Java Reference

Table of Contents

Neo4j v4.4

The Java Reference for Neo4j v4.4.

The Java Reference contains information on advanced Java-centric usage of Neo4j. Among the topics covered are embedding Neo4j in your own software and writing extensions.

The following topics are:

- Extending Neo4j — How to build unmanaged extensions and procedures.
- Using Neo4j embedded in Java applications — Instructions on embedding Neo4j in an application.
- The traversal framework — A walkthrough of the traversal framework. label:deprecated[]
- Transaction management — Details on transaction semantics in Neo4j.
- JMX metrics — How to monitor Neo4j with JMX and a reference of available metrics.

The traversal framework API has been deprecated and will be replaced in the next major release of Neo4j.

You might want to keep the Neo4j Javadocs (Neo4j Java API Documentation) handy while reading.

Who should read this?

The Java Reference is written for the advanced Java developer who is extending Neo4j's functionality, or embedding Neo4j in their own software.

Extending Neo4j

This section describes how to extend Neo4j and Cypher using procedures, functions, and plugins. This section introduces different methods to extend the standard Neo4j functionality. How to set up remote debugging is alsow explained.

Neo4j provides the following methods to extend the standard functionality:

- **Procedures and functions** extend the capabilities of the Cypher query language.
- **Authentication and authorization plugins** extend the Neo4j security framework.
- **Server extensions** enable new surfaces to be created in the HTTP API.

Writing extensions requires the user to be familiar with Java or other JVM programming languages, and to have an environment set up for compiling such code.

Best practices

It is also important to consider any security implications of deploying customized code. Refer to the Operations Manual → Securing Extensions for details on best practices for securing user-defined procedures and functions.

Since you will be running customized-built code and Neo4j in the same JVM, there are a few things you should keep in mind:

- Do not create or retain more objects than you strictly need to. Large caches in particular tend to promote more objects to the old generation, thus increasing the need for expensive full garbage collections.
- Do not use internal Neo4j APIs. They are internal to Neo4j and subject to change without notice, which may break or change the behavior of your code.
- If possible, avoid using Java object serialization or reflection in your code or in any runtime dependency that you use. Otherwise, if you cannot avoid using Java object serialization and reflection, then ensure that the `-XX:+TrustFinalNonStaticFields` JVM flag is disabled in `neo4j.conf`.

Neo4j customized code

User-defined procedures and *user-defined functions* are mechanisms that enable you to extend Neo4j by writing customized code, which can be invoked directly from Cypher. This is the preferred means for extending Neo4j.

Examples of use cases for procedures and functions are:

- To provide access to functionality that is not available in Cypher.
- To provide access to third party systems.
- To perform graph-global operations, such as counting connected components or finding dense nodes.
- To express a procedural operation that is difficult to express declaratively with Cypher.

Procedures and functions are written in Java and compiled into *jar* files. They are deployed to the database by dropping that *jar* file into the *plugins* directory on each standalone or clustered server. For the location of the *plugins* directory, refer to Operations Manual → File locations. The database must be re-started on each server to pick up new procedures and functions.

Procedures and functions can take arguments and return results. In addition, procedures can perform write operations on the database.

Type	Description	Syntax	Read/Write	Cardinality
`Procedure`	For each row the procedure takes parameters and returns multiple results.	`CALL abc(...)`	Update allowed.	Changes cardinality similarly to a `MATCH` clause (0, 1, or many).
`Scalar function`	For each row the function takes parameters and returns a single result.	`abc(...)`	Read-only.	Maintains cardinality, one for one.
`Aggregating function`	Consumes many rows and produces an aggregated result.	`WITH abc(...)`	Read-only.	Reduces cardinality, many down to one.

Neo4j also comes bundled with a number of *built-in* procedures and functions.

The available built-in procedures varies depending edition and mode, as described in Operations Manual → Procedures. Running `SHOW PROCEDURES` will display the full list of procedures available in a particular database instance, including user-defined procedures.

The built-in functions are described in Cypher Manual → Functions. Running `SHOW FUNCTIONS` will display the full list of all the functions available in a particular database instance, including user-defined functions.

Setting up a plugin project

This section describes how to prepare a project for writing user-defined procedures and functions in Neo4j. The following shows the steps to create and deploy a new procedure.

The example described in this section is available on GitHub (neo4j-examples/neo4j-procedure-template).

Set up a project with Maven

A project can be set up in any way that allows for compiling a procedure and producing a *jar* file.

Below are the main parts of the example configuration, using the Maven build system.

Excerpts from the Maven pom.xml file

```
<project
xmlns="http://maven.apache.org/POM/4.0.0"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://maven.apache.org/POM/4.0.0 http://maven.apache.org/xsd/maven-4.0.0.xsd">
  <modelVersion>4.0.0</modelVersion>

  <groupId>org.neo4j.example</groupId>
  <artifactId>procedure-template</artifactId>
  <version>1.0.0-SNAPSHOT</version>

  <packaging>jar</packaging>
  <name>Neo4j Procedure Template</name>
  <description>A template project for building a Neo4j Procedure</description>

  <properties>
    <neo4j.version>4.4.1</neo4j.version>
  </properties>
```

Build dependencies

Add a dependency section that includes the procedure and function APIs, which procedures and functions use at runtime.

The scope is set to `provided`, because once the procedure is deployed to a Neo4j instance, this dependency is provided by Neo4j. If non-Neo4j dependencies are added to the project, their scope should normally be `compile`.

```
<dependency>
 <groupId>org.neo4j</groupId>
 <artifactId>neo4j</artifactId>
 <version>${neo4j.version}</version>
 <scope>provided</scope>
</dependency>
```

Add dependencies that are necessary for testing the procedure.

Neo4j Harness, a utility that allows for starting a lightweight Neo4j instance. It is used to start Neo4j with a specific procedure or function deployed, which greatly simplifies testing.

Neo4j Java Driver, used to send Cypher statements that call the procedure or function.

JUnit, a common Java test framework.

```
<dependency>
 <groupId>org.neo4j.test</groupId>
 <artifactId>neo4j-harness</artifactId>
 <version>${neo4j.version}</version>
 <scope>test</scope>
</dependency>

<dependency>
 <groupId>org.neo4j.driver</groupId>
 <artifactId>neo4j-java-driver</artifactId>
 <version>4.4</version>
 <scope>test</scope>
</dependency>

<dependency>
 <groupId>junit</groupId>
 <artifactId>junit</artifactId>
 <version>4.12</version>
 <scope>test</scope>
</dependency>
```

Build steps

The steps that Maven will go through to build the project.

The goal is first to *compile* the source, then to *package* it in a *jar* that can be deployed to a Neo4j instance.

The Maven Shade plugin is used to package the compiled procedure. It also includes all dependencies in the package, unless the dependency scope is set to test or *provided*.

Once the procedure has been deployed to the *plugins* directory of each Neo4j instance and the instances have restarted, the procedure is available for use.

```
<build>
<plugins>
 <plugin>
   <artifactId>maven-compiler-plugin</artifactId>
   <configuration>
     <source>11</source>
     <target>11</target>
   </configuration>
 </plugin>
 <plugin>
   <artifactId>maven-shade-plugin</artifactId>
   <executions>
     <execution>
       <phase>package</phase>
       <goals>
         <goal>shade</goal>
       </goals>
     </execution>
   </executions>
 </plugin>
</plugins>
</build>
```

Values and types

This describes how to work with values and types when writing user-defined procedures and functions.

The *input* and *output* to and from a procedure or a function must be one of the supported types, as described in Cypher Manual → Values and types.

Composite types are supported via:

- `List<T>`, where `T` is one the supported types, and
- `Map<String, Object>`, where the values in the map must have one of the supported types.

The use of `Object` is supported for the case where the type is not known beforehand. Note, however, that the actual value must still have one of the aforementioned types.

The Cypher types and their equivalents in Java are outlined in the table below:

Table 1. Supported types

Cypher type	Java type
`String`	`String`
`Integer`	`Long`
`Float`	`Double`
`Boolean`	`Boolean`
`Point`	`org.neo4j.graphdb.spatial.Point`
`Date`	`java.time.LocalDate`
`Time`	`java.time.OffsetTime`
`LocalTime`	`java.time.LocalTime`
`DateTime`	`java.time.ZonedDateTime`
`LocalDateTime`	`java.time.LocalDateTime`
`Duration`	`java.time.temporal.TemporalAmount`
`Node`	`org.neo4j.graphdb.Node`
`Relationship`	`org.neo4j.graphdb.Relationship`
`Path`	`org.neo4j.graphdb.Path`

For more details, see the Neo4j Javadocs `org.neo4j.procedure.Procedure`.

Take note that there are two cases where more than one Java type is mapped to a single Cypher type. When this happens, type information is lost. If the following objects are returned from procedures, the original types cannot be recreated:

- A Cypher `Duration` is created when either a `java.time.Duration` or a `java.time.Period` is provided. If a `Duration` is returned, only the common interface `java.time.temporal.TemporalAmount` will remain.
- A Cypher `DateTime` is created when a `java.time.OffsetDateTime` is provided. If a `DateTime` is returned, it will be converted into a `java.time.ZonedDateTime`.

User-defined procedures

This describes how to write, test, and deploy a user-defined procedure for Neo4j.

A *user-defined procedure* is a mechanism that enables you to extend Neo4j by writing customized code, which can be invoked directly from Cypher. Procedures can take arguments, perform operations on the

database, and return results. For a comparison between user-defined procedures, functions, and aggregation functions see Neo4j customized code.

Call a procedure

To call a user-defined procedure, use a Cypher `CALL` clause. The procedure name must be fully qualified, so a procedure named `findDenseNodes` defined in the package `org.neo4j.examples` could be called using:

```
CALL org.neo4j.examples.findDenseNodes(1000)
```

A `CALL` may be the only clause within a Cypher statement or may be combined with other clauses. Arguments can be supplied directly within the query or taken from the associated parameter set. For full details, see the documentation in Cypher Manual → `CALL` procedure.

Create a procedure

Make sure you have read and followed the preparatory setup instructions in Setting up a plugin project.

The example discussed below is available as a repository on GitHub. To get started quickly you can fork the repository and work with the code as you follow along in the guide below.

1. Create integration tests.
2. Define the procedure.

Integration tests

The test dependencies include *Neo4j Harness* and *JUnit*. These can be used to write integration tests for procedures.

First, decide what the procedure should do, then write a test that proves that it does it right. Finally, write a procedure that passes the test.

Below is a template for testing a procedure that accesses Neo4j's full-text indexes from Cypher.

```
package example;

import org.junit.Rule;
import org.junit.Test;
import org.neo4j.driver.v1.*;
import org.neo4j.graphdb.factory.GraphDatabaseSettings;
import org.neo4j.harness.junit.Neo4jRule;

import static org.hamcrest.core.IsEqual.equalTo;
import static org.junit.Assert.assertThat;
import static org.neo4j.driver.v1.Values.parameters;

public class ManualFullTextIndexTest
{
    // This rule starts a Neo4j instance
    @Rule
    public Neo4jRule neo4j = new Neo4jRule()

            // This is the Procedure to test
            .withProcedure( FullTextIndex.class );

    @Test
    public void shouldAllowIndexingAndFindingANode() throws Throwable
    {
        // In a try-block, to make sure you close the driver after the test
        try( Driver driver = GraphDatabase.driver( neo4j.boltURI() , Config.build().withoutEncryption
().toConfig() ) )
        {

            // Given I've started Neo4j with the FullTextIndex procedure class
            //       which my 'neo4j' rule above does.
            Session session = driver.session();

            // And given I have a node in the database
            long nodeId = session.run( "CREATE (p:User {name:'Brookreson'}) RETURN id(p)" )
                    .single()
                    .get( 0 ).asLong();

            // When I use the index procedure to index a node
            session.run( "CALL example.index($id, ['name'])", parameters( "id", nodeId ) );

            // Then I can search for that node with lucene query syntax
            StatementResult result = session.run( "CALL example.search('User', 'name:Brook*')" );
            assertThat( result.single().get( "nodeId" ).asLong(), equalTo( nodeId ) );
        }
    }
}
```

Define a procedure

With the test in place, write a procedure procedure that fulfills the expectations of the test. The full example is available in the Neo4j Procedure Template repository.

Particular things to note:

- All procedures are annotated `@Procedure`.
- The procedure annotation can take three optional arguments: `name`, `mode`, and `eager`.
    - `name` is used to specify a different name for the procedure than the default generated, which is `class.path.nameOfMethod`. If `mode` is specified then `name` must be specified as well.
    - `mode` is used to declare the types of interactions that the procedure will perform. A procedure will fail if it attempts to execute database operations that violates its mode. The default `mode` is `READ`. The following modes are available:
        - `READ` This procedure will only perform read operations against the graph.

        - `WRITE` This procedure will perform read and write operations against the graph.
        - `SCHEMA` This procedure will perform operations against the schema, i.e. create and drop indexes and constraints. A procedure with this mode is able to read graph data, but not write.
        - `DBMS` This procedure will perform system operations such as user management and query management. A procedure with this mode is not able to read or write graph data.
    - `eager` is a boolean setting defaulting to `false`. If it is set to `true` then the Cypher planner will plan an extra `eager` operation before calling the procedure. This is useful in cases where the procedure makes changes to the database in a way that could interact with the operations preceding the procedure. For example:

      ```
      MATCH (n)
      WHERE n.key = 'value'
      WITH n
      CALL deleteNeighbours(n, 'FOLLOWS')
      ```

      This query could delete some of the nodes that would be matched by the Cypher query, and then the `n.key` lookup will fail. Marking this procedure as `eager` will prevent this from causing an error in Cypher code. However, it is still possible for the procedure to interfere with itself by trying to read entities it has previously deleted. It is the responsibility of the procedure author to handle that case.

- The context of the procedure, which is the same as each resource that the procedure wants to use, is annotated `@Context`.

The correct way to signal an error from within a procedure is to throw a `RuntimeException`.

Injectable resources

When writing procedures, some resources can be injected into the procedure from the database. To inject these, use the `@Context` annotation. The classes that can be injected are:

- `Log`
- `TerminationGuard`
- `GraphDatabaseService`
- `Transaction`

All of the above classes are considered safe and future-proof, and will not compromise the security of the database. There are also several classes that can be injected that are unsupported (restricted) and can be changed with little or no notice. Procedures written to use these restricted API's will not be loaded by default, and it will be necessary to use the `dbms.security.procedures.unrestricted` to load unsafe procedures. Read more about this config setting in Operations Manual → Securing extensions.

User-defined functions

This describes how to write, test and deploy a user-defined function for Neo4j.

User-defined functions are a simpler form of procedures that are read-only and always return a single value. Although they are not as powerful in capability, they are often easier to use and more efficient than procedures for many common tasks. For a comparison between user-defined procedures, functions, and aggregation functions see Neo4j customized code.

Call a user-defined function

User-defined functions are called in the same way as any other Cypher function. The function name must be fully qualified, so a function named `join` defined in the package `org.neo4j.examples` could be called using:

```
MATCH (p: Person) WHERE p.age = 36
RETURN org.neo4j.examples.join(collect(p.names))
```

Create a function

User-defined functions are created similarly to how procedures are created, but are instead annotated with `@UserFunction` and instead of returning a stream of values it returns a single value.

See Values and types for details on values and types.

For more details, see the Neo4j Javadocs for `org.neo4j.procedure.UserFunction`.

The correct way to signal an error from within a function is to throw a `RuntimeException`.

```
package example;

import org.neo4j.procedure.Name;
import org.neo4j.procedure.Procedure;
import org.neo4j.procedure.UserFunction;

public class Join
{
    @UserFunction
    @Description("example.join(['s1','s2',...], delimiter) - join the given strings with the given
delimiter.")
    public String join(
            @Name("strings") List<String> strings,
            @Name(value = "delimiter", defaultValue = ",") String delimiter) {
        if (strings == null || delimiter == null) {
            return null;
        }
        return String.join(delimiter, strings);
    }
}
```

Integration tests

Tests for user-defined functions are created in the same way as those for procedures.

