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SOFTWARE ENGINEERING PRACTICE

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# **rootJS**

**Node.js bindings for ROOT 6**

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# 1. Purpose

## Project Goal

The goal of this project is to create Node.js<sup>①</sup> bindings for ROOT<sup>②</sup>, thanks to which it will become possible to e.g. integrate ROOT into Node.js-based Web applications.

We aim specifically at ROOT 6 because its Low Level Virtual Machine(LLVM)-based C++ interpreter Cling offers many advantages, e.g. just-in-time compilation, over the one available in older ROOT versions.

## 1.1. Required criteria

The bindings should:

- work on Linux
- allow the user to interact with any ROOT class from the Node.js JavaScript interpreter
- accept C++ code for just-in-time compilation
- update dynamically following changes to C++ internals
- provide asynchronous wrappers for common I/O operations (i.e. file and tree access)

## 1.2. Optional criteria

The bindings should:

- support the streaming of data in JavaScript Object Notation (JSON) format compatible with JavaScript ROOT
- implement a web server based on Node.js to mimic the function of the ROOT HTTP server
- work OS independent (i.e. support Mac OS X, Linux operating systems)

## 1.3. Limiting criteria

The bindings should not:

- add any extending functionality to the existing ROOT framework
- necessarily support previous ROOT versions
- necessarily support future ROOT versions

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<sup>1</sup><https://nodejs.org/>

<sup>2</sup><https://root.cern.ch/>

## 2. Product usage

rootJS will be used to create web-applications that can:

- Expose processed data (that might otherwise be hard to access) and then visualize it locally
- Interact with data both stored somewhere accessible for the server or streamed via remote procedure call (RPC<sup>1</sup>)
- Run on any platform that supports a browser

### 2.1. Audience

Most users of rootJS will be used to working in Linux and with web servers. At the very least, they will be able to install ROOT and also be proficient in programming languages like JavaScript and C++.

- Scientists (e.g. particle physicists)
- Researchers
- Web-developers interested in creating applications based on ROOT

### 2.2. Operating conditions

rootJS will be used on servers that run ROOT and have access to the required data sources. As ROOT 6 currently runs on Linux and OS X only, usage of the bindings is limited to those platforms.

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<sup>1</sup><http://json-rpc.org>

## 3. Product environment

### Providing ROOT to Node.js

Node.js bindings for ROOT simplify the creation of client-server based ROOT applications. The bindings offer solutions based on state of the art web technology, especially the separation of data processing and visualization.

### 3.1. Software

#### 3.1.1 ROOT

ROOT is a software framework for data analysis and I/O. It can be used to process and especially visualize large amounts of scientific data, e.g. the petabytes of data recorded by the Large Hadron Collider experiments every year.

Since the framework comes with an interpreter for the C++ programming language it can be used for rapid and efficient prototyping. It also features a persistency mechanism for C++ objects. Therefore ROOT based applications are extensible and as feature rich as the C++ language itself. A detailed introduction to the ROOT framework can be found in the *ROOT primer*<sup>1</sup> on the CERN website.

Interfacing with ROOT is done dynamically, since ROOT shares all the necessary information in its (global) functions during runtime.

#### 3.1.2 Node.js

Node.js is an open source runtime environment. It is used to develop server side web applications and may act as a stand alone web server. It uses the Google V8 engine to execute JavaScript code.

The rootJS binding API will be developed as a so called native Node.js module written in C++. It interfaces directly with the V8 API to provide (non-blocking) encapsulation of ROOT objects as JavaScript equivalents.

### 3.2. Hardware

The bindings simply provide data structures for the encapsulation of ROOT objects and functions. Hence the additional hardware requirements of the bindings themselves should be negligible compared to ROOT's.

Calling a ROOT function via the binding API inside a Node.js application will take up a minimal amount of additional resources compared to a direct function call inside a native ROOT application. In conclusion, there are no additional hardware requirements for using the bindings on a computer which was able to run native ROOT applications before - this includes almost any modern desktop PC.

