
/* Function SolveSquareEquation
returns a tuple in which fields have
names*/
```

```
roots is SolveSquareEquation (a, b, c)
// roots is a tuple
x1 is roots.r1 // 1st root
x2 is roots.r2 // 2nd root
```

6. The range type explicitly defines a set of possible values objects of this type may have. There are 2 kinds of this type. Example

```
f: 1..6 /* f can have Integer values
between 1 and 6 */
g: 1|3|5|7 /* g can have odd Integer
values between 1 and 7 */
f := g // Compile-time error!
g := f // Compile-time error!
```

7. The routine type defines objects which are routines and it means that activation (call or application) of the routine associated with the object can be done later. Routines are treated as 1st class citizens. Example

```
foo (h: rtn (Type1, Type2): Type3) do
	/* foo can be called with routine
object which has the type function with
2 arguments of types Type1 and Type2
retrurning objects of type Type3*/
	x is h (new Type1, new Type2)
end
foo (rtn (Type1; Type2): Type3 do
return new Type3 end)
/* That is a valid call to foo with the
inline function */
```

8. The unit type defines objects which define types as 1st class citizens. One can declare an attribute of type unit and provide a full description of this unit at some time and then use the name of this attribute as a type for declaration of other entities.

```
Type0 is new unit
	foo do end
	init do end
	var attr: X
end /* Attribute Type0 has a type equal
to the unit type deduced by the
compiler. And this unit type is
characterized with members: routine
'foo', initialization procedure, and a
mutable attribute 'attr' */


Type1: unit is unit
	foo do … end
end /* Attribute Type1 is defined as
having type unit initialized with help
of inline unit declaration */
```

Or it is possible to specify the unit interface of interest and then dynamically assign conforming types to this variable. The order of unit members is not essential – that is the difference from tuples.

```
Type2: unit f1: T1; f2: T2; r1 (T1,
T2); r2 (T1): T2; init() end is new
unit
	r1 (T1, T2) do end
	r2 (T1): T2 do end
	init() do end
end
/*here the type of Type2 is limited
with some interface specified as unit
type. So any type which conforms to the
interface can be assigned toType2.
Initialization part should not repeat
the attributes specified in the type
description, but new ones may be added
and all routines should get their
bodies in do…end form or foreign or
abstract*/
Type3: ?unit foo (), init () end
/* Type3 attribute is not initialized
but we know its interface */
// Now we can use new types for
ordinary attributes declarations
a0 is new Type0.init()
a0.foo
a1 is new Type1
a1.foo
a2 is new Type2.init()
a2.r1(new T1, new T2)
a3: Type3 is new Type0.init ()
a3.foo
```

What else can be done with attributes of the unit type? By default, assignment works for them and they can be used for declarations. Of course, conformance rules are to be adjusted for such types. But it is possible to build such a unit type during the program execution like this

```
Type4 is new unit
end
Type4.add (rtn foo () do end, var x:
Integer)
Type4.add (y: Real; init do end)
… other code may be here
if Type4 is unit init () end do // Have
to check if proper init procedure in
place
	a4 is new Type4.init ()
	if a4 is unit foo () end do
```

```
        /* As we have no static
info on the interface of Type4 we
have to check for the expected
interface dynamically and then
use it
        */
        a4.foo ()
    end
end
```

```
unit unit /* Then it is necessary to
add such unit ‘unit’ into the kernel
library*/
    add (members: ()) do
        while member in members do
    Runtime.addMemberToUnit (this,
member)
        end
    end
end
```

One more aspect of such types is using them within the generics approach. Instead of parametrization by a constant of an enumerated type, one can provide an expression. See an example below

