

N4JS Language Specification

Table of Contents

	xvi
I. N4JS Language Specification	1
1. Introduction	8
1.1. Notation	8
1.1.1. Grammar Notation	8
1.1.2. Type Judgments and Rules and Constraints Notation	9
Typing Rules and Judgments	9
Types of an Element	9
1.2. Auxiliary Functions	10
1.2.1. Binding	10
1.2.2. Merging Types	11
Logic Formulars	11
1.2.3. Symbols and Font Convention	11
2. Grammar	12
2.1. Lexical Conventions	12
2.1.1. Identifier Names and Identifiers	12
2.1.2. This Keyword	14
2.1.3. Regular Expression Literals	14
2.1.4. Automatic Semicolon Insertion	14
2.1.5. JSDoc	14
3. Names	16
3.1. Access Control	16
3.2. Accessibility of Types, Top-Level Variables and Function Declarations	16
3.2.1. Accessibility of Members	18
3.2.2. Valid Names	23
3.2.3. Qualified Names	24
3.2.4. Name Duplicates	24
Lexical Environment	24
Duplicates and Shadowing	25
4. Types	27
4.1. Overview	27
4.2. Type Expressions	28
4.2.1. Syntax	29
4.2.2. Properties	30
4.2.3. Semantics	30
4.3. Type Inference	31
4.4. Generic and Parameterized Types	31
4.4.1. Generic Types	32
4.4.2. Type Variables	32
Properties	32
Semantics	32
Type Inference	33
4.4.3. Parameterized Types	34
Syntax	34

Properties	35
Semantics	35
Type Inference	38
4.5. Primitive ECMAScript Types	40
4.5.1. Undefined Type	41
4.5.2. Null Type	41
Semantics	42
4.5.3. Primitive Boolean Type	42
Semantics	42
4.5.4. Primitive String Type	42
Semantics	43
4.5.5. Primitive Number Type	43
Semantics	43
4.5.6. Primitive Type int	43
4.5.7. Primitive Symbol Type	44
4.6. Primitive N4JS Types	44
4.6.1. Any Type	44
Semantics	44
Type Inference	44
Default Type of Variables	44
4.6.2. Void Type	45
Semantics	45
4.6.3. Unknown Type	45
4.6.4. Primitive Pathselector and I18nKey	45
Semantics	46
4.7. Built-in ECMAScript Object Types	46
4.7.1. Semantics	47
4.7.2. Object Type	47
4.7.3. Function Object Type	47
4.7.4. Array Object Type	47
4.7.5. String Object Type	48
4.7.6. Boolean Object Type	48
4.7.7. Number Object Type	48
4.7.8. Global Object Type	48
4.7.9. Symbol	48
4.7.10. Promise	48
4.7.11. Iterator Interface	49
4.7.12. Iterable Interface	49
4.8. Built-In N4JS Types	49
4.8.1. N4Object	50
Semantics	50
4.8.2. N4Class	50
4.8.3. IterableN	50
4.9. Type Modifiers	50
4.9.1. Dynamic	50
4.9.2. Optional	51

4.9.3. Variadic	51
4.10. Union and Intersection Type (Composed Types)	52
4.10.1. Union Type	52
Syntax	52
Semantics	52
Warnings	55
4.10.2. Intersection Type	55
Syntax	55
Semantics	56
Warnings	57
4.10.3. Composed Types in Wildcards	58
4.10.4. Property Access for Composed Types	58
Properties of Union Type	58
Properties of Intersection Type	59
4.11. Constructor and Classifier Type	59
4.11.1. Syntax	60
4.11.2. Semantics	60
4.11.3. Constructors and Prototypes in ECMAScript 2015	63
4.12. This Type	63
4.12.1. Syntax	64
4.12.2. Semantics	65
4.13. Enums	67
4.13.1. Enums (N4JS)	67
Syntax	67
Semantics	68
4.13.2. String-Based Enums	70
II. Classifiers	73
5. N4JS Specific Classifiers	74
5.1. Properties	74
5.2. Common Semantics of Classifiers	75
5.3. Classes	75
5.3.1. Definition of Classes	75
Syntax	76
Properties	76
Type Inference	77
5.3.2. Semantics	77
5.3.3. Final Modifier	79
5.3.4. Abstract Classes	79
5.3.5. Non-Instantiable Classes	80
5.3.6. Superclass	80
5.4. Interfaces	81
5.4.1. Definition of Interfaces	81
Syntax	81
Properties	81
Type Inference	81
Semantics	82

5.5. Generic Classifiers	84
5.6. Definition-Site Variance	86
6. Members	89
6.1. Syntax	89
6.1.1. Properties	89
6.1.2. Semantics	90
6.2. Methods	91
6.2.1. Syntax	91
6.2.2. Properties	92
6.2.3. Semantics	93
6.2.4. Final Methods	95
6.2.5. Abstract Methods	96
6.2.6. Generic Methods	96
6.3. Default Methods in Interfaces	97
6.3.1. Asynchronous Methods	97
6.4. Constructors	97
6.4.1. Structural This Type in Constructor and Spec Parameter	99
Field name conflicts with structural member name	100
Spec-style Constructor	100
Example: Anonymous Interface in Constructor	101
Example: Spec Object and Subclasses	101
Superfluous Properties in Spec-style Constructor]	102
6.4.2. Callable Constructors	103
6.4.3. Covariant Constructors	103
Covariant Constructors	104
Covariant Constructors in Interfaces	105
6.5. Data Fields	105
6.5.1. Syntax	106
6.5.2. Properties	106
Semantics	107
Attributes	107
Type Inference	107
6.5.3. Assignment Modifiers	107
Final Data Fields	108
6.5.4. Field Accessors (Getter/Setter)	108
Syntax	108
Getter and Setter	109
Properties	110
Semantics	110
6.6. Static Members	110
6.6.1. Access From and To Static Members	111
6.6.2. Generic static methods	113
6.6.3. Static Members of Interfaces	113
6.7. Redefinition of Members	114
6.7.1. Overriding of Members	115
6.7.2. Implementation of Members	115

Member Consumption	116
Member Implementation	116
7. Structural Typing	120
7.1. Syntax	120
7.2. Definition Site Structural Typing	121
7.3. Use-Site Structural Typing	122
7.4. Structural Read-only, Write-only and Initializer Field Typing	126
7.5. Public Setter Annotated With <code>ProvidesInitializer</code>	127
7.6. Structural Types With Optional Fields	128
7.7. Structural Types With Access Modifier	129
7.8. Structural Types With Additional Members	129
7.8.1. Syntax	129
Semantics	130
8. Functions	132
8.1. Function Type	132
8.1.1. Properties	132
8.1.2. Type Inference	133
8.1.3. Autoboxing of Function Type	138
8.1.4. Arguments Object	139
arguments.callee	139
arguments as formal parameter name	139
Usage of arguments object	139
8.2. ECMAScript 5 Function Definition	140
8.2.1. Function Declaration	140
Syntax	140
Semantics	141
8.2.2. Function Expression	142
Syntax	142
Semantics and Type Inference	142
8.3. ECMAScript 2015 Function Definition	142
8.3.1. Generator Functions	142
8.3.2. Arrow Function Expression	143
Syntax	143
Semantics and Type Inference	144
8.4. ECMAScript Proposals Function Definition	144
8.4.1. Asynchronous Functions	144
Syntax	144
Semantics	145
8.4.2. Asynchronous Arrow Functions	147
8.5. N4JS Extended Function Definition	147
8.5.1. Generic Functions	147
8.5.2. Promisifiable Functions	148
9. Conversions and Reflection	150
9.1. Auto-Boxing and Coercing	150
9.1.1. Coercing	150
9.1.2. Auto-Boxing of Primitives	151

9.1.3. Auto-Boxing of Function Expressions and Declarations	151
9.2. Auto-Conversion of Objects	152
9.2.1. Auto-Conversion of Class Instances	152
Auto-Conversion of Interface Instances	153
9.2.2. Auto-Conversion of Enum Literals	153
9.3. Type Cast and Type Check	153
9.3.1. Type Cast	153
9.3.2. Type Check	154
9.4. Reflection meta-information	155
9.4.1. Reflection for Classes	155
9.4.2. Reflection for Interfaces	157
9.4.3. Reflection for Enumerations	157
9.5. Conversion of primitive types	157
10. Expressions	159
10.1. ECMAScript 5 Expressions	159
10.1.1. The this Literal	159
Semantics	160
Type Inference	161
Effect of Nominal This Type	163
10.1.2. Identifier	165
Syntax	165
Semantics	165
Type Inference	166
10.1.3. Literals	166
Type Inference	166
Integer Literals	166
10.1.4. Array Literal	167
Syntax	167
Type Inference	168
10.1.5. Object Literal	169
Syntax	169
Properties	170
Semantics	171
Scoping and linking	171
Type Inference	172
10.1.6. Parenthesized Expression and Grouping Operator	172
Syntax	172
Type Inference	172
10.1.7. Property Accessors	173
Syntax	173
Properties	173
Semantics	174
Type Inference	175
10.1.8. New Expression	176
Syntax	176
Semantics	176

Type Inference	177
10.1.9. Function Expression	178
10.1.10. Function Calls	178
Syntax	178
Semantics	179
Type Inference	179
10.1.11. Postfix Expression	180
Syntax	180
Semantics and Type Inference	180
10.1.12. Unary Expression	181
Syntax	181
Semantics	181
Type Inference	182
10.1.13. Multiplicative Expression	182
Syntax	182
Semantics	182
Type Inference	183
10.1.14. Additive Expression	183
Syntax	183
Semantics	183
Type Inference	183
10.1.15. Bitwise Shift Expression	184
Syntax	184
Semantics	184
Type Inference	184
10.1.16. Relational Expression	185
Syntax	185
Semantics	185
Type Inference	187
10.1.17. Equality Expression	187
Syntax	187
Semantics	187
Type Inference	188
10.1.18. Binary Bitwise Expression	188
Syntax	188
Semantics	188
Type Inference	189
10.1.19. Binary Logical Expression	189
Syntax	189
Semantics	189
Type Inference	189
10.1.20. Conditional Expression	190
Syntax	190
Semantics	190
Type Inference	190
10.1.21. Assignment Expression	191

Syntax	191
Semantics	191
Type Inference	192
10.1.22. Comma Expression	192
Syntax	192
Semantics	193
Type Inference	193
10.2. ECMAScript 6 Expressions	193
10.2.1. The super Keyword	193
Semantics	194
10.3. ECMAScript 7 Expressions	196
10.3.1. Await Expression	196
10.4. N4JS Specific Expressions	196
10.4.1. Class Expression	196
Syntax	196
Semantics and Type Inference	196
10.4.2. Cast (As) Expression	196
Syntax	196
10.4.3. Semantics and Type Inference	197
11. Statements	198
11.1. ECMAScript 5 Statements	198
11.1.1. Function or Field Accessor Bodies	198
11.1.2. Variable Statement	198
Syntax	198
Semantics	199
Type Inference	200
11.1.3. If Statement	200
Syntax	200
Semantics	200
11.1.4. Iteration Statements	201
Syntax	201
Semantics	202
11.1.5. Return Statement	202
Syntax	202
Semantics	202
11.1.6. With Statement	203
Syntax	203
Semantics	203
11.1.7. Switch Statement	203
Syntax	203
Semantics	203
11.1.8. Throw, Try, and Catch Statements	203
Syntax	203
Type Inference	204
11.1.9. Debugger Statement	204
Syntax	204

Semantics	204
11.2. ECMAScript 6 Statements	204
11.2.1. Let	204
11.2.2. Const	204
Semantics	205
11.2.3. for ... of statement	205
Syntax	205
Semantics	205
11.2.4. Import Statement	206
Syntax	206
Semantics	207
Dynamic Imports	210
Immutability of Imports	210
11.2.5. Export Statement	211
Syntax	211
Semantics	212
12. Annotations	213
12.1. Introduction	213
12.1.1. Syntax	213
12.1.2. Properties	213
12.1.3. Element-Specific Annotations	214
12.1.4. General Annotations	214
IDEBUG	214
12.1.5. Syntax	214
Semantics	215
Suppress Warnings	216
12.2. Declaration of Annotations	216
13. Extended Features	217
13.1. Array and Object Destructuring	217
13.1.1. Syntax	217
13.1.2. Semantics	217
13.2. Dependency Injection	219
13.2.1. DI Components and Injectors	219
DIComponent Relations	221
13.2.2. Binders and Bindings	222
13.2.3. Injection Points	224
Field Injection	224
Constructor Injection	225
Method Injection	226
Provider	226
13.2.4. N4JS DI Life Cycle and Scopes	227
Injection Cycles	227
Default Scope	230
Singleton Scope	230
Per Injection Chain Singleton	232
13.2.5. Validation of callsites targeting N4Injector methods	233

13.2.6. N4JS DI Annotations	233
N4JS DI @GenerateInjector	234
N4JS DI @WithParentInjector	234
N4JS DI @UseBinder	235
N4JS DI @Binder	235
N4JS DI @Bind	236
N4JS DI @Provides	236
N4JS DI @Inject	237
N4JS DI @Singleton	237
13.3. Test Support	238
13.4. Polyfill Definitions	238
13.4.1. Runtime Polyfill Definitions	239
13.4.2. Static Polyfill Definitions	240
13.4.3. Transpiling static polyfilled classes	241
14. Components	243
14.1. N4JS Platform Architecture	243
14.1.1. Overview	243
14.2. Component Types	245
14.2.1. Apps	245
14.2.2. Processors	245
14.2.3. Libraries	245
14.2.4. Runtime Environment and Runtime Libraries	245
14.2.5. Tests	246
14.3. Component Content	246
14.4. Component Manifest	246
14.4.1. Syntax	246
14.4.2. Properties	250
14.5. Component Dependencies	254
14.5.1. Runtime Environment Resolution	255
14.6. Modules	255
14.7. NumberFour Archives (NFAR)	256
14.7.1. N4 Deployment Descriptor	257
14.8. Properties Files	258
14.8.1. Syntax [[N4 Deployment Descriptor Syntax]]	258
14.8.2. Constraints	258
14.9. API and Implementation Components	258
14.9.1. Execution of API and Implementation Components	259
14.10. API and Implementation With DI	260
15. PlainJS	263
15.1. Type Inference and Validation for Plain JS	263
15.2. External Declarations	263
15.2.1. Declaring externals	265
15.2.2. Instantiating external classes	265
15.2.3. Implementation of External Declarations	266
15.2.4. Example	267
15.3. Global Definitions	268

15.4. Runtime Definitions	268
15.5. Applying Polyfills	269
16. JSDoc	271
16.1. General N4JSDoc Features	271
16.1.1. Provided Inline Tags	271
@code	271
@link	271
16.2. N4JSDoc for User Projects	271
16.2.1. Standard Tags	271
@author	271
@param	271
@return	271
16.2.2. Test Related Tags	271
@testee	271
@testeeFromType	272
@testeeType and @testeeMember	273
@reqid in Tests	275
16.3. N4JSDoc for API and Implementation Projects	275
16.3.1. @apiNote	275
16.3.2. API Project Tags	275
@apiState	275
17. Grammars	276
17.1. Type Expressions Grammar	276
17.2. N4JS Language Grammar	279
18. JSObjects	302
18.1. Object	302
18.1.1. Attributes	302
18.1.2. Methods	302
18.1.3. Static Methods	302
18.2. String	303
18.2.1. Attributes	303
18.2.2. Methods	303
18.2.3. Static Methods	305
18.3. Boolean	305
18.3.1. Static Methods	305
18.4. Number	305
18.4.1. Static Attributes	305
18.4.2. Methods	306
18.4.3. Static Methods	306
18.5. Function	306
18.5.1. Attributes	306
18.5.2. Methods	306
18.6. Error	307
18.6.1. Attributes	307
18.6.2. Static Methods	307
18.7. Array	307

18.7.1. Methods	307
18.7.2. Static Methods	308
18.8. Date	308
18.8.1. Static Methods	308
18.8.2. Methods	309
18.9. Math	311
18.9.1. Static Attributes	311
18.9.2. Static Methods	312
18.10. RegExp	313
18.10.1. Attributes	313
18.10.2. Methods	313
18.11. JSON	313
18.11.1. Attributes	313
18.11.2. Methods	313
18.11.3. Static Methods	314
19. N4JS Objects	315
19.1. Reflection Model	315
19.2. Error Types	322
19.2.1. N4ApiNotImplemented	322
20. Bibliography	324

List of Figures

4.1. cdVarianceChart	38
4.2. Classifier and Constructor Type Subtype Relations	61
8.1. Function Variance Chart	134
13.1. Complex DIComponents Relations	222
14.1. N4JS Component Overview	243
14.2. Content of a Component	244
14.3. Overview of API tests with DI	260
14.4. API tests with static DI	261
14.5. Types view and Instances view	262
19.1. N4JS Reflection Classes	315

List of Tables

3.1. Type Access Control	17
3.2. Member Access Control	20
3.3. Different forms of module and type specifiers.....	24
5.1. Extensibility of Types	79
6.1. Consumption of methods	118
7.1. Available Fields of Structural Types	122
13.1. DI No Bindings	231
13.2. DI Transitive Bindings	231
13.3. DI Re - Binding	231
13.4. DI Child Binding[tab:diChildBinding]	232

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Abstract

This document contains the NumberFour JavaScript Specification.

Revision History

Date	Tasks	Author	Description
2013-03-21	–	v.Pilgrim	initial commit
2016-03-13	–	v.Pilgrim	public release, version 0.3 (alpha)
2016-05-31		mor	support for definition-site variance, cf. [sec:DefinitionSite-Variance]
2016-07-18		mor	rename manifest property <code>artifactId</code> to <code>projectId</code> ; remove <code> projectName</code>
2016-09-09		mor	add <code>@Covariant-Constructor</code> , cf. ??? , plus related adjustments

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Chapter 1. Introduction

This specification defines the N4JS language.

In general, the N4 JavaScript dialect used is identical to the standard ECMAScript as defined in the 6th edition of ECMA-262, also known as ECMAScript 2015, referred to as [ECMA15a].

1.1. Notation

1.1.1. Grammar Notation

For the specification of the syntax and structure of elements, we use a slightly augmented similar to the grammar language of Xtext [Grammar Language¹](#).

Similar to [ECMA11a], we define types with properties only for the purpose of explanation and usage within this specification. We use the Xtext notation style to assign values to meta-properties. Particularly, we use the Xtext notation for collection (`+ =`) and boolean (`? =`) values. These properties are written in italics. Enumerations are defined similar to Xtext. In order to allow the specification of default values, which are often defined by omitting the value, we always define the literal explicitly if it can be defined by the user.

The following lists informally defines the grammar:

Terminal

Terminals (or terminal strings) are enclosed in single quotes, e.g., `terminal`.

Enumerations

Rules which contain only terminals used as values for properties are marked with `enum` for enumeration.

Properties

Values of non-terminals, e.g., other rules, can be assigned to properties. The property name and the assignment are not part of the original syntax and only used for the meta description. E.g., `name=Identifier`.

Collection Properties

If a property is a collection, values are added to that list via `+ =`. E.g., `property+ = Value`.

Boolean Properties

Boolean properties are set to false by default, if the value (usually a terminal) is found, the boolean value is set to true. Often, the name of the property is similar to the terminal. E.g., `final?='final'?`.

Properties of a non-terminal are sometimes listed again below the grammar. In that case, often pseudo properties are introduced which are derived from other properties and which are only used for simplification.

¹ <http://www.eclipse.org/Xtext/documentation.html#grammarLanguage>

1.1.2. Type Judgments and Rules and Constraints Notation

Typing Rules and Judgments

Definition: Rule

We use the common notation for rules such as type inference rules ²], that is

$$\frac{\text{premises}}{\text{conclusion}} \quad \text{rule name}$$

premises is the rule's premises (e.g., the expression to be inferred), *conclusion* the result of the rule. *rulename* is an optional condition which may be omitted.

Both parts of the rule may contain multiple expressions, which are concatenated via and. For example, the following $\frac{P_1 \quad P_2 \quad P_3}{C}$ can be read as '`if P1, P2, and P3 are all true, then C is true as well`'.

The following judgments (with relation symbols) are used:

subtype `<` , **type** :

in which the left hand side is a declaration or expression, and the right hand side a type. We also use `.` as a function returning the (inferred) type of an expression.

expectedTypeIn :

a relation with three arguments: *containerexpression:type* means, that *expression* is expected to be a subtype of *type* inside *container*

The following statement, for example, defines transitivity of subtypes (in a simplified manner):

$$\frac{\Gamma B \vdash lt;:A \quad \Gamma \vdash Clt;:B}{\Gamma \vdash C:lt;:A}$$

is the context containing (bound) type variables etc., can be read as `entails`. Thus, the rule can be read as follows: if the type B is a subtype of type A in context (i.e. with constraints on type variables specified in), and if type C is a subtype of B, then C is also a subtype of A in context .

In rules, we sometimes omit the environment if it is not needed. New information is sometimes added to the environment, in particular, substitutions (that is binding type variables to a type). The set of substitutions is written with (theta). If new substitutions are explicitly added to that set, we write $(V \leftarrow T)$ (V is substituted with type T). Often, these bindings are computed from a parameterized type reference which declares type arguments which are bound to the type variables of the generic declaration. In this case we simply write (p) , in which p is the parameterized type declaration. As these new substitutions must become part of a (newly) created environment, we then usually write (p) . These substitutions are usually omitted.

Types of an Element

A variable or other typed element may be associated with three types:

² A brief introduction can be found at <http://www.cs.cornell.edu/~ross/publications/mixedsite/tutorial.html>. In general, we refer the reader to cite:[Pierce02a]

1. Declared type: the type explicitly specified in the code, e.g., .
2. Inferred type: the type inferred by the type inferencer, e.g., infers the type of s to `string`. I.e. $\Gamma \vdash s : string$ will be true, or $[\$! < :string \$!]$. If an element is annotated with a type, i.e. it has a declared type, the inferred type will always be the declared type.
3. Actual type: the actual type of a variable during runtime. This type information is not available at compile time and ignored in this specification.

These types are not type declarations but type references, in fact, as they may be parameterized. For the sake of simplicity, we often omit the `Ref` suffix to shorten formulas. Consequently, we define the following properties and pseudo properties for typed elements such as variables:

The explicitly declared type, this is usually a real property of the construct. Not all elements allow the specification of a declared type, such as expressions.

or ..: This pseudo property is the inferred type computed by the type inferencer.

A pseudo property for elements with a `declaredType` property. It is similar to the inferred type, i.e. `e.type = e`

1.2. Auxiliary Functions

This section describes some auxiliary functions required for definition of type inference rules later on.

1.2.1. Binding

Binding an identifier (variable reference) to a variable declaration (or variable definition) is not part of this specification as this is standard ECMAScript functionality. However, some valid ECMAScript bindings are permitted due to visibility constraints.

Definition: Binding Relation

We define a pseudo relation `bind:VariableReference × VariableDeclaration` which binds a reference, i.e. an identifier, to a declaration (e.g., variable declaration).

Binding of variable references to declaration is defined by ECMAScript already. Type references only occur in type expressions, how these are handled is explained in [sec:Type_Expressions].

We usually omit this binding mechanism in most rules and use the reference similarly to the declaration or definition it is bound to. If a variable reference `r`, for example, is bound to a variable declaration `D`, i.e. `bind(r, D)`, we simply write `r.type` instead of `bind(r, D).D.type` to refer to the type expression (of the variable).

³

A `DeclaredType` references the type declaration by its simple name that has been imported from a module specifier. We define the method `bind` for declared types as well:

Definition: Binding Relation of Types

³ One can interpret this similar to delegate methods, that is, instead of writing `r.binding().getType()`, a method `r.getType() \{ return binding().getType(); }` is defined.

We define a pseudo relation $bind:DeclaredType \times ClassInterfaceEnum$ which binds a type reference, i.e. a simple name, to the type declaration.

1.2.2. Merging Types

In some cases we have to merge types, e.g., types of a union type or item types of an array. For that purpose, we define a method $merge$ as follows.

[Merge Function][def:Merge Function] We define a pseudo function $merge:Type \times Type \rightarrow Type$

The idea of this function is to remove duplicates. For example; if a union type contains two type expressions te_1 and te_k , and if $\tau(te_1) = \tau(te_2)$, then $merge(\tau(te_1), \tau(te_2))$ contains only one element. The order of the elements is lost, however.

Logic Formulars

In general, we use a pragmatic mixture of pseudo code, predicate logic, and OCL. Within constraints (also within the inference rules), the properties defined in the grammar are used.

In some rules, it is necessary to type the rule variables. Instead of explicitly checking the metatype (via $\mu(X) = :MetaType$), we precede the variable with the type, that is: $:MetaTypeX$.

Instead of **type casting** elements, often properties are simply accessed. If an element does not define that element, it is either assumed to be false or null by default.

If a property p is optional and not set, we write $p = null$ to test its absence. Note that $p = null$ is different from $p = Null$, as the latter refers to the null type. Non-terminals may implicitly be subclasses. In that case, the concrete non-terminal, or type, of a property may be subject for a test in a constraint.

1.2.3. Symbols and Font Convention

Variables and their properties are printed in italic when used in formulas (such as rules). A dot-notation is used for member access, e.g. $v.name$. Also defined functions are printed in italic, e.g., $acc(r, D)$. Properties which define sets are usually ordered and we assume 0-indexed access to elements, the index subscripted, e.g., $v.methods_i$.

We use the following symbols and font conventions:

$\wedge, \vee, , \neg$:: Logical and, or, exclusive or (xor), and not. $, , \ldots$:: Logical implication, if and only if, and if-then-else. $, , \emptyset$:: Boolean true, boolean false, null (i.e., not specified, e.g., $v.sup =$ means that there are no *sup* (super class) specified), empty set. $\in, \notin, \cup, \cap, |$:: Element of, not an element of, union set, intersection set, cardinality of set x . (X) :: Power set of X , i.e. $(X) = \{U:U \subseteq X\}$. $\exists, , \forall$:: Exists, not exists, for all; we write $\exists x, 8230;8203; z:P(x, 8230;8203; z)$ and say **there exists** $x, 8230;8203; z$ **such that predicate P is true**. Note that $x:P(x) \forall x:\neg P(x)$. $\mu(.)$:: (mu) read **metatype of**; metatype of a variable or property, e.g., $\mu(x) = :Class8230;8203;8230;8203; . x$:: Sequence of elements x_1, x_n . E.g., if we want to define a constraint that the owner of a members of a class C is the class, we simply write $Cmembers.owner = C$ instead of $\forall m \in Cmembers:m.owner = C$ or even more complicated with index variables.

Sequences are 1-based, e.g., a sequence s with length $|s| = n$, has elements s_1, s_n .

Chapter 2. Grammar

2.1. Lexical Conventions

IDE-7¹

As a super language on top of ECMAScript, the same lexical conventions are supported as described in [ECMA11a(p.S7)] within strict mode. Some further constraints are defined, however, restricting certain constructs. These constraints are described in the following.

2.1.1. Identifier Names and Identifiers

Cf. [ECMA11a(p.S7.6)], [ECMA11a(p.S11.1.2, p.p.63)] and [ECMA11a(p.S01.2, p.p.51ff)].

As a reminder, identifiers are defined as follows in the ECMAScript specification:

```
IdentifierName: IdentifierStart* IdentifierPart;
IdentifierStart : UnicodeLetter | '_';
               \ UnicodeEscapeSequence
```

N4JS supports a limited form of computed-names for member declarations:

```
N4JSPropertyName:
  '[' (SymbolLiteralComputedName | StringLiteralComputedName) ']' ;
;

SymbolLiteralComputedName: N4JSIdentifier '.' N4JSIdentifier ;
StringLiteralComputedName: STRING ;
```

As can be seen, a computed-name must be either

- a symbol reference, e.g. `Symbol.iterator`,
- a string literal, i.e., a compile time known constant. This notation is useful when interoperating with libraries that define members whose names contain special characters (e.g., a field name starting with commercial-at)

IDE-1220²
IDE-1734³

In N4JS, identifiers are further constrained in order to avoid ambiguities and to make code more readable. Some of these constraints will lead to errors, others only to warnings. They do not apply for identifiers declared in definitions file (n4jsd) in order to enable declaration of external entities.

1. If the following constraints do not hold, errors are created.

¹ <https://jira.numberfour.eu/browse/IDE-7>

² <https://jira.numberfour.eu/browse/IDE-1220>

³ <https://jira.numberfour.eu/browse/IDE-1734>

- a. Leading `$` (dollar sign) character is prohibited for any variable name such as fields, variables, types functions and methods.
- b. Leading `_` (underscore) character is not allowed for identifying any functions or methods.

N4JS identifier recommendations

- 1 If the following constraints do not hold, warnings are created.
- 2 Variable names should, in general, be constructed from the 26 ASCII upper and lower case alphabetic letters (a..z, A..Z), from the 10 decimal digits (0..9) and from the `_` (underline). Although the usage of the international characters are allowed (according to the ECMAScript specification) it is discouraged because these characters may not be read or understood well in every circumstance.⁴

1. Type (and Type Variable) Identifiers

```
TypeIdentifier: [_A-Z] [_a-zA-Z0-9]*  
TypeVariableIdentifier: [_A-Z] [_a-zA-Z0-9]*
```

2. Package Identifiers

```
PackageIdentifier: [_a-z] [._a-zA-Z0-9]*; // i.e. the folder names, must not end with .
```

3. Member Identifiers and Enum Literals

```
InstanceFieldIdentifier: [_a-z] [_a-zA-Z0-9]*  
StaticFieldIdentifier: [_A-Z] [_A-Z0-9]* ([_A-Z0-9]+)*  
EnumLiteral: [_A-Z] [_A-Z0-9]* ([_A-Z0-9]+)*
```

4. Variable and Parameter Names

```
VariableIdentifier: [_a-zA-Z0-9]*  
#ParameterIdentifier: [_a-z] [_a-zA-Z0-9]*
```

5. Methods

```
MethodIdentifier: [_a-z] [_a-zA-Z0-9]*;
```

6. Annotations

```
AnnotationIdentifier: [_A-Z] [_a-zA-Z0-9]*
```

The following rules describe how fully qualified names of elements are created. Note that these fully qualified names cannot be used in N4JS directly. Though they may be shown in error messages etc. to identify elements.

```
TypeIdentifier: [A-Z] [a-zA-Z0-9]*;
```

⁴ <http://javascript.crockford.com/code.html>

```
PackageIdentifier: [a-zA-Z0-9]*;
FQNTType: (PackageIdentifier '.')+ TypeIdentifier;
```

2.1.2. This Keyword

Cf. [[ECMA11a\(p.S11.1.1, p.p.63\)](#)]

2.1.3. Regular Expression Literals

Cf. [[ECMA11a\(p.S7.8.5\)](#)]

IDE-95⁵

2.1.4. Automatic Semicolon Insertion

Cf. [[ECMA11a\(p.S7.9\)](#)]

ASI is supported by the parser, however warnings are issued.

IDE-95⁶

2.1.5. JSDoc

IDE-56⁷
IDE-57⁸

JSDoc are comments similar to JavaDoc in Java for documenting types, functions and members. There is no semantic information expressed in JSDoc, that is, the behavior of a program must not change if all the JSDoc is removed. The JSDoc tags and overall syntax is a mixture of tags defined by the [Google Closure Compiler](#)⁹, Java's [JavaDoc](#)¹⁰ tool and N4-specific tags.

JSDoc comments are multiline comments, starting with `/**`

(instead of simple multiline comments, starting with `/*`).

```
MultiLineComment: '/*' MultiLineCommentChars? '*' // from ECMAScript specification
JSDoc:         '/*' MultiLineCommentChars? '*'
```

In general, JSDoc comments are placed directly before the annotated language element. In some cases, this is slightly different, such as for method parameters, for example, where it is then explicitly specified.

The content of JSDoc comments will be covered in more detail in upcoming chapters. For documentation purposes, multi- and single-line descriptions are used in several constructs.

⁵ <https://jira.numberfour.eu/browse/IDE-95>

⁶ <https://jira.numberfour.eu/browse/IDE-95>

⁷ <https://jira.numberfour.eu/browse/IDE-56>

⁸ <https://jira.numberfour.eu/browse/IDE-57>

⁹ <https://developers.google.com/closure/compiler/docs/js-for-compiler>

¹⁰ <http://www.oracle.com/technetwork/java/javase/documentation/index-jsp-135444.html>

```
MLVALUE:      ([^@]+[^\\n]+)+;
SLVALUE:      ([^\\n]+);
```

MLVALUE

short for **multi-line value**. This is usually only used for the general description of types or members.

SLVALUE

short for **single-line value**. This is a description which ends at the end of a line. It is usually used in combination with other tags, e.g., to further describe a parameter of a method.

Chapter 3. Names

Visibility defines the scope in which a declaration is visible, that is in which context references can be bound to the declaration. *Access control* defines the extent to which types and members are accessible beyond their immediate context. Access control may, therefore, restrict the visibility of a declaration by limiting its scope.

Extensibility refers to whether a given type can be subtyped, or in the case of members, whether they can be overridden. Access control is a prerequisite for extensibility which is further explained in [???](#)

3.1. Access Control

 IDE-84¹
 IDE-556²

Types from one project may or may not be made accessible to another project. Likewise, members from a given type may or may not be made accessible to members existing outside that type. For example, if a developer writes an application which uses a library, which types within that library can the application see? Given a type that is set as visible, which members of that type can the application see?

Accessing a type or member actually means that a reference is bound to a declaration with the same identifier.

We distinguish the following contexts from which an element is accessed as follows:

1. Module or type: access from elements in the same module or type.
2. Subtype: access from a subtype.
3. Project: access from the same project.
4. Vendor: access from different project of the same vendor.
5. World: access from anything else.

Accessibility is defined by modifiers on types and members, e.g., via the `statement`, and by the annotation. Extensibility is defined by the annotation respectively.

3.2. Accessibility of Types, Top-Level Variables and Function Declarations

 IDE-84³
 IDE-556⁴
 IDE-707⁵

¹ <https://jira.numberfour.eu/browse/IDE-84>

² <https://jira.numberfour.eu/browse/IDE-556>

³ <https://jira.numberfour.eu/browse/IDE-84>

We define types (classes, interfaces, enums) whereby each type has members (fields and methods, depending on the kind of type). When we define a type, we need to define whether it is visible only for the specifying module, project or whether that type should be accessible from outside of that project.

The same is true for variable declarations and function declarations defined as top-level elements of a module.

The following type access modifiers are supported by N4JS:

```
enum TypeAccessModifier:      project
| public;
```

If a type is not exported, its visibility is private. If a type has declared visibility , it may additionally be marked as internal via the annotation . Thus, we have the following set of type access modifiers:

TAM

=

<literal> private </literal> <literal> project </literal>, <literal> public@Internal </literal>, <literal> public </literal>

That is, in N4JS, only the type access modifiers and are available. The redundant modifier serves only documentation purpose and can be synthesized if the modifier is present.

All other modifiers used here are synthesized as shown in the next example:

Synthesized Type Access Modifiers in N4JS

```
class C0 {}                      // private
export class C1 {}                // project
export project class C1 {}        // project
export @Internal public class C1 {} // public@Internal
export public class C2 {}          // public

var v0;                           // private
export var v1;                    // project
export project var v1;            // project
export @Internal public var v3;   // public@Internal
export public var v2;              // public

function f0() {}                  // private
export function f1() {}            // project
export project function f1() {}    // project
export @Internal public function f3() {} // public@Internal
export public function f2() {}      // public
```

The access control levels are defined as listed in .

Table 3.1. Type Access Control

Type Access				
Modifier	Module	Project	Vendor	World

⁴ <https://jira.numberfour.eu/browse/IDE-556>

⁵ <https://jira.numberfour.eu/browse/IDE-707>

Type Access				
private	yes	no	no	no
project	yes	yes	no	no
public@Internal	yes	yes	yes	no
public	yes	yes	yes	yes

TAM is a totally ordered set: *privatelt;projectlt;public@Internallt;public*

The following constraints for type access modifiers for a given type T (which may be a classifier declaration, a function or a variable) must hold:

- It is an error if T is not exported but defined as `project`, `public` or `public@Internal`.
- It is an error if an annotation `@Internal` is present on a module private or `project` visible type.
- The type modifier for all built-in ECMAScript types is `public`.
- The *default modifier* for user declared exported declarations is `project`. That is, this modifier is assumed if no modifier is explicitly specified.

Definition: Type Accessibility T

The function $\alpha_T: TypeReference \times TypeDeclaration \rightarrow Boolean$ computes whether a given type, (top-level) variable or function reference can access the declaration that it references. α_T is defined with .

Formally, we define α_T for a given reference r and a module top level variable, function or type declaration D as follows: ⁶

$\alpha_T(r, D) = public \wedge r.vendor = D.vendor \wedge \alpha_T(r, D) = public@Internal \wedge r.vendor = D.vendor \wedge \alpha_T(r, D) = project \wedge r.vendor = D.vendor$

If the type of the arguments is clear from the context, we simply write $\alpha(r, D)$ instead of $\alpha_T(r, D)$.

Accessibility for types is only checked for types that manifest themselves in the concrete syntax of the N4JS file. Types that do not have to be written to concrete syntax may be used even if they are generally not accessible. This is illustrated by the following example:

```
export public class D {
    public takeC(): C { ... }
    public acceptC(c: C): void { ... }
}
/* private */ class C {}
```

```
var d: D = new D()
d.acceptC( d.takeC() )
```

3.2.1. Accessibility of Members

⁶ See for definitions of metatype properties.

Accessibility at the member level is only applicable when the type itself is accessible. If you cannot access the type, you cannot access any of its members. Note that inherited members (from an interface or class) become members of a class. For example, if `B extends A`, and if `A` is not accessible to some client `C` but `B` is, then the members of `A` are indirectly accessible to `C` in so far as they are accessed via `B`. This is true in particular for interfaces, as their properties are possibly merged into the consuming class (cf. [???](#)).

The following member access modifiers are supported by N4JS:

```
enum MemberAccessModifier:    private
                            | project
                            | protected
                            | public;
```

The modifiers and may be annotated with . Thus, we can define the following set of member access modifiers: `MAMamp;= { private, protected@Internal, protected, amp;project, public@Internal, public }` `protected@Internal` and `public@Internal` are synthesized tags and were introduced as shorthand notation for the `@Internal` annotation together with `protected` or `public` access modifiers. The modifier is the default one and it can be omitted. As with the type access modifiers, not all member access modifiers are available in N4JS. Instead, they are synthesized from different construct as shown in the next example.

```
export @Internal public class C {

    private f0;          // private
    f1;                  // project
    project f2;          // project
    @Internal protected f3; // protected@Internal
    protected f4;          // protected
    @Internal public f5;  // public@Internal
    public f6;            // public

    private m0() {}      // private
    m1() {}              // project
    project m2() {}      // project
    @Internal protected m3() {} // protected@Internal
    protected m4() {}      // protected
    @Internal public m5() {} // public@Internal
    public m6() {}        // public
}
```

⁷ <https://jira.numberfour.eu/browse/IDE-84>

⁸ <https://jira.numberfour.eu/browse/IDE-556>

⁹ <https://jira.numberfour.eu/browse/IDE-707>

MAM does not define a totally ordered set. However, its subset $MAM \setminus \{public@Internal\}$ is a totally ordered set¹⁰: $private \ll project \ll protected@Internal \ll protected \ll public$

??? shows which members are accessible from where.

[[Member Access Controls]]

Table 3.2. Member Access Control

Access Modifier	Inside Module	Inside Project	Vendor	Vendor Subtypes	Other Projects	Everywhere
<code>private</code>	yes	no	no	no	no	no
<code>project</code>	yes	yes	no	no	no	no
<code>protect-ed@Internal</code>	yes	yes	yes	no	no	no
<code>protect-ed</code>	yes	yes	yes	no	yes	no
<code>pub-lic@In-ternal</code>	yes	yes	yes	yes	no	no
<code>public</code>	yes	yes	yes	yes	yes	yes

We define the relation $\alpha_m : TAM \times MAM$ as follows:

$\alpha_m : TAM \times MAM$ as follows: $\alpha_m := \{(private, private), (project, project), (public@Internal, public@Internal)\}$

We further define the relation $\geq : TAM \times MAM$ as follows:

$tam \geq mam \exists mam' \in MAM : tam = mam' \wedge mam' \geq mam$ Less, greater than etc. are defined accordingly.

α_m] The function $\alpha_m : MemberReference \times MemberDeclaration \rightarrow Boolean$ computes if a given reference can access the member declaration that it references.

Note that α_m and β_m are different functions. A reference can only bind to a declaration if it can access the declaration. However, β_m requires more condition to work (correct metatypes, no shadowing etc).

Formally, we define α_m for a given reference r and member declaration M as follows:¹¹

¹²]

```
math:[\begin{aligned}
&\& \text{infer}\{\alpha_m(r, M)\}{M.acc = \text{lenum}\{public\}} \\
&\& \text{infer}\{\alpha_m(r, M)\}{r.vendor = M.vendor \& M.acc = \text{lenum}\{public@Internal\}} \\
&\& \text{infer}\{\alpha_m(r, M)\}{r.owner \in r.receiver.super^* \& M.acc = \text{lenum}\{protected\}} \\
\end{aligned}]
```

¹⁰ That is, for application developers not providing a library or a public API available to other vendors, member access modifiers behave almost similar to modifiers known from Java.

¹¹ See ??? for definitions of metatype properties. Note that $r.receiver$ always refers to a type declaration in the context of an expression as the receiver type of r . The declaring type of the member declaration is considered to be the receiver type of the member reference rather than the type that originally declares the member declaration.

¹² Note, the Java-like access restriction for members of visibility `protected` or `protected@Internal` to code that is responsible for the implementation of that object. [Gosling14a(p.S6.6.2, p.p.166)]

```
&\infer{\alpha_m(r, M)}{r.owner \in r.receiver.super^* \& r.vendor = M.vendor \& M.acc = \lceil enum\{protected@Internal\} \rceil}\\
&\infer{\alpha_m(r, M)}{r.project = M.project \& M.acc = \lceil enum\{project\} \rceil}\\
&\infer{\alpha_m(r, M)}{r.module = r.module \& M.acc = \lceil enum\{private\} \rceil}\\
\end{aligned}\]]
```

If the type of the arguments is clear from the context, we simply write $\alpha(r, M)$ instead of $\alpha_m(r, M)$.

Although private members are accessible inside a module, it is not possible to redefine (override etc.) these members (see [???](#)).

The following constraints for member access modifiers must hold:

1. The *default modifier* for members of user-declared classes is `project`.
 2. The *default modifier* for members of interfaces is the same as the visibility of the interface itself, except for private interfaces. For private interfaces, the default modifier for members is `project`.
 3. The modifier for enum literals is always `public`.
 4. Private members of a classifier are visible and accessible within a module, i.e. you can access the private method of a class, for instance, when the use of the class as receiver is in the same module where the class has been defined. In case of inheritance, private members are visible if the host (e.g. the class) is in the same module as the provider (the extended class). This also means that abstract members of a class are allowed to be defined private as they may be overridden within a module.
-

```
export project interface I {
    project foo();
}

// This interface may be used publicly, but since the inherited method foo() is project
// visible only,
// it is not possible to implement that interface in other projects.
export public interface J extends I {

}

// Since the visibility of foo is set to public here, it is possible to implement this
// interface in other projects.
export public interface K extends I {
    @Override public foo();
}

// Since foo is private, it is not possible to subclass the class in other modules. Still, it
// is possible to use it in other projects.
// XPECT noerrors -->
export public abstract class C {
    private abstract foo();

    public static C instance() {
        // return some default instance
        ...
    }
}
```

As demonstrated in the following snippet, class can be used but not subclassed in other modules:

```

import C from "C"

// XPECT errors --> "Cannot extend class C: cannot implement one or more non-accessible
abstract members: method C.foo." at "C"
export public abstract class Sub extends C {
}

// XPECT noerrors -->
var c: C = C.instance();

```

Members of non-visible types are, in general, not visible for a client. Members may become visible, however, if they are accessed via a visible type which inherits these members. The following examples demonstrate two different scenarios:

[[ex:Declaring type vs receiver type]] It is especially noteworthy that the declaring type of a member is generally not considered for the accessibility of that member but only the receiver type is relevant.

```

class Base {
    public m(b: Base): void {}
}
export public class ApiType extends Base {

}

import * as N from "Base";

var t = new N.ApiType();
// member can be accessed although type Base is not exported:
t.m(t);

```

The property access to the member `m` is valid because it fulfills the constraints for accessibility. The receiver of the property access is `t` of type `ApiType`. That type is exported and accessible. Therefore, the inherited member `m` is also considered valid since it is also defined `public`.

This rule allows for defining a common functionality in module or project visible types that becomes accessible via exported, visible subtypes.

The following example demonstrates the behavior when non-visible types are used as return types. In this case, all the members of the non-visible types are not accessible, even if they have a public access modifier.

```

class A {
    foo(): void{}
}
export public class C {
    public getHidden(): A { return new A(); }
}

import * as N from "A"

class Client {
    f(): void {

```

```
var c = new N.C();
// XPECT noerrors --> Getting an instance the hidden type is possible
var hidden = c.getHidden();
// XPECT errors --> "The method foo is not visible." at "foo"
hidden.foo();
}
}
```

3.2.2. Valid Names

For identifier and property names, the same constraints as in ECMAScript [ECMA11a(p.S7.6)] [ECMA11a(p.S7.6.1.2)] [ECMA11a(p.S11.6)] are applied.

Identifier names in N4JS are defined similar to [ECMA11a(p.S11.6)], making it possible to even use reserved words (keywords etc.). For some element types, errors or warnings are issued in order to prevent problems when using these names.

5Forbidden Identifier Names in N4JS[req:Identifier_Names_in_N4JS] In N4JS mode, errors are generated in the following cases:

GH-207¹³

1. A name of a type equals
 - a. an access modifier
 - b. `set` or `get`
 - c. an ECMAScript keyword
 - d. a boolean literal
 - e. the name of a base type
2. The name of a function or function expression equals (but not the method)
 - a. an ECMAScript keyword
 - b. a reserved future ECMAScript word

6Undesired Identifier Names in N4JS[req:Undesired_Identifier_Names_in_N4JS] In N4JS mode, warnings are generated in the following cases:

1. The name of a member (of a non external type)
 - a. equals the name of a base type ¹⁴ but the type of the variable is different from that type
 - b. is not static nor const but starts with an upper case letter
2. The name of a non-external n4 types (class, interface, enum) starts with a lower case letter
3. The name of a variable (incl. formal parameter or catch variable and fields)
 - a. equals an N4JS keyword

¹³ <https://github.com/NumberFour/N4JS/issues/207>

¹⁴ `string`, `boolean`, `number`, `any`, `null`

- b. equals the name of a base type but the type of the variable is different from that type
- c. is not `const` but starts with an upper case letter

3.2.3. Qualified Names

In N4JS source code, types can only be referenced using their simple name. There is no such thing as a fully-qualified type name in N4JS or ECMAScript. Types are uniquely identified by their simple name, maybe together with an import and the module specifier given there. Clashes between simple names of imported type and locally declared types can be resolved by importing the type under an alias.

In some cases, however, we need to define references to types or even members. For example, if we want to reference certain members in JSDoc comments or for unambiguous error messages. For this reason, we formally define qualified names even if they cannot occur in source code.

[Type Names](#) shows the different names of a given type `C`, defined in a module `M.n4js`, defined in a package `p` of a project `MyProject`.

Table 3.3. Different forms of module and type specifiers.

Name	Example
Simple Type Name	<code>C</code>
(Plain) Module Specifier	<code>p/M</code>
Complete Module Specifier	<code>MyProject/p/M</code>
Complete Type Specifier	<code>MyProject/p/M.C</code>

Simple type names are used throughout N4JS code in order to refer to types. The different forms of module specifiers are only used in import declarations in the string following the keyword.

3.2.4. Name Duplicates

There might be cases where two (or more) scopes created by different entities with the same (simple) name overlap. Those situations can be referred to as shadowing, hiding, or obscuring. While they are not the same, many of those cases are not allowed in N4JS. For simplicity we refer to them all as shadowing or duplication (see below). Rule of thumb is that N4JS allows everything that is allowed in JavaScript StrictMode.

Lexical Environment

N4JS handles scopes similar to ECMAScript, so that function scope is applied to variables declared with `var` (and parameters), and block scope for variables is declared with `let` or `const`. In general, ECMAScript defines *Lexical Environments* as a specification type used to define the association of Identifiers to specific variables and functions based upon the lexical nesting structure of ECMAScript code. [[ECMA11a\(p.10.2\)](#)].

Elements that introduce lexical environments:

```
FunctionDefinition, VariableDeclaration, CatchBlock, WithStatement, ImportDeclaration
```

N4JS specific declarations:

```
N4ClassDeclaration, N4InterfaceDeclaration, N4EnumDeclaration, N4Method-
Declaration.
```

Additionally, a built-in lexical environment that defines global scope exists for every `Script`.

Since N4JS is extended (and a bit more strict) JS strict mode, *Object environment records* created by `WithStatement` are not taken into account when resolving duplicates. This applies to both N4JS mode and JS strict mode. In unrestricted JS the `WithStatement` is allowed but duplicates are not validated.



In case of names introduced by `ImportDeclaration`s only `NamedImportSpecifiers`s are taken into account (their import name or its alias if available). `WildcardImportSpecifiers`s are not taken into account. Potential optimizations by compiler or user annotation are also not currently taken into account during analysis.

Duplicates and Shadowing

Definition: Shadowing Overriding Duplicates

Two elements with the same name declared in the same lexical environment (cf. [ECMA11a(p.S10.2.2.1)]) are called *duplicates*. An element defined in an environment *shadows* all elements with the same name in outer environments.

In class hierarchies, a member with the same name as a member defined in a supertype is said to override the latter. Overriding is discussed in .

For the following constraints, we make the following assumptions:

- Names of function expressions or declarations are handles similar to locally declared elements in the function. Function declarations are additionally declaring a name in their outer scope.
- The implicit formal parameter `arguments` is treated similar to declared formal parameters.
- Formal parameters are defined in the lexical environment of a function, that is, they are defined in the same lexical environment as local `var`-variables or other declarations in that function.
- The "global" environment contains objects globally defined by the execution environment.

There must be no two elements defined in the same lexical environment with the same name, that is, there must be no duplicates.

8Forbidden Shadowing[req:Forbidden_Shadowing] In general, shadowing is allowed in N4JS. But it is not allowed in the following cases:

- No element defined in the standard global scope must be shadowed.
- There must be no function shadowing another function.
- Elements defined in catch blocks must not shadow elements defined all parent non-catch-block environments.
- In the script environment, it is not allowed to use the name 'arguments'. ¹⁵

¹⁵This conflicts with the implicit parameter arguments introduced by the transpiler when wrapping the script/module into a definition function.

??? shows nested lexical environments with named elements declared inside (all named `x` here), the forbidden cases are marked with arrows (the numbers at the left side refer to the numbers in [req:Forbidden_Shadowing]).

[[Forbidden shadowing]] 

Rational:

- We expect only few named nested functions. Since this is expected to be a rare case, no shadowing should occur there as this is maybe not expected by the programmer.
- It is typical that nested environments define local variables. In particular helper variables (such as `i: number i` or `s: string`) are expected to be used quite often. Since this is a typical case, we allow shadowing for local variables.
- Function declarations may shadow type declarations. However, both entities are to be handled completely differently, so that an error will occur if the shadowing is ignored by the programmer anyway.

Chapter 4. Types

4.1. Overview

N4JS is essentially ECMAScript with the inclusion of types. In the following sections we will describe how types are defined and used in N4JS.

Besides standard JavaScript types, the following metatypes are introduced:

- Classifiers, that is class or interface (see)
- Enum

Classifiers, methods and functions may be declared generic.

Types are related to each other by the subtype relation.

Definition: Subtype Relation

We use subtype for the general subtype relation or type conformance. In nominal typing, TS means that S is a (transitive) supertype of T . Generally in structural typing, this means that T conforms to S . is defined transitive reflexive by default. We write $l;$ to refer to the transitive non-reflexive relation, that is $Tlt;STS \wedge T \neq S$

Whether nominal or structural typing is used depends on the declaration of the type or the reference. This is explained further in .

For convenience reasons, we sometimes revert the operator, that is $TSS:gt;T$ We write TS if T is not type conforming to S . (cf. [[Gosling12a\(p.S4.10\)](#)])

Join and meet are defined as follows:

Definition: Join and Meet

```
A type math:[$J$] is called a
_join_ (or least common supertype, ) of a pair of types math:[$S$]
and math:[$T$], written math:[$S \join T = J$], if +
math:[[\begin{aligned}
& S \subtype J \\
& T \subtype J \\
& \forall L: (S \subtype L) \land (T \subtype L) \rightarrow J \subtype L \end{aligned}]]
Similarly, we say that a type math:[$M$] is a _meet_ (or greatest
common subtype, ) of math:[$S$] and math:[$T$], written
math:[$S \meet T = M$], if +
math:[[\begin{aligned}
& M \subtype S \\
& M \subtype T \\
& \forall L: (L \subtype S) \land (L \subtype T) \rightarrow L \subtype M \end{aligned}]]
```

Note that this declarative definition needs to be specified in detail for special cases, such as union and intersection types. Usually, the union type of two types is also the join.

summarizes all predefined types, that is primitive and built-in ECMAScript and N4JS types. Specific rules for the subtype relation are defined in the following sections. This type hierarchy shows `any` and `undefined` as the top and bottom type (cf. [Pierce02a(p.15.4)]) We define these types here explicitly:

Definition: Top and Bottom Type

We call *Top* the top type, if for all types *T* the relation *TTop* is true. We call *Bot* the bottom type, if for all types *T* the relation *Bot_T* is true. In N4JS, *Top* = $\langle \text{literal} \rangle \text{any} \}$, the bottom type *Bot* = $\langle / \text{literal} \rangle \text{undefined} \}$.

`null` is almost similar to *Bot*, except that it is not a subtype of `undefined`.



For every primitive type there is a corresponding built-in type as defined in [ECMA11a], e.g. and . There is no inheritance supported for primitive types and built-in types – these types are final.

Although the diagram shows inheritance between `void` and `undefined`, this relationship is only semantic: `void` is a refinement of `undefined` from a type system viewpoint. The same applies to the relation of `object` as well as the subtypes shown for `string` and `String`.

[[ex:Type Examples, Class Hierarchy]] In the following examples, we assume the following classes to be given:

```
// C <: B <: A
class A{}
class B extends A{}
class C extends B{}

// independent types X, Y, and Z
class X{} class Y{} class Z{}

// interfaces I, I1 <: I, I2 <: I, I3
interface I
interface I1 extends I {}
interface I2 extends I {}
interface I3 {}

// class implementing the interfaces
class H1 implements I1{}
class H12 implements I1,I2{}
class H23 implements I2,I3{}

// a generic class with getter (contra-variance) and setter (co-variance)
class G<T> {
    get(): T;
    set(x: T): void;
}
```

4.2. Type Expressions

In contrast to ECMAScript, N4JS defines static types. Aside from simple type references, type expressions may be used to specify the type of variables.

4.2.1. Syntax

summarizes the type expression grammar. Depending on the context, not all constructs are allowed. For example, the variadic modifier is only allowed for function parameters.

References to user-declared types are expressed via `ParameterizedTypeRef`. This is also true for non-generic types, as the type arguments are optional. See [Section 4.4.3, “Parameterized Types”](#) for details on that reference.

For qualified names and type reference names, see

The type expressions are usually added to parameter, field, or variable declarations as a suffix, separated with colon (':'). The same is true for function, method, getter or setter return types. Exceptions in the cases of object literals or destructuring are explained later on.

The following two listings show the very same code and type annotations are provided on the left hand side. For simplicity, `is` always used as type expression.¹

```
var x: string;
var s: string = "Hello";
function f(p: string): string {
    return p;
}
class C {
    f: string;
    s: string = "Hello";
    m(p: string): string {
        return p;
    }
    get x(): string {
        return this.f;
    }
    set x(v: string) {
        this.f = v;
    }
}
```

```
var x;
var s = "Hello";
function f(p) {
    return p;
}
class C {
    f;
    s = "Hello";
    m(p) {
        return p;
    }
    get x() {
        return this.f;
    }
    set x(v) {
```

¹ In the N4JS IDE, type annotations are highlighted differently than ordinary code.

```
    this.f = v;
}
}
```

The code on the right hand side is almost all valid ECMAScript 2015, with the exception of field declarations in the class. These are moved into the constructor by the N4JS transpiler.

4.2.2. Properties

Besides the properties indirectly defined by the grammar, the following pseudo properties are used for type expressions: Properties of :

If true, variable of that type is variadic. This is only allowed for parameters. Default value: *false*.

If true, variable of that type is optional. This is only allowed for parameters and return types. This actually means that the type *T* actually is a union type of . Default value: *false*.

optvar = *var* *v opt*, reflect the facts that a variadic parameter is also optional (as its cardinality is [0..*n*).\$])

Pseudo property referencing the variable declaration (or expression) which **owns** the type expression.

4.2.3. Semantics

The ECMAScript types *undefined* and *null* are also supported. These types cannot be referenced directly, however. Note that **void** and *undefined* are almost similar. Actually, the inferred type of a types element with declared type of **void** will be *undefined*. The difference between void and undefined is that an element of type void can never have another type, while an element of type undefined may be assigned a value later on and thus become a different type. **void** is only used for function and method return types.

Note that not any type reference is allowed in any context. Variables or formal parameters must not be declared **void** or union types must not be declared dynamic, for example. These constraints are explained in the following section.

The types mentioned above are described in detail in the next sections. They are hierarchically defined and the following list displays all possible types. Note that all types are actually references to types. A type variable can only be used in some cases, e.g., the variable has to be visible in the given scope.

ECMAScript Types

Predefined Type

Predefined types, such as String, Number, or Object; and .

Array Type

[Section 4.7.4, “Array Object Type”.](#)

Function Type

Described in [???, ../06_funtions/Functions.xml](#)².

Any Type

[Section 4.6.1, “Any Type”.](#)

² [../06_funtions/Functions.xml#function_type](#)

N4Types

Declared Type

(Unparameterized) Reference to defined class [Section 5.3, “Classes”](#) or enum [Section 4.13, “Enums”](#).

Parameterized Type

Parameterized reference to defined generic class or interface; [Section 4.4.3, “Parameterized Types”](#).

This Type

[Section 4.12, “This Type”](#).

Constructor and Type Type

Class type, that is the meta class of a defined class or interface, [Section 4.11, “Constructor and Classifier Type”](#).

Union Types

Union of types, [Section 4.10.1, “Union Type”](#).

Type Variable

Type variable, [Section 4.4.2, “Type Variables”](#).

Type expressions are used to explicitly declare the type of a variable, parameter and return type of a function or method, fields (and object literal properties).

4.3. Type Inference

If no type is explicitly declared, it is inferred based on the given context, as in the expected type of expressions or function parameters, for example. The type inference rules are described in the remainder of this specification.

Definition: Default Type

In N4JS mode , if no type is explicitly specified and if no type information can be inferred, `any` is assumed as the default type.

In JS mode, the default type is `any+`.

Once the type of a variable is either declared or inferred, it is not supposed to be changed.

[Variable type is not changeable] Given the following example.

```
var x: any;
x = 42;
x-5; // error: any is not a subtype of number.
```

Type of `x` is declared as `any` in line 1. Although a number is assigned to `x` in line 2, the type of `x` is not changed. Thus an error is issued in line 3 because the type of `x` is still `any`.

At the moment, N4JS does not support type guards or, more general, effect system (cf. [\[Nielson99a\]](#)).

4.4. Generic and Parameterized Types

Some notes on terminology:

Type Parameter vs. Type Argument

A type parameter is a declaration containing type variables. A type argument is a binding of a type parameter to a concrete type or to another type parameter. Binding to another type parameter can further restrict the bounds of the type parameter.

This is similar to function declarations (with formal parameters) and function calls (with arguments).

4.4.1. Generic Types

A class declaration or interface declaration with type parameters declares a generic type. A generic type declares a family of types. The type parameters have to be bound with type arguments when referencing a generic type.

4.4.2. Type Variables

A type variable is an identifier used as a type in the context of a generic class definition, generic interface definition or generic method definition. A type variable is declared in a type parameter as follows.

Syntax

```
TypeVariable:  
    name=IDENTIFIER  
    ('extends' declaredUpperBounds+=ParameterizedTypeRef  
     ('&' declaredUpperBounds+=ParameterizedTypeRef)*  
    )?  
;
```

[Type Variable as Upper Bound][ex:Type Variable as Upper Bound] Note that type variables are also interpreted as types. Thus, the upper bound of a type variable may be a type variable as shown in the following snippet:

```
class G<T> {  
    <X extends T> foo(x: X): void { }  
}
```

Properties

A type parameter defines a type variable, which type may be constrained with an upper bound.

Properties of **TypeVariable**:

Type variable, as type variable contains only an identifier, we use type parameter instead of type variable (and vice versa) if the correct element is clear from the context.

Upper bounds of concrete type bound to the type variable, i.e. a super class.

Semantics

[[req:10Type Variables]]

1. Enum is not a valid metatype in *declaredUpperBounds*.

2. Wildcards are not valid in *declaredUpperBounds*.
3. Primitives are not valid in *declaredUpperBounds*.
4. Type variables are valid in *declaredUpperBounds*.

GH-830³

A type variable can be used in any type expression contained in the generic class, generic interface, or generic function / method definition.

[F-bounded quantification][ex:F_bounded_quantification] Using a type variable in the upper bound reference may lead to recursive definition.

```
class Chain<C extends Chain<C, T>, T> {  
    next() : C { return null; }  
    m() : T { return null; }  
}
```

Type Inference

In many cases, type variables are not directly used in subtype relations as they are substituted with the concrete types specified by some type arguments. In these cases, the ordinary subtype rules apply without change. However, there are other cases in which type variables cannot be substituted:

1. Inside a generic declaration.
2. If the generic type is used as raw type.
3. If a generic function / method is called without type arguments and without the possibility to infer the type from the context.

In these cases, an unbound type variable may appear on one or both sides of a subtype relation and we require subtype rules that take type variables into account.

It is important to note that while type variables may have a declared upper bound, they cannot be simply replaced with that upper bound and treated like existential types. The following example illustrates this:

[Type variables vs. existential types][ex>TypeVariablesVsExistentialTypes]

```
class A {}  
class B extends A {}  
class C extends B {}  
  
class G<T> {}  
  
class X<T extends A, S extends B> {  
  
    m(): void {  
  
        // plain type variables:  
        var t: T;  
        var s: S;
```

³ <https://github.com/NumberFour/N4JS/issues/830>

```
t = s; // ERROR: "S is not a subtype of T." at "s"

// existential types:
var ga: G<? extends A>;
var gb: G<? extends B>;

ga = gb; // ok!
}

}
```

Even though the upper bound of is a subtype of 's upper bound (since $Blt;::A$), we cannot infer that is a subtype of (line 15), because there are valid concrete bindings for which this would not be true: for example, if were bound to and to .

This differs from existential types (see and and line 21): $lt;::$).

We thus have to define subtype rules for type variables, taking the declared upper bound into account. If we have a subtype relation in which a type variable appears on one or both sides, we distinguish the following cases:

1. If we have type variables on both sides: the result is true if and only if there is the identical type variable on both sides.
2. If we have a type variable on the left side and no type variable on the right side: the result is true if and only if the type variable on the left has one or more declared upper bounds.
 $\text{intersection}(\text{left.declaredUpperBounds}) lt;:: \text{right}$
This is the case for $<\text{literal}> (\text{TextendsB}) \} lt;:: </\text{literal}> A \}$ in which T is an unbound type variable and A, B two classes with $Blt;::A$.
3. In all other cases the result is false.

This includes cases such as

$<\text{literal}> B \} lt;:: </\text{literal}> (\text{TextendsA}) \}$ which is always false, even if $Blt;::A$ or
 $<\text{literal}> (\text{TextendsA}) \} lt;:: </\text{literal}> (\text{SextendsB}) \}$ which is always false, even if $A = B$.

We thus obtain the following definition:

[Subtype Relation for Type Variables][def:SubtypeRelationForTypeVariables] For two types T, S of which at least one is a type variable, we define

- if both T and S are type variables: $Tlt;::ST = S$
- if T is a type variable and S is not:
 $Tlt;::ST.declaredUpperBounds.size \geq i & \forall t \in T.declaredUpperBounds: tlt;::S$

4.4.3. Parameterized Types

References to generic types (cf.) can be parameterized with type arguments. A type reference with type arguments is called parameterized type.

Syntax

ParameterizedTypeRef:

```
ParameterizedTypeRefNominal | ParameterizedTypeRefStructural;

ParameterizedTypeRefNominal:
    declaredType=[Type|TypeReferenceName]
    (=> '<' typeArgs+=TypeArgument (',' typeArgs+=TypeArgument)* '>')?;

ParameterizedTypeRefStructural:
    definedTypingStrategy=TypingStrategyUseSiteOperator
    declaredType=[Type|TypeReferenceName]
    (=> '<' typeArgs+=TypeArgument (',' typeArgs+=TypeArgument)* '>')?
    ('with' TStructMemberList)?;

TypeArgument returns TypeArgument:
    Wildcard | TypeRef;

Wildcard returns Wildcard:
    '?'
    (
        'extends' declaredUpperBound=TypeRef
        | 'super' declaredLowerBound=TypeRef
    )?
;
```

Properties

Properties of parameterized type references (nominal or structural):

Referenced type by type reference name (either the simple name or a qualified name, e.g. in case of namespace imports).

The type arguments, may be empty.

Typing strategy, by default nominal, see for details

in case of structural typing, reference can add additional members to the structural type, see for details.

Pseudo Properties:

The `ImportSpecifier`, may be null if this is a local type reference. Note that this may be a `NamedImportSpecifier`. See `\autoref{sec:Import_Statement}` for details for details.

Returns simple name of type, that is either the simple name as declared, or the alias in case of an imported type with alias in the import statement.

Semantics

The main purpose of a parameterized type reference is to simply refer to the declared type. If the declared type is a generic type, the parameterized type references defines a *substitution* of the type parameters of a generic type with actual type arguments. A type argument can either be a concrete type, a wildcard or a type variable declared in the surrounding generic declaration. The actual type arguments must conform to the type parameters so that code referencing the generic type parameters is still valid.

[[req:11 Parameterized Types]] For a given parameterized type reference R with $G = R.declaredType$, the following constraints must hold:

- The actual type arguments must conform to the type parameters, that is:

$$\|G.typePars\| = |R.typeArgs| \wedge \forall i, 0 \leq i \leq |R.typeArgs| : R.typeArgs_i \leq |R.typePars|$$

We define type erasure similar to Java [[Gosling12a\(p.S4.6\)](#)] as a "mapping from types (possibly including parameterized types and type variables) to types (that are never parameterized types or type variables)". We write $\$T\$$ for the erasure of type T .¹ The notation $\$|T|$$ used in [[Gosling12a](#)] conflicts with the notation of cardinality of sets, which we use in case of union or intersection types for types as well. The notation used here is inspired by [[Crary02a](#)], in which a mapping is defined between a typed language λ to an untyped language λ° .

[Parameterized Type, Raw Type][def:Parameterized_Type] A parameterized type reference R defines a parameterized type T , in which all type parameters of $R.declaredType$ are substituted with the actual values of the type arguments. We call the type T^0 , in which all type parameters of $R.declaredType$ are ignored, the *raw type* or *erasure* of T .

We define for types in general:

- The erasure Gx of a parameterized type $Glt;T_1, 8230; 8203; T_ngt;$ is simply G .
- The erasure of a type variable is the erasure of its upper bound.
- The erasure of any other type is the type itself.

This concept of type erasure is purely defined for specification purposes. It is not to be confused with the `real` type erasure which takes place at runtime, in which almost no types (except primitive types) are available.

That is, the type reference in `var G<string> gs;` actually defines a type `G<string>`, so that $gs = Glt;stringgt;$. It may reference a type defined by a class declaration `class G<T>`. It is important that the type `G<string>` is different from `G<T>`.

If a parameterized type reference R has no type arguments, then it is similar to the declared type. That is, $R = T = R.declaredType$ if (and only if) $|R.typeArgs| = 0$.

In the following, we do not distinguish between parameter type reference and parameter type – they are both two sides of the same coin.

In Java, due to backward compatibility (generics were only introduced in Java 1.5), it is possible to use raw types in which we refer to a generic type without specifying any type arguments. This is not possible in N4JS, as there is no unique interpretation of the type in that case as shown in the following example. Given the following declarations:

```
class A{}  
class B extends A{}  
class G<T extends A> { t: T; }  
var g: G;
```

In this case, variable refers to the *raw type*. This is forbidden in N4JS, because two interpretations are possible:

1. is of type

2. is of type

In the first case, an existential type would be created, and must fail.

In the second case,
must fail.

In Java, both assignments work with raw types, which is not really save. To avoid problems due to different interpretations, usage of raw types is not allowed in N4JS.⁴

Calls to generic functions and methods can also be parameterized, this is described in [sec:Function_Calls]. Note that invocation of generic functions or methods does not need to be parameterized.

[Type Conformance][def:Type_Conformance] We define type conformance for non-primitive type references as follows:

```
* For two non-parameterized types math:[$T^0$] and
math:[$S^0$], math:[\[\begin{aligned}
\infer{T^0 <: S^0}{S^0 \in T^0.sup^* \cup T^0.interfaces^*}
\end{aligned}\}]
* For two parameterized types math:[$T<T_1,\dots,T_n>$] and
math:[$S<S_1,\dots,S_m>$] math:[\[\begin{aligned}
\infer{\hspace{10em}T <: S\hspace{10em}}{
\{T^0 <: S^0\} \\
\{(n=0 \lor m=0 \lor (n=m \rightarrow \forall i:\)) \\
\hspace{2em} \{T_i.upperBound <: S_i.upperBound\} \\
\hspace{1em} \land \{T_i.lowerBound :> S_i.lowerBound\})} \\
\end{aligned}\}]
\end{aligned}\]]
```

[[ex:Subtyping with parameterized types]] Let classes A, B, and C are defined as in the chapter beginning (*Clt;:Blt;:A*). The following subtype relations are evaluated as indicated:

G<A> <: G	-> false
G <: G<A>	-> false
G<A> <: G<A>	-> true
G<A> <: G<?>	-> true
G<? extends A> <: G<? extends A>	-> true
G<? super A> <: G<? super A>	-> true
G<? extends A> <: G<? extends B>	-> false
G<? extends B> <: G<? extends A>	-> true
G<? super A> <: G<? super B>	-> true
G<? super B> <: G<? super A>	-> false
G<? extends A> <: G<A>	-> false
G<A> <: G<? extends A>	-> true
G<? super A> <: G<A>	-> false
G<A> <: G<? super A>	-> true
G<? super A> <: G<? extends A>	-> false
G<? extends A> <: G<? super A>	-> false
G<?> <: G<? super A>	-> false
G<? super A> <: G<?>	-> true

⁴ Although raw type usage is prohibited, the N4JS validator interprets raw types according to the first case, which may lead to consequential errors.

$G<?> <: G<? extends A>$	$\rightarrow \text{false}$
$G<? extends A> <: G<?>$	$\rightarrow \text{true}$

shows the subtype relations of parameterized types (of a single generic type), which can be used as a cheat sheet.

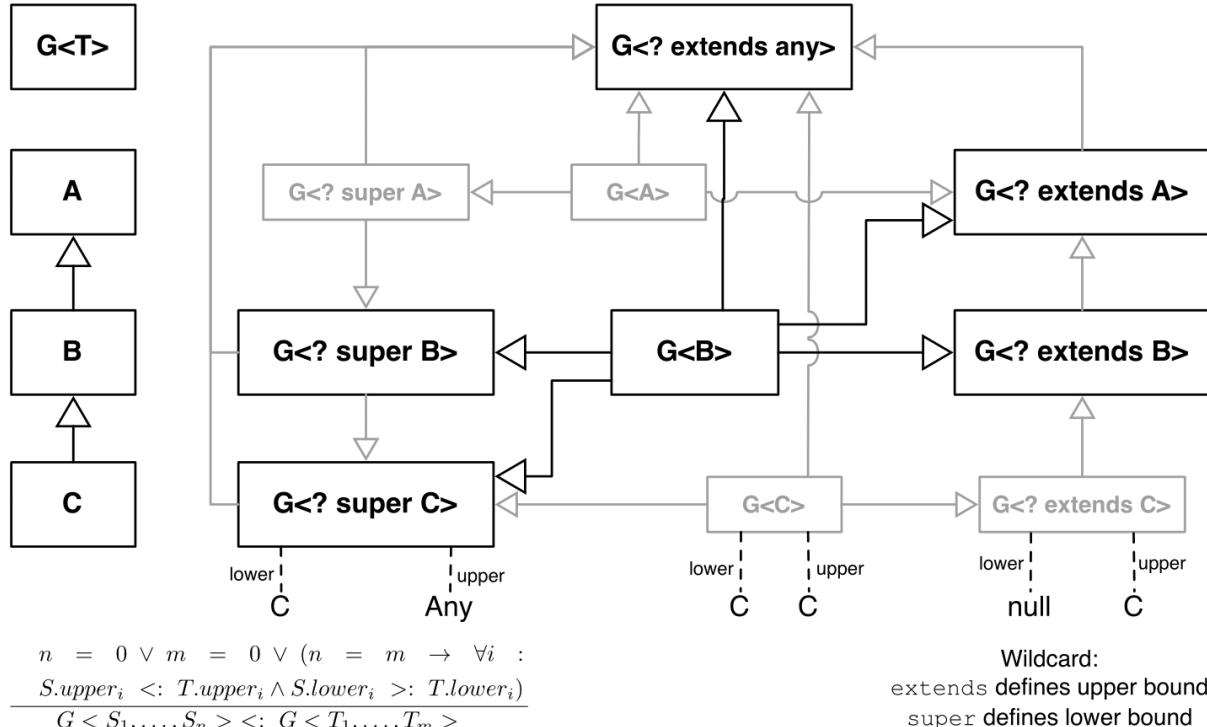


Figure 4.1. cdVarianceChart

Cheat sheet: subtype relation of parameterized types]

[[ex:Subtyping between different generic types]] Let classes G and H be two generic classes where:

```
class G<T> {}
class H<T> extends G<T> {}
```

Given a simple, non-parameterized class A , the following subtype relations are evaluated as indicated:

$G<A> <: G<A>$	$\rightarrow \text{true}$
$H<A> <: G<A>$	$\rightarrow \text{true}$
$G<A> <: H<A>$	$\rightarrow \text{false}$

Type Inference

Type inference for parameterized types uses the concept of existential types (in Java, a slightly modified version called capture conversion is implemented).

