


Nano JSON

Working with JSON formatted data in Isabelle/HOL and Isabelle/ML

Achim D. Brucker 

March 24, 2023

Department of Computer Science, University of Exeter, Exeter, UK
a.brucker@exeter.ac.uk

Abstract

JSON (JavaScript Object Notation) is a common format for exchanging data, based on a collection of key/value-pairs (the JSON objects) and lists. Its syntax is inspired by JavaScript with the aim of being easy to read and write for humans and easy to parse and generate for machines.

Despite its origin in the JavaScript world, JSON is language-independent and many programming languages support working with JSON-encoded data. This makes JSON an interesting format for exchanging data with Isabelle/HOL.

This AFP entry provides a JSON-like import-export format for both Isabelle/ML and Isabelle/HOL. On the one hand, this AFP entry provides means for Isabelle/HOL users to work with JSON encoded data without the need using Isabelle/ML. On the other and, the provided Isabelle/ML interfaces allow additional extensions or integration into Isabelle extensions written in Isabelle/ML. While format is not fully JSON compliant (e.g., due to limitations in the range of supported Unicode characters), it works in most situations: the provided implementation in Isabelle/ML and its representation in Isabelle/HOL have been used successfully in several projects for exchanging data sets of several hundredths of megabyte between Isabelle and external tools.

Keywords: JSON, JavaScript Object Notation, data exchange, data import, data export

Contents

1	Introduction	7
2	Implementation	9
2.1	An Import/Export of JSON-like Formats for Isabelle/HOL (Nano_JSON)	9
2.1.1	Defining a JSON-like Data Structure	9
	A HOL Data Type for JSON	10
	ML Implementation	10
2.1.2	Parsing Nano JSON	10
	ML Implementation	10
	Isar Setup: Cartouche and Isar-Top-level Binding	11
	Examples	12
2.1.3	Serializing Nano JSON	13
	ML Implementation	13
	Isar Setup	13
	Examples	13
2.1.4	Putting Everything Together	13
2.2	Query Infrastructure (Nano_JSON_Query)	13
	Isabelle/ML	14
	Isabelle/HOL	14
2.3	The Main Theory of Nano JSON (Nano_JSON_Main)	15
3	User's Guide and Examples	17
3.1	The Nano JSON Manual (Nano_JSON_Manual)	17
3.1.1	Isabelle/HOL	17
3.1.2	Isabelle/ML	18
3.2	Examples (Example)	18
3.3	Examples Real (Example_Real)	21

1 Introduction

JSON (JavaScript Object Notation) [5, 1] is a widely-used format for exchanging data, having replaced XML [2] in many areas. The structure of JSON is based on:

- A collection of key-value (name-value) pairs, also called JSON object. In programming languages, this corresponds, e.g., to data structures such as objects, records, structs, or hash tables.
- A finite list of values. In programming languages, this corresponds, e.g., to lists, sequences, or arrays.

The syntax of is inspired by JavaScript with the aim of being easy to read and write for humans (that are comfortable with curly-bracket programming languages) and easy to parse and generate for machines.

Despite its origin in the JavaScript world, JSON is language-independent and many programming languages support working with JSON-encoded data. This makes JSON an interesting format for exchanging data with Isabelle/HOL.

This AFP entry provides a JSON-like import-expert format for both Isabelle/ML and Isabelle/HOL. While this entry provides a simple formal model of JSON, formalizing an object-based data structure is not the aim of this AFP entry (for this, see, e.g., [4, 3]). The aim of this AFP entry is to provide means to work with JSON-encoded data in Isabelle, similar to the AFP entry “XML” [6] provides means to work with XML documents in Isabelle.

In more detail, this AFP entry provides two different ways for importing and exporting JSON-encoded data in Isabelle:

Isabelle/HOL: This AFP entry provides means for Isabelle/HOL users to work with JSON encoded data: it provides a HOL data type modelling the JSON format and new top-level Isar [7] commands to import and export JSON encoded files. Moreover, a new top-level Isar command is provided to parse JSON data that is stored “inline” within the Isabelle/HOL theory file.

