Development of Software Framework for Simulation in Radiotherapy

Status and Plan in 2005

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The Project

• “The Development of Software Framework for Simulation in Radiotherapy”
  – funded by the Core Research for Evolutinal Science and Technology (CREST) program organized by Japan Science and Technology Agency (JST) from 2003 to 2008

• Joint project among Geant4 developers, astro-physicists and medical physicists in Japan
Member Institutes

- High Energy Accelerator Research Organization (KEK)
- Ritsumeikan University (RITS)
- Kobe University
- Naruto University of Education
- Toyama National College of Maritime Technology
- Japan Aerospace Exploration Agency (JAXA)
- National Institute of Radiological Science (NIRS)
- National Cancer Center, Kashiwa
- Gunma University Faculty of Medicine
- Hyogo Ion Beam Medical Center (HIBMC)
- Kitasato University
Motivation

• Geant4 is not simple software and not easy to use in some case, if
  – geometry is very complex, and
  – physics related is not trivial
    • most of physics process are covered already, but still setting for selection or combination is difficult sometime
    • in very few case, new physics process is need to be implemented

• Simulation in particle therapy, especially, heavy ion therapy is one of such cases and very challenging for Geant4 developers’ too
  – Heavy ion physics also applicable to astro-phys
Project Goal

• Provide the framework and software toolkit for simulation in radiotherapy, especially, particle therapy
  – Well designed general purpose software
  – DICOM/DICOM-RT interface
  – Visualization/Interactivity
  – GRID computing
  – etc
• Physics validation is also the important subject
The system structure

- Knowledge DB
- GRID Deployment
- visualization/interactivity
- Scoring/Tally Package
- Physics List for Radiotherapy

Geant4

Dose Calculation Engines

- JQMD
- EGS4
- ...

DICOM interface

modeler
What is Geant4?

Introduction

The project web page:
http://cern.ch/geant4

  – Geant4 is a toolkit for the simulation of the passage of particles through matter. Its application areas include high energy physics and nuclear experiments, medical, accelerator and space physics studies. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, hadronic and optical processes, a large set of long-lived particles, materials and elements, over a wide energy range starting, in some cases, from 250 eV and extending in others to the TeV energy range. It has been designed and constructed to expose the physics models utilised, to handle complex geometries, and to enable its easy adaptation for optimal use in different sets of applications. The toolkit is the result of a worldwide collaboration of physicists and software engineers.
What is Geant4?

• Geant4 is the software toolkit to simulate interaction between particles and matter

• Geant4 is the successor of GEANT3, but designed and implemented from the scratch using C++

• Geant4 is designed to answer a variety of requirements came from HENP, heavy ion physics, cosmic ray physics, astrophysics, space science and medical applications using an Object-Oriented techniques to take into account of maintainceabilty and extendability.

• In order to meet such requirements, a high degree of functionality and flexibility are provided.
Advantages in Geant4

- Detailed geometry description
- Precise magnetic/electric field description
- Easier material composition
- Variety of physics process
  - Electro-magnetic
    - Down to 250 eV up to TeV
    - Optical photons
  - Hadronic
  - Heavy ion
  - User defined processes
- Fast or precise visualization
- Analysis tools and interactivity
- Extendability as software toolkit
- Open source
Disadvantage of Geant4

• Learning curve
  – Learning C++ and UNIX oriented development environment if you are new for these
  – If you are not a FORTRAN programmer, say a C or C++ programmer, this would be an advantage

• Complex
  – As other Monte Carlo codes

• Toolkit nature
  – Geant4 is not a black box to give correct results
    • Simulation without validation has no meaning
**Geant 4**

Geant 4 is a toolkit for the simulation of the passage of particles through matter. It has been developed and maintained by a worldwide collaboration of approximately 100 scientists.

Its application areas include high energy physics, astrophysics and nuclear physics experiments, medical, accelerator and space science studies.

**Simulation for physics, space, and medicine**

**Neutrinos**

Sudbury Neutrino Observatory confirms neutrino oscillation p. 9

**Tesla**

Electroplating steers superconducting cavity to new record p. 10

**Cosmophysics**

Joint symposium brings CERN, ESA and ESO together p. 16
Geant4 Collaboration

HARP

Collaborators also from non-member institutions, including
- Budker Inst. of Physics
- IHEP Protvinò
- MEPHI Moscow
- Pittsburg University

http://cern.ch/geant4
The global design of Geant4 was done by CERN and Japanese members in 1994 based on Object-Oriented methodology. The implementation is done in ANSI C++ language.

