Data intensive electromagnetic scattering simulation for planetary radar data analysis

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MARSIS instrument

Mars Advanced Radar for Subsurface and Ionosphere Sounding

To map the distribution of water in the upper portions of the crust of Mars

- Synthetic-aperture orbital sounding radar
- On board the ESA spacecraft Mars Express
- Two 20 meters elements nadir-looking dipole antenna
- Centre frequencies: 1.8, 3.0, 4.0, 5.0 MHz (1.0 MHz bandwidth) chirp

- Radar echoes will contain both surface and subsurface reflection components
- Surface backscattering from off-nadir directions is called ”clutter”
- Clutter can mask, or be mistaken for, subsurface echoes
Facet model of rough surface scattering
+
500-meter resolution elevation map of Mars from NASA MOLA instrument *(Mars Global Surveyor)*

Surface echo simulation
*Nouvel et al. (Radio Science vol.39, 2004)*

The facet model of rough surface scattering

Facet definition
Nouvel et al. (Radio Science vol.39, 2004)
A code for the simulation of radar wave surface scattering has been developed, based on the work of Nouvel et al. (2004), using the MOLA topographic dataset (Smith et al. 2001) to represent the Martian surface as a collection of flat plates called facets. The radar echo is computed as the coherent sum of reflections from all facets illuminated by the radar. The computational burden of every simulation is very high, but, thanks to a collaboration with CINECA, the code has been parallelized and ported for use in a Blue Gene/Q system. The code has been tested and its performance evaluated on the Fermi machine at CINECA.

The goal of this proposal is to use a parallelized and numerically optimized version of such a code to simulate the entire MARSIS dataset, consisting of several thousand observations, and to produce a dataset of simulated observations that will be made publicly available to the international scientific community for MARSIS data analysis. This wealth of information provides the only possible way to unambiguously identify subsurface echoes in MARSIS radargrams. Echoes reaching the radar after nadir surface echoes will be identified as coming from the subsurface if they are not present in simulations. Conversely, any secondary echo that is present in both real and simulated data must be interpreted as coming from the surface. Such dataset will be a unique contribution to subsurface sounding data analysis, and it is thus of interest for the whole scientific community studying Mars. A complete set of high fidelity simulations such as this will allow novel and more efficient ways to exploit MARSIS data, increasing the scientific return from the existing dataset. It will be possible, for example, to use automated procedures to detect subsurface interfaces, or to study the correlation between real and simulated surface echo strengths to detect unusual surface properties. For this reason, making such data available to the scientific community at large is an important aspect of this project. The most effective way to achieve this end is the co-location of the simulated dataset in the same public archives where MARSIS observations are freely available for download.

SHARAD (SHAllow RADar) - carried by NASA Mars Reconnaissance Orbiter

SHARAD observation (orbit 1948)

Clutter simulation

MOLA topography

**MARSIS clutter simulation**
MARSIS clutter simulator

Orbits (about 10000)

Echoes (about 1000)

Frequency bands

In band frequencies (hundreds)

Complex reflectivity calculation

Input: orbit data, MARSIS parameters, Mars elevation
Output: simulated echoes

MATLAB/OCTAVE version (R. Orosei)

Serial C version

Estimated time required for the calculation of a testing orbit (#2665) on a single core of the CINECA PLX cluster (Intel Westmere 2.40 GHz): 25.6 days

All the orbits: > 600 years

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Parallelization

- More orbits can run simultaneously
  - MPI
  - OpenMP

Further level of parallelization can be introduced whether accelerators are available (GPU, Intel MIC, ...)

No need for communications between MPI processes

Orbits (about 10000)
Echoes (about 1000)
Frequency bands
In band frequencies (hundreds)
Complex reflectivity calculation
Scalability

Tested on CINECA PLX and Fermi BG/Q clusters

PLX

Fermi
# Required resources

<table>
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<tr>
<th>Time required for the calculation of a testing orbit (#2665):</th>
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<tr>
<td>PLX (336 cores, 10%): 1.7 hours</td>
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<tr>
<td>Fermi (4096 cores, 2.5%): 0.43 hours (all the orbits: 180 days)</td>
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Input (*orbit data, MARSIS parameters, Mars elevation*): ~ 5GB

Output (*simulated echoes*): ~ 600GB

Memory allocation: 1.2TB (*per orbit, 4096 cores on Fermi*)
Conclusions

• Parallelization allows calculation on suitable hardware
• Computing resources allocation requested in 7th PRACE call
• Since the simulations of each echo and each orbit are independent, MPI is not necessary
• Application can be suitable for a Map-Reduce approach