Modeling the space environment and its effects on spacecraft and astronauts using SPENVIS

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The space environment (i.e. cosmic rays, radiation belts, solar energetic particles, plasmas, outgassing and micro-particles) poses many threats to spacecraft and astronauts. The Space Environment Information System (SPENVIS) is a web application that provides models and tools to space engineers and scientists to model the space environment around Mercury, Earth, Mars and Jupiter but also in the interplanetary medium. In addition, it allows the users to combine and chain results between different models enabling them to calculate the potential effects of the environments specific for their (planned) mission. The effects are divided in the following categories: ionizing dose, non-ionizing energy loss, radiation damage in solar cells, single event upsets, spacecraft charging, atomic oxygen erosion, and meteoroid and debris models. Since SPENVIS' introduction in 1996, the informatics technology has evolved considerably. In the last part of this paper, SPENVIS Next Generation is presented. The framework has been reviewed, restructured and reengineered using current web design techniques and programming methodologies, providing a new, extensible and distributed framework for the integration of current and future space environment models.

I.   Introduction

Space weather is the influence of solar electromagnetic and space particle radiation (solar energetic particles, galactic cosmic rays, and radiation belts), on technology (e.g. spacecraft, GPS navigation, communication, avionics) and human health (e.g. astronauts, high-latitude flights) on Earth and in space [9]. On the ground we are generally well shielded from the space weather environment by our planet's atmosphere and its magnetic field. However, satellites and astronauts are directly exposed to its hazardous effects. The danger becomes increasingly more substantial when moving away from Earth's protection (e.g. a spacecraft mission through the harsh radiation environment of Jupiter and its moons or a future manned missions to Mars). This is why it is important to model these environments and their effects on satellites, spacecraft and astronauts.

In the following, the European Space Agency (ESA[8]) Space Environment Information System (SPENVIS[9]) is introduced. The different models and tools that are integrated in this web framework to simulate the space environment and its various effects are also presented. The final part of this paper is dedicated to the conceptual innovations of the follow-up system, known as SPENVIS Next Generation, that is currently under development.

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[8] http://www.esa.int

[9] https://www.spenvis.oma.be

II. Using SPENVIS to model the space environment and its effects

SPENVIS is a user-friendly web application designed to help spacecraft engineers perform rapid analyses of space environment and its effects. Thanks to well-defined input forms and extensive help/background information pages, it allows engineers with relatively little familiarity with the models to produce reliable results. It is also based on internationally recognized standards, especially the European Cooperation for Space Standardization (ECSS).

Since its first development by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) in 1996, SPENVIS has been a successful ESA operational software for more than fifteen years. In the recent years, SPENVIS has also been integrated in ESA's Space Situational Awareness (SSA) Space Weather Service Network[10]. As a result, SPENVIS has established a mature user community of more than 16000 users from all over the globe that are using the system for various purposes including mission analysis and planning, education and scientific research.