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<sup>1</sup><https://root.cern.ch/root/html534/guides/primer/ROOTPrimer.html>

## 4. Product interface and functions

The rootJS bindings will not have a user interface, neither a graphical user interface nor a command line interface. This section will therefore specify the basic API of rootJS.

|       |   |
|-------|---|
| /I10/ | The rootJS module will expose a JavaScript object containing all accessible ROOT variables, functions and classes.  |
| /I20/ | Exposed variables may contain scalar values, in which case they will be accessible in their JavaScript counterparts.  |
| /I30/ | Exposed variables may be objects, which are recursively converted to JavaScript objects until only scalar values remain.  |
| /I40/ | Exposed variables may be enums, in which case the identifier of the currently selected value is returned instead of the corresponding integer.  |
| /I50/ | Every exposed method will be accessible via a proxy method, which handles parameter overloading, as JavaScript does not support overloading. If there is no method to handle the passed arguments, an exception will be thrown.   |
| /I55/ | A method may be called with an additional callback method that will be called after the original method has been executed.  |
| /I60/ | Exposed classes will be accessible via constructors returning the corresponding objects. A constructor will be accessible through a proxy function to support parameter overloading. If there is no method to handle the passed arguments, an exception will be thrown. |
| /I65/ | A constructor can be called with an additional callback method that will be executed after the object has been constructed.   |
| /I70/ | The classes are encapsulated in their namespaces from ROOT. Each namespace is an object containing namespaces or class constructors.  |
| /I80/ | Exceptions thrown by ROOT will be forwarded to JavaScript and can be treated as normal exceptions by JavaScript.  |
| /I90/ | Global variables are accessible via getter and setter methods to ensure their values are kept in sync with the ROOT framework.  |

## 5. Product data

The following data will be stored by the rootJS bindings:

|       |   |
|-------|---|
| /D10/ | All ROOT classes and methods with their corresponding signatures are saved as they are dynamically mapped to JavaScript equivalents. They are also needed to support C/C++ specific features such as method overloading.    |
| /D20/ | The ROOT environment state is preserved between calls from Node.js. This means that objects and variables are available until the rootJS session has ended or a reset was triggered explicitly.                             |
| /D30/ | The application context is derived from <i>TApplication</i> <sup>1</sup> , storing at least the program name and path.  |
| /D40/ | A map of <i>v8::handle</i> 's <sup>2</sup> identified by the address of ROOT objects will be stored to allow proper handling of cyclic references, i.e. prevention of stepping down in recursive object creation endlessly. |

<sup>1</sup><https://root.cern.ch/doc/master/classTApplication.html>

<sup>2</sup>[http://izs.me/v8-docs/classv8\\_1\\_1Handle.html](http://izs.me/v8-docs/classv8_1_1Handle.html)

## 6. System Models

### 6.1. Scenarios

The bindings do not affect core functionality of ROOT. Therefore we decided to give some examples on how the bindings might be used. The user in this case is a Node.js based application, that uses the rootJS bindings to interact with ROOT. As the actual implementation is not yet finalized, the scenarios only contain samples of simple interactions between an Application and ROOT.

#### 6.1.1 Web Viewer Scenario

|                                      |   |
|--------------------------------------|---|
| <i>Scenario name</i>                 | <b>WebViewer</b>  |
| <i>Abstract</i>                      | A browser based GUI for realtime representation of ROOT graphs.   |
| <i>Participating actor instances</i> | <u>WebViewer:Node.js</u> <sup>1</sup> ; <u>:ROOT</u> ; <u>:rootJS</u>   |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. <b>rootJS</b> is up and running initialize has already been executed.</li> <li>2. <b>WebViewer</b> calls the API method to get graphical output of the data ROOT has currently loaded. <ol style="list-style-type: none"> <li>(a) <b>rootJS</b> processes the request and calls the corresponding ROOT functionality.</li> <li>(b) <b>rootJS</b> receives ROOT output and streams it to <b>WebViewer</b>.</li> </ol> </li> <li>3. <b>WebViewer</b> uses the provided data to display the graph on its GUI. <ol style="list-style-type: none"> <li>(a) <b>Node.js</b> invokes ROOT I/O operations. <ol style="list-style-type: none"> <li>i. ROOT loads data and provides raw visualization data.</li> </ol> </li> <li>(b) <b>Node.js</b> serializes data and streams it to <b>WebViewer</b>.</li> </ol> </li> <li>4. <b>WebViewer</b> receives data and renders it in the browser.</li> </ol> |