```
var v1 is new Array[String, 5] /* v1
will be an array of strings with 5
elements properly initialized by Array
init procedure */
var v2 is new Array[String, 6] /* v1
will be an array of strings with 6
elements properly initialized by Array
init procedure */
v1 := v2
v2 := v1
/* Both assignments are valid as v1 and
v2 have the same type Array[String; N:
Integer] */
var v3 is new Array[String,
StandardIO.readInteger()] /* Actual
type of generic instantiation will be
identified during execution */
v1 := v3
v3 := v2
// Both assignments are valid as v1 and
v2 have the same type Array[String; N:
Integer]
```

4.1 TYPES COMPATIBILITY

It is essential to define well when assignments are valid and when overriding while inheriting works. The latter is described by the signature conformance while the assignment is driven by the following rule. The type of the expression on the right side of the assignment should either conform to the type of the writable on the left side or have a proper conversion routine be in place. So, type A is compatible with type B if A conforms to B or objects of type A can be converted into the objects of type B. Pictures below will use the legend that every oval denotes a unit and every arrow means inherits from aligned with the direction of the arrow. Rombus-ended edge means inheritance with no conformance (not able to make polymorphic assignments)

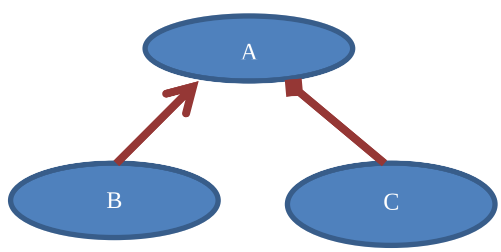
4.1.1 TYPES CONFORMANCE

1. The simplest case of conformance that every type conforms to itself.

```
a: A is new A
```

2. The next case is unit conformance based on the idea to check if there is a path in the inheritance graph between the current unit type and another one. And this path consists only of conformant inheritance edges.

```
unit A end
unit B extend A end /* That is a
conformant inheritance */
unit C extend ~A end /* That is a non-
conformant inheritance */
a: A is new B // OK! As B conforms to A
a: A is new C /* Compile-time error as
     C does not conform to A */
```



3. Next is when the type is generic instantiation then in addition to unit type conformance it is necessary to take into account type by type conformance of all elements of the instantiation. Note - square brackets are used to highlight generics. Access to tuples and arrays is done using parenthesis as these are function calls with parameters.

```
unit A[U, V] end
unit B[X, Y] extend A [X, Y] end
unit T1 end
unit T2 end
unit S1 extend T1 end
unit A[A, B, C] end
```

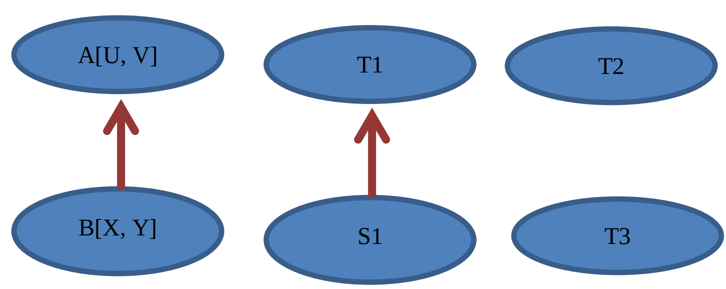
```
a: A[T1, T2] is new A [T1, T2] // OK!
a: A[T1, T2] is new A [S1, T2] // OK!
a: A[T1, T2] is new A [T1, S1] /* Compile time error: S1 does not conform to T2 */
a: A[T1, T2] is new B [T1, T2] // OK!
a: A[T1, T2] is new B [S1, T2] // OK!
a: A[T1, T2] is new B [T1, S1] // Compile time error: S1 does not conform to T2
a: A[T1, T2] is new A [T1, T2, S1] /* Compile time error as A with 3 generic parameters does not conform to A with 2 generic parameters */
```

4. And next is tuple conformance. All tuples are of the same type – tuple type and it means that we need to consider (similar to generic instantiations) by-element conformance of element types.