Below is a template for testing a user-defined function that joins a list of strings.

```
package example;

import org.junit.Rule;
import org.junit.Test;
import org.neo4j.driver.v1.*;
import org.neo4j.harness.junit.Neo4jRule;

import static org.hamcrest.core.IsEqual.equalTo;
import static org.junit.Assert.assertThat;

public class JoinTest
{
    // This rule starts a Neo4j instance
    @Rule
    public Neo4jRule neo4j = new Neo4jRule()

            // This is the function to test
            .withFunction( Join.class );

    @Test
    public void shouldAllowIndexingAndFindingANode() throws Throwable
    {
        // This is in a try-block, to make sure you close the driver after the test
        try( Driver driver = GraphDatabase.driver( neo4j.boltURI() , Config.build().withEncryptionLevel(
Config.EncryptionLevel.NONE ).toConfig() ) )
        {
            // Given
            Session session = driver.session();

            // When
            String result = session.run( "RETURN example.join(['Hello', 'World']) AS result").single().
get("result").asString();

            // Then
            assertThat( result, equalTo( "Hello,World" ) );
        }
    }
}
```

User-defined aggregation functions

This describes how to write, test and deploy a user-defined aggregation function for Neo4j.

User-defined aggregation functions are functions that aggregate data and return a single result. For a comparison between user-defined procedures, functions, and aggregation functions see Neo4j customized code.

Call a aggregation function

User-defined aggregation functions are called in the same way as any other Cypher aggregation function. The function name must be fully qualified, so a function named `longestString` defined in the package `org.neo4j.examples` could be called using:

```
MATCH (p: Person) WHERE p.age = 36
RETURN org.neo4j.examples.longestString(p.name)
```

Writing a user-defined aggregation function

User-defined aggregation functions are annotated with `@UserAggregationFunction`. The annotated function must return an instance of an aggregator class. An aggregator class contains one method

annotated with `@UserAggregationUpdate` and one method annotated with `@UserAggregationResult`. The method annotated with `@UserAggregationUpdate` will be called multiple times and enables the class to aggregate data. When the aggregation is done the method annotated with `@UserAggregationResult` is called once and the result of the aggregation will be returned.

See Values and types for details on values and types.

For more details, see the Neo4j Javadocs for `org.neo4j.procedure.UserAggregationFunction`.

The correct way to signal an error from within an aggregation function is to throw a `RuntimeException`.

```
package example;

import org.neo4j.procedure.Description;
import org.neo4j.procedure.Name;
import org.neo4j.procedure.UserAggregationFunction;
import org.neo4j.procedure.UserAggregationResult;
import org.neo4j.procedure.UserAggregationUpdate;

public class LongestString
{
    @UserAggregationFunction
    @Description( "org.neo4j.function.example.longestString(string) - aggregates the longest string found"
)
    public LongStringAggregator longestString()
    {
        return new LongStringAggregator();
    }

    public static class LongStringAggregator
    {
        private int longest;
        private String longestString;

        @UserAggregationUpdate
        public void findLongest(
                @Name( "string" ) String string )
        {
            if ( string != null && string.length() > longest)
            {
                longest = string.length();
                longestString = string;
            }
        }

        @UserAggregationResult
        public String result()
        {
            return longestString;
        }
    }
}
```

Integration tests

Tests for user-defined aggregation functions are created in the same way as those for normal user-defined functions.

Below is a template for testing a user-defined aggregation function that finds the longest string.

```
package example;

import org.junit.Rule;
import org.junit.Test;
import org.neo4j.driver.v1.*;
import org.neo4j.harness.junit.Neo4jRule;

import static org.hamcrest.core.IsEqual.equalTo;
import static org.junit.Assert.assertThat;

public class LongestStringTest
{
    // This rule starts a Neo4j instance
    @Rule
    public Neo4jRule neo4j = new Neo4jRule()

            // This is the function to test
            .withAggregationFunction( LongestString.class );

    @Test
    public void shouldAllowIndexingAndFindingANode() throws Throwable
    {
        // This is in a try-block, to make sure you close the driver after the test
        try( Driver driver = GraphDatabase.driver( neo4j.boltURI() , Config.build().withEncryptionLevel(
Config.EncryptionLevel.NONE ).toConfig() ) )
        {
            // Given
            Session session = driver.session();

            // When
            String result = session.run( "UNWIND ["abc", "abcd", "ab"] AS string RETURN
example.longestString(string) AS result").single().get("result").asString();

            // Then
            assertThat( result, equalTo( "abcd" ) );
        }
    }
}
```

Authentication and authorization plugins

This describes Neo4j support for customized-built authentication and authorization plugins.

Neo4j provides authentication and authorization plugin interfaces to support real-world deployment scenarios not covered by native users or the built-in configuration-based LDAP connector.

The SPI (Service Provider Interface) lives in the `com.neo4j.server.security.enterprise.auth.plugin.spi` package.

Customized-built plugins have access to the *<neo4j-home>* directory in case you want to load any customized settings from a file located there. Plugins can also write to the security event log.

Authentication plugin

The authentication plugin implements the `AuthenticationPlugin` interface with the `authenticate` method.

The example below shows a minimal authentication plugin that checks for Neo4j user with Neo4j password:

```
@Override
public AuthenticationInfo authenticate( AuthToken authToken )
{
    String principal = authToken.principal();
    char[] credentials = authToken.credentials();

    if ( principal.equals( "neo4j" ) && Arrays.equals( credentials, "neo4j".toCharArray() ) )
    {
        return (AuthenticationInfo) () -> "neo4j";
    }
    return null;
}
```

Authorization plugin

The authorization plugin implements the `AuthorizationPlugin` interface with the `authorize` method.

The example below shows a minimal authorization plugin that assigns the reader role to a user named neo4j:

```
@Override
public AuthorizationInfo authorize( Collection<PrincipalAndProvider> principals )
{
    if ( principals.stream().anyMatch( p -> "neo4j".equals( p.principal() ) ) )
    {
        return (AuthorizationInfo) () -> Collections.singleton( PredefinedRoles.READER );
    }
    return null;
}
```

Note the usage of the helper class `PredefinedRole`.

Simplified combined plugin

There is also a simplified combined plugin interface `AuthPlugin` that provides both authentication and authorization in a single method called `authenticateAndAuthorize`.

The example below shows a combined plugin verifying neo4j/neo4j credentials and returning reader role authorization:

```
@Override
public AuthInfo authenticateAndAuthorize( AuthToken authToken )
{
    String principal = authToken.principal();
    char[] credentials = authToken.credentials();

    if ( principal.equals( "neo4j" ) && Arrays.equals( credentials, "neo4j".toCharArray() ) )
    {
        return AuthInfo.of( "neo4j", Collections.singleton( PredefinedRoles.READER ) );
    }
    return null;
}
```

Extendable platform

Neo4j provides an extendable platform as some user deployment scenarios may not be easily configured through standard LDAP connector. One known complexity is integrating with LDAP user directory where groups have users as a member and the not other way around.

The example below first searches for a group that the user is member of, and then maps that group to the Neo4j role by calling the customized-built `getNeo4jRoleForGroupId` method:

```
@Override
public AuthInfo authenticateAndAuthorize( AuthToken authToken ) throws AuthenticationException
{
    try
    {
        String username = authToken.principal();
        char[] password = authToken.credentials();

        LdapContext ctx = authenticate( username, password );
        Set<String> roles = authorize( ctx, username );

        return AuthInfo.of( username, roles );
    }
    catch ( NamingException e )
    {
        throw new AuthenticationException( e.getMessage() );
    }
}

private LdapContext authenticate( String username, char[] password ) throws NamingException
{
    Hashtable<String,Object> env = new Hashtable<>();
    env.put( Context.INITIAL_CONTEXT_FACTORY, "com.sun.jndi.ldap.LdapCtxFactory" );
    env.put( Context.PROVIDER_URL, "ldap://0.0.0.0:10389" );

    env.put( Context.SECURITY_PRINCIPAL, String.format( "cn=%s,ou=users,dc=example,dc=com", username ) );
    env.put( Context.SECURITY_CREDENTIALS, password );

    return new InitialLdapContext( env, null );
}

private Set<String> authorize( LdapContext ctx, String username ) throws NamingException
{
    Set<String> roleNames = new LinkedHashSet<>();

    // Set up our search controls
    SearchControls searchCtls = new SearchControls();
    searchCtls.setSearchScope( SearchControls.SUBTREE_SCOPE );
    searchCtls.setReturningAttributes( new String[]{GROUP_ID} );

    // Use a search argument to prevent potential code injection
    Object[] searchArguments = new Object[]{username};

    // Search for groups that has the user as a member
    NamingEnumeration result = ctx.search( GROUP_SEARCH_BASE, GROUP_SEARCH_FILTER, searchArguments,
searchCtls );

    if ( result.hasMoreElements() )
    {
        SearchResult searchResult = (SearchResult) result.next();

        Attributes attributes = searchResult.getAttributes();
        if ( attributes != null )
        {
            NamingEnumeration attributeEnumeration = attributes.getAll();
            while ( attributeEnumeration.hasMore() )
            {
                Attribute attribute = (Attribute) attributeEnumeration.next();
                String attributeId = attribute.getID();
                if ( attributeId.equalsIgnoreCase( GROUP_ID ) )
                {
                    // Found a group that the user is a member of. See if it has a role mapped to it
                    String groupId = (String) attribute.get();
                    String neo4jGroup = getNeo4jRoleForGroupId( groupId );
                    if ( neo4jGroup != null )
                    {
                        // Yay! Add it to your set of roles
                        roleNames.add( neo4jGroup );
                    }
                }
            }
        }
    }
    return roleNames;
}
```

Read more about this and other plugin examples at https://github.com/neo4j/neo4j-example-auth-plugins.

Full-text index analyzer providers

This describes how to extend full-text index analyzers provided in Neo4j.

Full-text indexes always have an analyzer, which describes how text is analyzed for indexing and querying. The analyzer breaks the text up into smaller tokens, and processes these tokens with a number of filters. These filters can do many different things. For example, some remove stop-words, such as "the" and "is", while others transform the tokens by stemming them, or turn them into lower-case.

Which analyzer you should use depends on what you want to use the index for. For example, if the text being indexed belong to a special domain, such as email addresses, you would want an analyzer specific to that domain. Or if the text is always in a particular language, such as Russian, you could use an analyzer specific to that language.

Neo4j comes with a number of built-in analyzers. The full list of analyzers is available by calling the `db.index.fulltext.listAvailableAnalyzers()` procedure. The procedure returns the analyzer name, a short description, and the full list of stop-words used by the analyzer.

The default analyzer is the `standard-no-stop-words` analyzer. This default can be changed with the `dbms.index.fulltext.default_analyzer` setting. This setting only takes effect when a full-text index is created. Once a full-text index has been created, it remembers the analyzer in its index-specific settings.

It is possible to extend the available analyzers in Neo4j, by implementing an `AnalyzerProvider`. The `AnalyzerProvider` acts as a factory, which builds the concrete Lucene `Analyzer` instance used by the index. The following example creates a customized analyzer:

```
public class CustomAnalyzerProvider extends AnalyzerProvider ①
{
    public CustomAnalyzerProvider()                           ②
    {
        super( "custom-analyzer" );                           ③
    }

    @Override
    public Analyzer createAnalyzer()                          ④
    {
        try
        {
            return CustomAnalyzer.builder()                   ⑤
                    .withTokenizer( StandardTokenizerFactory.class )
                    .addTokenFilter( LowerCaseFilterFactory.class )
                    .addTokenFilter( StopFilterFactory.class, "ignoreCase", "false", "words",
"stopwords.txt", "format", "wordset" )
                    .build();
        }
        catch ( IOException e )
        {
            throw new UncheckedIOException( e );
        }
    }
}
```

① The `CustomAnalyzerProvider` class must be `public`, and it must extend the `org.neo4j.graphdb.schema.AnalyzerProvider` class.

② The `CustomAnalyzerProvider` class must additionally have a `public` constructor that takes no arguments. Without this constructor, the new analyzer provider will not be loaded by Neo4j. There will be no warnings logged when an analyzer provider is ignored for this reason, so take care.

③ The constructor must then call its super-constructor, and give the name of the `custom-analyzer` provider as an argument. This is the name that will be used to refer to this analyzer provider, when configuring indexes.

④ Lastly, the `createAnalyzer` method must be implemented. This method creates and returns the concrete `Analyzer` instance, that the indexes will use. If this method returns `null` or throws an exception, then the index will be marked as FAILED.

⑤ In this example, we are creating instances of Lucene's `CustomAnalyzer`. We can, however, create and return anything that extends the `org.apache.lucene.analysis.Analyzer` class.

Follow the guide in Setting up a plugin project, to learn how to package the customized `AnalyzerProvider` in a JAR file that can be integrated into Neo4j.

The analyzer providers are picked up by Neo4j via service loading. This means that in addition to having implemented the class above, we must also add the fully qualified class name to a service file, and put that file on the class path. These service files are usually included in the JAR file that contains the Neo4j extensions. In a typical Maven project, such as the one created by the guide above, the directory structure would look like this:

```
project/
   src/
      main/
         java/
            my_package/
               CustomAnalyzerProvider.java ①
         resources/
            META-INF/
               services/
                  org.neo4j.graphdb.schema.AnalyzerProvider ②
```

① This is the `CustomAnalyzerProvider` from our previous code example.

② This is the service loader file. It is a plain-text file that contains a line, with the fully qualified name, for each `AnalyzerProvider` we implement in our project. In this case, it contains a single line: `my_package.CustomAnalyzerProvider`.

In order for the `META-INF/services` resources to be handled correctly by the `maven-shade-plugin`, it may be necessary to include a service resource transformation to the plug-in configuration. This is an example of what that may look like:

```
<plugin>
  <groupId>org.apache.maven.plugins</groupId>
  <artifactId>maven-shade-plugin</artifactId>
  <executions>
    <execution>
      <goals>
        <goal>shade</goal>
      </goals>
      <configuration>
        <transformers>
          <transformer
implementation="org.apache.maven.plugins.shade.resource.ServicesResourceTransformer"/>
        </transformers>
      </configuration>
    </execution>
  </executions>
</plugin>
```

Consult the documentation on the Maven Shade Plugin for more details on this step.

Unmanaged server extensions

Introduction

Sometimes you will want a finer-grained level of control over your application's interactions with Neo4j than Cypher provides. For these situations you can use the unmanaged extension API.

This is a sharp tool, that enables users to deploy arbitrary JAX-RS classes to the server so be careful when using this. In particular, it is possible to consume lots of heap space on the server and degrade performance. If in doubt, please ask for help via one of the community channels.

The first step when writing an unmanaged extension is to create a project which includes dependencies to the Neo4j core jars. In Maven this would be achieved by adding the following lines to the pom file:

```
1 <dependency>
2     <groupId>org.neo4j</groupId>
3     <artifactId>neo4j</artifactId>
4     <version>4.4.1</version>
5     <scope>provided</scope>
6 </dependency>
```

Now you are ready to write your extension.

In your code, you will interact with the database using `DatabaseManagementService`, which you can access by using the `@Context` annotation. The following example serves as a template which you can base your extension on:

```
@Path( "/helloworld" )
public class HelloWorldResource
{
    private final DatabaseManagementService dbms;

    public HelloWorldResource( @Context DatabaseManagementService dbms )
    {
        this.dbms = dbms;
    }

    @GET
    @Produces( MediaType.TEXT_PLAIN )
    @Path( "/{nodeId}" )
    public Response hello( @PathParam( "nodeId" ) long nodeId )
    {
        // Do stuff with the database
        return Response.status( Status.OK ).entity( UTF8.encode( "Hello World, nodeId=" + nodeId ) ).
build();
    }
}
```

The full source code is found here: HelloWorldResource.java

Having built your code, the resulting jar file (and any customized dependencies) should be placed in the *$NEO4J_SERVER_HOME/plugins* directory. You also need to tell Neo4j where to look for the extension by adding some configuration in *neo4j.conf*:

```
#Comma separated list of JAXRS packages containing JAXRS Resource, one package name for each mountpoint.
dbms.unmanaged_extension_classes=org.neo4j.examples.server.unmanaged=/examples/unmanaged
```

Your `hello` method will now respond to `GET` requests at the URI:

```
http://{neo4j_server}:{neo4j_port}/examples/unmanaged/helloworld/{node_id}
```

For example:

```
curl http://localhost:7474/examples/unmanaged/helloworld/123
```

which results in:

```
Hello World, nodeId=123
```

Streaming JSON responses

When writing unmanaged extensions, you have greater control over the amount of memory that your Neo4j queries use. If you keep too much state around, it can lead to more frequent full Garbage Collection and subsequent unresponsiveness by the Neo4j server.