The orbit generator will be discussed first because most of the models implemented in SPENVIS require as input a set of point on a spacecraft trajectory or a user-defined set of geographic points. Then the space radiation sources, i.e. cosmic rays, radiation belts, solar energetic particles and plasmas, are discussed. The effect are divided in the following categories: spacecraft charging, ionizing and non-ionizing dose and single event effects. After that, the Geant4 tools are introduced. Finally the atmospheric models (e.g. atomic oxygen erosion) and meteoroids and space debris (MMOD) models are discussed.
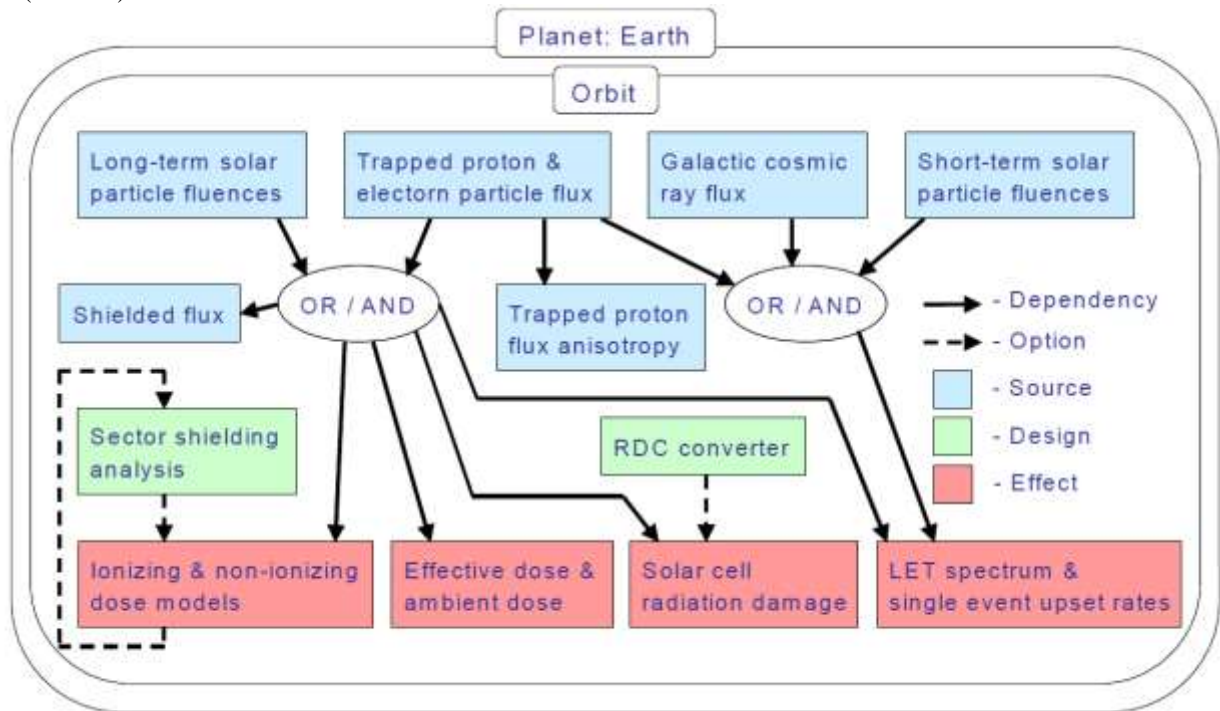

Figure 1: SPENVIS model interaction when simulation the environment around Earth and its effects.

A. Orbit generator

SPENVIS has it own orbit generator (SAPRE) that allows the computation of trajectory osculatory orbital elements using a numerical Runge-Kutta integration method using the eccentric anomaly as the independent variable. It was initially designed for simulating Earth's orbits but was later extended for orbits around Mars and Jupiter.

Users can create circular, elliptical or hyperbolic (i.e. flybys) orbits around the above mentioned planets. SPENVIS also allows the definition of some commonly used orbits around Earth like Heliosynchronous or Geostationary (GEO) orbits. In addition, the system provides the Near Earth Interplanetary orbit (NEI) option for generating a set of coordinates outside Earth's magnetosphere. In this case the resulting obit is a circular orbit at 90000 km altitude and an inclination of zero degrees. Furthermore, SPENVIS provides an option to specify a spacecraft trajectory using Two-line elements (TLEs). Lastly, users can upload into the system a file that contains a trajectory following the format specified in the SPENVIS help pages.

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[10] http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness

The SPENVIS system allows the definition of multiple orbit segments that are combined into a spacecraft mission. Users have to define the mission segment start and stop times or the segment lengths. These times and lengths are then used by other application to scale fluxes to segment and mission fluences, for instance. The start of the mission is defined by the start date of the first trajectory.

B. Space radiation environment models

The space radiation environment can be specified using the radiation belt, solar particle and galactic cosmic ray (GCR) models that are available in SPENVIS. The trapped radiation population (protons and electrons) is implemented through several models:
- NASA AP-8 [34] and AE-8 [43]
- CRRESPRO [24] and CRRESELE [8]
- SAMPEX/PET Low altitude proton model PSB97 [17]
- ESA-SEE1 update of NASA AE-8MIN [42]
- ONERA/DESP models POLE V1, V2 [7] and IGE-2006 [36]
- IRENE-AE9, IRENE-AP9 [14]
- Slot Region Radiation Environment Models (SRREMs)

The solar particle (protons and heavy ions) models are separated in solar particle fluxes and fluences models for studying respectively short and long term effects.