Isabelle/ML: This AFP entry also provides interfaces to the underlying implementation in Isabelle/ML, allowing to write users to write their on extensions that require features not (yet) exposed to the Isabelle/HOL level. For example, data type packages for specific variants of JSON that, e.g., should directly map to specific HOL data types or that need further encoding or conversions during export or import.

While the supported JSON-variant is not fully JSON compliant (e.g., due to limitations in the range of supported Unicode characters), it works in most situations: the provided implementation in Isabelle/ML and its representation in Isabelle/HOL have been used successfully in several projects for exchanging data sets of several hundredths of megabyte between Isabelle and external tools.

In summary, Nano JSON should enable you to work with JSON encoded data in Isabelle/HOL without the need of implementing parsers or serialization in Isabelle/ML. You should be able to implement mapping from the Nano JSON HOL data types to your own data types on the level of Isabelle/HOL (i.e., as executable HOL functions). Nevertheless, the provided ML routine that converts between the ML representation and the HOL representation of Nano JSON can also serve as a starting point for converting the ML representation to your own, domain-specific, HOL encoding.

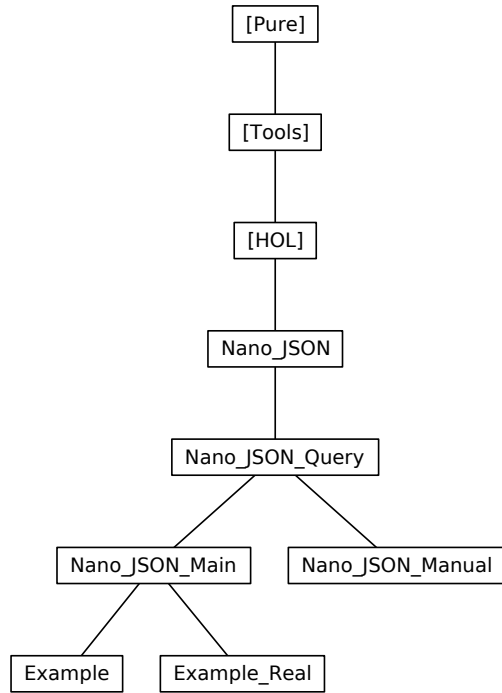


Figure 1.1: The Dependency Graph of the Isabelle Theories.

The rest of this document is automatically generated from the formalization in Isabelle/HOL, i.e., all content is checked by Isabelle. Overall, the structure of this document follows the theory dependencies (see Figure 1.1). If you want to understand the implementation of Nano JSON or want to use its API on the level of Isabelle/ML, you should consult chapter 2. If you are interested in using Nano JSON on the level of Isabelle/HOL or want to explore examples, please consult chapter 3.

2 Implementation

2.1 An Import/Export of JSON-like Formats for Isabelle/HOL (Nano_JSON)

theory

```
"Nano_JSON"
```

imports

```
Main
```

keywords

```
"JSON_file" :: thy_load  
and "JSON" :: thy_decl  
and "JSON_export" :: thy_decl  
and "defining" :: quasi_command
```

begin

This theory implements an import/export format for Isabelle/HOL that is inspired by JSON (JavaScript Object Notation). While the format defined in this theory is inspired by the JSON standard (<https://www.json.org>), it is not fully compliant. Most notably,

- only basic support for Unicode characters. In particular, JSON strings are mapped to a polymorphic type usually is either instantiated with the `string` or `String.literal`. Hence, the strings that can be represented in JSON are limited by the characters that Isabelle/HOL can handle (support on the Isabelle/ML level is less constrained).
- numbers are mapped to a polymorphic type, which can, e.g., be instantiated with
 - `real`. Note that this is not a faithful representation of IEEE754 floating point numbers that are assumed in the JSON standard. Moreover, this required that parent theories include `Complex_Main`.
 - `int`. This is recommended configuration, if the JSON files only contain integers as numerical data.
 - `string`. If not numerical operations need to be done, numerical values can also be encoded as HOL strings (or `String.literal`).