A common way that state can increase, is the creation of JSON objects to represent the result of a query which is then sent back to your application. Neo4j's Transactional Cypher HTTP endpoint (see HTTP API Docs → transactional Cypher endpoint) streams responses back to the client. For example, the following unmanaged extension streams an array of a person's colleagues:

```
@Path("/colleagues")
public class ColleaguesResource
{
    private DatabaseManagementService dbms;
    private final ObjectMapper objectMapper;

    private static final RelationshipType ACTED_IN = RelationshipType.withName( "ACTED_IN" );
    private static final Label PERSON = Label.label( "Person" );

    public ColleaguesResource( @Context DatabaseManagementService dbms )
    {
        this.dbms = dbms;
        this.objectMapper = new ObjectMapper();
    }

    @GET
    @Path("/{personName}")
    public Response findColleagues( @PathParam("personName") final String personName )
    {
        StreamingOutput stream = new StreamingOutput()
        {
            @Override
            public void write( OutputStream os ) throws IOException, WebApplicationException
            {
                JsonGenerator jg = objectMapper.getJsonFactory().createJsonGenerator( os, JsonEncoding
.UTF8 );
                jg.writeStartObject();
                jg.writeFieldName( "colleagues" );
                jg.writeStartArray();

                final GraphDatabaseService graphDb = dbms.database( "neo4j" );
                try ( Transaction tx = graphDb.beginTx();
                      ResourceIterator<Node> persons = tx.findNodes( PERSON, "name", personName ) )
                {
                    while ( persons.hasNext() )
                    {
                        Node person = persons.next();
                        for ( Relationship actedIn : person.getRelationships( OUTGOING, ACTED_IN ) )
                        {
                            Node endNode = actedIn.getEndNode();
                            for ( Relationship colleagueActedIn : endNode.getRelationships( INCOMING,
ACTED_IN ) )
                            {
                                Node colleague = colleagueActedIn.getStartNode();
                                if ( !colleague.equals( person ) )
                                {
                                    jg.writeString( colleague.getProperty( "name" ).toString() );
                                }
                            }
                        }
                    }
                    tx.commit();
                }

                jg.writeEndArray();
                jg.writeEndObject();
                jg.flush();
                jg.close();
            }
        };

        return Response.ok().entity( stream ).type( MediaType.APPLICATION_JSON ).build();
    }
}
```

The full source code is found here: ColleaguesResource.java

As well as depending on JAX-RS API, this example also uses Jackson — a Java JSON library. You will need to add the following dependency to your Maven POM file (or equivalent):

```
<dependency>
    <groupId>com.fasterxml.jackson.core</groupId>
    <artifactId>jackson-databind</artifactId>
    <version>2.10.2</version>
</dependency>
```

From Neo4j 3.5.15, a breaking change was introduced following an update to the Jackson dependency.

Jackson v1 is out of support, and has accumulated security issues such as:

- CVE-2017-7525
- CVE-2017-17485
- CVE-2017-15095
- CVE-2018-11307
- CVE-2018-7489
- CVE-2018-5968

For further information about Jackson v2, please see the Jackson Project on GitHub.

Our `findColleagues` method will now respond to `GET` requests at the URI:

```
http://{neo4j_server}:{neo4j_port}/examples/unmanaged/colleagues/{personName}
```

For example:

```
curl http://localhost:7474/examples/unmanaged/colleagues/Keanu%20Reeves
```

which results in:

```
{"colleagues":["Hugo Weaving","Carrie-Anne Moss","Laurence Fishburne"]}
```

Executing Cypher

You can execute Cypher queries by using the `GraphDatabaseService` that is injected into the extension. For example, the following unmanaged extension retrieves a person's colleagues using Cypher:

```
@Path("/colleagues-cypher-execution")
public class ColleaguesCypherExecutionResource
{
    private final ObjectMapper objectMapper;
    private DatabaseManagementService dbms;

    public ColleaguesCypherExecutionResource( @Context DatabaseManagementService dbms )
    {
        this.dbms = dbms;
        this.objectMapper = new ObjectMapper();
    }

    @GET
    @Path("/{personName}")
    public Response findColleagues( @PathParam("personName") final String personName )
    {
        final Map<String, Object> params = MapUtil.map( "personName", personName );

        StreamingOutput stream = new StreamingOutput()
        {
            @Override
            public void write( OutputStream os ) throws IOException, WebApplicationException
            {
                JsonGenerator jg = objectMapper.getJsonFactory().createJsonGenerator( os, JsonEncoding
.UTF8 );
                jg.writeStartObject();
                jg.writeFieldName( "colleagues" );
                jg.writeStartArray();

                final GraphDatabaseService graphDb = dbms.database( "neo4j" );
                try ( Transaction tx = graphDb.beginTx();
                      Result result = tx.execute( colleaguesQuery(), params ) )
                {
                    while ( result.hasNext() )
                    {
                        Map<String,Object> row = result.next();
                        jg.writeString( ((Node) row.get( "colleague" )).getProperty( "name" ).toString()
);
                    }
                    tx.commit();
                }

                jg.writeEndArray();
                jg.writeEndObject();
                jg.flush();
                jg.close();
            }
        };

        return Response.ok().entity( stream ).type( MediaType.APPLICATION_JSON ).build();
    }

    private String colleaguesQuery()
    {
        return "MATCH (p:Person {name: $personName })-[:ACTED_IN]->()<-[:ACTED_IN]-(colleague) RETURN
colleague";
    }
}
```

The full source code is found here: ColleaguesCypherExecutionResource.java

Your `findColleagues` method will now respond to `GET` requests at the URI:

```
http://{neo4j_server}:{neo4j_port}/examples/unmanaged/colleagues-cypher-execution/{personName}
```

For example:

```
curl http://localhost:7474/examples/unmanaged/colleagues-cypher-execution/Keanu%20Reeves
```

which results in:

```
{"colleagues": ["Hugo Weaving", "Carrie-Anne Moss", "Laurence Fishburne"]}
```

Testing your extension

Neo4j provides tools to help you write integration tests for your extensions. You can access this toolkit by adding the following test dependency to your project:

```
<dependency>
   <groupId>org.neo4j.test</groupId>
   <artifactId>neo4j-harness</artifactId>
   <version>4.4.1</version>
   <scope>test</scope>
</dependency>
```

The test toolkit provides a mechanism to start a Neo4j instance with a customized configuration and with extensions of your choice. It also provides mechanisms to specify data fixtures to include when starting Neo4j, as you can see in the example below:

```
@Path("")
public static class MyUnmanagedExtension
{
    @GET
    public Response myEndpoint()
    {
        return Response.ok().build();
    }
}

@Test
public void testMyExtension() throws Exception
{
    // Given
    HTTP.Response response = HTTP.GET( HTTP.GET( neo4j.httpURI().resolve( "myExtension" ).toString()
).location() );

    // Then
    assertEquals( 200, response.status() );
}

@Test
public void testMyExtensionWithFunctionFixture()
{
    final GraphDatabaseService graphDatabaseService = neo4j.defaultDatabaseService();
    try ( Transaction transaction = graphDatabaseService.beginTx() )
    {
        // Given
        Result result = transaction.execute( "MATCH (n:User) return n" );

        // Then
        assertEquals( 1, count( result ) );
        transaction.commit();
    }
}
```

The full source code of the example is found here: ExtensionTestingDocIT.java

Note the use of `server.httpURI().resolve( "myExtension" )` to ensure that the correct base URI is used.

If you are using the JUnit test framework, there is a JUnit rule available as well:

```
@Rule
public Neo4jRule neo4j = new Neo4jRule()
        .withFixture( "CREATE (admin:Admin)" )
        .withFixture( graphDatabaseService ->
        {
            try (Transaction tx = graphDatabaseService.beginTx())
            {
                tx.createNode( Label.label( "Admin" ) );
                tx.commit();
            }
            return null;
        } );

@Test
public void shouldWorkWithServer()
{
    // Given
    URI serverURI = neo4j.httpURI();

    // When I access the server
    HTTP.Response response = HTTP.GET( serverURI.toString() );

    // Then it should reply
    assertEquals(200, response.status());

    // and we have access to underlying GraphDatabaseService
    try (Transaction tx = neo4j.defaultDatabaseService().beginTx()) {
        assertEquals( 2, count(tx.findNodes( Label.label( "Admin" ) ) ));
        tx.commit();
    }
}
```

The full source code of the example is found here: JUnitDocIT.java

Setup for remote debugging

This describes how to configure Neo4j for remote debugging sessions.

In order to configure Neo4j for remote debugging sessions, the Java debugging parameters need to be passed to the Java process through the configuration. They live in the *conf/neo4j.conf* file.

In order to specify the parameters, you must add a line for the additional Java arguments like this:

```
dbms.jvm.additional=-agentlib:jdwp=transport=dt_socket,server=y,suspend=n,address=*:5005
```

This configuration will start Neo4j, ready for remote debugging attachment at localhost and port `5005`. Use these parameters to attach to the process from Eclipse, IntelliJ or your remote debugger of choice after starting the server.

Using Neo4j embedded in Java applications

This section describes how to use Neo4j embedded in Java applications.

The following topics are:

- Including Neo4j in your project
- Hello world
- Property values
- Using indexes
- Resource iterator — Managing resources in long-running transactions.
- Controlling logging
- Traversal
- Domain entities
- Graph algorithm examples
- Unique nodes — Getting or creating a unique node using Cypher and uniqueness constraints.
- Bolt connector — Accessing Neo4j embedded via the Bolt protocol.
- Terminate a transaction — How to terminate (abort) a long-running transaction from another thread.
- Cypher queries — How to use the Cypher query language with Java.
- Query parameters

When running your own code and Neo4j in the same JVM, there are a few things you should keep in mind:

- Do not create or retain more objects than you strictly need to. Large caches in particular tend to promote more objects to the old generation, thus increasing the need for expensive full garbage collections.
- Do not use internal Neo4j APIs. They are internal to Neo4j and subject to change without notice, which may break or change the behavior of your code.
- Do not enable the `-XX:+TrustFinalNonStaticFields` JVM flag when running in embedded mode.

Including Neo4j in your project

This topic describes how to embed Neo4j in your Java application.

After selecting the appropriate edition for your platform, you can embed Neo4j in your Java application by including the Neo4j library jars in your build. The following sections show how to do this by either altering the build path directly or by using dependency management.

Adding Neo4j to the build path

Get the Neo4j libraries from one of these sources:

- Extract a Neo4j zip/tarball, and use the *jar* files found in the *lib/* directory.
- Use the *jar* files available from Maven Central Repository.

Add the jar files to your project:

JDK tools

Append to `-classpath`

Eclipse

- Right-click on the project and then go *Build Path* → *Configure Build Path*. In the dialog, choose *Add External JARs*, browse to the Neo4j *lib/* directory and select all of the jar files.
- Another option is to use User Libraries.

IntelliJ IDEA

See Libraries, Global Libraries, and the Configure Library dialog.

NetBeans

- Right-click on the *Libraries* node of the project, choose *Add JAR/Folder*, browse to the Neo4j *lib/* directory and select all of the jar files.
- You can also handle libraries from the project node, see Managing a Project's Classpath.

Editions

The following table outlines the available editions and their names for use with dependency management tools.

Follow the links in the table for details on dependency configuration with Apache Maven, Apache Buildr, Apache Ivy, Groovy Grape, Grails, Scala SBT!

Table 2. Neo4j editions

Neo4j Edition	Dependency	Description
Community	org.neo4j:neo4j	A high performance, fully ACID transactional graph database.
Enterprise	org.neo4j:neo4j-enterprise	Adding advanced monitoring, online backup, and clustering.

Note that the listed dependencies do not contain the implementation, but pulls it in transitively.

For information regarding licensing, see the Licensing Guide.

Javadocs can be downloaded packaged in jar files from Maven Central or read at Neo4j Javadocs.

Adding Neo4j as a dependency

You can either go with the top-level artifact from the table above or include the individual components directly. The examples included here use the top-level artifact approach.

Additional information for Enterprise Edition users.

The examples below are only valid Neo4j Community Edition.

To add Neo4j Enterprise Edition as a dependency, please get in contact with Neo4j Professional Services.

See Operations Manual → Introduction for details about the Community and Enterprise Editions.

Maven

Add the dependency to your project along the lines of the snippet below. This is usually done in the *pom.xml* file found in the root directory of the project.

```
<project>
...
 <dependencies>
  <dependency>
   <groupId>org.neo4j</groupId>
   <artifactId>neo4j</artifactId>
   <version>4.4.1</version>
  </dependency>
  ...
 </dependencies>
...
</project>
```

Where the `artifactId` is found in the editions table.

Eclipse and Maven

For development in Eclipse, it is recommended to install the m2e plugin and let Maven manage the project build classpath instead, see above. This also adds the possibility to build your project both via the command line with Maven and have a working Eclipse setup for development.

Ivy

Make sure to resolve dependencies from Maven Central. You can use this configuration in your *ivysettings.xml* file:

```
<ivysettings>
  <settings defaultResolver="main"/>
  <resolvers>
    <chain name="main">
      <filesystem name="local">
        <artifact pattern="${ivy.settings.dir}/repository/[artifact]-[revision].[ext]" />
      </filesystem>
      <ibiblio name="maven_central" root="http://repo1.maven.org/maven2/" m2compatible="true"/>
    </chain>
  </resolvers>
</ivysettings>
```

With that in place, add Neo4j by adding this to your 'ivy.xml' file:

```
..
<dependencies>
  ..
  <dependency org="org.neo4j" name="neo4j" rev="4.4.1"/>
  ..
</dependencies>
..
```

The `name` can be found in the editions table above.

Gradle

The example below shows an example Gradle build script for including the Neo4j libraries:

```
def neo4jVersion = "4.4.1"
apply plugin: 'java'
repositories {
   mavenCentral()
}
dependencies {
   compile "org.neo4j:neo4j:${neo4jVersion}"
}
```

The coordinates (`org.neo4j:neo4j` in the example) are found in the editions table above.

Starting and stopping

To start the embedded DBMS you instantiate a `org.neo4j.dbms.DatabaseManagementService` and get the `org.neo4j.graphdb.GraphDatabaseService` as follows:

```
managementService = new DatabaseManagementServiceBuilder( databaseDirectory ).build();
graphDb = managementService.database( DEFAULT_DATABASE_NAME );
registerShutdownHook( managementService );
```

If you are using the Enterprise Edition of Neo4j in embedded standalone mode, you have to create your database with the `com.neo4j.dbms.api.EnterpriseDatabaseManagementServiceBuilder` to enable the Enterprise Edition features.