⁵ for *Featherweight Java with Generics*.

⁵ The general concept for checking type conformance and inferring types for generic and parameterized types is described in [Igarashi01a]

The concept of existential types with wildcard capture (a special kind of existential type) is published in [Torgersen05], further developed in [Cameron08b] (further developed in [Cameron09a] [Summers10], also see [Wehr08a] for a similar approach). The key feature of the Java generic wildcard handling is called capture conversion, described in [Gosling12a(p.S5.1.10)]. However, there are some slight differences to Java 6 and 7, only with Java 8 similar results can be expected. All these papers include formal proofs of certain aspects, however even these paper lack proof of other aspect

The idea is quite simple: All unbound wildcards are replaced with freshly created new types ⁶, fulfilling the constraints defined by the wildcard's upper and lower bound. These newly created types are then handled similar to real types during type inference and type conformance validation.

[[ex:Existential Type]] The inferred type of a variable declared as

,

that is the parameterized type, is an existential type E_1 , which is a subtype of A. If you have another variable declared as

another type E_2 is created, which is also a subtype of A. Note that $E_1 \neq E_2$! Assuming typical setter or getter in G, e.g. and , the following code snippet will produce an error:

This is no surprise, as actually returns a type E_1 , which is not a subtype of E_2 .

The upper and lower bound declarations are, of course, still available during type inference for these existential types. This enables the type inferencer to calculate the join and meet of parameterized types as well.

[[req:12Join of Parameterized Types]] The join of two parameterized types $Glt;T_{l}, T_{ngt}$; and $Hlt;S_{l}, S_{mgt}$; is the join of the raw types, this join is then parameterized with the join of the upper bounds of of type arguments and the meet of the lower bounds of the type arguments.

For all type rules, we assume that the upper and lower bounds of a non-generic type, including type variables, simply equal the type itself, that is for a given type T , the following constraints hold:
 $upper(T) = lower(T) = T$

[[ex:Upper and lower bound of parameterized types]] Assuming the given classes listed above, the following upper and lower bounds are expected:

```
G<A>           -> upperBound = lowerBound = A
G<? extends A> -> lowerBound = null, upperBound = A
G<? super A>   -> lowerBound = A, upperBound = any
G<??>          -> lowerBound = null, upperBound = any
```

This leads to the following expected subtype relations:

GH-260⁷

⁶ in the Java 8 spec and compiler, they are called type variables, which are types as well

⁷ <https://github.com/NumberFour/N4JS/issues/260>

```
(? extends A) <: A    -> true
(? super A) <: A      -> false
A <: (? extends A)   -> false
A <: (? super A)     -> true
```

Note that there is a slight difference to Java: In N4JS it is not possible to use a generic type in a raw fashion, that is to say without specifying any type arguments. In Java this is possible due to backwards compatibility with early Java versions in which no generics were supported.

In case an upper bound of a type variable shall consist only of a few members, it seems convenient to use additional structural members, like on interface I2 in the example [???](#) below. However, type variables must not be constrained using structural types (see constraint [???](#)). Hence, the recommended solution is to use an explicitly declared interface that uses definition site structural typing for these constraints as an upper bound (see interface in the example).

[\[\[ex:Use declared interfaces for lower bounds\]\]](#)

```
interface I1<T extends any with {prop : int}> { // error
}

interface ~J {
    prop : int;
}
interface I2<T extends J> {
```

4.5. Primitive ECMAScript Types

N4JS provides the same basic types as ECMAScript [[ECMA11a\(p.p.28\)](#)].

IDE-40⁸



In ECMAScript, basic types come in two flavors: as primitive types [[ECMA11a\(p.S8Types, p.p.28\)](#)] and as Objects [[ECMA11a\(p.S15, p.p.102\)](#)]. In N4JS, primitive types are written with lower cases, object types with first case capitalized. For example, `string` is the primitive ECMAScript string type, while `String` is an object.

The following ECMAScript primitive types are supported, they are written with lower case letters::

- `undefined` [[ECMA11a\(p.S8.3\)](#)]; cannot be used in type expression, see void below.
- `null` [[ECMA11a\(p.S8.3\)](#)]; cannot be used in type expression
- `boolean` [[ECMA11a\(p.S8.3\)](#)]
- `string` [[ECMA11a\(p.S8.4\)](#)]
- `number` [[ECMA11a\(p.S8.5\)](#)]

⁸ <https://jira.numberfour.eu/browse/IDE-40>

Although Object is a primitive type in [ECMA11a(p.S8.5)], it is interpreted here as an object type and described in .

Please note that primitive types are values (= no objects) so they have no properties and you cannot inherit from them.

4.5.1. Undefined Type

IDE-495⁹

The `undefined` type cannot be declared explicitly by the user by means of a type expression. Every variable that has not been assigned to a value has this value and type respectively. This applies also to functions that have no or an empty return statement. Note in ECMAScript there are three undefined elements:

- `undefined` as type (as used here)
- `undefined` as value (the only value of the undefined type)
- `undefined` is a property of the global object with `undefined` (value) as initial value. Since ECMAScript 5 it is not allowed to reassign this property but this is not enforced by all ECMAScript/JavaScript engines.

The type `undefined` will be inferred to false in a boolean expression. It is important to note that something that is not assigned to a value is `undefined` but not `null`.

Although it is not possible to use `undefined` in a type expression, there are two ways of declaring an element as undefined:

- For functions, the return type can be declared `void`, which is almost similar to `undefined`, see [Section 4.6.2, “Void Type”](#).
- (Local) Variables can be declared as by using the annotation `@Undefined`. This does not only set the type to `undefined`, but also prevents users from assigning a value to this variable. That is, `@Undefined` basically means that the value of the variable is constantly set to `undefined`.

[[ex:Undefined Annotation]] The following examples illustrate the use of the annotation:

```
var @Undefined undef;
undef = 1; // will issue an error!
```

The type `undefined` is a subtype of all types. That is, $\langle \text{literal} \rangle \text{ undefined} < / \langle \text{literal} \rangle lt; : T$ is an axiom and true for all types T .

4.5.2. Null Type

The `null` type cannot be declared explicitly by the user. Only the keyword `null` is inferred to type `null`.

⁹ <https://jira.numberfour.eu/browse/IDE-495>

Semantics

In contrast to `undefined`, it expresses the intentional absence of a value.

The `null` type can be assigned to any other type. That is, the type `null` is a subtype of all other types except `undefined`:

`<literal> null leftlt;: </literal> Type}right}right ≠ <literal> undefined </literal> amp;`

Please note that

- `null==undefined` evaluates to `true`
- `null==!=undefined` evaluates to `false`
- `typeof null` evaluates to `object`

Only the `null` keyword is inferred to type `null`. If `null` is assigned to a variable, the type of the variable is not changed. This is true, in particular, for variable declarations. For example in

```
var x = null;
```

the type of variable `x` is inferred to `any` (cf. [???](#)).

The type `null` will be inferred to false in a boolean expression.

The call `typeof null` will return 'object'.

4.5.3. Primitive Boolean Type

Represents a logical entity having two values, true and false.

Please note that a boolean primitive is coerced to a number in a comparison operation so that

Source	Result
<code>var a = true; console.log(a == 1)</code>	<code>prints true</code>
<code>var b = false; console.log(b == 0)</code>	<code>prints true</code>

Semantics

The type is subtype of : `boolean` ; `:any`

Variables of type `boolean` can be auto-converted (coerced) to `Boolean`, as described in [Section 9.1, "Auto-Boxing and Coercing"](#).

4.5.4. Primitive String Type

A finite sequence of zero or more 16-bit unsigned integer values (elements). Each element is considered to be a single UTF-16 code unit.

Also string as primitive type has no properties, you can access the properties available on the object String as string will be coerced to String on the fly but just for that property call, the original variable keeps its type:

```
var a = "MyString"
console.log(typeof a) // string
console.log(a.length) // 8
console.log(typeof a) // string
```

You can handle a primitive `string` like an object type `String` but with these exceptions:

- `typeof "MyString"` is `'string'` but `typeof new String("MyString")` is `'object'`
- `"MyString" instanceof String` or `instanceof Object` will return `false`, for `new String("MyString")` both checks evaluate to `true`
- `console.log(eval("2+2"))` returns `4`, `console.log(eval(new String("2+2")))` returns string `"2+2"`

This marks a difference to Java. In JavaScript, Unicode escape sequences are never interpreted as a special character.

Semantics

The `string` type is a subtype of `any`:

`stringlt;:any`

It is supertype of the N4JS primitive type `pathselector`, and `i18nKey`. Section 4.6.4, “Primitive Pathselector and I18nKey”

However, variables of type `string` can be auto-converted (coerced) to `string`, as described in ???.

4.5.5. Primitive Number Type

In ECMAScript numbers are usually 64-bit floating point numbers. For details see [ECMA11a(p.8.5)]. With prefix `0` you indicate that the number is octal based and with prefix `0x` it is marked as hexadecimal based.

`Nan` can be produced by e.g. `"0 / 0"` or `'1 - x'`. `typeof NaN` will return `number`.

Semantics

The type `number` is subtype of `any : <literal>numberlt;: </literal>any{}`

However, variables of type `number` can be auto-converted (coerced) to `Number`, as described in the section called “Integer Literals” .

4.5.6. Primitive Type int

Actually ECMAScript defines an internal type `int32`. A number of this type is returned by the binary or operation using zero as operand, e.g. ECMAScript’s internal type int32 can be represented in N4JS

by a built-in primitive type called `int`. For details on how numeric literals map to types `number` and `int`, refer to [???](#).



for the time being, built-in type `int` is synonymous to type `number`. This means one can be assigned to the other and a value declared to be of type `int` may actually be a 64-bit floating point number. ¹⁰

4.5.7. Primitive Symbol Type

The primitive type `symbol` is directly as in ECMAScript 6. Support for symbols is kept to a minimum in N4JS. While this primitive type can be used without any restrictions, the only value of this type available in N4JS is the built-in symbol `Symbol.iterator`. Other built-in symbols from ECMAScript 6 and the creation of new symbols are not supported. For more details, see [???](#).

4.6. Primitive N4JS Types

Additionally to the primitive ECMAScript types, the following N4JS-specific primitive types are supported:

- `any`: enables ECMAScript-like untyped variable declarations
- `void`: almost similar to `undefined`, except it can be used as a return type of functions and methods
- `unknown`: inferred in case of a type inference error
- `pathSelector<T>`, `i18nKey`: subtypes of `string`

4.6.1. Any Type

Any type is the default type of all variables for without a type declaration. It has no properties. A value of any other type can be assigned to a variable of type `any`, but a variable declared `any` can only be assigned to another variable declared with the type `any`.

Semantics

`any` is supertype of all other types. That is, $\langle \text{literal} \rangle \text{Type} < / \langle \text{literal} \rangle \text{left}`any} \}$ is an axiom and true for all types.

Type Inference

If a variable is explicitly declared as type `any`, the inferred type of that variable will always be `any`.

IDE-106¹¹

Default Type of Variables

If a type annotation is missing and no initializer is provided, then the type of a variable is implicitly set to `any`.

¹⁰ The rationale for having this limited implementation of type is that API designers already want to start providing hints where later only 32-bit integers will be used. For the time being, **this is checked neither statically nor at runtime!**

¹¹ <https://jira.numberfour.eu/browse/IDE-106>

In that case, the inferred type of that variable will always be `any` as well. If an initializer is provided, the declared type of the variable will be set to the inferred type of the initializer. Therefore in the latter case, the inferred type of the variable will always be the type of the initializer (cf. [???](#)).

If a variable is declared as type `,` it can be used just as every variable can be used in raw ECMAScript. Since every property can be get and set, the types of properties is inferred as as well. This is formally expressed in [Section 10.1.2, “Identifier”](#).

4.6.2. Void Type

The type `void` is the type returned by the ECMAScript `void` operator (see [???](#)), which is similar to `undefined`. However, the type `undefined` cannot be expressed explicitly in type expressions. Instead, it is possible to declare the return type of a function or method as `void` in order to state that the function does not return anything.

Semantics

- The type `void` may only be used to declare the return type of a function or method.
- If a function f is declared to return `void`, an error is created if a return statement contains an expression: $\text{amp};f.\text{returnType} = \text{void}\text{amp};\forall r, \mu(r) = \text{ReturnStatement}, r.\text{containingFunction} = f:r.\text{expression} =$
- If a function f is declared to return `void`, an error is issued if the function is called in any statement or expression but an expression statement directly: $\text{amp};f.\text{returnType} = \text{void}\text{amp};\forall e, \text{bind}(e, f):\mu(e.\text{container}) = \text{ExpressionStatement}$

The following type hierarchy is defined: `void` is only a subtype of itself but not of any other type and no other type is a subtype of void. `voidlt;:void` Since `void` cannot be used as the type of variables, fields, formal parameters, etc., a function or method with a return type of void cannot be used as an lvalue, e.g. it may not appear on the left-hand side of an assignment or in the argument list of a call expression (note the difference to plain JavaScript).

4.6.3. Unknown Type

Internally N4JS defines the type `unknown`. This type cannot be used by the user. Instead, it is inferred in case of errors. `unknown` behaves almost similar to `any+`. However no error messages once a variable or expression has been inferred to `unknown` in order to avoid consequential errors.

4.6.4. Primitive Pathselector and I18nKey

IDE-55 ¹²
IDE-379 ¹³

N4JS introduces three new types which are subtypes of string. These types are, in fact, translated to strings and do not add any new functionality. They are solely defined for enabling additional validation.

¹² <https://jira.numberfour.eu/browse/IDE-55>

¹³ <https://jira.numberfour.eu/browse/IDE-379>

- `pathSelector<T>` is a generic type for specifying path selector expressions. PathSelectors are used to specify a path to a property in a (JSON-like) model tree.
- The type variable defines the context type (or type of the root of the tree) in which the selector is to be validated. A path selector is defined as a string literal that has to conform to the path selector grammar . [PathSelector]. The context type is then used to perform a semantic validation of the path selector.
- is a string which refers to an internationalization key. The type is used to reference resource keys specified in resource files. In a project p , the type defines the transitive set of all resource keys accessible from p . Since resource keys are specified as strings, this means that the type defines a subset of all string literals that can be assigned to a variable of type in the current project. That means that an assignment of a string literal to a variable of type is only valid if that string literal is contained in the set defined by . Resource keys are declared in the properties files of a project and all resource keys from a project are accessible to any project depending on it.

Semantics

The N4JS primitive types `i18nKey` and `pathSelector<T>` are basically only marker types of strings for enabling additional validation. Thus, they are completely interchangeable with string types:
 $i18nKey : string \& string ; i18nKey pathSelector<T> : string \& string ; pathSelector<T> : string$

As special literals for these N4JS types do not exist, the type has to be explicitly specified in order to enable the additional validation. Note that this validation cannot be applied for more complicated expressions with parts which cannot be evaluated at compile time. For example, cannot be evaluated at compile time.

4.7. Built-in ECMAScript Object Types

N4JS supports all built-in ECMAScript objects [ECMA11a(p.S15)], interpreted as classes. Some of these object types are object versions of primitive types. The object types have the same name as their corresponding primitive type, but start with an upper case letter.

IDE-40¹⁴

The following types, derived from certain ECMAScript predefined objects and constructs, are supported by means of built-in types as they are required by certain expressions.

- `Object` [ECMA11a(p.p111)];
- `Function` [ECMA11a(p.p117)]; representing functions and function objects `???` but also methods (`???`)
- `Array` [ECMA11a(p.p122)], representing array objects, see Section 4.7.4, “Array Object Type”
- `String` [ECMA11a(p.p141)]
- `Boolean` [ECMA11a(p.p141)]
- `Number` [ECMA11a(p.p141)]

¹⁴ <https://jira.numberfour.eu/browse/IDE-40>

- `RegExp` [ECMA11a(p.p180)]; they can be constructed by means of special literals (cf. Section 10.1.3, “Literals”)
- global object type
- `Symbol`
- `Promise`
- `Iterator` and `Iterable`

All other ECMAScript types ([ECMA11a(p.S15)], such as `Math`, `Date`, or `Error` are supported by means of predefined classes. ECMAScript 2015 types are defined in the ECMAScript 2015 runtime environment. Since they are defined and used similar to user defined classes, they are not explained in further detail here. These predefined objects are kind of subtypes of .

4.7.1. Semantics

It is not possible to inherit from any of the built-in ECMAScript object types except for `Object` and `Error`, that is, to use one of these types as supertype of a class. From the N4JS language’s point of view, these built-in types are all final.

4.7.2. Object Type

`Object` [ECMA11a(p.S8.6)] is the (implicit) supertype of all declared (i.e., non-primitive) types, including native types. It models the ECMAScript type `Object`, except that no properties may be dynamically added to it. In order to declare a variable to which properties can be dynamically added, the type `Object+` has to be declared (cf. Section 4.9, “Type Modifiers”).

4.7.3. Function Object Type

The built-in object type `Function`, a subtype of `Object`, represents all functions, regardless of how they are defined (either via function expression, function declaration, or method declaration). They are described in detail in Section 4.7.3, “Function Object Type”.

Since `Function` is the supertype of all functions regardless of number and types of formal parameters, return type, and number and bounds of type parameters, it would not normally be possible to invoke an instance of `Function`. For the time being, however, an instance of `Function` can be invoked, any number of arguments may be provided and the invocation may be parameterized with any number of type arguments (which will be ignored), i.e. [req:Function_Call_Constraints] and [req:Parameterized_Function_Call_Constraints] do not apply.

4.7.4. Array Object Type

The `Array` type is generic with one type parameter, which is the item type. An array is accessed with the index operator, the type of the index parameter is `Number`. The type of the stored values is `typeArgs[0]` (cf. ???). Due to type erasure, the item type is not available during runtime, that is to say there are no reflective methods returning the item type of an array.

For an array type `A`, the following conditions must be true:

- $|A.typeArgs| = 1$

4.7.5. String Object Type

Object type version of `string`. It is highly recommend to use the primitive version only. Note that it is not possible to assign a primitive typed value to an object typed variable.

4.7.6. Boolean Object Type

Object type version of `boolean`. It is highly recommend to use the primitive version only. Note that it is not possible to assign a primitive typed value to an object typed variable.

4.7.7. Number Object Type

Object type version of `number`. It is highly recommend to use the primitive version only. Note that it is not possible to assign a primitive typed value to an object typed variable.

4.7.8. Global Object Type

IDE-245 ¹⁵

This is the globally accessible namespace which contains elements such as `undefined`, and in case of browsers, `window`. Depending on the runtime environment, the global object may have different properties defined by means of dynamic polyfills.

4.7.9. Symbol

IDE-1220 ¹⁶

The symbol constructor function of ECMAScript 2015. Support for symbols is kept to a minimum in N4JS:

- creating symbols with `var sym = Symbol("description")` is not supported.
- creating shared symbols with `var sym = Symbol.for("key")` is not supported. Also the inverse `Symbol.keyFor(sym)` is not supported.
- retrieving built-in symbols via properties in `Symbol` is supported, however, the only built-in symbol available in N4JS is the iterator symbol that can be retrieved with `Symbol.iterator`.

The rationale for this selective support for symbols in N4JS is to allow for the use (and custom definition) of iterators and iterables and their application in the loop with as little support for symbols as possible.

4.7.10. Promise

`Promise` is provided as a built-in type as in ECMAScript 2015. Also see [sec:Asynchronous_Functions] for asynchronous functions.

¹⁵ <https://jira.numberfour.eu/browse/IDE-245>

¹⁶ <https://jira.numberfour.eu/browse/IDE-1220>

4.7.11. Iterator Interface

IDE-1220¹⁷

A structurally typed interface for *iterators* as defined by the ECMAScript 6 iterator protocol.

Iterable in N4JS

```
// providedByRuntime
export public interface ~Iterator<T> {
    public next(): IteratorEntry<T>
}

// providedByRuntime
export public interface ~IteratorEntry<T> {
    public done: boolean;
    public value: T?;
}
```

Interface `IteratorEntry` was introduced mainly to work around IDEBUG-273; after solving this bug, this interface could be removed and replaced with a corresponding structural type reference as return type of method `next()`

GH-273¹⁸

4.7.12. Iterable Interface

IDE-1220p¹⁹

A structurally typed interface for objects that can be iterated over, i.e. *iterables* as defined by the ECMAScript 6 iterator protocol.

```
// providedByRuntime
export public interface ~Iterable<T> {
    public [Symbol.iterator](): Iterator<T>
}
```

Note that this interface's method is special in that a symbol is used as identifier. You can use the ordinary syntax for computed property names in ECMAScript 6 for overriding / implementing or invoking this method.

4.8. Built-In N4JS Types

N4JS additionally provides some built-in classes which are always available with the need to explicitly import them.

¹⁷ <https://jira.numberfour.eu/browse/IDE-1220>

¹⁸ <https://github.com/NumberFour/N4JS/issues/273>

¹⁹ <https://jira.numberfour.eu/browse/IDE-1220p>

4.8.1. N4Object

IDE-547²⁰

Although `N4Object` is a built-in type, it is not the default supertype. It is a subtype of `Object`.

Semantics

`<literal> N4Object </literal> | <literal> lt;:: <literal> Object </literal>`

4.8.2. N4Class

The type `N4Class` is used for extended reflection in N4JS.

4.8.3. IterableN

Currently there are built-in types `Iterable2<T1, T2> ... Iterable9<T1, ..., T9>`. They are mainly intended for type system support of array destructuring literals.

Not documented in detail yet, because we want to gain experience with current solution, first, and major refinement might be incoming...

4.9. Type Modifiers

Type expressions can be further described with type modifiers. The type modifiers add additional constraints to the type expression which are then used to perform a stricter validation of the source code. Type modifiers can not be used in type arguments.

The general type modifiers `nullable`, `nonnull` and `dynamic` can be used for variables, attributes, method parameters and method types. Optional and variadic modifiers can only be applied for formal parameters.

4.9.1. Dynamic

IDE-144²¹

The dynamic type modifier marks a type as being dynamic. A dynamic type behaves like a normal JavaScript object, so you can read/write any property and call any method on it. The default behavior for a type is to be static, that is no new properties can be added and no unknown properties can be accessed.

`lt;::` and `lt;::` is always true. Using dynamically added members of a dynamic type is never type safe. Using the operator on a subtype of is not allowed.

15Non-Dynamic Primitive Types[req:Non-Dynamic Primitive Types]

1. All primitive types except `any` must not be declared dynamic.

²⁰ <https://jira.numberfour.eu/browse/IDE-547>

²¹ <https://jira.numberfour.eu/browse/IDE-144>

2. Only parameterized type references and this type reference can be declared dynamic. ²²

4.9.2. Optional

IDE-145 ²³
IDE-1076 ²⁴

Only formal parameters and return types can be marked as optional.

An optional formal parameter can be omitted when calling the function / method; an omitted parameter has the value `undefined`. Every parameter after an optional parameter also has to be optional or variadic.

An optional return type indicates that the function / method need not be left via a return statement with an expression; in that case the return value is `undefined`. For constraints on using the optional modifier, see [Section 4.7.3, “Function Object Type”](#).

4.9.3. Variadic

IDE-146 ²⁵

Only method parameters can be marked as variadic. Marking a parameter as variadic indicates that method accepts a variable number of parameters. A variadic parameter implies that the parameter is also optional as the cardinality is defined as `[0..*$]`. No further parameter can be defined after a variadic parameter.

For a parameter *p*, the following condition must hold: *p.varp.opt*.

A parameter can, however, be declared either optional or variadic. That is to say that one can either write *Type = (optional)* or *8230;8203;Type*, but not *8230;8203;Type =*

Declaring a variadic method parameter of type *T* causes the type of the method parameter to become `Array<T>`. That is, declaring `function(string ...tags)` causes `tags` to be an `Array<string>` and not just a scalar `string` value.

To make this work at runtime, the compiler will generate code that constructs the `method parameter` from the `arguments` parameter explicitly passed to the function.

At runtime, a variadic parameter is never set to undefined. Instead, the array may be empty. This must be true even if preceding parameters are optionally and not arguments are passed at runtime.

GH-106 ²⁶

²² This is a consequence of the syntax definition.

²³ <https://jira.numberfour.eu/browse/IDE-145>

²⁴ <https://jira.numberfour.eu/browse/IDE-1076>

²⁵ <https://jira.numberfour.eu/browse/IDE-146>

²⁶ <https://github.com/NumberFour/N4JS/issues/106>

For more constraints on using the variadic modifier, see [Section 4.7.3, “Function Object Type”](#).

4.10. Union and Intersection Type (Composed Types)

Given two or more existing types, it is possible to compose a new type by forming either the union or intersection of the base types. The following sections define these *union* and *intersection* types in detail.

4.10.1. Union Type

IDE-142²⁷
IDE-385²⁸
IDE-383²⁹

Union type reflect the dynamic nature of JavaScript. Union types can be used almost everywhere (e.g., in variable declarations or in formal method parameters). The type inferencer usually avoids returning union types and prefers single typed joins or meets. *The most common use case for union types is for emulating method overloading*, as we describe later on.

³⁰ and [[Igarashi07a](#)], other languages that explicitly support the notion of union type include Ceylon [[King13a\(p.3.2.4/5\)](#)]

Syntax

For convenience, we repeat the definition of union type expression:

```
UnionTypeExpression: 'union' '{' typeRefs+=TypeRefWithoutModifiers (',' typeRefs  
+=TypeRefWithoutModifiers)* '}';
```

Semantics

An union type states that the type of a variable may be one or more types contained in the union type. In other words, a union type is a kind of type set, and the type of a variable is contained in the type set. Due to interfaces, a variable may conform to multiple types.

For a given union type $U = T_1, T_n$, the following conditions must hold:

1. Non-empty: At least one element has to be specified: $U.typeRefs \neq \emptyset$ ($n \geq 1$)
2. Non-dynamic: The union type itself must not be declared dynamic: $\neg U.dynamic$
3. Non-optional elements: $\forall T \in U.typeRefs \neg T.opt$

Let U be an union type.

- The union type is a common supertype of all its element types: $Tlt;:UT \in U.typeRefs$

²⁷ <https://jira.numberfour.eu/browse/IDE-142>

²⁸ <https://jira.numberfour.eu/browse/IDE-385>

²⁹ <https://jira.numberfour.eu/browse/IDE-383>

³⁰ For type theory about union types, [[Pierce02\(p.a15.7\)](#)

- More generally, a type is a subtype of a union type, if it is a subtype of at least one type contained in the union: $\text{Slt};:U \exists T \in U.\text{typeRefs}: \text{Slt};:T$
- A union type is a subtype of a type S , if all types of the union are subtypes of that type. ^{31}} $\} [U\text{lt};:S \forall T \in U.\text{typeRefs}:T \text{lt};:S]$
- Commutativity: The order of element does not matter: $A, B = B, A$
- Associativity: $A, B, C = A, B, C$
- Uniqueness of elements: A union type may not contain duplicates (similar to sets): $\& \forall 1 \leq i \leq k \leq n, T_1, T_n : T_i \neq T_k$

Let U be an union type. The following simplification rules are always automatically applied to union types.

- Simplification of union type with one element: If a union type contains only one element, it is reduced to the element: $T T$
- Simplification of union types of union types: A union type U containing another union types V is reduced to a single union type W , with $W.\text{typeRefs} = U.\text{typeRefs} \cup V.\text{typeRefs}$: $S_1, S_{k-1}, T_1, T_m, S_{k+1}, S_n S_1, S_{k-1}, T_1, T_m, S_{k+1}, S_n$
- Simplification of union type with undefined or null: Since undefined is the bottom type, and null is kind of a second bottom type, they are removed from the union: $T_1, T_{k-1}, <\text{literal}> \text{undefined}, T_k, T_n \} T_1, T_{k-1}, T_k, T_n T_1, T_{k-1}, T_k, T_n$
Note that the simplification rules for union types with one element are applied first.
- The structural typing strategy is propagated to the types of the union: $T_1, \dots, T_n T_1, T_n$

Remarks:

- The simplification rules may be applied recursively.
- For given types $B\text{lt};:A$, and the union type $U = A, B$, $U \neq B$. The types are equivalent, however: $A\text{lt};:U$ and $U\text{lt};:A$.

³²), in which the union is defined to be **the same type as** A . Although the meaning of **same** is not clear, it is possibly used as a synonym for **equivalent**.]

Let A , B , and C be defined as in the chapter beginning ($C\text{lt};:B\text{lt};:A$)

The following subtyping relations with union types are to be evaluated as follows ³³:

$A <: \text{union}\{A\}$	$\rightarrow \text{true}$
$A <: \text{union}\{A, B\}$	$\rightarrow \text{true}$
$B <: \text{union}\{A, B\}$	$\rightarrow \text{true}$
$C <: \text{union}\{A, B\}$	$\rightarrow \text{true}$
$A <: \text{union}\{B, C\}$	$\rightarrow \text{false}$
$B <: \text{union}\{B, C\}$	$\rightarrow \text{true}$
$C <: \text{union}\{B, C\}$	$\rightarrow \text{true}$
$\text{union}\{A\} <: A$	$\rightarrow \text{true}$
$\text{union}\{B\} <: A$	$\rightarrow \text{true}$

³¹ This rule is a generalization of the sub typing rules given in [Igarashi07a(p.p.40)

³² This is different from Ceylon ([King13a(p.3.2.3)

³³ See Example Class Hierarchy for class definitions.

union{B,C} <: A	-> true
union{A,B} <: B	-> false
union{X,Z} <: union{Z,X}	-> true
union{X,Y} <: union{X,Y,Z}	-> true
union{X,Y,Z} <: union{X,Y}	-> false

The simplification constraints are used by the type inferrer. It may be useful, however, to define union types with superfluous elements, as the next example demonstrates

[[ex:Superfluous elements in union type]]

```
class A{}  
class B extends A{}  
class C extends A{}  
  
function foo(p: union{A,B}) {..}
```

Although **B** is superfluous, it may indicate that the function handles parameters of type differently than one of type **A** or **C**.

Although a union type is a **LCST** of its contained (non-superfluous) types, the type inferrer usually does not create new union types when computing the join of types. If the join of types including at least one union type is calculated, the union type is preserved if possible. The same is true for meet.

For the definition of join and meet for union types, we define how a type is added to a union type:

The union of union types is defined similar to the union of sets. The union is not simplified, but it contains no duplicates.

If a type *A* is contained in a union type, then the union type is a common supertype, and (since it is the union itself) also the **LCST** of both types. This finding is the foundation of the definition of join of a (non-union) type with a union type:

The join *J* of a union type *U* with a type *T* is the union of both types: $amp;(UT) = JJ = U \cup T$

Remarks:

- Joining a union type with another type is not similar to joining the elements of the union type directly with another type. That is *A* join $union\{B, C\} \neq A$ join *B* join *C*
- The computed join is simplified according to the constraints defined above.

The meet of union types is defined as the meet of the elements. That is $amp;T_1, T_n ST_1 ST_n Samp;T_1, T_n S_1, S_m T_1 S_1, T_1 S_m, T_n S_1, T_n S_m$

Remarks:

- The meet of a union type with another type is not a union type itself. This gets clear when looking at the definition of meet and union type. While for a given $U = A, B, Alt;:U$ and $Blt;:U$, the opposite $Ult;:A$ is usually not true (unless *U* can be simplified to *A*). So, for AU , usually *U* cannot be the meet.

The upper and lower bound of a union type *U* is a union type *U'* containing the upper and lower bound of the elements of *U*: $upper(T_1, T_n) := upper(T_1),, upper(T_1) lower(T_1, T_n) := lower(T_1),, lower(T_1)$

Warnings

In case the `any` type is used in a union type, all other types in the union type definition become obsolete. However, defining other types along with the `any` type might seem reasonable in case those other types are treated specifically and thus are mentioned explicitly in the definition. Nevertheless the use of the `any` type produces a warning, since its use can indicate a misunderstanding of the union type concept and since documentation can also be done in a comment.

No union type shall contain an type: $any \in U.typeRefs$

Similar to the documentary purpose of using specific classes along with the `any` type is the following case. When two types are used, one of them a subtype of the other, then this subtype is obsolete. Still it can be used for documentary purposes. However, a warning will be produced to indicate unnecessary code. The warning is only produced when both of the types are either classes or interfaces, since e.g. structural types are supertypes of any classes or interfaces.

Union types shall not contain class or interface types which are a subtype of another class or interface type that also is contained in the union type.
 $TT \in U.typeRefs : \exists T \in U.typeRefs : (TT \text{lt;} : T \wedge \text{isClassOrInterface}(T) \wedge \text{isClassOrInterface}(TT))$

4.10.2. Intersection Type

IDE-142 35

IDE-385 36

IDE-383 37

Intersection type reflects the dynamic nature of JavaScript, similar to union type. As in Java, intersection type is used to define the type boundaries of type variables in type parameter definitions. They are inferred by the type inferencer for type checking (as a result of join or meet). In contrast to Java, however, intersection type can be declared explicitly by means of intersection type expression. ³⁸ and [Laurent12a], other languages supporting explicit notion of intersection type include Ceylon [King13a(p.3.2.4/5)].

Syntax

For convenience, we repeat the definition of intersection type expression and of type variables in which intersection types can be defined as in Java:

```
IntersectionTypeExpression: 'intersection' '{' typeRefs+=TypeRefWithoutModifiers (','
typeRefs+=TypeRefWithoutModifiers)* '}';

```

³⁴ <https://github.com/NumberFour/N4JS/issues/260>

³⁵ <https://jira.numberfour.eu/browse/IDE-142>

³⁶ <https://jira.numberfour.eu/browse/IDE-385>

³⁷ <https://jira.numberfour.eu/browse/IDE-383>

³⁸ For type theory about intersection types, see and , other languages supporting explicit notion of intersection type include Ceylon [Pierce02a(p.15.7)]

```
TypeVariable: name=IDENTIFIER ('extends' declaredUpperBounds+=ParameterizedTypeRefNominal
('&' declaredUpperBounds+=ParameterizedTypeRefNominal)*)?
```

Semantics

An intersection type may contain several interfaces but only one class. It virtually declares a subclass of this one class and implements all interfaces declared in the intersection type. If no class is declared in the intersection type, the intersection type virtually declares a subclass of an N4Object instead. This virtual subclass also explains why only one single class may be contained in the intersection.

27Intersection Type For a given intersection type I , the following conditions must hold:

1. The intersection must contain at least one type: $I.typeRefs \neq \emptyset$

2. Only one class must be contained in the intersection type:

$$(\exists C \in I.typeRefs; \mu 169; = <\text{literal}> Class) \} T \in I.typeRefs \setminus C; \mu(T) = <\text{literal}> Class\}$$

For the time being, only a warning is produced when more than one class is contained in the intersection type .

IDE-2302 ³⁹

3. Non-optional elements: $\forall T \in I.typeRefs \neg T.opt$

28Intersection Type Subtyping Rules[Intersection Type Subtyping Rules] Let I be an intersection type.

- An intersection type is a subtype of another type, if at least one of its contained types is a subtype of that type: footnote:[This rule is a generalization of the subtyping rules given in

[Laurent12a]Table 2, \$\cap^1\$ and \$\cap^2\$

$Ilt;:S \exists T \in I.typeRefs: Tlt;:S$

- A type is a subtype of an intersection type, if it is a subtype of all types contained in the intersection type: ⁴⁰ Table 2, \$\cap^1\$ and \$\cap^2\$

$Slt;:I \forall T \in I.typeRefs: Slt;:T$

- Non-optional elements: $\forall T \in I.typeRefs \neg T.opt$

Let I be an intersection type. The following simplification rules are always automatically applied to intersection types.

- The structural typing strategy is propagated to the types of the intersection: $T_1, \dots, T_n T_1, T_n$

These subtyping rules are similar to Ceylon. ⁴¹]

³⁹ <https://jira.numberfour.eu/browse/IDE-2302>

⁴⁰ This rule is a generalization of the subtyping rules given in [Laurent12a]

⁴¹ In Ceylon, for a given union type $U = T_1 | T_2$ and intersection type $I = T_1 \& T_2$ (with ' $|$ ' is union and ' $\&$ ' is intersection), $T_1lt;:U$ and $T_2lt;:U$ is true, and $T_1lt;:I$ and $T_2lt;:I$ is true. We should define that as well (if it is not already defined). Cf [King13a(p.3.2.4/5)]

During validation, intersection types containing union or other intersection types may be inferred. In this case, the composed types are flattened. The aforementioned constraints must hold. We also implicitly use this representation in this specification.

Let A, B, and C be defined as in the chapter beginning ($Clt::Blt::A$)

The following subtyping relations with intersection types are to be evaluated as follows ⁴²:

A <: intersection{A}	-> true
A <: intersection{A,A}	-> true
intersection{A,X} <: A	-> true
intersection{X,A} <: A	-> true
A <: intersection{A,X}	-> false
intersection{A,X} <: intersection{X,A}	-> true
H12 <: intersection{I1,I2}	-> true
intersection{I1,I2} <: H12	-> false
H1 <: intersection{I1,I2}	-> false
H23 <: intersection{I1,I2}	-> false
B <: intersection{A}	-> true
intersection{I1,I2} <: I	-> true
H12 <: intersection{I,I2}	-> true
A <: intersection{A,Any}	-> true
intersection{A,Any} <: A	-> true

The join of intersection types is defined as the join of the elements. That is $\text{amp};T_1, T_n ST_1 ST_n Samp;T_1, T_n S_1, S_m T_1 S_1, T_1 S_m, T_n S_1, T_n S_m$

30Meet with intersection Type[req:Meet_with_intersection_Type] The meet of intersection types is defined over their elements. That is $\text{amp};T_1, T_n ST_1 S_1, T_n Samp;T_1, T_n S_1, S_m T_1 S_1, T_1 S_m, T_n S_1, T_n S_m$

The upper and lower bound of an intersection type I is a union type I' containing the upper and lower bound of the elements of I :
 $\text{upper}(T_1, T_n) := \text{upper}(T_1),, \text{upper}(T_1)$ $\text{lower}(T_1, T_n) := \text{lower}(T_1),, \text{lower}(T_1)$

GH-260 ⁴³

Warnings

Using `any` types in intersection types is obsolete since they do not change the resulting intersection type. E.g. the intersection type of A, B and `any` is equivalent to the intersection type of A and B. However, using the `any` type is no error because it can be seen as a neutral argument to the intersection. Nevertheless the use of the `any` type produces a warning, since its use can indicate a misunderstanding of the intersection type concept and since it always can be omitted.

No intersection type shall contain an type: $\text{any} \in I.typeRefs$

The use of the `any` type in an intersection type is similar to the following case. When two types are used, one of them a supertype of the other, then this supertype is obsolete. Hence, a warning will be

⁴² See Example Class Hierarchy for class definitions.

⁴³ <https://github.com/NumberFour/N4JS/issues/260>

produced to indicate unnecessary code. The warning is only produced when both of the types are either classes or interfaces, since e.g. structural types are supertypes of any classes or interfaces.

Intersection types shall not contain class or interface types which are a supertype of another class or interface type that also is contained in the intersection type.
 $T \in I.typeRefs : \exists TT \in I.typeRefs : (TT \subset; T \wedge isClassOrInterface(T) \wedge isClassOrInterface(TT))$

4.10.3. Composed Types in Wildcards

Composed types may appear as the bound of a wildcard. The following constraints apply ⁴⁴

A composed type may appear as the upper or lower bound of a wildcard. In the covariant case, the following subtype relations apply:

```
union{ G<? extends A>, G<? extends B> } <: G<? extends union{A,B}>
G<? extends intersection{A,B}> <: intersection{ G<? extends A>, G<? extends B> }
```

In the contra variant case, the following subtype relations apply:

```
union{ G<? super A>, G<? super B> } <: G<? super intersection{A,B}>
G<? super union{A,B}> <: intersection{ G<? super A>, G<? super B> }
```

4.10.4. Property Access for Composed Types

It is possible to directly access properties of union and intersection types. The following sections define which properties are accessible.

Properties of Union Type

As an (unfortunately oversimplified) rule of thumb, the properties of a union type $U = T_1 \sqcup T_2$ are simply the intersection of the properties $U.properties = T_1.properties \cap T_2.properties$. It is not quite that simple, however, as the question of "equality" with regards to properties has to be answered.

For a given union type $U = T_1 \sqcup T_2$, the following constraints for its members must hold:

$\forall a \in U.attributes :$

$\text{amp}; \forall k \in \{1, 2\} : \exists a_k \in T_k.attributes : a_k.access > private \text{amp}; \wedge a.access = \min(a_1.access, a_2.access) \text{amp}; \wedge a.name = a_1.name = a_2.name \text{amp}; \wedge a.type = a_1.type = a_2.type$

$\forall m \in U.methods :$

$\text{amp}; \exists m_1 \in T_1.methods, m_2 \in T_2.methods, \text{amp}; \quad \text{with } p = m.f.parse \wedge p' = m_1.f.parse \wedge p'' = m_2.f.parse, \text{WLOG } |p| \leq |p'| : \text{amp}; \quad \forall k \in \{1, 2\} : \exists a_k \in T_k.attributes : a_k.access > private \text{amp}; \wedge a.access = \min(a_1.access, a_2.access) \text{amp}; \wedge a.name = a_1.name = a_2.name \text{amp}; \wedge a.type = a_1.type = a_2.type$

Remarks on union type's members:

- Fields of the same type are merged to a composed field with the same type. Fields of different types are merged to a getter and setter.

⁴⁴ see "Covariance and contravariance with unions and intersections" at <http://ceylon-lang.org/documentation/1.1/tour/generics/>

- The return type of a composed getter is the *union* type of the return types of the merged getters.
- The type of a composed setter is the *intersection* type of the types of the merged setters.
- Fields can be combined with getters and/or setters:
 - fields combined with getters allow read-access.
 - non-const fields combined with setters allow write-access.
 - non-const fields combined with getters *and* setters, i.e. each type has either a non-const field or both a getter and a setter of the given name, allow both read- and write-access.

Again, types need not be identical; for read-access the *union* of the fields' types and the getters' return types is formed, for write-access the *intersection* of the fields' types and the setters' types is formed. In the third case above, types are combined independently for read- and write-access if the getters and setters have different types.

- The name of a method's parameter is only used for error or warning messages and cannot be referenced otherwise.
- The return type of a composed method is the *union* type of the return types of the merged methods.
- A composed method parameter's type is the *intersection* type of the merged parameters types.

Properties of Intersection Type

As an (unfortunately oversimplified) rule of thumb, the properties of an intersection type $I = T_1 \& T_2$ are the union of properties $I.properties = T_1.properties \cup T_2.properties$. It is not quite that simple, however, as the question of "equality" with regards to properties has to be answered.

For a given intersection type $I = T_1 \& T_2$, the following constraints for its members must hold:
 $\forall a \in I.attributes:$

$$\text{amp;} (\exists a_1 \in T_1.attributes, a_1.accgt;private) \vee (\exists a_2 \in T_2.attributes, a_2.accgt;private) \text{amp;} \wedge a.name = \begin{cases} a_1.name & \text{amp;} a_1 \neq null \wedge (a_2.name \\ \text{amp;} \dots) \end{cases}$$

$\forall m \in I.methods:$

$$\text{amp;} (\exists m_1 \in T_1.methods, m_1.accgt;private) \vee (\exists m_2 \in T_2.methods, m_2.accgt;private) : \text{amp;} \quad \text{with } p = m.f \text{ parsamp;} \quad \wedge \text{if } m_1 \text{ exists}$$

Remarks on intersection type's methods:

- The name of a method's parameter is only used for error or warning messages and cannot be referenced otherwise.
- The return type of a method is the *intersection* type of the return types of the merged methods.
- A method parameter's type is the *union* type of the merged parameters types.

4.11. Constructor and Classifier Type

A class definition as described in [Section 5.3, “Classes”](#) declares types. Often, it is necessary to access these types directly, for example to access static members or for dynamic construction of instances.

These two use cases are actually slightly different and N4JS provides two different types, one for each use case: constructor and classifier type.⁴⁵ The constructor is basically the classifier type with the additional possibility to call it via in order to create new instances of the declared type.

Both `meta` types are different from Java's type `Class<T>`, as the latter has a defined set of members, while the N4JS metatypes will have members according to a class definition. The concept of constructors as metatypes is similar to ECMAScript 2015 [ECMA15a(p.14.5)]..

4.11.1. Syntax

```
ConstructorTypeRef returns ConstructorTypeRef: 'constructor' '{}' typeArg = [TypeArgument]
' }';

ClassifierTypeRef returns ClassifierTypeRef: 'type' '{}' typeArg = [TypeRef] ' }';
```

4.11.2. Semantics

 IDE-786⁴⁶

1. Static members of a type T are actually members of the classifier type .
2. The keyword in a static method of a type T actually binds to the classifier type .
3. The constructor type is a subtype of the classifier type :
 $\forall T:<\text{literal}>\text{constructor}\{T\} </\text{literal}>\text{lt};:<\text{literal}>\text{type}\{T\} </\text{literal}>$
4. If a class B is a subtype (subclass) of a class A , then the classifier type also is a subtype of :
 $<\text{literal}>\text{type}\{B\} </\text{literal}>\text{lt};:<\text{literal}>\text{type}\{A\} </\text{literal}>\text{Blt};:A$
5. If a class B is a subtype (subclass) of a class A , and if the constructor function of B is a subtype of the constructor function of A , then the classifier type also is a subtype of :
 $<\text{literal}>\text{constructor}\{B\} </\text{literal}>\text{lt};:<\text{literal}>\text{constructor}\{A/\text{literal}>\} \text{Blt};:A \& B.\text{ctorlt};:A.\text{ctor}$ The subtype relation of the constructor function is defined in . In the case of the default constructor, the type of the object literal argument depends on required attributes.

This subtype relation for the constructor type is enforced if the constructor of the super class is marked as `final`, see [???](#) for details.

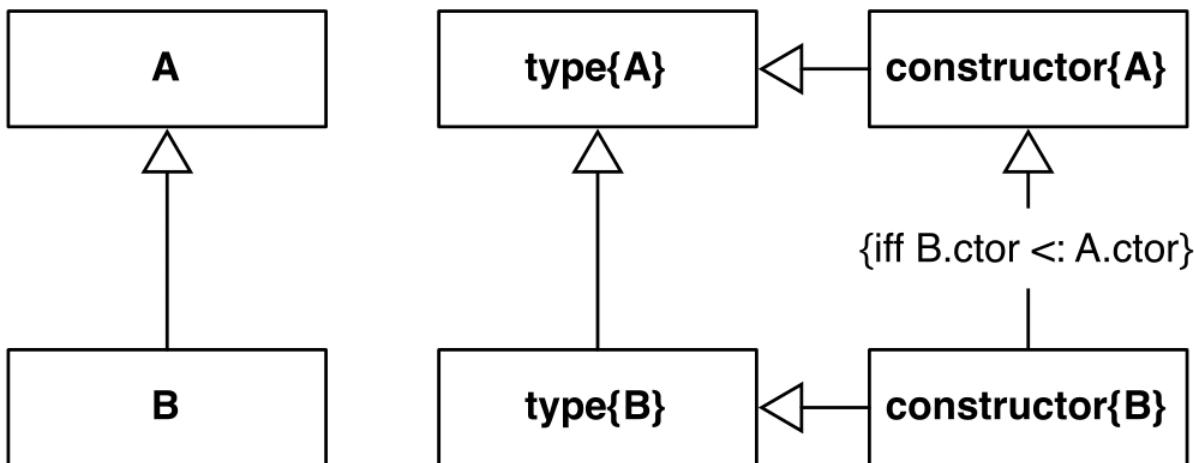
6. The type of a classifier declaration or classifier expression is the constructor of that class:
 $C:\text{constructor}[C]\} \{\mu\text{C} \in \{ \text{type}\{\text{classifierDefinition}\} \} \} \text{end}\{\text{aligned}\}\}]$
7. A class cannot be called as a function in ECMAScript. Thus, the constructor and type type are only subtype of :
 $\forall T:\forall T:\text{amp};\text{constructor}\{T\} \text{lt};:\text{Object}\text{amp};\text{type}\{T\} \text{lt};:\text{Object}$
8. If the type argument of the constructor is not a declared type (i.e., a wildcard or a type variable with bounds), the constructor cannot be used in a new expression. Thus, the constructor function signature becomes irrelevant for subtype checking. In that case, the following rules apply:
 $\text{constructor}\{S\} \text{lt};:\text{constructor}\{T\} S.\text{upperlt};:T.\text{upperamp};\text{amp};T.\text{lowerlt};:S.\text{loweramp};\text{amp};\mu(T) \neq \text{DeclaredTypeWithAccessMo}$

⁴⁵ The classifier type is, in fact, the `type type` or `metatype` of a type. We use the term classifier type in the specification to avoid the bogus `type type` terminology.

⁴⁶ <https://jira.numberfour.eu/browse/IDE-786>

Note that this is only true for the right hand side of the subtyping rule. A constructor type with a wildcard is never a subtype of a constructor type without a wildcard.

The figure [Figure 4.2, “Classifier and Constructor Type Subtype Relations”](#) shows the subtype relations defined by the preceding rules.



[Figure 4.2. Classifier and Constructor Type Subtype Relations](#)

Consequences:

- Overriding of static methods is possible and by using the constructor or classifier type, polymorphism for static methods is possible as well.

[\[\[ex:Static Polymorphism\]\]](#)

```

class A {
    static foo(): string { return "A"; }
    static bar(): string { return this.foo(); }
}
class B extends A {
    @Override
    static foo(): string { return "B"; }
}

A.bar(); // will return "A"
B.bar(); // will return "B", as foo() is called polymorphical
  
```

- It is even possible to refer to the constructor of an abstract class. The abstract class itself cannot provide this constructor (it only provides a type..), that is to say only concrete subclasses can provide constructors compatible to the constructor.

[\[\[ex:Constructor of Abstract Class\]\]](#)

```
abstract class A {}
```

⁴⁷ <https://github.com/NumberFour/N4JS/issues/221>

```
class B extends A {}  
function f(ctor: constructor{A}): A { return new ctor(); }  
  
f(A); // not working: type{A} is not a subtype of constructor{A}.  
f(B); // ok
```

Allowing wildcards on constructor type references has pragmatic reasons. The usage of constructor references usually indicates very dynamic scenarios. In some of these scenarios, e.g., in case of dynamic creation of objects in the context of generic testing or injectors, arbitrary constructors may be used. Of course, it won't be possible to check the correct new expression call in these cases – and using new expressions is prevented by N4JS if the constructor reference contains a wildcard. But other constraints, implemented by the client logic, may guarantee correct instantiation via more dynamic constructors, for example via the ECMAScript 2015 reflection API. In order to simplify these scenarios and preventing the use of `any`, wildcards are supported in constructors. Since a constructor with a wildcard cannot be used in a new expression anyway, using a classifier type is usually better than using a constructor type with wildcard.

Using wildcards on classifier types would have the same meaning as using the upper bound directly. That is, a type reference `type{? extends C}` can simply be replaced with `type{C}`, and `type{?}` with `type{any}`.

To conclude this chapter, let us compare the different types introduced above depending on whether they are used with wildcards or not:

1. having a value of type `constructor{C}`, we know we have ...

- a constructor function of `{C}` or a subclass of `{C}`,
- that can be used for instantiation (i.e. the represented class is not abstract),
- that has a signature compatible to the owned or inherited constructor of `{C}`.

This means we have the constructor function of class `{C}` (but only if is non-abstract) or the constructor function of any non-abstract subclass of `{C}` with an override compatible signature to that of `{C}`'s constructor function.

2. having a value of type `constructor{? extends C}`, we know we have ...

- a constructor function of `{C}` or a subclass of `{C}`,
- that can be used for instantiation (i.e. the represented class is not abstract).

So, same situation as before except that we know nothing about the constructor function's signature. However, if `{C}` has a covariant constructor, cf. [???](#), we can still conclude that we have an override compatible constructor function to that of `{C}`, because classes with covariant constructors enforce all their subclasses to have override compatible constructors.

3. have a value of type `type{? extends C}` or `type{C}` (the two types are equivalent), we know we have ...

- an object representing a type (often constructor functions are used for this, e.g. in the case of classes, but could also be a plain object, e.g. in the case of interfaces),
- that represents type `{C}` or a subtype thereof,

- that cannot be used for instantiation (e.g. could be the constructor function of an abstract class, the object representing an interface, etc.).

Slightly simplified, we can say that in the first above case we can always use the value for creating an instance with `new`, in the second case only if the referenced type has a covariant constructor, cf. ???, and never in the third case.

4.11.3. Constructors and Prototypes in ECMAScript 2015

The figure below for two classes A and B in ECMAScript 2015 shows the constructors, prototypes, and the relations between them for the following ECMAScript 2015 code.

```
class A {}  
class B extends A {}  
  
var b = new B();
```

Note that the diagram shows plain ECMAScript 2015 only. Further note that `A` is defined without an `extends` clause, which is what ECMAScript 2015 calls a *base class* (as opposed to a *derived class*). The constructor of a base class always has `Function.prototype` as its prototype. If we had defined `A` as `class A extends Object {}` in the listing above, then the constructor of `A` would have `Object`'s constructor as its prototype (depicted in as a dashed red arrow), which would make a more consistent overall picture.

[[Constructors and prototypes]] image::fig/ctorsProtosInES6.png[title="Constructors and prototypes for two classes A and B in ECMAScript 2015 (not N4JS!)"]

Base classes in the above sense are not available in N4JS. If an N4JS class does not provide an `extends` clause, it will implicitly inherit from built-in class `N4Object`, if it provides an `extends` clause stating `Object` as its super type, then it corresponds to what is shown in ??? with the red dashed arrow.

4.12. This Type

IDE-377⁴⁸
IDE-785⁴⁹
GH-228⁵⁰

The keyword may represent either a literal (cf. ???) or may refer to the type. In this section, we describe the latter case.

Typical use cases of the type include:

- declaring the return type of instance methods
- declaring the return type of static methods

⁴⁸ <https://jira.numberfour.eu/browse/IDE-377>

⁴⁹ <https://jira.numberfour.eu/browse/IDE-785>

⁵⁰ <https://github.com/NumberFour/N4JS/issues/228>

- as formal parameter type of constructors in conjunction with use-site structural typing
- the parameter type of a function type expression, which appears as type of a method parameter
- the parameter type in a return type expression (`this`, `constructor{this}`)
- an existential type argument inside a return type expression for methods (e.g. `ArrayList<? extends this> method() {...}`)

The precise rule where it may appear is given below in [???](#).

The `this` type is similar to a type variable, and it is bound to the declared or inferred type of the receiver. If it is used as return type, all return statements of the methods must return the `this` keyword or a variable value implicitly inferred to a `this` type (e.g. `var x = this; return x;`).

[[Simple This Type]] .Simple This Type

```
class A {  
    f(): this {  
        return this;  
    }  
}  
class B extends A {}  
  
var a: A; var b: B;  
a.f(); // returns something with the type of A  
b.f(); // returns something with the type of B
```

`this` can be thought of as a type variable which is implicitly substituted with the declaring class (i.e. this type used in a class `{A}` actually means `<? extends A>`).

4.12.1. Syntax

```
ThisTypeRef returns ThisTypeRef:  
    ThisTypeRefNominal | ThisTypeRefStructural;  
  
ThisTypeRefNominal returns ThisTypeRefNominal:  
    {ThisTypeRefNominal} 'this'  
;  
ThisTypeRefStructural returns ThisTypeRefStructural:  
    typingStrategy=TypingStrategyUseSiteOperator  
    'this'  
    ('with' '{' ownedStructuralMembers+=TStructMember* '}')?  
;
```

The keyword `this` and the type expression `this` look similar, however they can refer to different types. The type always refers to the type of instances of a class. The `this` keyword refers to the type of instances of the class in case of instance methods, but to the classifier the of the class in case of static methods. See [???](#) for details.

[[ex:This keyword and type in instance and static context]] Note that the following code is not working, because some usages below are not valid in N4JS. This is only to demonstrate the types.

```
class C {
    instanceMethod() {
        var c: this = this;
    }
    static staticMethod() {
        var C: type{this} = this;
    }
}
```

Structural typing and additional members in structural referenced types is described in [???](#).

4.12.2. Semantics

[[req:37 This Type]]

IDE-538 ⁵¹

- used in the context of a class is actually inferred to an existential type inside the class itself.
- the type may only be used
 - as the type of a formal parameter of a constructor, if and only if combined with use-site structural typing.
 - at covariant positions within member declarations, except for static members of interfaces.

Remarks

- Due to the function subtype relation and constraints on overriding methods (in which the overriding method has to be a subtype of the overridden method), it is not possible to use the type in formal parameters but only as return type. The following listing demonstrates that problem:

```
class A {
    bar(x: this): void { ... } // error
    // virtually defines: bar(x: A): void
}
class B extends A {
    // virtually defines: bar(x: B): void
}
```

As the `this` type is replaced similar to a type variable, the virtually defined method `bar` in is not override compatible with `bar` in `{A}`.

In case of constructors, this problem does not occur because a subclass constructor does not need to be override compatible with the constructor of the super class. Using `this` as the type of a constructor's parameter, however, would mean that you can only create an instance of the class if you already have an instance (considering that due to the lack of method overloading a class can have only a single constructor), making creation of the first instance impossible. Therefore, `this` is also disallowed as the type of a constructor's parameter.

⁵¹ <https://jira.numberfour.eu/browse/IDE-538>

- The difference between the type `this` and the keyword `this` is when and how the actual type is set: The actual type of the `this` type is computed at compile (or validation) time and is always the containing type (of the member in which the type expression is used) or a subtype of that type – this is not a heuristic, this is so by definition. In contrast, the actual type of the keyword `this` is only available at runtime, while the type used at compilation time is only a heuristically computed type, in other words, a good guess.
- The value of the `this` type is, in fact, not influenced by any `@This` annotations. Instead of using `this` in these cases, the type expressions in the `@This` annotations can be used.
- The `this` type is always bound to the instance-type regardless of the context it occurs in (non-static or static). To refer to the this-classifier (static type) the construct `type{this}` is used.

IDE-785 52

[[ex:this type in function-type-expression]]

```
class A {
    alive: boolean = true;
    methodA(func: {function(this)}): string {
        func(this); // applying the passed-in function
        return "done";
    }
}
```

The use of `this` type is limited to situations where it cannot be referred in mixed co- and contra-variant ways. In the following example the problem is sketched up. 53

GH-263 54

[[ex:problems with this type and type arguments]]

```
// Non-working example, see problem in line 15.
class M<V> { public value: V; }
class A {
    public store: M<{function(this)}>; // usually not allowed, but let's assume it would be
    possible----
}
class B extends A { public x=0; } // type of store is M<{function(B)}>

var funcA = function(a: A) {/*...something with a...*/}
var funcB = function(b: B) { console.log(b.x); }
var a: A = new A(); var b: B = new B();
b.store.value = funcA // OK, since {function(A)} <: {function(B)}
b.store.value = funcB // OK.

var a2: A = b; // OK, since B is a subtype of A
a2.store.value( a ) // RUNTIME ERROR, the types are all correct, but remember b.store.value
was assigned to funcB, which can only handle subtypes of B !
```

52 <https://jira.numberfour.eu/browse/IDE-785>

53 The phenomenon is described in IDEBUG-263

54 <https://github.com/NumberFour/N4JS/issues/263>

4.13. Enums

IDE-327 [55](#)
IDE-980 [56](#)

Enums are an ordered set of literals. Although enums are not true classes, they come with built-in methods for accessing value, name and type name of the enum.

In N4JS, two flavours of enumerations are distinguished: ordinary enums (N4JS) and string based enums. Ordinary enums (or in short, enums) are used while programming in N4JS. String based enums are introduced to access enumerations derived from standards, mainly developed by the W3C, in order to access the closed set of string literals defined in webIDL syntax.

4.13.1. Enums (N4JS)

Definition and usage of an enumeration:

```
// assume this file to be contained in a package "myPackage"
enum Color {
    RED, GREEN, BLUE
}

enum Country {
    DE : "276",
    US : "840",
    TR : "792"
}

var red: Color = Color.RED;
var us: Country = Country.US;

console.log(red.name); // --> RED
console.log(red.value); // --> RED
console.log(red.n4class.fqn); // --> myPackage.Color
console.log(red.toString()); // --> RED

console.log(us.name); // --> US
console.log(us.value); // --> 840
console.log(us.n4classfqn); // --> myPackage.Country
console.log(us.toString()); // --> 840
```

Syntax

IDE-8 [57](#)
IDE-327 [58](#)

[55](#) <https://jira.numberfour.eu/browse/IDE-327>

[56](#) <https://jira.numberfour.eu/browse/IDE-980>

[57](#) <https://jira.numberfour.eu/browse/IDE-8>

[58](#) <https://jira.numberfour.eu/browse/IDE-327>

```
N4EnumDeclaration:  
    annotations+=Annotation*  
    (accessModifier=N4JSTypeAccessModifier)?  
    'enum' name=IDENTIFIER  
    '{'  
        literals+=N4EnumLiteral (',' literals+= N4EnumLiteral)*  
    '}';  
  
N4EnumLiteral:  
    name=IDENTIFIER (':' value=StringLiteral)?
```

Semantics

The enum declaration E is of type `type{E}` and every enumeration is implicitly derived from `{N4Enum}`. There are similarities to other languages such as Java, for example, where the literals of an enum are treated as final static fields with the type of the enumeration and the concrete enumeration provides specific static methods including the literals. This leads to the following typing rules:

For a given enumeration declaration E with literals L , the following type rules are defined:

1. Every enumeration E is a subtype of the base type : $<\text{literal}> \text{type}E </\text{literal}> \text{type}N4Enum\}$
2. Every literal L of an enumeration E is of the type of the enumeration: $L:EL \in E.\text{literals}$ That means that every literal is a subtype of : $L <\text{literal}> N4Enum </\text{literal}> L \in E.\text{literals}$
3. Since the implementation of enumerations may vary per runtime, enum literals are not objects: $L <\text{literal}> Object </\text{literal}> L \in E.\text{literals}$

The base enumeration type is defined as follows ⁵⁹

```
/**  
 * Base class for all enumeration, literals are assumed to be static constant fields of  
 concrete subclasses.  
 */  
public object N4Enum extends any {  
  
    /**  
     * Returns the name of a concrete literal  
     */  
    public get name(): string  
  
    /**  
     * Returns the value of a concrete literal. If no value is  
     * explicitly set, it is similar to the name.  
     */  
    public get value(): string  
  
    /**  
     * Returns a string representation of a concrete literal, it returns  
     * the same result as value()  
     */  
    public toString(): string
```

⁵⁹ This is pseudo N4JS code as it is not possible to infer from `any` or define abstract static methods.

```
/**  
 * Returns the meta class object of this enum literal for reflection.  
 * The very same meta class object can be retrieved from the enumeration type directly.  
 */  
public static get n4type(): N4EnumType  
  
//IDE-785 this as return type in static  
  
/**  
 * Returns array of concrete enum literals  
 */  
public static get literals(): Array<? extends this>  
  
/**  
 * Returns concrete enum literal that matches provided name,  
 * if no match found returns undefined.  
 */  
public static findLiteralByName(name: string): this  
  
/**  
 * Returns concrete enum literal that matches provided value,  
 * if no match found returns undefined.  
 */  
public static findLiteralByValue (value: string): this  
}
```

Enums do not define a type hierarchy except that they are subtypes of `N4Enum`. In particular, `EObject` for all enums. Still, enums could be used similarly to objects:

- enum types could be used on the right hand side of the `instanceof` operator.
- enum variables could be used with the `typeof` operator, returning the simple name of the enumeration.
- enum variables used with the `+` operator will always be converted to `string`.
- enum variables must not be used in a context in which a boolean or number type is expected.

[[req:39Unique literal names]]

- $\forall i, j: literals[i.name = literals[j].name \text{ iff } i = j]$ Literal names have to be unique.

[[req:40Enum Literals are Singletons]] Enum literals are singletons:
 $\forall e_1, e_2, \mu(e_1) = \mu(e_2) = <\text{literal}> N4EnumLiteral </\text{literal}> \wedge e_1 = e_2 : e_1 <\text{literal}> = = \} e_2 e_1 </\text{literal}> = = = \} e_2$

[[ex:Enumeration List]] Due to the common base type `N4Enum` it is possible to define generics accepting only enumeration, as shown in this example:

```
enum Color { R, G, B}  
  
class EList<T extends N4Enum> {  
    add(t: T) {}  
    get(): T { return null; }  
}
```

```
var colors: EList<Color>;
colors.add(Color.R);
var c: Color = colors.get();
```

4.13.2. String-Based Enums

IDE-1221⁶⁰

In current web standards [W3C:Steen:14:XL], definitions of enumerations are often given in webIDL syntax. While the webIDL-definition assembles a set of unique string literals as a named enum-entity, the language binding to ECMAScript refers to the usage of the members of these enumerations only. Hence, if an element of an enumeration is stored in a variable or field, passed as a parameter into a method or function or given back as a result, the actual type in JavaScript will be `string`. To provide the N4JS user with some validations regarding the validity of a statement at compile time, a special kind of subtypes of `string` are introduced: the string-based enum using the `@StringBased` annotation. (See also other string-based types like `pathSelector<T>` and `i18nKey` in Section 4.6.4, “Primitive Pathselector and I18nKey”.)

String-based enums do not have any kind of runtime representation; instead, the transpiler will replace each reference to a literal of a string-based enum by a corresponding string literal in the output code. Furthermore, no meta-information is available for string-based enums, i.e. the `n4type` property is not available. The only exception is the static getter `literals`: it is available also for string-based enums and has the same meaning. In case of string-based enums, however, there won’t be a getter used at runtime; instead, the transpiler replaces every read access to this getter by an array literal containing a string literal for each of the enum’s literals.

[[req:41String-Based Enum Type Rules]] For a string-based enum declaration E_S with literals L_S the following type rules are defined:

1. Every string-based enumeration E_S is a subtype of the base type `N4StringBasedEnum`:
 $type E_S \subseteq N4StringBasedEnum$ which itself is not related to the standard enumeration type `N4Enum`.
2. `N4StringBasedEnum` is a subtype of `string` $N4StringBasedEnum \subseteq string$
3. Each literal in L_S of a string-based enumeration E_S is of the type of the string-based enumeration.
 $l \in L_S \subseteq E_S$
4. `???` also applies for `N4StringBasedEnum`.
5. `[???`] also applies for `N4StringBasedEnum`.
6. References to string-based enums may only be used in the following places:
 - a. in type annotations
 - b. in property access expressions to refer to one of the enum’s literals
 - c. in property access expressions to read from the static getter `literals`

In particular, it is invalid to use the type of a string-based enum as a value, as in

⁶⁰ <https://jira.numberfour.eu/browse/IDE-1221>

```
@StringBased enum Color { RED, GREEN, BLUE }
var c = Color;
```

Gecko-Engine webIDL XMLHttpRequestResponseType as taken from [W3C:Steen:14:XL]

```
enum XMLHttpRequestResponseType {
  "",
  "arraybuffer",
  "blob",
  "document",
  "json",
  "text" //, ... and some mozilla-specific additions
}
```

Compatible Definition of this Enumeration in N4JS, provided through a runtime-library definition:

File in source-folder: w3c/dom/XMLHttpRequestResponseType.n4js

```
@StringBased enum XMLHttpRequestResponseType {
  vacant : "",
  arrayBuffer : "arraybuffer",
  blob : "blob",
  document : "document",
  json : "json",
  text : "text"
}
```

Usage of the enumeration in the definition files of the runtime-library. Note the explicit import of the enumeration.

XMLHttpRequestResponse.n4jsd

```
@@ProvidedByRuntime
import XMLHttpRequestResponseType from "w3c/dom/XMLHttpRequestResponseType";
@Global
export external public class XMLHttpRequestResponse extends XMLHttpRequestEventTarget {
  // ...
  // Setter Throws TypeError Exception
  public responseType: XMLHttpRequestResponseType;
  // ...
}
```

Client code importing the runtime-library as defined above can now use the Enumeration in a type-safe way:

String-Based Enumeration Usage

```
import XMLHttpRequestResponseType from "w3c/dom/XMLHttpRequestResponseType";

public function process(req: XMLHttpRequest) : void {
  if( req.responseType == XMLHttpRequestResponseType.text ) {
    // do stuff ...
  } else {
```

```
// signal unrecognized type.  
var errMessage: req.responseType + " is not supported"; // concatenation of two  
strings.  
show( errMessage );  
}  
}
```

Part II. Classifiers

Chapter 5. N4JS Specific Classifiers

N4JS provides three new metatypes: class, interface, and enums. In this section we describe classes and interfaces. These metatypes, called *classifiers*, share some common properties which are described before type specific properties are outlined in the following sections.

All of these metatypes can be marked with type access modifiers:

```
enum N4JSTypeAccessModifier: project | public;
```

5.1. Properties

Properties defined by syntactic elements:

annotations :

Arbitrary annotations, see [Chapter 12, Annotations](#) for details.

accessModifier :

N4JS type access modifier: `public`, or `project`; `public` can be combined with `@Internal`; if `export` is *true* the default is else the default is `private`. task:IDE-84[]

name :

The simple name of a classifier. If the classifier is defined by an anonymous class expression, an artificial but unique name is created. The name needs to be a valid identifier, see [???](#).

typePars :

Collection of type parameters of a generic classifier; empty by default.

ownedMembers :

Collection of owned members, i.e. methods and fields defined directly in the classifier and, if present, the explicitly defined constructor. Depending on the concrete classifier, additional constraints are defined.

typingStrategy :

The definition-site typing strategy. By default nominal typing is used. See [???](#)for details.

The following pseudo properties are defined via annotations:

export :

Boolean property set to true if the `export` modifier is set. If value is true, the classifier may be accessible outside the project. task:IDE-84[]

final :

Boolean property which is set to final if annotation `@Final` is set. Also see [???](#)

deprecated :

Boolean property set to true if annotation `@Deprecated` is set. task:IDE-138[]

We additionally define the following pseudo properties:

acc :

Type access modifier as described in [???](#), it is the aggregated value of the `accessModifier` and the `export` property.

owned{Fields|Methods|Getters|Setters|Accessors} :

Filters ownedMembers by metatype, short for

$x \in \text{ownedMembers}, \mu(x) = \text{Field}$ etc.

members :

Reflexive transitive closure of all members of a classifier and its super classifiers, see below on how this is calculated.

fields|methods|getters|setters|accessors :

Filters members by metatype, short for

$x \in \text{members}, \mu(x) = \text{Field}$ etc.

superClassifiers :

Classes and interface may extend or implement classes or interfaces. Any class or interface extended or interface implemented is called *super classifier*. We distinguish the directly subtyped classifiers and from the transitive closure of supertypes *superClassifiers**

5.2. Common Semantics of Classifiers

For a given type C , and supertypes

$\text{superClassifiers} = \{S_1, S_2, \dots, S_n\}$ directly subtyped C ,

the following constraints must be true:

1. The supertypes must be accessible to the subtype: S_1, S_2, \dots, S_n must be accessible to C .
2. All type parameters of the direct supertypes have to be bound by type arguments in the subtype and the type arguments have to be substitutable types of the type parameters.
$$\forall 0 \leq i \leq n : \forall P \in S_i : \exists A \in C \text{typeArgs} : \text{bind}(A, P) \wedge A.\text{upperBound} \leq P.\text{upperBound}$$
3. Wildcards may not be used as type argument when binding a supertype's type parameters.
4. A classifier cannot be directly subtyped directly multiple times: $\forall S_i, S_j (i, j \in \{1..n\}) : S_i = S_j \Rightarrow i = j$

In order to simplify the following constraints, we use the pseudo property *members* to refer to all members of a classifier. This includes all members directly declared by the classifier itself, i.e. the *ownedMember*, and all members inherited from its super classifiers. The concrete mechanisms for inheriting a member are different and further constraint (cf. [???](#)). A classifier only inherits its members from its direct supertypes, although the supertypes may contain members inherited from their supertypes.

5.3. Classes

5.3.1. Definition of Classes

Classes are either declared with a class declaration on top level, or they can be used as anonymous classes in expressions. The latter may have a name, which may be used for error messages and reflection.

At the current stage, class expressions are effectively disabled at least until the semantics of them are finalized in ECMAScript 6.

In N4JS (as in many other languages) multi-inheritance of classes is not supported. Although the **diamond problem** (of functions being defined in both superclasses) could be solved via union and inter-

section types, this would lead to problems when calling these super implementations. This is particularly an issue due to JavaScript not supporting multiple prototypes.¹ Interfaces, however, allow for multi-inheritance. Since the former can also define functions with bodies, this is not a hard restriction.

Syntax

Syntax N4 Class Declaration and Expression

```
N4ClassDeclaration <Yield>:  
  => (  
    N4ClassDeclaration  
    annotations+=Annotation*  
    (declaredModifiers+=N4Modifier)*  
    'class' typingStrategy=TypingStrategyDefSiteOperator? name=BindingIdentifier<Yield>?  
  )  
  TypeVariables?  
  ClassExtendsClause<Yield>?  
  Members<Yield>  
;  
  
N4ClassExpression <Yield>:  
  {N4ClassExpression}  
  'class' name=BindingIdentifier<Yield>?  
  ClassExtendsClause<Yield>?  
  Members<Yield>;  
  
  
fragment ClassExtendsClause <Yield>*:  
  'extends' (  
    =>superClassRef=ParameterizedTypeRefNominal ('implements' ClassImplementsList)?  
    | superClassExpression=LeftHandSideExpression<Yield>  
  )  
  | 'implements' ClassImplementsList  
;  
  
fragment ClassImplementsList*:  
  implementedInterfaceRefs+=ParameterizedTypeRefNominal  
  (',' implementedInterfaceRefs+=ParameterizedTypeRefNominal)*  
;  
  
fragment Members <Yield>*:  
  '{'  
  ownedMembers+=N4MemberDeclaration<Yield>*  
  '}'  
;
```

Properties

These are the properties of class, which can be specified by the user: Syntax N4 Class Declaration and Expression

¹ E.g., for given `class A{ foo(A) :A{} } class B{ foo(B) :B{} }`, a class C could be defined as `class C{ foo(union{A,B}) :intersection{A,B} {} }`. In this case it would then be a syntactical problem (and even worse - a conceptual problem) of how to call the super methods defined in A and B from C.

abstract :

Boolean flag indicating whether class may be instantiable; default is *false*, see [Section 5.3.4, “Abstract Classes”](#).

external :

Boolean flag indicating whether class is a declaration without implementation or with an external (non-N4JS) implementation; default is *false*, see [???](#).

defStructural :

Boolean flag indicating whether subtype relation uses nominal or structural typing, see [???](#) for details.

superType / sup :

The type referenced by *superType* is called direct superclass of a class, and vice versa the class is a direct subclass of *superType*. Instead of *superType*, we sometimes simply write *sup*. The derived set *sup⁺* is defined as the transitive closures of all direct and indirect superclasses of a class. If no supertype is explicitly stated, classes are derived from **N4Object**.

implementedInterfaces\$/interfaces\$] :

Collection of interfaces directly *implemented* by the class; empty by default. Instead of *implementedInterfaces*, we simply write *interfaces*.

ownedCtor :

Explicit constructor of a class (if any), see [???](#).