(solar particle fluence models)
- King [21]
- JPL-91 [12]
- Rosenqvist et al. [32]
- ESP – PSYCHIC total fluence and worst case event models [44,45,47]
- SAPPHIRE [19]

(solar particle flux models)
- CREME-86 [1]
- CREME-96 [41]
- Xapsos et al. [46]
- SAPPHIRE [19]

The International Standard for estimating the radiation impact of galactic cosmic rays on hardware and on biological and other objects in space is the ISO15390 model. It accounts for the variations of the GCR particle fluxes due to changes in solar activity and in the large scale heliospheric magnetic field (the sun's polar magnetic field) throughout 22-year cycles. Other models included in SPENVIS are:
- CREME-86 [1]
- CREME-96 Sol. Minimum [41,21]
- Nymmik et al. [26,27]

In the magnetosphere magnetic shielding is applied for attenuating the proton and heavy ion fluxes whereby assuming full ionized particles. Secondary particle radiation generated through interaction of energetic particles with shielding material and the upper atmosphere, can be analysed with the Geant4 tools as described in paragraph D.

C. Effect models

The space environment may induce numerous problems in space systems and impact the health of astronauts. To estimate the impact of the radiation and plasma environment, SPENVIS provides tools for Spacecraft charging, Ionizing and non-ionizing Dose and Single Event Effects (SEEs).

1. Spacecraft charging

Spacecraft/plasma interactions and penetrating energetic electrons (> 100 keV) can electrically charge the surface of the spacecraft and its internal components to high potentials with a resulting electrostatic discharge leading to anomalies and damage.

Toos for spacecraft charging analysis included in SPENVIS are:
- LEOPOLD, providing the principal parameters that characterise the low Earth and polar orbital environments
- SOLARC, giving an estimate of the current collection and power loss experienced by a solar array in the low Earth orbit plasma environment

- EQUIPOT, that computes the equilibrium potential of a surface using a simple model of differential charging
- DICTAT, a simulation tool for 1D internal charging analysis that contains the built-in environment FLUMIC model [31] and can can be used to give practical worst-case environments throughout the terrestrial radiation belts.

The first three tools are part of the the ESA ESPIRE suite [6]. The DICTAT tool developed by Rodgers et al. [22] is applicable for planar and cylindrically symmetric cases. In addition to the various tools, SPENVIS also includes a collection of satellite data during charging events from the GORIZONT/ADIPE and CRRES/LEPA missions.

2. Total ionizing and non-ionizing dose

SPENVIS uses trapped particle and solar proton fluence spectra to estimate doses behind Al shielding produced through ionization and non-ionization energy loss. Both have a cumulative effect resulting in a gradual loss of performance with eventual device failure and biological damage. Cumulative dose curves and total doses are produced in SPENVIS with SHIELDOSE, SHIELDOSE-2, SHIELDOSE-2Q (for ionization) and the NIEL model. Main inputs, next to the environment, are the target material and shielding distributions for which a geometry tool is available. NIEL curves for different target materials and incoming particles (electrons and elemental ions) can be calculated with the INFN Screened Relativistic Non-Ionising Energy Loss tool incorporated into SPENVIS.

For solar cell degradation due to space radiation, EQFLUX [38,3] and MC-SCREAM are implemented in SPENVIS. The EQFLUX programme calculates solar cell 1 MeV damage equivalent electron fluences for exposure to the fluences predicted by the trapped radiation models for Earth or Jupiter and the solar proton flux models. MC-SCREAM computes the end-of-life (EOL) solar cell performance in space, using NIEL in radiation damage correlations and montecarlo simulations for propagating the particle fluxes through the coverglass and energy deposit inside the cell.

