Scala 3 Reference / Experimental / Explicit Nulls

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Explicit Nulls

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Explicit nulls is an opt-in feature that modifies the Scala type system, which makes reference types (anything that extends `AnyRef`) *non-nullable*.

This means the following code will no longer typecheck:

```
val x: String = null // error: found `Null`, but required `String`
```

Instead, to mark a type as nullable we use a union type

```
val x: String | Null = null // ok
```

A nullable type could have null value during runtime; hence, it is not safe to select a member without checking its nullity.

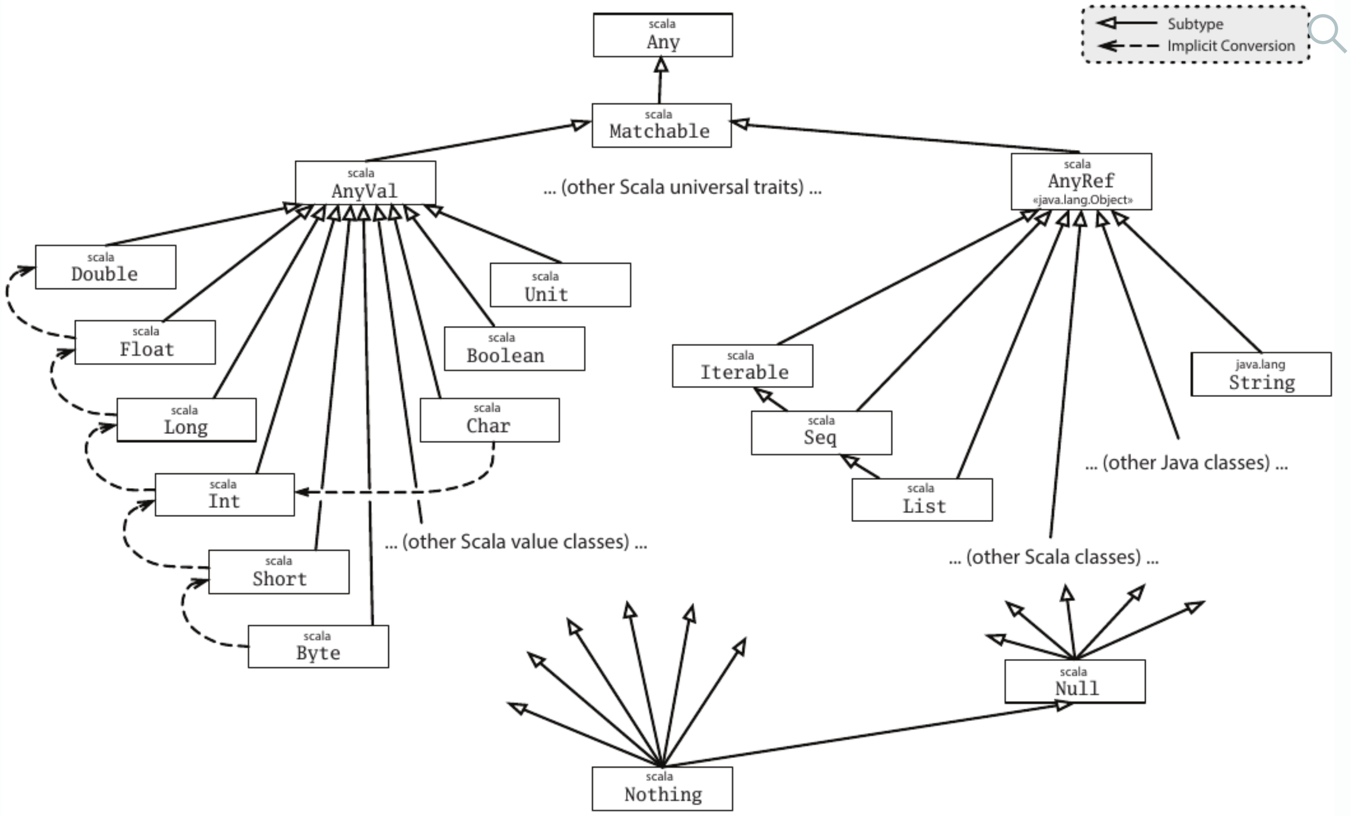
```
x.trim // error: trim is not member of String | Null
```

Explicit nulls are enabled via a `-Yexplicit-nulls` flag.

Read on for details.