If you are intending to operate embedded clusters, then you should use the `com.neo4j.dbms.api.ClusterDatabaseManagementServiceBuilder` with appropriate configuration. For maintainability purposes, you can define your embedded DBMS configuration in the *neo4j.conf* file as follows:

```
dbms.mode=CORE
dbms.default_advertised_address=core01.example.com
dbms.default_listen_address=0.0.0.0
causal_clustering.discovery_type=LIST
causal_clustering.initial_discovery_members=core01.example.com,core02.example.com,core03.example.com
dbms.connector.bolt.enabled=true
dbms.connector.http.enabled=true
```

```
var managementService = new ClusterDatabaseManagementServiceBuilder( homeDirectory )
    .loadPropertiesFromFile( "/path/to/neo4j.conf" )
    .build();
```

It is also possible to use the builder, and specify all the parameters programmatically:

```
var defaultAdvertised = new SocketAddress( "core01.example.com" );
var defaultListen = new SocketAddress( "0.0.0.0" );

var initialMembers = List.of(
    new SocketAddress( "core01.example.com" ),
    new SocketAddress( "core02.example.com" ),
    new SocketAddress( "core03.example.com" )
);

var managementService = new ClusterDatabaseManagementServiceBuilder( homeDirectory )
    .setConfig( GraphDatabaseSettings.mode, CORE )
    .setConfig( GraphDatabaseSettings.default_advertised_address, defaultAdvertised )
    .setConfig( GraphDatabaseSettings.default_listen_address, defaultListen )
    .setConfig( CausalClusteringSettings.discovery_type, DiscoveryType.LIST )
    .setConfig( CausalClusteringSettings.initial_discovery_members, initialMembers )
    .setConfig( BoltConnector.enabled, true )
    .setConfig( HttpConnector.enabled, true )
    .build();
```

It is important to carefully consider which services you want to enable, and on which ports and interfaces. If you do not require Bolt or HTTP then it can be better to leave those disabled.

The `DatabaseManagementService` and `GraphDatabaseService` instances can be shared among multiple threads. Note however, that you cannot create multiple services pointing to the same database.

To stop the database, call the `shutdown()` method:

```
managementService.shutdown();
```

To make sure Neo4j is shut down properly, add a shutdown hook:

```
private static void registerShutdownHook( final DatabaseManagementService managementService )
{
    // Registers a shutdown hook for the Neo4j instance so that it
    // shuts down nicely when the VM exits (even if you "Ctrl-C" the
    // running application).
    Runtime.getRuntime().addShutdownHook( new Thread()
    {
        @Override
        public void run()
        {
            managementService.shutdown();
        }
    } );
}
```

Starting an embedded database with configuration settings

To start Neo4j with configuration settings, a Neo4j properties file can be loaded like this:

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( directory )
    .loadPropertiesFromFile( pathToConfig + "neo4j.conf" ).build();
GraphDatabaseService graphDb = managementService.database( DEFAULT_DATABASE_NAME );
```

Configuration settings can also be applied programmatically, like so:

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( directory)
    .setConfig( GraphDatabaseSettings.pagecache_memory, "512M" )
    .setConfig( GraphDatabaseSettings.transaction_timeout, Duration.ofSeconds( 60 ) )
    .setConfig( GraphDatabaseSettings.preallocate_logical_logs, true ).build();
GraphDatabaseService graphDb = managementService.database( DEFAULT_DATABASE_NAME );
```

Starting an embedded read-only instance

If you want a *read-only view* of the database, create an instance this way:

```
managementService = new DatabaseManagementServiceBuilder( dir ).setConfig( GraphDatabaseSettings
.read_only_database_default, true ).build();
graphDb = managementService.database( DEFAULT_DATABASE_NAME );
```

Obviously, the database has to already exist in this case.

Concurrent access to the same database files by multiple (read-only or write) instances is not supported.

Hello world

This describes how to create and access nodes and relationships.

For information on project setup, see Including Neo4j in your project.

A Neo4j graph consists of:

- nodes
- relationships that connects the nodes
- properties on both nodes and relationships

All relationships have a type. For example, if the graph represents a social network, a relationship type could be `KNOWS`. If a relationship of the type `KNOWS` connects two nodes, that is likely to represent two people that know each other. A lot of the semantics of a graph is encoded in the relationship types of the application. Although relationships are directed, they are equally traversed regardless of direction.

The source code of this example is found here: EmbeddedNeo4j.java

Preparing the database

Relationship types can be created by using an enum. In this example, you only need a single relationship type. This is how to define it:

```
private enum RelTypes implements RelationshipType
{
    KNOWS
}
```

You can also prepare some variables to use:

```
GraphDatabaseService graphDb;
Node firstNode;
Node secondNode;
Relationship relationship;
private DatabaseManagementService managementService;
```

The next step is to start the database server. Note that if the directory given for the database does not already exist, it will be created.

```
managementService = new DatabaseManagementServiceBuilder( databaseDirectory ).build();
graphDb = managementService.database( DEFAULT_DATABASE_NAME );
registerShutdownHook( managementService );
```

Starting a database server is an expensive operation, so do not start up a new instance every time you need to interact with the database. The instance can be shared by multiple threads, and transactions are thread confined.

As seen, you can register a shutdown hook that will make sure the database shuts down when the JVM exits.

```
private static void registerShutdownHook( final DatabaseManagementService managementService )
{
    // Registers a shutdown hook for the Neo4j instance so that it
    // shuts down nicely when the VM exits (even if you "Ctrl-C" the
    // running application).
    Runtime.getRuntime().addShutdownHook( new Thread()
    {
        @Override
        public void run()
        {
            managementService.shutdown();
        }
    } );
}
```

Next step is to interact with the database.

Wrapping operations in a transaction

All operations have to be performed in a transaction. This is a deliberate design decision, since we believe transaction demarcation to be an important part of working with a real enterprise database. The example below illustrates transaction handling in Neo4j:

```
try ( Transaction tx = graphDb.beginTx() )
{
    // Database operations go here
    tx.commit();
}
```

For more information on transactions, see Transaction management and the Neo4j Javadocs for `org.neo4j.graphdb.Transaction`.

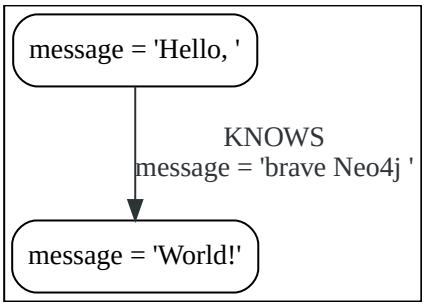
For brevity, wrapping of operations in a transaction is not spelled out throughout the manual.

Creating a small graph

You can now create a few nodes. The API is very intuitive as you can see in the Neo4j Javadocs (they are included in the distribution as well).
This is how to create a small graph consisting of two nodes, connected with one relationship and some properties:

```
firstNode = tx.createNode();
firstNode.setProperty( "message", "Hello, " );
secondNode = tx.createNode();
secondNode.setProperty( "message", "World!" );

relationship = firstNode.createRelationshipTo( secondNode, RelTypes.KNOWS );
relationship.setProperty( "message", "brave Neo4j " );
```

You now have a graph that looks like this:



Printing the result

After you have created your graph, you can read from it and print the result.

```
System.out.print( firstNode.getProperty( "message" ) );
System.out.print( relationship.getProperty( "message" ) );
System.out.print( secondNode.getProperty( "message" ) );
```

Which will output:

```
Hello, brave Neo4j World!
```

Removing the data

In this case, the data will be removed before committing:

```
// let's remove the data
firstNode = tx.getNodeById( firstNode.getId() );
secondNode = tx.getNodeById( secondNode.getId() );
firstNode.getSingleRelationship( RelTypes.KNOWS, Direction.OUTGOING ).delete();
firstNode.delete();
secondNode.delete();
```

Deleting a node which still has relationships when the transaction commits will fail. This is to make sure relationships always have a start node and an end node.

Shutting down the database server

Finally, shut down the database server *when the application finishes:*

```
managementService.shutdown();
```

Property values

This describes how both nodes and relationships can have properties.

Properties are named values where the name is a string. Property values can be either a primitive or an array of one primitive type. For example `String`, `int` and `int[]` values are valid for properties.

`NULL` is **not a valid** property value. Setting a property to `NULL` is equivalent to deleting the property.

Table 3. Property value types

Type	Description
`boolean`	
`byte`	8-bit integer.
`short`	16-bit integer.
`int`	32-bit integer.
`long`	64-bit integer.
`float`	32-bit IEEE 754 floating-point number.
`double`	64-bit IEEE 754 floating-point number.
`char`	16-bit unsigned integers representing Unicode characters.
`String`	Sequence of Unicode characters.
`org.neo4j.graphdb.spatial.Point`	A 2D or 3D point object in a given coordinate system.

Type	Description
`java.time.LocalDate`	An instant capturing the date, but not the time, nor the timezone.
`java.time.OffsetTime`	An instant capturing the time of day, and the timezone offset, but not the date.
`java.time.LocalTime`	An instant capturing the time of day, but not the date, nor the timezone.
`java.time.ZonedDateTime`	An instant capturing the date, the time, and the timezone.
`java.time.LocalDateTime`	An instant capturing the date and the time, but not the timezone.
`java.time.temporal.TemporalAmount`	A temporal amount. This captures the difference in time between two instants.

For further details on float/double values, see Java Language Specification.

Note that there are two cases where more than one Java type is mapped to a single Cypher type. When this happens, type information is lost. If these objects are returned from procedures, the original types cannot be recreated:

- A Cypher `Duration` is created when either a `java.time.Duration` or a `java.time.Period` is provided. If a `Duration` is returned, only the common interface `java.time.temporal.TemporalAmount` will remain.
- A Cypher `DateTime` is created when a `java.time.OffsetDateTime` is provided. If a `DateTime` is returned, it will be converted into a `java.time.ZonedDateTime`.

Strings that contain special characters can have inconsistent or non-deterministic ordering in Neo4j. For details, see Cypher Manual → Sorting of special characters.

Using indexes

It is possible to create and use all the index types described in Cypher Manual → Indexes.

This section demonstrates how to work with indexes with an example of a user database. For information about how to create an index on all `User` nodes that have a `username` property, see Cypher Manual → Create a single-property index for nodes.

The source code used in this example is found here: EmbeddedNeo4jWithIndexing.java

Begin with starting the database server:

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( databaseDirectory
).build();
GraphDatabaseService graphDb = managementService.database( DEFAULT_DATABASE_NAME );
```

Then you can configure the database to index users by name. This only needs to be done once. However, note that schema changes and data changes are not allowed in the same transaction. Each transaction must either change the schema or the data, but not both.

```
IndexDefinition usernamesIndex;
try ( Transaction tx = graphDb.beginTx() )
{
    Schema schema = tx.schema();
    usernamesIndex = schema.indexFor( Label.label( "User" ) )  ①
            .on( "username" )                                  ②
            .withName( "usernames" )                           ③
            .create();                                         ④
    tx.commit();                                               ⑤
}
```

① A single-property index is defined on a label in combination with a property name. Start your index definition by specifying the node label.

② Next, define the property that should be part of this index. Index all nodes with the `User` label, that also have a `username` property. This way, you can find `User` nodes by their `username` properties.

③ An index always has a name. If you don't specify a name, one will be generated for you.

④ Calling `create` is necessary in order for the index definition to be created in the database. This index is now created, but it still only exists in our current transaction.

⑤ Committing the transaction commits our new index to the database. It will become available for use once it has finished populating itself with the existing data in our database.

Indexes are populated asynchronously when they are first created. It is possible to use the core API to wait for index population to complete:

```
try ( Transaction tx = graphDb.beginTx() )
{
    Schema schema = tx.schema();
    schema.awaitIndexOnline( usernamesIndex, 10, TimeUnit.SECONDS );
}
```

It is also possible to query the progress of the index population:

```
try ( Transaction tx = graphDb.beginTx() )
{
    Schema schema = tx.schema();
    System.out.println( String.format( "Percent complete: %1.0f%%",
        schema.getIndexPopulationProgress( usernamesIndex ).getCompletedPercentage() ) );
}
```

Now you can add the users:

```
try ( Transaction tx = graphDb.beginTx() )
{
    Label label = Label.label( "User" );

    // Create some users
    for ( int id = 0; id < 100; id++ )
    {
        Node userNode = tx.createNode( label );
        userNode.setProperty( "username", "user" + id + "@neo4j.org" );
    }
    System.out.println( "Users created" );
    tx.commit();
}
```

Please read Resource iterator on how to properly close `ResourceIterators` returned from index lookups.

And this is how to find a user by ID:

```
Label label = Label.label( "User" );
int idToFind = 45;
String nameToFind = "user" + idToFind + "@neo4j.org";
try ( Transaction tx = graphDb.beginTx() )
{
    try ( ResourceIterator<Node> users =
                tx.findNodes( label, "username", nameToFind ) )
    {
        ArrayList<Node> userNodes = new ArrayList<>();
        while ( users.hasNext() )
        {
            userNodes.add( users.next() );
        }

        for ( Node node : userNodes )
        {
            System.out.println(
                    "The username of user " + idToFind + " is " + node.getProperty( "username" ) );
        }
    }
}
```

When updating the name of a user, the index is updated as well:

```
try ( Transaction tx = graphDb.beginTx() )
{
    Label label = Label.label( "User" );
    int idToFind = 45;
    String nameToFind = "user" + idToFind + "@neo4j.org";

    for ( Node node : loop( tx.findNodes( label, "username", nameToFind ) ) )
    {
        node.setProperty( "username", "user" + (idToFind + 1) + "@neo4j.org" );
    }
    tx.commit();
}
```

When deleting a user, it is automatically removed from the index:

```
try ( Transaction tx = graphDb.beginTx() )
{
    Label label = Label.label( "User" );
    int idToFind = 46;
    String nameToFind = "user" + idToFind + "@neo4j.org";

    for ( Node node : loop( tx.findNodes( label, "username", nameToFind ) ) )
    {
        node.delete();
    }
    tx.commit();
}
```

In case you change your data model, you can drop the index as well:

```
try ( Transaction tx = graphDb.beginTx() )
{
    IndexDefinition usernamesIndex = tx.schema().getIndexByName( "usernames" ); ①
    usernamesIndex.drop();
    tx.commit();
}
```

① You look up the index by the index name you gave it when you created it. Index names are guaranteed to be unique, to ensure that you will not mistakenly find and drop the wrong index.

Resource iterator

This describes best practices for managing resources in long-running transactions.

Inside a long-running transaction it is good practice to ensure that any `org.neo4j.graphdb.ResourceIterator` obtained inside the transaction are closed as early as possible. This is either achieved by exhausting the iterator or by explicitly calling its close method.

Below is an example of how to work with a `ResourceIterator`. As you do not exhaust the iterator, you can close it explicitly using the `close()` method.