3. Single Event Effects

In the space radiation environment high energy protons and heavy ions may cause either destructive (or potentially destructive) effects or transient effects in sensitive devices through direct ionization or nuclear interactions. Single event upset (SEU) analysis for semiconductor devices exposed to trapped proton, solar and galactic cosmic ray particles can be done in SPENVIS with the specific SEU tool (based on the CREME-86 SEU code [1]) and SPENVIS integrated Geant4 tools (described below). Single event effects induced by neutrons are not considered in SPENVIS.

D. Geant4 tools

Geant4 (GEometry ANd Tracking version 4) is a software toolkit for the simulation of the passage of particles through matter using Monte Carlo techniques [2]. Today, a number of dedicated Geant4-based tools exist that can be employed for the planning of space and planetary exploration missions. In particular, SPENVIS provides interfaces to various Geant4 tools that can be used for instrument and detector response verification, space radiation shielding optimisation, component effects, support of scientific studies to the analysis of biological effects and astronaut radiation hazards.

Sector Shielding Analysis Tool (SSAT) [40] can be used to perform ray tracing from user defined point within a geometry to determine shielding levels and shielding distributions [23]. The geometry is defined by a GDML file that can either be uploaded by a user or generated by the Geometry definition tool inside SPENVIS.

The Multi-Layered Shielding Simulation Software (MULASSIS) [22] allows someone to perform radiation analysis for one-dimensional layered geometry while the Geant4 Radiation Analysis for Space (GRAS) tool [35] can be used for also performing general space radiation analysis for 3D geometries. Both can calculate particle fluences behind some shielding or ionising and non-ionising doses deposited on some spacecraft component. In addition, they can be used for calculating dose equivalent or equivalent dose received by astronauts. Moreover, MC-SCREAM tool is using MULASSIS to calculate NIEL based damage equivalent fluences for solar cells.

Geant4-based Microdosimetry Analysis Tool (GEMAT) can be used to study dosimetry effects of space radiation on micro-electronics and micro-sensors [18]. GEMAT has its own geometry builder where users can construct a geometrical model in terms of layers, contact and depletion volumes

MAGNETOCOSMICS [10] can be used for visualizing charged particle trajectories and magnetic field lines around Earth. In addition, it can be used for calculating cut-off rigidities as a function of position. PLANETOCOSMICS [11] allows someone to define planetary magnetic fields, atmosphere and soil. It can be used for simulating the interaction of cosmic rays with the planetary environment. PLANETOCOSMICS is available for Mercury, Earth and Mars. For Jupiter, the PLANETOCOSMICS-J update [39] can be used to simulate the interaction of energetic particles with the Jovian Galilean moon environment (JOREM) [18].

Finally, the Mars Energetic Radiation Environment Model (MEREM) [15] contains dMEREM. This is a detailed Geant4 radiation simulation model that takes into account detailed soil and atmosphere composition in order to provide more accurate analysis for a specific site.

E. Atmospheric models

The implementation of atmospheric and ionospheric models runs in combination with the orbit generator for the following (semi)empirical models:

- Mass-Spectrometer-Incoherent-Scatter (NRLMSISE-00) [29]
- Marshall Engineering Thermosphere (MET-V 2.0) [28]
- Drag Temperature Model (DTMB78) [4]
- International Reference Ionosphere (IRI2001) [5]
- NeQuick Ionosphere Electron Density Model (NeQuick v2.0) [25]

SPENVIS calculates the density of one particle type at each orbital point. In addition, the flux of this particle type on an oriented plate is determined, as well as the orbital fluence and total mission fluence. For atomic oxygen, a material erosion factor can be applied to estimate material loss due to oxydation.

The coordinate grid generator is also implemented as one single geographical point, as a profile or as a two-dimantional map for all the above mentioned models as well as for the Horizontal Wind Model (HWM93).

