

Appendix C

Exchange of Thermal Model Algorithms via STEP-TAS

Alain Fagot
(DOREA, France)

Hans Peter de Koning Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

In this presentation the next evolution of the exchange of thermal analysis models for space via STEP-TAS will be explained.

Apart from representing the pure passive thermal behaviour, space thermal analysis models have from the beginning (in the 60's) supported modeling of active behaviour, e.g.:

- thermostat or PID controlled heaters
- fluid lines
- Peltier elements
- thermal switches

and complex non-linear behaviour like temperature or pressure dependent material properties, interaction with hydraulic system elements and phase change in materials.

This was implemented in tools like ESATAN and SINDA through so-called user-defined logic blocks in a dedicated language called "MORTRAN", an extension of FORTRAN77. In order to fully exchange such thermal models TMMverter is developed, where TMM stands for Thermal Mathematical Model, the common name used for ESATAN and SINDA like thermal models. TMMverter is an extension of the existing TASverter tool. The first version will address the full exchange of thermal models between ESATAN and SINDA.

In order to achieve this complex task, a number of different data processing technologies and data exchange standards are combined:

- The ESATAN and SINDA model definition files are parsed using the ANTLR lexer/parser open source software.
- The structural parts of the models are converted into traditional STEP-TAS EXPRESS based data structures and .stp files, using a Python SDK generated with the Expressik tool.
- The user-defined logic (i.e. algorithmic) parts of the models are converted to a prefix mathematical language expressed in JSON (JavaScript Object Notation) and embedded into EXPRESS instances in the STEP-TAS .stp file.

This allows mapping from and back to the FORTRAN-based ESATAN and SINDA languages with minimal loss of information. The presentation will show how this approach could be beneficially used in many other applications.






**Mechanical Engineering Department
Thermal and Structures Division**

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TMMverter
**Exchange of Thermal Model Algorithms via
STEP-TAS**

Alain Fagot (DOREA France) alain.fagot@dorea.fr	Hans Peter de Koning (ESA / ESTEC, Noordwijk, The Netherlands) (ESA/ESTEC D/TEC-MCV) hans-peter.de.koning@esa.int	Harrie Rooijackers (ESA / ESTEC, Noordwijk, The Netherlands) (ESA/ESTEC D/TEC-MCV) harrie@thermal.esa.int
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DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00



Topics





- Introduction to TMMverter


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Introduction to TMMverter







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- Next evolution of space thermal analysis model exchange via STEP-TAS
- STEP-TAS Conformance Classes 1 to 8 address static (passive) part of thermal models
- However, space thermal analysis models also capture active behaviour
 - Thermostat or PID controlled heaters
 - Fluid lines
 - Peltier elements
 - Thermal switches
 - Non-linear temperature or pressure dependent material properties
 - Interaction with hydraulic system elements
 - Phase change in materials
- Was implemented in tools like ESATAN and SINDA through so-called user-defined logic blocks in dedicated language called "MORTRAN", an extension of FORTRAN77
- Therefore development of "TMMverter" - extension of TASverter
 - TMM stands for Thermal Mathematical Model
 - Will become part of TASverter when mature
- Version 1 will address full exchange between ESATAN and SINDAfluint

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<http://www.dorea.fr>
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- Introduction to TMMverter
- Thermal Mathematical Models

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Thermal Mathematical Models







- **Thermal Mathematical Models in ESATAN and SINDAfluint are mainly divided in two categories:**
 - **Data Blocks**
 - Definition of sub models, nodes and conductors
 - Assignment of TMM software CONTROL values (variables defined in the software)
 - Definition and assignment of user variables and arrays
 - **Operation Blocks**
 - Definition of specific Algorithms for execution and output in FORTRAN or MORTRAN language
 - Instructions to be performed prior to the program solution, at the beginning or the end of each time step iteration
- **It can be observed similarities, but also differences between ESATAN and SINDAfluint blocks**




