Current Status and Prospects

Makoto Asai (SLAC)
ENSAR2 workshop: GEANT4 in nuclear physics
April 26, 2019
Current Status and Prospects

M. Asai (SLAC)

Contents

- Recent developments
- Highlights of user applications
- Geant4 license
- Following up
- Geant4 – the future
Recent developments
Geant4 History

• Early discussions, for example at CHEP 1994 @ San Francisco
• Dec ’94 – R&D project start
• Apr ’97 - First alpha release
• Jul ’98 - First beta release
• Dec ’98 - First Geant4 public release - version 1.0

• Several major architectural revisions
  – E.g. STL migration, “cuts per region”, parallel worlds, multithreading

• Dec 8th, ’17 – Geant4 version 10.4 release
  – Feb 12th, ’19 - Geant4 10.4-patch03 release
• Dec 7th, ’18 – Geant4 version 10.5 release
  – Apr 17th, ’19 - Geant4 10.5-patch01 release

• We currently provide one public release every year.
  – Next scheduled release – Geant4 10.6 on Dec 6th, ’19

R&D phase (RD44)

Production phase

Retroactive patch release

Current version
10.4 came with new user’s guides and new logo
Geant4 version 10 series

- The release in 2013 was a major release.
  - Geant4 version 10 – release date: Dec. 6, 2013
- The highlight is its multi-threading capability.
  - The world first large-scale physics software fully multithreaded
- Geant4 version 10 series will be evolving.
  - Performance improvements (both in physics and computing)
  - Missing functionalities yet to be migrated to multithreading,
  - Additional APIs
  - Additional functionalities
  - New physics

**Current Status and Prospects**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Proof of principle</td>
<td>MT code integrated into G4</td>
<td>API re-design</td>
<td>Production ready</td>
<td>Further refinement</td>
</tr>
<tr>
<td>Identify objects to be shared</td>
<td>First testing</td>
<td>Example migration</td>
<td>Public release</td>
<td></td>
</tr>
<tr>
<td>First testing</td>
<td></td>
<td>Further testing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ATLAS: "The 10% CPU improvement we gain from the move from G4 9.6 to 10.1 is invaluable to the collaboration."
Many core, many thread

- For three years we have provided support for running Geant4 on KNC.
  - ATLAS, CMS successfully multithreaded
- We will soon extend our support to KNL.
  - With KNL, thanks to x86 binary compatibility including the use of gcc, work-flow is tremendously simplified.

<table>
<thead>
<tr>
<th>System</th>
<th>Time to completion (5k events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xeon E5-2620 @ 2.1 GHz (12 cores, 24 threads)</td>
<td>570 s</td>
</tr>
<tr>
<td>KNC (31s1P) @ 1.0 GHz (228 threads)</td>
<td>1000 s</td>
</tr>
<tr>
<td>KNL (7210, quadrant mode, MCDRAM only) @ 1.3 GHz (255 threads)</td>
<td>378 s (x3 improvement w.r.t. KNC)</td>
</tr>
<tr>
<td>KNL (shared library)</td>
<td>480 s (25% slower than static library)</td>
</tr>
</tbody>
</table>
More memory-efficient, more HPC friendly

<table>
<thead>
<tr>
<th>Version</th>
<th>Intercept</th>
<th>Memory/thread</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.6 (seq.)</td>
<td>113 MB</td>
<td>(113 MB)</td>
</tr>
<tr>
<td>10.0.p02-seq</td>
<td>170 MB</td>
<td>(170 MB)</td>
</tr>
<tr>
<td>10.0.p02-MT</td>
<td>151 MB</td>
<td>28 MB</td>
</tr>
<tr>
<td>10.3.beta-MT</td>
<td>148 MB</td>
<td>9 MB</td>
</tr>
</tbody>
</table>

Memory space required for Intel Xeon Phi 3120A
Full-CMS geometry (GDML), 4 Tesla field, 50 GeV π⁻ (FTFP_BERT)

- Geant4 has successfully run with a combination of MT and MPI on Mira Bluegene/Q Supercomputer (@ANL) with all of its 3 million threads
  - Full-CMS geometry & field
- I/O is the limiting factor to scale large concurrent threads:
  - Granular input data files, output data/histograms, etc.
  - 2017 work item
  - Targeting also Cori @ NERSC