F. Meteoroids and space debris models

Both natural meteoroids and man-made space debris particles represent a serious hazard to space vehicles in orbit around the Earth. Nearly all meteoroids originate from comets or asteroids, and are generally distributed isotropically (termed 'sporadic' meteors), except those that retain their parent body orbit, which are termed 'meteor streams'. The total meteoroid environment is thus comprised of the average of the sporadic meteors together with the yearly average of meteor streams. Also co-existent with the natural particle flux are space debris particles, most of which are in high-inclination orbits, and consist of spent rocket stages, inactive payloads, debris from exploded satellites, etc.

The meteoroid and debris models included in SPENVIS are:

- the Grün meteoroid model [16]
- the MASTER debris model [37]
- the NASA90 debris model [20]

For the particle/wall interaction two models are included in SPENVIS that are based on:

- the ESABASE User Manual [13]
- the Micrometeoroid and Orbital Debris (MMOD) Shield Ballistic Limit Analysis Program [33]

III.   SPENVIS Next Generation

Despite its great success the current SPENVIS system has some limitations. It lacks flexibility when it comes to model coupling, i.e. model execution follows a very rigid workflow. In addition, there is a rather unnatural splitting of the interface between orbital and positional models. Futhermore, model developers have no easy way to plug-in new models into the system and the current system has reduced capabilities for the import of user data. Finally it lacks advanced machine-to-machine access making it quite difficult to connect and interact with other software.

Lately, a new system known as SPENVIS Next Generation (SPENVIS-NG[11]) has been developed under ESA's GSTP-5 programme by an international consortium consisting of Space Application Services, Deimos Space, DH Consultancy and Etamax and led by the space weather section of BIRA-IASB. SPENVIS-NG is a complete redesign of the existing system and provides a web-based, service-oriented and distributed framework.

A. A new distributed framework architecture

The main design goal of SPENVIS-NG is to create a flexible, scalable, secure and extensible framework for the integration of space weather models and tools. SPENVIS-NG system is decomposed into components and the interfaces between the components are defined. Components are designed to be configurable so that component instances can be deployed to a different hardware node in a geographically distributed environment.

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[11] http://www.spenvis-ng.eu/

Figure 2: Overview of the components and actors in SPENVIS-NG

Figure 2 provides an overview of all available components:

- The *Back-End* (BE) is the heart of the SPENVIS-NG framework. It offers all its services through a number of SOAP interfaces, e.g. user management or workflow execution services.
- The *Human Machine Interface* (HMI) component offers users a web-based graphical user interface: this is the most common entry point of a user to SPENVIS-NG.
- An *Remote Execution Node* (REN) hosts a number of space weather models or tools, packaged in a standard manner called "Model Bundle", which makes these models easily pluggable in or out. The actual number crunching (model execution) takes place within such a node.
  As many nodes of this type can be used: this ensures scalability. An Execution Node does not expose any GUI. Its configuration is done with simple configuration files. Populating the node with Model Bundles can be done using a SOAP interface, or with the Software Development Kit (SDK).
  A particular site (e.g. a research institute) can host one or more Execution Nodes. That way, users of models do not have to be aware of the specific geographical location where the models have been deployed.
- The *Software Development Kit* (SDK) provides supporting help tools for the 3rd party models developers (especially: how to properly package a model as a valid "Model Bundle" and afterwards upload them in a chosen Execution Node). This also includes templates and "How to" documentation. An SDK is meant to be locally installed and used at the place of a model developer. See chapter C for more details.
- The *Application Program Interface* (API) is a small application component, which allows an external application or system to use the SPENVIS-NG public services. This makes task automation possible. This is explained in detail in chapter D.

To ensure security, every data entity (e.g. workflow, projects, resource, etc.) on the Back-End has an associated access control list (ACL), which determines the permissions associated with that resource. Each attempt to perform any operation with the object is intercepted and authorization is performed using the ACL.

A model binary is always kept private to a given Execution Node, and never leaves this Execution Node. The only model specific information exchanged between Nodes is limited to the so-called "Model Bundle Abstract", which includes general description information only such as model license and security information, and excludes any form of executable file (e.g. scripts).