While the provided JSON import and export mechanism is not fully compliant to the JSON standard (hence, its name “Nano JSON”), it should work with most real-world JSON files. Actually, it has already served well in various projects, allowing us to simply exchange data between Isabelle/HOL and external tools.

2.1.1 Defining a JSON-like Data Structure

We start by modelling a HOL data type for representing the abstract syntax of JSON, which consists out of objects, lists (called arrays), numbers, strings, and Boolean values.

A HOL Data Type for JSON

```
datatype ('string, 'number) json =  
  OBJECT "('string * ('string, 'number) json) list"  
  | ARRAY "('string, 'number) json list"  
  | NUMBER "'number"  
  | STRING "'string"  
  | BOOL "bool"  
  | NULL
```

Using the data type ('string, 'number) json, we can now represent JSON encoded data easily in HOL, e.g., using the concrete instance (string, int) json:

```
definition example01::<(string, int) json> where  
"example01 =  
  OBJECT [('menu', OBJECT [('id', STRING 'file'), ('value', STRING 'File'),  
    ('popup', OBJECT [('menutem', ARRAY  
      [OBJECT [('value', STRING 'New'),  
        ('onclick', STRING 'CreateNewDoc()')]),  
      OBJECT [('value', STRING 'Open'),  
        ('onclick', STRING 'OpenDoc()')]),  
      OBJECT [('value', STRING 'Close'),  
        ('onclick', STRING 'CloseDoc()')])])])  
    )]), ('flag', BOOL True), ('number', NUMBER 42)  
]"
```

ML Implementation

The translation of the data type ('string, 'number) json to Isabelle/ML is straight forward with the exception that we do not need to distinguish different String representations. In addition, we also provide methods for converting JSON instances between the representation as Isabelle terms and the representation as Isabelle/ML data structure.

<ML>

The file Nano_JSON_Type.ML provides the Isabelle/ML structure Nano_Json_Type:NANO_JSON_TYPE. When first argument of the functions Nano_Json_Type.term_of_real and Nano_Json_Type.term_of_json is true, then warnings are reported to the the output window of Isabelle. Otherwise, warning will be ignored. Furthermore, the two arguments of type typ of the function Nano_Json_Type.term_of_json represent the HOL target type for JSON strings and numerical values. An example invocation of this function looks as follows:

<ML>

2.1.2 Parsing Nano JSON

In this section, we define the infrastructure for parsing JSON-like data structures as well as for importing them into Isabelle/HOL. This implementation was inspired by the "Simple Standard ML JSON parser" from Chris Cannam.

ML Implementation

Configuration Attributes. We start by preparing the infrastructure for three configuration attributes, using the Isabelle/Isar attribute mechanism:

⟨ML⟩

The attribute “JSON_num_type” (default int) allows for configuring the HOL-type used representing JSON numerals.

⟨ML⟩

The attribute “JSON_string_type” (default string) allows for configuring the HOL-type used representing JSON string.

⟨ML⟩

The Boolean attribute “JSON_verbose” (default: false) allows for enabling warnings during the JSON processing.

Lexer. The following Isabelle/ML signatures captures the lexer:

⟨ML⟩

The file `Nano_JSON_Lexer.ML` provides the Isabelle/ML structure `Nano_Json_Lexer : NANO_JSON_LEXER`. It provides the function `Nano_Json_Lexer.tokenize_string` which, as the name suggests, tokenizes a string (containing a JSON object).

⟨ML⟩

The file `Nano_JSON_Parser.ML` provides the Isabelle/ML structure `Nano_Json_Parser : NANO_JSON_PARSER`. The two main functions:

- First, `Nano_Json_Parser.json_of_string` parsing a string (containing a JSON object) and returning its abstract syntax (i.e., an instance of the type `Nano_Json_Type.json`).
- Second, `Nano_Json_Parser.term_of_json_string`, which parses a string into a HOL term. As for `Nano_Json_Type.term_of_json`, the first argument decides if warnings are printed and the next two arguments determine the HOL type representations for JSON strings and numerical values.