From the beginning, application in multi area, HENP, space, medical and so on was considered for the design. Always the design is updated according to new requirements.

A class category maintained by an independent working group.

Japanese contribution is more than 90% 9/17
History of Geant4

- Dec ’94 - Project start
- Apr ’97 - First alpha release
- Jul ’98 - First beta release
- Dec ’98 - First Geant4 public release
- …
- Dec ’03 - Geant4 6.0 release
- Mar ’04 - Geant4 6.1 release
- Jun ’04 - Geant4 6.2 release
- Dec 17th, ’04 - Geant4 7.0 release
  - Feb 26th, ’05 - Geant4 7.0-patch01 release
- two to three public releases every year and bimonthly beta releases in between public releases
Achievement in our project

2003-2004
Concept of design and Strategy

• Common software parts are provided as software toolkit
  – User can adopt for their own target with minimal modification or addition of a class derived from the base class provided
    • In many cases, the same or similar geometry are used
    • Requirements on physics processes looks similar

• Framework based on PYTHON for more functionality and usability

• visualization and computer aided user assistance tool will be provided as independent software
• Parallelization of simulation and GRID computing

• Independent DICOM-G4 interface
  – DICOM-RT is also taken into account
    • Standardization is not yet ready and need adoption for different extension at each facility, anyway
  – DICOM example in the Geant4 distribution has problems and should be fixed
    • Quick fixes are already in the new release

• Validation against experiments
  – proton beam first then carbon
Use case and requirement sampling

- All of 6 facilities for particle therapy in Japan and one in Italy have been interviewed
  - NIRS
  - NCC-EAST
  - HIBMC
  - WERC
  - SCC
  - University of Tsukuba
  - INFN LNS at Catania, Italy

- Information on components in beam line and also treatment room have been gathered also
Alpha version of the class diagram for geometry description. Still further study is under going.
Validation against proton data

• Comparison between data taken at HIBMC and it’s simulation based on Geant4 has been performed using rapid prototyping
• Geant4 well reproduced the measurements
Bragg peak

Comparison between measurement at HIBMC and Geant4 simulation proton beam with 150, 190 and 230 MeV
Spread Out Bragg Peak (SOBP)

The small bump in the measurement is thought to be a fan beam effect.

**150 MeV**

- (a) 150 MeV SOBP90
- (b) 190 MeV SOBP90

**190 MeV**

- (a) 150 MeV SOBP120
- (b) 190 MeV SOBP120

**SOBP 9cm**

**SOBP 12cm**
DICOM and visualization

• Please look at the detail on the poster (Number 10) by Dr. Akinori Kimura at this conference
• Geant4-DICOM and DICOM-RT(still HIBM only) interface
• Visualizer for DICOM image + dose distribution + analysis results
DICOM interface

Dose distribution in the plastic phantom visualized by Geant4 Open-GL package.
Computer aided geometry design

For a first example, electron accelerator head design tool has been designed and implemented.

With GUI, design change can be manipulated easily and C++ source code to describe the geometry setup for Geant4 will be produced automatically.
Parallelism and GRID deployment

• Event level parallelism has been implemented for general purpose using MPI-C++ interface
  – No other component, but just MPI implementation is necessary, such as MPICH
    • Independent from the TOP-C example in G4 distribution
• Parallel simulation over the Internet is realized by GRID middleware in our case Globus and also LCG2
• Web interface to access GRID from behind the hospital firewall is under development
Event parallelism using MPI w/o TOP-C

### Table

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More than 10 hours for single processing

PC farm: 2CPUx20 nodes
Equal number of slaves on each node

Simulation of protons in water phantom at HIBMC

Single process: 1000000 events in 704 minutes
GRID virtual organization has been realized by CERN LCG2 middleware.

Still under development.

File sharing across the sites on Internet has been realized by San Diego Storage Resource Broker.
Summary

• Geant4 is well established software toolkit for simulating interaction between particles and matter
  – Already applied in many fields and well reproduced measurements
• Our project is developing the software framework and toolkit for particle therapy
• Also validation against data are done very seriously
• We welcome very much the contact from any other facility who have an interest to use our product for their simulation
• We would like to visit and interview facilities in other countries, too for sampling use cases and requirements