```
a: (T1, T2) is (new T1, new T2) // OK!
a: (T1, T2) is (new S1, new T2) // OK! S1 conforms to T1
a: (T1, T2) is (new T1, new S1) /* Compile time error: S1 does not conform to T2 */
a: (T1, T2) is (new S1, new T2, new S1) /* OK! as all elements of the longer tuple, which has corresponding elements in the shorter one, conform to them */
```

5. And last but not least is unit type conformance. All unit types are of the same type – 'unit', similar to tuple conformance. So, we need to look at a member after a member to check if they conform to each other. The difference from tuples that tuples have an order of elements in the tuple but unit types not. But every member of the unit type has a name. And search by name identifies the subset of members which will define the conformance. So, if we have two unit types A and B then A conforms to B if for every member of A there is a member with the same name in B and its signature in A conforms to the signature of the corresponding member in B and B has not other members. Common sense logic brings the idea that to an empty unit any unit type will conform. Any 'thinner' unit type will always accommodate in terms of conformance the 'thicker' one.

```
var A is unit end /* Empty unit - means any unit! */
var B is unit
	foo (T1, T2): T3
	goo (T3)
	var attr: T1 := (T1) // it has setter with an argument of type T1
end
var C is unit
	foo (S1, T2): T3
	goo (T3)
end
var D is unit
	foo (S1, T2): T3
	goo (T3)
	var attr: T1 := (S1) // it has setter with an argument of typer S1
	too (T1, T2, T3)
end
A := B // OK, any type will conform to empty type
B := C // Compile time error as C lacks member called attr
B:= D /* All D members cover all B members in terms of conformance and D has extra members - it is thicker than B */
```



4.1.2 TYPES CONVERTABILITY

And now let's consider conversion routines as they also play important roles in assignments. There are two types of conversion routines: from-conversion and to-conversion. The first one is a procedure with one parameter and the second one is a function with no arguments. Let's examine the following example

```
unit A
	:= (other: T) do end
	/* That is a from-conversion procedure, which has some algorithm how to perform a conversion from objects of type T into the objects of current type A */
	:= (): T do end
```

```
    /* That is a to-conversion function which creates a proper object of type T and
        works well for assignments too */
    foo (arg: T) do end // Just some procedure 'foo' with one argument
end
unit T end // Empty unit
var a is new A /* We need to create a valid object of type A first. To ensure A invariant is held */
a := new T /* And then we can assign to an object of type A the object of type T using the from-convertor procedure. The right side of the assignment has an expression of type T and as T has a conversion function to type A, it will be called after the object of type T was created by new */


a: A is new T /* That is incorrect (compile-time error) as object a of type A was not created yet */


A.foo (new T) /* That is Ok as T conforms to T. A capital means that we access unit A as a module - supplier of some functionality */
A.foo (new A) /* That is OK as unit A has to-conversion function to type T, the semantics of any routine call is that arguments passing is an assignment of parameters to arguments so conformance and conversion functions will work and that is why conversion functions are marked with the ':=' sign */
```

And let's consider one more example which combines inheritance with tuples.

```
unit PolarCoordinates extend (radius: Real; angle: Real)
    init (r: as radius; a: as angle) do
        radius := r
        angle := a
    end
end
unit CartesianCoordinates extend (x: Real; y: Real)
    init (h: as x; v: as y) do
        x := h
        y := v
    end
end
var point1 is new PolarCoordiantes.make (5.0, 30.0)
var point2 is new CartesianCoordinates.create (4.6, 7.7)
point1 := point2 /* Compile time error as type CartesianCoordinates does not conform to PolarCoordiantes */
point2 := point1 /* Compile time error as type PolarCoordiantes does not conform to CartesianCoordinates */
var tuple : (Real, Real) is point1 // It works! As point1 is descendant of tuple
tuple := point2 // It works too as popint2 is a descendant of a tuple as well
point1 := (5.5, 6.6) // Compile-time error as point1 is not a tuple
point2 := (4.4, 7.7) // Compile-time error as point2 is not a tuple
```

And if one likes to extend basic types functionality then try something like this

```
val unit MyInt extend Integer
    := (that: Integer) do … end
end
var x is new MyInt
x := 6 /* That is OK only because there is a from-conversion procedure defined */
x: MyInt is 7 /* That is a compile-time error as Integer does not conform to MyInt */
```

And now a brief review of routines' signature conformance which also has similarity with generic instantiation conformance and uses tuple conformance. If we have routine foo with signature S1 and routine goo with signature S2 then S2 conforms to S1 if they have the same number of elements and every type element of signature S1 conforms to the appropriate element of signature S1. Let's consider the following example