The parser `MLNano_Json_Parser.term_of_json_string` can now be used, on the Isabelle/ML-level as follows:

⟨ML⟩

Isar Setup: Cartouche and Isar-Top-level Binding

The JSON Cartouche. First, we define a cartouche that allows using JSON syntax within HOL expressions:

```
syntax "_cartouche_nano_json" :: "cartouche_position ⇒ 'a" ("JSON _")
```

⟨ML⟩

In the following, we briefly illustrate the use of the JSON cartouche and the attribute for mapping JSON types to HOL types:

```
declare [[JSON_string_type = string]]
```

```
lemma <y == JSON <{"name": true}> >
```

```
  <proof>
```

```
declare [[JSON_string_type = String.literal]]
```

```
lemma <y == JSON <{"name": true}> >
```

```
  <proof>
```

```
declare [[JSON_string_type = string]]
```

```
lemma <y == JSON<{"name": [true,false,"test"]}>> >
  <proof>
```

```
lemma <y == JSON<{"name": [true,false,"test"],
                  "bool": true,
                  "number" : 1 }>> >
  <proof>
```

Isar Top-Level Commands. Furthermore, we define two Isar top-level commands: one that allows for importing JSON data from the file system, and one for defining JSON “inline” within Isabelle theory files.

<ML>

Examples

Now we can use the JSON Cartouche for defining JSON-like data “on-the-fly”. Note that you need to escape quotes within the JSON Cartouche, if you are using quotes as lemma delimiters, e.g.,:

```
lemma "y == JSON<{"name": [true,false,"test"]}>"
  <proof>
```

Thus, we recommend to use the Cartouche delimiters when using the JSON Cartouche with non-trivial data structures:

```
lemma < example01 == JSON <{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
},
  "flag": true,
  "number": 42
}>>
  <proof>
```

We can define new JSON data “inline”, using the Isar keyword **JSON**:

```
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}, "flag":true, "number":42}
> defining example04
```

Moreover, we can define new JSON data by reading it from a file, using the Isar keyword **JSON_file**:

```
JSON_file "example.json" defining example03
```

```
thm example03_def example04_def
```

```
lemma "example03 = example04"  
  <proof>
```

2.1.3 Serializing Nano JSON

In this section, we define the necessary infrastructure to serialize (export) data from HOL using a JSON-like data structure that other JSON tools should be able to import.

ML Implementation

<ML>

The file `Nano_JSON_Serializer.ML` provides the Isabelle/ML structure `Nano_Json_Serializer:NANO_JSON_SERIALIZER`. It provides functions for serializing JSON data from its abstract syntax as well as from its HOL term representations. Moreover, variants are provided that try to pretty print the output with the goal of making it easier to read for humans.

Isar Setup

<ML>

Examples

We can now serialize JSON and print the result in the output window of Isabelle/HOL:

```
JSON_export example01  
thm example01_def
```

Alternatively, we can export the serialized JSON into a file:

```
JSON_export example01 file example01
```

2.1.4 Putting Everything Together

For convenience, we provide an ML structure that provides access to both the parser and the serializer:

<ML>

```
end
```

2.2 Query Infrastructure (Nano_JSON_Query)

```
theory  
  Nano_JSON_Query
```

```
imports  
  Nano_JSON
```

```
begin
```

In this theory, we define various functions for working with JSON data, i.e., the data types defined in the theory `Nano_JSON.Nano_JSON`. These query functions are useful for building more complex functionality of

JSON encoded data. One could think of them as something like jq (<https://stedolan.github.io/jq/>) for Isabelle.

Isabelle/ML

$\langle ML \rangle$

The file Nano_JSON_Query.ML provides the Isabelle/ML structure Nano_Json_Query:NANO_JSON_QUERY.