Figure 6.1: WebViewer scenario

<sup>1</sup>The **WebViewer** is not part of this project; it may be another Node.js package using the rootJS bindings



### 6.1.2 Event Viewer Scenario

|                                      |   |
|--------------------------------------|---|
| <i>Scenario name</i>                 | <b>EventViewer</b>  |
| <i>Abstract</i>                      | A Web based event viewer providing a visualisation of experimental data, showing signals particles have produced in the detector. The web viewer is split into the back-end, server part, with access to the data source and enough resources to process the data, and the front-end, client part, that is a modern-enough Web browser, and responsible only for visualisation itself and interaction with the user.  |
| <i>Participating actor instances</i> | <u>Server:Node.js Application</u> ; <u>:ROOT</u> ; <u>EventViewer:Browser</u> ; <u>:rootJS</u>  |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. <b>EventViewer</b> requests visual updates from <b>Server</b>.</li> <li>2. <b>Server</b> interfaces with <b>ROOT</b> via <b>rootJS</b>.</li> <li>3. <b>ROOT</b> acquires data from external source. <ol style="list-style-type: none"> <li>(a) External, dedicated readout hardware is used to access the data source.</li> <li>(b) <b>ROOT</b> processes incoming data in a timely manner.</li> </ol> </li> <li>4. <b>ROOT</b> passes the data prepared for (3D) visualisation to the <b>Server</b> via <b>rootJS</b>.</li> <li>5. <b>Server</b> publishes its data as JSON stream over the web.</li> <li>6. <b>EventViewer</b> renders received data locally e.g. using WebGL.</li> </ol> |

Figure 6.2: EventViewer scenario

## 6.2. Use Cases

As stated in 6.1 the bindings don't add functionality. We therefore opted to represent the three most basic functions a nodeJS client application may access through our bindings. How and in what context these functions are called is up to the respective applications.



Figure 6.3: use case overview

### 6.2.1 UseROOTGlobal

|                                      |  |
|--------------------------------------|--|
| <i>Use case name</i>                 | UseROOTGlobal  |
| <i>Participating actor instances</i> | Initiated by NodeJSApplication; Processed by rootJS; Communicates with ROOT  |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. The NodeJSApplication requests access to a global variable of ROOT.</li> <li>2. rootJS sends a request to the corresponding ROOT variable.</li> <li>3. ROOT returns the requested variable value.</li> <li>4. The value is passed from rootJS to the NodeJSApplication.</li> </ol> |
| <i>Entry condition</i>               | rootJS has been initialized.   |
| <i>Exit condition</i>                | The value has been returned to the NodeJSApplication.  |

Figure 6.4: Use case: UseROOTGlobal

### 6.2.2 UseROOTObject

|                                      |   |
|--------------------------------------|---|
| <i>Use case name</i>                 | UseROOTObject   |
| <i>Participating actor instances</i> | Initiated by NodeJSApplication; Processed by rootJS, ProxyObject; Communicates with ROOT  |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. The NodeJSApplication requests access to a ROOT object by calling a constructor function.</li> <li>2. rootJS encapsulates the requested ROOT object within a ProxyObject that was created recursively.</li> <li>3. rootJS stores the created ProxyObject in a cache memory.</li> <li>4. The ProxyObject is exposed to the NodeJSApplication.</li> </ol> |
| <i>Entry condition</i>               | rootJS has been initialized.  |
| <i>Exit condition</i>                | The reference of the ProxyObject has been return to the NodeJSApplication.  |

Figure 6.5: Use case: UseROOTObject

### 6.2.3 UseROOTFunction

|                                      |   |
|--------------------------------------|---|
| <i>Use case name</i>                 | UseROOTFunction   |
| <i>Participating actor instances</i> | Initiated by <code>NodeJSApplication</code> ; Processed by <code>rootJS</code> , <code>ProxyObject</code> ; Communicates with <code>ROOT</code>   |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. The <code>NodeJSApplication</code> requests access to a <code>ROOT</code> function.</li> <li>2. <code>rootJS</code> calls the corresponding <code>ROOT</code> function.</li> <li>3. <code>ROOT</code> responds.</li> <li>4. <code>rootJS</code> encapsulates the returned <code>ROOT</code> object within a <code>ProxyObject</code>.</li> <li>5. The <code>ProxyObject</code> is exposed to the <code>NodeJSApplication</code>.</li> </ol> |
| <i>Entry condition</i>               | <code>rootJS</code> has been initialized.   |
| <i>Exit condition</i>                | The reference of the <code>ProxyObject</code> has been return to the <code>NodeJSApplication</code> .   |