And we additionally define the following pseudo properties:

ctor :

Explicit or implicit constructor of a class, see .

fields :

Further derived properties for retrieving all methods (property *methods*), fields (property *fields*), static members (property *staticOwnedMembers*), etc. can easily be added by filtering properties *members* or *ownedMembers*.

Type Inference

The type of a class declaration or class expression *C* (i.e., a class definition in general) is of type `{C}` if it is not abstract, that is if it can be instantiated. If it is abstract, the type of the definition simply is `{C} :`

C:constructor C ⊢ C abstractamp; C:typeCC abstract

The type of supertypes and implemented interfaces is always the nominal type, even if the supertype is declared structurally. *amp;T.sup:\$bind(T.sup, S)amp;I:SI ∈ T.interfacesamp;bind(I, S)*

5.3.2. Semantics

This section deals with the (more or less) type-independent constraints on classes.

Class expressions are not fully supported at the moment.

IDE-171²

² <https://jira.numberfour.eu/browse/IDE-171>

Definition: Transitive closure of members

The reflexive transitive closure of members of a class is indirectly defined by the override and implementation constraints defined in .

Note that since overloading is forbidden, the following constraint is true:

$$\forall m_1, m_2 \in \text{members}: m_1.\text{name} = m_2.\text{name} \wedge m_1 = m_2 \vee \text{accessorPair}(m_1, m_2)$$

³

Remarks: Class and method definition is quite similar to the proposed ECMAScript version 6 draft [[ECMA15a\(p.S13.5\)](#)], except that an N4 class and members may contain

- annotations, abstract and access modifiers
- fields
- types
- implemented interfaces

Note that even `static` is used in ECMAScript 6.

Mixing in members (i.e. interface's methods with default implementation or fields) is similar to mixing in members from roles as defined in [[Dart13a\(p.S9.1\)](#)]. It is also similar to default implementations in Java 8 [[Gosling15a](#)]. In Java, however, more constraints exist, (for example, methods of interfaces must be public).

This first example shows a very simple class with a field, a constructor and a method.

```
class C {
    data: any;

    constructor(data: any) {
        this.data = data;
    }

    foo(): void {}
}
```

[[ex:Extend and implement]] The following example demonstrate how a class can extend a superclass and implement an interface.

```
interface I {
    foo(): void
}

class C {}

class X extends C implements I {
    @Override
    foo(): void {}
}
```

A class *C* is a subtype of another classifier *S* (which can be a class or interface) if the other classifier *S* is (transitively) contained in the supertypes (superclasses or implemented interfaces) of the class:

³ $\text{accessorPair}(m_1, m_2)$ is defined as follows: $(\mu(m_1) = \text{getter} \wedge \mu(m_2) = \text{setter}) \vee (\mu(m_1) = \text{setter} \wedge \mu(m_2) = \text{getter})$

TClass left[TClass\ right]\{left=right\}[shortcut] \\ \infer{\tee \type{TClass}\ left \subtype{TClass]\ right}\{\tee left.superType.declaredType \subtype right\}\end{aligned}\]]

1. The implicit supertype of all classes is `N4Object`. All classes with no explicit supertype are inherited from `N4Object`.
2. If the supertype is explicitly set to `Object`, then the class is not derived from `N4Object`. Meta-information is created similar to an `N4Object`-derived class. Usually, there is no reason to explicitly derive a class from `Object`.
3. External classes are implicitly derived from , unless they are annotated with `@N4JS` (cf.???).

5.3.3. Final Modifier

IDE-147⁴

Extensibility refers to whether a given classifier can be subtyped. Accessibility is a prerequisite for extensibility. If a type cannot be seen, it cannot be subclassed. The only modifier influencing the extensibility directly is the annotation `@Final`, which prevents all subtyping. The following table shows how to prevent other projects or vendors from subtyping by also restricting the accessibility of the constructor:

Table 5.1. Extensibility of Types

Type C Settings	Subclassed in		
	Project	Vendor	World
<code>C.final</code>	no	no	no
<code>C.ctor.accessModifier=\l enum{project}</code>	yes	no	no
<code>C.ctor.accessModifier=\l enum{public@Internal}</code>	yes	yes	no

Since interfaces are always to be implemented, they must not be declared final.

5.3.4. Abstract Classes

A class with modifier `abstract` is called an *abstract class* and has its *abstract* property set to true. Other classes are called *concrete classes*.

1. A class *C* must be declared abstract if it owns or inherits one or more abstract members and neither *C* nor any interfaces implemented by *C* implements these members. A concrete class has to, therefore, implement all abstract members of its superclasses' implemented interfaces. Note that a class may implement fields with field accessors and vice versa.
2. An abstract class may not be instantiated.

⁴ <https://jira.numberfour.eu/browse/IDE-147>

3. An abstract class cannot be set to final (with annotation @Final).

IDE-553⁵
IDE-553⁶
IDE-148⁷

1. A member declared as abstract must not have a method body (in contrary a method not declared as abstract have to have a method body).
2. Only methods, getters and setters can be declared as abstract (fields cannot be abstract).
3. It is not possible to inherit from an abstract class which contains abstract members which are not visible in the subclass.
4. An abstract member cannot be set to final (with annotation @Final).
5. Static members may not be declared abstract.

IDE-553⁸
IDE-553⁹
IDE-553¹⁰

5.3.5. Non-Instantiable Classes

To make a class non-instantiable outside a defining compilation unit, i.e. disallow creation of instances for this class, simply declare the constructor as private. This can be used for singletons.

IDE-149¹¹

5.3.6. Superclass

47Superclass For a class C with a supertype $S = C.sup$, the following constraints must hold

- $C.sup$ must reference a class declaration S
- S must be extendable in the project of C
- $C \notin C.sup^+$
- All abstract members in S must be accessible from C :
 $\forall M \in S.members: M.abstract \Rightarrow M$ is accessible from C
(note that M need not be an owned member of S and that this constraint applies even if C is abstract).

All members of superclasses become members of a class. This is true even if the owning classes are not directly accessible to a class. The member-specific access control is not changed.

⁵ <https://jira.numberfour.eu/browse/IDE-553>

⁶ <https://jira.numberfour.eu/browse/IDE-553>

⁷ <https://jira.numberfour.eu/browse/IDE-148>

⁸ <https://jira.numberfour.eu/browse/IDE-553>

⁹ <https://jira.numberfour.eu/browse/IDE-553>

¹⁰ <https://jira.numberfour.eu/browse/IDE-553>

¹¹ <https://jira.numberfour.eu/browse/IDE-149>

5.4. Interfaces

IDE-12¹²
IDE-169¹³
IDE-328¹⁴
IDE-1236¹⁵

5.4.1. Definition of Interfaces

Syntax

IDE-8¹⁶

Syntax N4 Interface Declaration

```
N4InterfaceDeclaration <Yield>:  
  => (  
    {N4InterfaceDeclaration}  
    annotations+=Annotation*  
    (declaredModifiers+=N4Modifier)*  
    'interface' typingStrategy=TypingStrategyDefSiteOperator?  
    name=BindingIdentifier<Yield>?  
  )  
  TypeVariables?  
  InterfaceImplementsList?  
  Members<Yield>  
;  
  
fragment InterfaceImplementsList*:  
  'implements' superInterfaceRefs+=ParameterizedTypeRefNominal  
  (', ' superInterfaceRefs+=ParameterizedTypeRefNominal)*  
;
```

Properties

These are the additional properties of interfaces, which can be specified by the user:

Collection of interfaces extended by this interface; empty by default. Instead of *superInterfaces*, we simply write *interfaces*.

Type Inference

The type of an interface declaration *I* is of type `I`:

I:typeI

¹² <https://jira.numberfour.eu/browse/IDE-12>

¹³ <https://jira.numberfour.eu/browse/IDE-169>

¹⁴ <https://jira.numberfour.eu/browse/IDE-328>

¹⁵ <https://jira.numberfour.eu/browse/IDE-1236>

¹⁶ <https://jira.numberfour.eu/browse/IDE-8>

Semantics

Interfaces are used to describe the public API of a classifier. The main requirement is that the instance of an interface, which must be an instance of a class since interfaces cannot have instances, provides all members declared in the interface. Thus, a (concrete) class implementing an interface must provide implementations for all the fields, methods, getters and setters of the interface (otherwise it the class must be declared abstract). The implementations have to be provided either directly in the class itself, through a superclass, or by the interface if the member has a default implementation.

A field declaration in an interface denotes that all implementing classes can either provide a field of the same name and the same(!) type or corresponding field accessors. If no such members are defined in the class or a (transitive) superclass, the field is mixed in from the interface automatically. This is also true for the initializer of the field.

All instance methods, getters and setters declared in an interface are implicitly abstract if they do not provide a default implementation. The modifier `abstract` is not required, therefore, in the source code. The following constraints apply:

For any interface I , the following must hold:

1. Interfaces may not be instantiated.
2. Interfaces cannot be set to final (with annotation `@Final`): $\neg I.final$.
3. Members of an interface must not be declared private. The default access modifier in interfaces is the the type's visibility or , if the type's visibility is .
4. Members of an interface, except methods, must not be declared :
 $\forall m \in I.member: m.final \Rightarrow m \in I.methods$ (note: not allowing field accessors to be declared final was a deliberate decision, because it would complicate the internal handling of member redefinition; might be reconsidered at a later time)
5. The literal may not be used in the initializer expression of a field of an interface.

This restriction is required, because the order of implementation of these fields in an implementing class cannot be guaranteed. This applies to both instance and static fields in interfaces, but in case of static fields, `this` is also disallowed due to `???`.

It is possible to declare members in interfaces with a smaller visibility as the interface itself. In that case, clients of the interface may be able to use the interface but not to implement it.

In order to simplify modeling of runtime types, such as elements, interfaces do not only support the notation of static methods but constant data fields as well. Since [IDL \[OMG14a\]](#) is used to describe these elements in specifications (and mapped to JavaScript via rules described in [\[W3C12a\]](#)) constant data fields are an often-used technique there and they can be modeled in N4JS 1:1.

As specified in [???](#), interfaces cannot contain a constructor i.e. $\forall m \in I.ownedMethods: m.name \neq 'constructor'$.

[\[\[ex:Simple Interfaces\]\]](#) The following example shows the syntax for defining interfaces. The second interface extends the first one. Note that methods are implicitly defined abstract in interfaces.

```
interface I {  
    foo(): void
```

```
}
```

```
interface I2 extends I {
    someText: string;
    bar(): void
}
```

If a classifier C implements an interface I , we say I is *implemented* by C . If C redefines members declared in I , we say that these members are *implemented* by C . Members not redefined by C but with a default implementations are *mixed in* or *consumed* by C . We all cases we call C the *implementor*.

Besides the general constraints described in , the following constraints must hold for extending or implementing interfaces:

For a given type I , and $\{I_1, 8230;8203; I_n\}$ directly extended by I , the following constraints must be true:

1. Only interfaces can extend interfaces: $I, I_1, 8230;8203; I_n$ must be interfaces.
2. An interface may not directly extend the same interface more than once:
 $I_i = I_j \Rightarrow i = j$ for any $i, j \in \{1..n\}$.
3. An interface may (indirectly) extend the same interface J more than once only if
 - a. J is not parameterized, or
 - b. in all cases J is extended with the same type arguments for all invariant type parameters.

Note: for type parameters of J that are declared covariant or contravariant on definition site, different type arguments may be used.

4. All abstract members in $I_i, i \in \{1, 8230;8203; n\}$, must be accessible from I :
 $\forall i \in \{1, 8230;8203; n\} : M \in I_i.members \wedge M.abstract \Rightarrow M$ is accessible from I
(note that M need not be an owned member of I_i).

50Implementing Interfaces[req:Implementing_Interfaces] For a given type C , and $\{I_1, 8230;8203; I_n\}$ directly implemented by C , the following constraints must be true:

1. Only classes can implement interfaces: C must be a Class.
2. A class can only implement interfaces: $I_1, 8230;8203; I_n$ must be interfaces.
3. A class may not directly implement the same interface more than once:
 $I_i = I_j \Rightarrow i = j$ for any $i, j \in \{1..n\}$.
4. A class may (indirectly) implement the same interface J more than once only if
 - a. J is not parameterized, or
 - b. in all cases J is implemented with the same type arguments for all invariant type parameters.

Note: for type parameters of J that are declared covariant or contravariant on definition site, different type arguments may be used.

5. All abstract members in $I_i, i \in \{1, 8230;8203; n\}$, must be accessible from C :
 $\forall i \in \{1, 8230;8203; n\} : M \in I_i.members \wedge M.abstract \Rightarrow M$ is accessible from C
(note that M need not be an owned member of I_i).

For default methods in interfaces, see .

5.5. Generic Classifiers

IDE-38 ¹⁷
IDE-39 ¹⁸

Classifiers can be declared generic by defining a type parameter via .

Definition: Generic Classifiers

A generic classifier is a classifier with at least one type parameter. That is, a given classifier C is generic if and only if $|C.typeParams| \geq 1$.

If a classifier does not define any type parameters, it is not generic, even if its superclass or any implemented interface is generic.

The format of the type parameter expression is described in [Section 4.4.3, “Parameterized Types”](#). The type variable defined by the type parameter’s type expression can be used just like a normal type inside the class definition.

If using a generic classifier as type of a variable, it may be parameterized. This is usually done via a type expression (cf. [???](#)) or via `type-arg` in case of supertypes. If a generic classifier defines multiple type variables, these variables are bound in the order of their definition. In any case, all type variables have to be bound. That means in particular that raw types are not allowed. (cf [???](#) for details).

If a generic classifier is used as super classifier, the type arguments can be type variables. Note that the type variable of the super classifier is not lifted, that is to say that all type variables are to be explicitly bound in the type references used in the `extend`, `with`, or `implements` section using `type-arg`. If a type variable is used in to bound a type variable of a type parameter, it has to fulfil possible type constraints (upper/lower bound) specified in the type parameter.

This example demonstrates how to define a generic type and how to refer to it in a variable definition.

```
export class Container<T> {
    private item: T;

    getItem(): T {
        return this.item;
    }

    setItem(item: T): void {
        this.item = item;
    }
}
```

This type can now be used as a type of a variable as follows

¹⁷ <https://jira.numberfour.eu/browse/IDE-38>

¹⁸ <https://jira.numberfour.eu/browse/IDE-39>

```
import Container from "p/Container"

var stringContainer: Container<string> = new Container<string>();
stringContainer.setItem("Hello");
var s: string = stringContainer.getItem();
```

In line 3, the type variable `T` of the generic class `Container` is bound to `string`.

[Binding of type variables with multiple types] For a given generic class `G`

```
class A{}
class B{}
class C extends A{}

class G<S, T extends A, U extends B> {
```

the variable definition

```
var x: G<Number, C, B>;
```

would bind the type variables as follows:

<code>S</code>	<code>Number</code>	Bound by first type argument, no bound constraints defined for <code>s</code> .
<code>T</code>	<code>C</code>	Bound by second type argument, <code>C</code> must be a subtype of <code>A</code> in order to fulfill the type constraint.
<code>U</code>	<code>B</code>	Bound by third type argument, <code>extends</code> is reflexive, that is <code>B</code> fulfills the type constraint.

For a given generic superclass `SuperClass`

```
class SuperClass<S, T extends A, U extends B> {};
```

and a generic subclass `SubClass`

```
class SubClass<X extends A> extends SuperClass<Number, X, B> {...};
```

the variable definition

```
var s: SubClass<C>;
```

would bind the type variables as follows:

TypeVariable	Bound to	Explanation
<code>SuperClass.S</code>	<code>Number</code>	Type variable <code>s</code> of supertype <code>SuperClass</code> is bound to <code>Number</code> .

TypeVariable	Bound to	Explanation
Super- Class.T	Sub- Class.X=C	Type variable <code>T</code> of supertype <code>SuperClass</code> is bound to type variable <code>X</code> of <code>SubClass</code> . It gets then indirectly bound to <code>C</code> as specified by the type argument of the variable definition.
Super- Class.U	B	Type variable <code>U</code> of supertype <code>SuperClass</code> is auto-bound to <code>C</code> as no explicit binding for the third type variable is specified.
SubClass.X	C	Bound by first type argument specified in variable definition.

5.6. Definition-Site Variance

In addition to use-site declaration of variance in the form of Java-like wildcards, N4JS provides support for definition-site declaration of variance as known from languages such as C# and Scala.

The *variance* of a parameterized type states how its subtyping relates to its type arguments' subtyping. For example, given a parameterized type and plain types and , we know

- if `G` is **covariant** w.r.t. its parameter `T`, then $BA \Rightarrow Glt;Bgt;Glt;Agt;$
- if `G` is **contravariant** w.r.t. its parameter `T`, then $BA \Rightarrow Glt;Agt;Glt;Bgt;$
- if `G` is **invariant** w.r.t. its parameter `T`, then $BAamp;\Rightarrow Glt;Agt;Glt;Bgt;BAamp;\Rightarrow Glt;Agt;Glt;Bgt;$

Note that variance is declared per type parameter, so a single parameterized type with more than one type parameter may be, for example, covariant w.r.t. one type parameter and contravariant w.r.t. another.

Strictly speaking, a type parameter/variable itself is not co- or contravariant; however, for the sake of simplicity we say " `T` is covariant" as a short form for " `G` is covariant with respect to its type parameter `T`" (for contravariant and invariant accordingly).

To declare the variance of a parameterized classifier on definition site, simply add keyword `in` or `out` before the corresponding type parameter:

```
class ReadOnlyList<out T> { // covariance
    // ...
}

interface Consumer<in T> { // contravariance
    // ...
}
```

In such cases, the following constraints apply.

Given a parameterized type with a type parameter , the following must hold:

1. `T` may only appear in variance-compatible positions:
 - a. if `T` is declared on definition site to be **covariant**, then it may only appear in covariant positions within the type's non-private member declarations.
 - b. if `T` is declared on definition site to be **contravariant**, then it may only appear in contravariant positions within the type's non-private member declarations.

- c. if `T` is **invariant**, i.e. neither declared covariant nor declared contravariant on definition site, then it may appear in any position (where type variables are allowed).

Thus, no restrictions apply within the declaration of private members and within the body of field accessors and methods.

2. definition-site variance may not be combined with incompatible use-site variance:

- a. if `T` is declared on definition site to be **covariant**, then no wildcard with a **lower** bound may be provided as type argument for `T`.
- b. if `T` is declared on definition site to be **contravariant**, then no wildcard with an **upper** bound may be provided as type argument for `T`.
- c. if `T` is **invariant**, i.e. neither declared covariant nor declared contravariant on definition site, then any kind of wildcard may be provided as type argument.

Unbounded wildcards are allowed in all cases.

For illustration purposes, let's compare use-site and definition-site declaration of variance. Since use-site variance is more familiar to the Java developer, we start with this flavor.

```
class Person {  
    name: string;  
}  
class Employee extends Person {}  
  
interface List<T> {  
    add(elem: T)  
    read(idx: int): T  
}  
  
function getNameOfFirstPerson(list: List<? extends Person>): string {  
    return list.read(0).name;  
}
```

Function `getNameOfFirstPerson` below takes a list and returns the name of the first person in the list. Since it never adds new elements to the given list, it could accept `List`s of any subtype of `Person`, for example a `List<Employee>`. To allow this, its formal parameter has a type of `List<? extends Person>` instead of `List<Person>`. Such use-site variance is useful whenever an invariant type, like `List` above, is being used in a way such that it can be treated as if it were co- or contravariant.

Sometimes, however, we are dealing with types that are inherently covariant or contravariant, for example an `ImmutableList` from which we can only read elements would be covariant. In such a case, use-site declaration of variance is tedious and error-prone: we would have to declare the variance whenever the type is being used and would have to make sure not to forget the declaration or otherwise limit the flexibility and reusability of the code (for example, in the above code we could not call `getNameOfFirstPerson` with a `List<Employee>`).

The solution is to declare the variance on declaration site, as in the following code sample:

```
interface ImmutableList<out T> {
```

```
// add(elem: T) // error: such a method would now be disallowed
    read(idx: int): T
}

function getNameOfFirstPerson2(list: ImmutableList<Person>): string {
    return list.read(0).name;
}
```

Now we can invoke `getNameOfFirstPerson2` with a `List<Employee>` even though the implementor of `getNameOfFirstPerson2` did not add a use-site declaration of covariance, because the type `ImmutableList` is declared to be covariant with respect to its parameter `T`, and this applies globally throughout the program.

Chapter 6. Members

IDE-12¹
IDE-381²

A member is either a method (which may be a special constructor function), a data field, or a getter or a setter. The latter two implicitly define an accessor field. Similar to object literals, there must be no data field with the same name as a getter or setter.

Redefinition of members (overriding, implementation and consumption) is described in .

6.1. Syntax

Syntax N4JS member access modifier

```
enum N4JSMemberAccessModifier: private | project | protected | public;  
  
N4MemberDeclaration: N4MethodDeclaration | N4FieldDeclaration | N4GetterDeclaration |  
N4SetterDeclaration;
```

6.1.1. Properties

Members share the following properties:

annotations

Arbitrary annotations, see [Chapter 12, Annotations](#) for details.

accessModifier\$

N4JS member access modifier: `private`, `project`, `protected`, or `public`; the latter two can be combined with `@Internal`; default is `project` for classes and private interfaces. For a non-private interface defaults to the interface's visibility. task:IDE-84[]

name

The simple name of the member, that is an identifier name (cf. ???).

static

Boolean property to distinguish instance from classifier members, see [Section 6.6, “Static Members”](#).

The following pseudo properties are defined via annotations:

deprecated

Boolean property set to true if annotation `@Deprecated` is set. task:IDE-138[]

And we additionally define the following pseudo properties:

acc

Member access modifier as described in ???, it is the aggregated value of the `accessModifier` and the `export` property.

¹ <https://jira.numberfour.eu/browse/IDE-12>

² <https://jira.numberfour.eu/browse/IDE-381>

owner

Owner classifier of the member.

typeRef

Type of the member—this is the type of a field or the type of the method which is a function type (and not the return type).

assignability

Enumeration, may be one of the following values:

set: Member may only be set, i.e. it could only be used on the left hand side of an assignment.

get: Member may only be retrieved, i.e. it could only be used on the right hand side of an assignment. This is the default setting for methods.

any: Member may be set or retrieved, i.e. it could only be used on the left or right hand side of an assignment. This is the default setting for fields.



assignability is related but not equal to writable modifiers used for fields. We define a partial order on this enumeration as follows:
 $lt; (l, r) \iff \{ (set, any), (get, any) \}$

abstract

All members have a flag *abstract*, which is user-defined for methods, getters and setter, but which is always false for fields.

The following pseudo property is set to make fields compatible with properties of an object literal, however it cannot be changed:

configurable

Boolean flag reflecting the property descriptor *configurable*, this is always set to false for members.

6.1.2. Semantics

The members of a given classifier C must be named such that the following constraints are met:

1. No two members may have the same name, except one is static and the other is non-static:
 $\forall m_1, m_2 \in C.\text{ownedMembers}, m_1 \neq m_2 : m_1.name \neq m_2.name \vee m_1.static \neq m_2.static$
2. The member name must be a valid identifier name, see .

IDE-550³
IDE-551⁴

Thus, `over_loading_` of methods is not supported ⁵ and no field may have the same name as a method. However, `over_riding_` of methods, getters, and setters are possible, see [Section 6.7, “Redefinition of Members”](#). Static members may also have the same name as non-static members ⁶, `ClassBody :`

³ <https://jira.numberfour.eu/browse/IDE-550>

⁴ <https://jira.numberfour.eu/browse/IDE-551>

⁵ In order to emulate method overloading, union types are to be used.

⁶ cite[ECMA15a(p214)]

`ClassElementList` indicates that it is possible to have the same name for instance and static members.]

The dollar character `$` is not allowed for user-defined member identifier, as the dollar sign is used for rewriting private members.

6.2. Methods

IDE-8⁷
IDE-12⁸

Methods are simply JavaScript functions. They are defined similarly to methods as proposed in [ECMA15a(p.S13.5)] except for the type information and some modifiers.

6.2.1. Syntax

Syntax Method Declaration

```
N4MethodDeclaration <Yield>:
    => ({N4MethodDeclaration}
        annotations+=Annotation*
        accessModifier=N4JSMemberAccessModifier?
        (abstract?='abstract' | static?='static')?
        TypeVariables?
        (
            generator?='*' LiteralOrComputedPropertyName<Yield> ->
        MethodParamsReturnAndBody <Generator=true>
            | AsyncNoTrailingLineBreak LiteralOrComputedPropertyName<Yield> ->
        MethodParamsReturnAndBody <Generator=false>
            )
        ) ';'?
    ;
;

fragment MethodParamsAndBody <Generator>*:
    StrictFormalParameters<Yield=Generator>
    (body=Block<Yield=Generator>)?
;

fragment MethodParamsReturnAndBody <Generator>*:
    StrictFormalParameters<Yield=Generator>
    (':' returnTypeRef=TypeRef)?
    (body=Block<Yield=Generator>)?
;

fragment LiteralOrComputedPropertyName <Yield>*:
    name=IdentifierName | name=STRING | name=NumericLiteralAsString
    | '[' (=>((name=SymbolLiteralComputedName<Yield> | name=StringLiteralAsName) ']') |
    computeNameFrom=AssignmentExpression<In=true,Yield> ']')
;
```

⁷ <https://jira.numberfour.eu/browse/IDE-8>

⁸ <https://jira.numberfour.eu/browse/IDE-12>

```
SymbolLiteralComputedName <Yield>:  
    BindingIdentifier<Yield> ('.' IdentifierName)?  
;  
  
BindingIdentifier <Yield>:  
    IDENTIFIER  
    | <!Yield> 'yield'  
    | N4Keyword  
;  
  
IdentifierName: IDENTIFIER | ReservedWord | N4Keyword;  
NumericLiteralAsString: DOUBLE | INT | OCTAL_INT | HEX_INT | SCIENTIFIC_INT;  
StringLiteralAsName: STRING;  
  
// see ~\autoref{sec:Asynchronous_Functions}~  
fragment AsyncNoTrailingLineBreak *: (declaredAsync?='async' NoLineTerminator)?;  
  
fragment StrictFormalParameters <Yield>*:  
    '(' (fpars+=FormalParameter<Yield> (',' fpars+=FormalParameter<Yield>) *)? ')'   
;  
  
FormalParameter <Yield>:  
    {FormalParameter} BindingElementFragment<Yield>  
;  
  
fragment BindingElementFragment <Yield>*:  
    (=> bindingPattern=BindingPattern<Yield>  
    | annotations+=Annotation*  
    (  
        variadic?='...'? name=BindingIdentifier<Yield> ColonSepTypeRef?  
    )  
    )  
    ('=' initializer=AssignmentExpression<In=true, Yield>)?  
;  
  
fragment ColonSepTypeRef*:  
    ':' declaredTypeRef=TypeRef  
;
```

6.2.2. Properties

Methods have all the properties of members and the following additional properties can be explicitly defined:

abstract

Method is declared but not defined.

typePars

Collection of type parameters of a generic method; empty by default.

returnTypeRef

Return type of the method, default return type is *Void*. The type of the method as a member of the owning classifier is not the method's return type but is instead a function type.

fpars

List of formal parameters, may be left empty.

body

The body of the method (this is not available in the pure types model)

The following pseudo properties are defined via annotations:

final

Boolean flag set to true if annotation `@Final` is set. Flag indicates that method must not be overridden in subclasses; see [???](#).

declaresOverride

Flag set to true if annotation `@Overrides` is set. Flag indicates that method must override a method of a superclass; see [..](#).

Additionally, we define the following pseudo properties:

overrides

True if method overrides a super method or implements an interface method, false otherwise.

typeRef

Type of the method. This is, in fact, a function type (and not the return type).

enumerable

The following pseudo property is set to make methods compatible with properties of an object literal, however it cannot be changed:

Boolean flag reflecting the property descriptor `enumerable`, this is always set to false for methods.

6.2.3. Semantics

Since methods are ECMAScript functions, all constraints specified in [???](#) apply to methods as well. This section describes default values and function type conformance which is required for overriding and implementing methods.

In addition, method declarations and definitions have to comply with the constraints for naming members of classifiers (cf. [???](#)) and with the constraints detailed in the following sections on final methods ([???](#)), abstract methods ([???](#) and method overriding and implementation ([Section 6.7.1, “Overriding of Members”, Section 6.7.2, “Implementation of Members”](#)).

The following constraints are defined for methods in ECMAScript 6 [[ECMA15a\(p.207\)](#)]

- `It is a Syntax Error if any element of the BoundNames of StrictFormalParameters also occurs in the VarDeclaredNames of FunctionBody.`
- `It is a Syntax Error if any element of the BoundNames of StrictFormalParameters also occurs in the LexicallyDeclaredNames of FunctionBody.`

Methods – like functions – define a variable execution environment and therefore provide access to the actual passed-in parameters through the implicit variable inside of their bodies (c.f. [???](#)).

Methods are similar to function definitions but they must not be assigned to or from variables. The following code issues an error although the type of the method would be compatible to the type of the variable :

```
class C {
    m(): void {}
}

var v: {function():void} = new C().m;
```

54Method Assignment[req:Method_Assignment]

1. Different from ECMAScript 2015, methods are defined as readonly, that is, it is not possible to dynamically re-assign a property defined as method with a new value. This is because assigning or re-assigning a method breaks encapsulation. Methods are the API of a class, their implementation is internal to the class.
2. When assigning a method to a variable, a warning is issued since this would lead to an detached this reference inside the method when it is called without explicitly providing the receiver. No warning is issued only if it is guaranteed that no problems will occur:
 - a. The method's body can be determined at compile time (i.e., it has been declared `@Final`) and it lacks usages of `this` or `super`. This is true for instance and static methods.
 - b. The method is the constructor.

© GH-224⁹



The following code demonstrates problems arising when methods are assigned to variables in terms of function expressions. Given are two classes and instances of each class as follows:

```
class C {
    m(): void {} 
    static k(): void {}
}

class D extends C {
    @Override m(): void { this.f() }
    f(): void {}

    @Override static k(): void { this.f() }
    static f(): void {}
}

var c: C = new C();
var d: C = new D(); // d looks like a C
```

Assigning an instance method to a variable could cause problems, as the method assumes this to be bound to the class in which it is defined. This may work in some cases, but will cause problems in particular in combination with method overriding:

```
var v1: {@This(C)function():void} = c.m;
var v2: {@This(C)function():void} = d.m;

v1.call(c);
```

⁹ <https://github.com/NumberFour/N4JS/issues/224>

```
v2.call(c);
```

Calling `c.m` indirectly via `v1` with `c` as this object will work. However, it won't work for `v2`: the method is overridden in `D`, and the method in expects other methods available in `D` but not in `C`. That is, the last call would lead to a runtime error as method `f` which is called in `D.m` won't be available.

The same scenario occurs in case of static methods if they are retrieved polymorphically via the variables of type `constructor{C}`:

```
var ctor: constructor{C} = C;
var dtor: constructor{C} = D;

var v3: {@This(constructor{C})function():void} = ctor.k;
var v4: {@This(constructor{C})function():void} = dtor.k;
```

In both cases, the problem could be solved by restricting these kinds of assignments to final methods only. In the static case, the problem would also be solved by accessing the static method directly via the class type (and not polymorphically via the constructor). Both restrictions are severe but would be necessary to avoid unexpected runtime problems.

The following example shows a problem with breaking the encapsulation of a class.

```
class C {
    x: any = "";
    f(): void { this.g(this); }
    g(c: C): void { c.h(); }
    h(): void {}
}
class D extends C {

    @Override f(): void {
        this.g(this.x);
    }
    @Override g(c: any) {
        // do nothing, do not call h()
    }
}

var c = new C();
var d = new D();

var v5: {@This(C)function():void} = c.f;
var v6: {@This(C)function():void} = d.f;

v5.call(c)
v6.call(c)
```

In `D`, method `g` is overridden to accept more types as the original method defined in `C`. Calling this new method with receiver type `C` (as done in the last line) will cause problems, as in `D` not only `f` has been adapted but also `g`. Eventually, this would lead to a runtime error as well.

6.2.4. Final Methods

By default, methods can be overridden. To prevent a method from being overridden, it must be annotated with `@Final`.

Of course, a method cannot be declared both abstract and final (cf. [???](#)). Private methods are implicitly declared final. Because static methods can be overridden in subclasses (which is different to Java), they also can be marked as final.

Default methods in interfaces, cf. [???](#), may also be declared `@Final`.

If a method in an interface is provided with a body, it may be declared final. This will ensure that the given method's body will be in effect for all instances of the interface. Note that this means that; (a) a class implementing that interface must not define a method with the same name and (b) a class inheriting a method of that name cannot implement this interface. The latter case is illustrated here:

```
interface I {
    @Final m(): void {}
}

class C1 {
    m(): void {}
}

// error at "I": "The method C1.m cannot override final method I.m."
class C2 extends C1 implements I {
```

6.2.5. Abstract Methods

A method can be declared without defining it, i.e. without providing a method body, and is then called an *abstract method*. Such methods must be declared with modifier `abstract` and have their property `abstract` set to true. Constraints for abstract methods are covered in [???](#) (see [???](#)).

In interfaces, methods are always abstract by default and they do not have to be marked as abstract. If a method in an interface provides a body, then this is the default implementation. See [Section 6.7.2, “Implementation of Members”](#) about how the default implementation may be mixed in the consumer.

6.2.6. Generic Methods

Methods of generic classes can, of course, refer to the type variables defined by type parameters of the generic class. These type variables are used similarly to predefined or declared types. Additionally,

¹⁰ <https://jira.numberfour.eu/browse/IDE-157>

¹¹ <https://jira.numberfour.eu/browse/IDE-38>

¹² <https://jira.numberfour.eu/browse/IDE-39>

methods may be declared generic independently from their containing class. That is to say that type parameters (with type variables) can be defined for methods as well, just like for generic functions (see [Section 8.5.1, “Generic Functions”](#)).

For a given generic method m of a class C , the following constraint must hold:

$$\forall tp_m \in m.typeParams, tp_C \in C.typeParams : tp_m.name \neq tp_C.name$$

Since type variables can be used similarly to types in the scope of a generic class, a generic method may refer to a type variable of its containing class.

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

If a generic type parameter is not used as a formal parameter type or the return type, a warning is generated unless the method overrides a member inherited from a super class or interface.

6.3. Default Methods in Interfaces

If a method declared in an interface defines a body, then this is the so-called *default implementation* and the method is called a *default method*. This will be mixed into an implementor of the interface if, and only if, neither the implementing class nor any of its direct or indirect superclasses already provides an implementation for this method; for details see [the section called “Member Consumption”](#). Since the implementor is not known, some constraints exist for the body. I.e., no access to super is possible, cf. [???](#).

In order to declare an interface to provide a default implementation in a definition file, annotation `@ProvidesDefaultImplementation` can be used, cf. [???](#).

When a method in an interface is provided with a default implementation, it may even be declared `@Final`, see [???](#).

6.3.1. Asynchronous Methods

N4JS implements the `async/await` concept proposed for ECMAScript 7, which provides a more convenient and readable syntax for writing asynchronous code compared to using built-in type `Promise` directly. This concept can be applied to methods in exactly the same way as to declared functions. See [???](#) and [???](#) for details.

6.4. Constructors

 IDE-159 ¹³

A constructor is a special function defined on a class which returns an instance of that class. The constructor looks like a normal method with name "constructor". The constructor can be defined explicitly or implicitly and every class has an (implicit) constructor.

¹³ <https://jira.numberfour.eu/browse/IDE-159>

For a given a class C , the constructor is available via two properties:

the explicitly defined constructor (if any).

the explicit or implicit constructor.

If C is provided with an explicit constructor, we have $C.ctor = C.ownedCtor$ and $C.ownedCtor \in C.ownedMembers$. Note that $C.ctor \notin C.ownedMethods$ in all cases.

The return type of the constructor of a class C is C . If C has type parameters T_1, T_2, \dots, T_n , then the return type is $Clt;T_1, T_2, \dots, T_ngt;$. The constructor is called with the operator. Since the return type of a constructor is implicitly defined by the class, it is to be omitted. By this definition, a constructor looks like the following:

```
class C {
    public constructor(s: string) {
        // init something
    }
}
```

Constructors define a variable execution environment and therefore provide access to the actual passed-in parameters through the implicit variable inside of their bodies (c.f. [???](#)).

For a constructor $ctor$ of a class C , the following conditions must hold:

1. $ctor$ must neither be abstract nor static nor final and it must not be annotated with `@Override`.
2. If a class does not explicitly define a constructor then the constructor's signature of the superclass constructor is assumed.
3. If a class defines a constructor with formal parameters then this constructor has to be called explicitly in constructors defined in subclasses.
4. If a super constructor is called explicitly, this call must be the only expression of an expression statement which has to be the first statement of the body.
5. Constructors may appear in interfaces, but some restrictions apply:
 - a. constructors in interfaces must not have a body.
 - b. constructors in interfaces or their containing interface or one of its direct or indirect super interfaces must be annotated with `@CovariantConstructor`.
6. A constructor must not have an explicit return type declaration.
7. The implicit return type of a constructor is `this?`.

Properties of object literals may be called `constructor`. However they are not recognized as constructors in these cases.

[[req:Initialization of Final Fields in the Constructor]]

1. Required attributes must be initialized:

$\forall a \in C.attr: a.required \exists e \in r.elements: a.name = e.name$

Note on syntax: ECMAScript 6 defines constructors similarly, [ECMA15a(p.S13.5)]. In ECMAScript 6 the super constructor is not called automatically as well.

The super literal used in order to call super methods is further described in [???](#).

6.4.1. Structural This Type in Constructor and Spec Parameter

IDE-651 [14](#)

The use of a structural this reference as a formal parameter type is possible only in constructors. This parameter can be annotated with `@Spec` which causes the compiler to generate initialization code.

Simply using `$~~$this` as a type in the constructor causes the constructor to require an object providing all public fields of the class for initialization purposes. The fields have to be set manually as shown in the following code snippet.

```
class A{
    public s: string;
    public constructor(src: ~~~this) {
        this.s = src.s;
    }
}
```

Remarks:

- The type of the formal parameter `this` refers to the structural field type, see for details on structural typing. It contains all public fields of the type.
- Subclasses may override the constructor and introduce additional parameters. They have to call the super constructor explicitly, however, providing a parameter with at least all required attributes of the superclass. Usually the type `this` is replaced with the actual subclass, but in the case of a `super()` call the `this` type of structural formal parameters is replaced with the `this` type of the superclass, hence only required fields of the superclass must be present.

GH-262 [15](#)

As with other structural references, it is possible to add the structural reference with additional structural members, which can be used to initialize private fields which become not automatically part of the structural field type. For example:

```
class A{
    public s: string;
    private myPrivateNumber: number;
    public constructor(src: ~~~this with { x: number; }) {
        this.s = src.s;
        this.myPrivateNumber = src.x;
```

[14](#) <https://jira.numberfour.eu/browse/IDE-651>

[15](#) <https://github.com/NumberFour/N4JS/issues/262>

```

    }
}

```

Defining additional members may become a problem if a subclass defines public fields with the same name, as the `$~~$this` type will contain these fields in the subclass. This is marked as an error in the subclass.

.Names of additional members of structural this type in constructor

GH-81 ¹⁶

If the structural this type is used in a constructor of a class C , and if this structural reference contains an additional structural member SM , the following constraints must hold true:

1. For any subclass S of C , with $S.ctor = C.ctor$ (the subclass does not define its own constructor), S must not contain a public member with same name as SM :

$$amp;Slt;:C, S.ctor = C.ctoramp; \quad M \in S.members:amp; \quad M.acc = public \wedge M.name = SM.name$$
2. C itself must not contain a public member with same name as SM :

$$M \in C.members:amp; M.acc = public \wedge M.name = SM.name$$

Field name conflicts with structural member name

The situation described in [???](#) is demonstrated in the following code fragment:

```

class A {
    private myPrivateNumber: number;
    public constructor(src: ~this with { x: number; }) {
        this.myPrivateNumber = src.x;
    }
}

class B extends A {
    public x: number; // will cause an error message
}

```

@Spec-style Constructor

The tedious process of copying the members of the parameter to the fields of the class can be automated via the annotation if the argument has *ithis* structural initializer field typing. For more details about this typing can be found in [???](#). This can be used as shown in the following listing:

```

class A {
    public constructor(@Spec spec: ~i~this) {}
}

```

Spec-style Constructor

1. Annotation `@Spec` may only appear on a formal parameter of a constructor.

¹⁶ <https://github.com/NumberFour/N4JS/issues/81>

2. Only a single formal parameter of a constructor may be annotated with `@Spec`.
3. If a formal parameter is annotated with `@Spec`, the parameter's type must be *this* or *ithis* (i.e. use-site structurally typed *this*).
4. Fields provided by the parameter, but not defined in the structural field type, are *not* used to set fields.
5. Non-`public` fields explicitly added to the spec parameter are copied as well.
6. Even if the `@Spec` annotation is used, the super constructor must be called accordingly.
7. The type of an additional member which match owned non-public field must be subtype of the field's type: $\forall s \in ctor.fpar.structuralMembers, ctor.fpar.spec: \exists f \in ctor.owner.ownedFields \Rightarrow sf$
8. *ithis* constructor ignores superfluous properties provided by an object literal. These ignored properties are *not* used to set non-*public* fields.
9. Since use-site structural initializer field types can be defined via public, non-static, non-optional writable fields, *ithis* constructor accepts those properties provided by an object literal which has the corresponding readable fields. These properties will be initialized.

 GH-134 17

Example: Anonymous Interface in Constructor

The base class `A` in the examples redefines the constructor already defined in `N4Object`. This is not generally necessary and is only used here to make the example legible.

```
class A {
    public s: string;
    public constructor(@Spec spec: ~i~this) {
        // initialization of s is automatically generated
    }
}
class B extends A {
    public t: string;
    private n: number;
    public constructor(spec: ~~this with {n: number;}) {
        super(spec); // only inherited field s is set in super constructor
    }
}
```

Example: Spec Object and Subclasses

[[ex:Spec Object and Subclasses]]

```
class A1 {
    public s: string;
    public n: number;
    public constructor(@Spec spec: ~i~this) {}
}
```

¹⁷ <https://github.com/NumberFour/N4JS/issues/134>

```

class B extends A1 {
    public constructor() {
        super({s:"Hello"}); // <-- error, n must be set in object literal
    }
}
class C extends A1 {
    public constructor() {
        super({s:"Hello"}); // <-- error, n must be set in object literal
        this.n = 10; // <-- this has no effect on the super constructor!
    }
}

class A2 {
    public s: string;
    public n: number?; // now n is optional!
    public constructor(@Spec spec: ~i~this) {}
}
class D extends A2 {
    public constructor() {
        super({s:"Hello"}); // and this is ok now!
        this.n = 10; // this explains why it is optional
    }
}

class A3 {
    public s: string;
    public n: number = 10; // now n is not required in ~this
    public constructor(@Spec spec: ~i~this) {}
}
class E extends A3 {
    public constructor() {
        super({s:"Hello"}); // and this is ok now!
    }
}

```

The last case (class E) demonstrates a special feature of the typing strategy modifier in combination with the `this` type, see [???](#) for details.

The constructor in class `B` contains an error because the super constructor expects all required attributes in `A1` to be set. The additional initialization of the required field `A1.n` as seen in `C` does not change that expectation. In this example, the field `n` should not have been defined as required in the first place.

Optional fields like `n?` in class `A2` or fields with default values like `n=10` in class `A3` are not required to be part of the `spec` object.

Superfluous Properties in Spec-style Constructor]

Each non-*public* field has to be set in the constructor via the `with` to the parameter otherwise properties are *not* used to set non-*public* fields.

```

class C {
    public s: string;
    n: number;
    constructor(@Spec spec: ~i~this) {}
}

```

```
// n is ignored here
new C( { s: "Hello", n: 42 });

// but:
var ol = { s: "Hello", n: 42 };
// "ol may be used elsewhere, we cannot issue warning here" at "ol"
new C(ol) ;

// of course this is true for all superfluous properties
// weird is not used in constructor
new C( { s: "Hello", weird: true } );
```

6.4.2. Callable Constructors

6.4.3. Covariant Constructors

Usually, the constructor of a subclass need not be override compatible with the constructor of its super class. By way of annotation `@CovariantConstructor` it is possible to change this default behavior and enforce all subclasses to have constructors with override compatible signatures. A subclass can achieve this by either inheriting the constructor from the super class (which is usually override compatible, with the special case of `@Spec` constructors) or by defining a new constructor with a signature compatible to the inherited constructor. The same rules as for method overriding apply.

The `@CovariantConstructor` annotation may be applied to the constructor, the containing classifier, or both. It can also be used for interfaces; in fact, constructors are allowed in interfaces only if they themselves or the interface is annotated with `@CovariantConstructor` (see [???](#)).

Definition: Covariant Constructor

A classifier C is said to *have a covariant constructor* if and only if one of the following applies:

1. C has a direct super class C' and C' is annotated with `@CovariantConstructor` or C' has a constructor annotated with `@CovariantConstructor`.
2. C has a directly implemented interface I and I is annotated with `@CovariantConstructor` or I has a constructor annotated with `@CovariantConstructor`.
3. C has a direct super class or directly implemented interface that *has a covariant constructor* (as defined here).

Note that C does not need to have an owned(!) constructor; also a constructor inherited from a super class can be declared covariant.

The following rules apply to covariant constructors.

Covariant Constructors

1. Annotation `@CovariantConstructor` may only be applied to classes, interfaces, and constructors. Annotating a constructor with this annotation, or its containing classifier, or both have all the same effect.

2. Given a class *C* with an owned constructor *ctor* and a super class *Sup* that has a covariant constructor (owned or inherited, see), then

- a. *Supconstructor* must be accessible from *C*,
- b. *ctor* must be override compatible with *S.constructor*: *overrideCompatible(ctor, S.constructor)*

This constraint corresponds to [???](#) except for the `Override` annotation, which is not required, here.

3. Given a classifier *C* implementing interface *I* and *I* has a covariant constructor (owned or inherited, see [???](#)), we require

- a. *I.constructor* must be accessible from *C*,
- b. an implementation-compatible constructor *ctor* must be defined in *C* with *overrideCompatible(ctor, I.constructor)*

This constraint corresponds to [???](#) except for the `@Override` annotation, which is not required, here.

- c. Given a classifier *C* without an owned constructor and an extended class or interface *Sup* that has a covariant constructor (owned or inherited, see [???](#)), we require the inherited constructor *ctor* of *C* within the context of *C* to be override compatible to itself in the context of *Sup*. Using notation *m[T\$]* to denote that a member *m* is to be treated as defined in container type *T*, which means the this-binding is set to *T*, we can write: *overrideCompatible(ctor[C, ctor[Sup]] \end{aligned})* This constraint does not correspond to any of the constraints for the redefinition of ordinary members.

The following example demonstrates a use case for covariant constructors. It shows a small class hierarchy using covariant constructors, `Cls` and `Cls2`, together with a helper function `createAnother` that creates and returns a new instance of the same type as its argument `value`.

Covariant Constructors

```
class A {}
class B extends A {}

@CovariantConstructor
class Cls {
    constructor(p: B) {}
}

class Cls2 extends Cls {
    constructor(p: A) { // it's legal to generalize the type of parameter 'p'
        super(null);
    }
}

function <T extends Cls> createAnother(value: T, p: B): T {
    let ctor = value.constructor;
    return new ctor(p);
}

let x = new Cls2(new A());
let y: Cls2;
```

```
y = createAnother(x, new B());
```

In the code of `???` we would get an error if we changed the type of parameter `p` in the constructor of `Clas2` to some other type that is not a super type of `B`, i.e. the type of the corresponding parameter of `Clas1`'s constructor. If we removed the `@CovariantConstructor` annotation on `Clas1`, we would get an error in the new expression inside function `createAnother`.

The next example illustrates how to use `@CovariantConstructor` with interfaces and shows a behavior that might be surprising at first sight.

Covariant Constructors in Interfaces

```
@CovariantConstructor
interface I {
    constructor(p: number)
}

class C implements I {
    // no constructor required!
}

class D extends C {
    // XPECT errors --> "Signature of constructor of class D does not conform to overridden
    // constructor of class N4Object: {function(number)} is not a subtype of {function()}." at
    // "constructor"
    constructor(p: number) {}
}
```

Interface `I` declares a covariant constructor expecting a single parameter of type `number`. Even though class `C` implements `I`, it does not need to define an owned constructor with such a parameter. According to `???TITLE???`, it is enough for `C` to have a constructor, either owned or inherited, that is override compatible with the one declared by `I`. Class `C` inherits the default constructor from `N4Object`, which does not have any arguments and is thus override compatible to `I`'s constructor.

In addition, subclasses are now required to have constructors which are override compatible with the constructor of class `C`, i.e. the one inherited from `N4Object`. The above example shows that this is violated even when repeating the exact same constructor signature from interface `I`, because that constructor now appears on the other side of the subtype test during checking override compatibility.

6.5. Data Fields

 IDE-381¹⁸

A data field is a simple property of a class. There must be no getter or setter defined with the same name as the data field. In ECMAScript 6, a class has no explicit data fields. It is possible, however, to implicitly define a data field by simply assigning a value to a variable of the `this` element (e.g. `this.x = 10` implicitly defines a field `x`). Data fields in N4JS are similar to these implicit fields in ECMAScript 6 except that they are defined explicitly in order to simplify validation and user assistance.

¹⁸ <https://jira.numberfour.eu/browse/IDE-381>

6.5.1. Syntax

```
N4FieldDeclaration <Yield>:
    {N4FieldDeclaration}
    annotations+=Annotation*
    FieldDeclarationImpl<Yield>
;

fragment FieldDeclarationImpl <Yield>*:
    accessModifier=N4JSMemberAccessModifier?
    (static?='static' | const?='const')?
    LiteralPropertyName<Yield> ColonSepTypeRef? ('=' expression=Expression<In=true,Yield>)?
    ;
;
```

6.5.2. Properties

Fields have the following properties which can be explicitly defined:

typeRef

Type of the field; default value is *Any*.

expr

Initializer expression, i.e. sets default value.

static

Boolean flag set to true if field is a static field.

const

Boolean flag set to true if field cannot be changed. Note that *const* fields are automatically static. Const fields need an initializer. Also see [???](#).

Note that *const* is *not* the (reversed) value of the property descriptor *writable* as the latter is checked at runtime while *const* may or may not be checked at runtime.

The following pseudo properties are defined via annotations for setting the values of the property descriptor:

enumerable

Boolean flag reflecting the property descriptor *enumerable*, set via annotation `@Enumerable(true|false)`. The default value is `.`

declaredWriteable

Boolean flag reflecting the property descriptor *writable*, set via annotation `@Writeable(true|false)`. The default value is `.`

final

Boolean flag making the field read-only, and it must be set in the constructor. Also see [???](#).

Derived values for fields

readable

Always true for fields.

abstract

Always false for fields.

writeable

Set to false if field is declared const or final. In the latter case, it may be set in the constructor (cf. [Section 6.5.3, “Assignment Modifiers”](#)).

Semantics

Attributes

For any attribute a if a class C , the following constraints must hold:

1. A required data field must not define an initializer:

$a.requiredDataInit = null$

2. There must be no other member with the same name of a data field f . In particular, there must be no getter or setter defined with the same name: $\text{amp; } \forall m \in f.owner.members : m \neq f \text{ and } m.name \neq f.name$

If a subclass should set a different default value, this has to be done in the constructor of the subclass.

For the relation of data fields and field accessors in the context of extending classes or implementing interfaces see [???](#).

Type Inference

The type of a field is the type of its declaration: $\text{amp; } f:d$

The type of a field declaration is either the declared type or the inferred type of the initializer expression:
 $\text{amp; } d:Td.declaredType \neq \text{amp; } T = d.declaredType \text{amp; } d:Td.declaredType = \text{amp; } d.expression \neq E = d.expression \text{amp; } E \notin \{ \text{null}, \text{undefined} \}$

If the type contains type variables they are substituted according to type parameters which are provided by the reference:

$TField\ tfield:Ttfield.typeRef:T$

6.5.3. Assignment Modifiers

IDE-946 ¹⁹

Assignment of data fields can be modified by the assignment modifiers (similar to constant variable declarations, see [Section 11.2.2, “Const”](#)) and **@Final**.

Const Data Fields [[req:Const_Data_Fields]] For a data field f marked as **const**, the following constraints must hold:

¹⁹ <https://jira.numberfour.eu/browse/IDE-946>

1. An initializer expression must be provided in the declaration (except in n4jsd files): $f.expr \neq$
2. A constant data field is implicitly static and must be accessed only via the classifier type. It is not possible, therefore, to use the `this` keyword in the initializer expression of a constant field:
 $sub \in f.expr^*: sub = "this"$
3. A constant data field must not be annotated with `@Final`: $f.const \Rightarrow \neg f.final$
4. Constant data fields are not writeable (cf. [???](#)): $f.const \Rightarrow \neg f.writeable$

Final Data Fields

For a data field f marked as `@Final`, the following constraints must hold:

1. A final data field must not be modified with `const` or `static`: $f.final \Rightarrow \neg f.const \wedge \neg f.declaredStatic$
2. A final data field is not writeable: $f.final \Rightarrow \neg f.writeable$ A final field may, however, be set in the constructor. See [???](#) for details.
3. A final data field must be either initialized by an initializer expression or in the constructor. If the field is initialized in the constructor, this may be done either explicitly or via a spec-style constructor.

$$amp; f.expr \neq amp; \vee (\exists assignExp:assignExpr.containingFunction = f.owner.constructoramp; \wedge assignExpr.left.target = "the constructor")$$

GH-575 20

6.5.4. Field Accessors (Getter/Setter)

IDE-160 21
 IDE-381 22

Instead of a simple data field, a field can be defined by means of the getter and setter accessor methods. These accessor methods are similar to the accuser methods in object literals:

Syntax

IDE-8 23

```
N4GetterDeclaration <Yield>:
  => ({N4GetterDeclaration}
  annotations+=Annotation*
  accessModifier=N4JSMemberAccessModifier?
  (abstract?='abstract' | static?='static')?
  GetterHeader<Yield>)
```

²⁰ <https://github.com/NumberFour/N4JS/issues/575>

²¹ <https://jira.numberfour.eu/browse/IDE-160>

²² <https://jira.numberfour.eu/browse/IDE-381>

²³ <https://jira.numberfour.eu/browse/IDE-8>

```
(body=Block<Yield>) ? ';'?
;

fragment GetterHeader <Yield>*:
('get' -> LiteralOrComputedPropertyName <Yield> '(' ')' ColonSepTypeRef?)
;

N4SetterDeclaration <Yield>:
=>({N4SetterDeclaration}
annotations+=Annotation*
accessModifier=N4JSMemberAccessModifier?
(abstract?='abstract' | static?='static')?
'set'
->LiteralOrComputedPropertyName <Yield>
)
(' fpar=FormalParameter<Yield> ') (body=Block<Yield>) ? ';'?
;
```

Notes with regard to syntax: Although ECMAScript 6 does not define fields in classes, it defines getter and setter methods similarly (cf. [ECMA15a(p.S13.3, p.p.209)]).

Getter and Setter

[[ex:Getter and Setter]] The getter and setter implementations usually reference data fields internally. These are to be declared explicitly (although ECMAScript allows creating fields on the fly on their first usage (see task IDE-422)). The following example demonstrates a typical usage of getter and setter in combination with a data field. The getter lazily initializes the field on demand. The setter performs some notification.

 IDE-422²⁴

Getter Setter

```
class A {}

class C {
    private _data: A = null;

    public get data(): A {
        if (this._data==null) {
            this._data = new A();
        }
        return this._data;
    }

    public set data(data: A) {
        this._data = data;
        this.notifyListeners();
    }

    notifyListeners(): void {
        // ...
    }
}
```

²⁴ <https://jira.numberfour.eu/browse/IDE-422>

}

Properties

Derived values for field accessors:

`readable`

True for getters and false for setters.

`writable`

False for getters and true for setters.

Semantics

There must be no field or method with the same name as a field accessor (follows from [???](#)). In addition, the following constraints must hold:

Field Accessors

- The return type of a getter must not be `void`.
- The type of the parameter of a setter must not be `void`.
- If a getter g is defined or consumed (from an interface) or merged-in (via static polyfill) in a class C and a setter s with $s.name = g.name \wedge s.static = g.static$ is inherited by C from one of its super classes, then C must define a setter s' with $s'.name = g.name \wedge s'.static = g.static$ ²⁵. The same applies to setters, accordingly.
- [???](#), [???](#), and [???](#) apply to field accessors accordingly (getter / setter overriding).



A getter and setter with the same name need not have the same type, i.e. the getter's return type need not be the same as a subtype of the type of the setter's parameter (the types can be completely unrelated). ²⁶

Getters and setters – like functions – define a variable execution environment and therefore provide access to the actual passed-in parameters through the implicit `arguments` variable inside of their bodies (c.f. [???](#)).

6.6. Static Members

IDE-151 ²⁷
 IDE-505 ²⁸

²⁵ This is required, because in Javascript a getter shadows a corresponding setter defined further up in the prototype chain; likewise a setter shadows a corresponding getter.

²⁶ Thus, the type of one accessor is not used to infer the type of the other one. E.g., from `set x(string s)`, we cannot infer `get x()` to return `string` — instead, the getter is inferred to return `any`.

²⁷ <https://jira.numberfour.eu/browse/IDE-151>

²⁸ <https://jira.numberfour.eu/browse/IDE-505>

Static data fields, field accessors and methods are quite similar to instance members, however they are not members of instances of the type but the type itself. They are defined similarly to instance members except that they are specified with the modifier `static`. Since they are members of the type, the `this` keyword is not bound to instances of the class, but again to the type itself. This is similar as in ECMAScript 6 ([ECMA15a(p.14.5.15)]). Since static members are not instance but type members, it is even possible that a static member has the same name as an instance member.

Note that static members are not only allowed in classes but also in interfaces, but there are important differences (for example, no inheritance of static members of interfaces, cf. Section ???).

[[req:Static member not abstract]] For a static field accessor or method *s*, the following constraint must hold:

- $s.\text{static} \neg s.\text{abstract}$

Like instance methods, static methods of classes are inherited by subclasses and it is possible to override static methods in subclasses. The very same override constraints are valid in this case as well.

6.6.1. Access From and To Static Members

Accessing Static Members

Let *m* be a static member of class `C`. Except for write-access to fields, which will be explained later, you can access *m* via:

1. The class declaration instance, i.e. the classifier or constructor type, `constructor{C}`, i.e. `C.m`
2. The class declaration instance of a subtype, i.e. the classifier or constructor type, i.e. `D.m`, if `D` is a subclass of `C`.
3. `v.m`, if `v` is a variable of type `C` (i.e. classifier type as defined in ???) or a subtype thereof.
4. `this.m` inside the body of any static method declared in `C` or any sub-class of `C`.
5. Via a type variable *T* which upper bound is a subclass of `C`,
e.g., `function <T extends C> f() {T.m}` task:GH-222[]

It is not possible to access instance members from static members. This is true in particular for type variables defined by a generic classifier.

[[req:write_access_of_static_data_fields]] For static data fields and static setter *f* the following constraint must hold:

IDE-1071²⁹
 GH-442³⁰

- For every assign expression *assignExpr* with $f.\text{static} \wedge \text{assignExpr.left} = T.f \rightarrow T = f.\text{owner}$.
- For every writing unary expression *u* with $u.\text{op} \in \{++,--\} \wedge f.\text{static} \wedge u.\text{expression} = T.f \rightarrow T = f.\text{owner}$.

²⁹ <https://jira.numberfour.eu/browse/IDE-1071>

³⁰ <https://github.com/NumberFour/N4JS/issues/442>

In the special case of *m* being a static data field, write-access is only possible via the defining type name `C.m`. So in the list above, only the first line can be used when assigning values to a field. Note that this only applies to fields and set-accessors. ³¹

It is even possible to call a static field accessor or method of a class using dynamic polymorphism, as demonstrated in the following example:

Static members of classes, inheritance and polymorphism

```
class A {
    static m(): void { console.log('A#m'); }

    static foo(): void { console.log('A#foo'); }

    static bar(): void {
        this.foo();
    }
}

class B extends A {
    @Override
    static foo(): void { console.log('B#foo'); }
}

A.m(); // will print "A#m"
B.m(); // will print "A#m" (m is inherited by B)

var t: type{A} = A;
t.foo(); // will print "A#foo"
t = B;
t.foo(); // will print "B#foo"

// using 'this':

A.bar(); // will print "A#foo"
B.bar(); // will print "B#foo"
```

This is quite different from Java where static methods are not inherited and references to static methods are statically bound at compile time depending on the declared type of the receiver (and not its value):

Static members in Java

```
// !!! JAVA CODE !!!
public class C {

    static void m() { System.out.println("C#m"); }
```

³¹ The technical reason for this rule is the way properties are stored in JavaScript. Take for an example subclass-write access : `class C { static f="a"; } with class D extends C { } . Now the data field f on C can also be queried using D (var q=D.f;) but writing (D.f="b";) would introduce a newly created property f on class D , which differs from the one defined on C . It would do this without explicitly overriding the inherited property. Subsequent reads to D.f would route to this 'accidentally' introduced property. Such a behavior would not be expected and therefore has been disallowed. Note that this write restriction applies to data-fields and to field setters.`

```

public static void main(String[] args) {
    final C c = null;
    c.m(); // will print "C#m" (no NullPointerException at runtime)
}
}

```

6.6.2. Generic static methods

IDE-151³²
IDE-38³³
IDE-39³⁴

It is not possible to refer to type variables of a generic class, as these type variables are never bound to any concrete types. A static method can, however, be declared generic. Generic static methods are defined similarly to generic instance methods. Since they cannot refer to type variables of a generic class, the constraint to avoid type variables with equal names (see [???](#)) does not need to hold for generic static methods.

6.6.3. Static Members of Interfaces

Data fields, field accessors and methods of interfaces may be declared static. A few restrictions apply:

1. Static members of interfaces may only be accessed directly via the containing interface's type name (this means, of the four ways of accessing static members of classes defined in [???](#)[TITLE](#)[???](#) above, only the first one applies to static members of interfaces).
2. The `this` literal may not be used in static methods or field accessors of interfaces and it may not be used in the initializer expression of static fields of interfaces. See [???](#).
3. The `super` literal may not be used in static methods or field accessors of interfaces (in fact, it may not be used in interfaces at all, cf. [???](#)).

GH-386³⁵

Note that the `this` type as a return type for methods is only allowed for instance methods and as an argument type only in constructors (structurally typed). There is no need to disallow these cases for static interface methods in the constraints above.

In general, static members may not be abstract, cf. [???](#), which applies here as well. Static methods and field accessors of interfaces, therefore, always have to provide a body.

Static members of interfaces are much more restricted than those of classes. Compare the following example to [???](#) for classes above:

Example: Static members of interfaces

³² <https://jira.numberfour.eu/browse/IDE-151>

³³ <https://jira.numberfour.eu/browse/IDE-38>

³⁴ <https://jira.numberfour.eu/browse/IDE-39>

³⁵ <https://github.com/NumberFour/N4JS/issues/386>

```

interface I {
    static m(): void { console.log('I#m'); }
}

interface J extends I {}

I.m(); // prints "I#m"
J.m(); // ERROR! (m is not inherited by J)

var ti: type{I} = I;
ti.m(); // ERROR! (access to m only allowed directly via type name I)
ti = J;
ti.m(); // ERROR! (access to m only allowed directly via type name I)

```

The last line in is the reason why access to static members has to be restricted to direct access via the type name of the containing interfaces.

6.7. Redefinition of Members

Members defined in classes or interfaces can be redefined by means of being overridden or implemented in subclasses, sub-interfaces, or implementing classes. Fields and methods with default implementation defined in interfaces can be consumed by the implementor, but certain restrictions apply.

70Override Compatible[Override Compatible] A member M is *override compatible* to a member S if and only if the following constraints hold:

1. The name and static modifiers are equal: $M.name = S.name \wedge M.static = S.static$
2. The metatypes are compatible:
 $\mu(S) = Method \wedge \mu(M) = Method \Rightarrow \mu(S) = Field \wedge \mu(M) = Field \Rightarrow \mu(M) \in Field, Getter, Setter \wedge \mu(S) = Getter \wedge \mu(M) = Getter \Rightarrow \mu(M) \in Field, Getter$
3. The overridden member must not be declared final: $\neg S.final$
4. Overridden member declared const can only be overridden (redefined) by const members:
 $S.const \Leftrightarrow M.const$
5. It is not possible to override a non-abstract member with an abstract one: $\neg M.abstract \vee S.abstract$
6. The types are compatible:
 $(\mu(M) \in Method, Getter, Field \wedge \mu(S) \neq Setter) \wedge (\mu(S) \in Setter, Field \wedge \mu(M) \neq Getter \wedge \neg S.const) \Rightarrow M \neq S$
7. The access modifier is compatible: $M.access \geq S.access$

We define a relation $overrideCompatible(M, S)$ accordingly.

Members overriding or implementing other members must be declared as override. If a member does not override another, however, it must not be declared as override.

If and only if a member M of a class C (extending a class S and interfaces I_i) does not override or implement another member, then it must not be declared as override. That is the following constraint must hold:

$$\neg M.override \wedge M \in C.supermembers \cup \bigcup_{i=1}^n I_i.members \wedge M.name = M.name \wedge M.static = M.static \wedge M.access \geq S.access$$

6.7.1. Overriding of Members

⌘IDE-12³⁶
⌘IDE-158³⁷

In general, the N4 platform supports overriding members by redefining them in sub-classes. This definition allows for overriding of static methods, but it does not apply to constructors because $C.ctor \notin C.ownedMethods$.

Given a class C and a superclass Sup . If for an instance or static member M defined in C a member S exists with $\exists S \in Sup.members : M.name = S.name \wedge M.static = S.static$ then we call M the overriding member and S the overridden member. In that case the following constraints must hold:

1. S must be accessible from C
2. M must be override compatible with S : $overrideCompatible(M, S)$
3. If S is a field and M is an accessor, then an additional accessor M' must exists so that M, M' are an accessor pair for S :
 $\mu(S) = Field \wedge \mu(M) = Accessor \wedge \Rightarrow \exists M' \in C.member : \mu(M') = Accessor \wedge \mu(M) \neq \mu(M')$
 $overrideCompatible(M', S) \wedge \{\mu(M), \mu(M')\} = \{Field, Accessor\}$
4. M must be declared as override: $M.override$

Remarks:

- An overridden method, getter, or setter may called via `super`. Note that this is not possible for fields.
- There is no 'hiding' of fields as in Java, instead there is field overriding.
- It is not possible to override a field with a consumed getter and an overridden setter, because the getter is not consumed if there exists a field in a superclass. In this case, the consuming and extending class needs to define the accessor pair explicitly. The same is true for other combination of accessors and fields.
- Overriding a field usually makes only sense if the visibility of the field is to be increased.

6.7.2. Implementation of Members

⌘IDE-12³⁸
⌘IDE-158³⁹
⌘IDE-700⁴⁰
⌘IDE-1236⁴¹

Definition: Interface and Class Member Sets

³⁶ <https://jira.numberfour.eu/browse/IDE-12>

³⁷ <https://jira.numberfour.eu/browse/IDE-158>

³⁸ <https://jira.numberfour.eu/browse/IDE-12>

³⁹ <https://jira.numberfour.eu/browse/IDE-158>

⁴⁰ <https://jira.numberfour.eu/browse/IDE-700>

⁴¹ <https://jira.numberfour.eu/browse/IDE-1236>

For the following constraints, we define two helper sets M_C and M_I as follows: Given a C , and interface $I_1, 8230;8203; I_n$, implemented by C , with $M_{Camp} = C.ownedMembers \cup \{m \in C.superType.members | m.accessor \neq private\}$ $M_I = \bigcup_{i=1}^n I_i.members$. Note that these sets already contain only non-private data fields.

Member Consumption

Definition: Member Consumption and Implementation

A member M defined in an interface I is *consumed* by an implementor C , if it becomes a member of the class, that is, $M \in C.members$.

A member M is consumed if there is no member defined in the implementor with the same name and if there is no non-private non-abstract member with that name inherited by the implementor from its superclass.[There had been the idea of preventing static members of being consumed. However, this would break the type subtype relation.]

If the implementor defines the member itself, then the member is implemented rather than consumed.

The concrete rules are described in the following;

It is not always possible to directly consume a member. In general, a rather conservative strategy is used: if two implemented interfaces define the same (non-abstract) member then the implementor must redefine the member in order to solve conflicts. Even if the two conflicting members have the same types, the implementor must redefine them as we generally assume semantic differences which the consumer has to be aware of. Data fields defined in interfaces, in particular, are assumed to be concrete. It is not, therefore, possible to consume a field defined in two implemented interfaces.

Given a classifier C ⁴², and interfaces $I_1, 8230;8203; I_n$ implemented (or extended) by C , and sets M_C and M_I as defined in . A non-static member M defined in any interface I_i is merged into the consumer (C), if for all other (possible) members M' of C $\forall M' \in M_C \cup M_I \setminus M : M.name = M'.name \wedge \neg M'.static$ the following constraints hold:

1. The other member's meta type matches the meta type of the merge candidate:
 $\mu(M) = Method \Rightarrow \mu(M') = Method \wedge \mu(M) \neq Method \Rightarrow \mu(M') \in Field, FieldAccessor$
2. The other member is abstract and not owned by the consumer:
 $\mu(M) = \mu(M') \vee \mu(M) = Field \Rightarrow M'.abstract \wedge M' \notin C.ownedMembers$
3. The merge candidate's access modifier is not less than the modifier of the other member:
 $\mu(M) = \mu(M') \vee \mu(M) = Field \Rightarrow M.access \geq M'.access$
4. The merge candidate's type compatible with the other member:
 $\mu(M) \in Method, Getter, Field \wedge \mu(M') \neq Setter \Rightarrow M.access \in Setter, Field \wedge \mu(M') \neq Getter \Rightarrow M.access \in Setter, Field$

Member Implementation

For any non-static abstract member M defined in an interface I implemented (or extended) by a classifier C , M must be accessible from C and one or two member(s) in C must exist which are implementa-

⁴² C could either be a class or an interface.

tion-compatible with M . The implementing member(s) must be declared as override if they are directly defined in the consumer.

1. M must be accessible from C .
2. An implementation-compatible member M' must exist in C :

a. if M is not a field:
 $\mu(M) \neq Field \Rightarrow \exists M' \in C.members : \text{overrideCompatible}(M', M) \wedge (M' \in C.ownedMembers \Rightarrow F' \in C.ownedMembers \Rightarrow \mu(M') = Field)$

b. if M is a field, then either an implementation-compatible field F' or an accessor pair G', S' must exist:
 $\mu(M) = Field \Rightarrow \exists F' \in C.fields : \text{overrideCompatible}(F', M) \wedge (F' \in C.ownedMembers \Rightarrow F' \in C.ownedFields \Rightarrow \mu(F') = Field)$

Methods defined in interfaces are automatically declared abstract if they do not provide a default implementation. This can also be expressed explicitly via adding the **abstract** modifier. If a class implementing an abstract interface does not implement a method declared in the interface, the class needs to be declared abstract (cf. [???](#)).

Consequences for method implementation:

1. It may be required for the implementor to explicitly define a method in order to solve type conflicts produced by methods of different interfaces with same name but different signatures.
2. Methods in an implementor cannot decrease the accessibility of methods from implemented interfaces, that is
 $\forall M \in C.methods, M' \in I_i.methods(i = 1n) : M.name = M'.name \Rightarrow M.access \neq private \wedge M.access \geq M'.access$
3. Methods in the implementor must be a supertype [43](#) of methods from implemented interfaces. That is to say the implemented methods are override-compatible.
4. There may be several methods M_1, M_2, \dots, M_n defined in different implemented interfaces and a single owned method M' in M_C . In this case, the above constraints must hold for *all* methods. In particular, M' 's signature must conform to all conflicting methods' signatures. This is possible by using union types for the arguments and an intersection type as return type. Such a method M' is said to *resolve* the conflict between the implemented (and also inherited) methods.
5. Since abstract methods may become part of the implementor methods, the implementor must either define these methods or it must be declared abstract itself. Since interfaces are abstract by default, responsibility for implementing abstract methods is passed on to any implementor of interfaces.
6. If two implemented interfaces provide (non-abstract) members with the same name, they are not automatically consumed by the implementor even if the types would be similar. In these cases, the implementor has to redefine the members in order to be aware of possible semantic differences.

 IDE-752 [44](#)

There is currently no separate annotation to indicate that methods are implemented or overridden in order to solve conflicts. We always use the **@Override** annotation.

[43](#) As defined in [???](#) for function types.

[44](#) <https://jira.numberfour.eu/browse/IDE-752>

[[ex:Method Consumption]]

Table Method Consumption shows simple examples of above rules. Assuming that `class C` extends super `class S` and implements interface `I1` and `I2`:

```
class C extends S implements I1, I2 { ... }
```

The columns describe different scenarios in which a method (with same name) is defined in different classifiers. We assume that the defined methods are always non-abstract (i.e. have default implementations), non-private and have the same signature. The last row shows which method will be actually used in class `C`. If the method is defined in class `C`, and if this method is printed bold, then this means that the method is required to be defined in `C` in order to solve conflicts.

Table 6.1. Consumption of methods

Interface <code>I1</code>	M_{I1}	M_{I1}	M_{I1}	M_{I1}	M_{I1}	M_{I1}
Interface <code>I2</code>			M_{I2}		M_{I2}	M_{I2}
<code>class S</code>				M_S	M_S	M_S
<code>class C</code>		M_C	M_C			M_C
<code>∈ Cmembers</code>	M_{I1}	M_C	M_C	M_S	M_S	M_C

Consuming Field Initializers

Aside from the fields themselves, an implementor *always* consumes the field initialization if the field is consumed – this is how the consumption is noticed at runtime.