Isabelle/HOL

```

fun nj_filter' :: <'a  $\Rightarrow$  'a list  $\times$  ('a, 'b) json  $\Rightarrow$  ('a list  $\times$  ('a, 'b) json) list>
  where
    <nj_filter' key (prfx, OBJECT json) = ((map ( $\lambda$  (k,v). (prfx@[k],v)) (filter ( $\lambda$  (k,_). key
= k) json) )
      @ (List.concat (map (nj_filter' key) (map ( $\lambda$  (k,v). (prfx,v)) json)))
    >
    | <nj_filter' key (prfx, ARRAY json) = (List.concat (map (nj_filter' key) (map ( $\lambda$  v. (prfx,v))
json)))>
    | <nj_filter' _ _ (NUMBER _) = []>
    | <nj_filter' _ _ (STRING _) = []>
    | <nj_filter' _ _ (BOOL _) = []>
    | <nj_filter' _ _ (NULL) = []>

```

```

definition nj_filter :: <'a  $\Rightarrow$  ('a, 'b) json  $\Rightarrow$  ('a list  $\times$  ('a, 'b) json) list> where
  <nj_filter key json = nj_filter' key ([],json)>

```

```

fun nj_update :: <(('a, 'b) json  $\Rightarrow$  ('a, 'b) json)  $\Rightarrow$  'a  $\Rightarrow$  ('a, 'b) json  $\Rightarrow$  ('a, 'b) json>
  where
    <nj_update f key (OBJECT kjson) = OBJECT (map ( $\lambda$  (k,json). if k = key
      then (k, f json)
      else (k, nj_update f key json))
kjson)>
    | <nj_update f key (ARRAY json) = ARRAY (map (nj_update f key) json)>
    | <nj_update _ _ (NUMBER n) = NUMBER n>
    | <nj_update _ _ (STRING s) = STRING s>
    | <nj_update _ _ (BOOL b) = BOOL b>
    | <nj_update _ _ NULL = NULL>

```

Examples. The following illustrates a simple example of the nj_filter function.

```

declare [[JSON_string_type=String.literal]]

```

```

JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}

```

```
    }  
  }, "flag":true, "number":42}  
> defining example_literal_literal  
  
value <nj_filter (STR ''onclick'') example_literal_literal>  
  
end
```

2.3 The Main Theory of Nano JSON (Nano_JSON_Main)

```
theory  
  Nano_JSON_Main  
imports  
  Nano_JSON_Query  
begin  
  
  This is the main entry point into the Nano_JSON session for users of this AFP entry.  
  
end
```


3 User's Guide and Examples

3.1 The Nano JSON Manual (Nano_JSON_Manual)

theory

Nano_JSON_Manual

imports

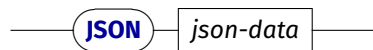
Nano_JSON_Query

begin

3.1.1 Isabelle/HOL

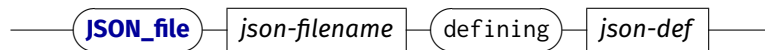
On the Isabelle/HOL level, we provide three new commands for working with JSON formatted data.

JSON. For defining JSON data within HOL terms, we provide the following command:



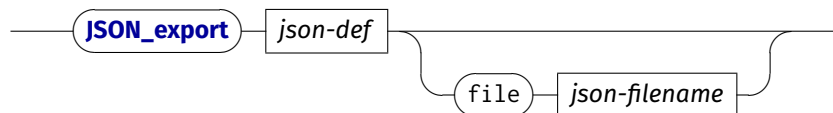
where *json-data* is a cartouche containing the JSON data.

JSON_file. For reading JSON data from an external file, we provide the command



where *json-filename* is the path (file name) of the JSON file that should be read and *json-def* is the name the HOL definition representing the JSON data is bound to.

JSON_export. For serializing (exporting) JSON encoded data, we provide the command



where *json-def* is the definition of the JSON data that should be exported. Optionally a file name (*json-filename*) can be provided. If a file name is provided, it is used for storing the serialized data in Isabelle's virtual file system. If no file name is provided, the serialized data is printed in Isabelle's output window.

Configuration. We provide three configuration attributes:

- The attribute `JSON_num_type` (default `int`) allows for configuring the HOL-type used representing JSON numerals.
- The attribute `JSON_string_type` (default `string`) allows for configuring the HOL-type used representing JSON string.
- The attribute `JSON_verbose` (default: `false`) allows for enabling warnings during the JSON processing.