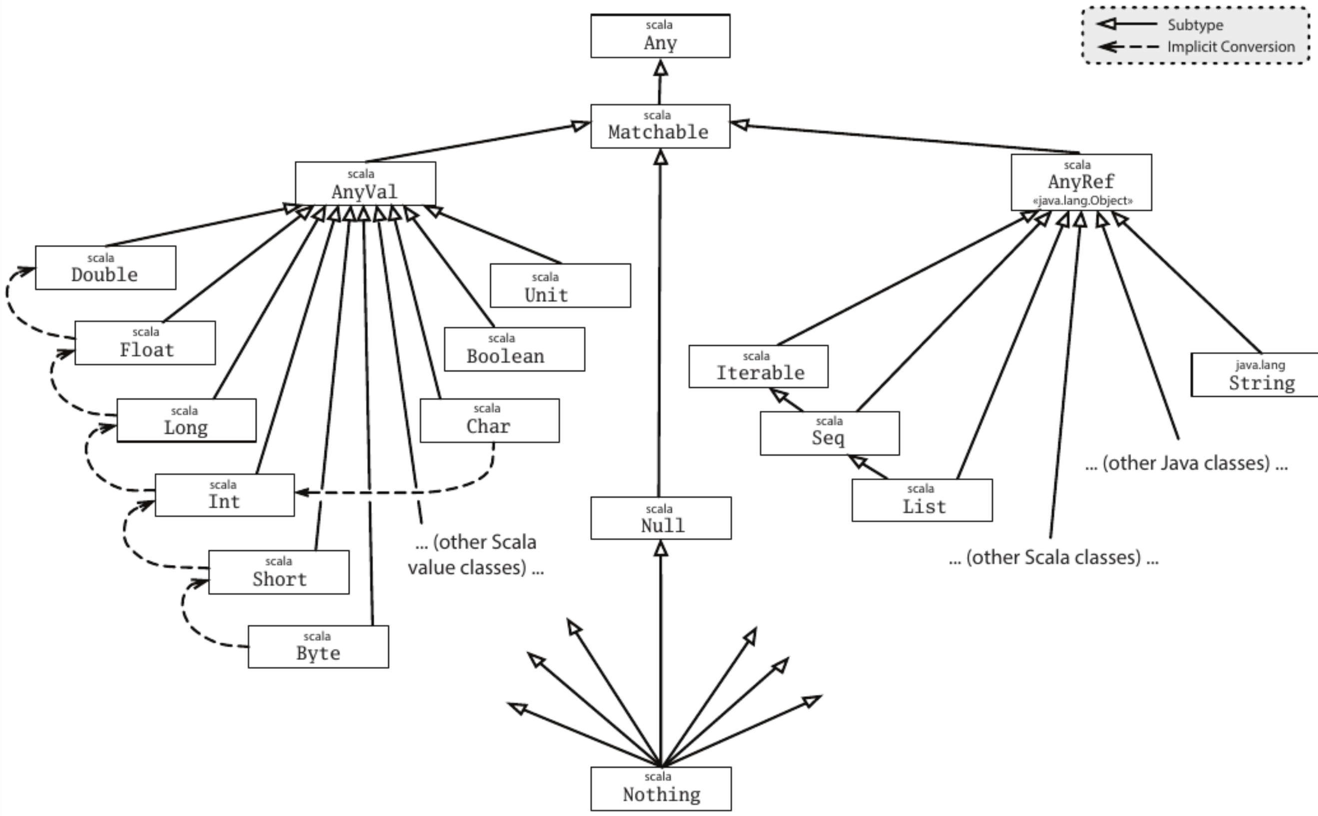
New Type Hierarchy

Originally, `Null` is a subtype of all reference types.



When explicit nulls is enabled, the type hierarchy changes so that `Null` is only a subtype of `Any` and `Matchable`, as opposed to every reference type, which means `null` is no longer a value of `AnyRef` and its subtypes.

This is the new type hierarchy:



After erasure, `Null` remains a subtype of all reference types (as forced by the JVM).

Working with `Null`

To make working with nullable values easier, we propose adding a few utilities to the standard library. So far, we have found the following useful:

- An extension method `.nn` to "cast away" nullability

  ```
  extension [T](x: T | Null)
    inline def nn: T =
      assert(x != null)
      x.asInstanceOf[T]
  ```

  This means that given `x: String | Null`, `x.nn` has type `String`, so we can call all the usual methods on it. Of course, `x.nn` will throw a NPE if `x` is `null`.

