Geant4 Beginner Course Material

Mihály Novák
CERN EP-SFT

version: 0.0.1 (`Geant4-11.00`)

May 9, 2022

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Tutorial on *Geant4* for users interested to begin or improve their usage of the Geant4 particle transport simulation toolkit. Appropriate for creating simulation applications in any domain, with emphasis on topics most relevant to experiments in High Energy or Nuclear Physics. This material was prepared for an interactive hands-on based tutorial course interspersed by lectures providing the necessary background information for building a progressively more complex application from scratch extensible to real use.

The course is expected to be of interest to novices and those with basic or partial familiarity with *Geant4*. Participants are expected to have a reasonable knowledge of C++.

Part I

Course Material

1 Introduction

1.1 What is *Geant4*?

Geant4 is an open source **toolkit** for developing applications that simulates the passage of particles through matter. It is very important to understand the difference between being a **toolkit** or a concrete simulation application with a main **program**. *Geant4* as a **toolkit** *provides* all the necessary *components* that are needed *to* **describe** *and to* **solve** *particle transport* simulation *problems*.

A concrete simulation problem, with its own unique *geometrical, material configurations*, *physics* modelling *setting* etc., can be **described** by using these components eventually *leading to a given simulation application with a* **main program**. After the description of a unique simulation problem is given, *Geant4* as a **toolkit** also provides the solution of the underlying particle transport modelling problem. The **Monte Carlo method** is utilised by *Geant4* to **solve** the related transport equations taking into account the geometrical, physics, etc. constraints provided by the **toolkit** based description of the application. This eventually leads to a *setp-by-step* computation of the particle transport through the given geometry (hence the name GEometry ANd Traking), where each of the step is limited by either a geometry (e.g. volume boundary) or a physics (e.g. bremsstrahlung photon emission of an e^-) related constraint. Several interaction points are provided for the users during this solution process for collecting and propagating information over a wide range of granularity: from the smallest, i.e. individual step level up to a complete run.

It is important to recognise, that *different* particle transport modelling *problems* require *different descriptions* (e.g. different geometry, physics configuration, etc.) *while the solution* of the transport problem itself as well as the possible user interaction points *are generic*, i.e. independent from the details of the concrete problem. This is achieved by *Geant4* through providing carefully designed **interfaces** both for the **description** of the simulation problem as well as for the user interactions (e.g. for the detector geometry description). These interfaces decouples or **abstracts** away the concrete implementation of the related components (e.g. the concrete detector geometry) from the solution algorithm while ensures that the required functionalities and information are supplied.

1.2 Our goal in the next few days

Geant4 **toolkit developers** work directory on the toolkit continuously extending and improving its modelling, description, etc. functionalities. *Geant4* **application developers** work on developing simulation applications by describing a well defined particle transport simulation problem and configuration making use of the available functionalities of the toolkit. These simulation applications can then be utilised by any **users** to obtain the results of the related simulation problem, usually with some possible further configuration options made available by the application developer (e.g. primary particle type and/or energy). The **toolkit developers** also provides example application that very often demonstrate a particular functionality of the toolkit. These example applications are also provided by toolkit.

Our goal is to make the very first steps in the next few days on the way to become a *Geant4* **application developer**. In order to do so, you will become familiar with the most important building blocks provided by the *Geant4* **toolkit** to describe any particle transport simulation problem. These definitely include the so-called **mandatory** as well as some of the **optional components**. While the **mandatory components**, such as the detector description, physics configuration, primary generator are essentially needed to define a particular simulation problem, the **optional** components provide the possibility to collect all the required information during the solution of the simulation problem.

1.3 Format

As mentioned above, *Geant4* application development requires the implementation of (at least the mandatory) C++ interfaces provided by the toolkit to define the particular simulation problem. As in most cases of programming, implementing example applications, with steadily increasing complexity while acquiring the theoretical background information required by the next step, provides an efficient way to reach a confident level of experience. This tutorial was designed along this experience as well. Therefore, we will implement a concrete particle transport simulation problem together from scratch in a step-by-step way. Each implementation step will be preceded by a detailed explanation of the required related theoretical background. A relatively simple simulation problem was selected in order to keep focusing on a generic *Geant4* application structure with a clear understanding of the role of the most important components and their relations instead of diving deep in one particular direction. In spite of it simplicity, our target application problem represents very well the structure of a generic *Geant4* application. Therefore, the format and content of the tutorial provide the opportunity for acquiring rather confident basic *Geant4* application developer skills.