3.1.2 Isabelle/ML

We refer users who want to use or extend Nano JSON on the Isabelle/ML level to the ML signatures shown in the implementation chapter, i.e., chapter 2.

end

3.2 Examples (Example)

theory

Example

imports

Nano_JSON_Main

begin

In this theory, we illustrate various small examples of importing or exporting of JSON data from Isabelle/HOL. The examples in this theory do not use the type `real` to avoid the need to depend on the theory “Complex_Main”.

JSON <

```
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}, "flag":true, "number": -42}
```

> **defining** example_default

thm example_default_def

JSON_export example_default

JSON_export example_default **file** example_default

declare [[JSON_string_type=string, JSON_num_type = nat]]

JSON <

```
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
```

```

    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}, "flag":true, "number": 42}
> defining example_string_nat
thm example_string_nat_def
JSON_export example_string_nat
JSON_export example_string_nat file example_string_nat

declare [[JSON_string_type=string, JSON_num_type = int]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":42}
> defining example_string_int

thm example_string_int_def
JSON_export example_string_int
JSON_export example_string_int file example_string_int

declare [[JSON_string_type=String.literal, JSON_num_type = int]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":42}
> defining example_literal_int
thm example_literal_int_def
JSON_export example_literal_int
JSON_export example_literal_int file example_literal_int

declare [[JSON_string_type=string, JSON_num_type = string]]
JSON <
{"menu": {

```

```

    "id": "file",
    "value": "File",
    "popup": {
      "menuitem": [
        {"value": "New", "onclick": "CreateNewDoc()"},
        {"value": "Open", "onclick": "OpenDoc()"},
        {"value": "Close", "onclick": "CloseDoc()"}
      ]
    }
  }, "flag":true, "number":-42}
> defining example_string_string
thm example_string_string_def
JSON_export example_string_string
JSON_export example_string_string file example_string_string

declare [[JSON_string_type=String.literal, JSON_num_type = String.literal]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":42}
> defining example_literal_literal
thm example_literal_literal_def
JSON_export example_literal_literal
JSON_export example_literal_literal file example_literal_literal

xxxx

```

Using the top level Isar commands defined in the last section, we can now easily define JSON-like data:

```

JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":42}
> defining example02

thm example02_def

```

```

declare [[JSON_string_type = String.literal]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}, "flag":true, "number":42}
> defining example02'

```

```

thm example02'_def

```

<ML>

Moreover, we can import JSON from external files:

```

lemma "example01 = example03"
  <proof>

```

```

end

```

3.3 Examples Real (Example_Real)

```

theory
  Example_Real
imports
  Nano_JSON_Main
  Complex_Main
begin

```

In this theory, we illustrate various small examples of importing or exporting of JSON data from Isabelle/HOL. The examples in this theory make use `real`. This is possible, as this theory imports the theory `Complex_Main`.

```

declare [[JSON_num_type = real]]

```

```

JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}, "flag":true, "number":-42.8}