B. The concept of a workflow

The workflow is a central concept of the new system. Models plugged into SPENVIS-NG are seen as consumers/producers of data streams (namely known as resources). The models/tools are combined in workflows where the resources required by a model are connected to either resources produced by another model or resources provided by the user (workflow input), and where the produced resources are returned to the user (workflow output). In this way workflows allow to better address the need of each user by programming predefined scenarios. Workflows also allow tuning the user interface of models, for example by fixing in advance some parameters, hiding

intermediate resources or by re-grouping the input fields differently. The logical structure of the SPENVIS workflow is illustrated in Figure 3.
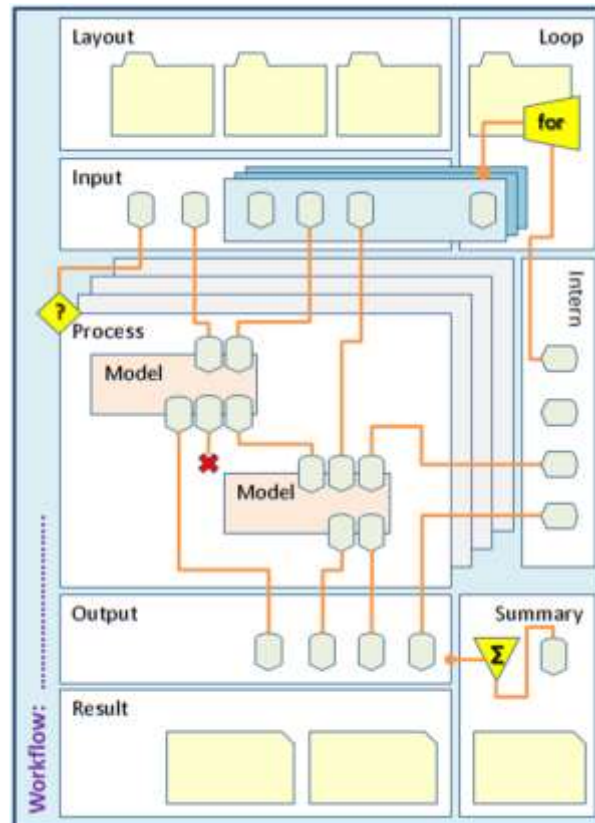

Figure 3: Representation of the workflow concept

When the system runs a workflow the models are executed sequentially and the requested model outputs are collected at the end. In some cases, there are too many possible combinations between models. To deal with these cases, the concept of an atomic workflow has been created. Similar to atoms that form together a molecule, atomic workflows can be combined to form the desired workflow. The user has than to specify which parent workflow execution he wants to use.

C. Supporting the model developers
A Software Development Kit (SDK) has been developed and can be distributed upon request as a ZIP file. The model developers have to install it locally. During the installation the tool performs various checks in order to ensure that the local development environment meets all the necessary requirements e.g. the existence of the GNU Compiler Collection (GCC), required environment variables etc.

The "Software Development Kit and Remote Execution Node Manual" is also distributed as part of the SDK package. This document contains a tutorial guide (for Linux and Windows users), a hints and tips section and instructions for installing and configuring a remote execution node.

The SDK includes an example of a toy model bundle. In combination with the tutorial it allows the model developers to quickly familiarize themselves with the concept of the SPENVIS-NG model bundle. It also contains a basic extension package with some dedicated tools like the Saxon-HE package, STILTS, the UniradCsvReader and UniradCsvWriter wrappers and the Python VOTable parser.

The SDK also provides a dedicated tool that allows the model developer to interact with a remote execution node. In this way, a model developer can install a remote execution node for testing the model bundle locally. Note that this execution node can be disconnected from the system and available only to a particular model developer. This tool offers various functionalities that include deploying a model bundle or removing an existing one, requesting an execution, zipping and downloading the execution results etc.

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Finally, the SDK includes an XML Validation tool for validating manifests and workflows against the defined SPENVIS-NG schemas.

D. Application Programmer's Interface

As already mentioned before, the system has been designed in such a way that it also allows a machine to machine interface based on web services for interoperability with other software. More specifically, the system exposes a number of web services allowing any third-party software to access the SPENVIS-NG user's resources. A dedicated application programming interface (API) tool written in Python has been developed for this purpose.

