Methodology of Physics Simulation Software

CALOR 2000

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A mission critical application

- ESA, December 1999:
  1st production launch Ariane 5.
- Payload: XMM X-ray telescope.
- Objectives of software simulation:
  - discover sources of radiation-induced degradation experienced by CCDs of another x-ray telescope;
  - compute radiation levels for XMM’s CCDs and determine protection procedures before launch.
Physics models transparency

- Open source analysis of GEANT4 multiple scattering model in the limit of corrected Rutherford scattering (TRIM).
- Tests on GEANT4 integrators in $B$ field to certify $\sim 100$micron accuracy on $\sim 10$m trajectories.
- Open source analysis of GEANT4 energy loss parameters to guarantee tracking accuracy on $\sim 10$s nm paths in the mirrors coating.
- Particles’ back-tracking by GEANT4 stepping history recording.
Simulation results of proton, X-ray, and electron interactions with magnets and mirrors. X-ray double reflection mechanism, electrons deflection systems, and protons-induced CCDs damage in Chandra and XMM X-ray telescopes.
Simulation predictive power

- Flux (at 1.3 MeV) on XMM RGS spectrometer:
  = 0.7 million protons / cm$^2$ / month.
- Flux (at 200 keV) on XMM EPIC camera:
  = 60 million protons / cm$^2$ / month.
- => EPIC camera needs to be protected.
- Before XMM launch, decision to close Al doors on EPIC when orbit will cross radiation belts.
- XMM correctly operating in orbit with no damage since almost 1 year.
Validation concepts

- In software engineering, validation of software is wrt the user requirements.
- “Validation” of HEP simulation software results is usually wrt physics data.
- But, even assuming results are OK, how many software parameters were used to allow the program to fit the data?
- And if need to validate simulation results before knowing the physics data (see XMM case)?
Software Reliability Model

- **SRM** is defined to quantify the reliability and validability of delivered simulation software to the fulfillment of certain conditions.
- Increasing levels of reliability and validability correspond to the fulfillment of more stringent conditions.
SRM levels

- **Level 0**: Different object code is provided and used for different use-cases.
- **Level 1**: The same publicly distributed object code is used for different use-cases.
- **Level 2**: Different source code is provided and used for different use-cases.
- **Level 3**: The same publicly distributed source code is used for different use-cases.
- **Level 4**: The same public source code also exposes all the parameters which influence the results.
Results Validability Model

- **RVM** is defined to quantify the reliability and validability of produced simulation results to the fulfillment of certain conditions.
- Increasing levels of reliability and validability correspond to the fulfillment of more stringent conditions.
RVM levels

- **Level 0**: Simulation results match known exp. results using parameterisations based on those data.
- **Level 1**: Simulation results match known, but independent, experimental results.
- **Level 2**: Simulation results match known exp. results and are (re)produced by random users.
- **Level 3**: Simulation results match known exp. results with a controlled number of parameters.
- **Level 4**: Simulation results correctly anticipate unknown experimental results.
The fundamental GEANT4 requirement is to make the physics modelling transparent to the user, so that he/she can understand *HOW* the results are produced, hence improving the scientific validation process.

No numbers must be hard-coded in formulae and algorithms, but only variables and constants should be used. Constants are initialized to their numerical value followed by the given physical units.

An extensive set of units is defined in GEANT4 and all the numerical quantities are expressed through units explicitly. Consequently, the full GEANT4 physics is independent from the units chosen by the user.
GEANT4 methods (2)

The way cross sections are calculated (via analytical formulae, data files, etc.) is clearly exposed via Object-Oriented design and it is separated from the way they are accessed and used in the algorithms.

Similarly to cross-sections, the way final states are computed is separated from the tracking and can be split in models by energy range, particle type and material.

Open interface to data libraries: ENDF/B, JENDL, FENDL, CENDL, ENSDF, JEF, BROND, EFF, MENDL, IRDF, SAID, EPDL, EEDL, EADL, SANDIA, ICRU, .....