Integration of USolids extensions for vectorisation in Geant4, Root and Geant vector prototype

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Abstract:

The latest release series 1.x of the VecGeom package [1] now incorporates all functionalities of the original USolids library [2]. VecGeom provides the whole set of major geometrical primitives, extending them with vector signatures and with revised algorithms exploiting SIMD instructions. VecGeom can be exercised through the Geant4 simulation toolkit [3] in a transparent way, replacing the original primitives and implicitly configuring the toolkit to execute SIMD instructions for the underlying algorithms. In a similar way, VecGeom can be used through ROOT [4], by replacing its default primitives. VecGeom is also used as the main geometry modeler for the Geant Vector Prototype [5], where it is possible in addition to exploit the provided Vector signatures and navigation features of the package for exercising multi-particle transport.
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Executive summary

The Geant4 simulation toolkit can now make use of VecGeom primitives, by fully replacing the functionalities provided by the original Geant4 shapes and running in scalar mode. The latest Geant4 release 10.5 has been fully tested against VecGeom v01.01.00, performing validation also on realistic detector setups. Full integration of the VecGeom primitives is also possible in ROOT as well as in the Geant Vector Prototype.

1. INTRODUCTION

The latest release v01.01.00 of VecGeom includes all major geometrical primitives defined as part of the GDML schema [6]: among these: Box, Orb, Trapezoid (Trap), Simple Trapezoid (Trd), Sphere (+ spherical section), Tube (+ cylindrical section), Cone (+ conical section), Generic Trapezoid (Arb8), Polycone, Polyhedron, Paraboloid, Torus (+ toroidal section), Hyperboloid, Extruded Solid (simple and generic), Tetrahedron, Tessellated Solid and Multi-Union structure. Both the Geant4 simulation toolkit and ROOT have been tested and validated against the geometrical primitives included in VecGeom and can be transparently configured to make use of vector SIMD (Single Instructions Multiple Data) instructions featuring the algorithms implemented in VecGeom. The Geant Vector Prototype, on the other hand, fully relies on VecGeom as the primary geometry package.
2. DESIGN AND IMPLEMENTATION

The VecGeom library has been designed to exploit efficient use of vector SIMD hardware instructions to accelerate geometry calculations for either single track or multi-track queries as those performed in detector simulation. Algorithms of most geometrical primitives have been revised and reimplemented to achieve this and vector signatures introduced for allowing multi-track queries (see Fig. 1).

Diagram: Levels of vectorization implemented in VecGeom: (a) Vector signatures for queries to geometrical primitives to allow for parallel detection of collisions, and (b) Internal algorithm vectorization for selected primitives, boosting performance also for current serial simulations like in Geant4.

The latest version of VecGeom (v01.01.00) uses VecCore [7], a wrapper library that provides an abstraction layer on top of existing SIMD libraries, such as Vc [8] and UME::SIMD [9], which thanks to the usage of templated types, allows for writing generic vectorized code not bound to a specific hardware architecture. Only at compilation time the code gets specialized for a specific type of backend (scalar, SSE, AVX, AVX2...), allowing to enable vectorization while maintaining code readability, maintainability and portability.

Both Geant4 and ROOT can be configured to make use of VecGeom, therefore replacing in a transparent way the original built-in primitives of the packages with those provided in VecGeom. The proper backend SIMD library will be picked up, based on the chosen installation.
3. CONCLUSIONS
The VecGeom package now incorporates all the functionalities of the original USolids library and has been integrated in order to be used by Geant4 and ROOT packages to replace the built-in geometrical primitives with the new ones implemented in VecGeom, exploiting efficient use of vector SIMD hardware instructions. VecGeom is also used as the main geometry modeler for the Geant Vector Prototype.
4. REFERENCES

ANNEX: GLOSSARY

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<td>GDML</td>
<td>Geometry Description Markup Language</td>
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