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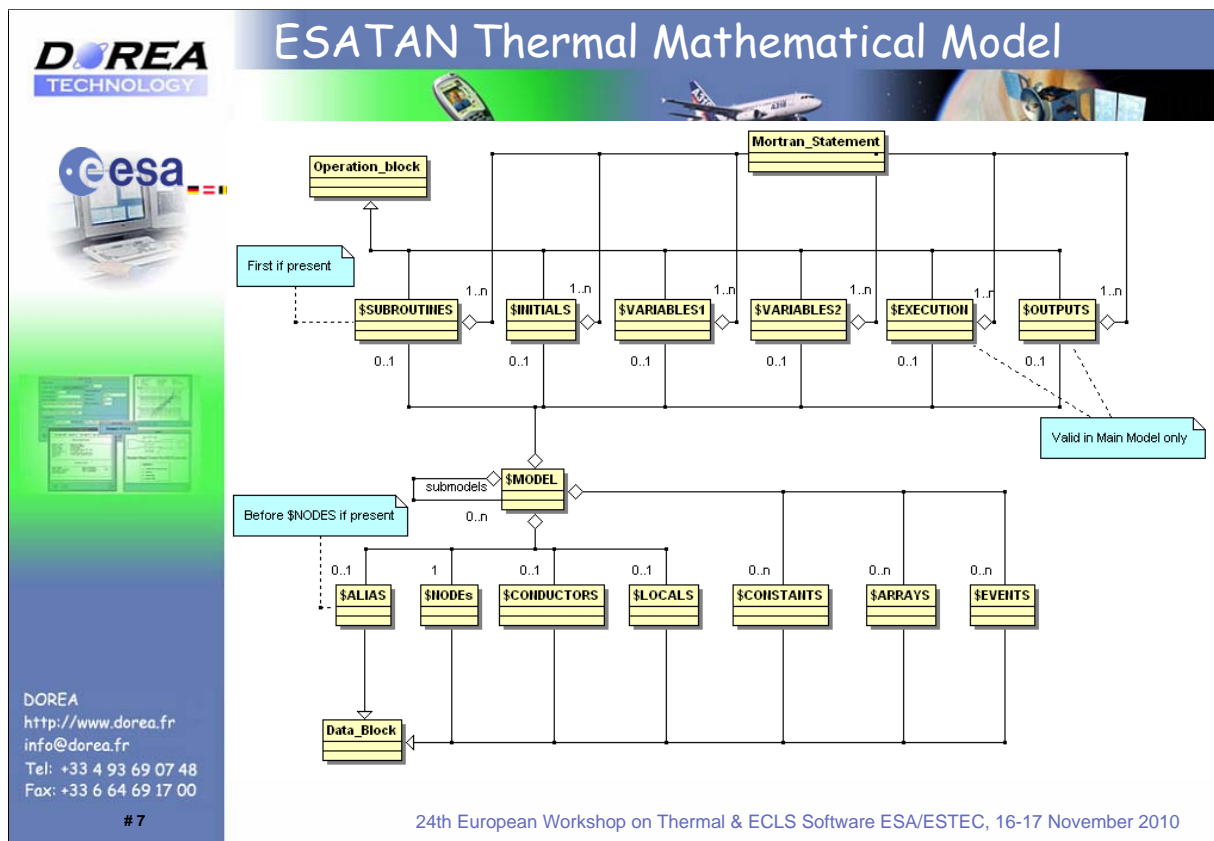
SINDAfluint Thermal Mathematical Model

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DOREA TECHNOLOGY



Topics

- Introduction to TMMverter
- Thermal Mathematical Models
- User Defined Logic


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User Defined Logic








- **User-defined logic** blocks is defined in a dedicated language called "MORTRAN", an extension of FORTRAN77
- **User-defined logic** is mainly used in Operations Blocks, but also in some Data Blocks:
 - Loop for Node or Conductor Definition
 - Use of expressions in quantities assignments
- **The MORTRAN extension syntax is specific to each TMM software**


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<http://www.dorea.fr>
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User Defined Logic - Example in Data Block





- **Nodes or Conductors definition using loop**
 - **ESATAN**

```

# *****
$NODES
# *****
#
FOR KL1 = 1 TO 20 DO
  FOR KL2 = KL1 TO 20 STEP 2 DO
    KL4 = 10;
    KL3 = KL2 + 1;
  END DO
  KL2 = KL1 + 1 ;
  DKL1 = 'PCB node', T = 5.0*KL2, C = 0.0;
END DO
B999, T = 1.;