During this process, we will heavily rely on information supplied by the *Geant4* Book For Application Developers completed by the source code inspection of the related interfaces and other toolkit component implementations.

Take-home

Geant4 is a **toolkit** which means that provides the building blocks to describe your particle transport problems, then the generic solution of the transport problem using the Monet Carlo method. Toolkit developers extends the description, modelling, etc. functionalities of the toolkit while application developers provides final simulation applications based on the toolkit that can be utilised by the users.

Tip: The example applications, provided by the **toolkit developers** as part of the toolkit itself, serve as a good starting point for developing your own application. Try to find the closest to your needs, use it as a starting point and modify, extend according to your own modelling problem.

What's next?

Before starting to implement our target simulation problem, the next section ensures that we are all on the same (or at least similar) page regarding some technical details: understanding of some key C++ object oriented concepts such as *interfaces*, becoming familiar with our local *Geant4* implementation and *CMake* build system, etc.

Bals lashd

Let's cite something from the application doxygen documentation here e.g. the first the section of the final application description (not doxygen) *final application* then now the doxygen documentation of the detector construction `YourDetectorConstruction`

Here I use a link to a Geant4 file that is on GitHub G4Electron.hh then I use a G4 class name `G4ClassNames`

`file names: ../fname`

`environment variables: G4INSTALL`

`G4ClassNames`

Geant4

```
#include "G4Something.hh"

int main() {

  std::cout << " Someting " << std::endl;
  return 0;
}
```

---

2 Preliminaries

Some of the most important elements of the technical environment will be review very briefly in this section before moving to *Geant4*. This will include a brief recap of the most relevant (C++) *object oriented(OO) concepts* such as **interface** or a quick view on the *Geant4 toolkit* **installation**. We will get familiar with the **Virtual Machine(VM)** environment that will be used during the tutorial while we will understand how the `CMake` build system makes our life easier. These are all essential technical elements that we will heavily rely on during this course.

2.1 Our most important object oriented concept: *interface*

Geant4 provides the solution to particle transport simulation problems *independently form the details* by *abstracting them away*. It has already been mentioned in the *Introduction*, that this could be achieved by carefully designed **interfaces** that a concrete application needs to implement. Since the simulation problem is actually defined by implementing a set of *Geant4* interfaces, a clear understanding of how this object oriented concept works is essential for the rest of the course.

Interface is a very important object oriented concept that *captures some of the important commonalities* (behaviour, ability, etc.) of different type of objects into a *common base*. This common base *doesn't know anything about the details* of the common behaviour in a particular type of object, just *serves as a blueprint for the different types*. Then the different types take this blueprint and implement their own particular way of that common behaviour. Note, that it also ensures that all the different types that implements a common base/blueprint, for sure has that common behaviour or ability.

As a *simple example*, suppose that we are developing a solution algorithm that at a given point requires the sum area of all the 2D shapes that the user defines as part of the input (I know… but keep it simple.). So the sub-problem is the *area computation* of different 2D *shapes*. We know that each 2D shape has an *area* (the commonality) but the way of its computation depends on the actual shape (different types). So one might define a *common base for all* the 2D *shapes* that contains the *common ability* of providing the *area computation* ability without implementing anything. Then *the individual shape types* takes this common base and *implements their way of area computation*. So eventually, the common functionality is **only defined in the base** but **implemented in the concrete types**. Therefore, our base serves as an *interface for* 2D *shape area computation*. Also note, that all the possible different shape types can implement our interface, even those that we do not know. Therefore, using an interface decouples the solution from the details (i.e. the actual area computation) and the remaining part of algorithm can be completed without knowing all the details.