<table>
<thead>
<tr>
<th># of CPU</th>
<th># of threads</th>
<th>Speed-up factor</th>
<th>efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>80</td>
<td>79</td>
<td>98.8%</td>
</tr>
<tr>
<td>20</td>
<td>160</td>
<td>158</td>
<td>98.8%</td>
</tr>
<tr>
<td>40</td>
<td>320</td>
<td>317</td>
<td>99.0%</td>
</tr>
<tr>
<td>80</td>
<td>640</td>
<td>626</td>
<td>97.8%</td>
</tr>
<tr>
<td>160</td>
<td>1280</td>
<td>1251</td>
<td>97.7%</td>
</tr>
<tr>
<td>320</td>
<td>2560</td>
<td>2297</td>
<td>89.7%</td>
</tr>
<tr>
<td>640</td>
<td>5120</td>
<td>3555</td>
<td>69.4%</td>
</tr>
</tbody>
</table>

Tachyon-2 supercomputer @ KISTI (South Korea)
FTFP_BERT physics validation benchmark
Detector geometry & cross-section tables

MEMORY SPACE

Transient per event data (tracks, hits, etc.)

AVAILABLE CORES

Active cores

Without MT

Available cores

Unused cores

Active cores

With MT

AVAILABLE CORES

Actiie cores
User’s code migration

• If you have a running code with version 9.6 and you want to stick to sequential mode, you do not need to migrate. It should run with version 10.0.
  – Except for a few obsolete interfaces that you had already seen warning messages in v9.6.

• Migration of user’s code to multi-threading mode of Geant4 version 10.0 should be fairly easy and straightforward.
  – Migration guide is available.
  – Geant4 users guides are updated with multi-threading features.
  – Most examples have been migrated to multi-threading.
  – Geant4 tutorials based on version 10.0 has already started.

• G4MTRunManager collects run objects from worker threads and “reduces”.

• Toughest part of the migration is making user’s code thread-safe.
  – It is always a good idea to clearly identify which class objects are thread-local.

• Every file I/O for local thread is a challenge
  – Input : primary events : examples are offered in the migration guide.
  – Output : event-by-event hits, trajectories, histograms
Tessellated solids

- **G4TessellatedSolid**
  - Generic solid defined by a number of facets (G4VFace)
    - Facets can be triangular (G4TriangularFace) or quadrangular (G4QuadrangularFace)
  - Constructs especially important for conversion of complex geometrical shapes imported from CAD systems
  - But can also be explicitly defined:
    - By providing the vertices of the facets in *anti-clock wise* order, in *absolute* or *relative* reference frame
    - GDML binding

- **G4ExtrudedSolid** is re-implemented to internally use **G4TessellatedSolid**.
Geometry updates – New solid library

• An important effort was begun in the last few years to write a new solid library, reviewing at the algorithmic level most of the primitives and provides an enhanced, optimized and well-tested implementation to be shared among software packages.

• In most cases considerable performance improvement was achieved.
  – For example, the time required to compute intersections with the tessellated solid was dramatically reduced with the adoption of spatial partitioning for composing facets into a 3D grid of voxels.

• Such techniques allow speedup factors of a few thousand for relatively complex structures having of order 100k to millions of facets, which is typical for geometry descriptions imported from CAD drawings.
  – Consequently, it is now possible to use tessellated geometries for tuning the precision in simulation by increasing the mesh resolution, something that was not possible before.

<table>
<thead>
<tr>
<th>Method</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside</td>
<td>2423x</td>
</tr>
<tr>
<td>DistanceToIn</td>
<td>1334x</td>
</tr>
<tr>
<td>DistanceToOut</td>
<td>1976x</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of facets</td>
<td>164.149</td>
</tr>
<tr>
<td>Number of voxels</td>
<td>100.000</td>
</tr>
<tr>
<td>Memory saved compared with original Geant4</td>
<td>22% (51MB)</td>
</tr>
</tbody>
</table>
New “multi-union” solid

- In addition to a full set of highly optimized primitives and a tessellated solid, the library includes a new "multi-union" structure implementing a composite set of many solids to be placed in 3D space.
- This differs from the simple technique based on Boolean unions, with the aim of providing excellent scalability on the number of constituent solids.
- The multi-union adopts a similar voxelization technique to partition 3D space, allowing dramatically improved speed and scalability over the original implementation based on Boolean unions.