  Don't use `.nn` on mutable variables directly, because it may introduce an unknown type into the type of the variable.

- An `unsafeNulls` language feature.

  When imported, `T | Null` can be used as `T`, similar to regular Scala (without explicit nulls).

  See UnsafeNulls section for more details.

Unsoundness

The new type system is unsound with respect to `null`. This means there are still instances where an expression has a non-nullable type like `String`, but its value is actually `null`.

The unsoundness happens because uninitialized fields in a class start out as `null`:

```
class C:
  val f: String = foo(f)
  def foo(f2: String): String = f2

val c = new C()
// c.f == "field is null"
```

The unsoundness above can be caught by the compiler with the option `-Ysafe-init`. More details can be found in safe initialization.

Equality

We don't allow the double-equal (`==` and `!=`) and reference (`eq` and `ne`) comparison between `AnyRef` and `Null` anymore, since a variable with a non-nullable type cannot have `null` as value. `null` can only be compared with `Null`, nullable union (`T | Null`), or `Any` type.

For some reason, if we really want to compare `null` with non-null values, we have to provide a type hint (e.g. `: Any`).

```
val x: String = ???
val y: String | Null = ???

x == null       // error: Values of types String and Null cannot be compared with == or !=
x eq null       // error
"hello" == null // error

y == null       // ok
y == x          // ok

(x: String | Null) == null  // ok
(x: Any) == null            // ok
```

Java Interoperability

The Scala compiler can load Java classes in two ways: from source or from bytecode. In either case, when a Java class is loaded, we "patch" the type of its members to reflect that Java types remain implicitly nullable.

Specifically, we patch

- the type of fields
- the argument type and return type of methods

We illustrate the rules with following examples:

- The first two rules are easy: we nullify reference types but not value types.

```
class C {
  String s;
  int x;
}
```

==>

```
class C:
  val s: String | Null
  val x: Int
```

- We nullify type parameters because in Java a type parameter is always nullable, so the following code compiles.

```
class C<T> { T foo() { return null; } }
```

==>

```
class C[T] { def foo(): T | Null }
```

Notice this is rule is sometimes too conservative, as witnessed by

```
class InScala:
  val c: C[Bool] = ???  // C as above
  val b: Bool = c.foo() // no longer typechecks, since foo now returns
Bool | Null
```

- We can reduce the number of redundant nullable types we need to add. Consider

```
class Box<T> { T get(); }
class BoxFactory<T> { Box<T> makeBox(); }
```

==>

```
class Box[T] { def get(): T | Null }
class BoxFactory[T] { def makeBox(): Box[T] | Null }
```

Suppose we have a `BoxFactory[String]`. Notice that calling `makeBox()` on it returns a `Box[String] | Null`, not a `Box[String | Null] | Null`. This seems at first glance unsound ("What if the box itself has `null` inside?"), but is sound because calling `get()` on a `Box[String]` returns a `String | Null`.

Notice that we need to patch *all* Java-defined classes that transitively appear in the argument or return type of a field or method accessible from the Scala code being compiled. Absent crazy reflection magic, we think that all such Java classes *must* be visible to the Typer in the first place, so they will be patched.

- We will append `Null` to the type arguments if the generic class is defined in Scala.

```
class BoxFactory<T> {
  Box<T> makeBox(); // Box is Scala-defined
  List<Box<List<T>>> makeCrazyBoxes(); // List is Java-defined
}
```

==>

```
class BoxFactory[T]:
  def makeBox(): Box[T | Null] | Null
  def makeCrazyBoxes(): java.util.List[Box[java.util.List[T] | Null]] | Nu
```

In this case, since `Box` is Scala-defined, we will get `Box[T | Null] | Null`. This is needed because our nullability function is only applied (modularly) to the Java classes, but not to the Scala ones, so we need a way to tell `Box` that it contains a nullable value.

The `List` is Java-defined, so we don't append `Null` to its type argument. But we still need to nullify its inside.