Figure 6.6: Use case: UseROOTFunction

### 6.2.4 UseJIT (Cling)

|                                      |  |
|--------------------------------------|--|
| <i>Use Case name</i>                 | UseJIT   |
| <i>Participating actor instances</i> | Initiated by <b>NodeJSApplication</b> ; Processed by <b>rootJS</b> , <b>Cling</b> ; Communicates with <b>ROOT</b>  |
| <i>Flow of events</i>                | <ol style="list-style-type: none"> <li>1. The <b>NodeJSApplication</b> wants to execute <b>ROOT</b> specific C++ code (given as string) during runtime.</li> <li>2. <b>rootJS</b> forwards the instructions to <b>Cling</b>.</li> <li>3. <b>Cling</b> evaluates the received instructions using JIT compilation concepts and dynamically modifies the state of <b>ROOT</b>.</li> <li>4. <b>rootJS</b> takes care of encapsulating exceptions possibly thrown by <b>Cling</b> or <b>ROOT</b> during evaluation and execution.</li> <li>5. <b>rootJS</b> provides the evaluation results and corresponding return values to the <b>NodeJSApplication</b>.</li> </ol> |
| <i>Entry condition</i>               | <b>rootJS</b> and <b>Cling</b> have been initialized.  |
| <i>Exit condition</i>                | <b>rootJS</b> either confirms the proper execution of the specified instructions or forwards thrown exceptions to the <b>NodeJSApplication</b> .   |

Figure 6.7: Use case: just-in-time compilation

### 6.3. Object Models

Figure 6.7 illustrates what the rootJS architecture may look like. Client applications relying on this architecture will incorporate the ROOT framework through a *ROOTPrototype* object. The API's entry point method *ROOTPrototype::init* uses V8 to create the actual interface to the available variables, functions and classes of ROOT.

Functions provided through this interface internally call *methodProxy* to determine the associated ROOT function via the callee's function name. This allows the handling of supplied callback functions by passing them over the *args* parameter.

Constructor functions provided through the interface internally call *classProxy* instead of *methodProxy* to generate encapsulating JavaScript objects through the *ProxyObjectFactory*. A *ROOTPrototype* object provides the *globalGetter* and *globalSetter* methods to access ROOT's global variables. Again interfacing with global objects is done through *ProxyObjects* generated by the *ProxyObjectFactory*.

The *ProxyObjectFactory* instantiates a class realizing the *ProxyObject* interface. The actual class type is given through the supplied *type* parameter. If the *getV8Handle* method is called on *ProxyObjects* encapsulating C++ scalar types (like int, long, string, etc.) it will simply return the corresponding *v8::Handle* with the value at a defined address in memory.

However, calling the *getV8Handle* method on *ProxyObjects* encapsulating C++ objects will prompt recursive calls to the *ProxyObjectFactory* for every (member) variable the native object holds. This allows to dynamically assemble the encapsulating object. To handle cyclic references a caching mechanism (*ProxyObjectCache*), that stores already created *v8::Handles*, is used.

A sample process of interfacing with a ROOT object using this architecture is shown in Figure 6.9.