```

```
> defining example_default_real
```

```
thm example_default_real_def
```

```
JSON_export example_default_real
```

```
JSON_export example_default_real file example_default_real
```

```
declare [[JSON_string_type=string, JSON_num_type = int]]
```

```
JSON <
```

```
{ "menu": {  
  "id": "file",  
  "value": "File",  
  "popup": {  
    "menuitem": [  
      { "value": "New", "onclick": "CreateNewDoc()" },  
      { "value": "Open", "onclick": "OpenDoc()" },  
      { "value": "Close", "onclick": "CloseDoc()" }  
    ]  
  }  
}, "flag": true, "number": 42 }
```

```
> defining example_string_int
```

```
thm example_string_int_def
```

```
JSON_export example_string_int
```

```
JSON_export example_string_int file example_string_int
```

```
declare [[JSON_string_type=String.literal, JSON_num_type = int]]
```

```
JSON <
```

```
{ "menu": {  
  "id": "file",  
  "value": "File",  
  "popup": {  
    "menuitem": [  
      { "value": "New", "onclick": "CreateNewDoc()" },  
      { "value": "Open", "onclick": "OpenDoc()" },  
      { "value": "Close", "onclick": "CloseDoc()" }  
    ]  
  }  
}, "flag": true, "number": 42 }
```

```
> defining example_literal_int
```

```
thm example_literal_int_def
```

```
JSON_export example_literal_int
```

```
JSON_export example_literal_int file example_literal_int
```

```
declare [[JSON_string_type=string, JSON_num_type = real]]
```

```
JSON <
```

```
{ "menu": {  
  "id": "file",  
  "value": "File",  
  "popup": {  
    "menuitem": [  
      { "value": "New", "onclick": "CreateNewDoc()" },  
      { "value": "Open", "onclick": "OpenDoc()" },  
    ]  
  }  
}
```

```

        {"value": "Close", "onclick": "CloseDoc()"}
    ]
}
}, "flag":true, "number": 42.8}
> defining example_string_real
thm example_string_real_def
JSON_export example_string_real
JSON_export example_string_real file example_string_real

declare [[JSON_string_type=String.literal, JSON_num_type = real]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":42.8}
> defining example_literal_real
thm example_literal_real_def
JSON_export example_literal_real
JSON_export example_literal_real file example_literal_real

declare [[JSON_string_type=string, JSON_num_type = string]]
JSON <
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [
      {"value": "New", "onclick": "CreateNewDoc()"},
      {"value": "Open", "onclick": "OpenDoc()"},
      {"value": "Close", "onclick": "CloseDoc()"}
    ]
  }
}
}, "flag":true, "number":-42.5}
> defining example_string_string
thm example_string_string_def
JSON_export example_string_string
JSON_export example_string_string file example_literal_string

declare [[JSON_string_type=String.literal, JSON_num_type = String.literal]]
JSON<
{"menu": {
  "id": "file",
  "value": "File",
  "popup": {
    "menuitem": [

```

```
    {"value": "New", "onclick": "CreateNewDoc()"},
    {"value": "Open", "onclick": "OpenDoc()"},
    {"value": "Close", "onclick": "CloseDoc()"}
  ]
}
}, "flag":true, "number":-42.5}
> defining example_literal_literal
thm example_literal_literal_def
JSON_export example_literal_literal
JSON_export example_literal_literal file example_literal_literal

end
```


Bibliography

- [1] T. Bray, editor. The JavaScript object notation (JSON) data interchange format. Online: <https://datatracker.ietf.org/doc/html/rfc8259>. Dec. 2017.
- [2] T. Bray, J. Paoli, C. M. Sperberg-McQueen, E. Maler, and F. Yergeau. Extensible markup language (xml) 1.0 (fifth edition). W3C Recommendation, 2008. Available at <http://www.w3.org/TR/REC-xml/>.
- [3] A. D. Brucker and M. Herzberg. The Core DOM. *Archive of Formal Proofs*, Dec. 26, 2018. ISSN: 2150-914x. URL: <http://www.brucker.ch/bibliography/abstract/brucker.ea-afp-core-dom-2018>. http://www.isa-afp.org/entries/Core_DOM.html, Formal proof development.
- [4] A. D. Brucker and B. Wolff. An extensible encoding of object-oriented data models in HOL. *USenglish. Journal of Automated Reasoning*, 41:219–249, 3, 2008. ISSN: 0168-7433. DOI: 10.1007/s10817-008-9108-3. URL: <http://www.brucker.ch/bibliography/abstract/brucker.ea-extensible-2008-b>.
- [5] ECMA-404: The JSON data interchange syntax. Online: <https://www.ecma-international.org/publications-and-standards/standards/ecma-404/>. Dec. 2017.
- [6] C. Sternagel and R. Thiemann. XML. *Archive of Formal Proofs*, Oct. 2014. ISSN: 2150-914x. <http://isa-afp.org/entries/XML.shtml>, Formal proof development.
- [7] M. M. Wenzel. *Isabelle/Isar – a versatile environment for human-readable formal proof documents*. PhD thesis, TU München, München, Feb. 2002. URL: <http://tumb1.biblio.tu-muenchen.de/publ/diss/in/2002/wenzel.html>.