The API is an agnostic wrapper. It is able to call the following SOAP web services provided by the Back-End:

- SecureTokenService: services related to user authentication (log in, log out, …)
- WorkflowManagementService: retrieve a list of available user and public workflows
- WorkflowExecutionManagementService: initialize workflow execution, retrieve workflow execution results, …
- ProjectManagementService: services related to projects (create or delete a project, access it, …)
- ResourceManagementService: services to find and retrieve resources (workflow execution inputs and outputs)

The API can be used either via a command line interface (CLI), using INI-style configuration files, or as a Python library. An example API code to execute a workflow can be found in appendix A. This workflow creates first a geostationary orbit, then calculates the electron fluence with the AE-8 model and finally runs SD2Q to estimate the dose behind an aluminium shielding.

E. Linking SPENVIS-4 with the SPENVIS-NG Remote Execution Node

It is generally acknowledged that SPENVIS-NG at its current status is not yet ready to become publicly available and some features of the new system require further development. Nevertheless, parts of SPENVIS-NG are mature enough and can be exposed to the user community. In this spirit, a link has been established between SPENVIS-4 and SPENVIS-NG that allows the execution of models installed on a remote execution node of the latter and driven by the user interface of the former. In particular, a new release of SPENVIS-4 allows the execution of GRAS v4.0, MULASSIS v1.26 and IRENE 1.50 that have been installed in SPENVIS-NG using user input provided by SPENVIS-4.

IV. Conclusion

The space environment (i.e. cosmic rays, radiation belts, solar energetic particles, plasmas, outgassing and micro-particles) poses a threat to spacecraft and astronauts. Through the years, ESA's SPENVIS has been proven to be a useful tool for the space engineering community when it comes to assess and mitigate the mission-related risks. Following the success of SPENVIS, BIRA-IASB takes the lead to architect a novel framework that includes new web design techniques and overcomes the limitations of the current system.

Appendix

A. Example API program

The following code is written in Python 2.6 and needs the SPENVIS-NG API to execute:

```
import sapi
import random
import string
import time
import sys

def randomword(length):
    return ''.join(random.choice(string.lowercase) for i in range(length))

def is_running(ssn, myId):
    """Check if workflow execution is still running"""
    status = s.getExecutionStatus(ssn, myId)
```

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```
        return True if hasattr(status,'state') and status.state == "RUNNING"
else False

    # Some variables must be defined by the user here.
    ## User name. Should be the same than the one in the config file.
    username = 'stijn'

    ## Project name where the execution is to be saved. The project must
already exists.
    prjname = 'test'

    ## Path to the workflow to be executed. Can be public or private. The path
can be checked using the HMI, in the "Workflow" menu.
    workflow = '/common/workflows/GEO_AE8_SD2Q'

    ## Name of the execution. Here we use a fixed part and a random alphabetic
section. This is done to produce unique names for each script execution and
avoid collisions.
    execname = 'GEO_AE8_SD2Q-' + randomword(10)

    ## VOTable containing the input data necessary for the execution.
    votFile = 'geo_ae8_sd2q_input.vot'

    ## XML file containing the links between the required parameters to start
    ## an execution and the associated resource in the input VOT.
    ## The text @path@ will be replaced by the actual path automatically.
    datamodel = 'geo_ae8_sd2q_datamodel.xml'

    # End of user-defined variables.

    # Log in
    print("Logging in the system.")
    s = sapi.Session("global.conf", "")
    s.readglobalconfig()
    ssn = s.login()

    # Create execution.
    print "Creating the execution. "
    myId=s.createExecution(ssn, username, prjname, execname, workflow, votFile,
datamodel)

    # Print the execution ID returned. Can be useful to check in the HMI.
    print "Execution name: " + execname + " "
    print "Execution ID: " + str(myId)

    # Start execution
    print "Starting the execution. "
    sys.stdout.flush()
    s.startExecution(ssn, myId)
    sys.stdout.flush()
    print "Execution started. "