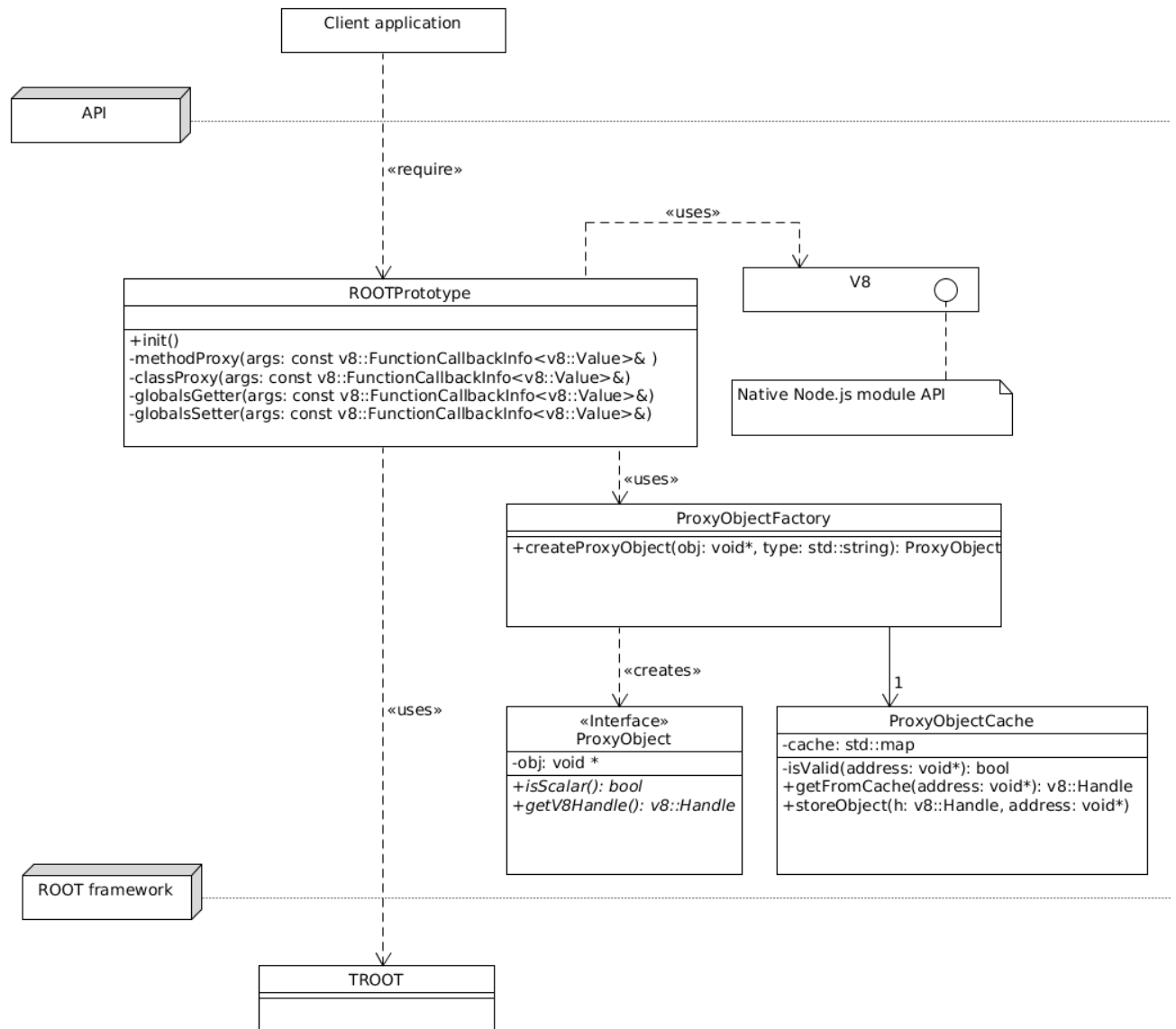


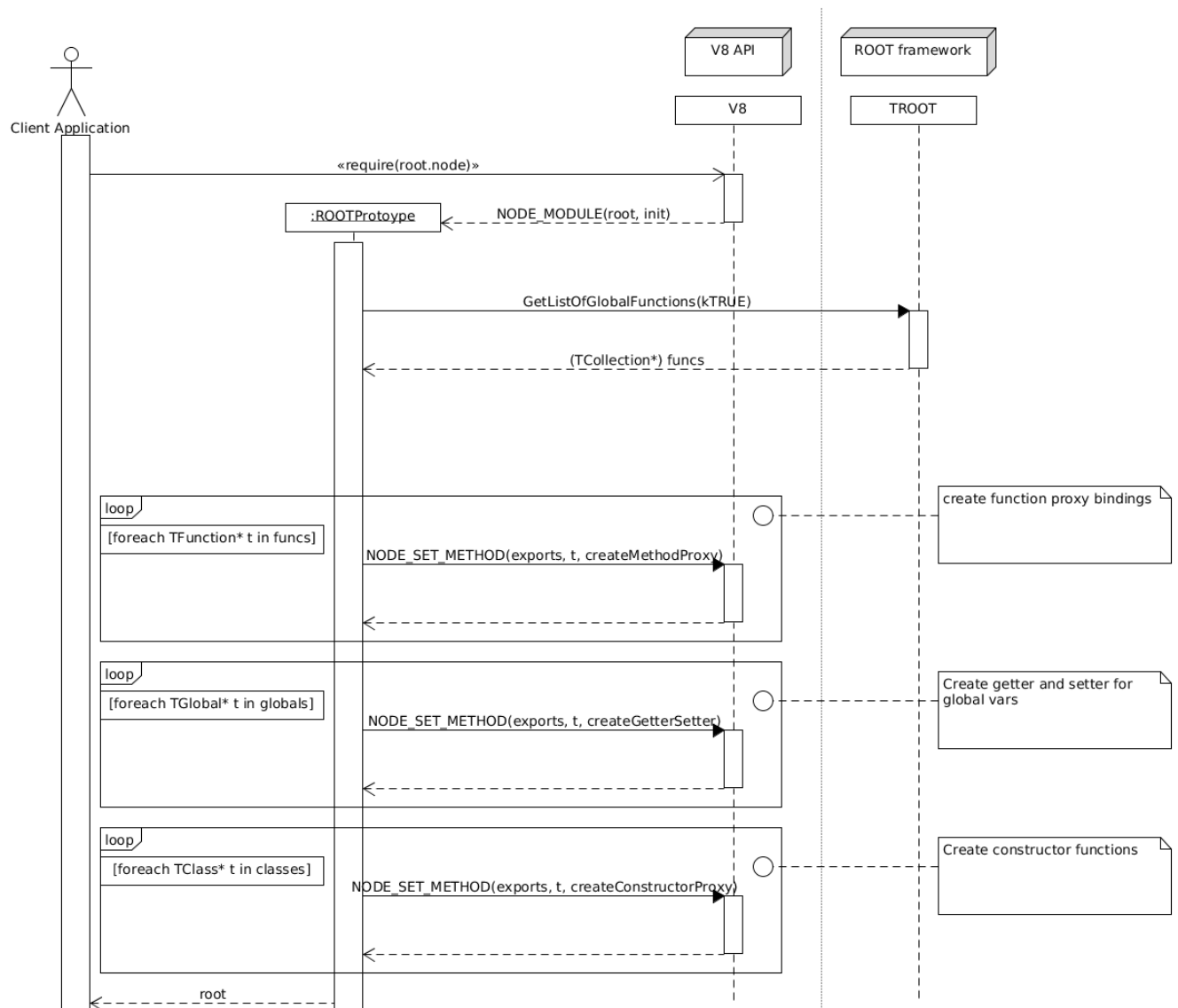
Figure 6.8: basic architecture draft



## 6.4. Dynamic Models

### 6.4.1 Startup sequence

The following figure shows how rootJS gets initialized after being called the first time by a client application. As bindings do not add any functionality of their own, the client application is not further specified. After the bindings are initialized the client application may use any ROOT functionality through a *ROOTPrototype* object provided by the rootJS API.



### 6.4.2 Opening a file

The following figure shows how to open a root file via rootJS. After the usual initialization process has been completed (see above), a TFile object is created using the rootJS API. A callback is provided because the file is being parsed by ROOT during the opening process, which might take some time depending on file size and complexity. The rootJS bindings call the TFile constructor before returning to the JavaScript application via callback, and the constructor is being called by the class proxy. After the construction phase rootJS has a valid TFile object, which is then handed over to the CreateProxyObject factory method which creates the correct proxy object. The factory object recursively creates a v8 handle which is returned to the JavaScript code running in node.JS, in this case via callback.