```

Temperature defined using algorithmic expression

- **SINDAfluint**



```

HEADER NODE DATA,SPACE
-999,abszro,0.0
$ SPACE SINK
HEADER NODE DATA,CBAY
GEN 1,5,1,70.0,-1.0
$ CARGO BAY PANELS




```

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User Defined Logic - Example in Operation Block

■ ESATAN

```

# *****
$EXECUTION
# *****
  HEADER = 'Simple Parameterised PCB Model'
  CALL SOLVFM
#
# *****
$OUTPUTS
# *****
  FORMAT = '*'
  CALL PRNCV(' ', 'GL, GR, GV, GF, GP, M, G', CURRENT, 'NODE', 'conductors.csv')
  CALL DMPGFF(' ', 'NODES, CONDUCTORS, CONSTANTS',
    &
    CURRENT, 'group1')
  CALL PRNDB(' ', 'L, T, QI, C', CURRENT)
  CALL PRQNOD('PCB node', CURRENT)
  CALL PRNDBL(' ', 'GL', CURRENT)
    
```

■ SINDAfluint



```

C *****
HEADER OPERATIONS
C *****
BUILD WHOLE,SATT,CBAY,SPACE
  UCAL = 'ORBITAL AVERAGE IN CARGO BAY'
  CALL STEADY
C *****
HEADER OUTPUT CALLS,SATT
C *****
  IF(NSOL .LE. 1 .AND. LOOPCT .EQ. 0)RETURN
  CALL TPRINT('ALL')
    
```




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User Defined Logic - Nodes referencing

■ ESATAN

```

$MODEL mod0_35
$MODEL sub_mod0_35
$MODEL subsub_35
$NODES
D3 = 'PCB node', T = 0.0, C = 0.5;
$ENDMODEL subsub_35
$ENDMODEL sub_mod0_35
$NODES
D1 = 'Arithmetic node', T = 0.0, C = 0.0;
B99999, T=100.;
$CONDUCTORS
GL(1, subsub_35:3) = .5;
GL(1, 99999) = 1.;
$ENDMODEL mod0_35
    
```

Reference to Node
3 in sub-model
subsub_35

■ SINDAfluint

```

HEADER NODE DATA, SUB00001 $ mod0_35
  1,0.0,-1.0 $ Arithmetic node
  -99999,100.0,0.0

HEADER CONDUCTOR DATA, SUB00001 $ mod0_35
  1, 1, SUB00002.3, 0.5
  2, 1, 99999, 1.0

HEADER NODE DATA, SUB00003 $ mod0_35/sub_mod0_35
  2,0.0,0.7 $ PCB node
HEADER NODE DATA, SUB00002 $ mod0_35/sub_mod0_35/subsub_35
  3,0.0,0.5 $ PCB node
    
```



One sub-model level
=> Model is flattened

Reference to Node
3 in sub-model
SUB00002


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Topics







- Introduction to TMMverter
- Thermal Mathematical Models
- User Defined Logic
- TMMverter operating mode


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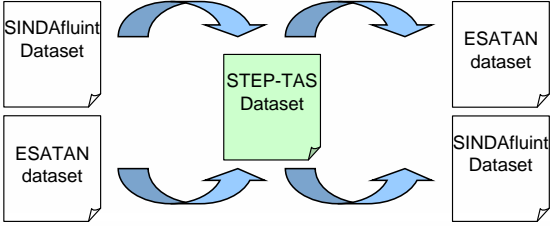



TMMverter operating mode





- **TMMverter**
 - Reads Thermal Mathematical Models including Model content and User Logic
 - Translates TMM content in **STEP-TAS v6** format
 - Reads back TMM content from STEP-TAS dataset
 - Writes back Thermal Mathematical Models





```

graph TD
    S1[SINDAfluint Dataset] <--> ST[STEP-TAS Dataset]
    E1[ESATAN dataset] <--> ST
    
```