New in v10.4
G4MultiUnion

G4MultiUnion* munion_solid = new G4MultiUnion(“UnitedBoxes”);

for( int i=0 ; i < nNode ; i++)
{
    G4Box* aBox = new G4Box(...);
    G4ThreeVector pos = G4ThreeVector(...);
    G4RotationMatrix rot = G4ThreeVector(...);
    G4Transform3D tr = G4Transform3D(rot, pos);
    munion_solid -> AddNode( *aBox, tr );
}

munion_solid -> Voxelize();

Note : G4MultiUnion is a solid. Use it to create a logical volume.
New features in EM physics

- Multiple/single scattering
  - Introduction of optional displacement on geometrical boundary
  - New G4LowEWenzalVIModel for low-energy applications
- Gamma processes
  - Photo-effect and Compton cross-sections at low-energy integrated
- High-energy models
  - Improvements in gamma->muons, positron->hadrons and positron->muons
  - Synchrotron radiation for all particle types
- Atomic de-excitation
  - New alternative fluorescence dataset (Bearden)
- New radiolysis process for water and silicon
  - Physics stage followed by physico-chemical and chemical stage
- Introduction of phonon transport with a new concept of crystal
- Channeling effect in straight and bent crystal
- Lots of code refinements along with MT

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New features in hadronic physics

- FTFP_BERT is now the recommended physics list for most of high-energy use-cases
- Generation of Isomer (a.k.a. metastable nuclides)
  - by default lifetime > 1 nsec
- Neutron_HP is extended to Particle_HP to cover p, d, t, α
- Alternative low-energy neutron model with GND (Generalized Nuclear Data) format
- Liege intra-nuclear cascade model (INCLXX) extended up to 20 GeV
- FTF model extended to nucleus-nucleus and antinucleus-nucleus interactions
- Radioactive decay redesigned with rare decay channels
- New hadron stopping models based on Bertini
- Decommission of LHEP and CHIPS models
Hadronic Model Inventory

- At rest absorption, $\mu$, $\pi$, K, anti-p
- Radioactive decay

High Prec. Particle
- LEND
- High prec. neutron

Evaporation
- Fermi breakup
- Multifragment
- Photon Evap

Pre-compound

QMD (ion-ion)

Wilson Abrasion

Electro-nuclear dissociation

Photo-nuclear, electro-nuclear, muon-nuclear

INCL++

Binary cascade

Bertini-style cascade

1 MeV 10 MeV 100 MeV 1 GeV 10 GeV 100 GeV 1 TeV

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New biasing scheme

- Event biasing (a.k.a. variance reduction) scheme has been fully revised at version 10.
- It allows treating many biasing options in coherent manner.
- Such options include:
  - Physics process biasing: alters physics process
    - Cross-section biasing, forced interaction, forced passage, etc.
    - Biasing final products of an interaction, e.g. distribution
  - Non-physics biasing: alters the transportation of particle
    - Geometrical importance, splitting / Russian roulette, weight window, etc.
- Easily extensible to new (or user-defined) options
- Well-integrated with built-in scoring functionalities.
- New examples are available.

Five of 100 MeV neutrons on Pb/Scinti calorimeter.
Left: analogue simulation Right: splitting with geometrical importance and probability control.
New features in analysis, GUI and visualization

- New built-in fully-multithreaded histogramming tool
  - 1-D and 2-D histograms and scatter plots, n-tuples
  - Data format compatible with ROOT, XML, AIDA, CSV
- Extensible to other format
- GUI and visualization
  - New Qt driver with OpenGL
    - Viewer properties and picking panel, dock-able widgets
  - Multithread output filtering
    - More than 30% faster drawing on OpenGL
  - Magnetic field lines
Geant4 – A Simulation Toolkit

http://www.geant4.org/

S. Agostinelli et al.
Geant4: a simulation toolkit

J. Allison et al.
Geant4 Developments and Applications
S. Agostinelli et al.
Geant4: a simulation toolkit

10,258 documents have cited:
Recent developments in Geant4

J. Allison et al.

Recent developments in Geant4

J. Allison\textsuperscript{a,b}, K. Amako\textsuperscript{a,c}, J. Apostolakis\textsuperscript{d}, P. Arce\textsuperscript{e}, M. Asai\textsuperscript{f}, T. Aso\textsuperscript{g}, E. Baglin\textsuperscript{h}, A. Bagulya\textsuperscript{i}, S. Banerjee\textsuperscript{j}, G. Barrand\textsuperscript{k}, B.R. Beck\textsuperscript{l}, A.G. Bogdanov\textsuperscript{m}, D. Brandt\textsuperscript{n}, J.M.C. Brown\textsuperscript{o}, H. Burkhardt\textsuperscript{p}, Ph. Canali\textsuperscript{q}