```
Label label = Label.label( "User" );
int idToFind = 45;
String nameToFind = "user" + idToFind + "@neo4j.org";
try ( Transaction tx = graphDb.beginTx();
      ResourceIterator<Node> users = tx.findNodes( label, "username", nameToFind ) )
{
    Node firstUserNode;
    if ( users.hasNext() )
    {
        firstUserNode = users.next();
    }
    users.close();
    // ... Do stuff with the firstUserNode we found ...
}
```

Controlling logging

This describes how to control logging in Neo4j embedded using the Neo4j embedded logging framework.

Neo4j embedded provides logging via its own `org.neo4j.logging.Log` layer, and does not natively use any existing Java logging framework. All logging events produced by Neo4j have a name, a level and a message. The name is a FQCN (fully qualified class name).

Neo4j uses the following log levels:

Level Name	Description
`ERROR`	For serious errors that are almost always fatal.
`WARN`	For events that are serious, but not fatal.
`INFO`	Informational events.
`DEBUG`	Debugging events.

To enable logging, an implementation of `org.neo4j.logging.LogProvider` must be provided to the `org.neo4j.dbms.api.DatabaseManagementServiceBuilder`, as follows:

```
LogProvider logProvider = new MyCustomLogProvider( output );
managementService = new DatabaseManagementServiceBuilder( databaseDirectory ).setUserLogProvider(
logProvider ).build();
```

Traversal

This describes traversing into another graph.

For more information about traversals, see The traversal framework.

The traversal API described in this section has been deprecated and will be replaced in the next major release of Neo4j.

The Matrix

This is the first graph to traverse into:

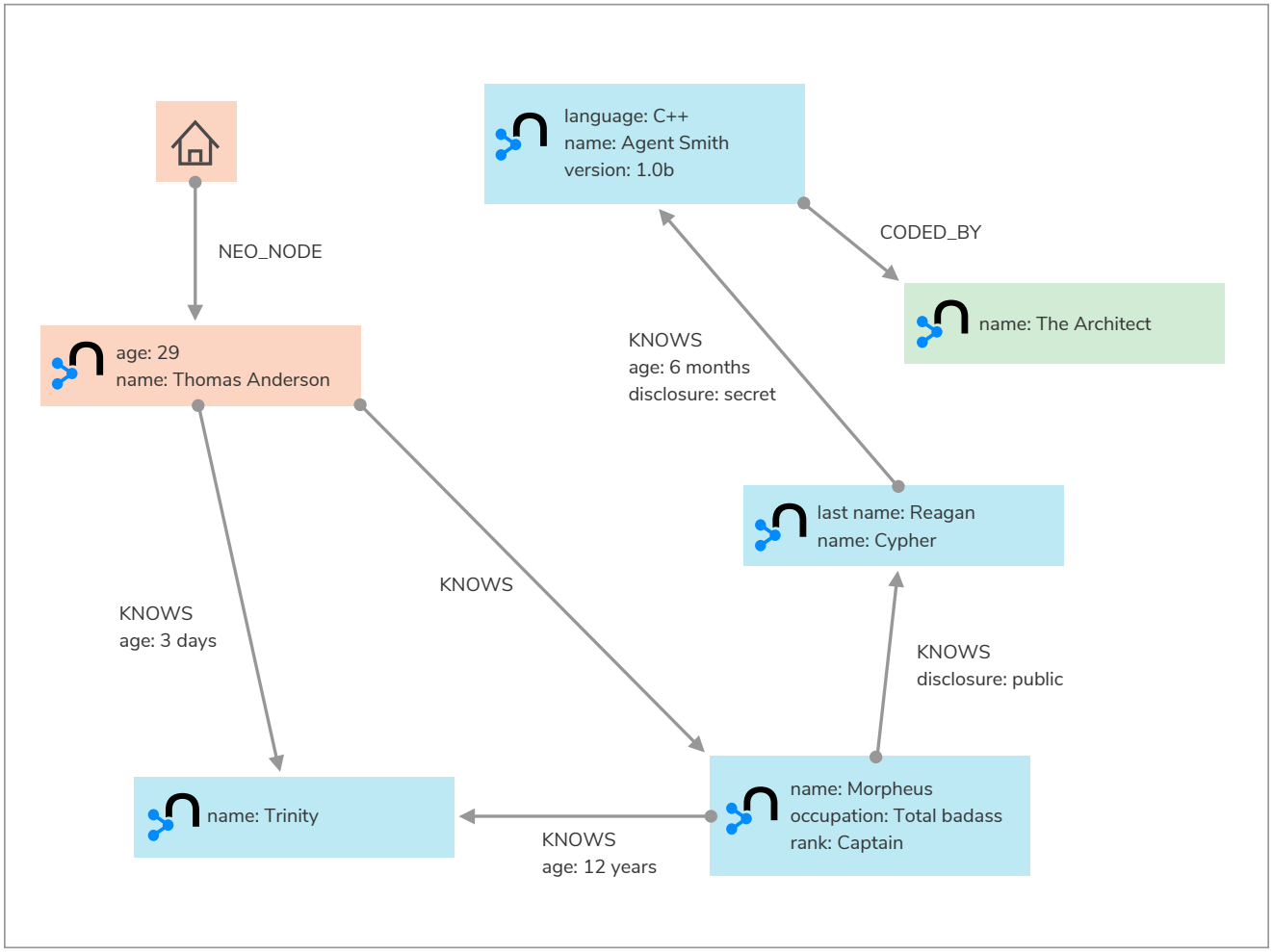


Figure 1. Matrix node space view

The source code of this example is found here: NewMatrix.java

Friends and friends of friends:

```
private Traverser getFriends( Transaction transaction, final Node person )
{
    TraversalDescription td = transaction.traversalDescription()
            .breadthFirst()
            .relationships( RelTypes.KNOWS, Direction.OUTGOING )
            .evaluator( Evaluators.excludeStartPosition() );
    return td.traverse( person );
}
```

You can perform the actual traversal and print the results:

```
int numberOfFriends = 0;
String output = neoNode.getProperty( "name" ) + "'s friends:\n";
Traverser friendsTraverser = getFriends( tx, neoNode );
for ( Path friendPath : friendsTraverser )
{
    output += "At depth " + friendPath.length() + " => "
              + friendPath.endNode()
                      .getProperty( "name" ) + "\n";
    numberOfFriends++;
}
output += "Number of friends found: " + numberOfFriends + "\n";
```

Which will give you the following output:

```
Thomas Anderson's friends:
At depth 1 => Morpheus
At depth 1 => Trinity
At depth 2 => Cypher
At depth 3 => Agent Smith
Number of friends found: 4
```

Who coded the Matrix?

```
private Traverser findHackers( Transaction transaction, final Node startNode )
{
    TraversalDescription td = transaction.traversalDescription()
        .breadthFirst()
        .relationships( RelTypes.CODED_BY, Direction.OUTGOING )
        .relationships( RelTypes.KNOWS, Direction.OUTGOING )
        .evaluator(Evaluators.includeWhereLastRelationshipTypeIs( RelTypes.CODED_BY ) );
    return td.traverse( startNode );
}
```

Print out the result:

```
String output = "Hackers:\n";
int numberOfHackers = 0;
Traverser traverser = findHackers( tx, getNeoNode( tx ) );
for ( Path hackerPath : traverser )
{
    output += "At depth " + hackerPath.length() + " => " + hackerPath.endNode().getProperty( "name" ) +
"\n";
    numberOfHackers++;
}
output += "Number of hackers found: " + numberOfHackers + "\n";
```

Now you know who coded the Matrix:

```
Hackers:
At depth 4 => The Architect
Number of hackers found: 1
```

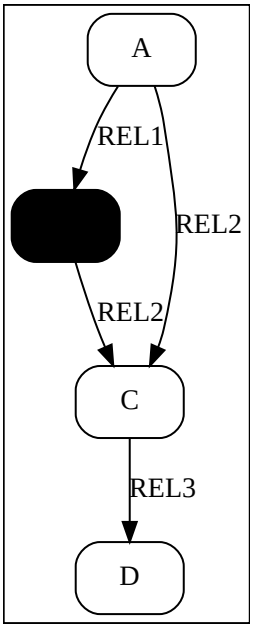
Walking an ordered path

This example shows how to use a path context holding a representation of a path.

The source code of this example is found here: OrderedPath.java

Create a toy graph:

```
Node A = tx.createNode();
Node B = tx.createNode();
Node C = tx.createNode();
Node D = tx.createNode();

A.createRelationshipTo( C, REL2 );
C.createRelationshipTo( D, REL3 );
A.createRelationshipTo( B, REL1 );
B.createRelationshipTo( C, REL2 );
```



Now, the order of relationships (`REL1` → `REL2` → `REL3`) is stored in an `ArrayList`. Upon traversal, the `Evaluator` can check against it to ensure that only paths are included and returned that have the predefined order of relationships:

```
final ArrayList<RelationshipType> orderedPathContext = new ArrayList<>();
orderedPathContext.add( REL1 );
orderedPathContext.add( withName( "REL2" ) );
orderedPathContext.add( withName( "REL3" ) );
TraversalDescription td = tx.traversalDescription()
    .evaluator( new Evaluator()
    {
        @Override
        public Evaluation evaluate( final Path path )
        {
            if ( path.length() == 0 )
            {
                return Evaluation.EXCLUDE_AND_CONTINUE;
            }
            RelationshipType expectedType = orderedPathContext.get( path.length() - 1 );
            boolean isExpectedType = path.lastRelationship()
                    .isType( expectedType );
            boolean included = path.length() == orderedPathContext.size() && isExpectedType;
            boolean continued = path.length() < orderedPathContext.size() && isExpectedType;
            return Evaluation.of( included, continued );
        }
    } )
    .uniqueness( Uniqueness.NODE_PATH ); ①
```

① Note that we set the uniqueness to `Uniqueness.NODE_PATH`, as you want to be able to revisit the same node during the traversal, but not the same path.

Perform the traversal and print the result:

```
Traverser traverser = td.traverse( tx.getNodeById( A.getId() ) );
PathPrinter pathPrinter = new PathPrinter( "name" );
for ( Path path : traverser )
{
    output += Paths.pathToString( path, pathPrinter );
}
```

Which will output:

```
(A)--[REL1]-->(B)--[REL2]-->(C)--[REL3]-->(D)
```

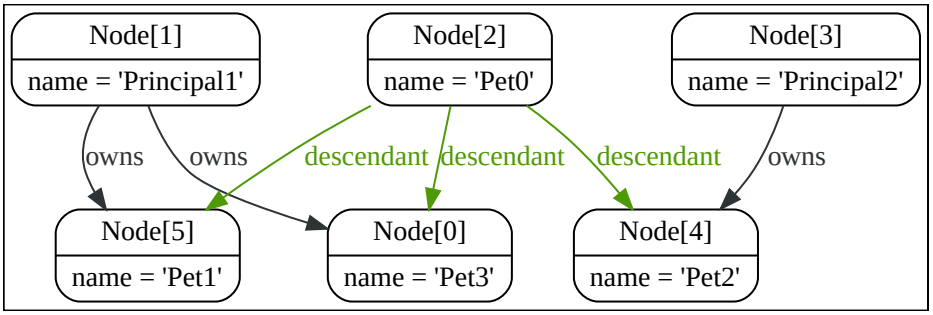
In this case, a customized class is used to format the path output. This is how it is done:

```
static class PathPrinter implements Paths.PathDescriptor<Path>
{
    private final String nodePropertyKey;

    public PathPrinter( String nodePropertyKey )
    {
        this.nodePropertyKey = nodePropertyKey;
    }

    @Override
    public String nodeRepresentation( Path path, Node node )
    {
        return "(" + node.getProperty( nodePropertyKey, "" ) + ")";
    }

    @Override
    public String relationshipRepresentation( Path path, Node from, Relationship relationship )
    {
        String prefix = "--", suffix = "--";
        if ( from.equals( relationship.getEndNode() ) )
        {
            prefix = "<--";
        }
        else
        {
            suffix = "-->";
        }
        return prefix + "[" + relationship.getType().name() + "]" + suffix;
    }
}
```

Uniqueness of Paths in traversals

This example is demonstrating the use of node uniqueness. Below an imaginary domain graph with Principals that own pets that are descendant to other pets.

Descendants example graph



In order to return all descendants of `Pet0` which have the relation `owns` to `Principal1` (`Pet1` and `Pet3`), the Uniqueness of the traversal needs to be set to `NODE_PATH` rather than the default `NODE_GLOBAL`. This way nodes can be traversed more that once, and paths that have different nodes but can have some nodes in common (like the start and end node) can be returned.

```
Node dataTarget = data.get().get( "Principal1" );
String output = "";
int count = 0;
try ( Transaction transaction = graphdb().beginTx() )
{
    start = transaction.getNodeById( start.getId() );
    final Node target = transaction.getNodeById( dataTarget.getId() );
    TraversalDescription td = transaction.traversalDescription()
            .uniqueness( Uniqueness.NODE_PATH )
            .evaluator( new Evaluator()
    {
        @Override
        public Evaluation evaluate( Path path )
        {
            boolean endNodeIsTarget = path.endNode().equals( target );
            return Evaluation.of( endNodeIsTarget, !endNodeIsTarget );
        }
    } );

    Traverser results = td.traverse( start );
}
```

This will return the following paths:

```
(2)-[descendant,2]->(0)<-[owns,5]-(1)
(2)-[descendant,0]->(5)<-[owns,3]-(1)
```

In the default `path.toString()` implementation, `(1)--[knows,2]->(4)` denotes a node with `ID=1` having a relationship with `ID=2` or type `knows` to a node with `ID=4`.

Let's create a new `TraversalDescription` from the old one, having `NODE_GLOBAL` uniqueness to see the difference.

The `TraversalDescription` object is immutable, so we have to use the new instance returned with the new uniqueness setting.

```
TraversalDescription nodeGlobalTd = tx.traversalDescription().uniqueness( Uniqueness.NODE_PATH ).
evaluator( new Evaluator()
{
    @Override
    public Evaluation evaluate( Path path )
    {
        boolean endNodeIsTarget = path.endNode().equals( target );
        return Evaluation.of( endNodeIsTarget, !endNodeIsTarget );
    }
} ).uniqueness( Uniqueness.NODE_GLOBAL );
Traverser results = nodeGlobalTd.traverse( start );
```

Now only one path is returned:

```
(2)-[descendant,2]->(0)<-[owns,5]-(1)
```

Domain entities

This describes one way to handle domain entities when using Neo4j.

Entities can be wrapped around a node. The same approach can be used with relationships.

The source code of the examples is found here: Person.java

First off, store the node and make it accessible inside the package:

```
private final Node underlyingNode;

Person( GraphDatabaseService databaseService, Transaction transaction, Node personNode )
{
    this.databaseService = databaseService;
    this.transaction = transaction;
    this.underlyingNode = personNode;
}

protected Node getUnderlyingNode()
{
    return underlyingNode;
}
```

Delegate attributes to the node:

```
public String getName()
{
    return (String)underlyingNode.getProperty( NAME );
}
```

Make sure to override these methods:

```
@Override
public int hashCode()
{
    return underlyingNode.hashCode();
}

@Override
public boolean equals( Object o )
{
    return o instanceof Person &&
            underlyingNode.equals( ( (Person)o ).getUnderlyingNode() );
}

@Override
public String toString()
{
    return "Person[" + getName() + "]";
}
```

Graph algorithm examples

For details on the graph algorithm usage, see the Neo4j Javadocs for `org.neo4j.graphalgo.GraphAlgoFactory`.

The source code used in the example is found here: PathFindingDocTest.java

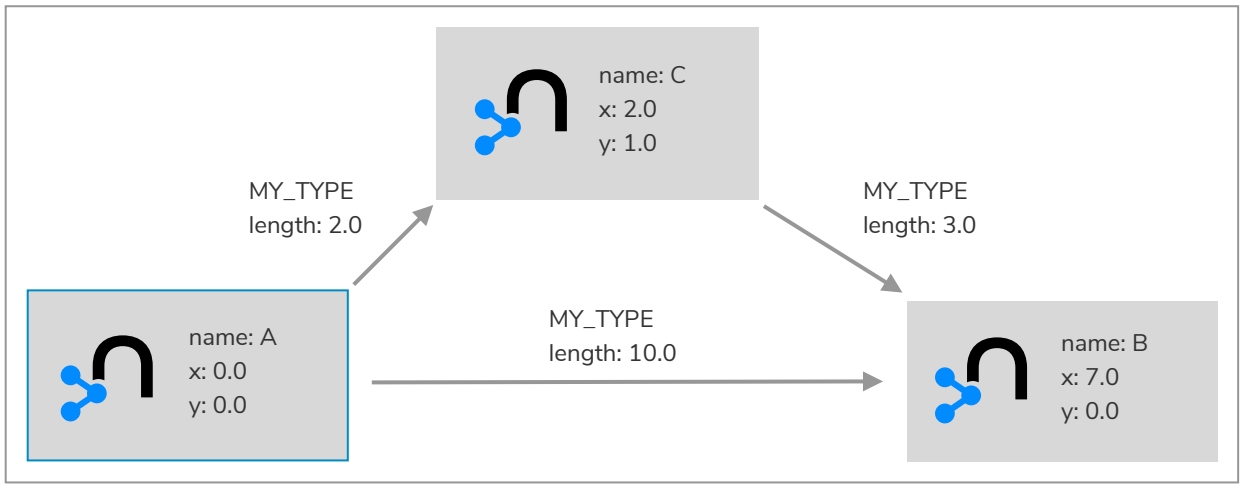
Calculating the shortest path (least number of relationships) between two nodes:

```
Node startNode = tx.createNode();
Node middleNode1 = tx.createNode();
Node middleNode2 = tx.createNode();
Node middleNode3 = tx.createNode();
Node endNode = tx.createNode();
createRelationshipsBetween( startNode, middleNode1, endNode );
createRelationshipsBetween( startNode, middleNode2, middleNode3, endNode );

// Will find the shortest path between startNode and endNode via
// "MY_TYPE" relationships (in OUTGOING direction), like f.ex:
//
// (startNode)-->(middleNode1)-->(endNode)
//
PathFinder<Path> finder = GraphAlgoFactory.shortestPath( new BasicEvaluationContext( tx, graphDb ),
    PathExpanders.forTypeAndDirection( ExampleTypes.MY_TYPE, Direction.OUTGOING ), 15 );
Iterable<Path> paths = finder.findAllPaths( startNode, endNode );
```

Using Dijkstra's algorithm to calculate cheapest path between node A and B where each relationship can have a weight (i.e. cost) and the path(s) with least cost are found.