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Topics







- Introduction to TMMverter
- Thermal Mathematical Models
- User Defined Logic
- TMMverter operating mode
- TMMverter Implementation


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Implementation technologies







- Implementation Language
 - Python Language has been selected in the continuity of TASverter (www.python.org)
- Parsing of Thermal Mathematical Models
 - Antlr V3 (ANOther Tool for Language Recognition) <http://www.antlr.org/>
 - Antlr lexical and semantic analyser code generated in Python
 - Use of ANTLRWorks – ANTLR grammar development environment
- Standard Repository Format
 - STEP-TAS V6 Application Protocol http://www.esa.int/thermal_control, click “Standards”
 - STEP-TAS Python Software Development Kit generated with Expressik – this SDK handles both Part21 and HDF5 formats
- Algorithm representation
 - JSON, Javascript Object Notation (<http://www.json.org>)
 - Simplejson – Python JSON encoder/decoder module
 - JSON encoded string representation is stored in STEP-TAS dataset


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General Architecture





- TMMverter architecture is organised around an Abstract Syntax Tree Model (AST)
 - The AST contains Class definitions of a common representation of TMM content (Blocks, Models, Nodes, Conductors, Mortran Statements, ...).
 - The AST is a Run-time memory representation
- Thermal Mathematical Models are parsed with Antlr (lexical and semantic analysis)
 - The Antlr grammars populate the AST Model
- A Set of Visitor Design Patterns have been implemented on AST Model
 - TAS writer visitor
 - ESATAN writer visitor
 - SINDAfluint visitor
 - JSON visitor (generates JSON encoded string to write in STEP-TAS).


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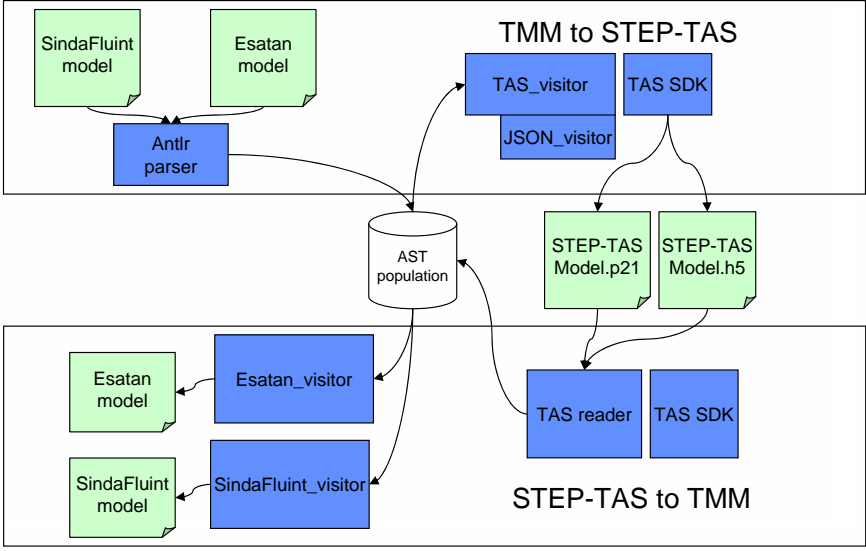
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General Architecture #2





```

            graph TD
            subgraph TMM_to_STEP_TAS [TMM to STEP-TAS]
            S1[SindaFluint model] --> AP[ANTLR parser]
            S2[Esatan model] --> AP
            AP --> AST[(AST population)]
            AST --> TV[TAS_visitor]
            AST --> JSV[JSON_visitor]
            TV --> TAS_SDK1[TAS SDK]
            JSV --> TAS_SDK1
            end



            subgraph STEP_TAS_to_TMM [STEP-TAS to TMM]
            ST1[STEP-TAS Model.p21] --> TR[TAS reader]
            ST2[STEP-TAS Model.h5] --> TR
            TR --> TAS_SDK2[TAS SDK]
            TAS_SDK2 --> EV[Esatan_visitor]
            TAS_SDK2 --> SV[SindaFluint_visitor]
            EV --> EM[Esatan model]
            SV --> SFM[SindaFluint model]
            end

            AST --> TV
            AST --> JSV
            AST --> TR
            
```