[[ex:Field and Field Initializer Consumption]]

```
/* XPECT output ~~~
<==
stdout:
s: C , t: D ,u: I1 ,v: I2
stderr:
==>
~~~ */

interface IO {
    v: string = "IO";
}

interface I1 {
    s: string = "I1";
    t: string = "I1";
    u: string = "I1";
}

interface I2 extends I1, IO {
    @Override
    t: string = "I2";
    @Override
    v: string = "I2";
}
```

```
class C {
    s: string = "C";
}

class D extends C implements I1, I2 {
    @Override
    t: string = "D";
}

var d = new D();

console.log(
    "s:", d.s, ", t:", d.t, ",u:", d.u, ",v:", d.v
)
```

We expect the following output (for each field):

- `d.s = "C"` : `s` is inherited from `C`, so it is not consumed from `I1` (or `I2`). Consequently, the initializer of `s` in `C` is used.
- `d.t = "D"` : `t` is defined in `D`, solving a conflict stemming from the definition of `t` in `I1` and `I2`. Thus, the initializer of `t` in `D` is used.
- `d.u = "I1"` : `u` is only defined in `I1`, thus the initializer defined in `I1` is used.
- `d.v = "I2"` : `v` is overridden in `I2`, so is the field initializer. This is why `d.v` must be assigned to `I2` and not `I0`.

Chapter 7. Structural Typing

IDE-673¹
IDE-680²
IDE-688³
IDE-691⁴

In general, N4JS uses nominal typing. This is to say that a duck is a duck only if it is declared to be a duck. In particular when working with external APIs, it is more convenient to use structural or duck typing. That is, a thing that can swim and quacks like a duck, is a duck.

Interfaces or classes can be used for this purpose with a *typing strategy modifier*. Given a type T , the simple \sim (tilde) can be added to its declaration (on definition-site) or in a reference (on use-site) to indicate that the type system should use structural typing rather than nominal typing.⁵ This means that some other type must provide the same members as type T to be deemed a structural subtype. However, the operator cannot be used anymore with the type or reference as this operator relies on the declaration information (or at least the closest thing available at runtime). In this case, T is, therefore, always a structural subtype of $\sim T$.

Sometimes it is convenient to refer only to the fields of a classifier, for example when the initial field values are to be provided in a variable passed to the constructor. In that case, the type can be modified with $\sim\sim$ (two tildes). This is only possible on use-site, i.e. on type references. Furthermore, only on the use-site, it is possible to consider only either readable or writable or fields by using the read-only r or write-only w structural field typing. For initialization blocks, it is even possible to use structural initializer field typing via the i operator.

7.1. Syntax

Structural typing is specified using the typing strategy modifier. There are two modifiers defined; one for definition-site and one for use-site structural typing.

Structural Type Operator and References

```
TypingStrategyUseSiteOperator returns TypingStrategy:  
  '~~' ('~~' | STRUCTMODSUFFIX)?;  
  
TypingStrategyDefSiteOperator returns TypingStrategy:  
  '~~';  
  
terminal STRUCTMODSUFFIX:  
  ('r' | 'i' | 'w') '~~'  
;
```

¹ <https://jira.numberfour.eu/browse/IDE-673>

² <https://jira.numberfour.eu/browse/IDE-680>

³ <https://jira.numberfour.eu/browse/IDE-688>

⁴ <https://jira.numberfour.eu/browse/IDE-691>

⁵ This kind of typing is used by TypeScript only. By defining a structural typed classifier or reference, it basically behaves as it would behave – without that modifier – in TypeScript.

```
ParameterizedTypeRefStructural returns ParameterizedTypeRefStructural:  
    definedTypingStrategy=TypingStrategyUseSiteOperator  
    declaredType=[Type|TypeReferenceName]  
    (=> '<' typeArgs+=TypeArgument (',' typeArgs+=TypeArgument)* '>')?  
    (=> 'with' '{' astStructuralMembers+=TStructMember* '}')?  
;  
  
ThisTypeRefStructural returns ThisTypeRefStructural:  
    definedTypingStrategy=TypingStrategyUseSiteOperator  
    'this'  
    ('with' '{' astStructuralMembers+=TStructMember* '}')?  
;
```

7.2. Definition Site Structural Typing

An interface or class can be defined to be used with structural typing by adding the structural modifier to its definition (or, in case of external classes, to the declaration). This changes the default type system strategy from nominal to structural typing for that type. That means that all types with the same members as the specified type are subtypes of that type, except for subtypes of `N4Object`. In the latter case, programmers are enforced to nominal declare the type relation.

If a type T is declared as structural at its definition, $T.defStructural$ is true.

[[req:Definition Site Structural Typing]]

1. The structurally defined type cannot be used on the right hand side of the `instanceof` operator:
 $x \text{ instanceof } T \Rightarrow \neg T.defStructural$

2. A type X is a subtype of a structurally defined type T either

- a. if it is not a subtype of `N4Object`⁶ but it contains all public, non-static members of that type
 $XTXN4Object \quad T.defStructural \wedge \forall m \in T.members, m.access = \text{public}, \neg m.static, m \neq T.ctor: \exists m' \in X.members: m.access =$
- b. if it is a subtype of `N4Object` which explicitly extends or implements the structurally defined type. $XTXN4Object \wedge T.defStructural \wedge T \in X.superTypes^*$
- c. A structurally defined type T is implicitly derived from `Object` if no other type is specified. In particular, a structurally defined type must not be inherited from $TObject$.
 $T.defStructural \Rightarrow TN4Object \wedge N4Object \notin T.superTypes^*$

[[ex:Declaration Site Structural Typing]] The following snippet demonstrates the effect of definition-site structural types by comparing them to nominal declared types:

[[!st:Declaration Site Structural Typing]]

Declaration Site Structural Typing

```
interface ~Tilde { x; y; }  
interface Nominal { x; y; }  
class C { public x; public y; }  
class D extends C implements Tilde { }
```

⁶We enforce programmers of N4JS to use nominal typing, therefore, it is not possible to bypass that principle by declaring a type as structural for normally defined classes (except those explicitly derived from `N4Object`).

```

function f(p: Tilde) {}
function g(p: Nominal) {}

f(new C());           // error: nominal typing, C does not implement ~Tilde
f(new D());           // ok, D is a nominal subtype (as it implements Tilde)
f({x:10,y:10});    // ok: Tilde is used with structural typing for non-N4-classifiers

```

Definition site structural typing may lead to unexpected results. For example;

```

class C{}
class ~E extends C{}

```

It may be unexpected, but `E` is not a subtype of `C`, i.e. `EC!` E.g., `instanceof` won't work with `E`, while it works with `C`!

7.3. Use-Site Structural Typing

Use-site structural typing offers several typing strategy modifiers to define the accessibility of public properties of classes and interfaces. They can be used e.g. on variable declarations like this: `var c : ~C` . The table [???](#) shows which properties of structural types can be accessed in the different type strategies. For example, when using the write-only structural strategy (i.e. `X`), only the writeable fields, can be accessed for writing. In the table, the term field to both, public datafields and accessors of type `X`. Non-public properties are never accessible in use-site structural types. In any field-structural type, methods of the referenced nominal type `X` are not available. The initializer structural typing provides readable fields for every writeable field of the references type.

[\[\[tab:Available Fields of Structural Types\]\]](#)

Table 7.1. Available Fields of Structural Types

Property of X	X	X	X	X	X
public method		∅	∅	∅	∅
public writable field			∅		∅
public readable field				∅	writable fields

Multiple structural typing strategies can be nested when there are multiple use sites, like in the example [???](#) below at the locations ST1 and ST2. In the example, the datafield `a.field` has the nested structural type `{\tsInitFld A}` and thus the datafield `a.field.df` is readable. Nested structural types are evaluated on the fly when doing subtype checks.

GH-12⁷

[\[\[ex:Nested Structural Typing Strategies\]\]](#)

⁷ <https://github.com/NumberFour/N4JS/issues/12>

```

class A {
    public df : string;
}

interface I<T> {
    public field : ~r~T; // ST1
}

var a : ~i~A; // ST2

```

The following example demonstrates the effect of the structural type modifiers:

[[ex:Effect of structural type modifiers on use-site]] Let's assume the type defined on the left. The following *pseudo* code snippets explicitly list the type with its members virtually created by a structural modifier. Note that this is pseudo code, as there are no real or virtual types created. Instead, only the subtype relation is defined accordingly:

Effect of structural type modifiers on use-site

Effect of structural type modifiers on use-site		
Type	Structural Type	Structural Field Type
<pre> var c:C class C { private x; public y; public f() private g() public get z():Z public set z(z:Z) } interface I { a; func(); } </pre>	<pre> var cstructural:~C class cstructural { public y; public f() public get z():Z public set z(z:Z) } interface ~I { a; func(); } </pre>	<pre> var cfields:~~C class cfields { public y; public get z():Z public set z(z:Z) } interface ~~I { a; } </pre>

Structural Read-only Field Type	Structural Write-only Field Type	Structural Initializer Field Type
<pre> var crofields:~r~C class crofields { public get y():Y public get z():Z } interface ~r~I { public get a():A } </pre>	<pre> var cwofields:~w~C class cwofields { public set y(y:Y) public set z(z:Z) } interface ~w~I { public set a(a:A) } </pre>	<pre> var cinitfields:~i~C class cinitfields { public get y():Y public get z():Z } interface ~i~I { public get a():A } </pre>

Note that even if a type is defined without the structural modifier, it is not possible to use `instanceof` for variables declared as structural, as shown in the next example:

Type	Structural Type	Structural Field Type
<pre>class C {...} interface I {...} foo(c: C, i: I) { c instanceof C; // ok c instanceof I; // ok }</pre>	<pre>class C {...} interface I {...} foo(c: ~C, i: ~I) { ^\color{red} \underline{c} ^\color{red} instanceof C; // error ^\color{red} \underline{c} ^\color{red} instanceof I; // error }</pre>	<pre>class C {...} interface I {...} foo(c: ~~C, i: ~~I) { ^\color{red} \underline{c} ^\color{red} instanceof C; // error ^\color{red} \underline{c} ^\color{red} instanceof I; // error }</pre>

- If a type is referenced with the structural type modifier `~`
- If a type is referenced with the structural read-only field type modifier `~r~`
- If a type is referenced with the structural write-only field type modifier `~w~`

We call T the (nominal) type T , T the structural version of T , T the structural field version of T , T the structural read-only field, T the structural write-only field and T the structural initializer field version of T .

1. The structural version of a type is a supertype of the nominal type: TT
2. The structural field version of a type is a supertype of the structural type: TT
3. The structural read-only field version of a type is a supertype of the structural field type: TT
4. The structural write-only field version of a type is a supertype of the structural field type: TT
5. The structural (field) version of a type cannot be used on the right hand side of the `instanceof` operator:
 $x instanceof E \Rightarrow E:Tamp; \neg (TrefStructuralamp; \vee TrefStructuralFieldamp;)$
That is, the following code will always issue an error: `x instanceof ~T`
6. A type X is a subtype of a structural version of a type T , if it contains all public, non-static members of the type T :
 $XT\forall m \in T.members, m.owner \notin N4Object, m.access = public, \neg m.static, m \neq T.ctor: \exists m' \in X.members: m'.access = public \wedge \neg m'.static$ ⁸
7. A type X is a subtype of a structural field version of a type T , if it contains all public, non-static and non-optional fields of the type T :
 $XT\forall m \in T.fields, m.owner \notin N4Object, m.access = public, \neg m.static, m \in X.fields: m.access = public \wedge \neg m.static \vee \exists m' \in X.fields: m'.access = public \wedge \neg m'.static \wedge m'.optional = false$
8. A type X is a subtype of a structural read-only field version of a type T , if it contains all public, non-optional and non-static readable fields of the type T :
 $XT\forall m \in T.fields \cup T.getters, m.owner \notin N4Object, m.access = public, \neg m.static, m \in X.fields \cup X.getters: m.access = public \wedge \neg m.access = private \wedge \neg m.access = protected \wedge \neg m.access = package$
9. A type X is a subtype of a structural write-only field version of a type T , if it contains all public, non-optional and non-static writable fields of the type T :
 $XT\forall m \in T.fields \cup T.setters, m.owner \notin N4Object, m.access = public, \neg m.static, \neg m.final, m \in X.fields \cup X.setters: m.access = public \wedge \neg m.access = private \wedge \neg m.access = protected \wedge \neg m.access = package$

⁸ Note that due to this relaxed definition (compared with definition-site structural types) it is possible to pass an `N4Object` instance to a function with a declared structural type parameter.

10A type X is a subtype of a structural field version of a type $this$, if it contains all public, non-static and non-optional fields, either defined via data fields or field get accessors, of the inferred type of `this`. All fields which have an initializer are handled as if they were optional.
 $X \in this:T \forall m \in T.\text{fields} \cup T.\text{setters}, m.\text{owner} \notin \text{N4Object}, m.\text{acc} = \text{public}, \neg m.\text{static}$ $m' \in X.\text{fields} \cup X.\text{getters}: m.\text{optional} \vee m.\text{def}$

11A structural field type T is a subtype of a structural type X , if X only contains fields (except methods inherited from `Object`) and if $TX.TXX.\text{methods} \setminus Object.\text{methods} = \emptyset \wedge TX$

12Use-site structural typing cannot be used for declaring supertypes of classes or interfaces. That is to say that structural types cannot be used after `extends`, `implements` or `with` in type declarations.⁹

Note that all members of `N4Object` are excluded. This implies that extended reflective features (cf. [???](#)) are not available in the context of structural typing. The `instanceof` operator is still working as described in [???](#), in that it can be used to check the type of an instance.

If a type X is a (nominal) subtype of T , it is, of course, also a subtype of T : $XTXT$ This is only a shortcut for the type inference defined above.

77Definition and Use-Site Precedence

If a type is structurally typed on both definition and use-site, the rules for use-site structural typing ([???](#) [TITLE???](#)) are applied.

Use-Site Structural Typing

The following example demonstrates the effect of the structural (field) modifier, used in this case for function parameters.

```
interface I { public x: number; public foo(); };
class C { public x: number; public foo() {}};

function n(p: I) {}
function f(p: ~I) {}
function g(p: ~~I) {}

n(new C());      // error: nominal typing, C does not implement I
f(new C());      // ok: C is a (structural) subtype of ~I
f({x:10});        // error, the object literal does not provide function foo()
g({x:10});        // ok: object literal provides all fields of I
```

[[ex:Structural types variable and instanceof operator]] It is possible to use a variable typed with a structural version of a type on the left hand side of the `instanceof` operator, as demonstrated in this example:

```
class C {
    public x;
    public betterX() { return this.x || 1; }
}

function f(p: ~~C) {
```

⁹ This is already constrained by the grammar.

```

if (p instanceof C) {
    console.log((p as C).betterX);
} else {
    console.log(p.x || 1);
}
}

```

The following table describes the member availability of `x` in various typing scenarios. Such as `X`, `X`, `X` and `X`.

Member of type X	<code>'~~X</code>	<code>'~r~X</code>	<code>'~w~X</code>	<code>'~i~X</code>
<code>private m0;</code>	—	—	—	—
<code>public set m1(m) { }</code>	write	—	write	read
<code>public get m2() {...}</code>	read	read	—	
<code>public m3;</code>	read/write	read	write	read
<code>public m4 = 'init.m4';</code>	read/write	read	write	read ?]
<code>public m5: any?;</code>	read?/write	read?	write	read?
<code>@Final public m6 = 'init.m6';</code>	read	read		
<code>@Final public m7;</code>	read	read		read
<code>public get m8() {...}</code>	read/write	read	write	read
<code>public set m8(m) { }</code>				

7.4. Structural Read-only, Write-only and Initializer Field Typing

IDE-1777 ¹⁰

Structural read-only, write-only and initializer field typings are extensions of structural field typing. Everything that is defined for the field structural typing must comply with these extension field typings. For the read-only type, readable fields (mutable and ones) and setters are considered, for the write-only type; only the setters and mutable fields are considered. Due to the hybrid nature of the initializer type it can act two different ways. To be more precise, a type `X` (structural initializer field type) is a supertype of `Y` (structural initializer field type) if for each public, non-static, non-optional writable field (mutable data field of setter) of `X`, there is a corresponding, public, non-static readable field of `Y`. All public member fields with annotation are considered to be mandatory in the initializer field typing constructors. The already-initialized fields can be either omitted from, or can be re-initialized via, an initializer field typing style constructor.

Subtype relationship between structural field typing [[ex:Subtype relationship between structural field typing]]

```
class A1 {
```

¹⁰ <https://jira.numberfour.eu/browse/IDE-1777>

```
public s: string;
}

class A2 {
    public set s(s: string) { }
    public get s(): string { return null; }
}

class A3 {
    @Final public s: string = null;
}

class A4 {
    public get s(): string { return null; }
}

class A5 {
    public set s(s: string) { }
}
```

7.5. Public Setter Annotated With `ProvidesInitializer`

Public setters with `ProvidesInitializer` annotation can declare optional fields implemented by means of field accessors instead of data fields. Data fields with an initializer are treated as optional in the initializer field type.

It is important to note that it is valid to use the `ProvidesInitializer` annotation for setters in `n4js` files and not only definition files.

[[ex:Setters with @ProvidesInitializer treated as optional]]

```
class C {
    private _y: int = 1;

    public get y() { return this._y; }
    @ProvidesInitializer
    public set y(v: int) { this._y = v; }

    public constructor(@Spec spec: ~i~this) { }
}

console.log(new C({}).y); // 1
console.log(new C({y: 42}).y); //24
```

7.6. Structural Types With Optional Fields

Public optional fields become a member of the structural (field) type as well. But they will be optional in the structural type, that is to say it is not necessary to define the field.

If a type defines an optional field then this type is always compatible with a type that does not define a field with same name and type but is equal in all other members.

[[ex:Optional field on one side]]

Optional field on one side

```
class C {
    public s: number;
    public t: string?;
}

class D {
    public s: number;
}

function f(c: ~C) {}
f(new D()); // ok: D is a (structural) subtype of ~C
function g(~D d) {}
g(new C()); // ok: C is a (structural) subtype of ~D
```

[[ex:Optional field on one side]]

Optional field on one side

```
class C {
    public s: number;
    public t: string?;
}

class D {
    public s: number;
    public t: string?;
}
```

```
class E {
    public s: number;
    public t: number?;
}

class F {
    public s: number;
    public t: string;
}

function f(c: ~C) {}
f(new D()); // ok: D is a (structural) subtype of ~C
f(new E()); // error: E is not (structural) subtype of ~C, as t types differ (string vs
             number)
f(new F()); // ok: F is a (structural) subtype of ~C
function g(f: ~F) {}
g(new C()); // ok: C is a (structural) subtype of ~F
```

7.7. Structural Types With Access Modifier

The access modifier of the subtype have to provide equal or higher visibility.

Access modifier in structural typing [[ex:Access modifier in structural typing]]

```
class C {
    public s: number;
}

class D {
    project s: number;
}

function f(c: ~C) {}
f(new D()); // error: D is no (structural) subtype of ~C, as visibility of s in D is lower
function g(d: ~D) {}
g(new C()); // ok: C is a (structural) subtype of ~D, as visibility of s in C is greater-
             than-or-equal to s in D
```

7.8. Structural Types With Additional Members

It is possible to add additional members when structurally referencing a declared type.

7.8.1. Syntax

```
TStructMember:
    TStructGetter | TStructGetterES4 | TStructSetter | TStructMethod | TStructMethodES4 |
    TStructField;

TStructMethod:
    =>
        ({TStructMethod} ('<' typeVars+=TypeVariable (',' typeVars+=TypeVariable)* '>')?
        returnTypeRef=TypeRef name=TypesIdentifier '('
            (fpars+=TAnonymousFormalParameter (',' fpars+=TAnonymousFormalParameter)*)? ')'
        ';'?;

TStructMethodES4 returns TStructMethod:
    =>
```

```
{ {TStructMethod} ('<' typeVars+=TypeVariable (',' typeVars+=TypeVariable)* '>')?
    name=TypesIdentifier '(''
    (fpars+=TAnonymousFormalParameter (',' fpars+=TAnonymousFormalParameter)* )? ')'
    (':' returnTypeRef=TypeRef)?
';'?;

TStructField:
(
    typeRef=TypeRef name=TypesIdentifier
    | name=TypesIdentifier (':' typeRef=TypeRef)?
)
';';

TStructGetter:
=> ({TStructGetter}
    declaredTypeRef=TypeRef
    'get'
    name=TypesIdentifier)
'(' ')' ';'?;

TStructGetterES4 returns TStructGetter:
=> ({TStructGetter}
    'get'
    name=TypesIdentifier)
'(' ')' (':' declaredTypeRef=TypeRef)? ';'?;

TStructSetter:
=> ({TStructSetter}
    'set'
    name=TypesIdentifier)
'(' fpar=TAnonymousFormalParameter ')' ';'?;

TAnonymousFormalParameter:
typeRef=TypeRef variadic?='...'? name=TIdentifier?
| variadic?='...'? (=> name=TIdentifier ':') typeRef=TypeRef;
```

Semantics

[[req:Additional structural members]]

It is only possible to add additional members to a type if use-site structural typing is used. The following constraints must hold:

1. For all additional members defined in a structural type reference, the constraints for member overriding (???) apply as well.
2. All additional members have the access modifier set to *public*.
3. Type variables must not be augmented with additional structural members.

Additional fields may be declared optional in the same way as fields in classes. The rules given in Section 7.6, “Structural Types With Optional Fields” apply accordingly. Consider the following example:

Additional optional members in structural typing

```
class C {
```

```
public f1: number;  
}  
  
var c1: ~C with { f3: string; } c1;  
var c2: ~C with { f3: string?; } c2;  
  
c1 = { f1:42 }; // error: "~Object with { number f1; } is not a subtype of ~C with { string  
f3; }."  
c2 = { f1:42 }; // ok!!
```

Augmenting a type variable T with additional structural members can cause collisions with another member of a type argument for T. Hence, type variables must not be augmented with additional structural members like in the following example.

Forbidden additional structural members on type variables

```
interface I<T> {  
    public field : ~T with {prop : int} // error "No additional structural members allowed on  
    type variables."  
}
```

Using an additional structural member on a type variable T could be seen as a constraint to T. However, constraints like this should be rather stated using an explicit interface like in the example below.

Use explicitly defined Interfaces

```
interface ~J {  
    prop : int;  
}  
interface II<T extends J> {  
}
```

Chapter 8. Functions

Functions, be they function declarations, expressions or even methods, are internally modeled by means of a function type. In this chapter, the general function type is described along with its semantics and type constraints. Function definitions and expressions are then introduced in terms of statements and expressions. Method definitions and special usages are described in [Section 6.2, “Methods”](#)

8.1. Function Type

IDE-12¹

A function type is modeled as (see [[ECMA11a\(p.S13, p.p.98\)](#)]) in ECMAScript .

Function types can be defined by means of;

- A function object ([???](#)).
- A function type expression ([???](#)).
- A function declaration ([???](#)).
- A method declaration ([Section 6.2, “Methods”](#)).

8.1.1. Properties

In any case, a function type declares the signature of a function and allows validation of calls to that function. A function type has the following properties:

`typePars`

(0-indexed) list of type parameters (i.e. type variables) for generic functions.

`fpars`

(0-indexed) list of formal parameters.

`returnType`

(possibly inferred) return type (expression) of the function or method.

`name`

Name of function or method, may be empty or automatically generated (for messages).

`body`

The body of the function, it contains statements *stmts*. The body is null if a function type is defined in a type expression, and it is the last argument in case of a function object constructor, or the content of the function definition body.

Additionally, the following pseudo properties for functions are defined:

`thisTypeRef`

The `this` type ref is the type to which the `this`-keyword would be evaluated if used inside the function or member. The inference rules are described in [???](#).

¹ <https://jira.numberfour.eu/browse/IDE-12>

fpars

List of formal parameters and the this type ref. This is only used for sub typing rules. If `this` is not used inside the function, then `any` is set instead of the inferred `thisTypeRef` to allow for more usages. The property is computed as follows:

$fpars = amp; this \text{ is used or explicitly declared} \& thisTypeRef + fpars \& any + fpars$

Parameters (in `pars`) have the following properties:

name

Name of the parameter.

type

Type (expression) of the parameter. Note that only parameter types can be variadic or optional.

The function definition can be annotated similar to [Section 6.2, “Methods”](#) except that the `final` and `abstract` modifiers aren’t supported for function declarations. A function declaration is always final and never abstract. Also, a function has no property advice set.

Semantics

Type Given a function type F , the following constraints must be true:

1. Optional parameters must be defined at the end of the (formal) parameter list. In particular, an optional parameter must not be followed by a non-optional parameter:

$F.fpars_i.optional \& i < F.fpars_k.optvar$

2. Only the last parameter of a method may be defined as variadic parameter:

$F.fpars_i.variadici = |F.fpars| - 1$

3. If a function explicitly defines a return type, the last statement of the transitive closure of statements of the body must be a return statement:

```
math: [\[\begin{aligned} & F.typeRef \neq Undefined \rightarrow \\ & |f.bodystmts| > 0 \\ & \& \land f.bodystmts^*_{-1} \& f.bodystmts^{*-1} \text{ is } \backslash \text{lstmtfbnf}\{ReturnStatement\} \\ & \end{aligned}\}]
```

1. If a function explicitly defines a return type, all return statements must return a type conform to that type:
 $F.typeRef \neq Undefined \& \forall r \in F.bodystmts, r \text{ is } ReturnStatement : r.expr \neq null \wedge r.expr.typeRef \neq F.typeRef$

8.1.2. Type Inference

Definition: Function Type Conformance, Non-Parameterized

For the given non-parameterized function types

F_{left} with $F_{left}fpars = L_0, L_1, 8230; 8203; L_k$ and $|F_{left}typesPars| = 0$

F_{right} with $F_{right}fpars = R_0, R_1, 8230; 8203; R_n$ and $|F_{right}typesPars| = 0$,

we say F_{left} conforms to F_{right} , written as $F_{left} \sqsubset; F_{right}$, if and only if:

- $F_{right}returnType = void$
- $(F_{left}returnType = void \wedge F_{right}opt)$

- $\vee (F_{left}returnTypeelt; F_{right}returnType \wedge \neg (F_{left}opt \wedge \neg F_{right}opt))$
- if $k \leq n$:
 - $\forall i, 1 \leq i \leq k : (R_i opt(L_i opt \vee L_i var) \wedge (R_i var L_i var))$
 - $\forall i, 1 \leq i \leq k : L_i : gt; R_i$
 - $L_k var = true \forall i, klt; i \leq n : L_K : gt; R_i$
 - else ($kgt; n$):
 - $\forall i, 1 \leq i \leq n : (R_i opt(L_i opt \vee L_i var) \wedge (R_i var L_i var))$
 - $\forall i, 1 \leq i \leq n : L_i : gt; R_i$
 - $\forall nlt; i \leq k : L_i opt \vee L_i var$
 - $R_n var = true \forall i, nlt; i \leq k : L_i : gt; R_n$

Figure 8.1, “Function Variance Chart” shows a simple example with the function type conformance relations.

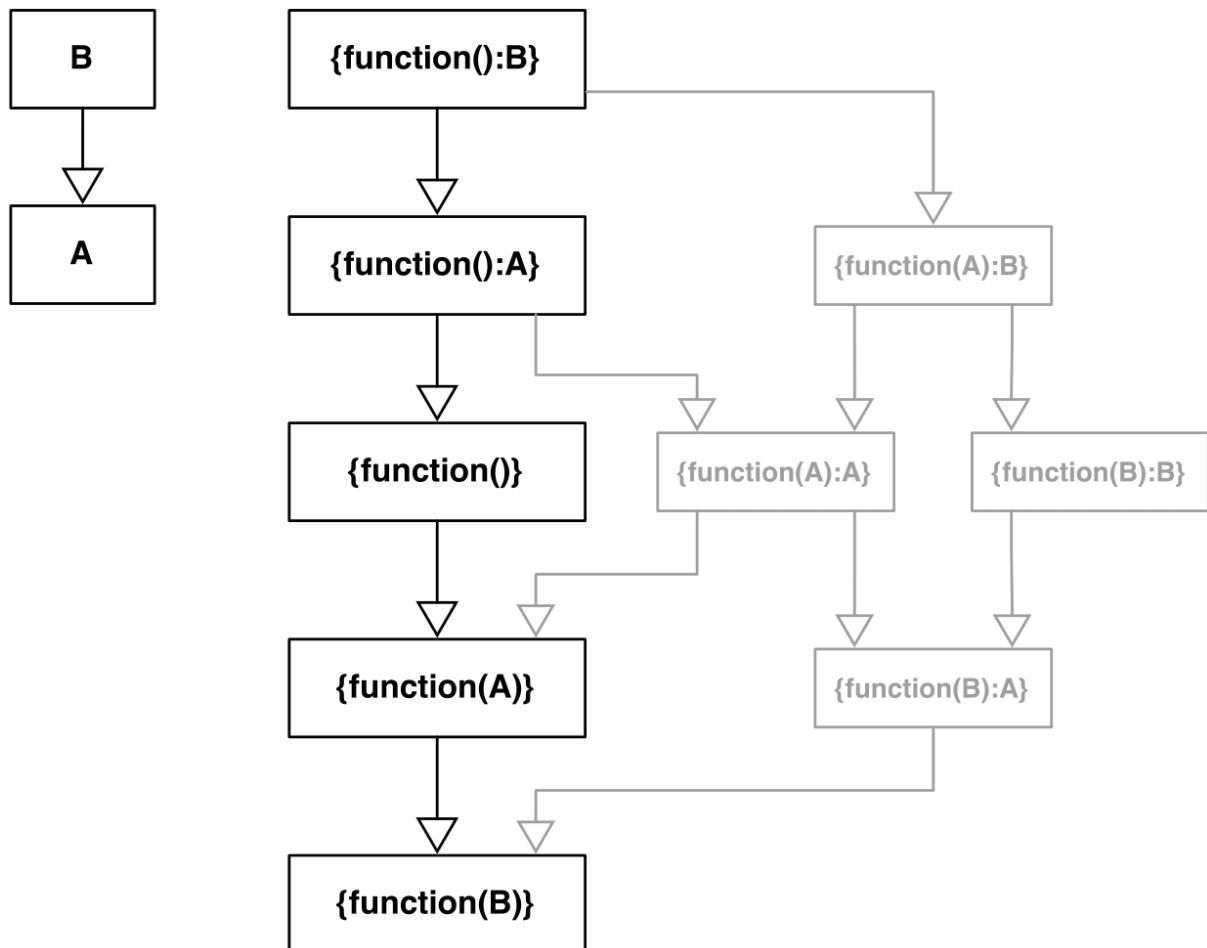


Figure 8.1. Function Variance Chart

`{function() } $<:$ {function(A) } $<:$ {function(A, A)}` might be surprising for Java programmers. However, in JavaScript it is possible to call a function with any number of arguments independently from how many formal parameters the function defines.

If a function does not define a return type, `any` is assumed if at least one of the (indirectly) contained return statements contains an expression. Otherwise is assumed. This is also true if there is an error due to other constraint violations.

amp;f('arglist ')':anybinds(f,F)amp;F.returnType = amp;exists r in returns(F) : r.expression ≠ amp;f('arglist ')':voidbinds(f,F)amp;F.with

amp;returns(F) : RETS {r in F.body.statements | u(r) = ReturnStatement} ∪ ∑_{s ∈ F.body.statements} returns(s)amp;returns(s) : RETS {sub ∈

Function type conformance [[ex:Function type conformance]] The following incomplete snippet demonstrates the usage of two function variables *f1* and *f2*, in which *f2lt;:f1* must hold true according to the aforementioned constraints. A function `bar` declares a parameter *f1*, which is actually a function itself. *f2* is a variable, to which a function expression is assigned. Function `bar` is then called with *f2* as an argument. Thus, the type of *f2* must be a subtype of the *f1*'s type.

```
function bar(f1: {function(A,B):C}) { ... }

var f1: {function(A,B):C} = function(p1,p2){...};
bar(f1);
```

The type of can be explicitly set via the annotation.

Function Subtyping [[ex:Function Subtyping]]

```
function f(): A{..}
function p(): void{..}

fAny(log: {function():any}){...}
fVoid(f: {function():void}){...}
fA(g: {function():A}){...}

fAny(f); // --> ok      A <: any
fVoid(f); // -->error    A !<: void
fA(f);   // --> ok (easy) A <: A

fAny(p); // --> ok      void <: any
fVoid(p); // --> ok      void <: void
fA(p);   // --> error    void !<: A
```

Subtyping with function types [[ex:Subtyping_with function types]] If classes A, B, and C are defined as previously mentioned (*Clt;:Blt;:A*)

The following subtyping relations with function types are to be evaluated as follows:

{function():void} <: {function():void}	-> true
{function(A):A} <: {function(A):A}	-> true
{function(A):void} <: {function(B):void}	-> true
{function():B} <: {function():A}	-> true

² <https://jira.numberfour.eu/browse/IDE-433>

```

{function(A):B} <: {function(B):A}           -> true
{function(A):A} <: {function(B):void}         -> true (!)
{function(A):A} <: {function(B):any}          -> true
{function(A):A} <: {function(B)}             -> true
{function(A):void} <: {function(B):any}         -> false (!)
{function(A):void} <: {function(B)}            -> true
{function(A):void} <: {function(B):A}           -> false

```

The following examples demonstrate the effect of optional and variadic parameters:

```

{function(A)} <: {function(B)}           -> true
{function(A...)} <: {function(A)}         -> true
{function(A, A)} <: {function(A)}         -> false
{function(A)} <: {function(A,A)}          -> true (!)
{function(A, A...)} <: {function(A)}        -> true
{function(A)} <: {function(A,A...)}         -> true (!)
{function(A, A...)} <: {function(B)}          -> true
{function(A?)} <: {function(A?)}           -> true
{function(A...)} <: {function(A...)}          -> true
{function(A?)} <: {function(A)}            -> true
{function(A)} <: {function(A?)}           -> false
{function(A...)} <: {function(A?)}          -> true
{function(A?)} <: {function(A...)}          -> true (!)
{function(A,A...)} <: {function(A...)}         -> false
{function(A,A?)} <: {function(A...)}          -> false
{function(A?,A...)} <: {function(A...)}         -> true
{function(A...)} <: {function(A?,A...)}         -> true
{function(A...)} <: {function(A?)}           -> true
{function(A?,A?)} <: {function(A...)}          -> true (!)
{function(A?,A?,A?)} <: {function(A...)}         -> true (!)
{function(A?)} <: {function()}              -> true (!)
{function(A...)} <: {function()}              -> true (!)

```

The following examples demonstrate the effect of optional return types:

```

{function():void} <: {function():void}           -> true
{function():X} <: {function():void}             -> true
{function():X?} <: {function():void}            -> true
{function():void} <: {function():Y}              -> false
{function():X} <: {function():Y}                -> X <: Y
{function():X?} <: {function():Y}               -> false (!)
{function():void} <: {function():Y?}             -> true (!)
{function():X} <: {function():Y?}               -> X <: Y
{function():X?} <: {function():Y?}              -> X <: Y

```

The following examples show the effect of the annotation:

```

{@This(A) function():void} <: {@This(X) function():void}    -> false
{@This(B) function():void} <: {@This(A) function():void}    -> false
{@This(A) function():void} <: {@This(B) function():void}    -> true
{@This(any) function():void} <: {@This(X) function():void}   -> true
{function():void} <: {@This(X) function():void}              -> true
{@This(A) function():void} <: {@This(any) function():void}   -> false
{@This(A) function():void} <: {function():void}              -> false

```

Definition: MISSING DEFINITION TITLE

For the given function types

F_{left} with $F_{left.typePars} = L_0, L_1, 8230; 8203; L_k$

F_{right} with $F_{right.typePars} = R_0, R_1, 8230; 8203; R_n$

we say F_{left} conforms to F_{right} , written as $F_{left}lt;:F_{right}$, if and only if:

- if $|F_{left.typePars}| = |F_{right.typePars}| = 0$:
 - $F_{left}lt;:F_{right}$ (cf. ???)
- else if $|F_{left.typePars}| > 0 \wedge |F_{right.typePars}| = 0$:
 - $\exists : () F_{left}lt;:F_{right}$ (cf. ???)

(i.e. there exists a substitution of type variables in F_{left} so that after substitution it becomes a subtype of F_{right} as defined by ???)
- else if $|F_{left.typePars}| = |F_{right.typePars}|$:
 - $\{ V_i^r \leftarrow V_j^l | 0 \leq i \leq n \} F_{left}lt;:F_{right}$ (accordingly)
 - $\forall 0 \leq i \leq n: V_i^l.upperBounds :gt; V_i^r.upperBounds$

with $F_{left.typePars} = V_0^l, V_1^l, 8230; 8203; V_n^l$ and $F_{right.typePars} = V_0^r, V_1^r, 8230; 8203; V_n^r$

(i.e. we replace each type variable in F_{right} by the corresponding type variable at the same index in F_{left} and check the constraints from ??? as if F_{left} and F_{right} were non-parameterized functions and, in addition, the upper bounds on the left side need to be supertypes of the upper bounds on the right side).

Note that the upper bounds on the left must be supertypes of the right-side upper bounds (for similar reasons why types of formal parameters on the left are required to be supertypes of the formal parameters' types in). Where a particular type variable is used, on co- or contra-variant position, is not relevant:

```
class A {}
class B extends A {}

class X {
    <T extends B> m(): T { return null; }
}
class Y extends X {
    @Override
    <T extends A> m(): T { return null; }
}
```

Method `m` in `X` may return an `A`, thus breaking the contract of `m` in `X`, but only if it is parameterized to do so, which is not allowed for clients of `X`, only those of `Y`. Therefore, the override in the above example is valid.

The subtype relation for function types is also applied for method overriding to ensure that an overriding method's signature conforms to that of the overridden method, see ??? (applies to method comnsumption

and implementation accordingly, see [???](#) and [???](#)). Note that this is very different from Java which is far more restrictive when checking overriding methods. As Java also supports method overloading: given two types A, B with $Blt;:A$ and a super class method `void m(B param)`, it is valid to override `m` as `void m(A param)` in N4JS but not in Java. In Java this would be handled as method overloading and therefore an `@Override` annotation on `m` would produce an error.

Upper and Lower Bound of a Function Type

The upper bound of a function type F is a function type with the lower bound types of the parameters and the upper bound of the return type: $upper(function(P_1, P_n):R) := function(lower(P_1),,lower(P_n)):upper$ ¹⁷⁴; The lower bound of a function type F is a function type with the upper bound types of the parameters and the lower bound of the return type: $lower(function(P_1, P_n):R) := function(upper(P_1),,upper(P_n)):lower$ ¹⁷⁴;

8.1.3. Autoboxing of Function Type

IDE-830³

Function types, compared to other types like String, come only in one flavour: the Function object representation. There is no primitive function type. Nevertheless, for function type expressions and function declarations, it is possible to call the properties of Function object directly. This is similar to autoboxing for strings.

```
// function declaration
var param: number = function(a,b){}.length // 2

function a(x: number) : number { return x*x; }
// function reference
a.length; // 1

// function variable
var f = function(m,l,b){/*...*/};
f.length; // 3

class A {
    s: string;
    sayS(): string{ return this.s; }
}

var objA: A = new A();
objA.s = "A";

var objB = {s:"B"}

// function variable
var m = objA.sayS; // method as function, detached from objA
var mA: {function(any)} = m.bind(objA); // bind to objA
var mB: {function(any)} = m.bind(objB); // bind to objB

m() // returns: undefined
mA() // returns: A
```

³ <https://jira.numberfour.eu/browse/IDE-830>

```
mB() // returns: B  
  
m.call(objA,1,2,3); // returns: A  
m.apply(objB,[1,2,3]); // returns: B  
m.toString(); // returns: function sayS(){ return this.s; }
```

8.1.4. Arguments Object

IDE-662⁴

A special arguments object is defined within the body of a function. It is accessible through the implicitly-defined local variable named `this.arguments`, unless it is shadowed by a local variable, a formal parameter or a function named `arguments` or in the rare case that the function itself is called 'arguments' [ECMA11a(p.S10.5, p.pp59)]. The argument object has array-like behavior even though it is not of type `array`:

- All actual passed-in parameters of the current execution context can be retrieved by 0-based index access.
- The `length` property of the arguments object stores the actual number of passed-in arguments which may differ from the number of formally defined number of parameters *fpars* of the containing function.
- It is possible to store custom values in the arguments object, even outside the original index boundaries.
- All obtained values from the arguments object are of type `any`.

In non-strict ES mode the property holds a reference to the function executed [ECMA11a(p.S10.6, p.p61)].

argumentscallee

In N4JS and in ES strict mode the use of `argumentscallee` is prohibited.

arguments as formal parameter name

In N4JS, the formal parameters of the function cannot be named `arguments`. This applies to all variable execution environments like field accessors (getter/setter, ???), methods (Section 6.2, "Methods") and constructors (???), where `FormalParameter` type is used.

Usage of arguments object

```
// regular function  
function a1(s1: string, n2: number) {  
    var l: number = arguments.length;  
    var s: string = arguments[0] as string;  
}  
  
class A {
```

⁴ <https://jira.numberfour.eu/browse/IDE-662>

```
// property access
get s(): string { return ""+arguments.length; } // 0
set s(n: number) { console.log( arguments.length ); } // 1
// method
m(arg: string) {
    var l: number = arguments.length;
    var s: string = arguments[0] as string;
}
}

// property access in object literals
var x = {
    a:5,
    get b(): string {
        return ""+arguments.length
    }
}

// invalid:
function z(){
    arguments.length // illegal, see next lines
    // define arguments to be a plain variable of type number:
    var arguments: number = 4;
}
```

8.2. ECMAScript 5 Function Definition

8.2.1. Function Declaration

Syntax

A function can be defined as described in [ECMA11a(p.S13, p.p.98)] and additional annotations can be specified. Since N4JS is based on [ECMA15a], the syntax contains constructs not available in [ECMA11a]. The newer constructs defined only in [ECMA15a] and proposals already implemented in N4JS are described in Section 8.3, “ECMAScript 2015 Function Definition” and Section 8.4, “ECMAScript Proposals Function Definition”.

In contrast to plain JavaScript, function declarations can be used in blocks in N4JSI. This is only true, however, for N4JS files, not for plain JS files.

IDE-1043⁵

Syntax Function Declaration and Expression

```
FunctionDeclaration <Yield>:
    => ({FunctionDeclaration})
    annotations+=Annotation*
    (declaredModifiers+=N4Modifier)*
    -> FunctionImpl <Yield,Yield,Expression=false>
) => Semi?
;
```

⁵ <https://jira.numberfour.eu/browse/IDE-1043>

```
fragment AsyncNoTrailingLineBreak *: (declaredAsync?='async' NoLineTerminator)?;

fragment FunctionImpl<Yield, YieldIfGenerator, Expression>*:
  'function'
  (
    generator?='*' FunctionHeader<YieldIfGenerator, Generator=true>
  FunctionBody<Yield=true, Expression>
  |  FunctionHeader<Yield, Generator=false> FunctionBody<Yield=false, Expression>
  )
;

fragment FunctionHeader<Yield, Generator>*:
  TypeVariables?
  name=BindingIdentifier<Yield>?
  StrictFormalParameters<Yield=Generator>
  (-> ':' returnTypeRef=TypeRef)?
;

fragment FunctionBody <Yield, Expression>*:
  <Expression> body=Block<Yield>
  |  <!Expression> body=Block<Yield>?
;
```

Properties of the function declaration and expression are described in in [Section 8.1, “Function Type”](#).

For this specification, we introduce a supertype *FunctionDefinition* for both, *FunctionDeclaration* and *FunctionExpression*. This supertype contains all common properties of these two subtypes, that is, all properties of *FunctionExpression*.

[Function Declaration with Type Annotation][ex:Function_Declaration_with_Type_Annotation]

```
// plain JS
function f(p) { return p.length }
// N4JS
function f(p: string): number { return p.length }
```

Semantics

IDE-224⁶

A function defined in a class’s method (or method modifier) builder is a method, see [Section 6.2, “Methods”](#) for details and additional constraints. The metatype of a function definition is function type ([Section 8.1, “Function Type”](#)), as a function declaration is only a different syntax for creating a object. Constraints for function type are described in [Section 8.1, “Function Type”](#). Another consequence is that the inferred type of a function definition *fdecl* is simply its function type *F*. *Ffdecl* Note that the type of a function definition is different from its return type *fdecl!*

1. In plain JavaScript, function declarations must only be located on top-level, that is they must not be nested in blocks. Since this is supported by most JavaScript engines, only a warning is issued.

⁶ <https://jira.numberfour.eu/browse/IDE-224>

8.2.2. Function Expression

A function expression [ECMA11a(p.S11.2.5)] is quite similar to a function declaration. Thus, most details are explained in .

Syntax

```
FunctionExpression:  
  ({FunctionExpression}  
   FunctionImpl<Yield=false,YieldIfGenerator=true,Expression=true>  
  )  
;
```

Semantics and Type Inference

In general, the inferred type of a function expression simply is the function type as described in Section 8.1, “Function Type”. Often, the signature of a function expression is not explicitly specified but it can be inferred from the context. The following context information is used to infer the full signature:

- If the function expression is used on the right hand side of an assignment, the expected return type can be inferred from the left hand side.
- If the function expression is used as an argument in a call to another function, the full signature can be inferred from the corresponding type of the formal parameter declaration.

Although the signature of the function expression may be inferred from the formal parameter if the function expression is used as argument, this inference has some conceptual limitations. This is demonstrated in the next example.

Example: Inference Of Function Expression’s Signature

In general, `{function() :any}` is a subtype of `{function() :void}` (cf. Section 8.1, “Function Type”). When the return type of a function expression is inferred, this relation is taken into account which may lead to unexpected results as shown in the following code snippet:

```
function f(cb: {function():void}) { cb() }  
f(function() { return 1; });
```

No error is issued: The type of the function expression actually is inferred to `{function() :any}`, because there is a return statement with an expression. It is not inferred to `{function() :void}`, even if the formal parameter of `f` suggests that. Due to the previously-stated relation `{function() :any} <: {function() :void}` this is correct – the client (in this case function `f`) works perfectly well even if `cb` returns something. The contract of arguments states that the type of the argument is a subtype of the type of the formal parameter. This is what the inferencer takes into account!

8.3. ECMAScript 2015 Function Definition

8.3.1. Generator Functions

Cf. [ECMA15a(p.S14.4)], also see [Kuizinas14a]. Syntax supported, semantic and transpilation not supported yet.

8.3.2. Arrow Function Expression

This is an ECMAScript 6 expression (see [ECMA15a(p.S14.2)]) for simplifying the definition of anonymous function expressions, aka lambdas or closures. The ECMAScript Specification calls this a function definition even though they may only appear in the context of expressions.

Along with Assignments, Arrow function expressions have the least precedence, e.g. they serve as the entry point for the expression tree.

Arrow function expressions can be considered syntactic window-dressing for old-school function expressions and therefore do not support the benefits regarding parameter annotations although parameter types may be given explicitly. The return type can be given as type hint if desired, but this is not mandatory (if left out, the return type is inferred). The notation `@=>` stands for an async arrow function (Section 8.4.2, "Asynchronous Arrow Functions").

Syntax

The simplified syntax reads like this:

```

ArrowExpression returns ArrowFunction:
  => (
    {ArrowFunction}
    (
      '(
        ( fpars+=FormalParameterNoAnnotations ( ',' fpars
        +=FormalParameterNoAnnotations )* )?
        ')'
        (':' returnTypeRef=TypeRef)?
      | fpars+=FormalParameterNoType
      )
      '=>'
    ) (
      (=> hasBracesAroundBody?='{' body=BlockMinusBraces '}') |
      body=ExpressionDisguisedAsBlock
    )
  ;
;

FormalParameterNoAnnotations returns FormalParameter:
  (declaredTypeRef=TypeRef variadic?='...')? name=JSIdentifier
;

FormalParameterNoType returns FormalParameter: name=JSIdentifier;

BlockMinusBraces returns Block: {Block} statements+=Statement*;

ExpressionDisguisedAsBlock returns Block:
  {Block} statements+=AssignmentExpressionStatement
;

```

⁷ <https://jira.numberfour.eu/browse/IDE-252>

```
AssignmentExpressionStatement returns ExpressionStatement: expression=AssignmentExpression;
```

Semantics and Type Inference

Generally speaking, the semantics are very similar to the function expressions but the devil's in the details:

- **arguments**: Unlike normal function expressions, an arrow function does not introduce an implicit **arguments** variable (Section 8.1.4, “Arguments Object”), therefore any occurrence of it in the arrow function’s body has always the same binding as an occurrence of **arguments** in the lexical context enclosing the arrow function.
- **this**: An arrow function does not introduce a binding of its own for the **this** keyword. That explains why uses in the body of arrow function have the same meaning as occurrences in the enclosing lexical scope. As a consequence, an arrow function at the top level has both usages of **arguments** and **this** flagged as error (the outer lexical context doesn’t provide definitions for them).
- **super**: As with function expressions in general, whether of the arrow variety or not, the usage of **super** isn’t allowed in the body of arrow functions.

In N4JS, a top-level arrow function can’t refer to **this** as there’s no outer lexical context that provides a binding for it.

In N4JS, a top-level arrow function can’t include usages of **arguments** in its body, again because of the missing binding for it.

8.4. ECMAScript Proposals Function Definition

8.4.1. Asynchronous Functions

IDE-1175⁸
IDE-1593⁹

To improve language-level support for asynchronous code, there exists an ECMAScript proposal ¹⁰ based on Promises which are provided by ES6 as built-in types. N4JS implements this proposal. This concept is supported for declared functions and methods (???) as well as for function expressions and arrow functions (Section 8.4.2, “Asynchronous Arrow Functions”).

Syntax

The following syntax rules are extracted from the real syntax rules. They only display parts relevant to declaring a function or method as asynchronous.

```
AsyncFunctionDeclaration <Yield>:  
  (declaredModifiers+=N4Modifier)*  
  declaredAsync?='async' NoLineTerminator 'function'
```

⁸ <https://jira.numberfour.eu/browse/IDE-1175>

⁹ <https://jira.numberfour.eu/browse/IDE-1593>

¹⁰ see <http://tc39.github.io/ecmascript-asyncawait/>

```
FunctionHeader<Yield,Generator=false>
FunctionBody<Yield=false,Expression=false> Semi
;

AsyncFunctionExpression:
declaredAsync?='async' NoLineTerminator 'function'
FunctionHeader<Yield=false,Generator=false>
FunctionBody<Yield=false,Expression=true>
;

AsyncArrowExpression <In, Yield>:
declaredAsync?='async' NoLineTerminator '('
(fpars+=FormalParameter<Yield>
( ',' fpars+=FormalParameter<Yield>)* )?
')' (':' returnTypeRef=TypeRef)? '=>'
( '{' body=BlockMinusBraces<Yield> '}'
| body=ExpressionDisguisedAsBlock<In>
)
;

AsyncMethodDeclaration:
annotations+=Annotation+ (declaredModifiers+=N4Modifier)* TypeVariables?
declaredAsync?='async' NoLineTerminator LiteralOrComputedPropertyName<Yield>
MethodParamsReturnAndBody
```

'async' is not a reserved word in ECMAScript and it can therefore be used either as an identifier or as a keyword, depending on the context. When used as a modifier to declare a function as asynchronous, then there must be no line terminator after the `async` modifier. This enables the parser to distinguish between using `async` as an identifier reference and a keyword, as shown in the next example.

Async as keyword and identifier

```
async ①
function foo() {}
// vs
async function bar(); ②
```

- ① In this snippet, the `async` on line 1 is an identifier reference (referencing a variable or parameter) and the function defined on line 2 is a non-asynchronous function. The automatic semicolon insertion adds a semicolon after the reference on line 1.
- ② In contrast, `async` on line 3 is recognized as a modifier declaring the function as asynchronous.

Semantics

The basic idea is to make code dealing with Promises easier to write and more readable without changing the functionality of Promises. Take this example:

A simple asynchronous function using `async/await`.

```
// some asynchronous legacy API using promises
interface DB {}
interface DBAccess {
  DataBase(): Promise<DB, ?>
```

```
loadEntry(db: DB, id: string): Promise<string,?>
}

var access: DBAccess;

// our own function using async/await
async function loadAddress(id: string) : string {
    try {
        var db: DB = await access.getDataBase();
        var entry: string = await access.loadEntry(db, id);
        return entry.address;
    }
    catch(err) {
        // either getDataBase() or loadEntry() failed
        throw err;
    }
}
```

The modifier `async` changes the return type of `loadAddress()` from `string` (the declared return type) to `Promise<string,?>` (the actual return type). For code inside the function, the return type is still `string`: the value in the return statement of the last line will be wrapped in a Promise. For client code outside the function and in case of recursive invocations, the return type is `Promise<string,?>`. To raise an error, simply throw an exception, its value will become the error value of the returned Promise.

If the expression after an `await` evaluates to a `Promise`, execution of the enclosing asynchronous function will be suspended until either a success value is available (which will then make the entire await-expression evaluate to this success value and continue execution) or until the Promise is rejected (which will then cause an exception to be thrown at the location of the await-expression). If, on the other hand, the expression after an `await` evaluates to a non-promise, the value will be simply passed through. In addition, a warning is shown to indicate the unnecessary `await` expression.

Note how method `loadAddress()` above can be implemented without any explicit references to the built-in type `Promise`. In the above example we handle the errors of the nested asynchronous calls to `getDataBase()` and `loadEntry()` for demonstration purposes only; if we are not interested in the errors we could simply remove the try/catch block and any errors would be forwarded to the caller of `loadAddress()`.

Invoking an `async` function commonly adopts one of two forms:

GH-620¹¹

- `var p: Promise<successType,?> = asyncFn()`
- `await asyncFn()`

These patterns are so common that a warning is available whenever both

- a. `Promise` is omitted as expected type; and
- b. `await` is also omitted.

¹¹ <https://github.com/NumberFour/N4JS/issues/620>

The warning aims at hinting about forgetting to wait for the result, while remaining non-noisy.

1. `async` may be used on declared functions and methods, and for function expressions. and arrow functions.
2. A function or method f with a declared return type R that is declared has an actual return type of `async`.



for the time being this applies also to functions with a void return type, producing the actual return type `Promise<void, ?>` (to be reconsidered).

3. Given a function or method f with a declared return type R that is declared , all return statements in f must have an expression of type R (and not of type).
4. `await` can be used in expressions directly enclosed in an `async` function, and behaves like a unary operator with the same precedence as in ES6.
5. Given an expression $expr$ of type T , the type of $(expr)$ is inferred to T if T is not a Promise or it is inferred to S if T is a Promise with a success value of type S , i.e. $Tlt;::$.

8.4.2. Asynchronous Arrow Functions

IDE-1494 ¹²

An `await` expression is allowed in the body of an `async` arrow function but not in the body of a non-`async` arrow function. The semantics here are intentional and are in line with similar constraint for function expressions.

8.5. N4JS Extended Function Definition

8.5.1. Generic Functions

A generic function is a function with a list of generic type parameters. These type parameters can be used in the function signature to declare the types of formal parameters and the return type. In addition, the type parameters can be used in the function body, for example when declaring the type of a local variable.

In the following listing, a generic function `foo` is defined that has two type parameters `s` and `t`. Thereby `s` is used as to declare the parameter type `Array<s>` and `t` is used as the return type and to construct the returned value in the function body.

Generic Function Definition

```
function <S,T> foo(s: Array<S>): T { return new T(s); }
```

If a generic type parameter is not used as a formal parameter type or the return type, a warning is generated.

¹² <https://jira.numberfour.eu/browse/IDE-1494>

8.5.2. Promisifiable Functions

In many existing libraries, which have been developed in pre-ES6-promise-API times, callback methods are used for asynchronous behavior. An asynchronous function follows the following conventions:

```
'function' name '(' 'arbitraryParameters ', ' callbackFunction ')'
```

Usually the function returns nothing (`void`). The callback function usually takes two arguments, in which the first is an error object and the other is the result value of the asynchronous operation. The callback function is called from the asynchronous function, leading to nested function calls (aka 'callback hell').

In order to simplify usage of this pattern, it is possible to mark such a function or method as `@Promisifiable`. It is then possible to 'promisify' an invocation of this function or method, which means no callback function argument has to be provided and a will be returned. The function or method can then be used as if it were declared with `async`. This is particularly useful in N4JS definition files (.n4jsd) to allow using an existing callback-based API from N4JS code with the more convenient `await`.

Given a function with an N4JS signature

```
f(x: int, cb: {function(Error, string)}): void
```

This method can be annotated with `Promisifiable` as follows:

```
@Promisifiable f(x: int, cb: {function(Error, string)}): void
```

With this annotation, the function can be invoked in four different ways:

```
f(42, function(err, result1) { /* ... */ }); // traditional
var promise: Promise<string,Error> = @Promisify f(42); // promise
var result3: string = await @Promisify f(42);           // long
var result4: string = await f(42);                      // short
```

The first line is only provided for completeness and shows that a promisifiable function can still be used in the ordinary way by providing a callback - no special handling will occur in this case. The second line shows how `f` can be promisified using the `@Promisify` annotation - no callback needs to be provided and instead, a `Promise` will be returned. We can either use this promise directly or immediately `await` on it, as shown in line 3. The syntax shown in line 4 is merely shorthand for `await @Promisify`, i.e. the annotation is optional after `await`.

A function or method `f` can be annotated with `@Promisifiable` if and only if the following constraints hold:

1. Last parameter of `f` is a function (the *callback*).

¹³ <https://jira.numberfour.eu/browse/IDE-2018>

2. The *callback* has a signature of

- `{function(E, T0, T1, ..., Tn): V}`, or
- `{function(T0, T1, ..., Tn): V}`

in which *E* is type `Error` or a subtype thereof, $T_0, 8230; 8203;$; T_n are arbitrary types except or its subtypes. *E*, if given, is then the type of the error value, and $T_0, 8230; 8203;$; T_n are the types of the success values of the asynchronous operation.

Since the return value of the synchronous function call is not available when using `@Promisify`, *V* is recommended to be `void`, but it can be any type.

3. The callback parameter may be optional. ¹⁴

According to ???, a promisifiable function or method may or may not have a non-void return type, and that only the first parameter of the callback is allowed to be of type `Error`, all other parameters must be of other types.

A promisifiable function *f* with one of the two valid signatures given in ??? can be promisified with `Promisify` or used with `await`, if and only if the following constraints hold:

1. Function *f* must be annotated with `@Promisifiable`.
2. Using `@Promisify f()` without `await` returns a promise of type `Promise<S,F>` where
 - *S* is `IterableN<T0,...,Tn>` if $n \geq 2$, `T` if $n = 1$, and `void` if $n = 0$.
 - *F* is `E` if given, `void` otherwise.
3. Using `await @Promisify f()` returns a value of type `IterableN<T0,...,Tn>` if $n \geq 2$, `T` if $n = 1$, and `void` if $n = 0$.
4. In case of using an `await`, the annotation can be omitted.
I.e., `await @Promisify f()` is equivalent to `await f()`.
5. Only call expressions using *f* as target can be promisified, in other words this is illegal:

```
var pf = @Promisify f; // illegal code!
```

¹⁴ Even in this case, the function will actually be called with the callback method which is then created by the transpiler. However, the callback is not given in the N4JS code).

Chapter 9. Conversions and Reflection

9.1. Auto-Boxing and Coercing

Coercing is the ability to implicitly cast one (primitive) type to another. Auto-Boxing is a special kind of coercing in that is the ability to automatically convert a primitive value type, such as `string`, `number`, or `boolean`, to its corresponding Object type version `String`, `Number`, `Boolean`. The capital letters in the latter are an essential distinction.

Conversion between primitives and object-representations of a datatype are not automatic in N4JS. Only in the cases of object-method invocations on a primitive type (for `string` to call `"abc".length`, for example) automatic conversion is applied.

Note that N4JS specific primitive types `pathselector` and `i18nkey` are handled similarly to `string`.

9.1.1. Coercing

IDE-379¹

In [ECMA11a], coercing is defined by means of the abstract specification method `ToPrimitive` [ECMA11a(p.S9.1)], also see [ECMA11a(p.S9.10)]. Other conversions, such as `ToNumber`, are not directly supported but reflected in the typing rules of expressions.

We express absence of automatic coercion here by means of subtype relations:
`Boolean` `boolean` `Boolean` `Number` `number` `number` `Number` `String` `string` `String` `String`

and for the N4JS specific types: `pathSelector` `lt;Tgt;` `string` `i18nKey` `string`

If a conversion between primitive and object type is desired, we require the user of N4JS to actively convert the values. The reason for that is the notably different behavior of object- and primitive-variants of a type in expression evaluation:

```
var bool: boolean = false;
var Bool: Boolean = new Boolean( false );

console.log( bool ? "true" : "false"); // prints "false"
console.log( Bool ? "true" : "false"); // prints "true"!
```

Conversion between a primitive type to its object-variant is achieved by the `new` operator. The `valueOf()` method converts the object-variant back to a primitive value.

```
// objects from literals:
var bo: Boolean = new Boolean( true ); // typeof bo: object
var no: Number = new Number( 42 ); // typeof no: object
```

¹ <https://jira.numberfour.eu/browse/IDE-379>

```

var so: String = new String( "foo" ); // typeof so: object

// to primitive
var b: boolean = bo.valueOf(); // typeof b: boolean -- true
var n: number = no.valueOf(); // typeof n: number -- 42
var s: string = so.valueOf(); // typeof s: string -- "foo"

// to object-type
bo = new Boolean( b );
no = new Number( n );
so = new String( s );

```

Conversion of variables of type `Object` or from one primitive type to another is expressed in terms of typing rules for expressions. That is, it is not possible to convert any `Object` to a primitive in general, but it is possible to do so in the context of certain expressions such as additive operator. The applied conversions are described in [???](#)

9.1.2. Auto-Boxing of Primitives

 IDE-835²

In [ECMA11a], autoboxing is defined by `\lstdnfs{ToObject}` [ECMA11a(p.S9.9)].

Auto-boxing is not directly supported in N4JS. Instead, primitive types virtually have the same members as their corresponding object types. It is then possible to use the auto-boxing feature when calling a member. In general, auto-boxing is only supported for accessing built-in read-only (immutable) properties. For example, `"some string value".split(" ")`; is supported but `"some string value".foo=1;` will be rejected as String does not allow properties to be added (cf. vs. , see [???](#)).

Auto-boxing often leads to problems, in particular in combination with dynamic types – this is why it is not directly supported in N4JS. For example,

```

var s: String+ = "Hello"; // will produce an error to prevent the following scenario:
s.prop = 1;
console.log(s.prop); // prints "undefined"

```

9.1.3. Auto-Boxing of Function Expressions and Declarations

 IDE-830³

Function expressions and declarations always define an object of type `Function`, thus coercing or auto-boxing is not required in case of functions:

It is always possible to use a function expression where a `Function` is required, and to use an object of type `Function` where a function expression is expected. This is only possible if the function signatures are subtype-compatible, see [???](#) for details.

² <https://jira.numberfour.eu/browse/IDE-835>

³ <https://jira.numberfour.eu/browse/IDE-830>

Still, it is always possible to call members of `Function`, e.g., `function(){}.length()`.

9.2. Auto-Conversion of Objects

9.2.1. Auto-Conversion of Class Instances

IDE-833⁴

All classes defined in N4JS modules implicitly subclass `N4Object`, which is a plain JavaScript Object type. The same auto-conversion rules defined for JavaScript `Object` therefore apply to `N4Object` instances as well.

The basic conversion uses the abstract JavaScript function `ToPrimitive` [ECMA11a(p.S9.1)], which relays on the specification method `Object` [ECMA11a(p.S8.12.8)]. `DefaultValue` calls `valueOf` or `toString` methods if they are defined by the class (in the `methods`-builder).

Note that according to the [ECMA11a], in most cases, objects are first converted into primitives. That is, in most cases, no extra hint is passed to `DefaultValue`. Thus `valueOf` usually takes precedence over `toString` as demonstrated in the following example:

Auto-Conversion

Assume some classes and corresponding instances defined as follows:

```
class A {}  
class B{  
    @Override public toString(): string { return "MyB" }  
}  
class C{  
    @Override public valueOf(): any { return 10 }  
}  
class D{  
    @Override public toString(): string { return "MyD" }  
    @Override public valueOf(): any { return 20 }  
}  
var a = new A(), b = new B(), c = new C(), d = new D();
```

Instances of these classes will be converted as demonstrated as follows:

```
console.log(a+"");           // [object Object]  
console.log(a+1);            // [object Object]1  
  
console.log(""+b+"");        // MyB  
console.log(1+b+1);          // 1MyB1  
  
console.log(c+"");           // 10  
console.log(c+1);             // 11  
  
console.log(d+"");           // 20
```

⁴ <https://jira.numberfour.eu/browse/IDE-833>

```
console.log(d+1); // 21
```

Auto-Conversion of Interface Instances

Instances of interfaces actually are instances of classes at runtime. The auto-conversion rules described in [Section 9.2.1, “Auto-Conversion of Class Instances”](#) are applied to instances declared as instances of interfaces as well.

9.2.2. Auto-Conversion of Enum Literals

Enumeration values are objects and thus follow the behavior for ECMAScript *Object* and *Function*. They have a custom *toString* method which returns the name of the enumeration value.

9.3. Type Cast and Type Check

9.3.1. Type Cast

(IDEBUG-56): Casting to TypeVars

IDE-161⁵
 IDE-928⁶

Type casts are expressed with the cast expression (`as`), see [???](#) for details.

We first define helper rules for the type cast constraints as follows:

$\text{isCPOE}(T) \wedge \mu(T) \in \{\text{TypeEnum}, \text{Class}, \text{Primitive}, \text{ObjectType}\} \mid \text{isCPOE}(T) \wedge \mu(T) \in \{\text{ClassifierType}, \text{TypeType}\} \wedge \mu(T.typeRef) \neq \text{TypeVariable}$

[[req:Cast Validation At Compile Time]] Given a type cast expression e in which $e.expr:S$ and target type T , the following constraints must hold:

1. T must be a classifier, enum, primitive, function type expression, classifier type, type variable, union or intersection type: $\mu(T) \in \{\text{any}, \text{Class}, \text{Interface}, \text{Enum}, \text{Primitive}, \text{ObjectType}, \text{FunctionTypeExpression}, \text{ClassifierType}, \text{TypeVariable}\}$
2. If S is a subtype of T , the cast is unnecessary and a warning will be generated.
3. If S and T are classes, enums or primitive types, then T must be a subtype of S . This is also true if T is an interface and the type of S cannot have subtypes, or vice versa.
4. If S is a class, enum or primitive type and T is a type-variable, then for each given boundary T_i^{up} of T of type class, enum or primitive S must be a member of the type hierarchy: ⁷ $\forall T_i^{up} \in T.upperBounds (\text{isCPOE}(T_i^{up}) (T_i^{up}.lt;:S \vee T_i^{up}.gt;:S))$
5. If S is a union or intersection type, then the type cast is valid if it is valid for at least one element of S .

⁵ <https://jira.numberfour.eu/browse/IDE-161>

⁶ <https://jira.numberfour.eu/browse/IDE-928>

⁷ i iterates over all boundaries

6. If S and T are generics, and if $S <superscript>0 = T </superscript>0$, a cast is possible if type arguments are sub- or supertypes of each other: ⁸

$$\mu(S) = \text{Classifier} \wedge \mu(T) = \text{Classifier} \wedge S <superscript>0 = T </superscript>0 \wedge (\forall S.typeArg_i : T.typeArg_i) \vee$$

7. If T is a union type, then the type cast is valid if it is valid for at least one element of T .

8. If T is an intersection type, then the type cast is valid if it is valid for all elements of T .

Note that `any` is a supertype of all other types, thus it is always possible to cast a variable of type `any` to other (non-composed) types.

9.3.2. Type Check

There are basically two ways of testing the type of a variable: `typeof` and `instanceof`. N4JS supports type comparison via the ECMAScript `instanceof` operator. The operator `instanceof` retains its standard ECMAScript behavior (e.g. checking whether a value is an instance of a constructor function), but has additional functionality when used with N4JS types.

 GH-293⁹

When used with an N4JS class, `instanceof` also supports checking against an interface. For N4JS enumeration values, it can be used to check whether the value is part of a specific enumeration.

`typeof` only returns a string with the name of the ECMAScript type, which is `Object` for all class instances.

N4 specific `string` types, that is `pathSelector` and `i18nkey` cannot be tested during runtime. These types, therefore, must not be used in `instanceof` expressions. The same is true for string-based enums and arrays which cannot be tested during runtime, thus string-based enum and array types are not permitted on the right-hand side of `instancesof` constructs. For all types for which the evaluation result of `instanceof` could be computed at compile time, the check is unnecessary and thus it is refused by the compiler. Using structural types on the right-hand side of `instancesof` constructs is also not permitted.

In order to avoid errors at runtime, the `instanceof` operator defines appropriate constraints, see [???](#) for details.

Type Check Example

Given the following classes and variable:

```
interface I{}
class S{}
class Sub extends S implements I{}

var x = new Sub();
```

`typeof x` will simply return `object`. The following table shows the difference between plain JavaScript `instanceof` and N4JS's `instanceof`:

⁸ i iterates over all type args

⁹ <https://github.com/NumberFour/N4JS/issues/293>

Check	JavaScript	N4JS
<code>x instanceof Sub</code>	<code>true</code>	<code>true</code>
<code>x instanceof S</code>	<code>true</code>	<code>true</code>
<code>x instanceof I</code>	<code>false</code>	<code>true</code>

9.4. Reflection meta-information

IDE-155 ¹⁰
 IDE-561 ¹¹
 IDE-137 ¹²
 IDE-980 ¹³

All N4JS classes, interfaces and enumerations provide meta-information that is used by the runtime and standard library. All classifiers (including enums) provide meta-information by means of a static getter `n4class`. Since it is static getter, it is actually an instance getter of the constructor (or classifier) of a type, which is the only way to retrieve that information in case of interfaces. For enums, this can be retrieved from instances as well.

This getter is of type `N4Class` which is a built-in type just like `N4Object`. It contains the following members:

`fqn`

The *FQN* of the type.

`n4superType`

The `N4Class` of the supertype, may be null if supertype is a not an .

`allImplementedInterfaces`

List of The *FQN* of implemented interfaces (transitively but without interfaces implemented by supertype)

`get isClass`

True if the type is an N4Class.

`get isInterface]`

True if the type is an N4Interface.

This meta-information is currently not available to non-N4 developers.

9.4.1. Reflection for Classes

The meta-information for classes is available by means of `N4Object`'s static getter `n4class`. Since it is static getter, it is actually an instance getter of the constructor of a type.

Reflection with `N4class`

¹⁰ <https://jira.numberfour.eu/browse/IDE-155>

¹¹ <https://jira.numberfour.eu/browse/IDE-561>

¹² <https://jira.numberfour.eu/browse/IDE-137>

¹³ <https://jira.numberfour.eu/browse/IDE-980>

This example demonstrates how these reflective features are accessed:

```
class A {}
class B extends A {}
var b = new B();
console.log(B.n4class.fqn);
console.log(b.constructor.n4class.fqn);
console.log(b.constructor.n4class.n4superType.fqn);
console.log(B.n4class.constructor.n4class.fqn);
```

Assuming this code is defined in file `A`, this will output

```
A.B
A.B
A.A
N4Class
```

The built-in types `N4Object` and `N4Class` are also accessible. They are not defined in a module, thus their `FQN` returns only their simple name.

Reflection with Built-In Types

```
console.log('N4Object.n4class.fqn: ' + N4Object.n4class.fqn)
console.log('N4Class.n4class.fqn: ' + N4Class.n4class.fqn)

class A {}
console.log('A.n4class.fqn: ' + A.n4class.fqn)
console.log('A.n4class.n4superType.fqn: ' + A.n4class.n4superType.fqn)
```

Assuming this code is defined in file `A`, this will output

```
N4Object.n4class.fqn: N4Object
N4Class.n4class.fqn: N4Class
A.n4class.fqn: A.A
A.n4class.n4superType.fqn: N4Object
```

Note that classes extending `Object` do not provide the static `n4class` getter, hat is

```
class B extends Object {}
console.log('B.n4class.fqn: ' + B.n4class.fqn)
```

would issue an error as cannot be resolved.

N4Class.of

The type has a method to retrieve the meta-information from instances (i.e. or enumeration literals using `)`) without using the constructor.

GH-195¹⁴

¹⁴ <https://github.com/NumberFour/N4JS/issues/195>

```

class C { }

interface I {}  class IIImpl implements I {}

enum E { L }

var c: C = new C();
var i: I = new IIImpl();
var e: E = E.L;

console.log(C.n4type.fqn);
console.log(N4Class.of(c).fqn);

console.log(I.n4type.fqn);
console.log(N4Class.of(i).fqn);

console.log(E.n4type.fqn);
console.log(N4EnumType.of(e).fqn);

```

9.4.2. Reflection for Interfaces

 IDE-980 ¹⁵

The meta-information of an interface *X* is available via getter `n4class` defined in the `type{x}`. This field is of type `N4Class` as well. Since an interface cannot have a super classs, the property `n4superTypes` will always be empty. Calling `isInterface` respectively on the returned `N4Class` instance will return true.

9.4.3. Reflection for Enumerations

```
var n: number; var b: boolean; var s: string;
```

The meta-information for enumerations is available by means of the getter `n4class`, either statically by using the enumeration type or (in terms of an instance getter) via a literal. Calling `isEnum` on the returned `N4Class` instance will return true.

9.5. Conversion of primitive types

Conversion between primitives is given as follows:

```
var n: number; var b: boolean; var s: string;
```

From	To	Conversion	Example
<code>string</code>	<code>number</code>	<code>Number...</code>	<code>n = Number("42");//42</code>
<code>string</code>	<code>boolean</code>	<code>N4Primitives.parseBoolean(...)</code>	<code>b=N4Primitives.parseBoolean("false");</code>

¹⁵ <https://jira.numberfour.eu/browse/IDE-980>

From	To	Conversion	Example
number	boolean	<code>Boolean(...)</code>	<code>b=Boolean(17.5); //true</code>
number	string	<code>Number.toString()</code>	<code>s=42.toString(); //"42"</code>
boolean	number	<code>N4Primitives.toNumber(...)</code>	<code>n=N4Primitives.toNumber(true);</code>
boolean	string	<code>Boolean.toString()</code>	<code>s=true.toString(); //"true" }</code>

Remarks:

1. ECMAScript doesn't define explicit conversion from string content. Implicit handling states all strings with `gt;0==true`. `N4Primitives.parseBoolean(x)` yields true for `x.trim().toLowerCase() .equals("true")`
2. The call to `Boolean(..)` for the arguments `0, -0, null, false, NaN, undefined` and `""` evaluate to `false`. All other values evaluate to `true`.
3. `Number` has several methods for converting a value to string [ECMA11a(p.S15.7.4)]: `toExponential(), toFixed(), toPrecision()`.
4. ECMAScript doesn't define explicit conversion from boolean to number. Implicit handling states true → 1 and false → 0, which `N4Primitives.toNumber()` yields.

Chapter 10. Expressions

For all expressions, we define the following pseudo properties:

containingExpression

The parent expression, in which an expression is contained, may be null.

containingStatement

The statement in which the expression is (indirectly) contained.

containingFunctionOrAccessor

The function, method, getter or setter in which the expression is (indirectly) contained, may be null

containingClass

The class in which the expression is (indirectly) contained, may be null.

probableThisTarget

The potential target of a this keyword binding, this is not necessarily the containing class or object literal. In case of instance methods of a class `T`, this usually is the classifier `T`; in case of static methods, it is the classifier type `type{type}`.

container

The direct owner of the expression.

The expressions and statements are ordered, describing first the constructs available in the 5th edition of ECMA-262, referred to as [ECMA11a] in the following. It is worth noting that the grammar snippets already use newer constructs in some cases.

10.1. ECMAScript 5 Expressions

IDE-232¹

[sec:ECMAScript_Expressions] N4JS supports the same expressions as ECMAScript. The semantics are described in [ECMA11(p.S11)]. In N4JS, some expressions are extended for supporting the declaration of types, annotations, or parameterized usages. These extensions and type-related aspects as well as specific N4JS constraints are described in this section.

Some operators come in different 'flavors', that is as binary operator, unary pre- or postfix operators, or assignment operators. For these operators, type constraints are only defined for the binary operator version and the other variants are deduced to that binary version. E.g., '+' and '=' are deduced to '+' (and simple assignment).

10.1.1. The this Literal

IDE-229²

IDE-505³

¹ <https://jira.numberfour.eu/browse/IDE-232>

² <https://jira.numberfour.eu/browse/IDE-229>

³ <https://jira.numberfour.eu/browse/IDE-505>

This section describes the `this` literal and the semantics of the `@This` annotation, the type `this` is described in [???](#).

Semantics

Semantics are similar to the original ECMAScript this keyword, see [[ECMA11a\(p.11.1.1, p.p.63\)](#)] Also see [[West06a](#)] and cite:[MozillaJSRef(<https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Operators/this>)]

Regarding the location where `this` may be used, the following restrictions apply:

The literal may not be used in

1. the initializer expression of static data fields in classes.
2. the initializer expression of data fields in interfaces (applies to both static and non-static).
3. static methods of interfaces and static field accessors of interfaces.

See also [req:StaticMembersOfInterfaces].

The use of `this` is illustrated with some examples as it can often be confusing. Type inference heuristics and explanations are provided in the next section.

this in unrestricted mode

In unrestricted mode, `this` is bound to the receiver. If there is no receiver it is bound to the global object, however, we often do not know exactly what the global object would be.