    # Check status until not in RUNNING state. It could be FINISHED or ERROR.
It will be "WAITING_FOR_INPUTS" if the startExecution step didn't work.
    n = 0
    while n < 100 :
        n = n + 1
```

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```
        status = s.getExecutionStatus(ssn, myId)
        if hasattr(status,'state'):
            if status.state == "RUNNING":
                print("Still in RUNNING state. ")
                time.sleep(5)
            else:
                print("New state: "+ status.state)
                break
        else:
            print "NO STATUS " + status
            break
    print n

    # Get VOTable for the whole output information
    print("Getting output VOTable.")
    outputvot = s.getVOT(ssn, username, prjname, execname)

    # Save the VOT to disk. It will be a zip file with all the content.
    target = open('output_votable.zip','wb')
    target.write(outputvot)
    target.close()
```

The input parameters (geo_ae8_sd2q_input.vot):

```
<?xml version="1.0" encoding="UTF-8"?>
<VOTABLE xmlns="http://www.ivoa.net/xml/VOTable/v1.2" version="1.2">
    <RESOURCE name="spenvis">
        <TABLE name = "instancetable">
            <GROUP name = "instancedata">
                <PARAM value="2011-01-01T00:00:00Z" datatype="char" arraysize="*"
name="segmentStartEpoch"/>
                <PARAM value="P1Y" datatype="char" name="segmentDuration"/>
                <PARAM             value="trajectoryDuration"         datatype="char"
name="trajectoryDurationSpecification"/>
                <PARAM value="P1D" datatype="char" name="trajectoryDuration"/>
                <PARAM                value="0.0"                datatype="double"
name="longitudeOfGeostationaryOrbit"/>
                <PARAM                 value="0"                datatype="boolean"
name="solarRadiationPressurePerturbation"/>
                <PARAM                value="1.0"                datatype="double"
name="exposureThresholdFlux"/>
                <PARAM value="solarMaximum" datatype="char" name="AE8mode"/>
                <PARAM                 value="0"                datatype="boolean"
name="AE8localTimeVariation"/>
                <PARAM value="50.000" datatype="char" name="AE8confidenceLevel"/>
                <PARAM                value="finiteSlab"            datatype="char"
name="shieldingConfiguration"/>
                <PARAM              value="Aluminium"             datatype="char"
name="shieldingMaterial"/>
                <PARAM value="Si" datatype="char" name="detectorMaterial"/>
                <PARAM value="10.0" datatype="double" name="numberOfOrbits"/>
            </GROUP>
        </TABLE>
    </RESOURCE>
</VOTABLE>
```

The contents of the data model (geo_ae8_sd2q_datamodel.xml):

```
<data>
```

```
<sapreEarth_input>
    <segmentStartEpoch>@path@segmentStartEpoch</segmentStartEpoch>
    <segmentDuration>@path@segmentDuration</segmentDuration>

<trajectoryDurationSpecification>@path@trajectoryDurationSpecification</trajectoryDurationSpecification>
    <trajectoryDuration>@path@trajectoryDuration</trajectoryDuration>
    <numberOfOrbits>@path@numberOfOrbits</numberOfOrbits>

<longitudeOfGeostationaryOrbit>@path@longitudeOfGeostationaryOrbit</longitudeOfGeostationaryOrbit>

<solarRadiationPressurePerturbation>@path@solarRadiationPressurePerturbation</solarRadiationPressurePerturbation>
    </sapreEarth_input>
    <trepAE8_input>

<exposureThresholdFlux>@path@exposureThresholdFlux</exposureThresholdFlux>
    <AE8mode>@path@AE8mode</AE8mode>

<AE8localTimeVariation>@path@AE8localTimeVariation</AE8localTimeVariation>
    <AE8confidenceLevel>@path@AE8confidenceLevel</AE8confidenceLevel>
    </trepAE8_input>
    <sd2q_input>

<shieldingConfiguration>@path@shieldingConfiguration</shieldingConfiguration>
    <shieldingMaterial>@path@shieldingMaterial</shieldingMaterial>
    <detectorMaterial>@path@detectorMaterial</detectorMaterial>
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Acknowledgments

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