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- Thermal Mathematical Models
- User Defined Logic
- TMMverter operating mode
- TMMverter Implementation
 - Antlr Parsing




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Antlr parsing

- TMM models are pre-processed before parsing
 - A flat intermediate model is created
 - Insertion of all "INCLUDE" statements contents
 - Reorganisation of Blocks to simplify Antlr grammars definition
- Antlr grammars (.g) are created with AntlrWorks

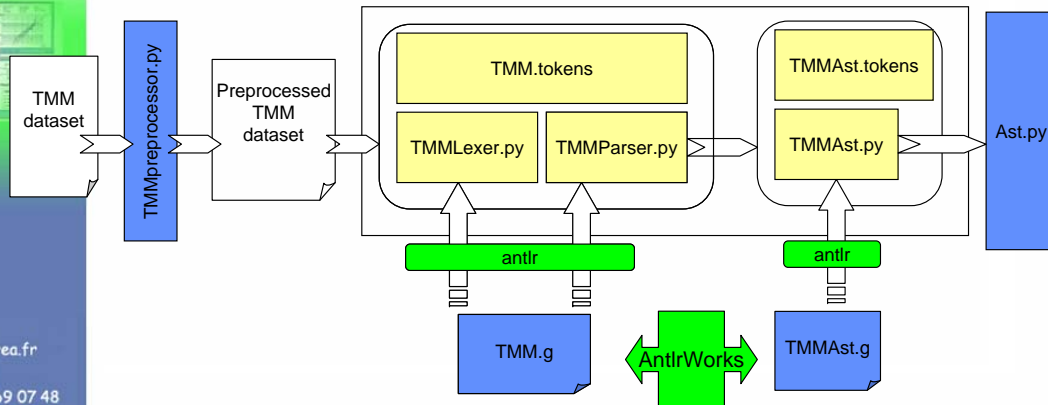

- TMM parsing is done in two steps (two grammars):
 - lexical and semantic analysis definition
 - Generate Tokens, Lexer and Parser
 - Populate an Antlr intermediate ast more compact.
 - Parsing of antlr ast
 - Antlr execution instructions populate the TMMverter AST

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<http://www.dorea.fr>
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Antlr parsing



The diagram illustrates the Antlr parsing workflow. It starts with a 'TMM dataset' which is processed by 'TMMpreprocessor.py' to create a 'Preprocessed TMM dataset'. This dataset is then fed into two parallel processing stages. The first stage uses 'TMM.g' (the TMM grammar) and 'antlr' to generate 'TMM.tokens' and 'TMMParser.py'. The second stage uses 'TMMAst.g' (the TMM AST grammar) and 'antlr' to generate 'TMMAst.tokens' and 'TMMAst.py'. Both 'TMMParser.py' and 'TMMAst.py' are used to process the 'Preprocessed TMM dataset' into 'Ast.py'. A central 'AntlrWorks' component is shown with bidirectional arrows connecting to the 'antlr' boxes. Logos for DOREA TECHNOLOGY and ESA are present at the top left.

- Process implemented twice:
 - For ESATAN
 - For SINDAfluint
- 2x2 grammars, 2 pre-processors

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Notes on Antlr parsing



- TMM models syntaxes combine:
 - Fortran Syntax
 - TMM specific Mortran statements
 - TMM pure syntax (nodes, conductors, ... definition)
- This does not make easy the definition of an Antlr grammar
- A support module has been implemented to help Antlr adapting the syntax recognition depending on statement location in the model
 - "node_def" rule is different if we are in a NODES block or in a MORTRAN Block (*{python boolean expression}?=>rule*)
Differs on the ending semicolon
 - Note the unique creation of an Antlr AST node for second grammar
 ->^(NODE t_node STRING? t_node_attr+)

```


node_def
:
{EPM.isInBlock('NODES')}?=>
(t_node (EQUAL STRING)? t_node_attr+ SEMICOL eol->^(NODE t_node STRING? t_node_attr+)
 t_fluidnode (EQUAL STRING)? t_fluidnode_attr+ SEMICOL eol->^(NODE t_fluidnode STRING? t_fluidnode_attr+))
{EPM.isInMortranBlock()}?=>
(t_node (EQUAL STRING)? t_node_attr+ eol->^(NODE t_node STRING? t_node_attr+)
 t_fluidnode (EQUAL STRING)? t_fluidnode_attr+ eol->^(NODE t_fluidnode STRING? t_fluidnode_attr+))
    
```