Highlights

- Multithreading resulted in a smaller memory footprint and nearly linear speed-up.
- Scoring options, faster geometry primitives, more versatile visualization were added.
- Improved electromagnetic and hadronic models and cross sections were developed.

https://doi.org/10.1016/j.nima.2016.06.125

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Highlights of Users Applications outside of HENP

To provide you some ideas how Geant4 would be utilized...
- **X-ray Multi-Mirror mission (XMM)**

Current Status and Prospects

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- Baffles
- Mirrors
- Telescope tube
- X-ray detectors (CCDs)

- Launch December 1999
- Perigee 7000 km
- Apogee 114000 km
- Flight through the radiation belts
**γ astrophysics**

**γ-ray bursts**

Typical telescope:
- Tracker
- Calorimeter
- Anticoincidence

- γ conversion
- electron interactions
- multiple scattering
- δ-ray production
- charged particle tracking
Geant4 in space

Akebono  RHESSI  ACE  New Horizons  LISA Pathfinder  LISA  JWST  INTEGRAL

Messenger  Fermi  SOHO  Herschel  Cassini

BepiColombo  Astro-H  GAIA

Suzaku  SWIFT  XMM-Newton  JUNO  Kaguya

JUICE  Chandrayaan-1  Chandrayaan-2

Columbus  EUSO  AMS  MAXI  ConeXpress  Chang’e-1  LRO
MSL Radiation Assessment Detector (RAD)

- RAD is a compact, highly capable radiation analyzer to characterize the full spectrum of space radiation (both charged & neutral particle).

- MSL RAD is currently characterizing the radiation environment on the surface of Mars.
International Space Station
PlanetoCosmics
Geant4 simulation of Cosmic Rays in planetary Atmosphere/Magnetosphere

Geant4 Simulation of the Propagation of Cosmic Rays through the Earth’s Atmosphere

Physikalisches Institut, University of Bern, CH-3012 Bern, Switzerland
Solar event gamma-rays

- Electron Bremsstrahlung – induced gammas in solar flares
- Compton back-scattering
  ➤ observable gamma-ray spectrum
  much softer than predicted by simple analytic calculations

Effects of Compton scattering on the Gamma Ray Spectra of Solar flares

Jun’ichi KOTOKU
National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, JAPAN
junichi.kotoku@nao.ac.jp

Kazuo MAKISHIMA¹ and Yukari MATSUMOTO²
Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0022
and
Mitsuhiro KOHAMA, Yukikatsu TERADA and Toru TAMAGAWA
RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama

¹Also at RIKEN
²Present address: Mitsubishi Electric Co., Ltd.

(Received ; accepted )

Abstract

Using fully relativistic GEANT4 simulation tool kit, the transport of energetic electrons generated in solar flares was Monte-Carlo simulated, and resultant bremsstrahlung gamma-ray spectra were calculated. The solar atmosphere was ap-
RADSAFE on SEE in SRAMs

TCAD Cell Structure: SRAM Cell

Single Charge Deposition in TCAD: Ne+W Event

SRAM Cell Upset

Geant4 Geometry and 523 MeV Neon Event

MRED Energy Deposition for 10^8 Events
Simulation of Radiation Events

- 63-MeV proton incident on a SiGe Heterojunction Bipolar Transistor (HBT)
- Iso-charge surfaces following a nuclear reaction

Courtesy of R.Reed (Vanderbilt U.)
Observed and Predicted SEU Rate for an SRAM

- SRAM used on NASA Messenger spacecraft
- Observed Average SEU Rate:
  - $1 \times 10^{-9}$ Events/Bit/Day
- Vendor predicted rate using CREME96:
  - $2 \times 10^{-12}$ Events/Bit/Day
  - Classical Method nearly a factor 500 lower than observed rate
- MRED rate (includes reaction products):
  - Between $1.3 \times 10^{-10}$ and $1.3 \times 10^{-9}$ Errors/Bit/Day

Courtesty of R. Reed (Vanderbilt U.)
Time evolution of the activation background

Comparison with Geant4

1 hour after irradiated
Black : experiment
Red : Geant4

1 day after irradiated
O : experiment
Red : Geant4
5 days after irradiated
● : experiment
Blue : Geant4

Ratio (simulation/experiment)

Simulation results agrees with experimental data within a factor of two in terms of the line intensities
Geant4 @ Medical Science

- Four major use cases
  - Beam therapy
  - Brachytherapy
  - Imaging
  - Irradiation study
4D RT Treatment Plan