- We don't nullify *simple* literal constant (`final`) fields, since they are known to be non-null

```
class Constants {
  final String NAME = "name";
  final int AGE = 0;
  final char CHAR = 'a';

  final String NAME_GENERATED = getNewName();
}
```

==>

```
class Constants:
  val NAME: String("name") = "name"
  val AGE: Int(0) = 0
  val CHAR: Char('a') = 'a'

  val NAME_GENERATED: String | Null = getNewName()
```

- We don't append `Null` to a field nor to a return type of a method which is annotated with a `NotNull` annotation.

```
class C {
  @NotNull String name;
  @NotNull List<String> getNames(String prefix); // List is Java-defined
  @NotNull Box<String> getBoxedName(); // Box is Scala-defined
}
```

==>

```
class C:
  val name: String
  def getNames(prefix: String | Null): java.util.List[String] // we
still need to nullify the paramter types
  def getBoxedName(): Box[String | Null] // we don't append `Null` to
the outmost level, but we still need to nullify inside
```

The annotation must be from the list below to be recognized as `NotNull` by the compiler. Check `Definitions.scala` for an updated list.

```
// A list of annotations that are commonly used to indicate
// that a field/method argument or return type is not null.
// These annotations are used by the nullification logic in
// JavaNullInterop to improve the precision of type nullification.
// We don't require that any of these annotations be present
// in the class path, but we want to create Symbols for the
// ones that are present, so they can be checked during nullification.
@tu lazy val NotNullAnnots: List[ClassSymbol] = ctx.getClassesIfDefined(
  "javax.annotation.Nonnull" ::
  "edu.umd.cs.findbugs.annotations.NonNull" ::
  "androidx.annotation.NonNull" ::
  "android.support.annotation.NonNull" ::
  "android.annotation.NonNull" ::
  "com.android.annotations.NonNull" ::
  "org.eclipse.jdt.annotation.NonNull" ::
  "org.checkerframework.checker.nullness.qual.NonNull" ::
  "org.checkerframework.checker.nullness.compatqual.NonNullDecl" ::
  "org.jetbrains.annotations.NotNull" ::
  "lombok.NonNull" ::
  "io.reactivex.annotations.NonNull" :: Nil map PreNamedString)
```

Override check

When we check overriding between Scala classes and Java classes, the rules are relaxed for `Null` type with this feature, in order to help users to working with Java libraries.

Suppose we have Java method `String f(String x)`, we can override this method in Scala in any of the following forms:

```
def f(x: String | Null): String | Null

def f(x: String): String | Null

def f(x: String | Null): String

def f(x: String): String
```

Note that some of the definitions could cause unsoundness. For example, the return type is not nullable, but a `null` value is actually returned.

Flow Typing

We added a simple form of flow-sensitive type inference. The idea is that if `p` is a stable path or a trackable variable, then we can know that `p` is non-null if it's compared with `null`. This information can then be propagated to the `then` and `else` branches of an if-statement (among other places).

Example:

```
val s: String | Null = ???
if s != null then
  // s: String

// s: String | Null

assert(s != null)
// s: String
```

A similar inference can be made for the `else` case if the test is `p == null`

```
if s == null then
  // s: String | Null
else
  // s: String
```

`==` and `!=` is considered a comparison for the purposes of the flow inference.

Logical Operators

We also support logical operators (`&&`, `||`, and `!`):

```scala
val s: String | Null = ???
val s2: String | Null = ???
if s != null && s2 != null then
  // s: String
  // s2: String

if s == null || s2 == null then
  // s: String | Null
  // s2: String | Null
else
  // s: String
  // s2: String
```

Inside Conditions

We also support type specialization *within* the condition, taking into account that `&&` and `||` are short-circuiting:

```scala
val s: String | Null = ???

if s != null && s.length > 0 then // s: String in `s.length > 0`
  // s: String

if s == null || s.length > 0 then // s: String in `s.length > 0`
  // s: String | Null
else
  // s: String
```

Match Case

The non-null cases can be detected in match statements.

```scala
val s: String | Null = ???

s match
  case _: String => // s: String
  case _ =>
```

Mutable Variable

We are able to detect the nullability of some local mutable variables. A simple example is:

```scala
class C(val x: Int, val next: C | Null)

var xs: C | Null = C(1, C(2, null))
```

```
// xs is trackable, since all assignments are in the same method
while xs != null do
  // xs: C
  val xsx: Int = xs.x
  val xscpy: C = xs
  xs = xscpy // since xscpy is non-null, xs still has type C after this line
  // xs: C
  xs = xs.next // after this assignment, xs can be null again
  // xs: C | Null
```

When dealing with local mutable variables, there are two questions:

1. Whether to track a local mutable variable during flow typing. We track a local mutable variable if the variable is not assigned in a closure. For example, in the following code `x` is assigned to by the closure `y`, so we do not do flow typing on `x`.

```
var x: String | Null = ???
def y =
  x = null

if x != null then
   // y can be called here, which would break the fact
   val a: String = x // error: x is captured and mutated by the closure,
not trackable
```

2. Whether to generate and use flow typing on a specific *use* of a local mutable variable. We only want to do flow typing on a use that belongs to the same method as the definition of the local variable. For example, in the following code, even `x` is not assigned to by a closure, we can only use flow typing in one of the occurrences (because the other occurrence happens within a nested closure).

```
var x: String | Null = ???
def y =
  if x != null then
    // not safe to use the fact (x != null) here
    // since y can be executed at the same time as the outer block
    val _: String = x
if x != null then
  val a: String = x // ok to use the fact here
  x = null
```

See more examples.