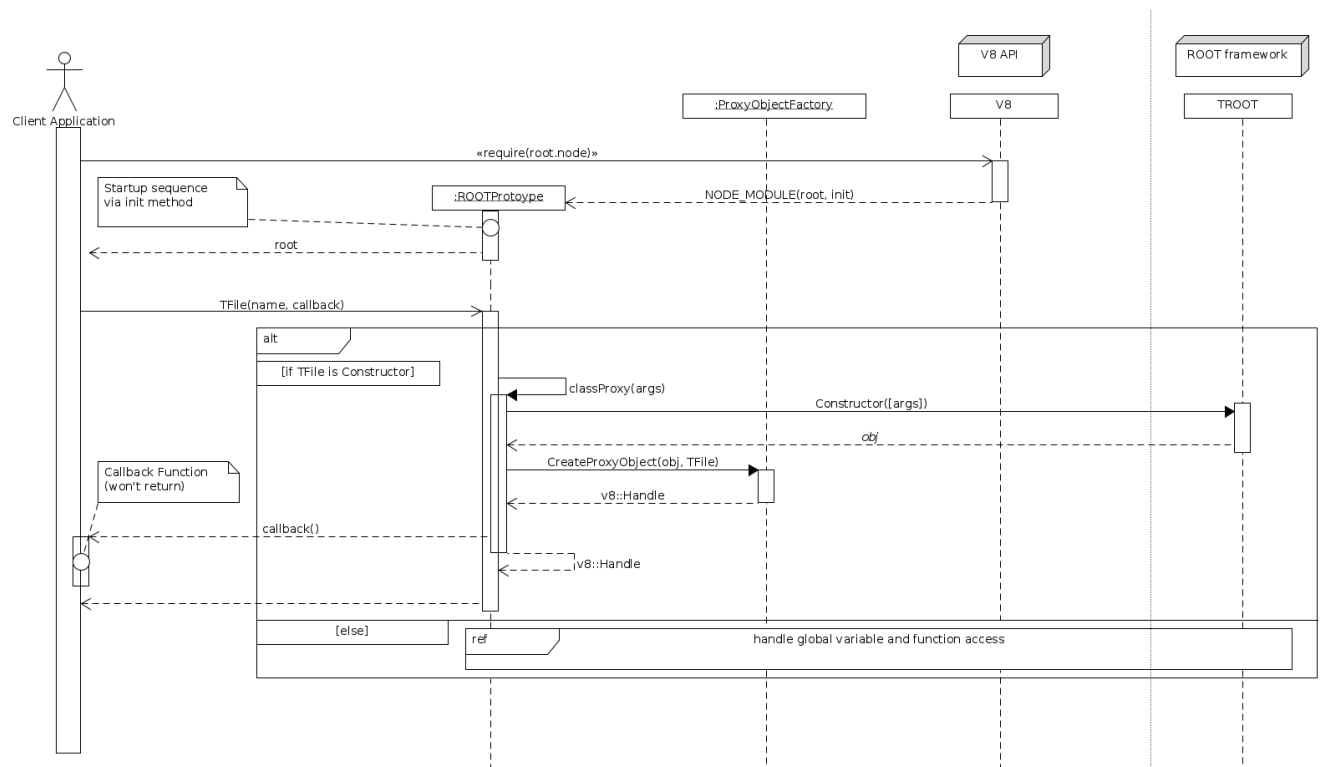


Figure 6.10: basic sequence used for opening a file

## 7. Global Test Cases

During the development process continuous integration tools will be used to run at least the following test cases:

|        |   |
|--------|---|
| /T10/  | Read all global variables.  |
| /T20/  | Write to all global variables that are not constant.  |
| /T30/  | Write to all global variables that are constant and ensure the correct Exception is thrown.   |
| /T40/  | Create instances of all classes with a public constructor.  |
| /T50/  | Call all methods of these objects with valid parameters, where valid means that the data type is correct, a method throwing an exception due to invalid input shall be considered as a passed test, a crash due to e.g. invalid memory read shall be considered as a failed test. |
| /T60/  | Read all public member variables of these classes.  |
| /T70/  | Write to all public member variables of these classes that are not constant.  |
| /T80/  | Write to all public member variables of these classes that are constant and ensure the correct exception is thrown.   |
| /T90/  | Create instances of classes with private constructors and ensure the correct exception is thrown.   |
| /T100/ | Apply the test cases described in /T60/ to /T90/ to static members and methods. Ensure the correct exceptions are thrown.   |
| /T110/ | Let Cling evaluate strings of valid C++ code during run time and ensure ROOT's state was modified as expected.  |
| /T120/ | Let Cling evaluate strings of syntactically invalid C++ code during run time and ensure the right exceptions are thrown and forwarded correctly.  |
| /T130/ | Let Cling evaluate strings of semantically invalid C++ code during run time and ensure the right exceptions are thrown and forwarded correctly.   |

## 8. Quality assurance

We will ensure correct functionality by writing unit tests for every class. Test cases will be run after every git push using continuous integration tools.