```
var name = "global a"; // assume the top level is similar to the global object
this.name; // <-- "global a"
function f() {
    return this.name; // <-- depends on call, usually "global a"
}
var o11 = {
    name: "John",
    greeting: "Hello " + this.name, // "Hello global a" -- we do not greet John!
}
var o12 = {
    name: "John",
    f: function() {
        this.name; // usually "John", as we assume f is called like o12.f()
        var g = function() {
            return this.name; // "global a"
        }
        return g(); // no receiver, this in nested function g will be global scope
    }
}
```

this in strict mode

In strict mode, `this` is bound to the receiver. If there is no receiver, it is bound to `undefined`. Thus, we will probably get a lot of errors:

```
"use strict"
```

```
var name = "global a"; // assume the top level is similar to the global object
this.name; // <-- error, this is undefined, there is no receiver
function f() {
    return this.name; // <-- depends on call, usually this produces an error as this is
    undefined
}
var o1 = {
    name: "John",
    greeting: "Hello " + this.name, // will produce an error, as this is undefined
}
var o2 = {
    name: "John",
    f: function() {
        this.name; // usually "John", as we assume f is called like o2.f()
        var g = function() {
            this.name; // an error, see call below:
        }
        return g(); // no receiver, this in nested function g is undefined
    }
}
```

this in N4JS mode

As in strict mode, `this` is bound to the receiver and if there is no receiver, it is bound to `undefined`. So the example above is also true for N4JS mode. Classes behave slightly differently:

```
class A {
    name = "John";
    greeting = "Hello " + this.name; // works, in N4JS classes, greeting is "Hello John"

    f() {
        return this.name; // this usually is instance object, similar to object literals.
    }

    g() {
        var h = function() {
            return this.name; // as in object literals: no receiver, no this.
        }
        return h();
    }
}
```

Note that in N4JS classes, is always bound to the instance when used in field initialization.

Type Inference

IDE-244⁴

The type is inferred from the `this` type is bound to. The inference, therefore, has to consider the original semantics as described in [ECMA11a(p.10.4., p.10.4.3, p.p.58)] . In ECMA Script the type of this is unfortunately determined by the function call and not by the function definition:

⁴ <https://jira.numberfour.eu/browse/IDE-244>

- By default, `this` is bound to the global object [ECMA11a(p.10.4.1.1)] . Unfortunately it is often unknown what the global object will be at run time (e.g., node.js differs from browsers).
- If a function is called without a receiver, `this` is bound to
 - the global object or
 - to `undefined` in strict mode.
- If a function is called with a receiver, `this` is bound to the receiver object.

Actually, `this` is bound to the newly created object if a function is called with the `new` operator. If a function is known to be invoked with an explicit `thisArg` (`apply()` etc.), the `@This` annotation can be used to explicitly set the `this` type. This annotation has precedence over otherwise inferred bindings.

IDE-1010⁵

In general, the actual `this` target can not be inferred from the context of the `this` keyword. A heuristic is defined, however, to compute the probable `this` type:

1. If the `this` keyword is used in some function annotated with an annotation , the type specified in the annotation is used. The inferred type is always nominal.
`"this":Tf = "this".containingFunctionOrAccessorf.hasAnnotation("@This")amp;T = f.annotation["@This"]{}\\ \\ \\ \end{aligned}]]`
2. If the `this` keyword is used in some `instance` method of a classifier or in an `instance` field initializer, is bound to the itself. If the `this` keyword is used in some `static` method of a classifier or in a `static` field initializer, the prototype type (or constructor) of the classifier is used, that is . In both cases, the target is determined by using the expressions's pseudo property . If the `this` keyword is used in a function expression assigned to an property of an object literal, the type of the object literal is used. Note that usually this is the type in instance methods, and the type in static methods.
`"this":TT = "this".probableThisTargetamp;T ≠`
3. In all other cases: Non-strict mode: `"this":globalmode = unrestricted` Strict mode and N4JS mode:
`"this":globalundefinedmode ≠ unrestricted`

IDE-785⁶
 IDE-185⁷

If the actual `this` type is defined as a structural type, the structural type information is moved to the `this` type itself. This is transparent to the user in general but maybe visible in case of error messages. That is to say that the actual `this` type is always a nominal type. This is indicated by the nominal modifier f (cf. [???](#) 1. and 2.).

91Valid Target and Argument for @This Annotation[req:ValidTargetAndArgumentForThisAnnotation]

IDE-802⁸

⁵ <https://jira.numberfour.eu/browse/IDE-1010>

⁶ <https://jira.numberfour.eu/browse/IDE-785>

⁷ <https://jira.numberfour.eu/browse/IDE-185>

⁸ <https://jira.numberfour.eu/browse/IDE-802>

1. The `@This` annotation is only allowed on declared functions, function expressions (including arrow functions), methods, and field accessors, i.e. getters and setters, except static members of interfaces.
2. The type declared by way of `@This(...)` an annotation of a method or field accessor must be a subtype of the member's containing classifier.

It is not allowed to use more than one annotation on an element.

Effect of Nominal This Type

Given the following declaration

```
@This(~Object with {a: string;}) f() {}
```

Since the this type is always nominal, `~ Object` becomes `Object`. In case of method call, however, the returned value becomes structural again. In case of error messages the type of the return type is then

```
~this[Object] with {a: string;}
```

For the sake of simplicity, additional structural members are usually omitted in error messages, leading to

```
~this[Object]
```

instead of

```
this[~Object]
```

This and Function Declaration [[ex:This and Function Declaration]] This example demonstrates the usage of functions annotated with `@This`. By using the argument `union{A,B}` it is possible to have two completely unrelated classes as the receiver type of the function `logger`. To pass an actual object the `apply()` method of the function is used.

```
[language=n4js, escapeinside={^}{^}]
class A {
    log: string() { return "A was logged"; }
}

class B {
    log: string() { return "B was logged"; }
}

@This(union{A,B})
function logger() { console.log("~ "+this.log()+" ~"); }

var a: A = new A();
logger.apply(a,[]); // prints "~ A was logged ~"
logger.apply( new B(),[]) // prints "~ B was logged ~"
```

This and Function Expressions [[ex:This and Function Expressions]] In this example a function is created via a function expression. The function is then assigned to member field of class B. Via annotating the expression with access to the receiver of type B is enabled.

```
[language=n4js,escapeinside={^}{^}]
class B {
    log(): string { return "B was logged"; }           // method
    logMe : @This(B) function():void; // reference to a function
}

var b: B = new B();
b.logMe = @This(B) function() { console.log("*>" +this.log() + "<*"); }
b.logMe(); // prints *>B was logged<*
```

This and Constructor Functions [[ex:This and Constructor Functions]] Note that if a function is called as a constructor function with new, the type of `this` can be declared via annotation `@This`, as shown in the following snippet:

```
[language=n4js,escapeinside={^}{^}]
@This(
    ~Object with {
        w: number; h: number;
        area: {function():number};
    })
function Box(w: number w, h: number) {
    this.w = w;
    this.h = h;
    this.area = @This(
        ~Object with {
            w: number; h: number;
            area: {function():number};
        }) function() { return this.w * this.h }
}
var bError = Box(1,2)
var bOK = new Box(1,2)
```

Inside the constructor function `Box`, `this` is bound to the structural type definition due to the annotation.

Inside the nested function `area`, `this` is bound to the receiver object (if the function is called like `bOK.area()`). Again, this depends on the way the nested function is called, which can usually not be determined at the declaration location. The nested function must then be annotated accordingly.

When calling this function, the type of this is checked against the declared this type, which would cause an error in the first case.

The use of the `@This` annotation is not allowed on methods.

IDE-2313⁹

⁹ <https://jira.numberfour.eu/browse/IDE-2313>



Using constructor functions is not recommended and an error or warning will be created. This is only useful for adapting third-party library code. Even in the latter case, it would probably make more sense to declare a (library) \emph{class} Rectangle rather than defining the constructor function.)

10.1.2. Identifier

Syntax

Identifiers as expressions are identifier references. They are defined as follows:

```
IdentifierRef <Yield>:  
  id=[types::IdentifiableElement|BindingIdentifier<Yield>]  
;  
  
BindingIdentifier <Yield>:  
  IDENTIFIER  
  | <!Yield> 'yield'  
  | N4Keyword  
;
```

Semantics

The type of an identifier *i* is resolved depending on its binding and scope respectively (cf. [EC-MA11a(p.10.2.2.1GetIdentifierReference, p.p.56)]). The following scopes (aka *Lexical Environments*) are defined:

- function local; local variables, parameters
- zero or more function closure in case of nested functions
- module
- global

These scope are nested as illustrated in .

Note that classes definitions and object literal do not define a scope: members of a class or properties of an object literal are to be accessed via `this`. Identifier references always reference declared elements, that is to say either variable, function, or class declarations. Properties of object literals or members of a class are referenced via *PropertyAccess - Expression.property* (see [Section 10.1.7, “Property Accessors”](#)).



An identifier may be bound to a variable (global or local variable, parameter, variable defined in a function's closure), or to a property of an object. The latter case is known as property access as further described in [Section 10.1.7, “Property Accessors”](#).

```
//Requirement  
//93Read Access to Identifier  
[[req:Read_Access_to_Identifier]]
```

```
If an identifier math:[$i$] is accessed, the bound declared element
math:[$D$] must be readable if it is not used on the left-hand side
of an assignment expression. math:[\[\begin{aligned}
& bind(i, D) \\
& \hspace{2em}\land \not\exists \ \text{type}\{\text{AssignmentExpression}\} \ ae \in i.\text{container}^*: \\
& \hspace{3em} ae.\text{left} = i \\
& \hspace{4em}\lor (\mu(ae.\text{left})=\text{type}\{\text{PropertyAccessExpression}\} \ \land ae.\text{left}.\text{property}=i): \\
\
& \Rightarrow D.\text{readable} \\ \end{aligned}\]]
```

Type Inference

IDE-244¹⁰

An identifier reference *i* is bound to an identifiable element *iid*, which is expressed with the function `bind(i, iid)`. The type of the reference is then inferred as follows: *IdentifierRef idref:Tidref.id:T*

10.1.3. Literals

cf. [ECMA11a(p.S11.1.3p.63, p.S7.8p.19ff)].

Type Inference

The type of a literal can directly be derived from the grammar. The following axioms are defined for literals:

`NullLiteral:null7.8.1amp;BooleanLiteral:boolean7.8.2amp;NumericLiteral:intornumber7.8.3amp;StringLiteral:string7.8.4amp;P`

Note that there are no literals specific for `pathSelector` or `i18nkey`.

Integer Literals

Numeric literals representing integers in the range of JavaScript's int32 are inferred to the built-in primitive type `int` instead of `number`. The following rules apply:

[[req:Numeric literals]]

- Numeric literals with a fraction or using scientific notation, e.g. `2.0` and `2e0`, respectively, are always inferred to `number`, even if they represent integers in the range of int32.
- Numeric literals that represent integers in the range of JavaScript's int32, i.e. from -2^{31} to $2^{31}-1$, are inferred to `int`.
- Hexadecimal and octal literals are always interpreted as positive numbers, so all values above `0x7fffffff` and `017777777777` lie outside the range of int32 and will thus be inferred to `number`; this is an important difference to Java. See below for further elaboration.

There are differences to numeric literals in Java:

¹⁰ <https://jira.numberfour.eu/browse/IDE-244>

	Java		JavaScript & N4JS	
Literal	Value	Type	Value	Type
2147483648	-2147483648	int	-2147483648	int
2147483647	2147483647	int	2147483647	int
0x7fffffff	2147483647	int	2147483647	int
0x80000000	-2147483648	int	+2147483648	number
0xffffffff	-1	int	4294967295	number
0x100000000	n/a		4294967296	number
017777777777	2147483647	int	2147483647	int
020000000000	-2147483648	int	+2147483648	number
037777777777	-1	int	4294967295	number
040000000000	0	int	4294967296	number
0100000000000	n/a		8589934592	number

The literals `0x100000000` and `0100000000000` produce a syntax error in Java.

Until IDE-1881 is complete, all built-in operations always return a `number` even if all operands are of type `int`. For the time being, we therefore interpret `-1` as a negative integer literal (inferred to `int`), but `-(1)` as the negation of a positive integer literal (inferred to `number`).

IDE-1881¹¹

10.1.4. Array Literal

Syntax

cf [ECMA11a(p.S11.1.4, p.p.63)]

```

ArrayLiteral <Yield> returns ArrayLiteral:
  {ArrayLiteral} '['
    elements+=ArrayPadding* (
      elements+=ArrayElement<Yield>
      (',' elements+=ArrayPadding* elements+=ArrayElement<Yield>)*
      (trailingComma?=',' elements+=ArrayPadding*)?
    )?
  ']'
;

/***
 * This array element is used to pad the remaining elements, e.g. to get the
 * length and index right
 */
ArrayPadding returns ArrayElement: {ArrayPadding} ',';
```

¹¹ <https://jira.numberfour.eu/browse/IDE-1881>

```
ArrayElement <Yield> returns ArrayElement: {ArrayElement} spread?='...'?
  expression=AssignmentExpression<In=true,Yield>;
```

Type Inference

IDE-244 ¹²
 IDE-342 ¹³

In general, an array literal is inferred as $\text{Array}_{\text{lt};T_{\text{gt}}}$ (similar to the type of `new Array()`). The interesting question is the binding of the type variable T .

The type of an array padding p is inferred as follows: $\text{amp};p:\text{undefined}$

The element type of an array literal is simply inferred as the (simplified) union of the type elements of the array. Thus, the type of an array literal a is inferred as follows: $\text{amp};(a):\text{Array}_{\text{lt};T_{\text{gt}}};a.\text{elements}:T_e \text{amp};T = \bigcup T_e$

In other languages not supporting union types, the element type is often inferred as the join ([LCST](#)) of the element types. Using a union type here preserves more information (as the actual types are still known). For many use cases the behavior is similar though, as the members of a union type are the members of the join of the elements of the union.

Note that `typeof [1,2,3]` does not return `Array<number>` (as ECMAScript is not aware of the generic array type), but `Object`.

The type for all variables declared in this example is inferred to

$\text{Array}_{\text{lt};\text{string}_{\text{gt}}};:$

```
var names1      = ["Walter", "Werner"];
var names2      = new Array("Wim", "Wendelin");
var names3      = new Array<string>(3); // length is 3
var names4: Array<string>;
```

Empty array literals are inferred to `any`, by default. We are not using `Array<?>` here because then a typical JavaScript pattern would no longer be supported:

```
var a = [];
a.push('hello'); // would fail if a and thus [] were inferred to Array<?>
```

There is an important exception, however: if a type expectation exists for the empty array literal and the expected type is `,` then this will be used as the type of the array literal.

95Empty array literal An empty array literal will be inferred as follows:

- If there is a type expectation for the empty array literal and the expected type is `,` for any type , then the type of the empty array literal will be inferred to .

¹² <https://jira.numberfour.eu/browse/IDE-244>

¹³ <https://jira.numberfour.eu/browse/IDE-342>

- Otherwise, the type of the empty array literal will be inferred to .

10.1.5. Object Literal

Syntax

Cf. [ECMA11a(p.S11.1.5, p.p.65ff)] The syntax of an object literal is given by:

```

ObjectLiteral <Yield>: {ObjectLiteral}
  '{'
    ( propertyAssignments+=PropertyAssignment<Yield>
      (',', propertyAssignments+=PropertyAssignment<Yield>)* ',', '?'
    )?
  '}'
;

PropertyAssignment <Yield>:
  PropertyNameValuePair<Yield>
  | PropertyGetterDeclaration<Yield>
  | PropertySetterDeclaration<Yield>
  | PropertyMethodDeclaration<Yield>
  | PropertyNameValuePairSingleName<Yield>
;

PropertyMethodDeclaration <Yield>:
  => ({PropertyMethodDeclaration}
    annotations+=Annotation*
    TypeVariables? returnTypeRef=TypeRef?
    (
      generator?= '*' LiteralOrComputedPropertyName<Yield> -
    >MethodParamsAndBody<Generator=true>
      | LiteralOrComputedPropertyName<Yield> ->MethodParamsAndBody
    <Generator=false>
      )
    )
  ';
';

PropertyNameValuePair <Yield>:
  => (
    {PropertyNameValuePair}
    annotations+=Annotation*
    declaredTypeRef=TypeRef? LiteralOrComputedPropertyName<Yield> ':'
  )
  expression=AssignmentExpression<In=true, Yield>
;

/*
 * Support for single name syntax in ObjectLiteral (but disallowed in actual object literals
 by ASTStructureValidator
 * except in assignment destructuring patterns)
 */
PropertyNameValuePairSingleName <Yield>:
  declaredTypeRef=TypeRef?
  identifierRef=IdentifierRef<Yield>
;
```

```

('=' expression=AssignmentExpression<In=true, Yield>) ?
;

PropertyGetterDeclaration <Yield>:
=> (
  {PropertyGetterDeclaration}
  annotations+=Annotation*
  GetterHeader<Yield>
)
body=Block<Yield=false>
;

PropertySetterDeclaration <Yield>:
=> (
  {PropertySetterDeclaration}
  annotations+=Annotation*
  'set'
  ->LiteralOrComputedPropertyName <Yield>
)
'(' fpar=FormalParameter<Yield> ')' body=Block<Yield=false>
;

```

```

import Address from "my/Address";
var simple = {name: "Walter", age: 72, address: new Address()};

```

Properties

PropertyAssignments have common properties of `PropertyNameValuePair`, `PropertyGetterDeclaration`, and `PropertySetterDeclaration`:

`annotations`

The annotations of the property assignment.

`name`

The name of the property. This may be an identifier, a string or a numeric literal. When comparing names, we implicitly assume the name to be converted to an identifier, even if this identifier is not a valid ECMAScript identifier.

`declaredType`

The declared type of the property which may be null. This property is a pseudo property for `PropertySetterDeclaration`, in this case it is derived from the declared type of the setter's formal parameter.

Additionally, we introduce the following pseudo properties to simplify constraints:

`isAccessor`

The read-only boolean property. This is true if the property assignment is a setter or getter declaration. This is comparable to ECMAScript's spec function `IsAccesso-`
`prDescriptor`. For a given property assignment p this is semantically equivalent to $\mu(p) = \text{PropertyGetterDeclaration} \vee \mu(p) = \text{PropertySetterDeclaration}$.

`isData`

The read-only boolean property. This is true if the property assignment is a name value pair. For a given property assignment p this is semantically equivalent to $\mu(p) = \text{PropertyNameValuePair}$. It is com-

parable to ECMAScript's spec function `isDataDescriptor`. The equation $isAccessor = \neg isData$ is always true.

Semantics

[[req:Object Literal]] For a given object literal ol the following constraints must hold (cf. [ECMA11a(p.p.66)]):

- Object literal may not have two PropertyNameValuePairs with the same name in strict mode (cf. 4.a):

$$mode = strict \wedge \forall pa \in ol.propertyAssignments, pa.isData \wedge pa' \in ol.propertyAssignments \wedge pa'.isAccessor \wedge pa'.name = pa.name$$
- Object literal may not have PropertyNameValuePair and PropertyGetterDeclaration/PropertySetterDeclaration with the same name (cf. 4.b/c):

$$\forall pa \in ol.propertyAssignments, pa.isData \wedge pgd \in ol.propertyAssignments \wedge \mu(pgd) \neq PropertyNameValuePair \wedge pa.name = pgd.name$$
- Object literal may not have multiple PropertyGetterDeclaration or PropertySetterDeclaration with the same name (cf. 4.d):

$$\forall pg \in ol.propertyAssignments, pg.isAccessor \wedge pg' \in ol.propertyAssignments \wedge pg.name = pg'.name \wedge \mu(pg) = \mu(pg') \wedge pg.name = pg'.name$$
- It is a SyntaxError if the Identifier `eval` or the Identifier `arguments` occurs as the Identifier in a PropertySetParameterList of a PropertyAssignment that is contained in strict code or if its Function-Body is strict code. [ECMA11a(p.p.66)]
- If two or more property assignments have the same name (and the previous conditions hold), then the types of these assignments must `conform`. That is to say that the inferred (but not declared) type of all assignments must be type of probably declared types and if the types are explicitly declared, they must be equal.
- In N4JS mode, the name of a property must be a valid N4JSIdentifier:

$$mode = n4js \wedge \forall pa \in ol.propertyAssignments \wedge \mu(pa.name) = N4JSIdentifier$$

Scoping and linking

IDE-173 ¹⁴

```
var p = {
    f: function() {
        console.log("p's f");
    },
    b: function() {
        this.f();
    },
    o: {
        nested: "Hello"
    }
};
p.b();
p.o.nested;
```

¹⁴ <https://jira.numberfour.eu/browse/IDE-173>

- Other properties within an object literal property can be accessed using this. In the expression of property name value pairs, however, `this` is not bound to the containing object literal, but usually to undefined or global.
- The properties of an object literal are accessible from outside.
- Nested properties of an object literal are also accessible from outside.

Type Inference

IDE-244 ¹⁵
IDE-343 ¹⁶
IDE-691 ¹⁷

An object literal implicitly extends `Object`, therefore, object literal types use structural typing. For details see [???](#). From a type systems point of view, the two variables `o1` and `st` below have the same type.

```
var o1 = {
  s: "hello",
  n: 42
}
var st: ~Object with { s: string; n: number;};
```

10.1.6. Parenthesized Expression and Grouping Operator

The grouping operator is defined here as a parenthesized expression.

Syntax

cf. [ECMA11a(p.S11.1.6, p.p.67)]

```
ParenExpression <Yield>: '(' expression=Expression<In=true,Yield> ')';
```

Type Inference

IDE-244 ¹⁸
IDE-345 ¹⁹

The type of the grouping operator simply is the type of its nested expression. The type if a parenthesized expression *pe* is inferred as follows:

amp;(*e*)*:Te:T11.1.6*

¹⁵ <https://jira.numberfour.eu/browse/IDE-244>

¹⁶ <https://jira.numberfour.eu/browse/IDE-343>

¹⁷ <https://jira.numberfour.eu/browse/IDE-691>

¹⁸ <https://jira.numberfour.eu/browse/IDE-244>

¹⁹ <https://jira.numberfour.eu/browse/IDE-345>

Parenthesized Expression Type Examples [[ex:Parenthesized Expression Type Examples]] In the following listing, the type of the plain expressions is equivalent to the parenthesized versions:

```
class A{} class B extends A{}

var f: boolean; var a: A a; var b: B;

/* simple      <->      parenthesized */
10;           (10);
"hello";      ("hello");
true;          (true);
a;            (a);
10-5;          (10-5);
f?a:b         (f?a:b);
```

10.1.7. Property Accessors

Syntax

Property accessors in N4JS are based on [ECMA11a(p.S11.2.1, p.p.67ff)]. They cannot only be used for accessing properties of an object, but also for accessing members of a class instance. In order to support parameterized calls, the syntax is extended to optionally allow type arguments.

```
ParameterizedPropertyAccessExpression:
    target=PrimaryExpression<Yield> ParameterizedPropertyAccessExpressionTail<Yield>
;

IndexedAccessExpression:
    target=PrimaryExpression<Yield> IndexedAccessExpressionTail<Yield>
;

fragment IndexedAccessExpressionTail <Yield>*:
    '[' index=Expression<In=true,Yield> ']'
;

fragment ParameterizedPropertyAccessExpressionTail <Yield>*:
    '.' TypeArguments? property=[types::IdentifiableElement|IdentifierName]
;
```

Note that in [ECMA11a], the `index access` is called *bracket notation*.

Properties

We define the following properties:

`target`

The receiver of the property access.

`index`

The index expression in case of an IndexedAccessExpression (returns `otherwise`).

`property`

The name of the property in case of non-indexed-access expressions (returns `otherwise`, although the index may be interpreted as property name).

We define the following pseudo properties:

isDotAccess

Read-only boolean property, returns true for non-index access expression (similar to $\mu(p) \neq \text{IndexedAccessExpression}$).

isIndexAccess

Read-only boolean property, returns true for index access expression (similar to $\mu(p) = \text{IndexedAccessExpression}$).

The equation $p.\text{isDotAccess} = \neg p.\text{isIndexAccess}$ is always true.

name

Returns the name of the property. This is either the *property* converted to a simple name or the index converted to a name (where possible) if it is an indexed-accessed expression.

Semantics

IDE-12²⁰

The parameterization is part of the property access in case of generic methods. For generic functions, a parameterized function call is introduced (cf.). The constraints are basically similar.

1. If dot notation is used in N4JS mode, the referenced property must exist unless receiver is a dynamic type:

$\text{amp}; \text{pae}.\text{isDotAccess} \wedge \neg R.\text{dynamp}, \exists m \in \text{pae}.\text{targettype}.\text{properties}: m.\text{name} = \text{pae}.\text{name}$

2. If dot notation is used and the referenced property exists, then the property must be accessible:

$\text{amp}; \text{pae}.\text{isDotAccess} \wedge \neg R.\text{dynamp}, (\exists m \in \text{pae}.\text{targettype}.\text{properties}: m.\text{name} = \text{pae}.\text{name}) \alpha(\text{pae}, m)$

3. If dot notation is used and the referenced property exists and this property is a member with a declared `@This` type (only possible for methods or field accessors), then the receiver must be a subtype of the declared `@This` type.

IDE-422²¹

IDE-656²²

IDE-1734²³

1. A limited form of computed-name indexed-access is allowed in N4JS mode. In case the receiver is of dynamic type, the index can be any expression . Otherwise, the indexed-access is limited in that the index must be a string literal. Feasible targets of such accesses are the same as for dot-access.

This notation is useful when interoperating with libraries that define members whose names contain special characters (for example, a field name starting with commercial-at).

²⁰ <https://jira.numberfour.eu/browse/IDE-12>

²¹ <https://jira.numberfour.eu/browse/IDE-422>

²² <https://jira.numberfour.eu/browse/IDE-656>

²³ <https://jira.numberfour.eu/browse/IDE-1734>

2. Additionally, an indexed-access expression is allowed when targeting one of the types

or subtypes, for (not including subtypes of and not for and), and for dynamic types. It is not allowed to access members of enums in particular. That is to say, for an indexed-access expression iae , the following constraint must hold:
 $\text{amp};ia.\text{target}T, T \in \text{Array}, \text{ArgumentType}, \text{string}, \text{String}, \text{Iterable}$ amp; $\text{v amp};ia.\text{target} = \text{Object}$

3. In N4JS mode, if the receiver is an array and is not dynamic, in case of index access the index expression must be a number:

$\text{amp};mode = n4js \wedge pae.\text{target.type} = \text{Array} \wedge pae.\text{isIndexAccess}$ amp; $\Rightarrow pae.\text{index}[\text{number} \backslash \text{end}\{\text{aligned}\}]$

4. In N4JS mode, if the receiver is a subtype of types or and is not dynamic, in case of index access the index expression must be a number:

$\text{amp};mode = n4js$ amp; $\wedge (pae.\text{target.string} \vee pae.\text{targetString})$ amp; $\wedge pae.\text{isIndexAccess}$ amp; $\Rightarrow pae.\text{indexnumber}$

5. In N4JS mode, if the receiver is an iterable and is not dynamic, in case of index access the index expression must be a property access expression to the built-in symbol :

$\text{amp};mode = n4js \wedge pae.\text{target.type} = \text{Iterable} \wedge pae.\text{isIndexAccess}$ amp; $\Rightarrow \text{amp}; \mu(pae.\text{index}) = \text{IndexedAccessExpression}$ amp;

GH-238²⁴

IDE-837²⁵

Although index access is very limited, it is still possible to use immediate instances of `Object` in terms of a map (but this applies only to index access, not the dot notation):

Object as Map

```
var map: Object = new Object();
map["Kant"] = "Imperative";
map["Hegel"] = "Dialectic";
map.spinoza = "Am I?"; // error: Couldn't resolve reference to IdentifiableElement
'spinoza'.
```

For a parameterized property access expression pae , the following constraints must hold:

1. The receiver or target must be a function or method: $pae.\text{target.typeFunction}$
2. The number of type arguments must match the number of type parameters of the generic function or method: $|pae.\text{typeArgs}| = |pae.\text{target.typeVars}|$
3. The type arguments of a parameterized property access expression must be subtypes of the boundaries of the parameters of the called generic method.

Also see constraints on read (???) and write (???) access.

Type Inference

²⁴ <https://github.com/NumberFour/N4JS/issues/238>

²⁵ <https://jira.numberfour.eu/browse/IDE-837>

Cf. [ECMA11a(p.S11.2.1, p.p.67ff)]

We define the following type inferencing rules for property accessors:

- The type of an indexed-access expression p is inferred as follows task:IDE-342]:

$$\text{amp};p:T \neg p.\text{target}.\text{dyn} \vee p.\text{index}.\text{type}[number \& \text{!}\text{ee } p.\text{target}: \text{\type}\{\text{Array}\langle T \rangle\} \text{!}\& \text{!}\text{infer}\{\text{!}\text{ee } p: \text{\type}\{\text{any}\}\}$$

$$\{\text{else}\} \text{!}\text{end}\{\text{aligned}\}]$$
- The type of a property access expression is inferred as follows:

$$\text{PropertyAccessExpression } expr:T174;expr.\text{target}:Ramp;expr.\text{property}:T$$
- The type of a parameterized access expression p is inferred as follows:

$$\text{amp};p:T \exists m \in p.\text{target}:m.\text{name} = p.\text{name} \text{amp};m:T \text{amp};p:\text{any}$$

10.1.8. New Expression

cf. [ECMA11a(p.S11.2.2, p.p.68)]

Syntax

```
NewExpression: 'new' callee=MemberExpression<Yield> (-> TypeArguments)?
  (=> withArgs?='(' Arguments<Yield>? ')' )?
```

```
import Address from "my/Address";

var a = new Address();
// a.type := my/Address

class C<T> {
  constructor(param: T) {}
}
var c = new C<string>("hello");
```

Semantics

Let ne be a new expression, with $ne.\text{callee}:C$. The following constraints must hold:

1. The callee must be a constructor type: $Clt::constructor\{?\}$ or a constructable type.

²⁶ <https://jira.numberfour.eu/browse/IDE-244>

²⁷ <https://jira.numberfour.eu/browse/IDE-182>

²⁸ <https://jira.numberfour.eu/browse/IDE-183>

²⁹ <https://jira.numberfour.eu/browse/IDE-192>

³⁰ <https://jira.numberfour.eu/browse/IDE-204>

2. Let O be the type argument of C , that is $C = \text{constructor}O$. In that case,

- a. O must not be an interface or enum: $\mu 169; O \notin \{\text{Interface}, \text{Enum}\}$
- b. O must not contain any wildcards.
- c. O must not be a type variable.

3. If C is not a constructor type, it must be a constructable type, that is one of the following:

$\{\text{Object}, \text{Function}, \text{String}, \text{Boolean}, \text{Number}, \text{Array}, \text{Date}, \text{RegExp}, \text{Error}\}$ In particular, it must not refer to a primitive type or a defined functions (i.e., subtypes of Function) cannot be used in new-expressions in N4JS.

Remarks:

to 1) The type of an abstract class A is $\text{type}A$. Or in other words: Only instantiable classes have an inferred type of $\text{constructor}\{\cdot\}$.

to 2) Even though it is possible to use the constructor type of an abstract class – concrete subclasses with override compatible constructor signature will be subclasses of this constructor.

to 3) It is not possible to refer to union or intersection at that location. So this is not explicitly denied here since it is not possible anyway.

Abstract classes and construction [[ex:Abstract classes and construction]] The following examples demonstrates the usage of abstract classes and constructor types, to make the first two constraints more clearer:

```
/* XPECT_SETUP eu.numberfour.n4js.spec.tests.N4JSSpecTest END_SETUP */

abstract class A {}
class B extends A {}

// XPECT errors --> "Cannot instantiate abstract class A." at "A"
var x = new A();
// XPECT noerrors -->
var y = new B();

function foo(ctor : constructor{A}) {
    // XPECT noerrors -->
    return new ctor();
}

// XPECT errors --> "type{A} is not a subtype of constructor{A}." at "A"
foo(A);
// XPECT noerrors -->
foo(B);
```

Type Inference

The type of a new expression ne is inferred as follows: $\text{amp}; ne : C \text{ne callee: constructor}C$

For classes, constructors are described in [???](#).

In N4JS it is not allowed to call new on a plain function. For example:

```
function foo() {}  
var x = new foo();
```

will issue an error.

10.1.9. Function Expression

See [???](#) for details.

10.1.10. Function Calls

IDE-186 ³¹
IDE-851 ³²

In N4JS, a function call [[ECMA11a\(p.S11.2.3\)](#)] is similar to a method call. Additionally to the ECMAScript's CallExpression, a ParameterizedCallExpression is introduced to allow type arguments passed to plain functions.

Syntax

IDE-177 ³³

Similar to [[ECMA11a\(p.S11.2.3, p.p.68ff\)](#)], a function call is defined as follows:

```
CallExpression <Yield>:  
    target=IdentifierRef<Yield>  
    ArgumentsWithParentheses<Yield>  
;  
  
ParameterizedCallExpression <Yield>:  
    TypeArguments  
    target=IdentifierRef<Yield>  
    ArgumentsWithParentheses<Yield>  
;  
  
fragment ArgumentsWithParentheses <Yield>*:  
    '(' Arguments<Yield>? ')'  
;  
  
fragment Arguments <Yield>*:  
    arguments+=AssignmentExpression<In=true,Yield> (',' arguments  
    +=AssignmentExpression<In=true,Yield>)* (',' spread?=...' arguments  
    +=AssignmentExpression<In=true,Yield>)?  
    | spread?=...' arguments+=AssignmentExpression<In=true,Yield>
```

³¹ <https://jira.numberfour.eu/browse/IDE-186>

³² <https://jira.numberfour.eu/browse/IDE-851>

³³ <https://jira.numberfour.eu/browse/IDE-177>

;

Semantics

101 Function Call Constraints

For a given call expression f bound to a method or function declaration F , the following constraints must hold:

- If less arguments are provided than formal parameters were declared, the missing formal parameters must have been declared optional:
 $|f.args| < |F.pars| \forall |f.args| < i \leq |F.pars| : F.pars_i \text{ optional}$
- If more arguments are provided than formal parameters were declared, the last formal parameter must have been declared variadic:
 $|f.args| > |F.pars| \forall |F.pars| - 1 \text{ variadic}$
- Types of provided arguments must be subtypes of the formal parameter types:
 $\forall 0 \leq i \leq \min(|f.args|, |F.pars|) : f.args_i \leq F.pars_i$
- If more arguments are provided than formal parameters were declared, the type of the exceeding arguments must be a subtype of the last (variadic) formal parameter type:
 $\forall |F.pars| < i \leq |f.args| : f.args_i \leq F.pars_{|F.pars|-1}$
- The number of type arguments in a parameterized call expression must be equal to the number of type parameters of the generic function / method and the type arguments must be subtypes of the corresponding declared upper boundaries of the type parameters of the called generic function.

Note that (for a limited time), constraints [???](#) and [???](#)[TITLE???](#) are not applied if the type of F is [Function](#). See [???](#).

Type Inference

IDE-244 [34](#)

A call expression $expr$ is bound to a method ([Section 6.2, “Methods”](#)) or function declaration (which may be part of a function definition [???](#) or specified via a function type [???](#)) F (via evaluation of [Member-Expression](#)). The type of the call is inferred from the function declaration or type F as follows:

$expr:T \text{ bind } (\text{expr}.\text{target}, F) \text{ and } F.\text{returnType}:T$

IDE-205 [35](#)

A generic method invocation may be parameterized as well. This is rarely required as the function argument types are usually inferred from the given arguments. In some cases, for instance with pathSelect-

[34](#) <https://jira.numberfour.eu/browse/IDE-244>

[35](#) <https://jira.numberfour.eu/browse/IDE-205>

tors, this is useful. In that case, the type variable defined in the generic method declaration is explicitly bound to types by using type arguments. See [???](#) for semantics and type inference.

[[ex:Generic Method Invocation]] This examples demonstrate how to explicitly define the type argument in a method call in case it cannot be inferred automatically.

```
class C {  
    static <T> foo(p: pathSelector<T>): void {...}  
};  
C.<my.Address>foo("street.number");
```

Note that in many cases, the type inferencer should be able to infer the type automatically. For example, for a method

```
function <T> bar(c: T, p: pathSelector<T>): void {...};
```

and a function call

```
bar(context, "some.path.selector");  
[source,n4js]
```

the type variable `T` can be automatically bound to the type of variable `context`.

10.1.11. Postfix Expression

Syntax

```
PostfixExpression returns Expression: LeftHandSideExpression  
    (=>({PostfixExpression.expression=current} /* no line terminator here */  
        op=PostfixOperator))?  
;  
enum PostfixOperator: inc='++' | dec='--';
```

Semantics and Type Inference

The type inference and constraints for postfix operators `'` and `--``, cf. [[ECMA11a\(p.S11.3.1, p.p.70\)](#)], [[ECMA11a\(p.S11.3.1, p.p.70\)](#)], are defined similarly to their prefix variants (unary expressions), see [Section 10.1.12, “Unary Expression”](#).

For a given postfix expression $u u$ with $uop \in \{++, --\}$ and $uexpression.type:T$, the following constraints must hold:

IDE-345³⁶

- In N4JS mode, the type T of the expression must be a number.

³⁶ <https://jira.numberfour.eu/browse/IDE-345>

- If $u.expression = \text{PropertyAccess } pa(p) \wedge p \text{ is Dot Access}$ both get p and set p must be defined.

IDE-737³⁷

10.1.12. Unary Expression

Syntax

We define the following unary operators and expression, similar to [ECMA11a(p.p.70ff)]

```
UnaryExpression returns Expression:
  PostfixExpression
  | ({UnaryExpression} op=UnaryOperator expression=UnaryExpression);
enum UnaryOperator: delete | void | typeof | inc='++' | dec='--' | pos='+' | neg='-' | inv='$sim$' | not='!';

```

Semantics

For semantics of the delete operator, see also cite:[MozillaJSRef(<https://developer.mozilla.org/en-US/docs/JavaScript/Reference/Operators/delete>)]

104 delete Operator Constraints[req:DeleteOperatorConstraints] For a given unary expression u with $u.op = \text{delete}$, the following constraints must hold:

- In strict mode, $u.expression$ must be a reference to a property of an object literal, a member of a class type, or to a property of the global type (i.e., the reference must be bound, and the bound target must not be a variable).
- In N4JS mode, the referenced property or member must not be declared in the containing type and the containing type reference must be declared dynamic.

There are no specific constraints defined for with $u.op = \text{void}$

IDE-345³⁸

There are no specific constraints defined for unary expression u with $u.op = \text{typeof}$.

IDE-345³⁹

107 Increment/Decrement Constraints[req:IncrementOperatorConstraints] For a given unary expression u with $u.op \in \{++, --\}$ and $u.expression \text{ type: } T$, the following constraints must hold:

- If mode is N4JS, the type T of the expression must be a number $\& UnaryExpression \text{ type: } \text{number}$
- If $u.expression = \text{PropertyAccess } pa(p) \wedge p \text{ is Dot Access}$ both get p and set p must be defined.

³⁷ <https://jira.numberfour.eu/browse/IDE-737>

³⁸ <https://jira.numberfour.eu/browse/IDE-345>

³⁹ <https://jira.numberfour.eu/browse/IDE-345>

108 Unary Plus/Minus/Bitwise Not Operator Constraints[req:UnaryPlusOperatorConstraints] For a given unary expression u with $u.op \in \{ +, -, \sim \}$ and $u.expression.type:T$, the following constraints must hold:

- In N4JS mode, the type T of the expression must be a number: $amp;UnaryExpressionExpression:number$

There are no specific constraints defined for with $u.op = !$.

Type Inference

The following operators have fixed types independent of their operand types:

```
math:[\[\begin{aligned}
&\backslash infer{\backslash tee \lstmtfbnf{'delete'}\ expression: \type{boolean}}{} \tag{\S 11.4.1} \\
&\backslash infer{\backslash tee \lstmtfbnf{'void'}\ expression: \type{undefined}}{} \tag{\S 11.4.2} \\
&\backslash infer{\backslash tee \lstmtfbnf{'typeof'}\ expression: \type{string}}{} \tag{\S 11.4.3} \\
&\backslash infer{\backslash tee \lstmtfbnf{('++' | '$--$' | '+' | '$-$ | '~')}\ expression: \type{number}}{} \tag{\S 11.4.4-8} \\
&\backslash infer{\backslash tee \lstmtfbnf{'}!'}\ expression: \type{boolean}}{} \tag{\S 11.4.9}\end{aligned}\]]
```

10.1.13. Multiplicative Expression

Syntax

Cf. [[ECMA11a\(p.p.73ff\)](#)]

```
MultiplicativeExpression returns Expression: UnaryExpression
  (=>({MultiplicativeExpression.lhs=current} op=MultiplicativeOperator)
   rhs=UnaryExpression)*;
enum MultiplicativeOperator: times='*' | div='/'
  | mod='%';
```

Semantics

110 Multiplicative Expression Constraints[req:MultiplicativeExpressionConstraints] For a given multiplicative expression the following constraints must hold in N4JS mode :

⁴⁰ <https://jira.numberfour.eu/browse/IDE-345>

⁴¹ <https://jira.numberfour.eu/browse/IDE-768>

⁴² <https://jira.numberfour.eu/browse/IDE-345>

⁴³ <https://jira.numberfour.eu/browse/IDE-244>

⁴⁴ <https://jira.numberfour.eu/browse/IDE-345>

- The types of the operands must be subtypes of number: *MultiplicativeExpressionExpression:number*

Type Inference

The inferred type of a multiplicative expression always is number: *MultiplicativeExpression:number*

10.1.14. Additive Expression

Syntax

Cf. [ECMA11a(p.p.75ff)]

```
AdditiveExpression returns Expression: MultiplicativeExpression
  (=> ({AdditiveExpression.lhs=current} op=AdditiveOperator) rhs=MultiplicativeExpression)*;
enum AdditiveOperator: add='+' | sub='-';
```

Semantics

111Additive Expression Constraints[req:AdditiveExpressionConstraints] For a given additive expression the following constraints must hold in N4JS mode:

- The types of the operands must be subtypes of number if the operator is not '+', otherwise, any type could be used: *AdditiveExpression eExpression:numbers.e.op ≠ AdditiveOperator.ADD*

Type Inference

The type of an additive expression is usually inferred to . The result for the addition operator may only be a number if both operands are numbers, booleans, or one is boolean or number and the other is undefined or null.

We first define two helper rules to simplify the addition operator condition:

45 <https://jira.numberfour.eu/browse/IDE-345>

46 <https://jira.numberfour.eu/browse/IDE-244>

47 <https://jira.numberfour.eu/browse/IDE-345>

48 <https://jira.numberfour.eu/browse/IDE-345>

49 <https://jira.numberfour.eu/browse/IDE-244>

50 <https://jira.numberfour.eu/browse/IDE-345>

```
amp;nb{nb(T)}{T = \type{number} \lor T = \type{boolean}} &\infer[nb]{nb(expr)}{nb\tee expr}\ \&\infer[un]{un(T)}{T = \type{undefined} \lor T = \type{null}} &\infer[un]{un(expr)}{un\tee expr.lhs \lor un\tee expr.rhs}\end{aligned}]]
```

The type of an additive expression e is inferred as follows:

$amp;e:string.op = '+'amp; \neg (nb(e.lhs) \wedge nb(e.rhs))amp; \neg (un(e) \wedge (nb(e.lhs) \vee nb(e.rhs)))amp;e:number$

```
1+2;          // number 3
"1"+"2";     // string "12"
"1"+2;        // string "12"
1+true;       // number 2
false+1;      // number 1
"1"+true;     // string "1true"
"1"+null;     // string "1null"
1+null;       // number 1
1+undefined;  // number NaN
"1"+undefined; // string "1undefined"
```

10.1.15. Bitwise Shift Expression

Syntax

Cf. [ECMA11a(p.p.76f)]

IDE-288 51

```
ShiftExpression returns Expression: AdditiveExpression
  (=> ({ShiftExpression.lhs=current} op=ShiftOperator rhs=AdditiveExpression))*;
;

ShiftOperator returns ShiftOperator:
  '>' '>' '>?' // SHR, USHR
  | '<' '<'    // SHL
;
```

Semantics

For a given bitwise shift expression e the following constraints must hold in N4JS mode:

IDE-345 52

IDE-771 53

- The types of the operands must be both number. *BitwiseShiftExpression Expression:number*

Type Inference

⁵¹ <https://jira.numberfour.eu/browse/IDE-288>

⁵² <https://jira.numberfour.eu/browse/IDE-345>

⁵³ <https://jira.numberfour.eu/browse/IDE-771>

The type returned by a bitwise shift expression is always :

amp; (Expression('lt;|gt;|gt;gt;') Expression):number 11.7.1/2

10.1.16. Relational Expression

Syntax

Cf. [ECMA11a(p.p.77ff)]

```

RelationalExpression returns Expression: ShiftExpression
  (=>({RelationalExpression.lhs=current} op=RelationalOperator rhs=ShiftExpression)*;

RelationalExpressionNoIn returns Expression: ShiftExpression
  (=>({RelationalExpression.lhs=current} op=RelationalOperatorNoIn rhs=ShiftExpression)*;

enum RelationalOperator:
  lt='<' | gt='>' | lte='<=' | gte='>=' | instanceof | in;
RelationalOperatorNoIn returns RelationalOperator:
  '<' | '>' | '<=' | '>=' | 'instanceof';

```

Semantics

113 Greater/Less (Equals) Operator Constraints[req:GreaterOperatorConstraints] For a given relational expression e with $e.op \in \{lt;, gt;, 8656;, gt;=\}$ in N4JS mode, the following constraints must hold:

- The operands must have the same type and the type must be either a number, string, or boolean:
amp;lhs ('lt;|8656;|gt;|gt;=') rhs lhs:Trhs:Tamp;T \in \{number, string, boolean\} *amp;lhs ('lt;|8656;|gt;|gt;=') rhs lhs:Trhs:O*

For a given relational expression e with $e.op = instanceof$, the following constraints must hold:

- The right operand of the instanceof operator must be a **Function** ⁵⁸]. Thus instanceof expressions are rewritten by the compiler for other types. Note that a reference to a class returns the constructor type, which actually is a function itself. In other words, *amp;lhs 'instanceof' rhs rhs:typeClass* is contained in the the first type rule.] , an object type reference ⁵⁹ or an enum type reference.

⁵⁴ <https://jira.numberfour.eu/browse/IDE-244>

⁵⁵ <https://jira.numberfour.eu/browse/IDE-345>

⁵⁶ <https://jira.numberfour.eu/browse/IDE-345>

⁵⁷ <https://jira.numberfour.eu/browse/IDE-345>

⁵⁸ Only **Function** implements the ECMAScript specification property `[[hasInstance]`

⁵⁹ Includes interfaces, since an interface type reference is a subtype of object type reference: `typeInterfaceType;:typeObject`

[amp;lhs 'instanceof' rhs rhs:Functionamp;lhs 'instanceof' rhs rhs:typeObjectamp;lhs 'instanceof' rhs rhs:typeN4Enum](#)
#IDE-652 **60**
[amp;lhs 'instanceof' rhs rhs:typeObjectamp;lhs 'instanceof' rhs rhs:typeN4Enum](#)
#IDE-681 **61**
[amp;lhs 'instanceof' rhs rhs:typeN4Enum](#)
#GH-631 **62**

The type of a definition site structural classifier C is not of type `c`. Thus, the `instanceof` operator cannot be used for structural types. Use-site structural typing is also not possible since `~` would be interpreted (by the parser) as a binary operator.

For a given relational expression e with $e.op = in$, the following constraints must hold:

[#IDE-345 **63**](#)

1. The right operand of the in operator must be an `Object`:

[amp;lhs 'in' rhs rhs:Object](#)

2. In N4JS mode, the left operand is restricted to be of type `string` or `number`:

[amp;lhs 'in' rhs lhs:string, number](#)

A special feature of N4JS is support for interface type references in combination with the `instance of` operator. The compiler rewrites the code to make this work.

[#IDE-561 **64**](#)

`instanceof` with Interface

The following example demonstrates the use of the operator with an interface. This is, of course, not working in pure ECMAScript.

```
interface I {}

class A implements I {}
class B extends A {}
class C {}

function f(name: string, p: any) {
    if (p instanceof I) {
        console.log(name + " is instance of I");
    }
}

f("A", new A())
f("B", new B())
f("C", new C())
```

60 <https://jira.numberfour.eu/browse/IDE-652>

61 <https://jira.numberfour.eu/browse/IDE-681>

62 <https://github.com/NumberFour/N4JS/issues/631>

63 <https://jira.numberfour.eu/browse/IDE-345>

64 <https://jira.numberfour.eu/browse/IDE-561>

This will print out

```
A is instance of I
B is instance of I
```

Type Inference

IDE-244 [65](#)
 IDE-345 [66](#)

The type of a relational expression always is ;
 $amp; lhs ('lt;|8656;|gt;|=instanceof|in') rhs :boolean11.8.1-6$

10.1.17. Equality Expression

Syntax

Cf. [[ECMA11a\(p.p.80ff\)](#)]

```
EqualityExpression returns Expression: RelationalExpression
  (=> ({EqualityExpression.lhs=current} op=EqualityOperator) rhs=RelationalExpression)*;

EqualityExpressionNoIn returns Expression: RelationalExpressionNoIn
  (=> ({EqualityExpression.lhs=current} op=EqualityOperator) rhs=RelationalExpressionNoIn)*;

enum EqualityOperator: same='===' | nsame='!=!' | eq='==' | neq='!=';
```

Semantics

IDE-345 [67](#)

There are no hard constraints defined for equality expressions.

In N4JS mode, a warning is created if for a given expression $lhs('==!=')rhs$, neither $lhs.upperlt;:rhs.upper$ nor $rhs.upperlt;:lhs.upper$ and no interface or composed type is involved as the result is constant in these cases.

IDE-773 [68](#)
 GH-260 [69](#)

Note that a warning is only created if the upper bounds do not match the described constraints. This is necessary for wildcards. For example in

[65](#) <https://jira.numberfour.eu/browse/IDE-244>

[66](#) <https://jira.numberfour.eu/browse/IDE-345>

[67](#) <https://jira.numberfour.eu/browse/IDE-345>

[68](#) <https://jira.numberfour.eu/browse/IDE-773>

[69](#) <https://github.com/NumberFour/N4JS/issues/260>

```
// with
class A{} class B extends A{}
function isFirst(ar: Array<? extends A>, b: B): boolean {
    return b === ar[0]
}
```

the type of array elements is `? extends A`.

Neither `?extendsAB` nor `B?extendsA` is true. This is why the upper bounds are to be used.

Type Inference

IDE-244 ⁷⁰
IDE-345 ⁷¹

In N4JS mode, using the non-strict equality operators `'==' | '!='` is only allowed for internal developers. External developers have to use the strict equality operators `'===' | '!=='`. The inferred type of an equality expression always is `boolean`.

`amp;lhs ('==!=!===!=!) rhs :boolean11.9`

10.1.18. Binary Bitwise Expression

Syntax

Cf. [ECMA11a(p.p.82ff)]

```
BitwiseANDExpression returns Expression: EqualityExpression
(=> ({BitwiseANDExpression.lhs=current} '&') rhs=EqualityExpression)*;

BitwiseANDExpressionNoIn returns Expression: EqualityExpressionNoIn
(=> ({BitwiseANDExpression.lhs=current} '&') rhs=EqualityExpressionNoIn)*;

BitwiseXORExpression returns Expression: BitwiseANDExpression
(=> ({BitwiseXORExpression.lhs=current} '^') rhs=BitwiseANDExpression)*;

BitwiseXORExpressionNoIn returns Expression: BitwiseANDExpressionNoIn
(=> ({BitwiseXORExpression.lhs=current} '^') rhs=BitwiseANDExpressionNoIn)*;

BitwiseORExpression returns Expression: BitwiseXORExpression
(=> ({BitwiseORExpression.lhs=current} '|') rhs=BitwiseXORExpression)*;

BitwiseORExpressionNoIn returns Expression: BitwiseXORExpressionNoIn
(=> ({BitwiseORExpression.lhs=current} '|') rhs=BitwiseXORExpressionNoIn)*;
```

Semantics

For a given bitwise bitwise expression e the following constraints must hold in N4JS mode:

⁷⁰ <https://jira.numberfour.eu/browse/IDE-244>

⁷¹ <https://jira.numberfour.eu/browse/IDE-345>

- The types of the operands must be both number. *BitwiseBitwiseExpression Expression:number*

Type Inference

The type returned by a binary bitwise expression is always :
amp; (Expression('amp;'||') Expression):number

10.1.19. Binary Logical Expression

Syntax

```

LogicalANDExpression returns Expression: BitwiseORExpression
  (=> ({LogicalANDExpression.lhs=current} '&&') rhs=BitwiseORExpression)*;
LogicalANDExpressionNoIn returns Expression: BitwiseORExpressionNoIn
  (=> ({LogicalANDExpression.lhs=current} '&&') rhs=BitwiseORExpressionNoIn)*;

LogicalORExpression returns Expression: LogicalANDExpression
  (=> ({LogicalORExpression.lhs=current} '||') rhs=LogicalANDExpression)*;
LogicalORExpressionNoIn returns Expression: LogicalANDExpressionNoIn
  (=> ({LogicalORExpression.lhs=current} '||') rhs=LogicalANDExpressionNoIn)*;

```

Semantics

117 Binary Logical Expression Constraints[req:BinaryLogicalExpressionConstraints] For a given binary logical expression *e* with *e.lhs.type:L* and *e.rhs.type:R* the following constraints must hold:

- In N4JS mode *L* must not be or .

Type Inference

The evaluation relies on ECMAScript's abstract operation `ToBoolean` [ECMA11a(p.p.43)]. A short-circuit evaluation strategy is used so that depending on the types of the operands, different result types may

⁷² <https://jira.numberfour.eu/browse/IDE-345>

⁷³ <https://jira.numberfour.eu/browse/IDE-244>

⁷⁴ <https://jira.numberfour.eu/browse/IDE-345>

⁷⁵ <https://jira.numberfour.eu/browse/IDE-775>

⁷⁶ <https://jira.numberfour.eu/browse/IDE-244>

be inferred. In particular, the inferred type usually is not `boolean` ((cf. [ECMA11a(p.S11.11., p.p.83f-f)]). The type inference does not take this short-circuit evaluation strategy into account, as it will affect the result in case one of the types is `null` either or `undefined`, which is not allowed in N4JS mode.

`amp; lhs 'amp;amp;||' rhs:lhs, rhs}`

10.1.20. Conditional Expression

Syntax

Cf. [ECMA11a(p.S11.12, p.p.84)]

```
ConditionalExpression returns Expression: LogicalORExpression
  (=> ({ConditionalExpression.expression=current} '?') trueExpression=AssignmentExpression
    ':'
    falseExpression=AssignmentExpression)?;

ConditionalExpressionNoIn returns Expression: LogicalORExpressionNoIn
  (=> ({ConditionalExpression.expression=current} '?') trueExpression=AssignmentExpression
    ':'
    falseExpression=AssignmentExpressionNoIn)?;
```

Semantics

IDE-776⁷⁷

118 Conditional Expression Constraints[req:ConditionalExpressionConstraints] For a given conditional expression e with $e.expression.type:C$, $e.trueExpression.type:T$, $e.falseExpression.type:F$ the following constraints must hold:

- A warning will be issued in N4JSmode if $e.expression$ evaluates to a constant value. That is to say $e.expression \in \{false, true, null, undefined\}$ or $C \in \{void, undefined\}$.

There are no specific constraints defined for the condition. The ECMAScript operation `ToBoolean` [ECMA11a(p.S9.2, p.p.43)] is used to convert any type to boolean.

Type Inference

IDE-348⁷⁸

The inferred type of a conditional expression is the union of the true and false expression (cf. [ECMA11a(p.S11.12, p.p.84)]): $cond ?'et ':ef.TT = et, ef$

[[ex:Type of Conditional Expressions]] Given the following declarations:

```
class A{}           class B extends A{}
```

⁷⁷ <https://jira.numberfour.eu/browse/IDE-776>

⁷⁸ <https://jira.numberfour.eu/browse/IDE-348>

```

class C{}           class D extends A{}
class G<T> { field: T; }

var ga: G<A>, gb: G<B>;
    a: A, b: B, c: C, d: D;
var boolean cond;

```

Then the type of the following conditional expression is inferred as noted in the comments:

```

cond ? a : a;                      // A
cond ? a : b;                      // union{A,B}
cond ? a : c;                      // union{A,C}
cond ? b : d;                      // union{B,D}
cond ? (cond ? a : b) : (cond ? c : d); // union{A,B,C,D}
cond ? (cond ? a : b) : (cond ? b : d); // union{A,B,D}
cond ? ga : gb;                   // union{G<A>,G<B>}

```

10.1.21. Assignment Expression

Syntax

```

[language=n4bnf,caption={Syntax Assignment
Expression},label={lst:EBNFAssignment},escapeinside={^}{^}]
AssignmentExpression <In, Yield>:
    lhs=Expression op=AssignmentOperator rhs=AssignmentExpression<In,Yield>
;
AssignmentOperator:
    '='
    | '*=' | '/=' | '%=' | '+=' | '-='
    | '<<=' | '>>=' | '>>>='
    | '&=' | '^=' | '|='
;
```

Semantics

IDE-349⁷⁹

For a given assignment *assignment* with *assignment.op = '='* the following constraints must hold:

1. *assignment.lhs* *assignment.rhs*

In the following inference rule and the constraint, '@' is to be replaced with the right part of one of the assignment operators listed above, that is,

$\text{@} \in \{ \text{'*}', '/', '%', '+', '-', '<<', '>>', '>>>', '&', '|', '^' \}$

120Compound Assignment For a given assignment *left op right*, with *op = '@='* but not , both, left and right must be subtypes of **number**.

For operator '*+=*' ,

⁷⁹ <https://jira.numberfour.eu/browse/IDE-349>

- if the left-hand side is a `number`, then `left '+right` must return a number as well. The right-hand side must, in fact, be a `number` (and not a `boolean`) here in order to avoid unexpected results.
- if the left-hand side is a `string`, then `left '+right` must return a string as well. That means that the right-hand side can be of `any` type.

The expected type for the left-hand side is `union{number, string}`.

The basic idea behind these constraints is that the type of the left-hand side is not to be changed by the compound assignment.

For a given assignment expression `assignExpr`, the left-hand side must be writeable or a final data field and the assignment must be in the constructor. Let `v` be the bound variable (or field) with `bind(assignExpr.left, v)`

$$v.writeable \vee v.final \wedgeamp; v.expr =amp; assignExpr.containingFunction = v.owner.constructoramp; \wedgeamp; \mu(assignExpr.left$$

The value of `writeable` is true for setters and usually for variables and data fields. Assignability of variables and data fields can be restricted via `const` or the `@Final` annotation. See [???](#)(data fields) and [Section 11.2.2, “Const”](#) (const variables) for details.

Also see [???](#) for read access constraint.

The left-hand side of an assignment expression may be an array or object literal and the assignment expression is then treated as a destructuring assignment. See [???](#) for details.

Type Inference

IDE-244 ⁸⁰
 IDE-349 ⁸¹

Similarly to [[ECMA11a\(p.S11.1, p.p.84ff\)](#)], we define type inference for simple assignment (`=`) and compound assignment (`op=`) individually.

The type of the assignment is simply the type of the right-hand side:

`amp;left '=right:Tright:T11.13.1`

Compound assignments are reduced to the former by splitting an operator '`@=`', in which '`@`' is a simple operator, into a simple operator expression with operator '`@`' and a simple assignment '`=`'. Since the type of the latter is the right-hand side, we can define:

`left '@=right:Tleft '@right:T11.13.1`

10.1.22. Comma Expression

Syntax

Cf. [[ECMA11a\(p.S11.14, p.p.85\)](#)]

⁸⁰ <https://jira.numberfour.eu/browse/IDE-244>

⁸¹ <https://jira.numberfour.eu/browse/IDE-349>

```
CommaExpression <In, Yield>:
    exprs+=AssignmentExpression<In,Yield> ',' exprs+=AssignmentExpression<In,Yield>
    (','     exprs+=AssignmentExpression<In,Yield>)*
;
```

Semantics

IDE-778 [82](#)

All expressions will be evaluated even though only the value of the last expression will be the result.

[Comma Expression][ex:CommaExpression] Assignment expressions precede comma expressions:

```
var b: boolean;
b = (12, 34, true); // ok, b=true
b = 12, 34, true ; // error, b=12 is invalid
```

Type Inference

IDE-244 [83](#)

Cf. [ECMA11a(p.S11.14, p.p.85)]

The type of a comma expression *cexpr* is inferred to the last expression:
 $cexpr:T_n = |cexpr.exprs|, cexpr.exprs_n:T_{11.14}$

10.2. ECMAScript 6 Expressions

10.2.1. The super Keyword

```
SuperLiteral: {SuperLiteral} 'super';
```

Apart from the use of keyword `super` in wildcards of type expressions (cf. [???](#)), there are two use cases for keyword `super`: super member access and super constructor calls.

Super Keyword

Two use cases for keyword `super`:

```
class B extends A {
    constructor() {
        // super call
        super();
    }
}
```

[82](#) <https://jira.numberfour.eu/browse/IDE-778>

[83](#) <https://jira.numberfour.eu/browse/IDE-244>

```

    }
    @Override
    m();: void {
        // super member access
        super.m();
    }
}

```

Semantics

IDE-645⁸⁴

`super` can be used to access the supertype's constructor, methods, getters and setters. The supertype is defined lexically, which is different from how `this` works.⁸⁵, Chapter 12.3.5 "The Super Keyword"; note the use of "HomeObject" instead of "thisValue"; also see this blog⁸⁶). Note that in [ECMA15a] Chapter 12.3.5 **The Super Keyword**, `super` is defined as a keyword but the syntax and semantics are defined in conjunction of member access.]

The type referenced with the super literal is always nominal. This is a consequence of references to types in extend clauses to be nominal. $\text{super}:T \wedge T.\text{typingStrategy} = \text{nominal}$

If the super literal s is used to access the super constructor of a class, all of the following constraints must hold:

1. The super constructor access must be a call expression: $\mu(cexpr) = \text{CallExpression} \wedge c.\text{target} = cexpr$
2. The super constructor call must be the expression of an expression statement exprStmt :
 $\text{exprStmt} = cexpr.\text{container} \wedge \mu(cexpr.\text{container}) = \text{ExpressionStatement}$
3. The containing statement $stmtExpr$ must be directly contained in a constructor body:
 $\text{exprStmt}.\text{containingFunction} = \text{Constructor} \wedge \text{exprStmt}.\text{container} = \text{exprStmt}.\text{containingFunction}.\text{body}$
4. There must be no access to and not return statement before the containing statement exprStmt .

Let si be the index of exprStmt in the constructor body:

$\text{exprStmt}.\text{container}.stmts_{si} = \text{exprStmt}$.

Then, the following constraint must hold⁸⁷

$\forall i \in [0, si - 1] \wedge \mu(exprStmt.container.stmts_i) \neq \text{ThisLiteral}, \text{ReturnStatement}$

GH-147⁸⁸

Further constraints with regard to super constructor calls are described in [???](#).

IDE-1753⁸⁹

⁸⁴ <https://jira.numberfour.eu/browse/IDE-645>

⁸⁵ See [ECMA15a]

⁸⁶ <http://www.2ality.com/2011/11/super-references.html>

⁸⁷ $e \in^* c$ is the transitive version of $e \in c$, that is, it e directly or indirectly contained in c .

⁸⁸ <https://github.com/NumberFour/N4JS/issues/147>

⁸⁹ <https://jira.numberfour.eu/browse/IDE-1753>

124Access Super Member with Super Literal[req:Access_Super_Member_with_Super_Literal] If the super literal s is used to access a member of the super class, all of the following constraints must hold, with $c = s.container.container$

1. The super literal must be the receiver of a method call (cf. remarks below):
 $\mu(c) = CallExpression \wedge c.target = PropertyAccessExpression \wedge c.target.target = s$
2. The super literal is used in a method or field accessor of a class: $\mu(s.containingClass) = Class$
3. The super literal must not be used in a nested function expression:
 $\mu(s.containingFunction = s.containingMethodOrFieldAccessor)$
4. If the return type of the method access via super is this, the actually bound this type will be the type of the calling class (and not of the class defining the method).
 $function(): Tsms.containingClass = Tamp; \mu(m) = Methodamp; m.returnType = this$

 GH-386⁹⁰

[[req:Super Literal Usage]] For super literals, either ??? or ??? must hold, no other usage is allowed.

Consequences:

- Since fields cannot be overridden (except for changing the access modifier), it is not possible nor allowed to access a field via `super`.
- Super literals must not be used with index access (e.g., `super["foo"]`)
- It is not possible to chain super keywords. That is, it is not possible to call `super.super.m()`.
- It is not allowed to use the super literal in interfaces or non-methods/accessors.
- Super cannot be used to call an overridden method of an implemented method from the overriding method in the implementing class.
- In order to be able to access a super method of a method M of a class C , exactly one non-abstract super method M' in a super class S of C must exist. This is assured by the standard rules for binding identifiers.

If super is used to access a super member, the receiver type is not changed. This is important in particular for static methods as demonstrated in the following example:

```

class A {
    static foo(): void { console.log("A") }
    static bar(): void {
        this.foo();
    }
}

class B extends A {

    @Override
    static foo(): void { console.log("B") }
    @Override

```

⁹⁰ <https://github.com/NumberFour/N4JS/issues/386>

```

static bar(): void {
    A.bar();           // outputs "A"
    super.bar();      // outputs "B"
}
}

B.bar();

```

In line 14, the receiver (which is similar to the this-binding in ECMAScript) is changed to `A`. In line 15, using `super`, the receiver is preserved, i.e. `B` coming from line 19.

10.3. ECMAScript 7 Expressions

10.3.1. Await Expression

In N4JS, `await` is implemented as a unary operator with the same precedence as `yield` in ECMAScript 6.

Constraints governing the use of `await` are given together with those for `async` in [???](#).

10.4. N4JS Specific Expressions

10.4.1. Class Expression

A class expression in N4JS is similar to a class expression in ECMAScript 6 [ECMA15a(p.14.5)]. .

Syntax

See [Section 5.3, “Classes”](#).

Semantics and Type Inference

The inferred type of a class expression simply is the class type as described in [???](#).

10.4.2. Cast (As) Expression

 IDE-161p 91

Syntax

```

CastExpression <Yield> returns Expression: expression=Expression 'as'
targetTypeRef=TypeRefForCast;

TypeRefForCast returns StaticBaseTypeRef:
    ParameterizedTypeRef
    | ThisTypeRef
    | ConstructorTypeRef

```

⁹¹ <https://jira.numberfour.eu/browse/IDE-161p>

```
| ClassifierTypeRef  
| FunctionTypeExpression  
| UnionTypeExpression  
| IntersectionTypeExpression
```

10.4.3. Semantics and Type Inference

The inferred type of the type cast expression is the target type: *expr "as" T:T*

The type cast returns the expression without further modifications. Type casts are simply removed during compilation so there will be no exceptions thrown at the cast until later when accessing properties which may not be present in case of a failed cast.

An error is issued if the cast is either unnecessary or cannot succeed. See further details in .

Chapter 11. Statements

For all statements, we define the following pseudo properties:

containingFunction

The function or method in which the statement is (indirectly) contained, this may be null.

containingClass

The class in which the statement is (indirectly) contained, this may be null.

The expressions and statements are ordered, at first describing the constructs available in the 5th edition of ECMA-262 referred to as [ECMA11a] in the following. The grammar snippets already use newer constructs in some cases.

11.1. ECMAScript 5 Statements

N4JS supports the same statements as ECMAScript. Some of these statements are enhanced with annotations [Chapter 12, Annotations](#) and type information.

Although some statements may return a value which can be used via certain constructs such as `eval`), no type is inferred for any statement. The compiler will always create a warning if a statement is used instead of an expression.

The following sections, therefore, do not define how to infer types for statement but how types and type annotations are used in these statements and the specific type constraints for a given statement.

All syntax definitions taken from [ECMA11a] are repeated here for convenience reasons and in order to define temporary variables for simplifying constraint definitions. If non-terminals are not defined here, the definition specified in [ECMA11a] is to be used.

11.1.1. Function or Field Accessor Bodies

126Dead Code[req:Dead_Code] For all statements in a function or field accessor (getter/setter) body, the following constraints must hold:

1. Statements appearing directly after return, throw, break, or continue statements (in the same block) are considered to be dead code and a warning is issued in these cases.

11.1.2. Variable Statement

Syntax

A var statement can declare the type of the variable with a type reference. This is described with the following grammar similar to [ECMA11a(p.S12.2, p.p.87)]:

```
VariableStatement <In, Yield>:  
=>({VariableStatement}  
'var'
```

```
)  
varDeclsOrBindings+=VariableDeclarationOrBinding<In,Yield,false> (',' varDeclsOrBindings  
+=VariableDeclarationOrBinding<In,Yield,false>)* Semi  
;  
  
VariableDeclarationOrBinding <In, Yield, OptionalInit>:  
    VariableBinding<In,Yield,OptionalInit>  
    |  VariableDeclaration<In,Yield,true>  
;  
  
VariableBinding <In, Yield, OptionalInit>:  
    => pattern=BindingPattern<Yield> (  
        <OptionalInit> ('=' expression=AssignmentExpression<In,Yield>)?  
        |  <!OptionalInit> '=' expression=AssignmentExpression<In,Yield>  
    )  
;  
  
VariableDeclaration <In, Yield, AllowType>:  
    {VariableDeclaration} VariableDeclarationImpl<In,Yield,AllowType>;  
  
fragment VariableDeclarationImpl <In, Yield, AllowType>*:  
    annotations+=Annotation*  
    (  
        <AllowType> =>(  
            name=BindingIdentifier<Yield> ColonSepTypeRef?  
        ) ('=' expression=AssignmentExpression<In,Yield>)?  
        |  <!AllowType> =>(  
            name=BindingIdentifier<Yield>  
            ('=' expression=AssignmentExpression<In,Yield>)?  
        )  
    );  
  


---

  
var any: any;  
// any.type := any  
  
var anyNull = null;  
// anyNull.type := any  
  
var s: string;  
// s.type := string  
  
var init = "Hi";  
// init.type := string  
  
const MESSAGE = "Hello World";  
// MESSAGE.type := string
```

Semantics

From a model and type inference point of view, variable and constant statements and declarations are similar except that the pseudo property `const` is set to false for variables and true for constants. Also see exported variable statement ([Section 11.2.5, “Export Statement”](#)) and constant statement and declaration ([Section 11.2.2, “Const”](#)).

For a given variable declaration d , the following constraints must hold:

- The type of the initializer expression must conform to the declared type:
 $d.expression \neq \wedge d.declaredTypeRef \neq d.expression.type.d.declaredTypeRef$
 - The initializer expression should not contain a reference to d except where the reference is contained in a class expression or function expression and the class is not immediately initialized or the function is not immediately invoked. In these cases, the code is executed later and the self-reference is not a problem.
- To clarify: **should not** means that only a warning will be produced.

```
// not ok (simple case)
var n = n + 1;

// ok (class expression not in version 0.1)
// var cls1 = class { static sfield1 = "hello"; field2 = cls1.sfield1; };

// not ok, immediately instantiated (class expression not in version 0.1)
// var cls2 = new class { field1 = "hello"; field2 = cls2.field1; };

// ok
var fun1 = function() : number { var x = fun1; return -42; };

// not ok, immediately invoked
var fun2 = function() : number { var x = fun2; return -42; }();
```

The variable statement may contain array or object destructuring patterns, see [???](#) for details.

Type Inference

The type of a variable is the type of its declaration: $amp;v:d$

The type of a variable declaration is either the declared type or the inferred type of the initializer expression:
 $amp;d:Td.declaredType \neq amp;T = d.declaredTypeamp;d:Td.declaredType = amp;d.expression \neq E = d.expressionamp;E \notin \{ null, undefined, true, false, NaN, infinity, -infinity \}$

11.1.3. If Statement

Syntax

Cf. [[ECMA11a\(p.S12.5, p.p.89\)](#)]

```
IfStatement <Yield>:
  'if' '(' expression=Expression<In=true,Yield> ')'
  ifStmt=Statement<Yield>
  (=> 'else' elseStmt=Statement<Yield>)?;
```

Semantics

There are no specific constraints defined for the condition, the ECMAScript operation [ToBoolean](#) [[ECMA11a\(p.S9.2, p.p.43\)](#)] is used to convert any type to boolean.

[\[\[req:If_Statement\]\]](#) In N4JS, the expression of an if statement must not evaluate to **void**. If the expression is a function call in particular, the called function must not be declared to return **void**.

11.1.4. Iteration Statements

Syntax

Cf. [ECMA11a(p.S12.6, p.p.90ff)]

The syntax already considers the for-of style described in .