Currently, we are unable to track paths with a mutable variable prefix. For example, `x.a` if `x` is mutable.

Unsupported Idioms

We don't support:

- flow facts not related to nullability (`if x == 0 then { // x: 0.type not inferred }`)
- tracking aliasing between non-nullable paths

```
val s: String | Null = ???
val s2: String | Null = ???
if s != null && s == s2 then
  // s: String inferred
  // s2: String not inferred
```

UnsafeNulls

It is difficult to work with many nullable values, we introduce a language feature `unsafeNulls`. Inside this "unsafe" scope, all `T | Null` values can be used as `T`.

Users can import `scala.language.unsafeNulls` to create such scopes, or use `-language:unsafeNulls` to enable this feature globally (for migration purpose only).

Assume `T` is a reference type (a subtype of `AnyRef`), the following unsafe operation rules are applied in this unsafe-nulls scope:

1. the members of `T` can be found on `T | Null`
2. a value with type `T` can be compared with `T | Null` and `Null`
3. suppose `T1` is not a subtype of `T2` using explicit-nulls subtyping (where `Null` is a direct subtype of Any), extension methods and implicit conversions designed for `T2` can be used for `T1` if `T1` is a subtype of `T2` using regular subtyping rules (where `Null` is a subtype of every reference type)
4. suppose `T1` is not a subtype of `T2` using explicit-nulls subtyping, a value with type `T1` can be used as `T2` if `T1` is a subtype of `T2` using regular subtyping rules

Addtionally, `null` can be used as `AnyRef` (`Object`), which means you can select `.eq` or `.toString` on it.

The program in `unsafeNulls` will have a similar semantic as regular Scala, but not equivalent.

For example, the following code cannot be compiled even using unsafe nulls. Because of the Java interoperation, the type of the get method becomes `T | Null`.

```
def head[T](xs: java.util.List[T]): T = xs.get(0) // error
```

Since the compiler doesn't know whether `T` is a reference type, it is unable to cast `T | Null` to `T`. A `.nn` need to be inserted after `xs.get(0)` by user manually to fix the error, which strips the `Null` from its type.

The intention of this `unsafeNulls` is to give users a better migration path for explicit nulls. Projects for Scala 2 or regular Scala 3 can try this by adding `-Yexplicit-nulls -language:unsafeNulls` to the compile options. A small number of manual modifications are expected. To migrate to the full explicit nulls feature in the future, `-language:unsafeNulls` can be dropped and add `import scala.language.unsafeNulls` only when needed.

```
def f(x: String): String = ???
def nullOf[T >: Null]: T = null

import scala.language.unsafeNulls

val s: String | Null = ???
val a: String = s // unsafely convert String | Null to String

val b1 = s.trim // call .trim on String | Null unsafely
val b2 = b1.length

f(s).trim // pass String | Null as an argument of type String unsafely

val c: String = null // Null to String

val d1: Array[String] = ???
val d2: Array[String | Null] = d1 // unsafely convert Array[String] to
Array[String | Null]
val d3: Array[String] = Array(null) // unsafe

class C[T >: Null <: String] // define a type bound with unsafe conflict bound

val n = nullOf[String] // apply a type bound unsafely
```

Without the `unsafeNulls`, all these unsafe operations will not be type-checked.

`unsafeNulls` also works for extension methods and implicit search.

```
import scala.language.unsafeNulls

val x = "hello, world!".split(" ").map(_.length)

given Conversion[String, Array[String]] = _ => ???

val y: String | Null = ???
val z: Array[String | Null] = y
```

Binary Compatibility

Our strategy for binary compatibility with Scala binaries that predate explicit nulls and new libraries compiled without `-Yexplicit-nulls` is to leave the types unchanged and be compatible but unsound.

More details

‹ Numer... MainA... ›