```
PathFinder<WeightedPath> finder = GraphAlgoFactory.dijkstra( new BasicEvaluationContext( tx, graphDb ),
    PathExpanders.forTypeAndDirection( ExampleTypes.MY_TYPE, Direction.BOTH ), "cost" );

WeightedPath path = finder.findSinglePath( nodeA, nodeB );

// Get the weight for the found path
path.weight();
```

Using A* to calculate the cheapest path between node A and B, where cheapest means, for example, the path in a network of roads which has the shortest length between node A and B. This is the example graph:



```
Node nodeA = createNode( "name", "A", "x", 0d, "y", 0d );
Node nodeB = createNode( "name", "B", "x", 7d, "y", 0d );
Node nodeC = createNode( "name", "C", "x", 2d, "y", 1d );
Relationship relAB = createRelationship( nodeA, nodeC, "length", 2d );
Relationship relBC = createRelationship( nodeC, nodeB, "length", 3d );
Relationship relAC = createRelationship( nodeA, nodeB, "length", 10d );

EstimateEvaluator<Double> estimateEvaluator = ( node, goal ) ->
{
    double dx = (Double) node.getProperty( "x" ) - (Double) goal.getProperty( "x" );
    double dy = (Double) node.getProperty( "y" ) - (Double) goal.getProperty( "y" );
    return Math.sqrt( Math.pow( dx, 2 ) + Math.pow( dy, 2 ) );
};
PathFinder<WeightedPath> astar = GraphAlgoFactory.aStar( new BasicEvaluationContext( tx, graphDb ),
        PathExpanders.allTypesAndDirections(),
        CommonEvaluators.doubleCostEvaluator( "length" ), estimateEvaluator );
WeightedPath path = astar.findSinglePath( nodeA, nodeB );
```

Unique nodes

This describes how to ensure uniqueness of a property when creating nodes.

Getting or creating a unique node using Cypher and uniqueness constraints.

For an overview of unique nodes, see Transaction management → Creating unique nodes.

The source code for the examples can be found here: GetOrCreateDocIT.java

Create a unique constraint:

```
try ( Transaction tx = graphdb.beginTx() )
{
    tx.schema()
        .constraintFor( Label.label( "User" ) )
        .assertPropertyIsUnique( "name" )
        .withName( "usernames" )
        .create();
    tx.commit();
}
```

Use `MERGE` to create a unique node:

```
Node result = null;
ResourceIterator<Node> resultIterator = null;
try ( Transaction tx = graphDb.beginTx() )
{
    String queryString = "MERGE (n:User {name: $name}) RETURN n";
    Map<String, Object> parameters = new HashMap<>();
    parameters.put( "name", username );
    resultIterator = tx.execute( queryString, parameters ).columnAs( "n" );
    result = resultIterator.next();
    tx.commit();
    return result;
}
```

The `MERGE` clause will either take a read-lock on the matching node already exists, or it will take a write-lock and ensure that the current transaction is the only one creating the node.

It is technically possible to use a "lock node" or a "lock property" but this should be avoided if possible. Using the "lock node" pattern is both difficult to do correctly, and it has worse performance characteristics

since it always involves a write-lock.

One might also be tempted to use Java synchronization for pessimistic locking, but this is dangerous. By mixing locks in Neo4j and in the Java runtime, it is possible to produce deadlocks that are not detectable by Neo4j. As long as all locking is done by Neo4j, all deadlocks will be detected and avoided.

Bolt connector

This describes how to open a Bolt connector to your embedded instance to get GUI administration and other benefits. Accessing Neo4j embedded via the Bolt protocol.

The Neo4j Browser and the official Neo4j Drivers use the Bolt database protocol to communicate with Neo4j. By default, Neo4j Embedded does not expose a Bolt connector, but you can enable one. Doing so allows you to connect the services Neo4j Browser to your embedded instance.

It also gives you a way to incrementally transfer an existing Embedded application to use Neo4j Drivers instead. Migrating to Neo4j Drivers means you can run Neo4j Embedded or Neo4j Server, without having to change your application code.

To add a Bolt Connector to your embedded database, you must add the Bolt extension to your class path. This is done by adding an additional dependency to your project:

```
<project>
...
 <dependencies>

  <dependency>
    <groupId>org.neo4j</groupId>
    <artifactId>neo4j-bolt</artifactId>
    <version>4.4.1</version>
  </dependency>
  ...
 </dependencies>
...
</project>
```

With this dependency in place, you can configure Neo4j to enable a Bolt connector:

The source code for the example can be found here: EmbeddedNeo4jWithBolt.java

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( DB_PATH )
    .setConfig( BoltConnector.enabled, true )
    .setConfig( BoltConnector.listen_address, new SocketAddress( "localhost", 7687 ) )
    .build();
```

Terminate a transaction

The describes how to terminate (abort) a long-running transaction from another thread.

The source code for the examples can be found here: TerminateTransactions.java

First, start the database server:

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( databaseDirectory
).build();
GraphDatabaseService graphDb = managementService.database( DEFAULT_DATABASE_NAME );
```

Then start creating an infinite binary tree of nodes in the database, as an example of a long-running transaction:

```
RelationshipType relType = RelationshipType.withName( "CHILD" );
Queue<Node> nodes = new LinkedList<>();
int depth = 1;

try ( Transaction tx = graphDb.beginTx() )
{
    Node rootNode = tx.createNode();
    nodes.add( rootNode );

    for (; true; depth++) {
        int nodesToExpand = nodes.size();
        for (int i = 0; i < nodesToExpand; ++i) {
            Node parent = nodes.remove();

            Node left = tx.createNode();
            Node right = tx.createNode();

            parent.createRelationshipTo( left, relType );
            parent.createRelationshipTo( right, relType );

            nodes.add( left );
            nodes.add( right );
        }
    }
}
catch ( TransactionTerminatedException ignored )
{
    return String.format( "Created tree up to depth %s in 1 sec", depth );
}
```

After waiting for some time, you decide to terminate the transaction. This is done from a separate thread:

```
tx.terminate();
```

Running this will execute the long-running transaction for about one second and prints the maximum depth of the tree that was created before the transaction was terminated. No changes are actually made to the data — because the transaction has been terminated, the end result is as if no operations were performed.

This is an example output:

```
Created tree up to depth 18 in 1 sec
```

Finally, the database can be shut down again:

```
managementService.shutdown();
```

Cypher queries

In Java, you can use the Cypher query language as per the example below.

The source code for the examples can be found here: JavaQuery.java

First, you can add some data:

```
DatabaseManagementService managementService = new DatabaseManagementServiceBuilder( databaseDirectory
).build();
GraphDatabaseService db = managementService.database( DEFAULT_DATABASE_NAME );

try ( Transaction tx = db.beginTx())
{
    Node myNode = tx.createNode();
    myNode.setProperty( "name", "my node" );
    tx.commit();
}
```

Execute a query:

```
try ( Transaction tx = db.beginTx();
      Result result = tx.execute( "MATCH (n {name: 'my node'}) RETURN n, n.name" ) )
{
    while ( result.hasNext() )
    {
        Map<String,Object> row = result.next();
        for ( Entry<String,Object> column : row.entrySet() )
        {
            rows += column.getKey() + ": " + column.getValue() + "; ";
        }
        rows += "\n";
    }
}
```

In the above example, you can also see how to iterate over the rows of the `org.neo4j.graphdb.Result`.

The code will generate:

```
n: Node[0]; n.name: my node;
```

When using an `Result`, you should consume the entire result (iterate over all rows using `next()`, iterating over the iterator from `columnAs()` or calling for example `resultAsString()`). Failing to do so will not properly clean up resources used by the `Result` object, leading to unwanted behavior, such as leaking transactions. In case you do not want to iterate over all of the results, make sure to invoke `close()` as soon as you are done, to release the resources tied to the result.

The recommended way to handle results is to use a try-with-resources statement. This will make sure that the result is closed at the end of the statement.

You can also get a list of the columns in the result like this:

```
List<String> columns = result.columns();
```

This gives you:

```
[n, n.name]
```

Use the following to fetch the result items from a single column. In this case, you will have to read the property from the node, and not from the result:

```
Iterator<Node> n_column = result.columnAs( "n" );
n_column.forEachRemaining( node -> nodeResult = node + ": " + node.getProperty( "name" ) );
```

In this case, there is only one node in the result:

```
Node[0]: my node
```

Only use this if the result only contains a single column, or you are only interested in a single column of the result.

`resultAsString()`, `writeAsStringTo()`, `columnAs()` cannot be called more than once on the same `Result` object, as they consume the result. In the same way, part of the result gets consumed for every call to `next()`. You should instead use only one and if you need the facilities of the other methods on the same query result instead create a new `Result`.

For more information on the Java interface to Cypher, see the Neo4j Javadocs.

For more information and examples for Cypher, see Neo4j Cypher Manual.

Query parameters

Here are some examples for query parameters. The examples below illustrate how to use parameters when executing Cypher queries from Java.

For more information on parameters see the Neo4j Cypher Manual.

Node ID:

```
Map<String,Object> params = new HashMap<>();
params.put( "id", 0 );

String query =
    "MATCH (n)" + "\n" +
    "WHERE id(n) = $id" + "\n" +
    "RETURN n.name";

Result result = transaction.execute( query, params );
```

Node object:

```
Map<String,Object> params = new HashMap<>();
params.put( "node", bobNode );

String query =
    "MATCH (n:Person)" + "\n" +
    "WHERE n = $node" + "\n" +
    "RETURN n.name";

Result result = transaction.execute( query, params );
```

Multiple node IDs:

```
Map<String,Object> params = new HashMap<>();
params.put( "ids", asList( 0, 1, 2 ) );

String query =
    "MATCH (n)" + "\n" +
    "WHERE id(n) IN $ids" + "\n" +
    "RETURN n.name";

Result result = transaction.execute( query, params );
```

String literal:

```
Map<String,Object> params = new HashMap<>();
params.put( "name", "Johan" );

String query =
    "MATCH (n:Person)" + "\n" +
    "WHERE n.name = $name" + "\n" +
    "RETURN n";

Result result = transaction.execute( query, params );
```

Numeric parameters for `SKIP` and `LIMIT`:

```
Map<String,Object> params = new HashMap<>();
params.put( "s", 1 );
params.put( "l", 1 );

String query =
    "MATCH (n:Person)" + "\n" +
    "RETURN n.name" + "\n" +
    "SKIP $s" + "\n" +
    "LIMIT $l";

Result result = transaction.execute( query, params );
```

Regular expression:

```
Map<String,Object> params = new HashMap<>();
params.put( "regex", ".*h.*" );

String query =
    "MATCH (n:Person)" + "\n" +
    "WHERE n.name =~ $regex" + "\n" +
    "RETURN n.name";

Result result = transaction.execute( query, params );
```

Create node with properties:

```
Map<String,Object> props = new HashMap<>();
props.put( "name", "Andy" );
props.put( "position", "Developer" );

Map<String,Object> params = new HashMap<>();
params.put( "props", props );

String query = "CREATE ($props)";

transaction.execute( query, params );
```

Create multiple nodes with properties:

```
Map<String,Object> n1 = new HashMap<>();
n1.put( "name", "Andy" );
n1.put( "position", "Developer" );
n1.put( "awesome", true );

Map<String,Object> n2 = new HashMap<>();
n2.put( "name", "Michael" );
n2.put( "position", "Developer" );
n2.put( "children", 3 );

Map<String,Object> params = new HashMap<>();
List<Map<String,Object>> maps = asList( n1, n2 );
params.put( "props", maps );

String query =
    "UNWIND $props AS properties" + "\n" +
    "CREATE (n:Person)" + "\n" +
    "SET n = properties" + "\n" +
    "RETURN n";

Result result = transaction.execute( query, params );
```

Setting all properties on node:

```
Map<String, Object> n1 = new HashMap<>();
n1.put( "name", "Andy" );
n1.put( "position", "Developer" );

Map<String, Object> params = new HashMap<>();
params.put( "props", n1 );

String query =
    "MATCH (n:Person)" + "\n" +
    "WHERE n.name = 'Michaela'" + "\n" +
    "SET n = $props";