```

IterationStatement <Yield>:
    DoStatement<Yield>
    |  WhileStatement<Yield>
    |  ForStatement<Yield>
;

DoStatement <Yield>: 'do' statement=Statement<Yield> 'while' '('
    expression=Expression<In=true,Yield> ')' => Semi?;

WhileStatement <Yield>: 'while' '(' expression=Expression<In=true,Yield> ')'
    statement=Statement<Yield>;

ForStatement <Yield>:
    {ForStatement} 'for' '('
    (
        // this is not in the spec as far as I can tell, but there are tests that rely on
        this to be valid JS
        =>(initExpr=LetIdentifierRef forIn?='in' expression=Expression<In=true,Yield>
        ')')
    |   (   ->varStmtKeyword=VariableStatementKeyword
        (
            =>(varDeclsOrBindings
            +=BindingIdentifierAsVariableDeclaration<In=false,Yield> (forIn?='in' | forOf?='of') -
            >expression=AssignmentExpression<In=true,Yield>?)
            |   varDeclsOrBindings
            +=VariableDeclarationOrBinding<In=false,Yield,OptionalInit=true>
            (
                (
                    ',', varDeclsOrBindings
                +=VariableDeclarationOrBinding<In=false,Yield,false>)* ';'*
                expression=Expression<In=true,Yield>? ';' updateExpr=Expression<In=true,Yield>?
                |   forIn?='in' expression=Expression<In=true,Yield>?
                |   forOf?='of' expression=AssignmentExpression<In=true,Yield>?
            )
        )
    |   initExpr=Expression<In=false,Yield>
        (
            ';' expression=Expression<In=true,Yield>? ';'*
            updateExpr=Expression<In=true,Yield>?
            |   forIn?='in' expression=Expression<In=true,Yield>?
            |   forOf?='of' expression=AssignmentExpression<In=true,Yield>?
        )
    |   ';' expression=Expression<In=true,Yield>? ';'*
            updateExpr=Expression<In=true,Yield>?
        )
    )
;

) statement=Statement<Yield>
;

ContinueStatement <Yield>: {ContinueStatement} 'continue' (label=[LabelledStatement|
BindingIdentifier<Yield>])? Semi;

```

```
BreakStatement <Yield>: {BreakStatement} 'break' (label=[LabelledStatement | BindingIdentifier<Yield>])? Semi;
```

Since *varDecl(s)* are **VariableStatement**s as described in ???, the declared variables can be type annotated.



Using for-in is not recommended, instead `_each` should be used.

Semantics

There are no specific constraints defined for the condition, the ECMAScript operation **ToBoolean** [ECMA11a(p.S9.2, p.p.43)] is used to convert any type to boolean.

For a given *f* the following conditions must hold:

- The type of the expression must be conform to object:
f.expressionlt;:union{ Object, string, ArgumentType }
- Either a new loop variable must be declared or an rvalue must be provided as init expression:
f.varDecl ≠ null ∨ (f.initExpr ≠ null ∧ isRValue(f.initExpr))
- The type of the loop variable must be a string (or a super type of string, i.e. any):
amp;(f.varDecl ≠ null ∧ f.varDeclstring) ∨ amp;(f.initExp ≠ null ∧ string.finitExpr)

11.1.5. Return Statement

Syntax

The returns statement is defined as in [ECMA11a(p.S12.9, p.p.93)] with

```
ReturnStatement <Yield>:
  'return' (expression=Expression<In=true,Yield>)? Semi;
```

Semantics

130Return statement[req:Return_statement]

1. Expected type of expression in a return statement must be a sub type of the return type of the enclosing function: *returnStmtexpression:TreturnStmt.containingFunction:FTamp;T = FT.returnType* Note that the expression may be evaluated to .
2. If enclosing function is declared to return , then either
 - no return statement must be defined
 - return statement has no expression
 - type of expression of return statement is
3. If enclosing function is declared to to return a type different from , then
 - all return statements must have a return expression

- all control flows must either end with a return or throw statement
4. Returns statements must be enclosed in a function. A return statement, for example, must not be a top-level statement.

11.1.6. With Statement

Syntax

The with statement is not allowed in N4JS, thus an error is issued.

```
WithStatement <Yield>:  
  'with' '(' expression=Expression<In=true,Yield> ')'  
  statement=Statement<Yield>;
```

Semantics

N4JS is based on strict mode and the with statement is not allowed in strict mode, cf. [ECMA11a(p.S12.10.1, p.p.94)].

131With Statement[req:With Statement] With statements are not allowed in N4JS or strict mode.

11.1.7. Switch Statement

Syntax

Cf. [ECMA11a(p.S12.11, p.p.94ff)]

```
SwitchStatement <Yield>:  
  'switch' '(' expression=Expression<In=true,Yield> ')' '{'  
  (cases+=CaseClause<Yield>)*  
  ((cases+=DefaultClause<Yield>)  
  (cases+=CaseClause<Yield>)* )? '}'  
;  
  
CaseClause <Yield>: 'case' expression=Expression<In=true,Yield> ':' (statements  
+=Statement<Yield>)*;  
DefaultClause <Yield>: {DefaultClause} 'default' ':' (statements+=Statement<Yield>)*;
```

Semantics

132Switch Constraints[req:Switch Constraints] For a given switch statement s , the following constraints must hold:

- For all cases $c \in s.cases$, $s.expr === c.expr$ must be valid according to the constraints defined in .

11.1.8. Throw, Try, and Catch Statements

Syntax

Cf. [ECMA11a(p.S12.13/14, p.p.96ff)]

```
ThrowStatement <Yield>:  
    'throw' expression=Expression<In=true,Yield> Semi;  
  
TryStatement <Yield>:  
    'try' block=Block<Yield>  
    ((catch=CatchBlock<Yield> finally=FinallyBlock<Yield>?) | finally=FinallyBlock<Yield>)  
;  
  
CatchBlock <Yield>: {CatchBlock} 'catch' '(' catchVariable=CatchVariable<Yield> ')'  
block=Block<Yield>;  
  
CatchVariable <Yield>:  
    =>bindingPattern=BindingPattern<Yield>  
    | name=BindingIdentifier<Yield>  
;  
  
FinallyBlock <Yield>: {FinallyBlock} 'finally' block=Block<Yield>;
```

There must be not type annotation for the catch variable, as this would lead to the wrong assumption that a type can be specified.

Type Inference

The type of the catch variable is always assumed to be `catchBlock.catchVariable:any`

11.1.9. Debugger Statement

Syntax

Cf. [ECMA11a(p.S12.15, p.p.97ff)])

```
DebuggerStatement: {DebuggerStatement} 'debugger' Semi;
```

Semantics

na

11.2. ECMAScript 6 Statements

N4JS export and import statements are similar to ES6 with some minor differences which are elaborated on below.

11.2.1. Let

Cf. [ECMA11a(p.13.2.1)], also Rauschmayer, 2ality: [Variables and scoping in ECMAScript 6](#)¹

11.2.2. Const

Cf. [ECMA15a(p.13.2.1)], also Rauschmayer, 2ality: [Variables and scoping in ECMAScript 6](#)²

¹ <http://www.2ality.com/2015/02/es6-scoping.html>

² <http://www.2ality.com/2015/02/es6-scoping.html>

Additionally to the `var` statement, the `const` statement is supported. It allows for declaring variables which must be assigned to a value in the declaration and their value must not change. That is to say that constants are not allowed to be on the left-hand side of other assignments.

```
ConstStatement returns VariableStatement: 'const' varDecl+=ConstDeclaration ( ',' varDecl  
+=ConstDeclaration )* Semi;
```

```
ConstDeclaration returns VariableDeclaration: typeRef=TypeRef? name=IDENTIFIER const?='='  
expression=AssignmentExpression;
```

Semantics

A `const` variable statement is more or less a normal variable statement (see [Section 11.1.2, “Variable Statement”](#)), except that all variables declared by that statement are not writable (cf. [???](#)). This is similar to constant data fields (cf. [???](#)).

All variable declarations of a `const` variable statement `constStmt` are not writeable:
 $\forall vdecl \in constStmt.varDecl: \neg vdecl.writable$

11.2.3. `for ... of` statement

ES6 introduced a new form of `for` statement: `for ... of` to iterate over the elements of an `Iterable`, cf. [???](#).

Syntax

See [Section 11.1.4, “Iteration Statements”](#)

Semantics

For a given f the following conditions must hold:

1. The value provided after `of` in a `for ... of` statement must be a subtype of `Iterable<?>`.
2. Either a new loop variable must be declared or a value must be provided as init expression:
 $f.varDecl \neq null \vee (f.initExpr \neq null \wedge \text{isRValue}(f.initExpr))$
3. If a new variable v is declared before `of` and it has a declared type T , the value provided after must be a subtype of $. If v does not have a declared type, the type of v is inferred to the type of the first type argument of the actual type of the value provided after .$
4. If a previously-declared variable is referenced before with a declared or inferred type of T , the value provided after `of` must be a subtype of `Iterable<? extends T>`.



`Iterable` is structurally typed on definition-site so non-N4JS types can meet the above requirements by simply implementing the only method in interface `Iterable` (with a correct return type).



The first of the above constraints (the type required by the ‘of’ part in a `for ... of` loop is `Iterable`) was changed during the definition of ECMAScript 6. This is implemented differently in separate implementations and even in different

versions of the same implementation (for instance in different versions of V8). Older implementations require an `Iterator` or accept both `Iterator` and/or `Iterable`.

Requiring an `Iterable` and not accepting a plain `Iterator` seems to be the final decision (as of Dec. 2014). For reference, see abstract operations `GetIterator` in [ECMA15a(p.S7.4.2)] and "CheckIterable" [ECMA15a(p.S7.4.1)] and their application in "ForIn/OfExpressionEvaluation" [ECMA15a(p.S13.6.4.8)] and `CheckIterable` and their application in `ForIn/OfExpressionEvaluation`. See also a related blog post³ that is kept up to date with changes to ECMAScript 6: "ECMAScript 6 has a new loop, `for-of`. That loop works with iterables. Before we can use it with `createArrayIterator()`, we need to turn the result into an iterable".

An array or object destructuring pattern may be used left of the `of`. This is used to destructure the elements of the `Iterable` on the right-hand side (not the `Iterable` itself). For details, see ???.

11.2.4. Import Statement

Cf. ES6 import [ECMA15a(p.15.2.2)], see also <https://babeljs.io/docs/usage/modules/>

Syntax

The grammar of import declarations is defined as follows:

```
ImportDeclaration:
  {ImportDeclaration}
  ImportDeclarationImpl
;

fragment ImportDeclarationImpl*:
  'import' (
    ImportClause importFrom?='from'
  )? module=[types::TModule|ModuleSpecifier] Semi
;

fragment ImportClause*:
  importSpecifiers+=DefaultImportSpecifier (',' ImportSpecifiersExceptDefault)?
  | ImportSpecifiersExceptDefault
;

fragment ImportSpecifiersExceptDefault*:
  importSpecifiers+=NamespaceImportSpecifier
  | '{' (importSpecifiers+=NamedImportSpecifier (',' importSpecifiers
+=NamedImportSpecifier)* ','?)? '}'
;

NamedImportSpecifier:
  importedElement=[types::TExportableElement|BindingIdentifier<Yield=false>]
  | importedElement=[types::TExportableElement|IdentifierName] 'as'
  alias=BindingIdentifier<Yield=false>
;

DefaultImportSpecifier:
```

³ available at: <http://www.2ality.com/2013/06/iterators-generators.html>

```
importedElement=[types::TExportableElement|BindingIdentifier<Yield=false>]
;

NamespaceImportSpecifier: (NamespaceImportSpecifier) '*' 'as' alias=BindingIdentifier<false>
(declaredDynamic?='+')?;

ModuleSpecifier: STRING;
```

These are the properties of import declaration which can be specified by the user:

annotations

Arbitrary annotations, see [Chapter 12, Annotations](#) and below for details.

importSpecifiers

The elements to be imported with their names.

Also see compilation as described in [Section 14.6, “Modules”](#), for semantics see following section.

```
import A from "p/A"
import {C,D,E} from "p/E"
import * as F from "p/F"
import {A as G} from "p/G"
import {A as H, B as I} from "p/H"
```

Semantics

Import statements are used to import identifiable elements from another module. Identifiable elements are

- types (via their type declaration), in particular
 - classifiers (classes, interfaces)
 - functions
- variables and constants.

IDE-190⁴

The module to import from is identified by the string literal following keyword `from`. This string must be a valid

- complete module specifier⁵:

```
import {A} from "ProjectA/a/b/c/M"
```

- plain module specifier:

```
import {A} from "a/b/c/M"
```

⁴ <https://jira.numberfour.eu/browse/IDE-190>

⁵ For more details on module specifiers, see [???](#).

- or project name only, assuming the project defines a main module in its manifest (using the **Main-Module** manifest property, [???](#)):

```
import {A} from "ProjectA"
```

For choosing the element to import, there are the exact same options as in ECMAScript6:

- named imports select one or more elements by name, optionally introducing a local alias:

```
import {C} from "M"
import {D as MyD} from "M"
import {E, F as MyF, G, H} from "M"
```

- namespace imports select all elements of the remote module for import and define a namespace name; the imported elements are then accessed via the namespace name:

```
import * as N from "M"
var c: N.C = new N.C();
```

- default imports select whatever element was exported by the remote module as the default (there can be at most one default export per module):

```
import C from "M"
```

The following constraints are defined on a (non-dynamic) import statement *i*:

- The imported module needs to be accessible from the current project.
- The imported declarations need to be accessible from the current module.

For named imports, the following constraints must hold:

- No declaration must be imported multiple times, even if aliases are used.
- The names must be unique in the module. They must not conflict with each other or locally declared variables, types, or functions.
- Declarations imported via named imports are accessible only via used name (or alias) and not via original name directly.

For wildcard imports, the following constraints must hold:

- Only one namespace import can be used per (target) module, even if different namespace name is used.
- The namespace name must be unique in the module. They must not conflict with each other or locally declared variables, types, or functions.
- Declarations imported via namespace import are accessible via namespace only and not with original name directly.

For namespace imports, the following constraints must hold:

- If the referenced module is a plain `.js` file, a warning will be created to use the dynamic import instead.

For default imports, the following constraints must hold:

IDE-1744⁶

- The referenced module must have a default export.

Cross-cutting constraints:

- No declaration can be imported via named import and namespace import at the same time.

Imports cannot be duplicated:

```
import * as A from 'A';
import * as A from 'A';//error, duplicated import statement

import B from 'B';
import B from 'B';//error, duplicated import statement
```

Given element cannot be imported multiple times:

```
import * as A1 from 'A';
import * as A2 from 'A';//error, elements from A already imported in A1

import B from 'B';
import B as B1 from 'B';//error, B/B is already imported as B

import C as C1 from 'C';
import C from 'C';//error, C/C is already imported as C1

import D as D1 from 'D';
import D as D2 from 'D';//error, D/D is already imported as D1

import * as NE from 'E';
import E from 'E';//error, E/E is already imported as NE.E

import F from 'F';
import * as NF from 'F';//error, F/F is already imported as F
```

Names used in imports must not conflict with each other or local declarations:

```
import * as A from 'A1';
import * as A from 'A2';//A is already used as namespace for A1

import B from 'B1';
import B1 as B from 'B2';//B us already used as import B/B1

import C1 as C from 'C1';
import * as C from 'C2'; //C is already used as import C1/C1
```

⁶ <https://jira.numberfour.eu/browse/IDE-1744>

```
import * as D from 'D1';
import D2 as D from 'D2';//D is already used as namespace for D1

import E from 'E';
var E: any; // conflict with named import E/E

import * as F from 'F';
var F: any; // conflict with namespace F
```

Using named imports, aliases and namespaces allows to refer to multiple types of the same name such as **A/A**, **B/A** and **C/A**:

```
import A from 'A';// local name A references to A/A
import A as B from 'B';//local name B references to B/A
import * as C from 'C';//local name C.A references to C/A
```

If a declaration has been imported with an alias or namespace, it is not accessible via its original name:

```
import * as B from 'A1';
import A2 as C from 'A2';

var a1_bad: A1;//error, A1/A1 is not directly accessible with original name
var a1_correct: B.A1;// A1/A1 is accessible via namespace B
var a2_bad: A2;//error, A2/A2 is not directly accessible with original name
var a2_correct: C;// A2/A2 is accessible via alias C
```

Dynamic Imports

N4JS extends the ES6 module import in order that modules without a **n4jsd** or **n4js** file (plain **js** modules) can be imported. This is done by adding **+** to the name of the named import.

136Dynamic Import

Let *i* be an import statement *i* with a dynamic namespace specifier. The following constraints must hold:

1. *i.module* must not reference an **n4js** file.
2. If *i.module* references an **n4jsd** file, a warning is to be created.
3. If the file referenced by *i.module* is not found, an error is created just as in the static case.

These constraints define the error level when using dynamic import: we receive no error for **js**, a warning for **n4jsd**, and an error for **n4js** files. The idea behind these distinct error levels is as follows: If only a plain **js** file is available, using the dynamic import is the only way to access elements from the **js** module. This might be an unsafe way, but it allows the access and simplifies the first steps. An **n4jsd** file may then be made available either by the developer using the **js** module or by a third-party library. In this case, we do not want to break existing code. There is only a warning created in the case of an available **n4jsd** file and a **js** file still must be provided by the user. Having an **n4js** file is a completely different story; no **n4jsd** file is required, no **js** file is needed (since the transpiler creates one from the **n4js** file) and there is absolutely no reason to use the module dynamically.

Immutability of Imports

Imports create always immutable bindings, c.f. [ECMA15a(p.8.1.1.5)] <http://www.ecma-international.org/ecma-262/6.0/index.html#sec-createimportbinding>

137 Immutable Import[req:Immutable Import] Let i be a binding to an imported element. It is an error if

- i occurs on the left-hand side as the assignment-target of an assignment expression (this also includes any level in a destructuring pattern on the left-hand side),
- i as a direct argument of a postfix operator ($/$),
- i as a direct argument of a operator,
- i as a direct argument of the `increment` or `decrement` unary operator ($/$)

11.2.5. Export Statement

Cf. ES6 import [ECMA15a(p.15.2.3)]

Syntax

Grammar of export declarations is defined as follows:

```

ExportDeclaration:
  {ExportDeclaration}
  ExportDeclarationImpl
;

fragment ExportDeclarationImpl*:
  'export' (
    wildcardExport?='*' ExportFromClause Semi
  | ExportClause ->ExportFromClause? Semi
  | exportedElement=ExportableElement
  | defaultExport?='default' (->exportedElement=ExportableElement |
  defaultExportedExpression=AssignmentExpression<In=true,Yield=false> Semi)
  )
;

fragment ExportFromClause*:
  'from' reexportedFrom=[types::TModule|ModuleSpecifier]
;

fragment ExportClause*:
  '{'
  (namedExports+=ExportSpecifier (',' namedExports+=ExportSpecifier)* ','?)?
  '}'
;

```

⁷ <https://github.com/NumberFour/N4JS/issues/119>

⁸ <https://jira.numberfour.eu/browse/IDE-1302>

```
ExportSpecifier:  
    element=IdentifierRef<Yield=false> ('as' alias=IdentifierName)?  
;  
  
ExportableElement:  
    N4ClassDeclaration<Yield=false>  
    | N4InterfaceDeclaration<Yield=false>  
    | N4EnumDeclaration<Yield=false>  
    | ExportedFunctionDeclaration<Yield=false>  
    | ExportedVariableStatement  
;
```

This are the properties of export declaration, which can be specified by the user:

exportedElement

The element to be exported, can be a declaration or a variable/const statement.

```
export public class A{}  
export interface B{}  
export function foo() {}  
export var a;  
export const c="Hello";
```

Semantics

With regard to type inference, export statements are not handled at all. Only the exported element is inferred and the **export** keyword is ignored.

In order to use types defined in other compilation units, these types have to be explicitly imported with an import statement.

Imported namespaces cannot be exported.

Declared elements (types, variables, functions) are usually only visible outside the declaring module if the elements are exported and imported (by the using module, cf. [????>>](#)).

Some special components (runtime environment and libraries, cf. [???](#), may export elements globally. This is done by annotating the export (or the whole module) with **@Global**, see [???](#) for details.

By adding **default** after the keyword **export**, the identifiable element can be exported as 'the default'. This can then be imported from other modules via default imports (see [???](#)).

Chapter 12. Annotations

IDE-139¹
IDE-260²
IDE-272³

12.1. Introduction

Annotations are used to further define meta properties of language elements such as types, variables and functions. These annotations are used by the compiler and validator to prohibit the developer from introducing constructs which are either not allowed or are unnecessary in certain contexts.

Since annotations are to be processed by the compiler and the compilation cannot be extended by third-party users for security reasons, annotations cannot be defined by developers. Instead, the compiler comes with a predefined set of annotations which are summarized here.

12.1.1. Syntax

Annotations are used similarly as in Java (although new annotations cannot be defined by the user). They are formally defined as follows:

```
Annotation:@ AnnotationNoAtSign;
ScriptAnnotation returns Annotation: '@@' AnnotationNoAtSign;

AnnotationNoAtSign returns Annotation:
    name=AnnotationName (=> '(' (args+=AnnotationArgument (',' args
    +=AnnotationArgument) *)? ')')?;

AnnotationArgument:
    LiteralAnnotationArgument | TypeRefAnnotationArgument
;

LiteralAnnotationArgument:
    literal=Literal
;

TypeRefAnnotationArgument:
    typeRef=TypeRef
;
```

12.1.2. Properties

We use the map notation for retrieving annotation properties and values from a list of annotations, for example `x.annotations[Required$]`, or shorter `x@Required`.

¹ <https://jira.numberfour.eu/browse/IDE-139>

² <https://jira.numberfour.eu/browse/IDE-260>

³ <https://jira.numberfour.eu/browse/IDE-272>

12.1.3. Element-Specific Annotations

The following annotations are element-specific and are explained in the corresponding sections:

Annotation	Element Types	Section
<code>@Internal</code>	<code>TypeDefiningElement, Member, Function, Export</code>	???
<code>@Undefined</code>	<code>Variable</code>	???
<code>@StringBased</code>	<code>Enum</code>	???
<code>@Final</code>	<code>Class, Member</code>	???
<code>@Spec</code>	<code>FPar</code>	???
<code>@Override</code>	<code>Method</code>	???
<code>@Promisifiable</code>	<code>Function</code>	???
<code>@Promisify</code>	<code>CallExpression</code>	???
<code>@This</code>	<code>Function</code>	???
<code>@N4JS</code>	<code>Class, Export Statement</code>	???
<code>@IgnoreImplementation</code>	<code>Script, ExportDeclaration, ExportableElement</code>	???
<code>@Global</code>	<code>External Declaration</code>	???
<code>@ProvidedByRuntime</code>	<code>External Declaration</code>	???
<code>@TestAPI</code>	<code>TypeDefiningElement, Member</code>	???
<code>@Polyfill</code>	<code>Class</code>	???
<code>@StaticPolyfill</code>	<code>Class</code>	???
<code>@StaticPolyfillAware</code>	<code>Script</code>	???
<code>@StaticPolyfillModule</code>	<code>Script</code>	???

- intended for internal use only; will be removed.

12.1.4. General Annotations

IDEBUG

`IDEBUG` is an annotation similar to Java's `@SuppressWarnings`. It changes the severity of an issue from an error to a warning so that code can be compiled regardless of validation errors. This is to be used for known IDE bugs only.

12.1.5. Syntax

```
'@IDEBUG' '(' bugID = INT ',' errorMessage=STRING ')'
```

The annotation is defined transitively and repeatable on script, type declaration, function and method level.

Semantics

This annotation will cause errors issued in the scope of the annotation (in the defined script, type, or method) to be transformed to warnings if their message text is similar to the *errorMessage* text. If *errorMessage* ends with ... (three dots as a single character, created by Eclipse to abbreviate messages), then the error's message text must start with the specified text.

If no matching error is found, the annotation itself will issue an error.

[IDEBUG][ex:IDEBUG] In the following code snippet, two errors are to be transformed to warnings.

```
export class TestDataBridge with IModuleTest {
    @IDEBUG(166, "{function(number):void} is not a subtype of {function(T):void}.")
    @IDEBUG(91, "Incorrect number of arguments: expected 1, got 2.")
    @Override public run(): void {
        var foo = new Foo(),
            cb = function(val: number): void {},
            db = DataBridge.<number>bind(foo, "bar");
        db.add(cb);
        Assert.isTrue(called);
    }
}
```

The first one would occur on line 8, since there is a bug in the IDE type system (as of writing this example) that type arguments are not correctly bound in case of function expressions used as callback methods. The annotation in line 2 transforms the error

```
{function(number):void} is not a subtype of {function(T):void}.
```

into a warning with the following text:

```
IDEBUG-166: {function(number):void} is not a subtype of {function(T):void}.
```

refers to the corresponding bug report, that is .

The annotation on line 3 was proposed as a workaround for [IDEBUG-91](#) which has been fixed.⁴ No error message is produced and an error will be issued on line 3 instead:

GH-166⁵

```
No matching error found, apparently bug IDEBUG-91 has been fixed or does not occur here.
```

⁴ Hopefully IDEBUG-166 is fixed at time of publication.

⁵ <https://github.com/NumberFour/N4JS/issues/166>

SUPPRESS WARNINGS

12.2. Declaration of Annotations

Chapter 13. Extended Features

13.1. Array and Object Destructuring

N4JS supports array and object destructuring as provided in ES6. This is used to conveniently assign selected elements of an array or object to a number of newly-declared or pre-existing variables or to further destructure them by using nested destructuring patterns.

¹, Verification [[Zhu13a](#); [Hudli13a](#)], Frameworks [[Lesiecki08a](#); [Betts13a](#); [Knol13a](#); [Dagger](#)], Verification , Frameworks]

13.1.1. Syntax

```
BindingPattern <Yield>:  
  ObjectBindingPattern<Yield>  
  | ArrayBindingPattern<Yield>  
;  
  
ObjectBindingPattern <Yield> returns BindingPattern:  
  {BindingPattern}  
  '{' (properties+=BindingProperty<Yield,AllowType=false> (',', properties  
+=BindingProperty<Yield,AllowType=false>)*) ? '}'  
;  
  
ArrayBindingPattern <Yield> returns BindingPattern:  
  {BindingPattern}  
  '['  
    elements+=Elision* (br/>      elements+=BindingRestElement<Yield>  
      (',', elements+=Elision* elements+=BindingRestElement<Yield>)*  
      (',', elements+=Elision*)?  
    )?  
  ']'  
;  
  
BindingProperty <Yield, AllowType>:  
  =>(LiteralBindingPropertyName<Yield> ':') value=BindingElement<Yield>  
  | value=SingleNameBinding<Yield,AllowType>  
;  
  
fragment LiteralBindingPropertyName <Yield>*:  
  declaredName=IdentifierName | declaredName=STRING | declaredName=NumericLiteralAsString  
  // this is added here due to special treatment for a known set of expressions  
  | '[' (declaredName=SymbolLiteralComputedName<Yield> | declaredName=STRING) ']'  
;
```

13.1.2. Semantics

The following example declares four variables `a`, `b`, `x`, and `prop2`. Variables `a` and `x` will have the value `hello`, whereas `b` and `prop2` will have value 42.

¹ Further reading on DI: : Basics [[Fowler04b](#); [Prasanna09a](#)

```
var [a,b] = ["hello", 42];

var {prop1:x, prop2} = {prop1:"hello", prop2:42};
```

In the case of `prop2`, we do not provide a property name and variable name separately; this is useful in cases where the property name also makes for a suitable variable name (called **single name binding**).

One of the most useful use cases of destructuring is in a `for...of` loop. Take this example:

```
var arr1 = [ ["hello",1,2,3], ["goodbye",4,5,6] ];
for(var [head,...tail] of arr1) {
    console.log(head,'/',tail);
}
// will print:
//   hello / [ 1, 2, 3 ]
//   goodbye / [ 4, 5, 6 ]

var arr2 = [ {key:"hello", value:42}, {key:"goodbye", value:43} ];
for(var {key,value} of arr2) {
    console.log(key,'/',value);
}
// will print:
//   hello / 42
//   goodbye / 43
```

Array and object destructuring pattern can appear in many different places:

- In a variable declaration (not just in variable statements but also in other places where variable declarations are allowed, e.g. plain for loops; called *destructuring binding*; see [???](#)).
- On the left-hand side of an assignment expression (the assignment expression is then called *destructuring assignment*; see [???](#)).
- In a `for...in` or `for...of` loop on the left side of the `in/of` (see [???](#)).
NOTE: It can also be used in plain statements, but then we actually have one of the above two use cases.
- With lists of formal parameters or function arguments (NOT SUPPORTED YET) .

IDE-1609²

For further details on array and object destructuring please refer to the ECMAScript 6 specification.

Type annotations can only be added when a new variable name is introduced since the short version would be ambiguous with the long one. For example:

```
var {x: someTypeOrNewVar} = ol
```

could either mean that a new variable is declared and is assigned to it, or that a new variable is declared with type . The longer form would look like this:

² <https://jira.numberfour.eu/browse/IDE-1609>

```
var {x: x: someType} = o1
```

We can make this more readable:

```
var {propOfO1: newVar: typeOfNewVar} = o1
```

13.2. Dependency Injection

This chapter describes DI mechanisms for N4JS. This includes compiler, validation and language extensions that allow to achieve DI mechanisms built in into the N4JS language and IDE.

N4JS DI support specifies a means for obtaining objects in such a way as to maximize reusability, testability and maintainability, especially compared to traditional approaches such as constructors, factories and service locators. While this can be achieved manually (without tooling support) it is difficult for non-trivial applications. The solutions that DI provides should empower N4JS users to achieve the above goals without the burden of maintaining so-called 'boilerplate' code.

image::fig/diTerms.PNG[[fig:diTerms] key: pass the dependency instead of letting the client create or find it]

Core terms

- **Service** - A set of APIs describing the functionality of the service.
- **Service Implementations** - One or more implementations of given service API.
- **Client** - Consumer of a given functionality, uses the given **Service Implementation**.
- **Injector** - Object providing **Service Implementation** of a specific **Service**, according to configuration.
- **Binding** - Part of configuration describing which interface implementing a subtype will be injected, when a given interface is requested.
- **Provider** - Factory used to create instances of a given **Service Implementation** or its sub-components, can be a method.
- **Injection Point** - Part of the user's code that will have the given dependency injected. This is usually fields, method parameters, constructor parameters etc.
- **di configuration** - This describes which elements of the user's code are used in mechanisms and how they are wired. It is derived from user code elements being marked with appropriate annotations, bindings and providers.
- **di wiring** - The code responsible for creating user objects. These are injectors, type factories/providers, fields initiators etc.

13.2.1. DI Components and Injectors

N4JS' DI systems is based on the notion of .

[DI Component][def:DI_Component] A is a N4Class annotated with

This annotation causes an *injector* to be created for (and associated to) the `DI`. `can be composed`; meaning that when requested to inject an instance of a type, a `DIC`'s injector can delegate this request to the injector of the containing `DIC`. An injector always prioritizes its own configuration before delegating to the container's injector. For validation purposes, a child `DI` can be annotated with `@WithParent` to ensure that it is always used with a proper parent.

Injector is the main object of `DI` mechanisms responsible for creating object graphs of the application. At runtime, injectors are instances of `N4Injector`.

The following constraints must hold for a class `C` marked as `DI`:

1. A subclass `S` of `C` is a `???` as well and it must be marked with `GenerateInjector`.
2. If a parent `DIC P` is specified via `WithParent`, then `P` must be a `\ac{DIC}` as well.
3. The injector associated to a `\ac{DIC}` is of type `N4Injector`. It can be retrieved via `N4Injector.of(DIC)` in which `DIC` is the `DIC`.
4. Injectors associated to `\ac{DIC}` are DI-singletons (cf. the section called “Singleton Scope”). Two calls to `N4Injector.of(DIC)` are different (as different `\ac{DIC}` are assumed).

IDE-1563³

We call the (transitive) creation and setting of values by an injector `I` caused by the creation of a root object `R` the *injection phase*. If an instance `C` is newly created by the injector `I` (regardless of the injection point being used), the injection is transitively applied on `C`. The following constraints have to hold:

IDE-1497⁴

1. Root objects are created by one of the following mechanisms:
 - a. Any class or interface can be created as root objects via an injector associated to a `\ac{DIC}`:
`var x: X = N4Injector.of(DIC).create(X);` in which `DIC` is a `\ac{DIC}`. Of course, an appropriate binding must exist.⁵
 - b. If a type has the injector being injected, e.g. via field injection `@Inject injector: N4Injector;`, then this injector can be used anytime in the control flow to create a new root object similar as above (using `create` method).
 - c. If a provider has been injected (i.e., an instance of `N4Provider`), then its method can be used to create a root object causing a new injection phase to take place.
2. If `C.ctor` is marked as injection point, all its arguments are set by the injector. This is also true for an inherited constructor marked as an injection point. See `???`. For all arguments the injection phase constraints have to hold as well. All fields of `C`, including `\emph{inherited}` once, marked as injection points are set by the injector. For all fields the injection phase constraints have to hold as well.

³ <https://jira.numberfour.eu/browse/IDE-1563>

⁴ <https://jira.numberfour.eu/browse/IDE-1497>

⁵ Usually, only the itself is created like that, e.g., `ar dic = N4Injector.of(DIC).create(DIC);`

3. All fields of *C*, including *inherited* once, marked as injection points are set by the injector. For all fields the injection phase constraints have to hold as well.

IDE-1264⁶
IDE-1264⁷
GH-441⁸

The injector may use a provider method (of a binder) to create nested instances.

The injector is configured with *Binders* and it tracks *Bindings* between types (). An N4JS developer normally would not interact with this object directly except when defining an entry-point to his application. *Injectors* are configured with *Binders* which contain explicit *Bindings* defined by an N4JS developer. A set of these combined with *implicit bindings* creates the *di configuration* used by a given injector. To configure given *Injectors* with given *Binder(s)* use `@UseBinder` annotation.

DIComponent Relations

A Parent-Child relation can be established between two DIComponents. Child DIComponents use the parent bindings but can also be configured with their own bindings or *change* targets used by a parent. The final circumstance is local to the child and is referred to as *rebinding*. For more information about bindings see . A Child-Parent relation is expressed by the annotation attached to a given DIComponent. When this relation is defined between DIComponents, the user needs to take care to preserve the proper relation between injectors. In other words, the user must provide an instance of the parent injector (the injector of the DIComponent passes as a parameter to `@WithParentInjector`) when creating the child injector (injector of the DIComponent annotated with `@WithParentInjector`).

[[ex:Simple DIComponents Relation]]

```

@GenerateInjector
class ParentDIComponent{ }

@GenerateInjector
@WithParentInjector(ParentDIComponent)
class ChildDIComponent{ }

var parentInjector = N4Injector.of(ParentDiCompoennt);
var childInjector = N4Injector.of(ChildDIComponent, parentInjector);

```

With complex DIComponent structures, injector instances can be created with a directly-declared parent and also with any of its children. This is due to the fact that any child can rebind types, add new bindings, but not remove them. Any child is, therefore, *compatible* with its parents.

Definition: Compatible DIComponent

A given DIComponent is compatible with another DIComponent if it has bindings for all keys in other component bindings.

⁶ <https://jira.numberfour.eu/browse/IDE-1264>

⁷ <https://jira.numberfour.eu/browse/IDE-1264>

⁸ <https://github.com/NumberFour/N4JS/issues/441>

$\exists DIC1, DIC2: DIC1.binding.key DIC2.binding.key DIC2lt;: DIC1$



Although subtype notation $lt;:$ is used here it does **not** imply actual subtype relations. It was used in this instance for lack of formal notations for DI concepts and because this is similar to the Liskov Substitution principle.

A complex Child-Parent relation between components is depicted in [Figure 13.1, “Complex DIComponents Relations”](#) and [???](#).

Figure 13.1. Complex DIComponents Relations

Complex DIComponents Relations

```

@GenerateInjector class A {}
@GenerateInjector @WithParentInjector(A) class B {}
@GenerateInjector @WithParentInjector(B) class C {}
@GenerateInjector @WithParentInjector(C) class D {}
@GenerateInjector @WithParentInjector(A) class B2 {}
@GenerateInjector @WithParentInjector(B2) class C2 {}
@GenerateInjector @WithParentInjector(C2) class D2 {}
@GenerateInjector @WithParentInjector(A) class X {}
@GenerateInjector @WithParentInjector(C) class Y {}

// creating injectors
var injectorA = N4Injector.of(A);
//following throws DICConfigurationError, expected parent is not provided
//var injectorB = N4Injector.of(B);
//correct declarations
var injectorB = N4Injector.of(B, injectorA);
var injectorC = N4Injector.of(C, injectorB);
var injectorD = N4Injector.of(D, injectorC);
var injectorB2 = N4Injector.of(B2, injectorA);
var injectorC2 = N4Injector.of(C2, injectorB2);
var injectorD2 = N4Injector.of(D2, injectorC2);

//Any injector of {A,B,C,D,b2,C2,D2} is valid parent for injector of X, e.g. D or D2
N4Injector.of(X, injectorD); //is ok as compatible parent is provided
N4Injector.of(X, injectorD2); //is ok as compatible parent is provided

N4Injector.of(Y, injectorC); //is ok as direct parent is provided
N4Injector.of(Y, injectorD); //is ok as compatible parent is provided

N4Injector.of(Y, injectorB2); //throws DICConfigurationError, incompatible parent is provided
N4Injector.of(Y, injectorC2); //throws DICConfigurationError, incompatible parent is provided
N4Injector.of(Y, injectorD2); //throws DICConfigurationError, incompatible parent is provided

```

13.2.2. Binders and Bindings

Binder allows an N4JS developer to (explicitly) define a set of *Bindings* that will be used by an *Injector* configured with a given *Binder*. There are two ways for *Binder* to define *Bindings*: [@Bind](#) (the section called “[N4JS DI @Bind](#)”) annotations and a method annotated with [@Provides](#).

Binder is declared by annotating a class with the annotation.

A *Binding* is part of a configuration that defines which instance of what type should be injected into an *injection point* (???) with an expected type.

Provider Method is essentially a *factory method* that is used to create an instance of a type. N4JS allows a developer to declare those methods (see ???) which gives them a hook in instance creation process. Those methods will be used when creating instances by the *Injector* configured with the corresponding *Binder*. A provider method is a special kind of binding (*key*) in which the return type of the method is the *key*. The *target* type is unknown at compile time (although it may be inferred by examining the return statements of the provide method).

A *binding* is a pair $\text{bind}(\text{key}, \text{target})$. It defines that for a dependency with a given key which usually is the expected type at the injection point. An instance of type *target* is injected.

A *binding* is called *explicit* if it is declared in the code, i.e. via `@Bind` annotation or `@Provides` annotation).

A *binding* is called *implicit* if it is not declared. An implicit binding can only be used if the *key* is a class and derived from the type at the injection point, i.e. the type of the field or parameter to be injected. In that case, the *target* equals the *key*.

GH-484⁹

A provider method *M* (in the binder) defines a binding $\text{bind}(M.\text{returnType}, X)$ (in which *X* is an existential type with $\exists X \text{target}.\text{returnType}$).

For simplification, we define

$$\text{key}^* = \begin{cases} \text{target}.\text{returnType}, & \text{if target is provider method} \\ \text{key}, & \text{otherwise (key is a type preference)} \end{cases}$$

and

$$\text{target}^* = \begin{cases} X \text{target}.\text{returnType}, & \text{if target is provider method} \\ \text{target}, & \text{otherwise (target is a type preference)} \end{cases}$$

140Bindings[req:Bindings] For a given binding $b = (\text{key}, \text{target})$, the following constraints must hold: ¹⁰

1. *key* must be either a class or an interface.
2. *target* must either be a class or a provider method.
3. If *b* is implicit, then *key* must be a class. If *key* references a type *T*, then *target* = *T* – even if *key* is a use-site structural type.
4. *key* and *target** can be nominal, structural or field-structural types, either definition-site or use-site.
The injector and binder needs to take the different structural reference into account at runtime!
5. *target***key* must hold
6. If during injection phase no binding for a given key is found, an is thrown.

IDE-1496¹¹
GH-418¹²

⁹ <https://github.com/NumberFour/N4JS/issues/484>

¹⁰ Note that other frameworks may define other constraints, e.g., arbitrary keys.

¹¹ <https://jira.numberfour.eu/browse/IDE-1496>

¹² <https://github.com/NumberFour/N4JS/issues/418>

141Transitive Bindings[req:Transtive_Bindings] If an injector contains two given bindings $b_1 = (key_1, target_1)$ and $b_2 = (key_2, key_1)$, an effective binding $b = (key_2, target_1)$ is derived (replacing b_1).

N4JS \ac{DI} mechanisms don't allow for injection of primitives or built-in types. Only user-defined N4Types can be used. In cases where a user needs to inject a primitive or a built-in type, the developer must wrap it into its own class.¹⁵ This is to say that none of the following metatypes can be bound: primitive types, enumerations, functions, object types, union- or intersection types. It is possible to (implicitly) bind to built-in classes.

While direct binding overriding or rebinding is not allowed, *Injector* can be configured in a way where one type can be separately bound to different types with implicit binding, *explicit binding* and in bindings of the child injectors. *Binding precedence* is a mechanism of *Injector* selecting a binding use for a type. It operates in the following order:

1. Try to use explicit binding, if this is not available:
2. Try to delegate to parent injectors (order of lookup is not guaranteed, first found is selected). If this is not available then:
3. Try to use use implicit binding, which is simply to attempt to create the instance.

If no binding for a requested type is available an error will be thrown.

13.2.3. Injection Points

By *injection point* we mean a place in the source code which, at runtime, will be expected to hold a reference to a particular type instance.

Field Injection

In its simplest form, this is a class field annotated with `@Inject` annotation. At runtime, an instance of the containing class will be expected to hold reference to an instance of the field declared type. Usually that case is called *Field Injection*.

The injector will inject the following fields:

1. All directly contained fields annotated with `@Inject`.
2. All inherited fields annotated with `@Inject`.
3. The injected fields will be created by the injector and their fields will be injected as well.

¹³ <https://github.com/NumberFour/N4JS/issues/498>

¹⁴ <https://github.com/NumberFour/N4JS/issues/461>

¹⁵ Also cf. blog posting about [micro types](http://www.markhneedham.com/blog/2009/03/10/oo-micro-types/) [<http://www.markhneedham.com/blog/2009/03/10/oo-micro-types/>], [tiny types](http://darrenhobbs.com/2007/04/11/tiny-types/) [<http://darrenhobbs.com/2007/04/11/tiny-types/>]

¹⁶ <https://github.com/NumberFour/N4JS/issues/400>

demonstrates simple field injection using default bindings. Note that all inherited fields (i.e. `A.xInA`) are injected and also fields in injected fields (i.e.)

Simple Field Injection

```
class X {
    @Inject y: Y;
}

class Y {}

class A {
    @Inject xInA: X;
}

class B extends A {
    @Inject xInB: X;
}

@GenerateInjector
export public class DIC {
    @Inject a: B;
}

var dic = N4Injector.of(DIC).create(DIC);
console.log(dic);           // --> DIC
console.log(dic.a);         // --> B
console.log(dic.a.xInA);    // --> X
console.log(dic.a.xInA.y);  // --> Y
console.log(dic.a.xInB);    // --> X
console.log(dic.a.xInB.y);  // --> Y
```

Constructor Injection

IDE-1262¹⁷

Parameters of the constructor can also be injected, in which case this is usually referred to as *Constructor Injection*. This is similar to *Method Injection* and while constructor injection is supported in N4JS, method injection is not (see remarks below).

When a constructor is annotated with `@Inject` annotation, all user-defined, non-generic types given as the parameters will be injected into the instance's constructor created by the dependency injection framework. Currently, optional constructor parameters are always initialized and created by the framework, therefore, they are ensured to be available at the constructor invocation time. Unlike optional parameters, variadic parameters cannot be injected into a type's constructor. In case of annotating a constructor with that has variadic parameters, a validation error will be reported. When a class's constructor is annotated with `@Inject` annotation, it is highly recommended to annotate all explicitly-defined constructors at the subclass level. If this is not done, the injection chain can break and runtime errors might occur due to undefined constructor parameters. In the case of a possible broken injection chain due to missing `@Inject` annotations for any subclasses, a validation warning will be reported.

If a class *C* has a constructor marked as injection point, the following applies:

¹⁷ <https://jira.numberfour.eu/browse/IDE-1262>

1. If C is subclassed by S , and if S has no explicit constructor, then S inherits the constructor from C and it will be an injection point handled by the injector during injection phase.
2. If S provides its own injector, $C.ctor$ is no longer recognized by the injector during the injection phase. There will be a warning generated in $S.ctor$ to mark it as injection point as well in order to prevent inconsistent injection behavior. Still, $C.ctor$ must be called in $S.ctor$ similarly to other overridden constructors.

GH-447 ¹⁸
 GH-458 ¹⁹

Method Injection

Other kinds of injector points are method parameters where (usually) all method parameters are injected when the method is called. In a way, constructor injection is a special case of the method itself.

Provider

IDE-1261 ²⁰

Provider is essentially a *factory* for a given type. By injecting an **N4Provider** into any injection point, one can acquire new instances of a given type provided by the injected provider. The providers prove useful when one has to solve re-injection issues since the depended type can be wired and injected via the provider rather than the dependency itself and can therefore obtain new instances from it if required. Provider can be also used as a means of delaying the instantiation time of a given type.

N4Provider is a public generic built-in interface that is used to support the re-injection. The generic type represents the dependent type that has to be obtained. The **N4Provider** interface has one single public method: `public T get()` which should be invoked from the client code when a new instance of the dependent type is required. Unlike any other unbound interfaces, the **N4Provider** can be injected without any explicit binding.

The following snippet demonstrates the usage of **N4Provider**:

```
class SomeService { }

@Singleton
class SomeSingletonService { }

class SomeClass {

    @Inject serviceProvider: N4Provider<SomeService>;
    @Inject singletonServiceProvider: N4Provider<SomeSingletonService>;

    void foo() {
```

¹⁸ <https://github.com/NumberFour/N4JS/issues/447>

¹⁹ <https://github.com/NumberFour/N4JS/issues/458>

²⁰ <https://jira.numberfour.eu/browse/IDE-1261>

```
console.log(serviceProvider.get() ===  
    serviceProvider.get()); //false  
  
console.log(singletonServiceProvider.get() ===  
    singletonServiceProvider.get()); //true  
}  
  
}
```

It is important to note that the `N4Provider` interface can be extended by any user-defined interfaces and/or can be implemented by any user-defined classes. For those user-defined providers, consider all binding-related rules; the extended interface, for example, must be explicitly bound via a binder to be injected. The binding can be omitted only for the built-in `N4Provider`s.

13.2.4. N4JS DI Life Cycle and Scopes

DI Life Cycle defines when a new instance is created by the injector as its destruction is handled by JavaScript. The creation depends on the scope of the type. Aside from the scopes, note that it is also possible to implement custom scopes and life cycle management via `N4JSProvider` and `Binder@Provides` methods.

Injection Cycles

IDE-1608 ²¹

[Injection Cycle][def:Injection_Cycle] We define an injection graph $G(V, E)$ as a directed graph as follows: V (the vertices) is the set types of which instances are created during the injection phase and which use . E (the edges) is a set of directed and labeled edges (v_1, v_2, label) , where label indicates the injection point:

1. $(T_o, T_f, \text{"field"})$, if T_f is the actualy type of an an injected field of an instance of type T_o
2. $(T_c, T_p, \text{"ctor"})$, if T_p is the type of a parameter used in a constructor injection of type T_c

One cycle in this graph is an injection cycle.

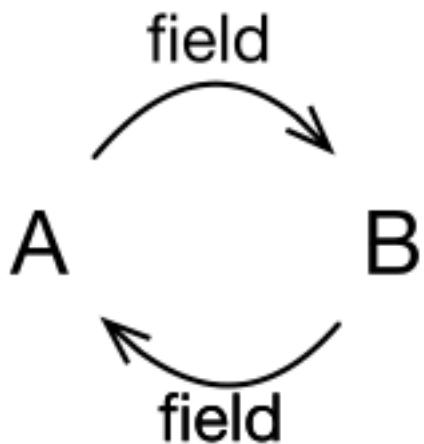
When injecting instances into an object, cycles have to be detected and handled independently from the scope. If this is not done, the following examples would result in an infinite loop causing the entire script to freeze until the engine reports an error:

[c]0.6

```
class A { @Inject b: B; }  
class B { @Inject a: A; }
```

[c]0.4

²¹ <https://jira.numberfour.eu/browse/IDE-1608>

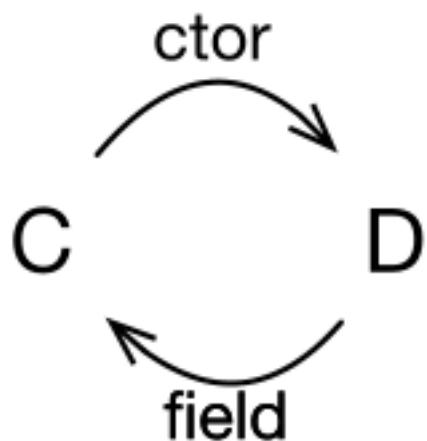


+

[c]0.6

```
class C { @Inject constructor(d: D) {} }
class D { @Inject c: C; }
```

[c]0.4

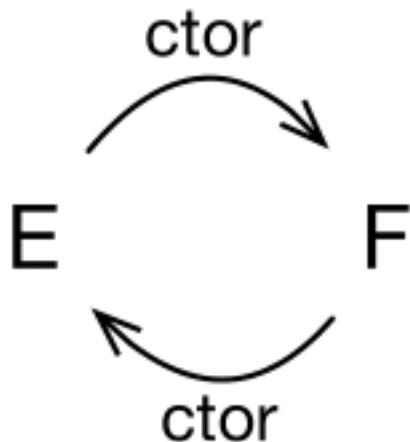


+

[c]0.6

```
class E { @Inject constructor(f: F) {} }
class F { @Inject constructor(e: E) {} }
```

[c]0.4



+

The injector needs to detect these cycles and resolve them.

144Resolution of Injection Cycles[req:Resolution_of_Injection_Cycles] A cycle $c \subset G$, with G being an injection graph, is resolved as follows:

1. If c contains no edge with $label = "ctor"$, the cycle is resolved using the algorithm described below.
2. If c contains at least one edge with $label = "ctor"$, a runtime exception is thrown.

Cycles stemming from field injection are resolved by halting the creation of new instances of types which have been already created by a containing instance. The previously-created instance is then reused. This makes injecting the instance of a (transitive) container less complicated and without the need to pass the container instance down the entire chain. The following pseudo code describes the algorithm to create new instances which are injected into a newly created object:

IDE-1608 22

```

function injectDependencies(object) {
    doInjectionWithCylceAwareness(object, {typeof object -> object})
}

function doInjectionWithCylceAwareness(object, createdInstancesPerType) {
    forall v $\in$ injectedVars of object {
        var type = retrieveBoundType(v)
        var instance = createdInstancesPerType.get(type)
        if (not exists instance) {
            instance = createInstance(type, createdInstancesPerType)
            doInjectionWithCylceAwareness(instance,
                createdInstancesPerType $\cap$ {type -> instance})
        }
    }
}
  
```

²² <https://jira.numberfour.eu/browse/IDE-1608>

```

        }
        v.value = instance;
    }
}

```

The actual instance is created in line 10 via `.value`. This function then takes scopes into account. The map is passed to that function in order to enable cycle detection for constructor injection. The following scopes are supported by the N4JS `\ac{DI}`, other scopes, cf. [Jersey custom scopes²³](#) and [Guice custom scopes²⁴](#), may be added in the future.

This algorithm is not working for constructor injection because it is possible to already access all fields of the arguments passed to the constructor. In the algorithm, however, the instances may not be completely initialized.

Default Scope

 IDE-1471²⁵

The default scope always creates a new instance.

Singleton Scope

 IDE-1260²⁶

The singleton scope (per injector) creates one instance (of the type with `@singleton` scope) per injector, which is then shared between clients.

The injector will preserve a single instance of the type of `s` and will provide it to all injection points where type of `s` is used. Assuming nested injectors without any declared binding where the second parameter is `s`, the same preserved singleton instance will be available for all nested injectors at all injection points as well.

The singleton preservation behavior changes when explicit bindings are declared for type `s` on the nested injector level. Let's assume that the type `s` exists and the type is annotated with `@Singleton`. Furthermore, there is a declared binding where the binding's second argument is `s`. In that case, unlike in other dependency injection frameworks, nested injectors may preserve a singleton for itself and all descendant injectors with `@Bind` annotation. In this case, the preserved singleton at the child injector level will be a different instance than the one at the parent injectors.

The tables below depict the expected runtime behavior of singletons used at different injector levels. Assume the following are injectors: `C`, `D`, `E`, `F` and `G`. Injector `C` is the top most injector and its nesting injector `D`, hence injector `C` is the parent of the injector `D`. Injector `D` is nesting `E` and so on. The most nested injector is `G`. Let's assume `I` is an interface, class `U` implements interface `I`.

²³ <https://jersey.java.net/documentation/latest/ioc.html>

²⁴ <https://github.com/google/guice/wiki/CustomScopes>

²⁵ <https://jira.numberfour.eu/browse/IDE-1471>

²⁶ <https://jira.numberfour.eu/browse/IDE-1260>

and class `V` extends class `U`. Finally assume both `U` and `V` are annotated with `@Singleton` at definition-site.

The example below depicts the singleton preservation for nested injectors without any bindings. All injectors use the same instance from a type. Type `J` is not available at all since it is not bound to any concrete implementation:

Table 13.1. DI No Bindings

Binding					
Injector nest-ing (<code>gt;</code>)	C	D	E	F	G
J	<code>NaN</code>	<code>NaN</code>	<code>NaN</code>	<code>NaN</code>	<code>NaN</code>
U	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>
V	<code>V₀</code>	<code>V₀</code>	<code>V₀</code>	<code>V₀</code>	<code>V₀</code>

The following example is configured by explicit bindings. At the root injector level, type `J` is binded to type `U`. Since the second argument of the binding is declared as a singleton at the definition-site, this explicit binding implicitly ensures that the injector and all of its descendants preserve a singleton of the bound type `U`. At injector level `C`, `D` and `E`, the same instance is used for type `J` which is type `U` at runtime. At injector level `E` there is an additional binding from type `U` to type `V` that overrules the binding declared at the root injector level. With this binding, each places where `J` is declared, type `U` is used at runtime. Furthermore, since `V` is declared as a singleton, both injector `F` and `G` are using a shared singleton instance of type `V`. Finally, for type `V`; injector `C`, `D` and `E` should use a separate instance of `V` other than injector level `F` and `G` because `V` is preserved at injector level `F` with the `U → V` binding.

Table 13.2. DI Transitive Bindings

Binding	<code>J → U</code>			<code>U → V</code>	
Injector nest-ing (>)	C	D	E	F	G
J	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>V₀</code>	<code>V₀</code>
U	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>V₀</code>	<code>V₀</code>
V	<code>V₁</code>	<code>V₁</code>	<code>V₁</code>	<code>V₀</code>	<code>V₀</code>

The following table depicts the singleton behaviour but unlike the above table, the bindings are declared for the interface `J`.

Table 13.3. DI Re - Binding

Binding	<code>J → U</code>			<code>J → V</code>	
Injector nest-ing (<code>gt;</code>)	C	D	E	F	G
J	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>V₀</code>	<code>V₀</code>
U	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>	<code>U₀</code>

V	V_1	V_1	V_1	V_0	V_0
---	-------	-------	-------	-------	-------

This table describes the singleton behavior when both bindings are configured at child injector levels but not the root injector level.

Table 13.4. DI Child Binding[tab:diChildBinding]

Binding		$U \rightarrow V$		$J \rightarrow U$	
Injector nesting (<i>gt;</i>)	C	D	E	F	G
J	<i>Nan</i>	<i>Nan</i>	<i>Nan</i>	U_0	U_0
U	U_1	V_0	V_0	U_0	U_0
V	V_1	V_0	V_0	V_0	V_0

Per Injection Chain Singleton

The per injection chain singleton is 'between' the default and singleton scope. It can be used in order to explicitly describe the situation which happens when a simple cycle is resolved automatically. It has more effects that lead to a more deterministic behavior.

Assume a provider declared as

```
var pb: Provider<B>;
```

to be available:

```
@PerInjectionSingleton
class A { }

class B { @Inject a: A; @Inject a1: A; }

b1=pb.get();
b2=pb.get();
b1.a != b2.a
b1.a == b1.a1
b2.a == b2.a1
```

```
@Singleton
class A { }

class B { @Inject a: A; @Inject a1: A; }

b1=pb.get();
b2=pb.get();
b1.a == b2.a
b1.a == b1.a1
b2.a == b2.a1
```

```
// no annotation
```

```

class A { }

class B { @Inject a: A; @Inject a1: A; }

b1=pb.get();
b2=pb.get();
b1.a != b2.a
b1.a != b1.a1
b2.a != b2.a1

```

13.2.5. Validation of callsites targeting N4Injector methods

IDE-1671²⁷

Terminology for this section:

- a value is **injectable** if it
 - either conforms to a user-defined class or interface (a non-parameterized one, that is),
 - or conforms to Provider-of-T where T is injectable itself.
- a classifier declaring injected members is said to **require injection**

To better understand the validations in effect for callsites targeting

```
N4Injector.of(ctorOfDIC: constructor{N4Object}, parentDIC: N4Injector?, ...providedBinders: N4Object)
```

we can recap that at runtime:

- The first argument denotes a DIC constructor.
- The second (optional) argument is an injector.
- Lastly, the purpose of **providedBinders** is as follows:
 - The DIC above is marked with one or more **@UseBinder**.
 - Some of those binders may require injection.
 - Some of those binders may have constructor(s) taking parameters.
 - The set of binders described above should match the providedBinders.

Validations in effect for callsites:

- **T** should be injectable (in particular, it may be an **N4Provider**).

13.2.6. N4JS DI Annotations

Following annotations describe API used to configure N4JSDI.

²⁷ <https://jira.numberfour.eu/browse/IDE-1671>

N4JS DI @GenerateInjector

3

name
@GenerateInjector

targets
N4Class

retention policy
RUNTIME

transitive
NO

repeatable
NO

arguments
NO

`@GenerateInjector` marks a given class as DIComponent of the graph. The generated injector will be responsible for creating an instance of that class and all of its dependencies.

N4JS DI @WithParentInjector

3

name
@WithParentInjector

targets
N4Class

retention policy
RUNTIME

transitive
NO

repeatable
NO

arguments
TypeRef

arguments are optional
NO

`@WithParentInjector` marks given *injector* as depended on other *injector*. The depended *injector* may use provided *injector* to create instances of objects required in its object graph.

Additional *WithParentInjector* constraints:

145DI WithParentInjector[req:DI_WithParentInjector]

1. Allowed only on annotated with `@GenerateInjector`.
2. Its parameter can only be annotated with `.`

N4JS DI `@UseBinder`

name
 `@UseBinder`

targets
 `N4Class`

retention policy
 `RUNTIME`

transitive
 `NO`

arguments
 `TypeRef`

arguments are optional
 `NO`

`@UseBinder` describes *Binder* to be used (configure) target *Injector*.

146 DI `UseInjector[req:DI_use_bindings]`

1. Allowed only on annotated with `@GenerateInjector`.
2. Its parameter can only be annotated with `@Bind`.

N4JS DI `@Binder`

name
 `@Binder`

targets
 `N4Class`

retention policy
 `RUNTIME`

transitive
 `NO`

repeatable
 `NO`

arguments
 `NONE`

`@UseBinder` defines a list of bind configurations. That can be either annotations on itself or its factory methods annotated with `@Bind`.

147 DI `binder[req:DI_Binder]`

1. Target `N4ClassDeclaration` must not be *abstract*.

2. Target `N4ClassDeclaration` must not be annotated with `@GenerateInjector`.
3. Target class cannot have *injection points*.

N4JS DI @Bind

name
 `@Bind`

targets
 `N4ClassDeclaration`

retention policy
 `RUNTIME`

transitive
 `NO`

arguments
 TypeRef key, TypeRef target

arguments are optional
 `NO`

Defines *binding* between type and subtype that will be used by injector when configured with target . See also for description of injectable types.

148 DI Bind[req:DI_bind]

1. Allowed only on `N4ClassDeclarations` that are annotated with `@Binder` ([the section called “N4JS DI @Binder”](#)).
2. Parameters are instances of one of the values described in [???](#).
3. The second parameter must be a subtype of the first one.

N4JS DI @Provides

name
 `@Provides`

targets
 `N4MethodDeclaration`

retention policy
 `RUNTIME`

transitive
 `NO`

repeatable
 `NO`

arguments
 `NONE`

arguments are optional
 `NO`

`@Provides` marks *factory method* to be used as part \ac{DI}. This is treated as *explicit binding* between declared return type and actual return type. This method is expected to be part of the `@Binder`. Can be used to implement custom scopes.

149 DI Provides[req:DI_provides]

1. Allowed only on `N4MethodDeclarations` that are part of a classifier annotated with `@Binder`.
2. Annotated method declared type returns instance of one of the types described in *injectable values* [???](#).

N4JS DI `@Inject`

name

`@Inject`

targets

N4Field, N4Method, constructor

retention policy

RUNTIME

transitive

NO

repeatable

NO

arguments

NO

`@Inject` defines the injection point into which an instance object will be injected. The specific instance depends on the injector configuration (bindings) used. Class fields, methods and constructors can be annotated. See [???](#) for more information.

150 DI Inject[req:DI_provides]

1. Injection point bindings need to be resolvable.
2. Binding for given type must not be duplicated.
3. Annotated types must be instances of one of the types described in [???](#).

N4JS DI `@Singleton`

name

`@Singleton`

targets

N4Class

retention policy

RUNTIME

transitive

NO

repeatable

NO

arguments

NO

In the case of annotating a class `s` with `@Singleton` on the definition-site, the singleton scope will be used as described in [the section called “Singleton Scope”](#).

13.3. Test Support

N4JS provides some annotations for testing. Most of these annotations are similar to annotations found in JUnit 4. For details see our Mangelhaft test framework (stdlib specification) and the N4JS-IDE specification.

In order to enable tests for private methods, test projects may define which project they are testing.

151Test API methods and types[req:Test_API_methods_and_types] In some cases, types or methods are only provided for testing purposes. In order to improve usability, e.g. content assist, these types and methods can be annotated with `@TestAPI`. There are no constraints defined for that annotation at the moment.

IDE-1468²⁸

13.4. Polyfill Definitions

IDE-1142²⁹

In plain JavaScript, so called *polyfill* (or sometimes called *shim*) libraries are provided in order to modify existing classes which are only prototypes in plain JavaScript. In N4JS, this can be defined for declarations via the annotation `@Polyfill` or `@StaticPolyfill`. One of these annotations can be added to class declarations which do not look that much different from normal classes. In the case of polyfill classes, the extended class is modified (or filled) instead of being subclassed.

We distinguish two flavours of polyfill classes: runtime and static.

- Runtime polyfilling covers type enrichment for runtime libraries. For type modifications the annotation `@Polyfill` is used.
- Static polyfilling covers code modifications for adapting generated code. The annotation `@StaticPolyfill` denotes a polyfill in ordinary code, which usually provides executable implementations.

A *polyfill class* (or simply *polyfill*) is a class modifying an existing one. The polyfill is not a new class (or type) on its own. Instead, new members defined in the polyfill are added to the modified class and existing members can be modified similarly to overriding. We call the modified class the *filled* class and the modification *filling*.

²⁸ <https://jira.numberfour.eu/browse/IDE-1468>

²⁹ <https://jira.numberfour.eu/browse/IDE-1142>

We add a new pseudo property *polyfill* to classes in order to distinguish between normal (sub-) classes and polyfill classes.

152Polyfill Class[req:Polyfill_Class] For a polyfill class P annotated with `@Polyfill` or `@StaticPolyfill`, that is $P.polyfill =$, all the following constraints must hold:

1. P must extend a class F , F is called the filled class: $P.super = F$
2. P 's name equals the name of the filled class and is contained in a module with same qualified name (specifier or global):

$$\wedge P.name = F.name \wedge P.containedModule.global = F.containedModule.global \wedge (P.containedModule.global \neq \text{null})$$
3. Both the polyfill and filled class must be top-level declarations (i.e., no class expression):

$$\wedge P.topLevel = \wedge F.topLevel = \text{true}$$
4. P must not implement any interfaces: $P.implementedInterfaces = \emptyset$
5. P must have the same access modifier (access, abstract, final) as the filled class:

$$\wedge P.accessModifier = F.accessModifier \wedge P.abstract = F.abstract \wedge P.final = F.final$$
6. If P declares a constructor, it must be override compatible with the constructor of the filled class:

$$\exists P.ownedCtor : P.ownedCtor \wedge F.ctor$$
7. P must define the same type variables as the filled class F and the arguments must be in the same order as the parameters (with no further modifications):

$$\wedge \forall i, 0 \leq i < |P.typeParams| \wedge P.typeParams[i] = F.typeParams[i] \wedge P.typeParams[i].name = P.super.typeArgs[i].name$$
8. All constraints related to member redefinition (cf. [???](#)) have to hold. In the case of polyfills, this is true for constructors (cf. [???](#)) and private members.

13.4.1. Runtime Polyfill Definitions

(Runtime) Libraries often do not provide completely new types but modify existing types. The ECMAScript Internationalization Standard [ECMA12a], for example, changes methods of the built-in class `\!stnfs{Date}` to be timezone aware. Other scenarios include new functionality provided by browsers which are not part of an official standard yet. Even ECMAScript 6 [ECMA15a] extends the predecessor [ECMA11a] in terms of new methods (or new method parameters) added to existing types (it also adds completely new classes and features, of course).

Runtime polyfills are only applicable to runtime libraries or environments and thus are limited to n4jsd files.

153Runtime Polyfill Class[req:Runtime_Polyfill_Class] For a runtime-polyfill class P annotated with `@Polyfill`, that is $P.staticpolyfill =$, all the following constraints must hold in addition to :

1. Both the polyfill and filled class are provided by the runtime (annotated with `@ProvidedByRuntime +`):
³⁰ $\wedge P.providedByRuntime = \wedge F.providedByRuntime = \text{true}$

154Applying Polyfills[req:Applying_Polyfills] A polyfill is automatically applied if a runtime library or environment required by the current project provides it. In this case, the following constraints must hold:

³⁰ This restriction has two reasons: Firstly, user-defined types with implementations would require to 'bootstrap' the polyfill, which is impossible to do automatically without serious constraints on bootstrap code in general. Secondly, instead of filling user-defined types, they can be subclasses. Mechanisms such as dependency injection could then solve almost all remaining problems.

1. No member must be filled by more than one polyfill.

13.4.2. Static Polyfill Definitions

Static polyfilling is a compile time feature to enrich the definition and usually also the implementation of generated code in N4JS. It is related to runtime polyfilling described in () in a sense that both fillings enrich the types they address. Despite this, static polyfilling and runtime polyfilling differ in the way they are handled.

Static polyfills usually provide executable implementations and are thus usually found in n4js files. However, they are allowed in n4jsd files, as well, for example to enrich generated code in an API project.

The motivation for static polyfills is to support automatic code generation. In many cases, automatically generated code is missing some information to make it sufficiently usable in the desired environment. Manual enhancements usually need to be applied. If we think of a toolchain, the question may arise how to preserve the manual work when a regeneration is triggered. Static polyfilling allows the separation of generated code and manual adjustments in separate files. The transpiler merges the two files into a single transpiled file. To enable this behaviour, the statically fillable types must be contained in a module annotated with `@staticPolyfillAware`. The filling types must also be annotated with `@staticPolyfill` and be contained in a different module with same specifier but annotated with `@staticPolyfillModule`. Static polyfilling is restricted to a project, thus the module to be filled as well as the filling module must be contained in the same project.

We add a new pseudo property `staticPolyfill` to classes in order to distinguish between normal (sub-) classes and static polyfill classes. We add two new pseudo properties to modules in order to modify the transpilation process. The mutually-exclusive properties `staticPolyfillAware` and `staticPolyfill` signal the way these files are processed.

In order to support efficient transpilation, the following constraint must hold in addition to constraints :

155 static poly fill layout [req:static_poly_fill_layout] For a static polyfill class P annotated with `@staticPolyfill`, that is $P.staticPolyfill = \text{true}$, all the following constraints must hold in addition to [req:Polyfill_Class]:

1. P 's name equals the name of the filled class and is contained in a module with the same qualified name: $\text{amp};P.name = F.name\text{amp}; \wedge P.containedModule.specifier = F.containedModule.specifier$
2. Both the static polyfill and the filled class are part of the same project: $\text{amp};P.project = F.project$
3. The filled class must be contained in a module annotated with `@StaticPolyfillAware`:
 $\text{amp};F.containedModule.staticPolyfillAware = \text{true}$
4. The static polyfill and the filled type must both be declared in an n4js file or both in an n4jsd file.

³¹ <https://jira.numberfour.eu/browse/IDE-1207>

³² <https://jira.numberfour.eu/browse/IDE-1735>

5. The filling class must be contained in a module annotated with :
 $P.\text{containedModule} \text{ staticPolyfillModule} =$
6. For a statically-filled class F there is at most one static polyfill:
 $(P_1 \text{ is static polyfill of } F \wedge P_2 \text{ is static polyfill of } F) \rightarrow P_1 = P_2$

156 Restrictions on static polyfilling [req:Restrictions_on_static_polyfilling] For a static polyfilling module M_P the following must hold:

1. All top-level elements are static polyfills: $T.\text{staticPolyfill} = \forall T \in M_P \wedge T.\text{topLevel} =$
2. It exists exactly one filled module M_F annotated with $\text{staticPolyfillAware}$ in the same project.
3. It is an error if two static polyfill modules for the same filled module exist in the same project:
 $M_1 = M_2 \wedge M_1.\text{specifier} = M_2.\text{specifier} \wedge M_1.\text{project} = M_2.\text{project} \wedge M_1.\text{staticPolyfillModul} = M_2.\text{staticPolyfillModul} =$

[[ex:Static polyfill]]

??? shows an example of generated code. ??? demonstrates the static polyfill. Note that the containing project has two source folders configured: `Project/src/n4js` and `Project/src/n4js-gen`.