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Topics








- Introduction to TMMverter
- Thermal Mathematical Models
- User Defined Logic
- TMMverter operating mode
- TMMverter Implementation
 - Antlr Parsing
 - STEP-TAS mapping


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STEP-TAS mapping










- TMM (sub)-models, nodes and conductors are mapped to:
 - Nrf_network_model,
 - Nrf_network_node,
 - Nrf_network_node_relationship
- Nodes and conductors defined in “Loops”
 - The loop definition is converted to a python script
 - The python script is executed on the fly by the parser
 - All nodes (or conductors) defined in the loop are created in the STEP-TAS dataset
- Nodes and conductor initial quantities
 - Literal values are stored in Nrf_datacube
 - Expression values are stored using
 - Nrf_quantity_value_prescription_for_item
 - Nrf_string_quantity_value_expression (the expression is converted to an encoded JSON string)
- Controls, User constants and variables, execution blocks are stored in Nrf_model_function(s)
 - Mortran statements and expressions are stored as JSON encoded strings

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 - User Logic encoding in JSON




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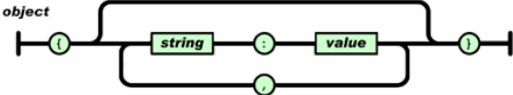
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User Logic encoding in JSON

- The JSON (Javascript Object Notation) format has been selected for encoding the Mortran/Fortran user logic embedded in ESATAN and SINDAfluint .
- JSON is built on two structures:
 - A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.
 - An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.





- Python implementation of JSON
 - JSON objects are defined with Python Dictionaries
 - JSON ordered list of values are defined with Python Lists
 - **encode** and **decode** methods convert JSON Python objects to Strings and vice versa
- The most suitable approach to capture user-defined logic in a neutral was found to be so called "prefix notation", as it is also used in MathML and a number of other mathematical interchange formats as well as e.g. the Lisp programming language.
 - The following simple mathematical expression:
 $3+4*5$
 could be written in prefix notation as:
 $(plus\ 3\ times(4\ 5))$
 and in JSON format:
 $\{ "plus" : [3, \{ "times" : [4, 5] \}] \}$


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Topics







- Introduction to TMMverter
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- TMMverter operating mode
- TMMverter Implementation
 - Antlr Parsing
 - STEP-TAS mapping
 - User Logic encoding in JSON
 - Control Variables and subroutine libraries


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Control variables and subroutine libraries







- ESATAN and SINDAfluint own specific Control variables and Subroutines
- These variables and subroutines have to be converted from the emitting to the destination TMM syntax
 - DTMIN <-> DTIMEL
 - DTMAX <-> DTIMEH
 - NLOOP <-> NLOOP, NLOOPS
 - RELXCA <-> DRLXCA
 - For library subroutines, not only subroutines name has to be translated but also name, number, order and value of parameters.
- Information about the emitting TMMModel is stored in STEP-TAS as to perform necessary conversion.
 - #522=NRF_TOOL_OR_FACILITY('TMMverter','ESATAN vs STEP-TAS converter',#1);
 - #522=NRF_TOOL_OR_FACILITY('TMMverter','SINDAfluint vs STEP-TAS converter',#1);


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 - Control Variables and subroutine libraries
- Conclusion

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Conclusion





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- First Bi-directional exchange between ESATAN and SINDA are possible since summer 2010 (TMMverter / TASverter)
- Second development phase has started to extend automatic conversion of TMM software subroutines and Mortran syntax
- General / programming language independent mechanism to transfer expressions and algorithms available in JSON
- Can be easily integrated into existing data exchange formats like XML and ISO 10303-21 (as annotated string)

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