Furthermore a function test will be executed, testing if all exposed elements are really accessible and working (see global test cases).

We will use the *Github issue tracker*<sup>1</sup> to track all issues we encounter, even issues that the reporter fixes himself should be tracked. Closing an issue in the issue tracker is only allowed if a test case is provided that both fails before and succeeds after the fix. This ensures that the same bug is not introduced multiple times by different people.

We will check the test coverage after every push to the Github repository. If the coverage decreases on a special method its developer needs to check if there is a branch that is not covered yet and possibly add new test cases for it.

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<sup>1</sup><https://github.com/rootjs/rootjs/issues>

## 9. Appendix

### 9.1. Glossary

#### Application programming interface (API)

A collection of tools, libraries and documentation for creating software. APIs expose functionality through specified interfaces, which allows to develop independent from the specific implementation

#### Asynchronous I/O

Using asynchronous I/O, an application does not have to wait for the data transmission to finish, but can continue in execution. This prevents leaving the CPU idle, as I/O operations are usually significantly slower than other tasks.

#### C++

A general purpose, object oriented programming language and one of the most widely used programming languages.

#### CERN

The European Organization for Nuclear Research.

#### Cling

An interactive C++ interpreter with a command line prompt that offers just-in-time compilation.

#### Compiler

A computer program that translates source code into another language.

#### enum

A data structure (enumeration) that contains named elements that can be compared to each other. Each element maps to a constant value.

#### Exception

"Exceptional conditions (Exceptions) are things that occur in a system that are not expected or are not a part of normal system operation. When the system handles these exceptional conditions improperly, it can lead to failures and system crashes." <sup>1</sup>

#### Framework

Extendable, generic software to be extended by user-written modules.

#### Git

A Version Control System (VCS).

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<sup>1</sup>[http://users.ece.cmu.edu/~koopman/des\\_s99/exceptions/](http://users.ece.cmu.edu/~koopman/des_s99/exceptions/)

**Github**

A host for Git repositories.

**Google V8 JavaScript**

An open-source JavaScript interpreter.

**HTTP**

The HyperText Transfer Protocol, used for data communication on the Internet.

**Interpreter**

A computer program that directly executes written instructions, without compiling them first.

**JavaScript**

An interpreted programming or script language created by Netscape.

**JavaScript Object Notation (JSON)**

A data format used for exchanging (data) objects between applications. The JSON format is easy to read and write for humans.

**Just-in-time (JIT) compilation**

Compilation method that tries to speed up interpreter based program execution by dynamically compiling the executed program (parts) at run time.

**Language bindings**

Expose an API to another programming language. This enables usage of low-level functionality in higher-level environments (such as the ROOT API in Node.js using the rootJS bindings).

**Large Hadron Collider (LHC)**

World's largest particle collider located in CERN.

**Linux**

A free and open source Unix based operating system.

**Low Level Virtual Machine (LLVM)**

A compiler infrastructure written in C++.

**Mac**

A Unix based operating system created by Apple.

**Method overloading**

Declaring a method multiple times within the same namespace using different parameters.

**Method signature**

A unique declaration which defines the name and the parameter list of a method.

**Node.js**

A runtime environment for developing server-side web applications written in JavaScript.

**Object**

An instance of a class containing data, such as variables, functions and data structures.

**Operating System**

A piece of software managing software and hardware resources, input/output, and also controls the overall operation of the computer system.

**ROOT**

A framework for data processing; developed at CERN and particularly used by particle physicists.

**Remote procedure call (RPC)**

Execute a routine in another address space without coding details for the remote interaction.

**Stream**

Potentially unlimited sequence of data elements made available over time.<sup>2</sup>

**Version Control System (VCS)**

Version Control Systems are used to track and (if necessary) revert changes made on a software project.

**Web Graphics Library (WebGL)**

WebGL enables hardware accelerated rendering of 3D content for web browsers.

**Windows**

A DOS based operating system created by Microsoft.

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<sup>2</sup><http://srfi.schemers.org/srfi-41/srfi-41.html>

## 9.2. Links

The Github repository for this document may be found at <https://github.com/rootjs/specifications>.  
The repository for the rootJS project itself is located at <https://github.com/rootjs/rootjs>.