```
unit A
    foo (T1; T2; T3): T4
end
unit B extend A
    override foo (U1; U2; U3): U4
end
```

So, in this example the signature of foo from A is ((T1, T2, T3), T4) and foo from B has ((U1, U2, U3), U4) and the task is equal to tuple conformance. Tuple ((U1, U2, U3), U4) conforms to the tuple ((T1, T2, T3): T4) as they have the same number of elements – 2 in this case (for the procedure we may just drop the return type) and for the first element we again have tuples conformance case - whether (U1, U2, U3) conforms to (T1, T2, T3) and check if U4 conforms to T4.

Some notes about the name and structural type equivalence. Below is an example in Ada, which presents name equivalence – type Integer_1 is not compatible with type Integer_2 as they have different names! But structurally they are identical.

```
type Integer_1 is range 1 .. 10;
type Integer_2 is range 1 .. 10;
A : Integer_1 := 8;
B : Integer_2 := A; -- illegal!
```

But we can choose between two different approaches.

The first one is right below

```
a : 1 .. 10 is 8
b : 1 .. 10 is a
```

Here a and b have the same type - range type 1 .. 10 and a can be assigned to b.

In the second case when one likes to introduce new types, type Integer_1 is different from Integer_2 and they are not compatible.

```
unit Integer_1 extend Integer
require
	this in 1 .. 10
end

unit Integer_2 extend Integer
require
	this in 1 .. 10
end
var a is new Integer_1
var b: Integer_2 is a // illegal! Compile-time error!
```

So, support of name equivalence is in place but the term name is treated a bit wider. 1 .. 10 is the type name, A | B – is the type name too, and (T1, T2, T3) is also a type and its name is a tuple (T1, T2, T3), type "**as this**" is compatible to the type of the unit where an attribute of such type was declared.

4.2 DUCK TYPING

The popular thing is duck typing. It also can be interpreted in terms of the conformance test. As an ability to fly means that we can imagine a hypothetical unit Flyable with one abstract procedure fly and check if the object of interest conforms to this unit-based type or not. The trick is that we do not need to enforce to change the inheritance graph for that. We need just to construct such a unit on the fly, keep it anonymous, and just apply the proper check. Let's consider the following example which is used for other programming languages

```
unit Duck // It can fly
	fly do
		StandardIO.print("Duck
			flying")
	end
end
unit Sparrow // It flies too
	fly do
		StandardIO.print("Sparrow
			flying")
	end
end
unit Whale // It does not fly but swims
	swim do
		StandardIO.print("Whale
	swimming")
	end
end

while animal in (Duck, Sparrow, Whale)
do // loop across the tuple/array
	if animal is unit fly () end
	do
	/* Here we check if object
'animal' conforms to the type which is
described as the anonymous unit-based
type which has only one routine – fly
with no arguments. The unit-based type
is specified as
	unit
		fly ()
	end
	All routines are specified
without their do…end|foreign||abstract
body, only routine signature matters
	*/
```

```
          animal.fly /* Now we can
type-safely call fly! */
      end
end
```

Here are a few caveats. What is the static type of animal to be determined by the type inference process? If units Duck, Sparrow, and Whale have the nearest common ancestor, this unit will be the type of animal. If such unit was not explicitly mentioned thru extend directives then Any will be such unit. So, the process terminates in any case. If there are several nearest common ancestors then the process can be run for them recursively. Of course, a programmer can specify the type of animal explicitly like `animal: Any`, but this removes the mystery.

The more general case will look like below

```
if object is unit field: Type1;
procedure (Type1, Type2); function
(Type1): Type2 end do
      /* Here we know for sure that we
can access any features of this
anonymous unit type */
      object.procedure (object.field,
object.function (object.field))
end
```

5. CONCLUSION

This paper presents the uniform type system which supports different models of programming, allows to have static typing with type inference, to have all types and values to be explicitly and fully defined using the same programming language. Types compatibility if fully and explicitly defined including conformance and type conversion which can be and conveniently used.

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