```
@@StaticPolyfillAware
export public class A {
    constructor() {...}
    m1(): void {...}
}

export public class B {
    constructor() {...}
    m2(): void {...}
}
```

```
@@StaticPolyfillModule
@StaticPolyfill
export public class B extends B {
    @Override
    constructor(... ) // replaces generated ctor of B
    @Override
    m1(): void {...} // adds overridden method m1 to B
    @Override
    m2(): void {...} // replaces method m2 in B
    m3(): void {...} // adds new method m3 to B
}
```

13.4.3. Transpiling static polyfilled classes

Transpiling static polyfilled classes encounters the special case that two different `n4js` source files with the same qualified name are part of the project. Since the current transpiler is file-based, both files would be transpiled to the same output destination and would therefore overwrite each other. The following pre-transpilation steps handle this situation:

- Current file to transpile is M
- If $M.\text{staticPolyfillAware} =$, then

- search for a second file G with same qualified name:
 $G.specifier = M.specifier \wedge G.project = M.project$
- If $\exists G$, then
 - merge G into current file $M \rightarrow M'$
 - conventionally transpile M'
 - else conventionally transpile M
- else, if $M.staticPolyfillModule = ,$
 - then *do nothing*. (Transpilation will be triggered for filled type separately.)
- else, conventionally transpile M

Chapter 14. Components

14.1. N4JS Platform Architecture

14.1.1. Overview

shows the N4JS components described in detail in this chapter.¹

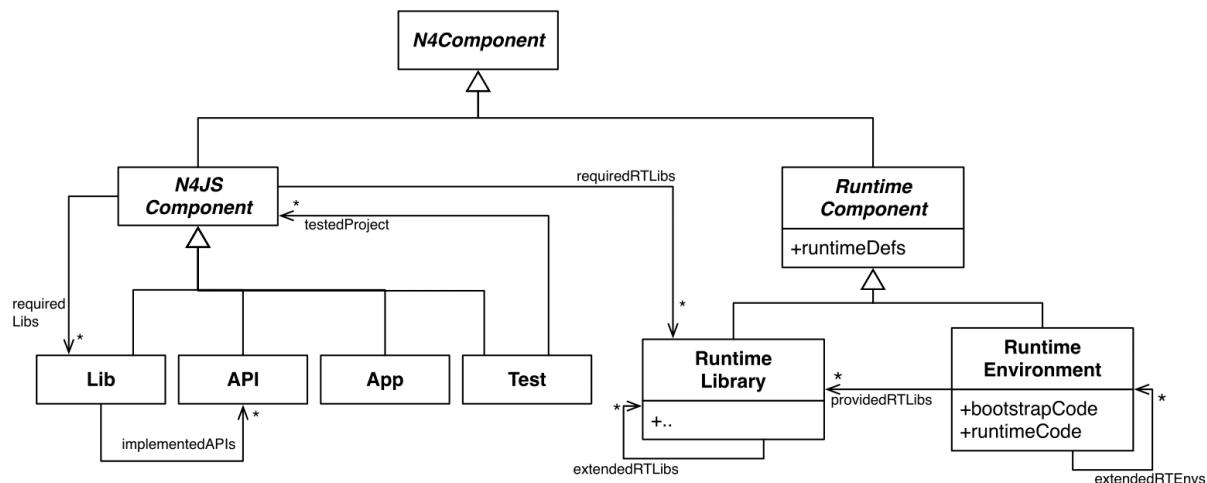


Figure 14.1. N4JS Component Overview

The N4JS platform distinguishes several types of components. The following components can only be created by internal developers:

Runtime Environment

Definition of a runtime environment such as ECMAScript 5. A Runtime Environment describes the base types provided by the runtime directly which are usually globally available. Other components do not directly rely on runtime environments, but on runtime libraries.

Runtime Library

Collections of types provided by the runtime. These types may be extensions to certain language specifications. E.g., the ECMAScript 6 collection classes are already provided by some environments otherwise only supporting ECMAScript 5. The collections are defined in terms of a runtime library which can then be provided by these environments. Runtime libraries may also contain polyfills to alter types predefined in the environment.

Test Environment

Not yet clear. Environments defined for tests

Test Library

Not yet clear. Libraries defined for tests supported by the to enable running tests and viewing test reports directly within the , such as *Mangelhaft*.

The following components can be created by external developers:

¹ Note that this diagram does not necessarily reflect the actual internal implementation but only the external view.

Apps

User-written N4JS applications running in a web browser (the reference browser is Chrome).

Processors

User-written N4JS processors running on Node.js.

Libraries

User-written libraries used by apps, processors or other libraries.

These components are described in detail later.

A component is similar to a single project in the N4JS IDE. It is shipped as NFAR archive and contains:

Manifest

The manifest describing the components, dependencies and metadata.

Resources

Resources such as images, N4ML files etc.

Sources

Source files of modules - actual N4JS files used in a project.

Compilation

Compiled, minified and concatenated versions of the N4JS files and other JS files.

Tests

Optional test sources and compiled tests.

Source Maps

Optional source maps.

Components contain modules. describes what can be contained in a component.

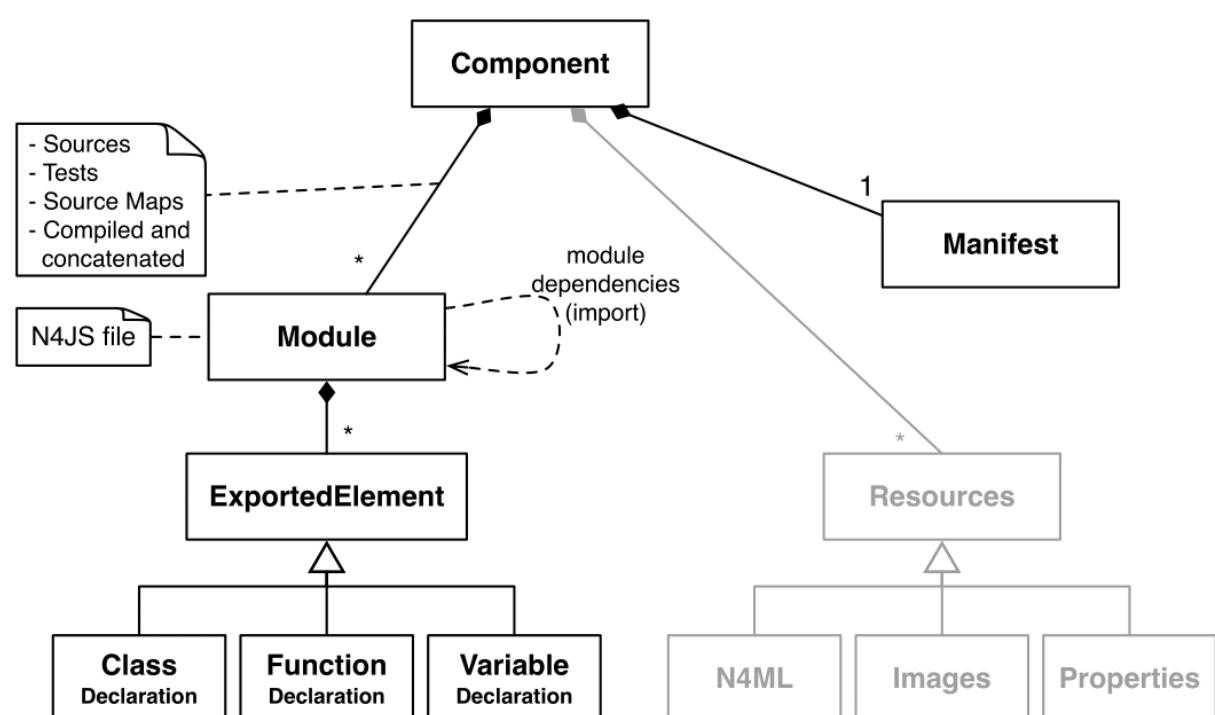


Figure 14.2. Content of a Component

14.2. Component Types

Different N4JS component types are described in this section. At compile time and runtime, dependent components have to be available. This is the responsibility of the user interface (or) and described in the specification.

14.2.1. Apps

Applications allow developers to bundle a project as an application and deploy it to an N4 environment. An application is visible to users of the N4 platform in the app store. Users can subscribe and use an application that is available in the app store.

14.2.2. Processors

Processors allow developers to bundle a project as a processor which can run asynchronously on an N4 environment. Users can deploy a processor to an N4 environment so that other developers can use its services.

14.2.3. Libraries

A library is a user project providing modules with declaration.

14.2.4. Runtime Environment and Runtime Libraries

IDE-1036²

Runtime environments and libraries define globally available elements (types, variables, functions) provided by the JavaScript engine. Both must contain *only* definition files (n4jsd) of which all elements are marked as (`@ProvidedByRuntime`) and (`@Global`)

Other projects may refer to a *single* runtime environment in their manifest via `RequiredRuntimeEnvironment` and to *multiple* runtime libraries via `RequiredRuntimeLibraries`

Both types of components are referenced, similarly to libraries, by their project Id. It is possible, however, to state that a specific component may be used instead of another one via the `CompatibleWith` field defined by an environment or library.

The concrete runtime environment and library are selected by the JavaScript engine. Deployment and execution scripts must ensure that a component can run on the given engine; the required environments and libraries must all be compatible with the provided environment. If no runtime environment is specified, a default an ECMAScript 5 runtime is assumed to be present.

Typical runtime environments are ES5 or ES6, typical runtime libraries are DOM or HTML.

In JavaScript, browsers and other execution environments provide built-in objects. In browsers, for example, the whole DOM is made available via built-in object types. In this case, even the global object also becomes a different type (in N4JS terms). Besides execution environments such as browsers or Node.js, libraries also provide functionality by exposing globally available functions. This is often used to

² <https://jira.numberfour.eu/browse/IDE-1036>

bridge execution environment inconsistencies. When browser API differences are adapted by a library, this is called a *polyfil*. Other adaptations, such as enabling ECMSScript 6 object types in ECMAScript 5 environments, are known as *shim*. Instead of directly supporting these kind of **hacks**, other components specify which runtime environment and libraries they depend on by specifying unique runtime ids. Possible shims (in case of environments) or polyfills (in case of libraries) are transparently provided by the execution environment and the bootstrap code.

14.2.5. Tests

IDE-1400³

Tests are special projects which contain tests for other projects.

157Test Project[req:Test_Project]

1. Tests have full access to the tested project including elements with visibility.
2. Only other test projects can depend on tests project. In other words, other components must not depend on test components.

In a test project, the tested projects can be specified via **testee**.

14.3. Component Content

A component is similar to a project in the N4JS IDE. It consists of sources, test sources, resources (such as images) and libraries (nears). These items are contained in separate folders alongside output folders and settings specified in the manifest file. The manifest file is stored at the root of the project (and explained in).

For build and production purposes, other files such as **pom.xml** or **.project** files are automatically derived from the . These files are not to be added manually.

14.4. Component Manifest

IDE-18⁴

14.4.1. Syntax

```
ProjectDescription:  
    ('ProjectId'      ':' projectId=N4mfIdentifier)  
    & ('ProjectType'   ':' projectType=ProjectType)  
    & ('ProjectVersion' ':' projectVersion=DeclaredVersion)  
    & ('VendorId'     ':' declaredVendorId=N4mfIdentifier)  
    & ('VendorName'   ':' vendorName=STRING)?  
  
    & ('MainModule'    ':' mainModule=STRING)?  
  
    // only available for runtime environments
```

³ <https://jira.numberfour.eu/browse/IDE-1400>

⁴ <https://jira.numberfour.eu/browse/IDE-18>

```

&   (extendedRuntimeEnvironment=ExtendedRuntimeEnvironment) ?

// only in case of runtime libraries or runtime environment:
&   (providedRuntimeLibraries=ProvidedRuntimeLibraries) ?

// not available in runtime environments:
&   (requiredRuntimeLibraries=RequiredRuntimeLibraries) ?

// only available in N4JS components (Apps, Libs, Processor)
&   (projectDependencies=ProjectDependencies) ?

// only available in N4JS components (Apps, Libs, Processor)
&   ('ImplementationId' ':' implementationId=N4mfIdentifier) ?

// only available in N4JS components (Apps, Libs, Processor)
&   (implementedProjects=ImplementedProjects) ?

//only RuntimeLibrary and RuntimeEnvironemnt
&   (initModules=InitModules) ?
&   (execModule=ExecModule) ?

&   ('Output'          ':' outputPath=STRING) ?
&   ('Libraries'        '{' libraryPaths+=STRING (',' libraryPaths+=STRING)* '}' )?
&   ('Resources'        '{' resourcePaths+=STRING (',' resourcePaths+=STRING)* '}' )?
&   ('Sources'          '{' sourceFragment+=SourceFragment+ '}' )?

&   ('ModuleFilters'    '{' moduleFilters+=ModuleFilter+ '}' )?

&   (testedProjects=TestedProjects) ?

&   ('ModuleLoader'    ':' moduleLoader=ModuleLoader) ?
;

enum ProjectType :
  APPLICATION = 'application' |
  APPLICATION = 'app' | //XXX deprecated. Will be removed soon. Use application instead.
  LIBRARY = 'library' |
  LIBRARY = 'lib' | //XXX deprecated. Will be removed soon. Use library instead.
  API = 'API' |
  RUNTIME_ENVIRONMENT = "runtimeEnvironment" |
  RUNTIME_LIBRARY = "runtimeLibrary" |
  TEST = "test"
;

ExecModule returns ExecModule:
  {ExecModule}
  'ExecModule' ':' execModule=BootstrapModule
;

TestedProjects returns TestedProjects:
  {TestedProjects}
  'TestedProjects' '{'
    (testedProjects+=TestedProject (',' testedProjects+=TestedProject)* )?
  '}'
;

```

```

InitModules returns InitModules:
{InitModules}
'InitModules' '{'
    (initModules+=BootstrapModule (',' initModules+=BootstrapModule)*)?
}'
;

ImplementedProjects returns ImplementedProjects:
{ImplementedProjects}
'ImplementedProjects' '{'
    (implementedProjects+=ProjectReference (',' implementedProjects+=ProjectReference)*)?
}'
;

ProjectDependencies returns ProjectDependencies:
{ProjectDependencies}
'ProjectDependencies' '{'
    (projectDependencies+=ProjectDependency (',' projectDependencies
+=ProjectDependency)*)?
}'
;

ProvidedRuntimeLibraries returns ProvidedRuntimeLibraries:
{ProvidedRuntimeLibraries}
'ProvidedRuntimeLibraries' '{'
    (providedRuntimeLibraries+=ProvidedRuntimeLibraryDependency (','
providedRuntimeLibraries+=ProvidedRuntimeLibraryDependency)*)?
}'
;

RequiredRuntimeLibraries returns RequiredRuntimeLibraries:
{RequiredRuntimeLibraries}
'RequiredRuntimeLibraries' '{'
    (requiredRuntimeLibraries+=RequiredRuntimeLibraryDependency (','
requiredRuntimeLibraries+=RequiredRuntimeLibraryDependency)*)?
}'
;

ExtendedRuntimeEnvironment returns ExtendedRuntimeEnvironment:
{ExtendedRuntimeEnvironment}
'ExtendedRuntimeEnvironment' :: extendedRuntimeEnvironment=ProjectReference
;

DeclaredVersion :
    major=INT ('.' minor=INT ('.' micro=INT)?)? ('-' qualifier=N4mfIdentifier)?
';

SourceFragment:
    sourceFragmentType=SourceFragmentType '{' paths+=STRING (',' paths+=STRING)* '}'
;

enum SourceFragmentType :
    SOURCE = 'source' | EXTERNAL = 'external' | TEST = 'test'
';

ModuleFilter:
    moduleFilterType=ModuleFilterType '{'
;
```

```
    moduleSpecifiers+=ModuleFilterSpecifier (',' moduleSpecifiers
+=ModuleFilterSpecifier)* '}'
;

BootstrapModule:
    moduleSpecifierWithWildcard=STRING ('in' sourcePath=STRING)?
;

ModuleFilterSpecifier:
    moduleSpecifierWithWildcard=STRING ('in' sourcePath=STRING)?
;

enum ModuleFilterType:
    NO_VALIDATE = 'noValidate' | NO_MODULE_WRAPPING = 'noModuleWrap'
;

ProvidedRuntimeLibraryDependency:
    project=SimpleProjectDescription
;

RequiredRuntimeLibraryDependency:
    project=SimpleProjectDescription
;

TestedProject:
    project=SimpleProjectDescription
;

/*
 * scope is optional, default scope is compile
 */
ProjectReference :
    project=SimpleProjectDescription
;

/*
 * scope is optional, default scope is compile
 */
ProjectDependency :
    project=SimpleProjectDescription
    (versionConstraint=VersionConstraint)?
    (declaredScope=ProjectDependencyScope)?
;

/*
 * vendorN4mfIdentifier is optional, if it is not specified, vendor id of current project is
used.
*/
SimpleProjectDescription :
    (declaredVendorId=N4mfIdentifier ':')? projectId=N4mfIdentifier
;

/*
 * If no version range is specified, lower version is inclusive.
*/
VersionConstraint:
    (

```

```
(exclLowerBound?='(' | '[') lowerVersion=DeclaredVersion
    ((',' upperVersion=DeclaredVersion (exclUpperBound?=')' | ']'))? | ')')
) | lowerVersion=DeclaredVersion
;

enum ProjectDependencyScope :
    COMPILE = 'compile' | TEST = 'test'
;

enum ModuleLoader:
    N4JS = 'n4js'
| COMMONJS = 'commonjs'
| NODE_BUILTIN = 'node_builtin'
;

// N4mfIdentifier: left off for simplicity, allows everything that starts with a letter, also
// allows keywords
// Path: project relative path
// ModuleSpecifierWithWildcard
```

14.4.2. Properties

The manifest, called `manifest.n4mf`, specifies the following information:

ProjectId

Compare to Maven pom / manifest symbolic name.

VendorId

This is similar to the group id in Maven.

VendorName

The *vendor* of the project as a string. This is optional and if not specified, vendor id is used as vendor name.

ProjectType

The *type* of the project. The following types of projects exists:

app

Application

lib

Library

test, api, runtimeEnvironment

Runtime Environment

runtimeLibrary

Runtime Library

DeclaredVersion

The *version* of the project. The version consists of a major, minor and micro version. The syntax of the version is given by:

```
DeclaredVersion :
    major=INT ('.' minor=INT ('.' micro=INT)? )? ('-' qualifier=ID)?
;
```

We use *qualifier* = *SNAPSHOT* in our Maven builds so that each build uses the latest available version of a project. The qualifier is only supported for this tooling and is removed during deployment. The lengths of the major, minor and micro numbers is additionally limited to four digits.

MainModule

(optional) A plain module specifier defining the project's `main module`. If this property is defined, other projects can import from this project using imports where the string following keyword `from` states the project name and not the complete module specifier (see [???](#)).

CompatibleWith

In the case of a runtime environment or library, this specifies to which other component this one is compatible to.

RequiredRuntimeEnvironment

Environment this project depends on. This is a simple project ID, runtime environments are not versioned. This is usually omitted and concrete environments are computed from the required N4JS libraries and runtime libraries.

RequiredRuntimeLibraries

Comma-separated list of runtime libraries this project depends on. These are a simple project IDs, runtime libraries are not versioned.

ProjectDependencies

The *dependencies* section describes which projects this project requires. A *dependency* has the following properties:

- The *vendorId*. This is optional. If no vendor id is given, the vendor id of the current project is also used as vendor id for this project dependency.
- The *projectId*
- Either the minimum excluded or included version and the maximum excluded or included version. If no version (range) is given [0.0.0, infinity) is assumed. If only one version (e.g. 1.0) is given this is interpreted as [1.0, infinity]. Writing (1.0) means (1.0, infinity).
- The *scope* of the dependency. The scopes are inspired by Maven [\[MavenDependencies\]](#) and the following scopes are supported:

compile

This dependency is needed for compilation of the project *and* it needs to exist on the environment when deploying it.

test

This dependency is only needed for compiling and running tests. *Types imported from a test dependency are only accessible from a test source fragment.*

The deployment descriptor of a project only contains dependencies with scope compile. If there is no scope explicitly set, the scope is set to [compile].

Output

Path to output folder, compilers may use subfolders inside this folder.

Libraries

List of paths to libraries, that is, folders in which nfars are found.

Resources

List of paths to resources, that is, folders in which images, css etc. is found.

Sources

List of source fragments. A source fragment is a path to sources (n4js or js), which are typically compiled to the output path, with a given type. There exist three different source fragment types:

- **Source**: files, will be available in scope for projects that defines this project as compile time dependency. A module contained in a source fragment of kind `source` can only access modules from other source fragments with kind `source` and from dependencies with scope `compile`. Files in sources will be validated and compiled to the output folder.
- **test**: files, will be available in scope for projects that defines this project as test time dependency. A module contained in a source fragment of kind `test` can access any module from other source fragments and from dependencies with any scope. Files in sources will be validated and compiled to the output folder (maybe a subfolder).
- **external**: Implementation of modules defined in definition files (n4jsd). These implementations are never validated nor fully compiled. Instead, they are only wrapped into module definitions and copied to the output folder. See [???](#) and [???](#) for details.

Filters for fine-tuning the validator and compiler. A filter is applied to modules matching the given module specifier which may contain wildcards, optionally restricted to modules defined in a specific source path. The following filters are supported:

noValidate

Modules matching this filter are not semantically validated. That is, they are still syntactically validated. If they are contained in source or test source fragments, it must be possible to bind references to declarations inside these modules. Note that switching off validation for n4js files is disallowed.

noModuleWrap

Files matching this filter are not wrapped into modules and they are not semantically validated. Since they are assumed to be wrapped into modules, declarations inside these modules cannot be referenced by n4js code.

Optional property that defines what module loader are supported by the modules in this component. Possible values are

n4js

(default) The modules in this component can be loaded with SystemJS or with CommonJS.

commonjs

Modules in this component must be loaded with CommonJS. When these modules are referenced in generated code (i.e. when importing from these modules), the module specifier will be prefixed with `@@cjs/`.

node_builtin

Modules in this component represent node built-in modules such as `fs` or `https`. When these modules are referenced in generated code (i.e. when importing from these modules), the module specifier will be prefixed with `@node/`.

Validation or module-wrapping can be turned off for certain files or folders via the manifest properties `no-validate` and `no-module-wrapping`. While this is mostly intended for external implementation modules below the source-external folder, it is also allowed for `.js` and `.n4js` files in the source folder.

1. The projectId used in the manifest file have to match the project name in file system as well as project name in the Eclipse workspace.
2. There must be an output directory specified so the compiler(s) can run.

159Paths Paths are constrained in the following way:

1. A path cannot appear more than one time within a source fragment type (same applies to paths in the resources section).
2. A path cannot be used in different source fragment types at same times.
3. A path can only be declared exclusively in one of the sections Output, Libraries, Resources or Sources.
4. A path must not contain wild cards.
5. A path has to be relative to the project path.
6. A path has to point to folder.
7. The folder a defined path points to must exist in the project (but in case of non-existent folders of source fragments, only a warning is shown).

GH-339⁵

160ModuleSpecifiers Module specifiers are constrained in the following way:

1. Within a module filter type no duplicate specifiers are allowed.
2. A module specifier is by default applied relatively to all defined source containers, i.e. if there src and src2 defined as source containers in both folders files are looked up that matches the given module specifier
3. A module specifier can be constrained to be applied only to a certain source container.
4. A module specifier is allowed to contain wildcards but it must resolve to some existing files in the project

161ModuleSpecifierWildcardConstraints

1. All path patterns are case sensitive.
2. all module specifiers will be matched.
3. all module specifiers will be matched.
4. matches all module specifiers whose qualified name consists of two segments where the first part matches test and the second part starts with an **A** and then two more characters.
5. - matches all module specifiers whose qualified name contains a segment that matches test and the last segment ends with an 'XYZ'.
6. A module specifier wild card isn't allowed to contain *******.
7. A module specifier wild card isn't allowed to contain relative navigation.
8. A module specifier wild card shouldn't contain the file extension (only state the file name (pattern) without extension, valid file extensions will then be used to match the file).

⁵ <https://github.com/NumberFour/N4JS/issues/339>

Examples of using external source fragments and filters are given in ()�.

[[ex:No validation and module wrapping example]] The following manifest shows the use of filters to disable validation and module wrapping.

```
ProjectId: Test
ProjectType: lib
ProjectVersion: 0.0.1-SNAPSHOT
VendorId: eu.numberfour
VendorName: "NumberFour AG"
Output: "src-gen"
Sources {
    source {
        "src1",
        "src2"
    }
    external {
        "external"
    }
}
Libraries {
    "lib"
}
Resources {
    "resources"
}
ModuleFilters {
    noValidate {
        "p/UglyHack",
        "**/*" in "src2"
    }
    noModuleWrap {
        "p/myAlreadyAsModuleHack"
    }
}
```

14.5. Component Dependencies

There are several dependencies between components. We can distinguish between `require` dependencies and `provide` dependencies.

`require`

N4JS Components require: +

- *APIs*
- *RuntimeLibraries* and
- *Libraries*

`provide`

- *Runtime Environments* provide *Runtime Libraries* and maybe extend other *Runtime Environments* (which means they provide the same runtime libraries as the extended environments and the same base types).

- SysLibs implement (`provide implementations` of) APIs

14.5.1. Runtime Environment Resolution

In order to execute (run, debug, or test) an *N4JS Component*, an actual *runner* has to be determined. Since runners support runtime environments, this basically means calculating runtime environments which provide all necessary runtime libraries needed by the component. This is done by computing the transitive closure of required runtime libraries and by comparing that with the transitive closure of runtime libraries provided by an environment.

14.6. Modules

IDE-8⁶

All N4JS files are modules, sometimes also called compilation unit (CU). This is the overall structure of a module, based on [[ECMA15a\(p.S14\)](#)].

```
Script: {Script}
    annotations+=ScriptAnnotation*
    scriptElements+=ScriptElement*;

/*
 * The top level elements in a script are type declarations, exports, imports or statements
 */
ScriptElement:
    AnnotatedScriptElement
    | N4ClassDeclaration<Yield=false>
    | N4InterfaceDeclaration<Yield=false>
    | N4EnumDeclaration<Yield=false>
    | ImportDeclaration
    | ExportDeclaration
    | RootStatement<Yield=false>
;
```

Grammar and semantics of import statement is described in ; of export statement is described in .

An import statement imports a variable declaration, function declaration, or N4 type declaration defined and exported by another module into the current module under the given alias (which is similar to the original name if no alias is defined). The name of the module is its project's source folder's relative path without any extension, see for details.

IDE-179⁷

This are the properties of script, which can be specified by the user:

Arbitrary annotations, see and below for details.

The content of the script.

⁶ <https://jira.numberfour.eu/browse/IDE-8>

⁷ <https://jira.numberfour.eu/browse/IDE-179>

And we additionally define the following pseudo properties:

File system path (path delimiter is always `' / '`) relative to the source fragment of the file without the extension. E.g.: given a source folder `src`, *path* of a module located at:

- `src/n4/lang/List.js` is `n4/lang/List`
- `src/n4/lang/Objects.prototypes` is `n4/lang/Objects`

Pseudo property consists of the project name and project version of the module followed by the path, the concrete syntax is:

`<project.name>-<project.version>/<module.path>`,

where project version includes all version parts except the qualifier.

E.g. given a module with path `n4/lang/List` in a project `lib` with version `1.0.0`, the *expandedPath* is `lib-1.0.0/n4/lang/List`.

Pseudo property contains all load time dependencies of this module.

Pseudo property contains all runtime dependencies of this module.

Pseudo property contains all dependencies of this module. This is the union of *loadtimeDeps* and *runtimeDeps* which maintains the ordering of both lists, with the *loadtimeDeps* at the front.

Pseudo properties to be set via annotations are explained in .

14.7. NumberFour Archives (NFAR)

IDE-19⁸
IDE-37⁹
IDE-46¹⁰

Compiled projects are packaged in a N4 bundle archive and use `nfar` as a file extension. A nfar file is a zip archive that contains all source files, compiled files and metadata of a project. It's used to deploy projects to:

- N4 environments via the N4 deployment web service
- Maven artifact repositories via the standard Maven deploy

A nfar archive has the following structure:

/resources/

contains all resources such as images and css files

/src/

contains all JavaScript and N4ML source files, but doesn't contain test source files.

/output/

contains the compiled JavaScript.

⁸ <https://jira.numberfour.eu/browse/IDE-19>

⁹ <https://jira.numberfour.eu/browse/IDE-37>

¹⁰ <https://jira.numberfour.eu/browse/IDE-46>

/model/

contains the compiled type model.

manifest.pmi

the manifest file

bundle.json

This is used to track the format/version of the contained data, so that we are able to see if two bundles are compatible with each other

package.json

This contains the *N4 deployment descriptor* required by the N4 deployment webservice. This file is only added to the nfar file when deploying it to a N4 environment! That means that it's not available in nfar files deployed to a Maven artifact repository.

14.7.1. N4 Deployment Descriptor

The N4 deployment descriptor of a project p is a NFON formatted file with the following structure:

```
{
    "@type": "n4.deployment.PackageDescription",
    "kind": "~$p.deploymentKind$~",
    "name": "~$p.name$~",
    "singleton": "~$p.type='LIBRARY'$~",
    "version": "~$p.version$~",
    "displayName": "",
    "buildComment": "",
    "allJavaScriptFile": "~$p.allJavaScriptFile$~",
    "allMinJavaScriptFile": "~$p.allMinJavaScriptFile$~",
    "dependentPackages": [
        // for (d in ~$p.dependencies$~)
        {
            "@type": "n4.deployment.DependencyInfo",
            "name": "~$d.name$~",
            "version": "~$d.version$~"
        }
    ],
    "properties": {
        "@type": "n4.coreservices.graph.deployment.AppProperties",
        "objectHandlers": [
            // for (o in ~$p.objectHandlers$~)
            {
                "@type": "n4.coreservices.graph.deployment.ObjectHandler",
                "type": "~$o.type$~",
                "viewId": "~$o.viewId$~",
                "viewType": "~$o.viewType$~",
                "perspectiveId": "~$o.perspectiveId$~",
                "onlyCreatedByApp": "~$o.onlyCreatedByApp$~",
                "actions": "~$o.actions$~",
                "docFileProvider": "~$o.docFileProvider$~",
                "docMimeTypeMatch": "~$o.docMimeTypeMatch$~"
            }
        ]
    }
}
```

14.8. Properties Files

Properties files have the file extension `properties` and describe how to localize text in a project. They basically define keys `???` with their values. The key is used during runtime to retrieve text localized to the user's locale.

14.8.1. Syntax [[N4 Deployment Descriptor Syntax]]

The syntax of a resource file is defined as:

```
ResourceFile: Comment* | $entry+=$ Entry*;
Comment:      '#' .* EOL;
Entry:        $key$ = KeyIdentifier '=' $value$ = .* EOL;
KeyIdentifier: LETTER (DIGIT | LETTER | '.')*;
```

14.8.2. Constraints

Properties files have to be stored in source fragment of type source. The *base folder* for storing the properties files of a project p is $pname/nls$. The language-specific resource files are stored in subfolders of the base folder. The base language (normally english) has to be located in a subfolder of the base folder. The resource files for other languages have to be located in a subfolder with the name given by syntax **<ISO Language Code>_<ISO Country Code>**, where ISO Language Code is given by the ISO-639 standard and ISO Country Code is given by the ISO-3166 standard.

All resource files stored in a language folder are compiled to a JavaScript file which exports all resource keys as an object literal.

The resource files of a project are automatically loaded. To access a resource key `key` stored in a resource file `my.properties`, you have to use the file name as a prefix (e.g. you have to use the key `my.key`).

14.9. API and Implementation Components

Instead of providing an implementation, N4JS components may only define an API by way of one or more n4jsd files which is then implemented by separate implementation projects. For one such API project, several implementation projects may be provided. Client code using the API will always be bound to the API project only, i.e. only the API project will appear in the client project's manifest under project dependencies. When launching the client code, the launcher will choose an appropriate implementation for each API project in the client code's direct or indirect dependencies and transparently replace the API project by the implementation project. In other words, instead of the API project's output folder, the implementation project's output folder will be put on the class path. Static compile time validations ensure that the implementation projects comply to their corresponding API project.

Note how this concept can be seen as an alternative way of providing the implementation for an n4jsd file: usually n4jsd files are used to define types that are implemented in plain JavaScript code or provided by the runtime; this concept allows for providing the implementation of an n4jsd file in form of ordinary N4JS code.

At this time, the concept of API and implementation components is in a prototype phase and the tool support is limited. The goal is to gain experience from using the early prototype support and then refine the concept over time.

Here is a summary of the most important details of this concept (they are all subject to discussion and change):

- Support for this concept, esp. validations, should not be built into the core language but rather implemented as a separate validation/analysis tool. Validation is currently provided in the form of a separate view: the API / Implementation compare view.
- A project that defines one or more other projects in its manifest under `ImplementedProjects` is called *implementation project*. A project that has another project pointing to itself via `ImplementedProjects` is called *API project*. Note that, at the moment, there is no explicit definition making a project an API project.
- An implementation project must define an implementation ID in its manifest using the `ImplementationID` property.
- For each public or `public@Internal` classifier or enum in an API project, there must be a corresponding type with the same fully-qualified name of the same or higher visibility in the implementation project. For each member of such a type in the API, there must exist a corresponding, owned *or* inherited type-compatible member in the implementation type.
- Beyond type compatibility, formal parameters should have the same name on API and implementation side; however, different names are legal but should be highlighted by API / Implementation tool support as a (legal) change.
- Comments regarding the state of the API or implementation may be added to the JSDoc in the source code using the special tag `@apiNote`. API / Implementation tool support should extract and present this information to the user in an appropriate form.
- If an API class C implements an interface I , it has to explicitly (re-) declare all members of I similar to the implementation. This is necessary for abstract classes anyway in order to distinguish the implemented methods from the non-implemented ones. For concrete classes, we want all members in C in order to be complete and avoid problems when the interface is changed or C is made abstract.

14.9.1. Execution of API and Implementation Components

When launching an N4JS component C under runtime environment RE , the user may(!) provide an implementation ID IID to run. Then, for each API project A in the direct or indirect dependencies of C an implementation project is chosen as follows:

1. Collect all implementation projects for A (i.e. projects that specify A in their manifest under `ImplementedProjects`).
2. Remove implementation projects that cannot be run under runtime environment RE , using the same logic as for running ordinary N4JS components (this step is not implemented yet!).
3. If there are no implementation projects left, show an error.
4. If IID is defined (i.e. user specified an implementation ID to run), then:
 - a. If there is an implementation project left with implementation ID IID , use that.

- b. Otherwise, show an error.
5. If *IID* is undefined, then
- a. If there is exactly 1 implementation project left, use it.
 - b. Otherwise, in UI mode prompt the user for a choice, in headless mode show an error.

Having found an implementation project I_n for each API project A_n , launch as usual except that whenever A_n 's output folder would be used, use I_n 's output folder (esp. when constructing a `class path`) and when loading or importing a type from A_n return the corresponding type with the same fully-qualified name from I_n .

14.10. API and Implementation With DI

API projects may use N4JS DI (???) language features which require Implementation projects to provide DI-compatible behaviour in order to allow a Client (implemented against an API project) to be executed with a given Implementation project. This is essential for normal execution and for test execution. Figure [Figure 14.3, “Overview of API tests with DI”](#) shows some of those considerations from test client point of view.

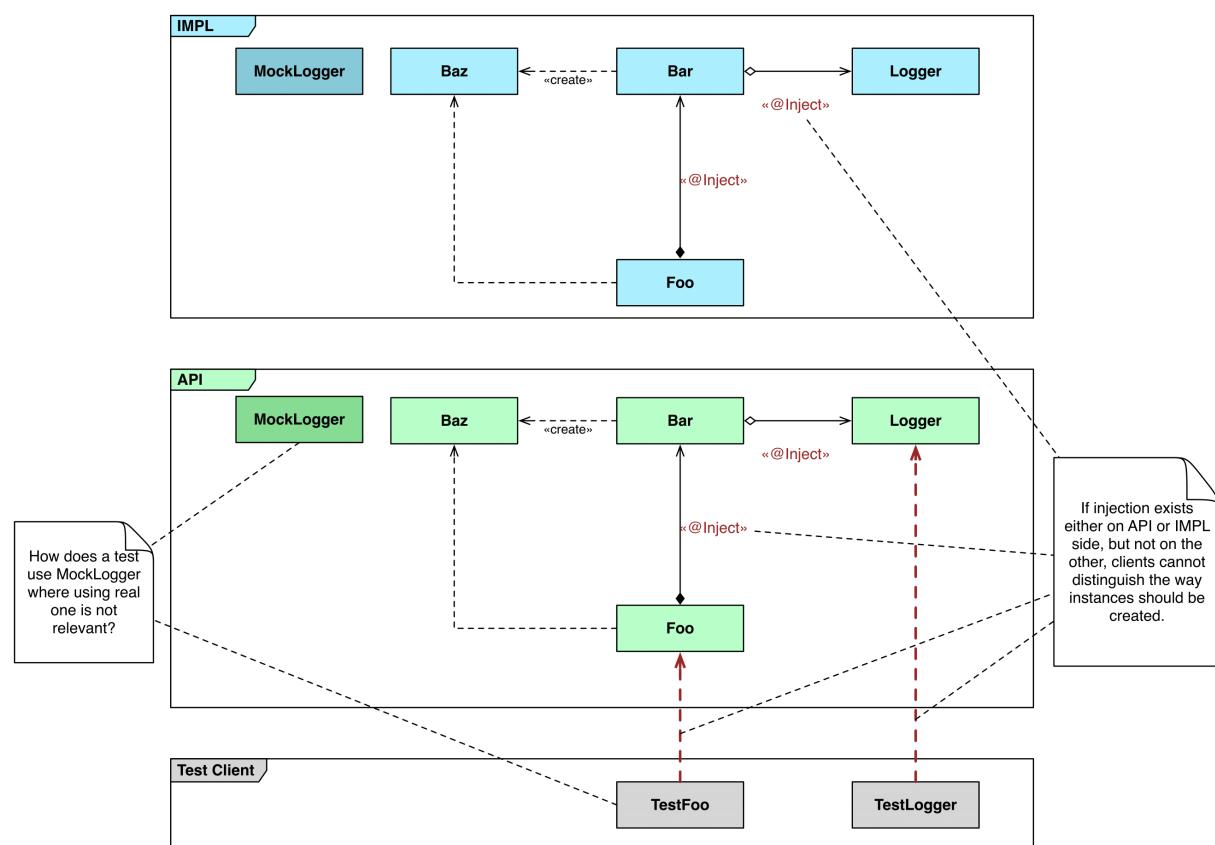


Figure 14.3. Overview of API tests with DI

Static DI mechanisms in N4JS allow an API project to enforce Implementation projects to provide all necessary information. This allows clients to work seamlessly with various implementations without specific knowledge about them or without relying on extra tools for proper project wiring. Figure [Figure 14.4, “API tests with static DI”](#) shows how API project defines project wiring and enforces certain level of testability.

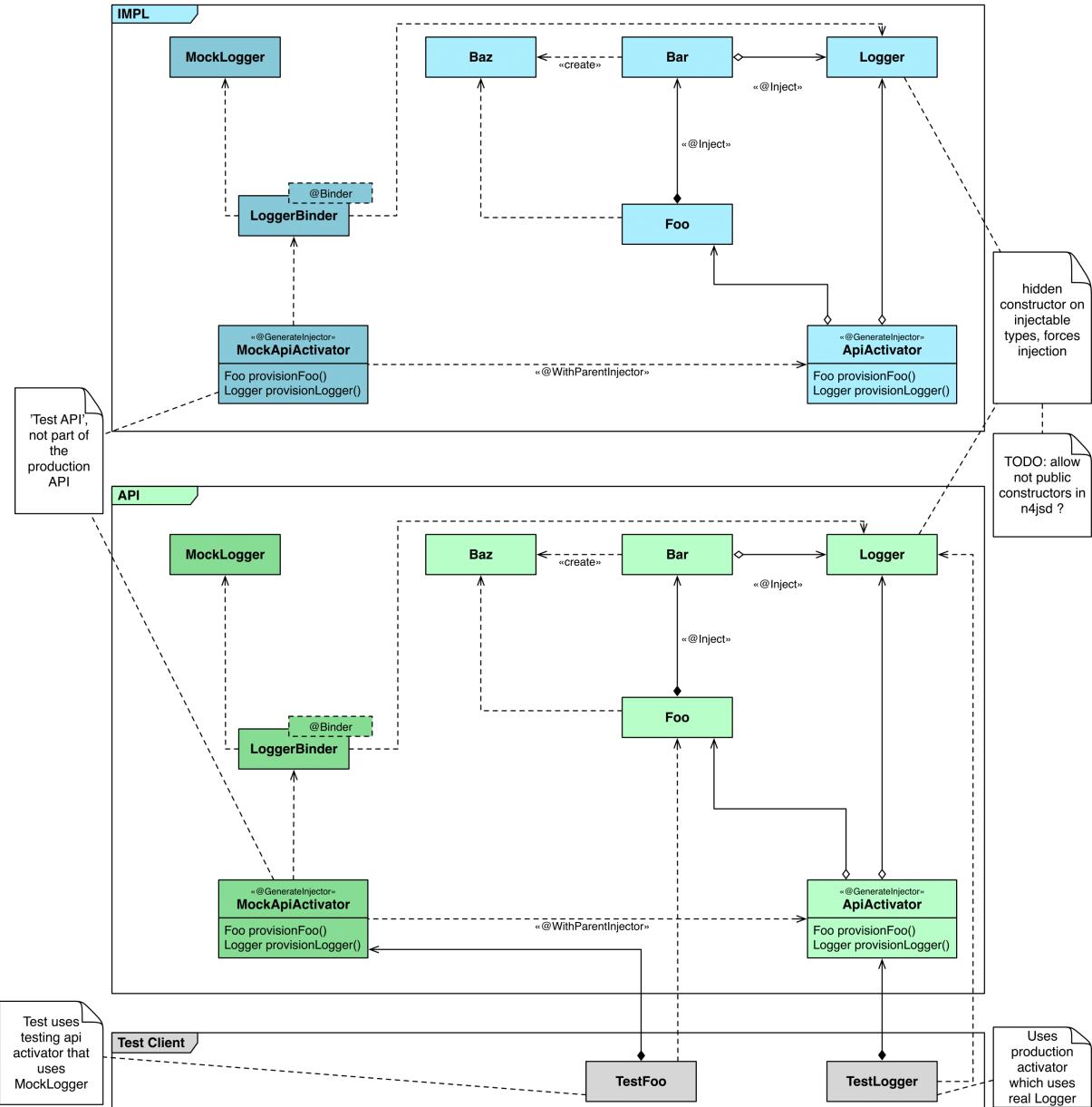


Figure 14.4. API tests with static DI

During Client execution, whether it is test execution or not, N4JS mechanisms will replace the API project with a proper Implementation project. During runtime DI mechanisms will take care of providing proper instances of implantation types. Figure [Figure 14.5, “Types view and Instances view”](#) shows Types View perspective of the client, and Instances View perspective of the client.

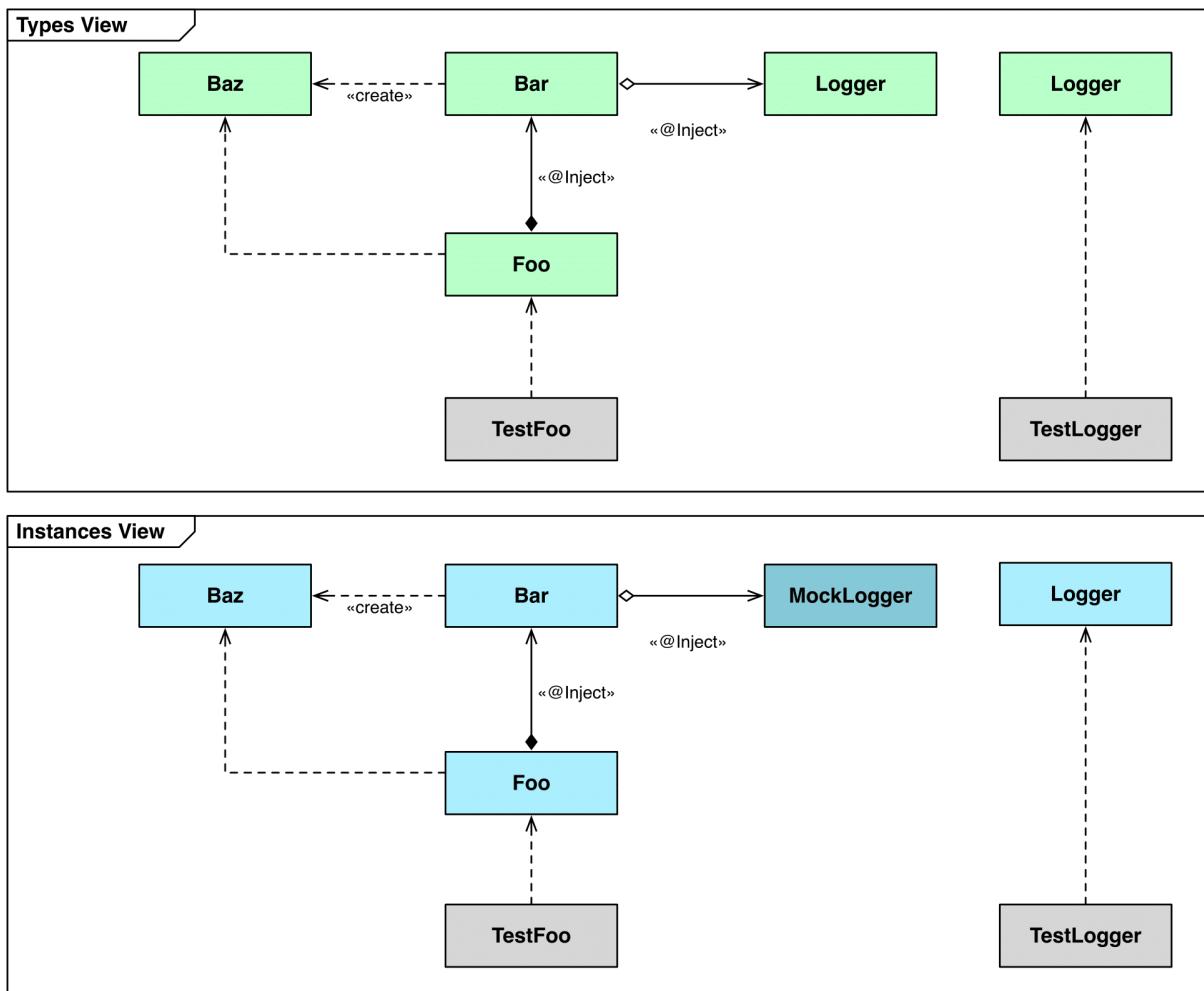


Figure 14.5. Types view and Instances view

Chapter 15. PlainJS

Since N4JS is a super set of JavaScript, is it both possible to use plain JavaScript in N4JS and vice versa. There may be some obstacles due to concepts introduced by N4JS to make code more maintainable and robust:

1. N4JS' static type system may complain about some older JavaScript hacks. Declared types, in particular, are assumed to be implicitly frozen.
2. In N4JS, modules are used as namespaces with explicit export and import statements. The notion of globals is not directly supported by N4JS as this leads to unexpected side effects (several components providing and thus overriding global definitions, for example).
3. N4JS defines a (ECMAScript 6 compatible) concept of object-oriented programming which may conflict with other plain JavaScript solutions.

To overcome these problems, N4JS provides a couple of techniques summarized in this chapter.

15.1. Type Inference and Validation for Plain JS

GH-45¹

In plain JavaScript mode:

1. All declared variables are inferred to `any+`.
2. All declared functions return and accept a variadic number of arguments of type `any+`.
3. It is allowed to use the `return` statement with or without an expression.
4. New expressions with a receiver of `any+` is allowed.
5. No type arguments are required for generic built-in types.
6. Assigning a value to a read-only variable is not checked.
7. Undeclared variables are treated as `any+` as well.

Note that this essentially disables all validation particularly since methods such as the 'import'-like function `require` are unknown.

15.2. External Declarations

IDE-572²
IDE-1236³

N4JS supports declaring external classes as a means to declare classes whose implementation is not N4JS so they can be used from N4JS. Together with structural typing , this allows N4JS to seamlessly

¹ <https://github.com/NumberFour/N4JS/issues/45>

² <https://jira.numberfour.eu/browse/IDE-572>

³ <https://jira.numberfour.eu/browse/IDE-1236>

integrate frameworks and libraries which have not been implemented in N4JS but in plain ECMAScript or another language.

[[External allowed occurrences]]

- Declarations with external flags are only allowed in files with the extension \$n4jsd\$ (so called N4JS definition files).
- Only external classes, external interfaces marked with `@N4JS`, external enums, external function declarations and structurally typed interfaces are allowed in a \$n4jsd\$ file.
- Declarations with external flags are allowed to subclass built-in type `Error` type and all of its descendants such as `EvalError`, `RangeError`, `ReferenceError`, `SyntaxError`, `TypeError` and `URIError`, although any of the error types are annotated with `@N4JS`.

The following explanations apply to all external declarations except where stated otherwise.

In general, an external declaration uses the same syntax as the declaration of a normal N4JS declaration with the addition of the modifier `external`.

External classifiers are always 'entirely external' in that it is not possible to combine defined methods and external methods within a single class or interface.

[[External classes inheritance]]

1. An external class *without* the `@N4JS` annotation can only inherit from another external class or from one of the built-in ECMAScript types (e.g. `Object`). That is, by default external classes are derived from `Object`.
2. An external class *with* the annotation `@N4JS` can only inherit from another external class annotated with `@N4JS` or from non-external N4JS classes.

[[Structurally typed interface implementation]]

1. An external class *without* the annotation `@N4JS` can only be implemented by structurally typed interfaces.
2. An external class *with* the annotation `@N4JS` can only be implemented by structurally typed interfaces annotated with `@N4JS`.
3. An external interface *without* the annotation `@N4JS` must be defined structurally.

[[External interface inheritance]]

1. An interface in a n4jsd file *without* the annotation `@N4JS` can only inherit from another interface within a n4jsd file.
2. An interface *with* the `@N4JS` annotation can only inherit from another interface annotated with `@N4JS`.

[[External class interface members]]

1. The static and instance methods, getters and setters of an external class must not have a method body.

2. The static and instance fields of an external class must not have an initializer.
3. The constructor of an external class without the annotation `@N4JS` must not be declared private.
4. Methods in interfaces with default implementation which cannot be expressed in the definition file must be annotated with `@ProvidesDefaultImplementation`. This is only allowed in interfaces annotated with `@N4JS`.
5. Fields in interfaces or classes with initializers which cannot be expressed in the definition file, must be annotated with `@ProvidesInitializer`. This is only allowed in classes or interfaces annotated with `@N4JS`.

 GH-431⁴
 IDE-1403⁵
 IDE-1509⁶

This means that in external classes, all members except constructors may be declared private even if the class is not annotated with `@N4JS`. In interfaces, however, private members are disallowed anyway, cf. .

[[Other external declarations]] Other external declarations

1. The literals of an external enum must not have a value.
2. An external function declaration must not have a body.

15.2.1. Declaring externals

By default, the implicit supertype of an external class is Object. If the `@N4JS` annotation is provided it is N4Object. If a superclass is explicitly given, the constraints from the previous section apply.

15.2.2. Instantiating external classes

In most cases, it is desirable to instantiate external classes from external projects. Publicly exporting the class definition and providing a public constructor is good practice.

In some cases, the instantiation from an outer scope is not wanted. A possible approach is to use a structurally typed interface instead of a class to link to the implementation.

In case of API-definitions (see ???), it might be useful to limit the visibility of classes to narrower scopes such as package or private.

External declarations can be instantiated if the following three requirements are fulfilled (not a constraint!):

- External declarations have to be exported and be marked as public so they are accessible from outside.
- The contained or inherited constructor of an external class must be public.

⁴ <https://github.com/NumberFour/N4JS/issues/431>

⁵ <https://jira.numberfour.eu/browse/IDE-1403>

⁶ <https://jira.numberfour.eu/browse/IDE-1509>

- The external class must be linked to an implementation module (see below Section 15.2.3, “Implementation of External Declarations”).

15.2.3. Implementation of External Declarations

GH-242⁷

All external declarations must be associated with an external implementation module in one way or another. Any time the external declaration is imported, the compiler generates code that imports the corresponding implementation module at runtime.

There are two possible ways of linking an external declaration to its corresponding implementation:

1. By naming convention defined in the manifest.
2. By declaring that the implementation is provided by the JavaScript runtime, see ??? for details.

The naming convention is based on the `external` source fragments defined in the manifest (???). If the implementation is provided by the runtime directly, then this can be also specified in the manifest by a module filter.

The implicit link via the naming convention is used to link an external class declaration to its non-N4JS implementation module. It does not effect validation, but only compilation and runtime. Essentially, this makes the compiler generate code so that at runtime, the linked implementation module is imported instead of the declaration module.

In most use cases of external declarations you also want to disable validation and module wrapping by specifying appropriate filters in the manifest.

Occasionally it is not possible for the validation to correctly detect a corresponding implementation element. For that reason, it is possible to disable validation of implementations completely via `@@ignoreImplementation`.

[[req:169Implementation of External Declarations]] For a given external declaration \$D\$ but not for API-definitions⁸, the following constraints must hold:

IDE-1099⁹

1. If the declaration is neither provided by runtime nor validation of implementation is disabled, a corresponding implementation must be found by the naming convention. If no such implementation is found, a warning is generated.

[[ex:External Definitions and Their Implementations]] If, in addition to standard `source`, the `source-external` fragment is provided in `Sources`, \$n4jsd\$ files in the folder tree below source folders will be related to modules of the same name in the external folders. This is shown in ???.

⁷ <https://github.com/NumberFour/N4JS/issues/242>

⁸ ???

⁹ <https://jira.numberfour.eu/browse/IDE-1099>



15.2.4. Example

Assume the following non-N4JS module:

```
module.exports = {
    "Point": function Point(x, y) {
        this.x = x;
        this.y = y;
    },
    "Circle": function Circle(center, radius) {
        this.center = center;
        this.radius = radius;
        this.scaleX = function(x){ this.x = x; }
        this.scaleY= function(y){ this.y = y; }
    }
}
```

Assuming

- shapes.js is placed in project folder /external/a/b/shapes.js
- shapes.n4jsd is placed in project folder /src/a/b/shapes.n4jsd
- manifest.n4mf defines src as source folder and external as external source folder

the following N4JS external class declarations in shapes.n4jsd are sufficient:

```
export external public class Point {
    x: number; y: number;
    constructor(x: number, y: number);
}

export external public class Circle {
    center: Point; radius: number;
    constructor(center: Point, radius: number);
}
```

Note that the class and interface names in n4jsd files must match those in the js files, respectively.

[[ex:Structural typed external interfaces]]

```
export external public interface ~Scalable {
    scaleX(factor: number);
    scaleY(factor: number);
}

export external public class Circle implements Scalable {
    center: Point;
    radius: number; x: number; y: number;

    @Override public scaleX(factor: number);
```

```

    @Override public scaleY(factor: number);

    constructor(center: Point, radius: number);
}

```

15.3. Global Definitions

 IDE-1036 ¹⁰

Existing JavaScript libraries and built-in objects provided by certain JavaScript environments often globally define variables. Although it is not recommended to use global definitions, this cannot always be avoided.

N4JS supports global definitions via the annotation `Global`. This annotation can only be defined on modules (via `@@Global`) – this means that all declarations in the module are globally defined. ¹¹

We introduce a new pseudo property `$global$` on all declared elements accordingly:

Boolean flag set to true if annotation `@Global` is set in containing module. Flag indicates that the exported element is globally available and must not be imported.

 IDE-1036 ¹²

Since definition of global elements is not supported by N4JS directly, this can be only used in external definitions. A declaration with `$global$` can be used without explicit import statement. It is not possible to import these declarations.

Global Definitions

For a declaration `D` with `$D.global=TRUE$`, not a polyfill (`$D.polyfill=FALSE$`), the following constraints must hold:

1. The name of the definition must not be equal to any primitive type (`string`, `number` etc.), `any`, or an built-in N4 type (`N4Object` etc.).
2. If the name of the definition equals a basic runtime time Object Type then the project must be a runtime environment: `\begin{aligned} &D.name \in \{ \text{'Object', 'Function', 'Array', 'String', 'Boolean'} \} \& D.type=\text{runtimeEnvironment} \end{aligned}`

15.4. Runtime Definitions

 IDE-1036 ¹³

¹⁰ <https://jira.numberfour.eu/browse/IDE-1036>

¹¹ Global basically means that the module defines no namespace on its own. Thus the annotation is a script/module related annotation.

¹² <https://jira.numberfour.eu/browse/IDE-1036>

¹³ <https://jira.numberfour.eu/browse/IDE-1036>

Some elements are predefined by the JavaScript runtime such as DOM elements by the browser or built-in ECMAScript or non-standard objects. These elements can be defined by means of external definitions; however, no actual implementation can be provided as these elements are actually provided by the runtime itself.

Since these cases are rather rare and in order to enable additional checks such as verification that a given runtime actually provides the elements, this kind of element can only be defined in components of type runtime environment or runtime library (cf [???](#)).

N4JS supports runtime definitions via the annotation `@ProvidedByRuntime`. This annotation can be defined

- on modules (via `@@ProvidedByRuntime`)—this means that all declarations in the module are provided by the runtime
- on export statements or declarations.

We introduce a new pseudo property `$providedByRuntime$` accordingly:

Boolean flag set to true if the annotation `@ProvidedByRuntime` is set. Flag indicates that the element is only declared in the module but its implementation is provided by the runtime.

Since built-in types are usually defined globally, the annotation `@ProvidedByRuntime` is usually used in combination with `@Global`.

Provided By Runtime

For a declaration `D` with `$D.providedByRuntime=TRUE$`, the following constraints must hold:

 IDE-1036 ¹⁴

1. The declaration must either be an export declaration itself or an exportable declaration.
2. The declaration must be contained in a definition module.
3. The declaration must be (indirectly) contained in a component of type `$\lceil\text{runtimeEnvironment}\rceil$` or `$\lceil\text{runtimeLibrary}\rceil$`.
4. There must be no implementation file with the same name as the definition module if annotation is defined for a whole module.

 IDE-1084 ¹⁵

15.5. Applying Polyfills

 IDE-1142 ¹⁶

¹⁴ <https://jira.numberfour.eu/browse/IDE-1036>

¹⁵ <https://jira.numberfour.eu/browse/IDE-1084>

¹⁶ <https://jira.numberfour.eu/browse/IDE-1142>

(Runtime) Libraries often do not provide completely new types but modify existing types. The ECMA-402 Internationalization Standard [ECMA12a], for example, changes methods of the built-in class `Date` to be timezone-aware. Other scenarios include new functionality provided by browsers which are not part of an official standard yet. Even ECMAScript 6 [ECMA15a] extends the predecessor [ECMA11a] in terms of new methods or new method parameters added to existing types. It also adds completely new classes and features, of course.

The syntax of runtime polyfills is described in section [???](#). Here, an example of applying a runtime polyfill is detailed.

[[ex:Object.observe with Polyfill]] The following snippet demonstrates how to define a polyfill of the built-in class to add the new ECMAScript 7 observer functionality. This snippet has to be defined in a runtime library or environment.

```
@@ProvidedByRuntime
@@Global

@Polyfill
export external public class Object extends Object {
    public static Object observe(Object object, Function callback, Array<string>? accept);

}
```

A client referring to this runtime library (or environment) can now access the observer methods as if it were defined directly in the original declaration of `Object`.

Chapter 16. JSDoc

In N4JS, comments starting with two asterisks (in `/** ... */`) are interpreted as documentation comments. The format is similar to JavaDoc or Google Closure annotations.

16.1. General N4JSDoc Features

We distinguish between line and inline tags. The format of the content of a tag is specific to the tag. Most line tags, however, contain a description which is simply multiline text with nested inline tags. Every comment may start with a description.

16.1.1. Provided Inline Tags

@code

Small code snippet, not validated yet.

@link

Link to a type of element, not validated or supported in navigation yet.

16.2. N4JSDoc for User Projects

16.2.1. Standard Tags

@author

Name of author, repeat for multiple authors. Name of author is not validated.

@param

Parameter description, not validated at the moment.

@return

Return description, not validated at the moment.

16.2.2. Test Related Tags

The following tags are supposed to be used only in tests.

@testee

IDE-1469¹

¹ <https://jira.numberfour.eu/browse/IDE-1469>

Link to type (maybe a function) or member tested by the test.

1. Tag can be only used on either
 - a. methods annotated with `@Test`
 - b. classes in test projects or folders, cf. [the section called “@testeeFromType”](#).
2. Tag requires a single argument, which is a fully qualified name to a type, including the module specifier. Format is like this: `moduleSpecifier .' typeName (('.'|#) memberName)?
3. Tag is *not* repeatable, that is a single test method (or class) can refer to only one testee.
4. Tag precedes the `reqid` tag, i.e., if a `@testee` is specified, the `reqid` will be ignored.

 GH-635²

[[ex:@testee Example]] The target element is to be fully qualified including the module specifier. The module specifier is simply the source folder relative path name with forward slashes. Type and element are added to that using dot as a separator. For example:

```
/**  
 * @testee some/package/Module.Type.member  
 */
```

@testeeFromType

 IDE-41³

Instead of directly linking a test method to a testee, the testee is to be derived from the linked testee of the test class. This is useful if a base test class is defined with generic tests, e.g., for testing methods defined in an interface and implemented by some classes. This base test class is then extended by concrete test classes, correctly setting up the test fixture, e.g., creating instances of some classes implementing the interfaces tested in the base class.

[[ex:Usage of testeeFromType]] In the following example, the `is` used. This tag will lead to a test documentation for `B.foo` and `C.foo`.

```
abstract class Base {  
  /**  
   * @testeeFromType  
   */  
  @Test testFoo() {...}  
}  
  
/**  
 * @testee B.foo  
 */
```

² <https://github.com/NumberFour/N4JS/issues/635>

³ <https://jira.numberfour.eu/browse/SL-41>

```
class TestB extends Base {}

/**
 * @testee C.foo
 */
class TestC extends Base {}
```

Note that the resulting spec has to be double-checked for consistency since it is easily possible that too many constraints are generated.

@testeeType and @testeeMember

IDE-41⁴

Specifying the testee at the test method directly should be sufficient for most cases. The `@testeeFromType` tag already provides support for some cases in which a base test class is reused by subtypes. This case usually only works if the base test class tests a single method only. If the base test class tests several methods and if a sub test class only provides a different fixture, this mechanism is not sufficient. For that purpose, the two tags `@testeeFromType` and `@@testeeMember` are to be used. They enable the separation of a test related to a specific member and the concrete receiver type of the tested member.

The `@testeeType` is to be defined in the test class JSDoc (actually, it is not recognized when defined in a member JSDoc). The `@testeeMember` is specified in the test method JSDoc. The "real" testee is then computed from the testee type and the testee method.

This only works for instance members, so far! Note: There is no validation for invalid combinations!

[[ex:testeeType and testeeMethod]] Assume the following testees:

```
class A {
    foo(): void { .. }
    bar(): void { .. this.foo(); .. }
}

class B extends A {
    @Override foo() { .. }
}
```

Assume that the tests have to ensure the same semantics for `bar`, which is maybe changed by a wrong implementation of `foo`. That is, `bar` is to be tested in case of the receiver type `A` and `B`. This can be achieved by the following tests:

```
/**
 * @testeeType A.A
 */
class ATest {
    fixture(): A { return new A(); }
```

⁴ <https://jira.numberfour.eu/browse/SL-41>

```

/**
 * @testeeMember bar
 */
@Test testBar(): void { assertBehavior( fixture().bar() ); }
}

/**
 * @testeeType B.B
 */
class BTest extends ATest {
    @Override fixture(): B { return new B(); }
}

```

This actually defines two tests, which is also recognized by the spec exporter:

1. `testBar` for a receiver of type `A`:

```
ATest's JSDoc @testeeType + ATest.testBar's JSDoc @testeeMember = testee
A.A.bar
```

2. `testBar` for a receiver of type `B`:

```
BTest's JSDoc @testeeType + ATest.testBar's JSDoc @testeeMember = testee
B.B.bar
```

Note that in all cases when `@testeeFromType` or `@testeeType / @testeeMember` is used, the resulting spec has to be double-checked for consistency. Consider if the multiplication of spec constraints is truly required, in particular if the original semantics of a method is not changed. Remember: It is possible to write API tests and omit the spec constraint generation simply by not adding the testee links.

[[ex:testeeType and testeeMethod with omitted constraints]]

Assume testees similar as in [???](#). Since the semantics of `bar` is not changed in `B`, it is probably not necessary to generate the same constraint in the documentation for `bar` twice (one in the section for class `A` and another one in the section of class `B`). Still, we want the test to be executed for both receivers. This is how it is achieved:

```

abstract class BaseTest {
    abstract fixture(): A;

    /**
     * @testeeMember bar
     */
    @Test testBar(): void { assertBehavior( fixture().bar() ); }
}

/**
 * @testeeType A.A
 */
class ATest extends BaseTest {
    fixture(): A { return new A(); }
}

class BTest extends BaseTest {
    @Override fixture(): B { return new B(); }
}

```

```
}
```

This actually defines two tests as in the previous example. Only one constraint is created in the spec by the spec exporter:

1. `testBar` for a receiver of type `A`:
`ATest`'s JSDoc `@testeeType` + `BaseTest.testBar`'s JSDoc `@testeeMember` = testee
`A.A.bar`

Although a test for receiver of type `B` is run, no additional constraint is created since there is no `@testeeType` available neither in `BTest` nor in `BaseTest`.

`@reqid` in Tests

ID of feature used in LaTeX-code for the requirements section. If no testee (via one of the tags above) is given, then the test is linked to the requirement with given id.

16.3. N4JSDoc for API and Implementation Projects

IDE-1509⁵

The following tags are supposed to be used in API and implementation projects.

16.3.1. `@apiNote`

Simple note that is shown in the API compare view.

16.3.2. API Project Tags

The following tags are supposed to be used in API projects only.

`@apiState`

State of type or member definition, e.g., stable or draft. This can be used to define a history. In this case, the tag has to be repeated. For example:

```
/**  
 * @apiState stable (WK)  
 * @apiState reviewed (JvP)  
 */
```

⁵ <https://jira.numberfour.eu/browse/IDE-1509>

Chapter 17. Grammars

N4JS extends the ECMAScript 2015 language grammar and combines it with type expression.



These grammars are slightly simplified versions of the "real" Xtext grammars used in the implementation. These grammars are post-processed and combined with additional validators so not all constructs are necessarily available in N4JS.

17.1. Type Expressions Grammar

```
TypeRef:  
    TypeRefWithoutModifiers => undefModifier=UndefModifierToken?  
    | undefModifier=UndefModifierToken;  
  
TypeRefWithoutModifiers:  
    ((ParameterizedTypeRef | ThisTypeRef) => dynamic?='+'?)  
    | ConstructorTypeRef  
    | ClassifierTypeRef  
    | FunctionTypeExpression  
    | UnionTypeExpression  
    | IntersectionTypeExpression;  
  
TypeRefFunctionTypeExpression:  
    ParameterizedTypeRef  
    | ConstructorTypeRef  
    | ClassifierTypeRef  
    | UnionTypeExpression  
    | IntersectionTypeExpression  
    ;  
  
TypeRefForCast:  
    ParameterizedTypeRef  
    | ThisTypeRef  
    | ConstructorTypeRef  
    | ClassifierTypeRef  
    | FunctionTypeExpression;  
  
TypeRefInClassifierType:  
    ParameterizedTypeRefNominal  
    | ThisTypeRefNominal;  
  
ThisTypeRef:  
    ThisTypeRefNominal | ThisTypeRefStructural;  
  
ThisTypeRefNominal:  
    'this';  
  
ThisTypeRefStructural:  
    definedTypingStrategy=TypingStrategyUseSiteOperator  
    'this'  
    ('with' TStructMemberList)?;  
  
FunctionTypeExpression:
```

```

'{
  '@' 'This' '(' declaredThisType=TypeRefFunctionTypeExpression ')')?
  'function'
  ('<' ownedTypeVars+=TypeVariable (',' ownedTypeVars+=TypeVariable)* '>')?
  ('' TAnonymousFormalParameterList ')
  (':' returnTypeRef=TypeRef)?
  '}';

fragment TAnonymousFormalParameterList*:
  (fpars+=TAnonymousFormalParameter (',' fpars+=TAnonymousFormalParameter)*)?
;

TAnonymousFormalParameter:
  variadic?='...'? (=> name=TIdentifier ':')? typeRef=TypeRef
;

UnionTypeExpression:
  'union' '{}' typeRefs+=TypeRefWithoutModifiers (',' typeRefs+=TypeRefWithoutModifiers)*
  '}';
;

IntersectionTypeExpression:
  'intersection' '{}' typeRefs+=TypeRefWithoutModifiers (',' typeRefs
+=TypeRefWithoutModifiers)* '}';
;

ParameterizedTypeRef:
  ParameterizedTypeRefNominal | ParameterizedTypeRefStructural;

ParameterizedTypeRefStructural:
  definedTypingStrategy=TypingStrategyUseSiteOperator
  declaredType=[Type|TypeReferenceName]
  (=>'<' typeArgs+=TypeArgument (',' typeArgs+=TypeArgument)* '>')?
  ('with' TStructMemberList)?;

fragment TStructMemberList*: '{' (astStructuralMembers+=TStructMember (';'|',')?)* '}';
;

TStructMember:
  TStructGetter
  | TStructSetter
  | TStructMethod
  | TStructField;
;

TStructMethod:
  =>
  ('<' typeVars+=TypeVariable (',' typeVars+=TypeVariable)* '>')?
  name=TypesIdentifier '('
  ) TAnonymousFormalParameterList '
  (':' returnTypeRef=TypeRef)?
;
;

TStructField:
  name=TypesIdentifier (':' typeRef=TypeRef)?
;
;

TStructGetter:
  => ('get'
  name=TypesIdentifier)
  '(' ')' (':' declaredTypeRef=TypeRef)?
;
;
```

```

TStructSetter:
    => ('set'
        name=TypesIdentifier)
        (' fpar=TAnonymousFormalParameter ')'
;

ParameterizedTypeRefNominal:
    declaredType=[Type|TypeReferenceName]
    (=> '<' typeArgs+=TypeArgument (',' typeArgs+=TypeArgument)* '>')?;

TypingStrategyUseSiteOperator:
    '~' ('~' | STRUCTMODSUFFIX)?;

TypingStrategyDefSiteOperator:
    '~';

terminal STRUCTMODSUFFIX:
    ('r' | 'i' | 'w') '~'
;

ConstructorTypeRef:
    'constructor' '{}' staticTypeRef=TypeRefInClassifierType '}';
;

ClassifierTypeRef:
    'type' '{}' staticTypeRef=TypeRefInClassifierType '}';
;

TypeReferenceName:
    IDENTIFIER ('.' IDENTIFIER)*;
;

TypeArgument:
    Wildcard | TypeRef;
;

Wildcard:
    => ('?') ((('extends' declaredUpperBound=TypeRef) | ('super'
        declaredLowerBound=TypeRef))?)?;
;

UndefModifierToken:
    '?';
;

TypeVariable:
    name=IDENTIFIER ('extends' declaredUpperBounds+=ParameterizedTypeRef ('&'
        declaredUpperBounds+=ParameterizedTypeRef)* )?;
;

TypesIdentifier:
    IDENTIFIER
    | 'get' | 'set' | 'abstract' | 'project'
    | 'union' | 'intersection'
    | 'as' | 'from' | 'type' | 'void' | 'null';
;

TIdentifier:
    TypesIdentifier
    | 'implements' | 'interface'
    | 'private' | 'protected' | 'public'
    | 'static'
;
;

terminal IDENTIFIER:
;
```

```
IDENTIFIER_START IDENTIFIER_PART*;

terminal INT:
    DECIMAL_INTEGER_LITERAL_FRAGMENT;

terminal ML_COMMENT:
    ML_COMMENT_FRAGMENT;

terminal SL_COMMENT:
    '//' (!LINE_TERMINATOR_FRAGMENT)*;

terminal EOL:
    LINE_TERMINATOR_SEQUENCE_FRAGMENT;

terminal WS:
    WHITESPACE_FRAGMENT++;

terminal fragment UNICODE_ESCAPE_FRAGMENT:
    '\\\\' ('u' (
        HEX_DIGIT (HEX_DIGIT (HEX_DIGIT HEX_DIGIT?)?)?
        | '{' HEX_DIGIT* '}'
    )?)?;

terminal fragment IDENTIFIER_START:
    UNICODE_LETTER_FRAGMENT
    | '$'
    | '_'
    | UNICODE_ESCAPE_FRAGMENT;

terminal fragment IDENTIFIER_PART:
    UNICODE_LETTER_FRAGMENT
    | UNICODE_ESCAPE_FRAGMENT
    | '$'
    | UNICODE_COMBINING_MARK_FRAGMENT
    | UNICODE_DIGIT_FRAGMENT
    | UNICODE_CONNECTOR_PUNCTUATION_FRAGMENT
    | ZWNJ
    | ZWJ;

terminal DOT_DOT:
    '..'
;
```

17.2. N4JS Language Grammar

```
Script: annotations+=ScriptAnnotation*
       scriptElements+=ScriptElement*;

ScriptElement:
    AnnotatedScriptElement
    | N4ClassDeclaration<Yield=false>
    | N4InterfaceDeclaration<Yield=false>
    | N4EnumDeclaration<Yield=false>
    | ImportDeclaration
    | ExportDeclaration
    | RootStatement<Yield=false>
```

```

;

AnnotatedScriptElement:
    AnnotationList (
        {ExportDeclaration.annotationList=current} ExportDeclarationImpl
        | {ImportDeclaration.annotationList=current} ImportDeclarationImpl
        | {FunctionDeclaration.annotationList=current}
            => ((declaredModifiers+=N4Modifier)* AsyncNoTrailingLineBreak
                ->FunctionImpl<Yield=false,YieldIfGenerator=false,Expression=false>)
        | (
            (
                {N4ClassDeclaration.annotationList=current}
                (declaredModifiers+=N4Modifier)*
                'class' typingStrategy=TypingStrategyDefSiteOperator?
                name=BindingIdentifier<Yield=false>
                TypeVariables?
                ClassExtendsClause<Yield=false>?
                | {N4InterfaceDeclaration.annotationList=current}
                    (declaredModifiers+=N4Modifier)*
                    'interface' typingStrategy=TypingStrategyDefSiteOperator?
                    name=BindingIdentifier<Yield=false>
                    TypeVariables?
                    InterfaceImplementsList?
                )
                Members<Yield=false>
            )
            | {N4EnumDeclaration.annotationList=current}
                (declaredModifiers+=N4Modifier)*
                'enum' name=BindingIdentifier<Yield=false>
                '{'
                literals+=N4EnumLiteral (',' literals+= N4EnumLiteral)*
                '}'
            )
        )
    ;
fragment TypeVariables*:
    '<' typeVars+=TypeVariable (',' typeVars+=TypeVariable)* '>'
    ;

ExportDeclaration:
    ExportDeclarationImpl
    ;

fragment ExportDeclarationImpl*:
    'export' (
        wildcardExport?='*' ExportFromClause Semi
        | ExportClause ->ExportFromClause? Semi
        | exportedElement=ExportableElement
        | defaultExport?='default' (->exportedElement=ExportableElement |
        defaultExportedExpression=AssignmentExpression<In=true,Yield=false> Semi)
    )
    ;

fragment ExportFromClause*:
    'from' reexportedFrom=[types::TModule|ModuleSpecifier]
    ;

fragment ExportClause*:

```

```

' { '
    (namedExports+=ExportSpecifier (',' namedExports+=ExportSpecifier)* ','?)?
' }'
;

ExportSpecifier:
    element=IdentifierRef<Yield=false> ('as' alias=IdentifierName)?
;

ExportableElement:
    AnnotatedExportableElement<Yield=false>
| N4ClassDeclaration<Yield=false>
| N4InterfaceDeclaration<Yield=false>
| N4EnumDeclaration<Yield=false>
| ExportedFunctionDeclaration<Yield=false>
| ExportedVariableStatement
;

AnnotatedExportableElement <Yield>:
    AnnotationList (
        {FunctionDeclaration.annotationList=current}
        (declaredModifiers+=N4Modifier)* AsyncNoTrailingLineBreak
        FunctionImpl<Yield, Yield, Expression=false>
    | {ExportedVariableStatement.annotationList=current}
        (declaredModifiers+=N4Modifier)*
        varStmtKeyword=VariableStatementKeyword
        varDeclsOrBindings+=ExportedVariableDeclarationOrBinding<Yield> ( ','
        varDeclsOrBindings+=ExportedVariableDeclarationOrBinding<Yield> )* Semi
    | (
        (
            {N4ClassDeclaration.annotationList=current}
            (declaredModifiers+=N4Modifier)*
            'class' typingStrategy=TypingStrategyDefSiteOperator?
            name=BindingIdentifier<Yield>
            TypeVariables?
            ClassExtendsClause<Yield>?
        | {N4InterfaceDeclaration.annotationList=current}
            (declaredModifiers+=N4Modifier)*
            ('interface') typingStrategy=TypingStrategyDefSiteOperator?
            name=BindingIdentifier<Yield>
            TypeVariables?
            InterfaceImplementsList?
        )
        Members<Yield>
    )
    | {N4EnumDeclaration.annotationList=current}
        (declaredModifiers+=N4Modifier)*
        'enum' name=BindingIdentifier<Yield>
    ' { '
        literals+=N4EnumLiteral ( ',' literals+= N4EnumLiteral)*
    ' }'
)
;

ImportDeclaration:
    ImportDeclarationImpl
;

```

```

fragment ImportDeclarationImpl*:
    'import' (
        ImportClause importFrom?='from'
        )? module=[types::TModule|ModuleSpecifier] Semi
    ;

fragment ImportClause*:
    importSpecifiers+=DefaultImportSpecifier (',' ImportSpecifiersExceptDefault)?
    | ImportSpecifiersExceptDefault
    ;

fragment ImportSpecifiersExceptDefault*:
    importSpecifiers+=NamespaceImportSpecifier
    | '{' (importSpecifiers+=NamedImportSpecifier (',' importSpecifiers
    +=NamedImportSpecifier)* ','?)? '}'
    ;