transaction.execute( query, params );
```

The traversal framework

The traversal API described in this section has been deprecated and will be replaced by a new version of the API in the next major release of Neo4j. This new version will be available in a future release of Neo4j 4.x, alongside the current version. The current version, as detailed below, will be removed in Neo4j 5.0.

For a detailed example on how to use the traversal framework, refer to The Neo4j Java Developer Reference v3.5.

This section provides an overview of the concepts of the traversal framework, and a detailed description of the Neo4j traversal framework Java API.

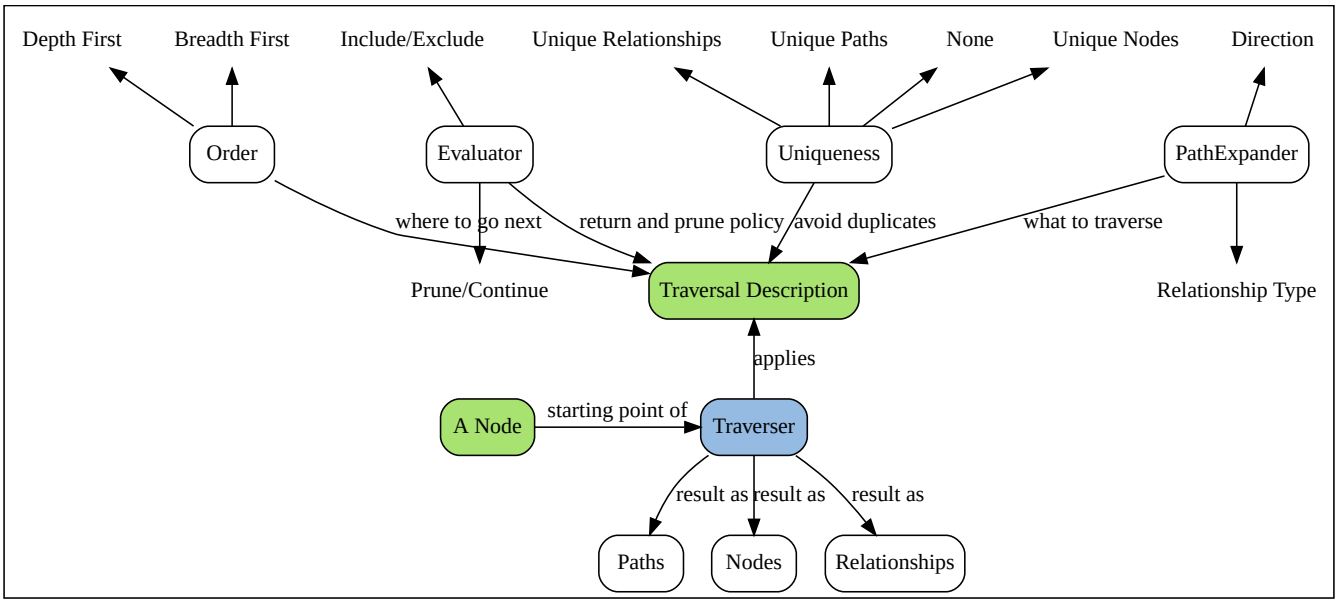
The Neo4j Traversal framework Java API is a callback-based, lazily-executed way of specifying desired movements through a graph in Java. Some traversal examples are collected under Traversal.

You can also use the Cypher query language as a powerful declarative way to query the graph.

Main concepts

Below is a short explanation of all different methods that can modify or add to a traversal description.

- *Pathexpanders* — define what to traverse, typically in terms of relationship direction and type.
- *Order* — for example depth-first or breadth-first.
- *Uniqueness* — visit nodes (relationships, paths) only once.
- *Evaluator* — decide what to return and whether to stop or continue traversal beyond the current position.
- *Starting nodes* where the traversal will begin.



Traversal framework Java API

The traversal framework is no longer supported. For a detailed example on how to use it, refer to The Neo4j Java Developer Reference v3.5.

The traversal framework consists of a few main interfaces in addition to `Node` and `Relationship`: `TraversalDescription`, `Evaluator`, `Traverser` and `Uniqueness` are the main ones. The `Path` interface also has a special purpose in traversals, since it is used to represent a position in the graph when evaluating that position. Furthermore the `PathExpander` (replacing `RelationshipExpander` and `Expander`) interface is central to traversals, but users of the API rarely need to implement it. There are also a set of interfaces for advanced use, when explicit control over the traversal order is required: `BranchSelector`, `BranchOrderingPolicy` and `TraversalBranch`.

TraversalDescription

The `TraversalDescription` is the main interface used for defining and initializing traversals. It is not meant to be implemented by users of the traversal framework, but rather to be provided by the implementation of the traversal framework as a way for the user to describe traversals. `TraversalDescription` instances are immutable and its methods returns a new `TraversalDescription` that is modified compared to the object the method was invoked on with the arguments of the method.

Relationships

Adds a relationship type to the list of relationship types to traverse. By default this list is empty and it means that it will traverse *all relationships*, regardless of type. If one or more relationships are added to this list *only the added* types will be traversed. There are two methods, one `including direction` and another one `excluding direction`, where the latter traverses relationships in both directions.

Evaluator

`Evaluators` are used for deciding, at each position (represented as a `Path`) whether the traversal should continue, and/or whether the node should be included in the result. Given a `Path`, it asks for one of four actions for that branch of the traversal:

- `Evaluation.INCLUDE_AND_CONTINUE`: Include this node in the result and continue the traversal.
- `Evaluation.INCLUDE_AND_PRUNE`: Include this node in the result, but do not continue the traversal.
- `Evaluation.EXCLUDE_AND_CONTINUE`: Exclude this node from the result, but continue the traversal.
- `Evaluation.EXCLUDE_AND_PRUNE`: Exclude this node from the result and do not continue the traversal.

More than one evaluator can be added.

Evaluators will be called for all positions the traverser encounters, even for the start node.

Traverser

The `Traverser` object is the result of invoking `traverse()` of a `TraversalDescription` object. It represents a traversal positioned in the graph, and a specification of the format of the result. The actual traversal is performed lazily each time the `next()`-method of the iterator of the `Traverser` is invoked.

Uniqueness

Sets the rules for how positions can be revisited during a traversal as stated in `Uniqueness`. Default if not set is `NODE_GLOBAL`.

A Uniqueness can be supplied to the `TraversalDescription` to dictate under what circumstances a traversal may revisit the same position in the graph. The various uniqueness levels that can be used in Neo4j are:

- `NONE`: Any position in the graph may be revisited.
- `NODE_GLOBAL` uniqueness: No node in the entire graph may be visited more than once. This could potentially consume a lot of memory since it requires keeping an in-memory data structure remembering all the visited nodes.
- `RELATIONSHIP_GLOBAL` uniqueness: no relationship in the entire graph may be visited more than once. Just like `NODE_GLOBAL` uniqueness, this could potentially use up a lot of memory. But since graphs typically have a larger number of relationships than nodes, the memory overhead of this uniqueness level could grow even quicker.
- `NODE_PATH` uniqueness: A node may not occur previously in the path reaching up to it.
- `RELATIONSHIP_PATH` uniqueness: A relationship may not occur previously in the path reaching up to it.
- `NODE_RECENT` uniqueness: Similar to `NODE_GLOBAL` uniqueness in that there is a global collection of visited nodes each position is checked against. This uniqueness level does however have a cap on how much memory it may consume in the form of a collection that only contains the most recently visited nodes. The size of this collection can be specified by providing a number as the second argument to the TraversalDescription.uniqueness()-method along with the uniqueness level.
- `RELATIONSHIP_RECENT` uniqueness: Works like `NODE_RECENT` uniqueness, but with relationships instead of nodes.

Depth first / Breadth first

These are convenience methods for setting preorder depth-first / breadth-first `BranchSelector` | `ordering` policies. The same result can be achieved by calling the `order` method with ordering policies from `BranchOrderingPolicies`, or to write your own `BranchSelector` / `BranchOrderingPolicy` and pass in.

Order - how to move through branches?

This is a more generic version of depthFirst/ breadthFirst methods in that it enables an arbitrary `BranchOrderingPolicy` to be injected into the description.

BranchSelector

A `BranchSelector` / `BranchOrderingPolicy` is used for selecting which branch of the traversal to attempt next. This is used for implementing traversal orderings. The traversal framework provides a few basic ordering implementations:

- `BranchOrderingPolicies.PREORDER_DEPTH_FIRST`: Traversing depth first, visiting each node before visiting its child nodes.
- `BranchOrderingPolicies.POSTORDER_DEPTH_FIRST`: Traversing depth first, visiting each node after visiting its child nodes.
- `BranchOrderingPolicies.PREORDER_BREADTH_FIRST`: Traversing breadth first, visiting each node before visiting its child nodes.
- `BranchOrderingPolicies.POSTORDER_BREADTH_FIRST`: Traversing breadth first, visiting each node after visiting its child nodes.

Breadth-first traversals have a higher memory overhead than depth-first traversals.

A `BranchSelector` carries state and hence needs to be uniquely instantiated for each traversal. Therefore it is supplied to the `TraversalDescription` through a `BranchOrderingPolicy` interface, which is a factory of `BranchSelector` instances.

A user of the Traversal framework rarely needs to implement his own `BranchSelector` or `BranchOrderingPolicy`, it is provided to let graph algorithm implementors provide their own traversal orders. The Neo4j Graph Algorithms package contains for example a `BestFirst` order `BranchSelector` / `BranchOrderingPolicy` that is used in BestFirst search algorithms such as A* and Dijkstra.

BranchOrderingPolicy

A factory for creating `BranchSelector`s to decide in what order branches are returned (where a branch's position is represented as a `Path` from the start node to the current node). Common policies are depth-first and breadth-first and that is why there are convenience methods for those. For example, calling `TraversalDescription#depthFirst()` is equivalent to:

```
description.order( BranchOrderingPolicies.PREORDER_DEPTH_FIRST );
```

TraversalBranch

An object used by the BranchSelector to get more branches from a certain branch. In essence these are a composite of a Path and a RelationshipExpander that can be used to get new TraversalBranches from the current one.

Path

`Path` is a general interface that is part of the Neo4j API. In the traversal API of Neo4j the use of Paths are twofold. Traversers can return their results in the form of the Paths of the visited positions in the graph that are marked for being returned. Path objects are also used in the evaluation of positions in the graph,

for determining if the traversal should continue from a certain point or not, and whether a certain position should be included in the result set or not.

PathExpander / RelationshipExpander

The traversal framework use the `PathExpander` (replacing `RelationshipExpander`) to discover the relationships that should be followed from a particular path to further branches in the traversal.

Expander

This is a more generic version of relationships where a `RelationshipExpander` is injected, defining all relationships to be traversed for any given node.

The `Expander` interface is an extension of the `RelationshipExpander` interface that makes it possible to build customized versions of an `Expander`. The implementation of `TraversalDescription` uses this to provide methods for defining which relationship types to traverse, this is the usual way a user of the API would define a `RelationshipExpander` — by building it internally in the `TraversalDescription`.

All the RelationshipExpanders provided by the Neo4j traversal framework also implement the Expander interface. For a user of the traversal API it is easier to implement the PathExpander/RelationshipExpander interface, since it only contains one method — the method for getting the relationships from a path/node, the methods that the Expander interface adds are just for building new Expanders.

How to use the Traversal framework

The traversal framework is no longer supported. For a detailed example on how to use it, refer to The Neo4j Java Developer Reference v3.5.

Transaction management

This topic describes transactional management and behavior.

In order to fully maintain data integrity and ensure good transactional behavior, Neo4j DBMS supports the ACID properties:

- Atomicity — If any part of a transaction fails, the database state is left unchanged.
- Consistency — Any transaction will leave the database in a consistent state.
- Isolation — During a transaction, modified data cannot be accessed by other operations.
- Durability — The DBMS can always recover the results of a committed transaction.

Specifically:

- All database operations that access the graph, indexes, or the schema must be performed in a transaction.
- The default isolation level is *read-committed isolation level*.
- Data retrieved by traversals is not protected from modification by other transactions.
- Non-repeatable reads may occur (i.e., only write locks are acquired and held until the end of the transaction).
- One can manually acquire write locks on nodes and relationships to achieve higher level of isolation — *serialization isolation level*.
- Locks are acquired at the Node and Relationship level.
- Deadlock detection is built into the core transaction management.

Interaction cycle

There are database operations that must be performed in a transaction to ensure the ACID-properties. Specifically operations that access the graph, indexes, or the schema are such operations. Transactions are single-threaded, confined, and independent. Multiple transactions can be started in a single thread and they will be independent from each other.

The interaction cycle of working with transactions looks like this:

1. Begin a transaction.
2. Perform database operations.
3. Commit or roll back the transaction.

It is very important to finish each transaction. The transaction will not release the locks or memory it has acquired until it has been finished.

The idiomatic use of transactions in Neo4j is to use a `try-with-resources` statement and declare `transaction` as one of the resources. Then start the transaction and try to perform graph operations. The last operation in the `try` block should commit or roll back the transaction, depending on the business logic.

In this scenario, `try-with-resources` is used as a guard against unexpected exceptions and as an additional safety mechanism to ensure that the transaction gets closed no matter what happens inside the statement block. All non-committed transactions will be rolled back as part of resource cleanup at the end of the statement. In case a transaction has been explicitly committed or rolled back, resource cleanup will not be required and the transaction closure will be an empty operation.

All modifications performed in a transaction are kept in memory. This means that very large updates must be split into several transactions in order to avoid running out of memory.

Isolation levels

Transactions in Neo4j use a *read-committed isolation level*, which means they will see data as soon as it has been committed but will not see data in other transactions that have not yet been committed. This type of isolation is weaker than serialization but offers significant performance advantages while being sufficient for the overwhelming majority of cases.

In addition, the Neo4j Java API enables explicit locking of nodes and relationships. Using locks gives the opportunity to simulate the effects of higher levels of isolation by obtaining and releasing locks explicitly. For example, if a write lock is taken on a common node or relationship, then all transactions will serialize on that lock — giving the effect of a *serialization isolation level*.

Lost updates in Cypher

In Cypher it is possible to acquire write locks to simulate improved isolation in some cases. Consider the case where multiple concurrent Cypher queries increment the value of a property. Due to the limitations of the *read-committed isolation level*, the increments might not result in a deterministic final value. If there is a direct dependency, Cypher will automatically acquire a write lock before reading. A direct dependency is when the right-hand side of a `SET` has a dependent property read in the expression, or in the value of a key-value pair in a literal map.

For example, the following query, if run by one hundred concurrent clients, will very likely not increment the property `n.prop` to 100, unless a write lock is acquired before reading the property value. This is because all queries would read the value of `n.prop` within their own transaction, and would not see the incremented value from any other transaction that has not yet committed. In the worst case scenario the final value would be as low as 1, if all threads perform the read before any has committed their transaction.

Example 1. Cypher can acquire a write lock

The following example requires a write lock, and Cypher automatically acquires one:

```
MATCH (n:Example {id: 42})
SET n.prop = n.prop + 1
```

Example 2. Cypher can acquire a write lock

This example also requires a write lock, and Cypher automatically acquires one:

```
MATCH (n)
SET n += {prop: n.prop + 1}
```

Due to the complexity of determining such a dependency in the general case, Cypher does not cover any of the example cases below.

Example 3. Complex Cypher

Variable depending on results from reading the property in an earlier statement:

```
MATCH (n)
WITH n.prop AS p
// ... operations depending on p, producing k
SET n.prop = k + 1
```

Example 4. Complex Cypher

Circular dependency between properties read and written in the same query:

```
MATCH (n)
SET n += {propA: n.propB + 1, propB: n.propA + 1}
```

To ensure deterministic behavior also in the more complex cases, it is necessary to explicitly acquire a write lock on the node in question. In Cypher there is no explicit support for this, but it is possible to work around this limitation by writing to a temporary property.

Example 5. Explicitly acquire a write lock

This example acquires a write lock for the node by writing to a dummy property before reading the requested value:

```
MATCH (n:Example {id: 42})
SET n._LOCK_ = true
WITH n.prop AS p
// ... operations depending on p, producing k
SET n.prop = k + 1
REMOVE n._LOCK_
```

The existence of the `SET n._LOCK_` statement before the read of the `n.prop` read ensures the lock is acquired before the read action, and no updates will be lost due to enforced serialization of all concurrent queries on that specific node.

Default locking behavior

- When adding, changing or removing a property on a node or relationship a write lock will be taken on the specific node or relationship.
- When creating or deleting a node a write lock will be taken for the specific node.
- When creating or deleting a relationship a write lock will be taken on the specific relationship and both its nodes.

The locks will be added to the transaction and released when the transaction finishes.

Deadlocks

Since locks are used it is possible for deadlocks to happen. Neo4j will however detect any deadlock (caused by acquiring a lock) before they happen and throw an exception. The transaction is marked for rollback before the exception is thrown. All locks acquired by the transaction will still be held but will be released when the transaction is finished (in the finally block as pointed out earlier). Once the locks are released, other transactions that were waiting for locks held by the transaction causing the deadlock, can proceed. The work performed by the transaction causing the deadlock can then be retried by the user if needed.

Experiencing frequent deadlocks is an indication of concurrent write requests happening in such a way that it is not possible to execute them while at the same time live up to the intended isolation and consistency. The solution is to make sure concurrent updates happen in a reasonable way. For example, given two specific nodes (A and B), adding or deleting relationships to both these nodes in random order for each transaction, will result in deadlocks when there are two or more transactions doing that concurrently. One option is to make sure that updates always happens in the same order (first A then B). Another option is to make sure that each thread/transaction does not have any conflicting writes to a node or relationship as some other concurrent transaction. This can, for example, be achieved by letting a single thread do all updates of a specific type.

Deadlocks caused by the use of other synchronization than the locks managed by Neo4j can still happen. Since all operations in the Neo4j API are thread safe unless specified otherwise, there is no need for external synchronization. Other code that requires synchronization should be synchronized in such a way that it never performs any Neo4j operation in the synchronized block.

Deadlock handling an example

Below, you will find an example of how deadlocks can be handled in procedures, server extensions, or when using Neo4j embedded.

The full source code used for the code snippet can be found at DeadlockDocTest.java.

When dealing with deadlocks in code, there are several issues you may want to address:

- Only do a limited amount of retries, and fail if a threshold is reached.

- Pause between each attempt to allow the other transaction to finish before trying again.
- A retry-loop can be useful not only for deadlocks, but for other types of transient errors as well.

Below is an example that shows how this can be implemented.

Example 6. Handling deadlocks using a retry loop

This example shows how to use a retry loop for handling deadlocks:

```
Throwable txEx = null;
int RETRIES = 5;
int BACKOFF = 3000;
for ( int i = 0; i < RETRIES; i++ )
{
    try ( Transaction tx = databaseService.beginTx() )
    {
        Object result = doStuff(tx);
        tx.commit();
        return result;
    }
    catch ( Throwable ex )
    {
        txEx = ex;

        // Add whatever exceptions to retry on here
        if ( !(ex instanceof DeadlockDetectedException) )
        {
            break;
        }
    }