Source: Lei Xing, Stanford University

Y. Yang, S. Huq, L Xing, Med. Phys, 2006
Lateral Motion of Lung Tumor
Single cell irradiation

- Example of single cell irradiation by 3 MeV alpha particles in a high-resolution cellular phantom
  - 4h or 24h incubated cell
  - 64 x 64 x 60 resolution
  - 0.36 x 0.36 x 0.16 μm$^3$ voxel size
- Full CENBG microbeam irradiation setup simulated

Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)
DNA in Geant4

most common DNA conformation in cells

Conversion of ProteinDataBank-format file ➤ Geant4

Courtesy of Sebasien Incerti (IN2P3-CNRS / CENBG)
Condensed Matter Physics in Geant4

• Phonon propagation, including focusing based on elasticity tensor (right)

• e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)
Bent crystal as a collimator

- Bent crystal can be used as a collimator to deflect particles of beam halo.
- This study will be extended for T-513 experiment at SLAC LCLS ESTB.

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Enrico Bagli (INFN/Ferrara)

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Those exterior walls, made of concrete 10 feet thick, offer their own challenge. Based on computer simulations run with the particle physics software GEANT4, the walls are expected to reduce the resolution to about 30 centimeters.

In addition, the team must also prepare for the high radiation levels present just outside of the reactor units.
Evaluating remediation of radionuclide contaminated forest near Iwaki, Japan, using radiometric methods

D.C.W. Sanderson\textsuperscript{a}, A.J. Cresswell\textsuperscript{a}, K. Tamura\textsuperscript{b}, T. Iwasaka\textsuperscript{c}, K. Matsuzaki\textsuperscript{d}

\textsuperscript{a} Scottish Universities Environmental Research Centre, East Kilbride, Glasgow G75 0QF, United Kingdom
\textsuperscript{b} Faculty of Life and Environmental Sciences, University of Tsukuba, Japan
\textsuperscript{c} Miraishiko Inc., Kanegaya, Asahi-ku, Yokohama, Japan
\textsuperscript{d} Yunodakesansonai, Iwaki, Japan

Received 24 December 2015, Revised 10 May 2016, Accepted 15 May 2016, Available online 24 May 2016
Muon tomography for nuclear threat detection

Main idea: Multiple Coulomb scattering is basically proportional to Z, so we can use it to discriminate materials by Z.

Note: angles exaggerated!
Muon tomography for nuclear threat detection

Simulated Truck
Red Boxes are Uranium
Blue are Lower Z Materials
Simulating x-ray cargo radiography
Uncovering Special Nuclear Materials by Low-energy Nuclear Reactor

P. B. Rose, A. S. Erickson, M. Mayer, J. Nattrass & I. Jovani

*Scientific Reports* 6, Article number: 24388 (2016)
doi:10.1038/srep24388

Download Citation

- Applied physics
- Imaging techniques

Figure 1: Illustration of the imaging method using a low-energy nuclear reaction radiation source.
Geant4 license
The New Geant4 License

In response to user requests for clarification of Geant4’s distribution policy, the collaboration recently announced a new license.

- Makes clear the user’s wide-ranging freedom to use, extend or redistribute Geant4, even as part of some for-profit venture.
- The license was released along with the latest Geant4 release 8.1.
- Simple enough that you can read and understand it.

http://cern.ch/geant4/license/
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Following up
Following up http://geant4.org/

- Please keep maintaining your Geant4 installation updated.
  - **Geant4 10.5.p01 is the current version**
  - Irregular patch releases may be more important than regular releases.
  - Check our web page regularly to find release news, or register to Geant4 announcement mailing list
    https://geant4.web.cern.ch/support/mailing_list_subscription

- If you have a question
  1. Look for our documents.
     - Users guides, Twiki pages, tips pages, examples and their READMEs, past tutorial materials
  2. Post your question on Geant4 HyperNews
     http://hypernews.slac.stanford.edu/HyperNews/geant4/cindex
     - Please make sure to do a bit of survey that no one else has already asked the same question before you.
  3. As the final method, write us a mail.
     - Avoid anonymous mail account such as hotmail, gmail, etc.
  4. Or, catch us at meetings/conferences/tutorials.
Following up http://geant4.org/

• If you identify an issue.
  – Geant4 Bugzilla https://bugzilla-geant4.kek.jp
  – You may also use Geant4 HyperNews to start with

• If you have a requirement / concern.
  – Geant4 Technical Forum
    https://geant4.web.cern.ch/collaboration/technical_forum
  – A few times per year, publicly open to any user to discuss requests, requirements and priorities that may concern functionality, performance, user support or any other Geant4-user related aspects.
  – Next Technical Forum will be held at Jefferson Lab (VA. U.S.) in September where Nuclear Physics requirements/priorities will be highlighted.
    • Contact me, Alberto and/or Dennis if you want to make a presentation.