NamedImportSpecifier:
    importedElement=[types::TExportableElement|BindingIdentifier<Yield=false>]
    | importedElement=[types::TExportableElement|IdentifierName] 'as'
    alias=BindingIdentifier<Yield=false>
    ;

DefaultImportSpecifier:
    importedElement=[types::TExportableElement|BindingIdentifier<Yield=false>]
    ;

NamespaceImportSpecifier: '*' 'as' alias=BindingIdentifier<false> (declaredDynamic?='+')?;

ModuleSpecifier: STRING;

FunctionDeclaration <Yield>:
    => ((declaredModifiers+=N4Modifier)* AsyncNoTrailingLineBreak
        -> FunctionImpl <Yield,Yield,Expression=false>
    ) => Semi?
    ;

fragment AsyncNoTrailingLineBreak *: (declaredAsync?='async' NoLineTerminator)?;

fragment FunctionImpl<Yield, YieldIfGenerator, Expression*>*:
    'function'
    (
        generator?='*' FunctionHeader<YieldIfGenerator,Generator=true>
        FunctionBody<Yield=true,Expression>
        | FunctionHeader<Yield,Generator=false> FunctionBody<Yield=false,Expression>
    )
    ;

fragment FunctionHeader<Yield, Generator*>*:
    TypeVariables?
    name=BindingIdentifier<Yield>?
    StrictFormalParameters<Yield=Generator>
    (-> ':' returnTypeRef=TypeRef)?
    ;

fragment FunctionBody <Yield, Expression*>*:
    <Expression> body=Block<Yield>
    | <!Expression> body=Block<Yield>?

```

```

;

ExportedFunctionDeclaration<Yield>:
    FunctionDeclaration<Yield>
;

FunctionTypeExpression:
    {types::FunctionTypeExpression}
    '{'
    ('@' 'This' '(' declaredThisType=TypeRefFunctionTypeExpression ')')?
    'function'
    ('<' ownedTypeVars+=TypeVariable (',' ownedTypeVars+=TypeVariable)* '>')?
    '('
    (fpars+=TAnonymousFormalParameter (',' fpars+=TAnonymousFormalParameter)*)?
    ')'
    (':' returnTypeRef=TypeRef)?
    '}';

AnnotatedFunctionDeclaration <Yield, Default>:
    annotationList=AnnotationList
    (declaredModifiers+=N4Modifier)* AsyncNoTrailingLineBreak
    FunctionImpl<Yield, Yield, Expression=false>
;

FunctionExpression:
    (FunctionImpl<Yield=false, YieldIfGenerator=true, Expression=true>
    )
;

AsyncFunctionExpression:
    =>(declaredAsync?='async' NoLineTerminator 'function')
        FunctionHeader<Yield=false, Generator=false> FunctionBody<Yield=false, Expression=true>
;

ArrowExpression <In, Yield>:
    => (
        (
            (' (fpars+=FormalParameter<Yield>
                (', ' fpars+=FormalParameter<Yield>)*)?
            ') (':' returnTypeRef=TypeRef)?
            | =>(declaredAsync?='async' NoLineTerminator '(')
                (fpars+=FormalParameter<Yield> (', ' fpars+=FormalParameter<Yield>)*)?
                ') (':' returnTypeRef=TypeRef)?
            | fpars+=BindingIdentifierAsFormalParameter<Yield>
        )
        '=>'
    )
    (-> hasBracesAroundBody?='{ body=BlockMinusBraces<Yield> '}')
    | body=ExpressionDisguisedAsBlock<In>
;
;

fragment StrictFormalParameters <Yield>*:
    (' (fpars+=FormalParameter<Yield> (', ' fpars+=FormalParameter<Yield>)*)? ')
;

BindingIdentifierAsFormalParameter <Yield>: name=BindingIdentifier<Yield>;

```

```

BlockMinusBraces <Yield>: statements+=Statement<Yield>*;

ExpressionDisguisedAsBlock <In>:
    statements+=AssignmentExpressionStatement<In>
;

AssignmentExpressionStatement <In>: expression=AssignmentExpression<In, Yield=false>;

AnnotatedExpression <Yield>:
    ExpressionAnnotationList (
        {N4ClassExpression.annotationList=current}
        'class' name=BindingIdentifier<Yield>?
        ClassExtendsClause<Yield>?
        Members<Yield>
    | {FunctionExpression.annotationList=current} AsyncNoTrailingLineBreak
        FunctionImpl<Yield=false, YieldIfGenerator=true, Expression=true>
)
;

TypeVariable:
    name=IdentifierOrThis
    ( 'extends' declaredUpperBounds+=ParameterizedTypeRefNominal
        ('&' declaredUpperBounds+=ParameterizedTypeRefNominal)*
    )?
;

FormalParameter <Yield>:
    BindingElementFragment<Yield>
;

fragment BindingElementFragment <Yield>*:
    (=> bindingPattern=BindingPattern<Yield>
    | annotations+=Annotation*
        (
            variadic?='...'? name=BindingIdentifier<Yield> ColonSepTypeRef?
        )
    )
    ('=' initializer=AssignmentExpression<In=true, Yield>)?
;

fragment ColonSepTypeRef*:
    ':' declaredTypeRef=TypeRef
;

Block <Yield>: => ('{' statements+=Statement<Yield>* '}');
RootStatement <Yield>:
    Block<Yield>
    | FunctionDeclaration<Yield>
    | VariableStatement<In=true, Yield>
    | EmptyStatement
    | LabelledStatement<Yield>
    | ExpressionStatement<Yield>
    | IfStatement<Yield>
    | IterationStatement<Yield>
    | ContinueStatement<Yield>
    | BreakStatement<Yield>
    | ReturnStatement<Yield>
    | WithStatement<Yield>
;
```

```

    | SwitchStatement<Yield>
    | ThrowStatement<Yield>
    | TryStatement<Yield>
    | DebuggerStatement
;

Statement <Yield>:
    AnnotatedFunctionDeclaration<Yield, Default=false>
    | RootStatement<Yield>
;

enum VariableStatementKeyword:
    var='var' | const='const' | let='let'
;

VariableStatement <In, Yield>:
    =>(varStmtKeyword=VariableStatementKeyword
    )
    varDeclsOrBindings+=VariableDeclarationOrBinding<In,Yield,false>
    (',' varDeclsOrBindings+=VariableDeclarationOrBinding<In,Yield,false>)* Semi
;

ExportedVariableStatement:
    (declaredModifiers+=N4Modifier)*
    varStmtKeyword=VariableStatementKeyword
    varDeclsOrBindings+=ExportedVariableDeclarationOrBinding<Yield=false>
    (',' varDeclsOrBindings+=ExportedVariableDeclarationOrBinding<Yield=false>)* Semi
;

VariableDeclarationOrBinding <In, Yield, OptionalInit>:
    VariableBinding<In,Yield,OptionalInit>
    | VariableDeclaration<In,Yield,true>
;

VariableBinding <In, Yield, OptionalInit>:
    => pattern=BindingPattern<Yield> (
        <OptionalInit> ('=' expression=AssignmentExpression<In,Yield>)??
        | <!OptionalInit> '=' expression=AssignmentExpression<In,Yield>
    )
;

VariableDeclaration <In, Yield, AllowType>:
    VariableDeclarationImpl<In,Yield,AllowType>;
;

fragment VariableDeclarationImpl <In, Yield, AllowType>*:
    annotations+=Annotation*
    (
        <AllowType> =>(
            name=BindingIdentifier<Yield> ColonSepTypeRef??
            ) ('=' expression=AssignmentExpression<In,Yield>)??
        | <!AllowType> =>(
            name=BindingIdentifier<Yield>
            ) ('=' expression=AssignmentExpression<In,Yield>)??
    )
;

ExportedVariableDeclarationOrBinding <Yield>:
    ExportedVariableBinding<Yield>
;
```

```

|   ExportedVariableDeclaration<Yield>
;

ExportedVariableBinding <Yield>:
=> pattern=BindingPattern<Yield> '=' expression=AssignmentExpression<In=true,Yield>
;

ExportedVariableDeclaration <Yield>:
    VariableDeclarationImpl<In=true,Yield,AllowType=true>
;
EmptyStatement: ';';
ExpressionStatement <Yield>: expression=Expression<In=true,Yield> Semi;

IfStatement <Yield>: 'if' '(' expression=Expression<In=true,Yield> ')'
    ifStmt=Statement<Yield> (=> 'else' elseStmt=Statement<Yield>) ?;

IterationStatement <Yield>:
    DoStatement<Yield>
|   WhileStatement<Yield>
|   ForStatement<Yield>
;

DoStatement <Yield>: 'do' statement=Statement<Yield> 'while'
    '(' expression=Expression<In=true,Yield> ')' => Semi?;
WhileStatement <Yield>: 'while' '(' expression=Expression<In=true,Yield> ')'
    statement=Statement<Yield>;

ForStatement <Yield>:
    'for' '('
    (
        =>(initExpr=LetIdentifierRef forIn?='in' expression=Expression<In=true,Yield>
    ')')
    |   (   ->varStmtKeyword=VariableStatementKeyword
        (
            =>(varDeclsOrBindings
+=BindingIdentifierAsVariableDeclaration<In=false,Yield>
            (forIn?='in' | forOf?='of') -
>expression=AssignmentExpression<In=true,Yield>?) )
        |   varDeclsOrBindings
+=VariableDeclarationOrBinding<In=false,Yield,OptionalInit=true>
        (
            (', ' varDeclsOrBindings
+=VariableDeclarationOrBinding<In=false,Yield,false>)* ';' '
            expression=Expression<In=true,Yield>? ';' '
updateExpr=Expression<In=true,Yield>?
            |   forIn?='in' expression=Expression<In=true,Yield>?
            |   forOf?='of' expression=AssignmentExpression<In=true,Yield>?
        )
    )
    |   initExpr=Expression<In=false,Yield>
    (
        ';' expression=Expression<In=true,Yield>? ';' '
updateExpr=Expression<In=true,Yield>?
        |   forIn?='in' expression=Expression<In=true,Yield>?
        |   forOf?='of' expression=AssignmentExpression<In=true,Yield>?
    )
    |   ';' expression=Expression<In=true,Yield>? ';' '
updateExpr=Expression<In=true,Yield>?

```

```
)  
')'  
) statement=Statement<Yield>  
;  
  
LetIdentifierRef:  
    id=[types::IdentifiableElement|LetAsIdentifier]  
;  
  
LetAsIdentifier: 'let';  
  
BindingIdentifierAsVariableDeclaration <In, Yield>:  
    name=BindingIdentifier<Yield>  
;  
  
ContinueStatement <Yield>: 'continue' (label=[LabelledStatement|BindingIdentifier<Yield>])?  
Semi;  
  
BreakStatement <Yield>: 'break' (label=[LabelledStatement|BindingIdentifier<Yield>])? Semi;  
  
ReturnStatement <Yield>: 'return' (expression=Expression<In=true,Yield>)? Semi;  
  
WithStatement <Yield>: 'with' '(' expression=Expression<In=true,Yield> ')'  
statement=Statement<Yield>;  
  
SwitchStatement <Yield>:  
    'switch' '(' expression=Expression<In=true,Yield> ')' '{'  
    (cases+=CaseClause<Yield>)*  
    ((cases+=DefaultClause<Yield>)  
    (cases+=CaseClause<Yield>))* '}'  
;  
  
CaseClause <Yield>: 'case' expression=Expression<In=true,Yield> ':' (statements  
+=Statement<Yield>)*;  
  
DefaultClause <Yield>: 'default' ':' (statements+=Statement<Yield>)*;  
  
LabelledStatement <Yield>: => (name=BindingIdentifier<Yield> ':') statement=Statement<Yield>;  
  
ThrowStatement <Yield>:  
    'throw' expression=Expression<In=true,Yield> Semi;  
  
TryStatement <Yield>:  
    'try' block=Block<Yield>  
    ((catch=CatchBlock<Yield> finally=FinallyBlock<Yield>?) | finally=FinallyBlock<Yield>)  
;  
  
CatchBlock <Yield>: 'catch' '(' catchVariable=CatchVariable<Yield> ')' block=Block<Yield>;  
  
CatchVariable <Yield>:  
    =>bindingPattern=BindingPattern<Yield>  
    | =>(name=BindingIdentifier<Yield> -> ColonSepTypeRef)  
    | name=BindingIdentifier<Yield>  
;  
  
FinallyBlock <Yield>: 'finally' block=Block<Yield>;  
  
DebuggerStatement:
```

```
'debugger' Semi;

PrimaryExpression <Yield>:
  ThisLiteral
  | SuperLiteral
  | IdentifierRef<Yield>
  | ParameterizedCallExpression<Yield>
  | Literal
  | ArrayLiteral<Yield>
  | ObjectLiteral<Yield>
  | ParenExpression<Yield>
  | AnnotatedExpression<Yield>
  | FunctionExpression
  | AsyncFunctionExpression
  | N4ClassExpression<Yield>
  | TemplateLiteral<Yield>
;

Parens <Yield>: '(' expression=Expression<In=true,Yield> ')';

IdentifierRef <Yield>:
  id=[types::IdentifiableElement|BindingIdentifier<Yield>]
;

SuperLiteral: 'super';

ThisLiteral: 'this';

ArrayLiteral <Yield>:
  '['
    elements+=ArrayPadding* (
      elements+=ArrayElement<Yield>
      (',' elements+=ArrayPadding* elements+=ArrayElement<Yield>)*
      (trailingComma?=',' elements+=ArrayPadding*)?
    )?
  ']'
;

ArrayPadding: ',';

ArrayElement <Yield>: spread?='...'? expression=AssignmentExpression<In=true,Yield>;

ObjectLiteral <Yield>: '{'
  propertyAssignments+=PropertyAssignment<Yield>
  (',' propertyAssignments+=PropertyAssignment<Yield>)* ','?
)？
''

PropertyAssignment <Yield>:
  AnnotatedPropertyAssignment<Yield>
  | PropertyNameValuePair<Yield>
  | PropertyGetterDeclaration<Yield>
  | PropertySetterDeclaration<Yield>
  | PropertyMethodDeclaration<Yield>
  | PropertyNameValuePairSingleName<Yield>
;
```

```

AnnotatedPropertyAssignment <Yield>:
    PropertyAssignmentAnnotationList (
        => ( {PropertyNameValuePair.annotationList=current} declaredTypeRef=TypeRef?
            LiteralOrComputedPropertyName<Yield> ':'
        ) expression=AssignmentExpression<In=true,Yield>
    | => ({PropertyGetterDeclaration.annotationList=current}
        GetterHeader<Yield>
        ) body=Block<Yield=false>
    | => ({PropertySetterDeclaration.annotationList=current}
        'set' -> LiteralOrComputedPropertyName <Yield>
        ) '(' fpar=FormalParameter<Yield> ')' body=Block<Yield=false>
    | => ({PropertyMethodDeclaration.annotationList=current}
        TypeVariables? returnTypeRef=TypeRef?
        (generator?='*' LiteralOrComputedPropertyName<Yield> ->MethodParamsAndBody
<Generator=true>
        | LiteralOrComputedPropertyName<Yield> -> MethodParamsAndBody
<Generator=false>
        )
        )
        ) ';'?
    | {PropertyNameValuePairSingleName.annotationList=current}
        declaredTypeRef=TypeRef? identifierRef=IdentifierRef<Yield>
        ( '=' expression=AssignmentExpression<In=true,Yield>)?)
;
;

PropertyMethodDeclaration <Yield>:
    => (TypeVariables? returnTypeRef=TypeRef?
        (
            generator?='*' LiteralOrComputedPropertyName<Yield>
            ->MethodParamsAndBody<Generator=true>
            | LiteralOrComputedPropertyName<Yield> ->MethodParamsAndBody
<Generator=false>
            )
        )
        )
        ';'?
;
;

PropertyNameValuePair <Yield>:
    => (
        declaredTypeRef=TypeRef? LiteralOrComputedPropertyName<Yield> ':'
    )
    expression=AssignmentExpression<In=true,Yield>
;
;

PropertyNameValuePairSingleName <Yield>:
    declaredTypeRef=TypeRef?
    identifierRef=IdentifierRef<Yield>
    ('=' expression=AssignmentExpression<In=true,Yield>)?
;
;

PropertyGetterDeclaration <Yield>:
    => (
        GetterHeader<Yield>
    )
    body=Block<Yield=false>
;
;

PropertySetterDeclaration <Yield>:
    => (

```

```

'set'
->LiteralOrComputedPropertyName <Yield>
)
(' fpar=FormalParameter<Yield> ') body=Block<Yield=false>
;

ParameterizedCallExpression <Yield>:
TypeArguments
target=IdentifierRef<Yield>
ArgumentsWithParentheses<Yield>
;

LeftHandSideExpression <Yield>:
MemberExpression<Yield> (
{ParameterizedCallExpression.target=current} ArgumentsWithParentheses<Yield>
(
{ParameterizedCallExpression.target=current} ArgumentsWithParentheses<Yield>
| {IndexedAccessExpression.target=current} IndexedAccessExpressionTail<Yield>
| {ParameterizedPropertyAccessExpression.target=current}
ParameterizedPropertyAccessExpressionTail<Yield>
| ->({TaggedTemplateString.target=current} template=TemplateLiteral<Yield>
)*
)?
;

fragment Arguments <Yield>*:
arguments+=AssignmentExpression<In=true,Yield>
(, ' arguments+=AssignmentExpression<In=true,Yield>)*
(, ' spread?='...' arguments+=AssignmentExpression<In=true,Yield>)??
| spread?='...' arguments+=AssignmentExpression<In=true,Yield>
;

fragment TypeArguments*:
'<' typeArgs+=TypeRef (, ' typeArgs+=TypeRef)* '>'
;

fragment ArgumentsWithParentheses <Yield>*:
(' Arguments<Yield>? ')
;

MemberExpression <Yield>:
=>('new' '.') 'target'
| => ('new') callee=MemberExpression<Yield> (-> TypeArguments)?
(=> withArgs?='(' Arguments<Yield>? ')
(
{IndexedAccessExpression.target=current} IndexedAccessExpressionTail<Yield>
| {ParameterizedPropertyAccessExpression.target=current}
ParameterizedPropertyAccessExpressionTail<Yield>
| {TaggedTemplateString.target=current} template=TemplateLiteral<Yield>
)*
)?
| PrimaryExpression<Yield> (
{IndexedAccessExpression.target=current} IndexedAccessExpressionTail<Yield>
| {ParameterizedPropertyAccessExpression.target=current}
ParameterizedPropertyAccessExpressionTail<Yield>
| {TaggedTemplateString.target=current} template=TemplateLiteral<Yield>
)*
;

```

```
fragment IndexedAccessExpressionTail <Yield>*:
    '[' index=Expression<In=true, Yield> ']'
;

fragment ParameterizedPropertyAccessExpressionTail <Yield>*:
    '.' TypeArguments? property=[types::IdentifiableElement|IdentifierName]
;

PostfixExpression <Yield>:
    LeftHandSideExpression<Yield> (
        =>({PostfixExpression.expression=current} op=PostfixOperator
        )
    )?
;

enum PostfixOperator: inc='++' | dec='--';

CastExpression <Yield>: PostfixExpression<Yield>
    (=>({CastExpression.expression=current} 'as') targetTypeRef=TypeRefForCast)?;

UnaryExpression <Yield>:
    CastExpression<Yield>
    | (op=UnaryOperator expression=UnaryExpression<Yield>);

enum UnaryOperator: delete | void | typeof | inc='++' | dec='--' | pos='+' | neg='-' |
    inv='~' | not='!';

MultiplicativeExpression <Yield>: UnaryExpression<Yield>
    (=>({MultiplicativeExpression.lhs=current} op=MultiplicativeOperator)
    rhs=UnaryExpression<Yield>)*;

enum MultiplicativeOperator: times='*' | div='/' | mod='%';

AdditiveExpression <Yield>: MultiplicativeExpression<Yield>
    (=>({AdditiveExpression.lhs=current} op=AdditiveOperator)
    rhs=MultiplicativeExpression<Yield>)*;

enum AdditiveOperator: add='+' | sub='-';

ShiftExpression <Yield>: AdditiveExpression<Yield>
    (=>({ShiftExpression.lhs=current} op=ShiftOperator rhs=AdditiveExpression<Yield>))*
;

ShiftOperator:
    '>' '>' '>'? |
    '<<' |
;

RelationalExpression <In, Yield>: ShiftExpression<Yield>
    =>({RelationalExpression.lhs=current} op=RelationalOperator<In>
    ->rhs=ShiftExpression<Yield>)*;

RelationalOperator <In>:
    '<' | '>' | '<=' | '>=' | 'instanceof' | <In> 'in';

EqualityExpression <In, Yield>: RelationalExpression<In, Yield>
```

```

(=>({EqualityExpression.lhs=current} op=EqualityOperator)
rhs=RelationalExpression<In,Yield>)*;

enum EqualityOperator: same==='==' | nsame='!=!' | eq==='==' | neq='!=';

BitwiseANDExpression <In, Yield>: EqualityExpression<In,Yield>
(=>({BinaryBitwiseExpression.lhs=current} op=BitwiseANDOperator)
rhs=EqualityExpression<In,Yield>)*;

BitwiseANDOperator: '&';

BitwiseXORExpression <In, Yield>: BitwiseANDExpression<In,Yield>
(=>({BinaryBitwiseExpression.lhs=current} op=BitwiseXOROperator)
rhs=BitwiseANDExpression<In,Yield>)*;

BitwiseXOROperator: '^';

BitwiseORExpression <In, Yield>: BitwiseXORExpression<In,Yield>
(=>({BinaryBitwiseExpression.lhs=current} op=BitwiseOROperator)
rhs=BitwiseXORExpression<In,Yield>)*;

BitwiseOROperator: '|';

LogicalANDExpression <In, Yield>: BitwiseORExpression<In,Yield>
(=> ({BinaryLogicalExpression.lhs=current} op=LogicalANDOperator)
rhs=BitwiseORExpression<In,Yield>)*;

LogicalANDOperator: '&&';

LogicalORExpression <In, Yield>: LogicalANDExpression<In,Yield>
(=>({BinaryLogicalExpression.lhs=current} op=LogicalOROperator)
rhs=LogicalANDExpression<In,Yield>)*;

LogicalOROperator: '||';

ConditionalExpression <In, Yield>: LogicalORExpression<In,Yield>
(=> ({ConditionalExpression.expression=current} '?')
trueExpression=AssignmentExpression<In=true,Yield>
':'
falseExpression=AssignmentExpression<In,Yield>)?;

AssignmentExpression <In, Yield>:
  AwaitExpression<In,Yield>
| PromisifyExpression<In,Yield>
| ArrowExpression<In,Yield>
| <Yield> YieldExpression<In>
| ConditionalExpression<In,Yield>
(=> ({AssignmentExpression.lhs=current} op=AssignmentOperator)
rhs=AssignmentExpression<In,Yield>)?;
;

YieldExpression <In>:
'yield' => many?='*'?
-> expression=AssignmentExpression<In,Yield=true>?
;

AssignmentOperator:
'='
| '*='
| '/='
| '%='
| '+='
| '-='
| '<='
| '>'
| '>?'?
| '>='
;
```

```

| '&=' | '^=' | '|='
;

AwaitExpression <In, Yield>:
=> ('await') expression=AssignmentExpression<In, Yield>;

PromisifyExpression <In, Yield>:
=> ('@' 'Promisify') expression=AssignmentExpression<In, Yield>;

Expression <In, Yield>:
AssignmentExpression<In, Yield> ({CommaExpression.exprs+=current}
', ' exprs+=AssignmentExpression<In, Yield>
(','     exprs+=AssignmentExpression<In, Yield>)*)?
;

TemplateLiteral <Yield>:
(
    segments+=NoSubstitutionTemplate
| segments+=TemplateHead segments+=Expression<In=true, Yield>? TemplateExpressionEnd
(
    segments+=TemplateMiddle segments+=Expression<In=true, Yield>?
    TemplateExpressionEnd
) *
    segments+=TemplateTail
)
;
;

TemplateExpressionEnd:
'}'
;
;

NoSubstitutionTemplate:
rawValue=NO_SUBSTITUTION_TEMPLATE_LITERAL
;
;

TemplateHead:
rawValue=TEMPLATE_HEAD
;
;

TemplateTail:
rawValue=TemplateTailLiteral;
;

TemplateMiddle:
rawValue=TemplateMiddleLiteral;
;

Literal:
NumericLiteral | BooleanLiteral | StringLiteral
| NullLiteral | RegularExpressionLiteral;
NullLiteral: 'null';
BooleanLiteral: (true?='true' | 'false');
StringLiteral: value=STRING;
NumericLiteral:
DoubleLiteral | IntLiteral | BinaryIntLiteral | OctalIntLiteral
| LegacyOctalIntLiteral | HexIntLiteral | ScientificIntLiteral;
DoubleLiteral: value=DOUBLE;
IntLiteral: value=INT;
OctalIntLiteral: value=OCTAL_INT;
LegacyOctalIntLiteral: value=LEGACY_OCTAL_INT;
;
```

```
HexIntLiteral: value=HEX_INT;
BinaryIntLiteral: value=BINARY_INT;
ScientificIntLiteral: value=SCIENTIFIC_INT;
RegularExpressionLiteral: value=REGEX_LITERAL;

NumericLiteralAsString:
    DOUBLE | INT | OCTAL_INT | HEX_INT | SCIENTIFIC_INT
;

IdentifierOrThis:
    IDENTIFIER
    | 'This'
    | 'Promisify'
    | 'target';

AnnotationName:
    IDENTIFIER
    | 'This'
    | 'target';

BindingIdentifier <Yield>:
    IDENTIFIER
    | <!Yield> 'yield'
    | N4Keyword
;
IdentifierName:
    IDENTIFIER | ReservedWord | N4Keyword
;
ReservedWord:
    'break' | 'case' | 'catch' | 'class' | 'const' | 'continue' | 'debugger' | 'default' |
    'delete'
    | 'do' | 'else' | 'export' | 'extends' | 'finally' | 'for' | 'function' | 'if' | 'import'
    | 'in' | 'instanceof' | 'new' | 'return' | 'super' | 'switch' | 'this' | 'throw' | 'try'
    | 'typeof' | 'var' | 'void' | 'while' | 'with' | 'yield'
    | 'null'
    | 'true' | 'false'
    | 'enum';
N4Keyword:
    'get' | 'set'
    | 'let'
    | 'project'
    | 'external' | 'abstract' | 'static'
    | 'as' | 'from' | 'constructor' | 'of' | 'target'
    | 'type' | 'union' | 'intersection'
    | 'This' | 'Await' | 'Promisify'
    | 'await'
    | 'async'
    | 'implements' | 'interface'
    | 'private' | 'protected' | 'public'
;
SymbolLiteralComputedName <Yield>:
    BindingIdentifier<Yield> ('.' IdentifierName)?
;
```

```

terminal DOUBLE:
    '.' DECIMAL_DIGIT_FRAGMENT+ EXPONENT_PART?
    | DECIMAL_INTEGER_LITERAL_FRAGMENT '.' DECIMAL_DIGIT_FRAGMENT* EXPONENT_PART?
;

terminal HEX_INT: '0' ('x' | 'X') INT_SUFFIX;

terminal BINARY_INT: '0' ('b' | 'B') INT_SUFFIX;

terminal OCTAL_INT: '0' ('o' | 'O') INT_SUFFIX;

terminal LEGACY_OCTAL_INT: '0' DECIMAL_DIGIT_FRAGMENT INT_SUFFIX;

terminal fragment INT_SUFFIX: IDENTIFIER_PART*;

terminal SCIENTIFIC_INT:
    DECIMAL_INTEGER_LITERAL_FRAGMENT EXPONENT_PART
;
;

terminal fragment EXPONENT_PART:
    ('e' | 'E') SIGNED_INT
    | IDENTIFIER
;

terminal fragment SIGNED_INT:
    ('+' | '-') DECIMAL_DIGIT_FRAGMENT+ IDENTIFIER?
;
;

terminal STRING:
    """ DOUBLE_STRING_CHAR* """
    | """ SINGLE_STRING_CHAR* """
;
;

terminal fragment DOUBLE_STRING_CHAR:
    !(LINE_TERMINATOR_FRAGMENT | '"' | '\\\\')
    | '\\\\' (LINE_TERMINATOR_SEQUENCE_FRAGMENT | !LINE_TERMINATOR_FRAGMENT)?
;
;

terminal fragment SINGLE_STRING_CHAR:
    !(LINE_TERMINATOR_FRAGMENT | '"' | '\\\\')
    | '\\\\' (LINE_TERMINATOR_SEQUENCE_FRAGMENT | !LINE_TERMINATOR_FRAGMENT)?
;
;

terminal fragment BACKSLASH_SEQUENCE:
    '\\\\' !(LINE_TERMINATOR_FRAGMENT)?
;
;

terminal fragment REGEX_CHAR:
    !(LINE_TERMINATOR_FRAGMENT | '\\\\' | '\\' | '[')
    | BACKSLASH_SEQUENCE
    | '[' REGEX_CHAR_OR_BRACKET* ']'
;
;

terminal fragment REGEX_CHAR_OR_BRACKET:
    !(LINE_TERMINATOR_FRAGMENT | '\\\\' | ']')
    | BACKSLASH_SEQUENCE
;
;
```

```

REGEX_LITERAL:
    ('/' | '/=') REGEX_TAIL?
;

terminal fragment ACTUAL_REGEX_TAIL:
    REGEX_CHAR+ ('/' IDENTIFIER_PART*)?
    | '/' IDENTIFIER_PART*
;

terminal fragment REGEX_START:
    ('/' | '/=')
;

terminal REGEX_TAIL: // post processed
    '>//1'
;
terminal TEMPLATE_HEAD:
    ``" TEMPLATE_LITERAL_CHAR* '$'+ '{'
;
terminal NO_SUBSTITUTION_TEMPLATE_LITERAL:
    ```" TEMPLATE_LITERAL_CHAR* '$'* ``"?
;
terminal fragment ACTUAL_TEMPLATE_END:
 TEMPLATE_LITERAL_CHAR* ('$'+ ('{' | `)`?) | `)`?)
;
terminal fragment TEMPLATE_LITERAL_CHAR:
 !(LINE_TERMINATOR_FRAGMENT | `''` | `\\` | '$')
 | '$'+ !('{' | `)` | '$')
 | LINE_TERMINATOR_SEQUENCE_FRAGMENT
 | `\\` (LINE_TERMINATOR_SEQUENCE_FRAGMENT | !LINE_TERMINATOR_FRAGMENT)?
;
TemplateTailLiteral:
 TEMPLATE_END?
;
TemplateMiddleLiteral:
 TEMPLATE_MIDDLE
;
terminal TEMPLATE_MIDDLE:
 '>//2' // will never be lexed
;
terminal TEMPLATE_END:
 '>//3' // will never be lexed
;
terminal fragment TEMPLATE_CONTINUATION:
 '>//4' // actually '}'
;
Semi: ';' // automatic semicolon insertion, post-processed
fragment NoLineTerminator*: NO_LINE_TERMINATOR?;

```

```
terminal NO_LINE_TERMINATOR:
 '//' // post-processed, will never be lexed
;
Annotation:'@' AnnotationNoAtSign;
ScriptAnnotation: '@@' AnnotationNoAtSign;

AnnotationNoAtSign:
 name=AnnotationName (=> '(' (args+=AnnotationArgument (',' args+=AnnotationArgument)*)?
')')?;

AnnotationArgument:
 LiteralAnnotationArgument | TypeRefAnnotationArgument
;

LiteralAnnotationArgument:
 literal=Literal
;

TypeRefAnnotationArgument:
 typeRef=TypeRef
;

AnnotationList:
 => ('@' -> annotations+=AnnotationNoAtSign) annotations+=Annotation*
;

ExpressionAnnotationList:
 annotations+=Annotation+
;

PropertyAssignmentAnnotationList:
 annotations+=Annotation+
;

N4MemberAnnotationList:
 {N4MemberAnnotationList} annotations+=Annotation+
;

TypeReferenceName:
 'void' | 'This' | 'await' | 'Promisify' | 'target' | QualifiedTypeReferenceName
;

QualifiedTypeReferenceName:
 IDENTIFIER ('.' IDENTIFIER)?
;
N4ClassDeclaration <Yield>:
 => (
 {N4ClassDeclaration}
 (declaredModifiers+=N4Modifier)*
 'class' typingStrategy=TypingStrategyDefSiteOperator? name=BindingIdentifier<Yield>?
)
 TypeVariables?
 ClassExtendsClause<Yield>?
 Members<Yield>
;

fragment Members <Yield>*:
```

```

'{'

ownedMembersRaw+=N4MemberDeclaration<Yield>*

'}'

;

fragment ClassExtendsClause <Yield>*:

'extends' (

 =>superClassRef=ParameterizedTypeRefNominal ('implements' ClassImplementsList)?

 | superClassExpression=LeftHandSideExpression<Yield>

)

| 'implements' ClassImplementsList

;

fragment ClassImplementsList*:

implementedInterfaceRefs+=ParameterizedTypeRefNominal

(',' implementedInterfaceRefs+=ParameterizedTypeRefNominal)*

;

N4ClassExpression <Yield>:

{N4ClassExpression}

'class' name=BindingIdentifier<Yield>?

ClassExtendsClause<Yield>?

Members<Yield>;

N4InterfaceDeclaration <Yield>:

=> (

 {N4InterfaceDeclaration}

(declaredModifiers+=N4Modifier)*

'interface' typingStrategy=TypingStrategyDefSiteOperator?

name=BindingIdentifier<Yield>?

)

TypeVariables?

InterfaceImplementsList?

Members<Yield>

;

fragment InterfaceImplementsList*:

'extends' superInterfaceRefs+=ParameterizedTypeRefNominal

(',' superInterfaceRefs+=ParameterizedTypeRefNominal)*

;

N4EnumDeclaration <Yield>:

=> (

 {N4EnumDeclaration}

(declaredModifiers+=N4Modifier)*

'enum' name=BindingIdentifier<Yield>?

)

'{'

(literals+=N4EnumLiteral (',' literals+=N4EnumLiteral)*)?

'}'

;

N4EnumLiteral: name=IdentifierOrThis (':' value=STRING)?;

enum N4Modifier: // validator applies further checks

 private | project | protected | public

 | external | abstract | static | const;

N4MemberDeclaration <Yield>:

AnnotatedN4MemberDeclaration<Yield>

| N4GetterDeclaration<Yield>

```

```

| N4SetterDeclaration<Yield>
| N4MethodDeclaration<Yield>
| N4FieldDeclaration<Yield>
| N4CallableConstructorDeclaration<Yield>
;

AnnotatedN4MemberDeclaration <Yield> returns N4MemberDeclaration:
 N4MemberAnnotationList (
 => ({N4GetterDeclaration.annotationList=current}
 (declaredModifiers+=N4Modifier)* GetterHeader<Yield>) (body=Block<Yield>)? ;
 | => ({N4SetterDeclaration.annotationList=current}
 (declaredModifiers+=N4Modifier)* 'set' -> LiteralOrComputedPropertyName
 <Yield> ('(' fpar=FormalParameter<Yield> ')') (body=Block<Yield>)? ;
 | => (
 {N4MethodDeclaration.annotationList=current} (declaredModifiers+=N4Modifier)*
 TypeVariables?
 (
 generator?='*' LiteralOrComputedPropertyName<Yield>
 ->MethodParamsReturnAndBody <Generator=true>
 | AsyncNoTrailingLineBreak LiteralOrComputedPropertyName<Yield>
 ->MethodParamsReturnAndBody <Generator=false>
)
) ;
 | {N4FieldDeclaration.annotationList=current} FieldDeclarationImpl<Yield>
)
;

fragment LiteralOrComputedPropertyName <Yield>*:
 name=IdentifierName | name=STRING | name=NumericLiteralAsString
 | '[' (=>((name=SymbolLiteralComputedName<Yield> | name=StringLiteralAsName) ']')
 | computeNameFrom=AssignmentExpression<In=true,Yield> ']')
;

fragment LiteralPropertyName <Yield>*:
 name=IdentifierName | name=STRING | name=NumericLiteralAsString
 | '[' (name=SymbolLiteralComputedName<Yield> | name=StringLiteralAsName) ']'
;

StringLiteralAsName:
 STRING
;

fragment FieldDeclarationImpl <Yield>*:
 (declaredModifiers+=N4Modifier)*
 LiteralPropertyName<Yield> ColonSepTypeRef? ('=' expression=Expression<In=true,Yield>)?
 ;
;

N4FieldDeclaration <Yield>:
 {N4FieldDeclaration}
 FieldDeclarationImpl<Yield>
;

N4MethodDeclaration <Yield>:
 => ({N4MethodDeclaration} (declaredModifiers+=N4Modifier)* TypeVariables?
 (

```

```
generator?='*' LiteralOrComputedPropertyName<Yield>
->MethodParamsReturnAndBody <Generator=true>
| AsyncNoTrailingLineBreak LiteralOrComputedPropertyName<Yield>
->MethodParamsReturnAndBody <Generator=false>
)
) ';'?
;

N4CallableConstructorDeclaration <Yield> returns N4MethodDeclaration:
 MethodParamsReturnAndBody <Generator=false> ';'?
;

fragment MethodParamsAndBody <Generator>*:
 StrictFormalParameters<Yield=Generator>
 (body=Block<Yield=Generator>)?
;

fragment MethodParamsReturnAndBody <Generator>*:
 StrictFormalParameters<Yield=Generator>
 (':' returnTypeRef=TypeRef)?
 (body=Block<Yield=Generator>)?
;

N4GetterDeclaration <Yield>:
 => ({N4GetterDeclaration}
 (declaredModifiers+=N4Modifier)*
 GetterHeader<Yield>
 (body=Block<Yield>)? ';'?
;
;

fragment GetterHeader <Yield>*:
 ('get' -> LiteralOrComputedPropertyName <Yield> '(' ')'
 ColonSepTypeRef?)?
;

N4SetterDeclaration <Yield>:
 => ({N4SetterDeclaration}
 (declaredModifiers+=N4Modifier)*
 'set'
 ->LiteralOrComputedPropertyName <Yield>
)
 ('(' fpar=FormalParameter<Yield> ')'
 (body=Block<Yield>)? ';'?
;
;

BindingPattern <Yield>:
 ObjectBindingPattern<Yield>
 | ArrayBindingPattern<Yield>
;
;

ObjectBindingPattern <Yield>:
 '{' (properties+=BindingProperty<Yield,AllowType=false>
 (','
 properties+=BindingProperty<Yield,AllowType=false>)*
)? '}'
;
;

ArrayBindingPattern <Yield>:
 '['
 elements+=Elision*
 elements+=BindingRestElement<Yield>
 (','
 elements+=Elision* elements+=BindingRestElement<Yield>)*
```

```
(',' elements+=Elision*)?
)
'
;

BindingProperty <Yield, AllowType>:
=>(LiteralBindingPropertyName<Yield> ':') value=BindingElement<Yield>
| value=SingleNameBinding<Yield,AllowType>
;

fragment LiteralBindingPropertyName <Yield>*:
declaredName=IdentifierName | declaredName=STRING | declaredName=NumericLiteralAsString
| '[' (declaredName=SymbolLiteralComputedName<Yield> | declaredName=STRING) ']'
;

SingleNameBinding <Yield, AllowType>:
varDecl=VariableDeclaration<In=true,Yield,AllowType>
;

BindingElement <Yield>:
=>(nestedPattern=BindingPattern<Yield>) ('='
expression=AssignmentExpression<In=true,Yield>)?
| varDecl=VariableDeclaration<In=true,Yield,AllowType=true>
;

BindingRestElement <Yield>:
rest?='...'?(
=>(nestedPattern=BindingPattern<Yield>)
('=' expression=AssignmentExpression<In=true,Yield>)?
| varDecl=VariableDeclaration<In=true,Yield,AllowType=true>
)
;

Elision:
','
;
```

---

---

# Chapter 18. JSObjects

The built-in ECMAScript Objects [[ECMA11a\(p.S15, p.pp.102\)](#)] are supported and their properties are annotated with types as described in this chapter. The semantics of these properties do not change. The short description is copied from [[ECMA11a](#)] repeated here for convenience.

## 18.1. Object

`Object` is the super type of all declared types and `N4Object`. It is almost similar to the JavaScript type `Object` except that no properties may be dynamically added to it. In order to declare a variable to which properties can be dynamically added, the `Object+` type has to be declared (cf. [???](#)).

### 18.1.1. Attributes

`constructor: Object`:

Returns a reference to the `Object` function that created the instance's prototype.

### 18.1.2. Methods

`toString(): Object`:

Returns a string representing the specified object.

`toLocaleString(): Object`:

Returns a string representing the object. This method is meant to be overridden by derived objects for locale-specific purposes.

`valueOf(): Object`:

Returns the primitive value of the specified object.

`hasOwnProperty(prop: String): Boolean`:

Returns a boolean indicating whether an object contains the specified property as a direct property of that object and not inherited through the prototype chain.

`isPrototypeOf(object: Object): Boolean`:

Returns a boolean indication whether the specified object is in the prototype chain of the object this method is called upon.

`propertyIsEnumerable(prop: String): Boolean`:

Returns a boolean indicating if the internal ECMAScript `DontEnum` attribute is set.

### 18.1.3. Static Methods

`getPrototypeOf(object: Object): Object`:

Returns the prototype of the specified object.

`create(object: Object, properties: Object=): Object`:

Creates a new object with the specified prototype object and properties.

`defineProperty(object: Object, prop: Object, descriptor: Object): Object`:

Defines a new property directly on an object or modifies an existing property on an object and returns the object.

```
defineProperties (object:Object, properties:Object) :Object :
```

Defines new or modifies existing properties directly on an object, returning the object.

```
seal (object:Object, properties:Object) :
```

Seals an object, preventing new properties from being added to it and marking all existing properties as non-configurable. Values of present properties can still be changed as long as they are writable.

```
freeze (object:Object) :Object :
```

Freezes an object: that is, prevents new properties from being added to it, prevents existing properties from being removed, prevents existing properties or their enumerability, configurability, or writability from being changed. In essence, the object is made effectively immutable. The method returns the object being frozen.

```
preventExtensions (object:Object) :Object :
```

Prevents new properties from ever being added to an object (i.e. prevents future extensions to the object).

```
isSealed (object:Object) :Boolean static :
```

Determine if an object is sealed.

```
isFrozen (object:Object) :Boolean :
```

Determine if an object is frozen.

```
isExtensible (object:Object) :Boolean :
```

Determines if an object is extensible (whether it can have new properties added to it).

```
keys (object:Object) :Array<String> :
```

Returns an array of all own enumerable properties found upon a given object in the same order as that provided by a for-in loop (the difference being that a for-in loop enumerates properties in the prototype chain as well).

## 18.2. String

String is a global object that may be used to construct String instances and is a sub class of Object.

### 18.2.1. Attributes

```
number: length
```

The length of a string.

### 18.2.2. Methods

```
String (thing:Object=)
```

```
anchor (anchorname:String) :String :
```

Creates an HTML anchor.

```
big () :String :
```

Returns a string in a big font.

```
blink () :String :
```

Returns a string in a blinking string.

**bold():String:**  
Returns a string in a bold font.

**charAt(index:Number):String:**  
Returns the character at a specified position.

**charCodeAt(index:Number):Number:**  
Returns the Unicode of the character at a specified position.

**concat(strings:String...):String:**  
Joins two or more strings.

**equals(object:Object):Boolean**

**equalsIgnoreCase(object:Object):Boolean**

**fromCharCode(num:Any...):String:**  
Returns a string created by using the specified sequence of Unicode values.

**fixed():String:**  
Returns a string as teletype text.

**fontcolor(color):String:**  
Returns a string in a specified color.

**fontsize(size):String:**  
Returns a string in a specified size.

**indexOf(searchValue, fromIndex:Number=):Number:**  
Returns the position of the first occurrence of a specified string value in a string.

**italics():String:**  
Returns a string in italic.

**lastIndexOf(searchValue, fromIndex:Number=):Number:**  
Returns the position of the last occurrence of a specified string value, searching backwards from the specified position in a string.

**link(url):String:**  
Returns a string as a hyperlink.

**localeCompare(otherString):Number:**  
This method returns a number indicating whether a reference string comes before or after or is the same as the given string in sort order.

**match(search\_value):String:**  
Searches for a specified value in a string.

**replace(findString,newString):String:**  
Replaces some characters with some other characters in a string.

**search(search\_string):Number:**  
Searches a string for a specified value.

**slice(beginSlice:Number, endSlice:Number=):String:**  
Extracts a part of a string and returns the extracted part in a new string.

**small():String:**  
Returns a string in a small font.

```
split(separator, howmany:Number=) :Array<String>:
 Splits a string into an array of strings.

strike():String:
 Returns a string with a strikethrough.

sub():String:
 Returns a string as subscript.

substr(start:Number, length:Number=) :String:
 Extracts a specified number of characters in a string, from a start index.

substring(beginIndex:number, endIndex:Number=) :String:
 Extracts the characters in a string between two specified indices.

sup():String:
 Returns a string as superscript.

toLocaleUpperCase():String:
 Returns a string in lowercase letters.

toString():String:
 Returns a String value for this object.

toUpperCase():String:
 Returns a string in uppercase letters.

valueOf():String:
 Returns the primitive value of a String object.
```

### 18.2.3. Static Methods

```
String(value:Object=) :
 Static constructor.
```

## 18.3. Boolean

`Boolean` does not have a super class.

### 18.3.1. Static Methods

```
Boolean(value:Object=) :Boolean
```

## 18.4. Number

`Number` does not have a super class.

### 18.4.1. Static Attributes

```
MAX_VALUE:Number :
 The largest representable number.

MIN_VALUE:Number :
 The smallest representable number.
```

**NaN : Number :**

Special 'not a number' value.

**NEGATIVE\\_INFINITY : Number :**

Special value representing negative infinity, returned on overflow.

**POSITIVE\\_INFINITY : Number :**

Special value representing infinity, returned on overflow.

## 18.4.2. Methods

**toExponential(numberOfDecimals : Number =) : String :**

Converts the value of the object into an exponential notation.

**toFixed(numberOfDecimals : Number =) : String :**

Formats a number to the specified number of decimals.

**toPrecision(numberOfDecimals : Number =) : String :**

Converts a number into an exponential notation if it has more digits than specified.

**valueOf() : Number :**

Returns the primitive value of a Number object.

**toString(radix : Number =) : String :**

Returns a String value for this object. The toString method parses its first argument and attempts to return a string representation in the specified radix (base).

## 18.4.3. Static Methods

**Number(value : Object =) : Number :**

Static constructor.

## 18.5. Function

**Function** does not have a super class.

### 18.5.1. Attributes

**prototype : Object :**

Allows the addition of properties to the instance of the object created by the constructor function.

**length : Number :**

Specifies the number of arguments expected by the function.

### 18.5.2. Methods

**apply(thisArg, argsArray : Array =) : Object :**

Applies the method of another object in the context of a different object (the calling object); arguments can be passed as an Array object.

**call(thisArg, arg... : Object) :**

Calls (executes) a method of another object in the context of a different object (the calling object); arguments can be passed as they are.

**bind(thisArg:Object,arg...):Function:**

Creates a new function that, when called, itself calls this function in the context of the provided this value with a given sequence of arguments preceding any provided when the new function was called.

## 18.6. Error

Error does not have a super class.

### 18.6.1. Attributes

**name:String:**

Error name.

**message:String:**

Error message.

### 18.6.2. Static Methods

**Error(message:Object=):Error:**

Static Constructor.

## 18.7. Array

**Array** is a generic type with the type parameter **E** and does not have a super class.

### 18.7.1. Methods

**concat(array...):Array<E>:**

Joins two or more arrays and returns the result.

**every(callback:Function):Boolean:**

Tests whether all elements in the array pass the test implemented by the provided function. The callback will be called with 3 arguments (elementValue,elementIndex,traversedArray).

**filter(callback:Function):Array<E>:**

Creates a new array with all elements that pass the test implemented by the provided function. The callback will be called with 3 arguments (elementValue,elementIndex,traversedArray).

**forEach(callback:Function,thisArg=):**

Calls a function for each element in the array. The callback will be called with 3 arguments (elementValue,elementIndex,traversedArray). Optionally with a thisObject argument to use as this when executing callback.

**indexOf(searchElement,fromIndex=):Number:**

Returns the first index at which a given element can be found in the array, or -1 if it is not present.

**join(separator=):String:**

Puts all the elements of an array into a string. The elements are separated by a specified delimiter.

**lastIndexOf(searchElement,fromIndex=):Number:**

Returns the last (greatest) index of an element within the array equal to the specified value. Will return -1 if none are found.

**length() :Number :**

The length returns an integer representing the length of an array.

**map(callback:Function,thisArg=) :Array :**

Creates a new array with the results of calling a provided function on every element in this array. The callback will be called with 3 arguments (elementValue,elementIndex,traversedArray). Optionally, with a thisObject argument to use as this when executing callback.

**pop() :E :**

Removes and returns the last element of an array.

**push(element...) :E :**

Adds one or more elements to the end of an array and returns the new length.

**reverse() :Array<E> :**

Reverses the order of the elements in an array.

**shift() :**

Removes and returns the first element of an array.

**slice(start:Number,end:Number=) :Array<E> :**

Returns selected elements from an existing array.

**some(callback:Function,thisArg=) :Boolean :**

Tests whether some element in the array passes the test implemented by the provided function. The callback will be called with 3 arguments (elementValue,elementIndex,traversedArray). Optionally, with a thisObject argument to use as this when executing callback.

**sort(sortByFunction:Function=) :Array<E> :**

Sorts the elements of an array. The function will be called with 2 arguments (a,b).

**splice(index:Number,how many:Number,element...) :Array<E> :**

Removes and adds new elements to an array. Returns the removed elements as an Array.

**toLocaleString():String :, toString():String :**

Returns a String value for Array.

**unshift(element...) :E :**

Adds one or more elements to the beginning of an array and returns the new length.

## 18.7.2. Static Methods

**Array(item:Object...) :**

Static constructor.

## 18.8. Date

**Date** does not have a super class.

### 18.8.1. Static Methods

**Date():Date :**

Static constructor.

```
Date(milliseconds:Number) :Date :
 Constructor.

Date(date:Date) :Date :
 Constructor.

Date(dateString:String) :Date :
 Constructor.

Date(year:Number,month:Number,day=Number=,hour:Number=,minute:Number=,second:Number=,millisecond:Number=) :Date :
 Constructor.

parse(dateString:String) :Date :
 Parses a string representation of a date, and returns the number of milliseconds since midnight Jan
 1, 1970.

now() :Number :
 Returns the numeric value corresponding to the current time.

UTC(year:Number,month:Number,date:Number=,hrs:Number=,min:Number=,sec:Number=,ms:Number=) :Number :
 UTC takes comma-delimited date parameters and returns the number of milliseconds between Jan-
 uary 1, 1970, 00:00:00, Universal Time and the time you specified.
```

## 18.8.2. Methods

```
getDate() :Number :
 Returns the day of the month from a Date object (from 1-31).

getDay() :Number :
 Returns the day of the week from a Date object (from 0-6).

getFullYear() :Number :
 Returns the year, as a four-digit number.

getHours() :Number :
 Returns the hour of a day (from 0-23).

getMilliseconds() :Number :
 Returns the milliseconds of a Date object (from 0-999).

getMinutes() :Number :
 Returns the minutes of a date (from 0-59).

getMonth() :Number :
 Returns the month from a date (from 0-11).

getSeconds() :Number :
 Returns the seconds of a date (from 0-59).

getTime() :Number :
 Returns the number of milliseconds since midnight Jan 1, 1970.

valueOf() :Number :
 Returns the primitive value of a Date object as a number data type, the number of milliseconds since
 midnight 01 January, 1970 UTC. This method is functionally equivalent to the getTime method.
```

**getTimezoneOffset () :Number :**

Returns the difference in minutes between local time and Greenwich Mean Time (GMT).

**getUTCDate () :Number :**

Returns the day of the month from a date according to Universal Time (from 1-31).

**getUTCDay () :Number :**

Returns the day of the week from a date according to Universal Time (from 0-6).

**getUTCFullYear () :Number :**

Returns the four-digit year from a date according to Universal Time.

**getUTCHours () :Number :**

Returns the hour of a date according to Universal Time (from 0-23).

**getUTCMilliseconds () :Number :**

Returns the milliseconds of a date according to Universal Time (from 0-999).

**getUTCMinutes () :Number :**

Returns the minutes of a date according to Universal Time (from 0-59).

**getUTCMonth () :Number :**

Returns the month from a Date object according to Universal Time (from 0-11).

**getUTCSeconds () :Number :**

Returns the seconds of a date according to Universal Time (from 0-59).

**getYear () :Number deprecated :**

Returns the year as a two-digit or a three/four-digit number, depending on the browser. Use getFullYear() instead!

 **setDate (day) :Number :**

Sets the day of the month from a Date object (from 1-31).

 **setFullYear (full year, month=, day=) :Number :**

Sets the year as a four-digit number.

 **setHours (hours, minutes=, seconds=, milis=) :Number :**

Sets the hour of a day (from 0-23).

 **setMilliseconds (mills) :Number :**

Sets the milliseconds of a Date object (from 0-999).

 **setMinutes (minutes, =seconds, =millis) :Number :**

Sets the minutes of a date (from 0-59).

 **setMonth " directType="Number (month, day=) :Number :**

Sets the month from a date (from 0-11).

 **setSeconds (seconds, millis=) :number :**

Sets the seconds of a date (from 0-59).

 **setTime (mills) :Number :**

Sets the number of milliseconds since midnight Jan 1, 1970.

 **setUTCDate (day) :Number :**

Sets the day of the month from a date according to Universal Time (from 0-6).

 **setUTCFullYear (fullyear, month=, day=) :Number :**

Sets the four-digit year from a date according to Universal Time.

**setUTCHours (hours, minutes=, seconds=, millis=) :Number :**  
Sets the hour of a date according to Universal Time (from 0-23).

**setUTCSeconds (seconds) :Number :**  
Sets the seconds of a date according to Universal Time (from 0-59).

**setUTCMilliseconds (milliseconds) :Number :**  
Sets the milliseconds of a date according to Universal Time (from 0-999).

**setUTCMinutes (minutes, seconds=, millis=) :Number :**  
Sets the minutes of a date according to Universal Time time (from 0-59).

**setUTCMonth (month, day=) :Number :**  
Sets the month from a Date object according to Universal Time (from 0-11).

**setUTCSeconds (seconds, millis=) :Number :**  
Sets the seconds of a date according to Universal Time (from 0-59).

**setYear (year) :Number deprecated :**  
Sets the year, as a two-digit or a three/four-digit number, depending on the browser. Use setFullYear() instead!!

**toDateString () :String :**  
Returns the date portion of a Date object in readable form.

**toLocaleDateString () :String :**  
Converts a Date object, according to local time, to a string and returns the date portion.

**toLocaleString () :String :**  
Converts a Date object, according to local time, to a string.

**toLocaleTimeString () :String :**  
Converts a Date object, according to local time, to a string and returns the time portion.

**toString () :String :**  
Returns a String value for this object.

**toTimeString () :String :**  
Returns the time portion of a Date object in readable form.

**toUTCString () :String :**  
Converts a Date object, according to Universal Time, to a string.

## 18.9. Math

**Math** is not instantiable and only provides static properties and methods.

### 18.9.1. Static Attributes

**E :Number :**

Euler's constant and the base of natural logarithms, approximately 2.718.

**LN2 :Number :**

Natural logarithm of 2, approximately 0.693.

**LN10 :Number :**

Natural logarithm of 10, approximately 2.302.

**LOG2E :Number :**

Base 2 logarithm of E, approximately 1.442.

**LOG10E :Number :**

Base 10 logarithm of E, approximately 0.434.

**PI :Number :**

Ratio of the circumference of a circle to its diameter, approximately 3.14159.

**SQRT1\\_2 :Number :**

Square root of 1/2; equivalently, 1 over the square root of 2, approximately 0.707.

**SQRT2 :Number :**

Square root of 2, approximately 1.414.

## 18.9.2. Static Methods

**abs (x) :Number :**

Returns the absolute value of a number.

**acos (x:Number) :Number :**

Returns the arccosine of a number.

**asin(x:Number) :Number :**

Returns the arcsine of a number.

**atan (x:Number) :Number :**

Returns the arctangent of a number.

**atan2 (y:Number , x:Number) :Number :**

Returns the arctangent of the quotient of its arguments.

**ceil (x) :Number :**

Returns the smallest integer greater than or equal to a number.

**cos (x) :Number :**

Returns the arctangent of the quotient of its arguments.

**exp (x) :Number :**

Returns Enumber, where number is the argument, and E is Euler's constant (2.718...), the base of the natural logarithm.

**floor (x) :Number :**

Returns the largest integer less than or equal to a number.

**log (x) :Number :**

Returns the natural logarithm (loge, also ln) of a number.

**max (value...) :Number :**

Returns the largest of zero or more numbers.

**min (value...) :Number :**

Returns the smallest of zero or more numbers.

**pow (base:Number , exponent:Number) :Number :**

Returns base to the exponent power, that is, baseexponent.

**random () :Number :**

Returns a pseudorandom number between 0 and 1.

**round (x:Number) :Number :**

Returns the value of a number rounded to the nearest integer.

**sin(x:Number) :Number :**

Returns the sine of a number.

**sqrt(x:Number) :Number :**

Returns the positive square root of a number.

**tan(x:Number) :Number :**

Returns the tangent of a number.

## 18.10. RegExp

**RegExp** does not have a super class.

### 18.10.1. Attributes

**global:Boolean :**

Whether to test the regular expression against all possible matches in a string, or only against the first.

**ignoreCase:Boolean :**

Whether to ignore case while attempting a match in a string.

**lastIndex:Number :**

The index at which to start the next match.

Whether or not to search in strings across multiple lines.

**source:String :**

The text of the pattern.

### 18.10.2. Methods

**exec(str:String) :Array :**

Executes a search for a match in its string parameter.

**test(str:String) :Boolean :**

Tests for a match in its string parameter.

## 18.11. JSON

**JSON** is a global object and a subclass of **Object**. Its functionality is provided by two static methods. It is not possible to create new instances of type JSON.

### 18.11.1. Attributes

The JSON object does not define own properties.

### 18.11.2. Methods

The JSON object does not define own methods.

### 18.11.3. Static Methods

The `parse` function parses a JSON text (a JSON-formatted String) and produces an ECMAScript value. The JSON format is a restricted form of ECMAScript literal. JSON objects are realized as ECMAScript objects. JSON arrays are realized as ECMAScript arrays. JSON strings, numbers, booleans, and null are realized as ECMAScript Strings, Numbers, Booleans, and null. For detailed information see [[ECMA11a\(p.S15.12.2\)](#)]

The optional `reviver` parameter is a function that takes two parameters (key and value). It can filter and transform the results. It is called with each of the key/value pairs produced by the `parse` and its return value is used instead of the original value. If it returns what it received, the structure is not modified. If it returns then the property is deleted from the result.

The `stringify` function returns a String in JSON format representing an ECMAScript value. It can take three parameters. The first parameter is required. The `value` parameter is an ECMAScript value which is usually an object or array, although it can also be a String, Boolean, Number or null.

The optional `replacer` parameter is either a function that alters the way objects and arrays are stringified or an array of Strings and Numbers that act as a white list for selecting the object properties that will be stringified.

The optional `space` parameter is a String or Number that allows the result to have whitespace injected into it to improve human readability.

For detailed information see [[ECMA11a\(p.S15.12.3\)](#)].

# Chapter 19. N4JS Objects

## 19.1. Reflection Model

IDE-1236<sup>1</sup>  
GH-344<sup>2</sup>

N4JS provided metadata for reflection (and introspection). This information is available via instances of some reflection model classes (described below) attached to types and (in some cases) functions.

The following class diagrams shows the defined classes. Note that for performance reasons, the actual structure may vary from the model.

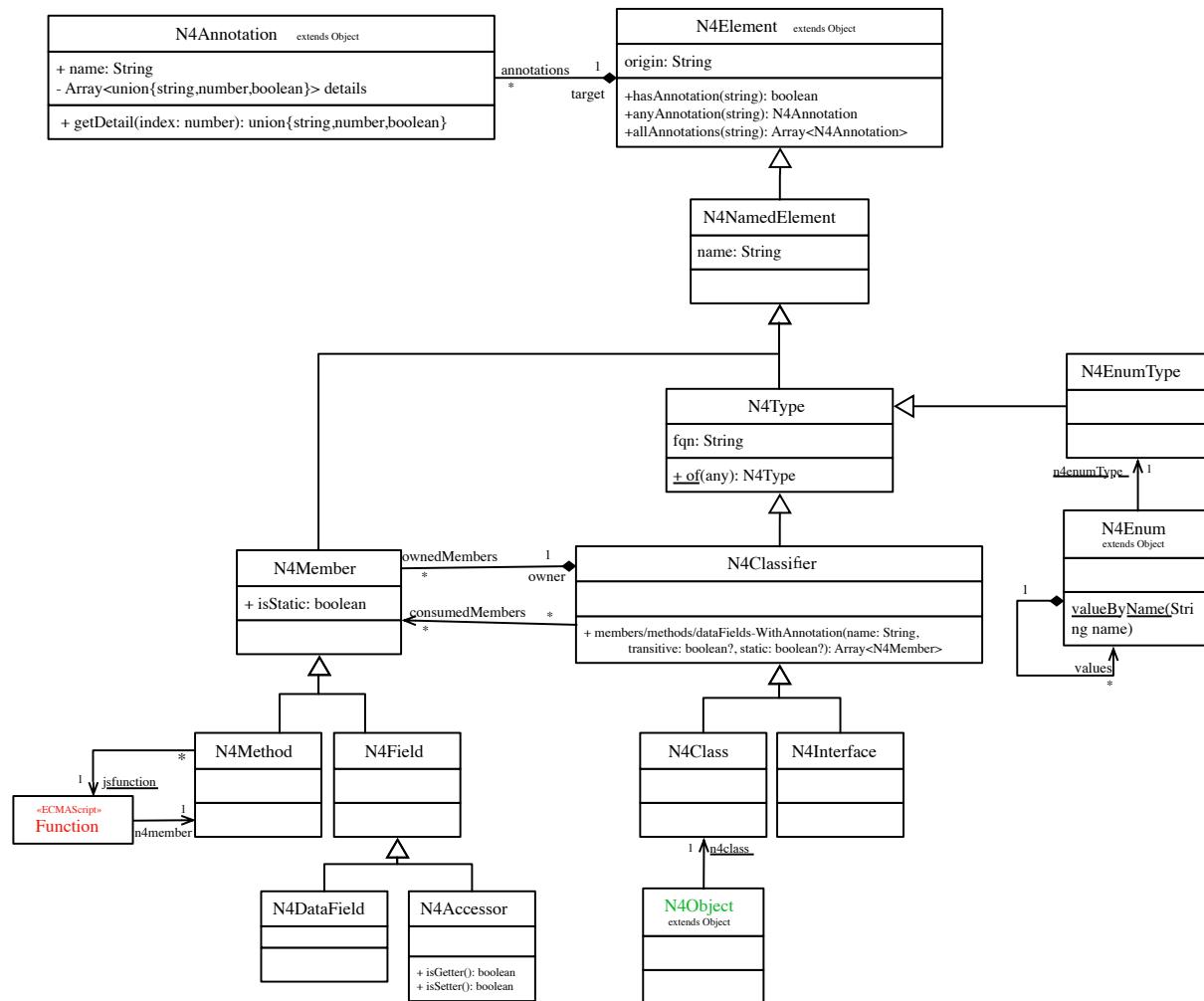


Figure 19.1. N4JS Reflection Classes

Remark: This section is work in progress. The final goal is to provide a metamodel similar to Ecore, but we will only add new features if needed.

<sup>1</sup> <https://jira.numberfour.eu/browse/IDE-1236>

<sup>2</sup> <https://github.com/NumberFour/N4JS/issues/344>

```
/**
 * Base class for all N4 reflective elements.
 */
export public abstract class N4Element extends Object {
 /**
 * Annotations attached to this element.
 */
 public Array<N4Annotation> annotations = [];

 /**
 * The origin string formed as <ID-VERSION>, where ID is containing project artefact id,
 and VERSION is its version
 */
 public String origin;

 /**
 * Returns true if an annotation with the given name is attached to the element.
 */
 public boolean hasAnnotation(string name) {
 return !!this.annotations[name];
 }

 /**
 * Returns any annotation with the given name attached to the element, or null if no such
 annotation is found.
 */
 public N4Annotation anyAnnotation(string name) {
 for (var i=this.annotations.length-1; i>=0; i--) {
 var a = this.annotations[i];
 if (a) {
 return a;
 }
 }
 return null;
 }
 /**
 * Returns all annotations with the given name attached to the element, or an empty array
 if no such annotations are found.
 */
 public Array<N4Annotation> allAnnotations(string name) {
 return this.annotations.filter(function(a) {return a.name==name});
 }
}

/**
 * Base class for all reflective classes with a name.
 */
export public abstract class N4NamedElement extends N4Element {
 /**
 * The simple name of a named element.
 */
 public string name;
}

/**
 * Base class for all reflective classes describing a type (declaration).
 */
```

```
/*
export public abstract class N4Type extends N4NamedElement {
 /**
 * The FQN of the type.
 */
 public string fqn;

 /**
 * Returns true if this N4Class describes an N4-class declaration.
 */
 public boolean get isClass() { return false; }

 /**
 * Returns true if this N4Class describes an N4-interface declaration.
 */
 public boolean get isInterface() { return false; }

 /**
 * Returns true if this N4Class describes an N4-enumeration declaration.
 */
 public boolean get isEnum() { return false; }
}

/**
 * Base class for meta types of classes or interfaces.
 */
export public abstract class N4Classifier extends N4Type {

 /**
 * The N4Class of the super type, may be null if super type is not an N4Class.
 */
 public N4Class n4superType;

 /**
 * Array of the FQN of all (transitively) implemented interfaces, i.e. interfaces
 * directly implemented by this class, its super
 * class or interfaces extended by directly implemented interfaces.
 */
 public Array<string> allImplementedInterfaces;

 /**
 * Array of all owned members, that is members defined in the class directly.
 * This field is private as it is an internal detail, members are accessed via methods
 * defined in this class.
 */
 private Array<N4Member> ownedMembers;

 /**
 * Array of all consumed members, that is members mixed into the classifier via interface
 * implementation and default methods.
 * This field is private as it is an internal detail, members are accessed via methods
 * defined in this class.
 */
 private Array<N4Member> consumedMembers;

 /**
 * Only used internally, must not be called by client.

```

```
/*
protected constructor(@Spec ~~this spec) {}

/**
 * Returns all members defined by this class directly, consumed, and inherited. The
boolean flags control which members are returned.
*
 * @param consumed if set, consumed members are returned as well (false by default)
 * @param inherited if set, inherited members are returned as well (false by default)
 * @param _static if set, static members are returned, otherwise instance members (false
by default).
 *
 * @return array of members, may be empty but never null
*/
public Array<? extends N4Member> members(boolean? consumed, boolean? inherited, boolean?
static) {
 return null; // TODO
}

/**
 * Returns all members defined in this classifier (or inherited) with an annotation
 * of given name attached to it. The boolean flags control which methods are returned.
*
 * @param name name of annotation to be used as filter
 * @param consumed if set, consumed members are returned as well (false by default)
 * @param inherited if set, inherited members are returned as well (false by default)
 * @param _static if set, static members are returned, otherwise instance members (false
by default).
 *
 * @return array of members, may be empty but never null
*/
public Array<? extends N4Member> membersWithAnnotation(string name, boolean?
consumed, boolean? inherited, boolean? _static) {
 return null; // TODO
}

/**
 * Returns all data fields defined by this class directly, consumed, and inherited. The
boolean flags control which data fields are returned.
*
 * @param consumed if set, consumed data fields are returned as well (false by default)
 * @param inherited if set, inherited data fields are returned as well (false by default)
 * @param _static if set, static data fields are returned, otherwise instance members
(false by default).
 *
 * @return array of data fields, may be empty but never null
*/
public Array<? extends N4DataField> dataFields(boolean? consumed, boolean?
inherited, boolean? _static) {
 return null; // TODO
}

/**
 * Returns all data fields defined in this classifier (or inherited) with an annotation
 * of given name attached to it. The boolean flags control which data fields are
returned.
*
 * @param name name of annotation to be used as filter
 * @param consumed if set, consumed data fields are returned as well (false by default)
 * @param inherited if set, inherited data fields are returned as well (false by default)

```

```
 * @param _static if set, static data fields are returned, otherwise instance members
 (false by default).
 * @return array of data fields, may be empty but never null
 */
public Array<? extends N4DataField> dataFieldsWithAnnotation(string name, boolean?
consumed, boolean? inherited, boolean? _static) {
 return null; // TODO
}

/**
 * Returns all methods defined by this class directly, consumed, and inherited. The
boolean flags control which methods are returned.
*
* @param consumed if set, consumed methods are returned as well (false by default)
* @param inherited if set, inherited methods are returned as well (false by default)
* @param _static if set, static methods are returned, otherwise instance members (false
by default).
* @return array of methods, may be empty but never null
*/
public Array<? extends N4Method> methods(boolean? consumed, boolean? inherited, boolean?
_static) {
 return null; // TODO
}

/**
 * Returns all methods defined in this classifier (or inherited) with an annotation
* of given name attached to it. The boolean flags control which methods are returned.
*
* @param name name of annotation to be used as filter
* @param consumed if set, consumed methods are returned as well (false by default)
* @param inherited if set, inherited methods are returned as well (false by default)
* @param _static if set, static methods are returned, otherwise instance members (false
by default).
* @return array of methods, may be empty but never null
*/
public Array<? extends N4Method> methodsWithAnnotation(string name, boolean?
consumed, boolean? inherited, boolean? _static) {
 return null; // TODO
}

}

/**
 * Meta information of an n4 class.
*/
export @Final public class N4Class extends N4Classifier {

 /**
 * Returns the N4Class instance for a given n4object. This is similar to
 * {@code n4object.constructor.n4type}, however it can also be used in interfaces
 * to get reflective information of the implementor.
 */
 public static N4Class of(N4Object n4object) {
 return n4object.constructor.n4type
 }
}
```

```
/**
 * Returns true if this N4Class describes an N4-class declaration.
 */
@Override
public boolean get isClass() { return true; }
}

/**
 * Meta information of an n4 interface.
 */
export @Final public class N4Interface extends N4Classifier {
 /**
 * Returns true if this N4Class describes an N4-interface declaration.
 */
 @Override
 public boolean get isInterface() { return true; }
}

/**
 * Description of a member, that is a method or field.
 */
export public abstract class N4Member extends N4Element {
 public string name;
}

/**
 * Description of a method.
 */
export @Final public class N4Method extends N4Member {
 public Function jsFunction;
}

/**
 * Description of a field, that is either a data field or an accessor.
 */
export public abstract class N4Field extends N4Member {
}

/**
 * Description of a simple data field.
 */
export @Final public class N4DataField extends N4Member {
}

/**
 * Description of an accessor, that is a getter or setter.
 */
export @Final public class N4Accessor extends N4Member {
 /**
 * Flag indicating whether accessor is a getter or setter, internal detail.
 */
 private boolean getter;
 /**
 * Returns true if accessor is a getter.
 */
 public boolean isGetter() { return this.getter; }
```

```
/**
 * Returns true if accessor is a setter.
 */
public boolean isSetter() { return ! this.getter; }
}

/**
 * Description of an N4Enum
 */
export @Final public class N4EnumType extends N4Type {
 /**
 * Returns true if this N4Clasifier describes an N4-enumeration declaration.
 */
 @Override public boolean get isEnum() { return true; }
 /**
 * Returns the N4EnumType instance for a given enum literal. This is similar to
 * {@code n4enum.constructor.n4type}.
 */
 public static N4EnumType of(N4Enum n4enum) {
 return n4enum.constructor.n4type
 }
}

/**
 * Base class for all enumeration, literals are assumed to be static constant fields of
 concrete subclasses.
 */
export public abstract class N4Enum extends Object {

 /**
 * Returns the name of a concrete literal
 */
 public abstract string get name();

 /**
 * Returns the value of a concrete literal. If no value is
 * explicitly set, it is similar to the name.
 */
 public abstract string get value();

 /**
 * Returns a string representation of a concrete literal, it returns
 * the same result as value()
 */
 @Override public string toString() { return this.value }

 /**
 * Returns the enum class object of this enum literal for reflection.
 * The very same meta class object can be retrieved from the enumeration type directly.
 */
 public abstract N4Enum get n4Enum();

 /**
 * Natively overridden by concrete enums.
 */
 public static Array<? extends N4Enum> get values() { return null; }
}
```

```
/**
 * Natively overridden by concrete enums.
 */
public static N4Enum valueByName(string name) { return null; }

/**
 * Returns the meta class object of this class for reflection.
 * The very same meta class object can be retrieved from an instance by calling
 * <code>instance.constructor.n4type</code>
 */
public static N4EnumType get n4type() { return null; }
}

/**
 * Annotation with value.
 */
export @Final public class N4Annotation extends Object {
 public string name;
 public union{string,number} value;
}

/**
 * The base class for all instances of n4 classes.
 */
export public class N4Object {
 /**
 * Returns the meta class object of this class for reflection.
 * The very same meta class object can be retrieved from an instance by calling
 * <code>instance.constructor.n4type</code>
 */
 // defined in types model, added by $makeClass:
 // public static N4Class get n4type() { return null; }
}
```

---

## 19.2. Error Types

N4JS provides additional Error types as subtypes of `Error`.

### 19.2.1. N4ApiNotImplemented

IDE-1510<sup>3</sup>

Considering API definitions and concrete implementations of those APIs the error `N4-Api\-\Not\-\Im\-\ple\-\men\-\ted\-\Error` is introduced to specifically report missing implementations. Instances of this error type are inserted internally during the transpilation of API-implementing projects. Whenever a difference to the API in form of a missing implementation is encountered, the transpiler will insert stub-code throwing an instance of `N4-Api\-\Not\-\Im\-\ple\-\men\-\ted\-\Error`.

API-testing projects can catch those errors and act accordingly. This enables tracking of completeness of implementations by counting the occasions an `N4-Api\-\Not\-\Im\-\ple\-\men\-\ted\-\Error` was encountered.

---

<sup>3</sup> <https://jira.numberfour.eu/browse/IDE-1510>

```
/**
 * Error type reporting a not implemented situation.
 */
public class N4ApiNotImplementedError extends Error { }
```

---

---

## Chapter 20. Bibliography