    // Wait so that we don't immediately get into the same deadlock
    if ( i < RETRIES - 1 )
    {
        try
        {
            Thread.sleep( BACKOFF );
        }
        catch ( InterruptedException e )
        {
            throw new TransactionFailureException( "Interrupted", e );
        }
    }
}

if ( txEx instanceof TransactionFailureException )
{
    throw ((TransactionFailureException) txEx);
}
else if ( txEx instanceof Error )
{
    throw ((Error) txEx);
}
else
{
    throw ((RuntimeException) txEx);
}
```

Delete semantics

When deleting a node or a relationship all properties for that entity will be automatically removed but the relationships of a node will not be removed. Neo4j enforces a constraint (upon commit) that all relationships must have a valid start node and end node. In effect, this means that trying to delete a node that still has relationships attached to it will throw an exception upon commit. It is, however, possible to

choose in which order to delete the node and the attached relationships as long as no relationships exist when the transaction is committed.

The delete semantics can be summarized as follows:

- All properties of a node or relationship will be removed when it is deleted.
- A deleted node cannot have any attached relationships when the transaction commits.
- It is possible to acquire a reference to a deleted relationship or node that has not yet been committed.
- Any write operation on a node or relationship after it has been deleted (but not yet committed) will throw an exception.
- Trying to acquire a new or work with an old reference to a deleted node or relationship after commit, will throw an exception.

Creating unique nodes

In many use cases, a certain level of uniqueness is desired among entities. For example, only one user with a certain email address may exist in a system. If multiple concurrent threads naively try to create the user, duplicates will be created.

The following are the main strategies for ensuring uniqueness, and they all work across cluster and single-instance deployments.

Single thread

By using a single thread, no two threads will even try to create a particular entity simultaneously. On cluster an external single-threaded client can perform the operations.

Get or create

Defining a uniqueness constraint and using the Cypher `MERGE` clause is the most efficient way to get or create a unique node. See Unique nodes for more information.

Transaction events

A `neo4j.org.graphdb.event.TransactionEventListener` can be registered to receive Neo4j database transaction events. Once it has been registered at a `org.neo4j.dbms.api.DatabaseManagementService` instance, it receives transaction events for the database with which it was registered. Listeners get notified about transactions that have performed any write operation, and that will be committed. If `Transaction#commit()` has not been called, or the transaction was rolled back with `Transaction#rollback()`, it will be rolled back and no events are sent to the listener.

Before a transaction is committed, the listeners's `beforeCommit` method is called with the entire diff of modifications made in the transaction. At this point the transaction is still running, so changes can still be made. The method may also throw an exception, which will prevent the transaction from being committed. If the transaction is rolled back, a call to the listener's `afterRollback` method will follow.

The order in which listeners are executed is undefined — there is no guarantee that changes made by one listener will be seen by other listeners.

If `beforeCommit` is successfully executed in all registered listeners, the transaction is committed and the `afterCommit` method is called with the same transaction data. This call also includes the object returned from `beforeCommit`.

In `afterCommit` the transaction has been closed, and access to anything outside `org.neo4j.graphdb.event.TransactionData` requires a new transaction to be opened. A `neo4j.org.graphdb.event.TransactionEventListener` gets notified about transactions that have any changes accessible via `org.neo4j.graphdb.event.TransactionData`. Some indexing and schema changes will not trigger these events.

The following example shows how to register a listener for a specific database, and perform basic operations on top of the transaction change set.

The full source code used for the code snippet can be found at TransactionEventListenerExample.java.

Example 7. TransactionEventListener

Register a transaction event listener and inspect the change set:

```
public static void main( String[] args ) throws IOException
{
    FileUtils.deleteDirectory( HOME_DIRECTORY );
    var managementService = new DatabaseManagementServiceBuilder( HOME_DIRECTORY ).build();
    var database = managementService.database( DEFAULT_DATABASE_NAME );

    var countingListener = new CountingTransactionEventListener();
    managementService.registerTransactionEventListener( DEFAULT_DATABASE_NAME, countingListener );

    var connectionType = RelationshipType.withName( "CONNECTS" );
    try ( var transaction = database.beginTx() )
    {
        var startNode = transaction.createNode();
        var endNode = transaction.createNode();
        startNode.createRelationshipTo( endNode, connectionType );
        transaction.commit();
    }
}

private static class CountingTransactionEventListener implements TransactionEventListener
<CreatedEntitiesCounter>
{
    @Override
    public CreatedEntitiesCounter beforeCommit( TransactionData data, Transaction transaction,
GraphDatabaseService databaseService ) throws Exception
    {
        return new CreatedEntitiesCounter( size( data.createdNodes() ), size( data
.createdRelationships() ) );
    }

    @Override
    public void afterCommit( TransactionData data, CreatedEntitiesCounter entitiesCounter,
GraphDatabaseService databaseService )
    {
        System.out.println( "Number of created nodes: " + entitiesCounter.getCreatedNodes() );
        System.out.println( "Number of created relationships: " + entitiesCounter
.getCreatedRelationships() );
    }

    @Override
    public void afterRollback( TransactionData data, CreatedEntitiesCounter state,
GraphDatabaseService databaseService )
    {
    }
}

private static class CreatedEntitiesCounter
{
    private final long createdNodes;
    private final long createdRelationships;

    public CreatedEntitiesCounter( long createdNodes, long createdRelationships )
    {
        this.createdNodes = createdNodes;
        this.createdRelationships = createdRelationships;
    }

    public long getCreatedNodes()
    {
        return createdNodes;
    }

    public long getCreatedRelationships()
    {
        return createdRelationships;
    }
}
```

JMX metrics

This topic describes how to access JMX for Neo4j DBMS to monitor metrics.

Neo4j provides different levels of monitoring facilities in order to supply a continuous overview of the system's health. For a description of the monitoring options, see Neo4j Operations Manual → Monitoring. Many of the metrics are exposed through JMX.

Please note that the available JMX MBeans and their names have been updated in Neo4j 4.0. Beans that duplicate metrics or monitoring options, described in Neo4j Operations Manual → Monitoring, have been removed.

Adjusting remote JMX access to Neo4j

Per default, the Neo4j Enterprise Server edition does not allow remote JMX connections. To enable this feature, you need to enable JMX Remote Management and also configure JMX for secure remote access, in the *conf/neo4j.conf* file.

Enable JMX Remote Management

Add the following lines to the *conf/neo4j.conf* file to enable JMX Remote Management. If you run into issues with automatic host name discovery, you can uncomment the following configuration line:

```
dbms.jvm.additional=-Djava.rmi.server.hostname=$THE_NEO4J_SERVER_HOSTNAME
```

```
dbms.jvm.additional=-Dcom.sun.management.jmxremote.port=3637
dbms.jvm.additional=-Dcom.sun.management.jmxremote.authenticate=true
dbms.jvm.additional=-Dcom.sun.management.jmxremote.ssl=false

# Some systems cannot discover host name automatically, and need this line configured:
# dbms.jvm.additional=-Djava.rmi.server.hostname=$THE_NEO4J_SERVER_HOSTNAME
```

Although SSL for JMX Remote Management is disabled throughout this document, to configure it based on your requirements you can follow the instructions in the Java SE 11 Monitoring and Management Guide.

Configure password authentication

Password authentication is enabled by default in JMX Remote Management. You can find information about setting up authentication with LDAP and file-based approach in the following sections.

Please refer to the Java SE 11 Monitoring and Management Guide for more options, including configuration steps for SSL client authentication.

LDAP authentication

You can configure your JAAS login configuration based on your infrastructure and save it in the *conf/jmx.ldap* configuration file.

```
Neo4jJMXConfig {
    com.sun.security.auth.module.LdapLoginModule REQUIRED
    userProvider="ldap://127.0.0.1:10389/ou=users,dc=example,dc=net"
    authIdentity="uid={USERNAME},ou=users,dc=example,dc=net"
    userFilter="(&(samaccountname={USERNAME})(objectClass=inetOrgPerson))"
    useSSL=false
    debug=false
    authzIdentity=monitorRole;
};
```

`userProvider`

Defines which LDAP server to connect and the node to perform the search against user entries.

`authIdentity`

Defines the distinguished name of the user to authenticate to the LDAP server. Note that the token `{USERNAME}` is replaced with the provided user name during authentication.

`userFilter`

Defines the search filter to be used while locating the user. Note that the token `{USERNAME}` is replaced with the provided user name during the search.

`useSSL`

Defines whether to enable SSL for the underlying LDAP connection.

`debug`

Defines whether to output debug info about the authentication session.

`authzIdentity`

Specifies which access role an authenticated user will be granted.

The above configuration is provided as an example and needs to be updated based on your infrastructure.

After finishing your JAAS configuration, configure JMX to use it by adding the following configuration items into *conf/neo4j.conf* file:

```
dbms.jvm.additional=-Dcom.sun.management.jmxremote.login.config=Neo4jJMXConfig
dbms.jvm.additional=-Djava.security.auth.login.config=/absolute/path/to/conf/jmx.ldap
```

With this setup, you can connect to JMX monitoring of the Neo4j server using `<IP-OF-SERVER>:3637`, with a valid username and password defined in your LDAP directory.

File-based authentication

The file-based password authentication stores the password in clear-text and is intended only for development use.

You can set your password for JMX remote access and save it in the *conf/jmx.password* configuration file. Please note that on Unix-based systems, the *jmx.password* file needs to be owned by the user that will run the server, and have permissions set to `0600`.

```
monitorRole password_to_be_changed
```

Next, configure access level and save it in *conf/jmx.access* configuration file.

```
monitorRole readonly
```

Finally, configure JMX to use the completed password and access files by adding the following configuration items into *conf/neo4j.conf* file:

```
dbms.jvm.additional=-Dcom.sun.management.jmxremote.password.file=/absolute/path/to/conf/jmx.password
dbms.jvm.additional=-Dcom.sun.management.jmxremote.access.file=/absolute/path/to/conf/jmx.access
```

With this setup, you can connect to JMX monitoring of the Neo4j server using `<IP-OF-SERVER>:3637`, with the username `monitor`, and the password `password_to_be_changed`.

Connecting to a Neo4j instance using JMX and JConsole

First, start your Neo4j instance, for example using:

```
$NEO4j_HOME/bin/neo4j start
```

Now, start JConsole with:

```
$JAVA_HOME/bin/jconsole
```

Connect to the process running your Neo4j database instance:

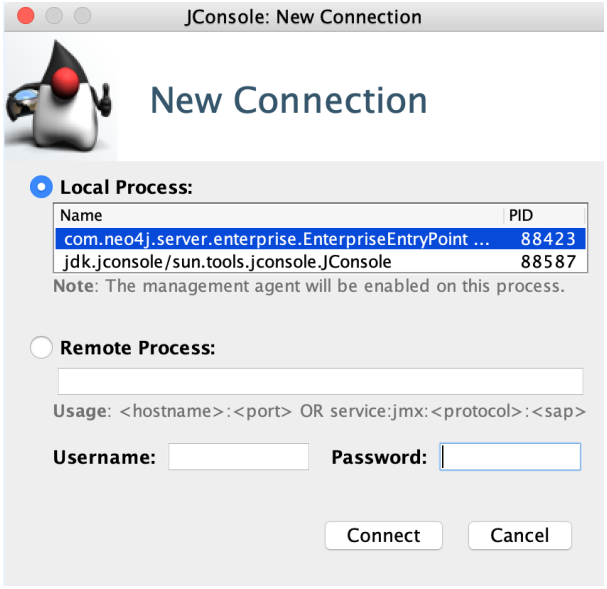


Figure 2. Connecting JConsole to the Neo4j Java process

Now, beside the MBeans exposed by the JVM, you will see be default `neo4j.metrics` section in the MBeans tab. Under that, you will have access to all the monitoring information exposed by Neo4j.

For opening JMX to remote monitoring access, please see Adjusting remote JMX access to Neo4j and the

JMX documention.

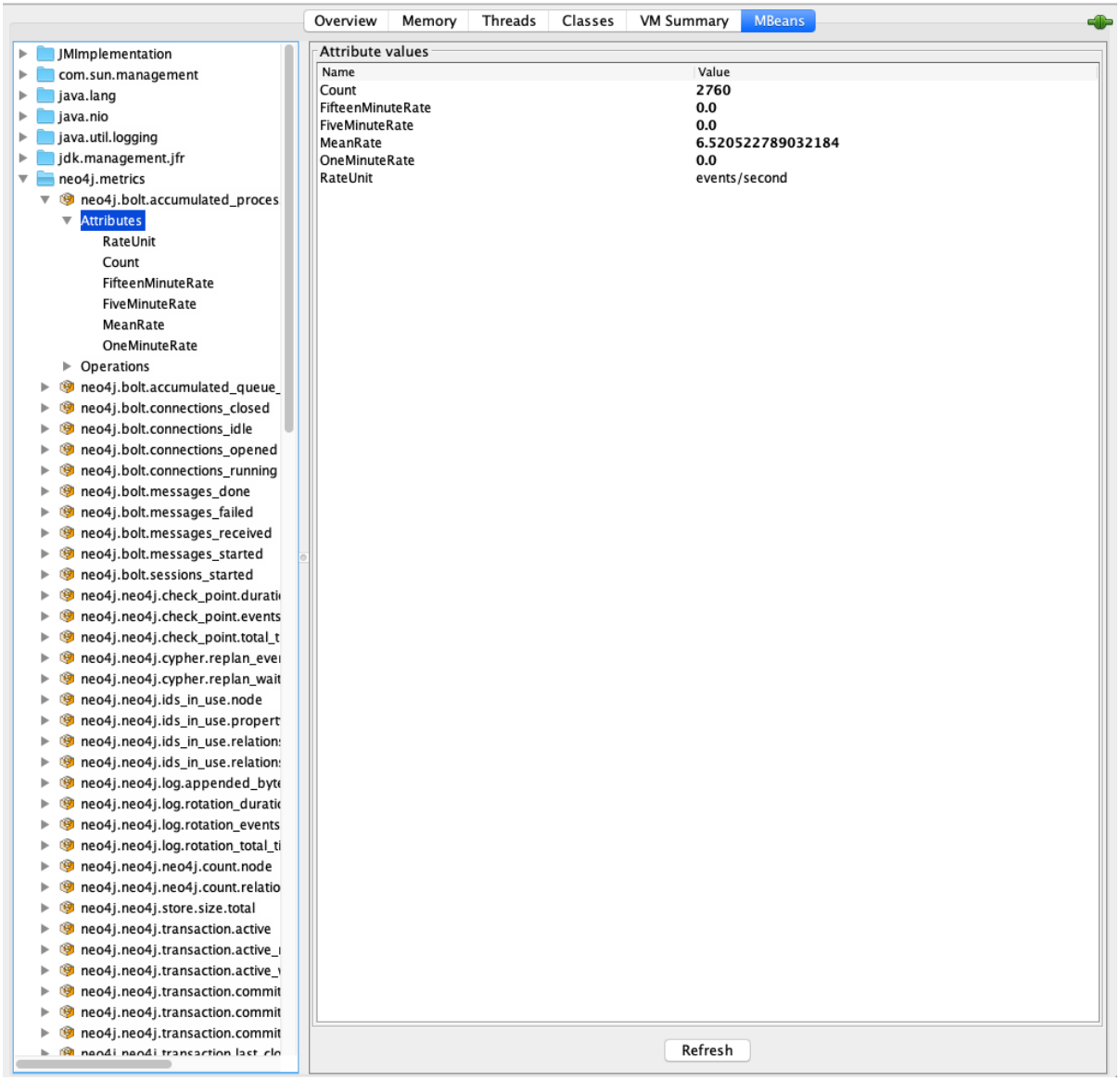


Figure 3. Neo4j MBeans View

License

Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0)

You are free to

Share

copy and redistribute the material in any medium or format

Adapt

remix, transform, and build upon the material

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms

Attribution

You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

NonCommercial

You may not use the material for commercial purposes.

ShareAlike

If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original.

No additional restrictions

You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Notices

You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation.

No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material.

See https://creativecommons.org/licenses/by-nc-sa/4.0/ for further details. The full license text is available at https://creativecommons.org/licenses/by-nc-sa/4.0/legalcode.