• If you want to make a contribution
  – For small fixes/enhancements : Geant4 GitHub
  – Large scale contribution : present at Geant4 Technical Forum and/or contact Geant4 WG coordinators.
Geant4 – the Future

Introduction
Geant4 is being used in many different fields where simulation of radiation passing through and interacting with matter is critical. User domains include high energy and nuclear physics, medical physics, and space engineering, shielding protection and more. Its abstract layers based on robust OOP design enables flexibility and extensibility of the code, and its open-source code and open collaboration have allowed substantial extensions of the code. New features are constantly being added to the code, while increasing attention is paid to improving software performance and robustness by employing cutting-edge software engineering technologies.

New physics
The flexibility and extensibility of Geant4 design allows it to be applied to new physics domain. These include the physics of condensed matter (photon tri-state transport in crystals, circuit of electrons and holes in semiconductors) and processes for bio-chemical substances and DNA.

Geometry
The flexibility and extensibility of Geant4 design also enables handling rich collection of shapes including CSG (Constructive Solid Geometry), Boolean operation, Bevelled solid, etc. and the user can easily add new shapes. Geant4 geometry navigation can deal with setups up to billions of volumes with automatic optimisation. In addition, geometry models can be “dynamic”, i.e. changing the setup at run-time, e.g. “moving - adapter”.

Software quality assurance
Geant4 uses modern tools to manage the code and improve code quality. From handling issues with JIRA to continuous testing integration with CLing/CX, profiler based optimisation, Quality Assurance (Covington, Valgrind, etc.) and IDE integration (Xcode, Eclipse, Visual Studio).

New era - Geant4 version 10 series
The new release of Geant4 – Version 10.0 (December 2013) includes thread-level parallelism via multi-threading. To efficiently use new computing architectures the workload of a single job is sub-divided to many worker threads each responsible for the simulation of one or more events. Version 10.0 has already shown good scalability on a number of different architectures: Intel Xeon servers, Intel Xeon Phi coprocessors and low-power ARM processors.

Investments for the future
Geant4 collaboration members are participating in various explorations of emerging technologies. These technologies include GPU/CUDA, OpenCL, OpenACC, vectorisation, DSLs, etc.
New physics – new opportunities

- Physics of O(100TeV)
- Specialized EM model for noble liquid (e.g. liq.Xe)
- Neutrino interactions
  - Should come with enriched event biasing options
- Electron/hole drift in semiconductor
- More phonon physics
- Channeling effects and physics with crystal structure in general
  - X-ray diffraction, neutron scattering in crystal
- Single atom irradiation
- Target material polarization
- Chemical reactions of radicals in DNA-scale
- New domains?

- Note: Geant4 kernel is robust enough over 20 years of evolution. This stability enables risk-free extensions to new physics.
New computing trends

• HPC and cloud friendliness
  – Seamlessly combining MPI and MT
  – Smart data collection from millions of threads

• Code re-engineering
  – Solid library, EM physics
  – Splitting transportation process
  – Sub-event level parallelization

• GPU as a co-processor
  – Off-loading some calculations to GPU, e.g. EM physics, thermal neutron physics, DNA physics and chemical processes, etc.

• Will be integrated into Geant4 with (hopefully) minimum API changes
To sum up

- Geant4 is a general purpose Monte Carlo simulation tool for elementary particles passing through and interacting with matter. It finds quite a wide variety of user domains including high energy and nuclear physics, space engineering, medical applications, material science, radiation protection and security.

- 2019 is the 20th year anniversary of Geant4 public releases. After 20 years with several architectural evolutions, Geant4 is still steadily evolving.
  - Latest major evolution was Geant4 version 10.0 released in December 2013 that is the first fully multithreaded general-purpose large-scale physics software in the world.
  - New physics models for coming experiments, e.g. hadronic model for multi-TeV regime, neutrino physics model, physics with crystal structure.
  - Given Geant4 is nowadays mission-critical for many users in all of above-mentioned domains, Geant4 is to be kept maintained and still evolving for at least next decade.