Different object oriented languages offer slightly different syntax for implemented such interfaces. In C++ the blueprint, that contains the definitions of the *common abilities as* **pure virtual method definitions**, is usually an **abstract base class**. The **concrete types** are derived then from this common base and implements the **pure virtual methods** of the base class. A method is declared to be **pure virtual** if it do not contain any implementation that achieved by the `= 0;` syntax. A class is called **abstract class** if it has at least one pure virtual method. Note, that it is **not possible to instantiate** objects from an **abstract class** simply because they have at least one unimplemented method (the pure virtual).

As an example, the following shows a possible implementation of the above 2D shape **area computation interface**. While the whole **abstract** *VShape2D* **base class** is shown, please note the **pure virtual** *VShape2D::Area()* method declaration. The complete working example is available under `applications/preliminaries/cpp-interface`.

```
// This is called "include guard": used to avoid double inclusion that would
// lead to double definition. Very good practice, check it and use.
#ifndef VSHAPE2D_HH
#define VSHAPE2D_HH

#include <string>

/**
 * @file   VShape2D.hh
 * @class  VShape2D
 * @author M. Novak
 * @date   May 2022
 *
 * **Interface**, i.e. base class with a **pure virtual** method, for 2D
 * shape area computations.
 *
 * This base class is an **interface** for 2D shape area computations. It has its
 * **pure virtual** Area() method. Therefore, this method **must be implemented
 * by each derived** classes. This ensures, that whatever type of an actuall 2D
 * shape is (derived from this base class) the Area() interface method will be
 * available. Therefore, the rest of the code can be developed without knowing
 * what 2D shapes will be eventually there: they will be all `VShape2D` types
 * providing their own implementation of the Area() interface method defined
 * in this base class.
 *
 * Note, that the **pure virtual** method makes this base class **abstract**,
 * i.e. objects cannot be instantiated directly form this base class.
 */

// The `VShape2D` base class definition.
class VShape2D {

public:

  // constructor: requires the name of the shape
  VShape2D(const std::string& name) : fName(name) { }
  // destructor: no dynamic memory allocation so nothing to do
  virtual ~VShape2D() { }

  // public method to get the name: short so we implement here
  const std::string& GetName() const { return fName; }

  /**
   * The area computation *interface* method.
   *
   * Example of a **pure virtual** method that makes this base class **abstract**.
   *
   * Each 2D shape has an area but all computed differently depending on the
   * actual type of the shape. This is why it's a **pure virtual method**, i.e.
```

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```
   * **each derived class must implement**.
   */
  virtual double Area() = 0;

  /**
   * *Optional* perimeter computation method.
   *
   * Example of a **virtual** method with defult implementation in the base class.
   *
   * Each 2D shape has its own way of computing the perimeter just like the area.
   * However, we decided that actually the perimeter is not important for our
   * algorithm in most cases of shapes. Therefore, this default implementation
   * is available for each derived class and will be invoked unless the concrete
   * derived class provides its own implementation. The derived `Square` class
   * implements this method while `Circle` relyes on this defult base class
   * implementation.
   */
  virtual double Perimeter() { return 0.0; }


private:

 // name of the shape
 std::string  fName;

};

#endif // VSHAPE2D_HH
```

And a possible implementation of the **concrete** *Square* **class** that **implements the** area computation **interface** for the concrete *square* shape type. Technically it means that the *Square* class is **derived from** the *VShape2D* **abstract base** and **implements its pure virtual interface method**.

```
#ifndef SQUARE_HH
#define SQUARE_HH

// inlcude the base class definition
#include "VShape2D.hh"

/**
 * @file   Square.hh
 * @class  Square
 * @author M. Novak
 * @date   May 2022
 *
 * @brief Derived class that implements the VShape2D interface for Square-s.
 */

// square is a derived from the 2D shape base class
class Square : public VShape2D {

public:
```

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```
  // constructor: requires the length of the side
  // - it calls the base class constructor by passing the required name
  Square(double lside) : VShape2D("mySquare"), fSideLength(lside) { }

  // no dynamic memeory allocation so nothing to do at destruction
  ~Square() { }


  /**
   * Actual implementation of the area computation interface method of the
   * base class.
   *
   * Square **must implement** the VShape2D::Area base class method since that's
   * a **pure virtual method**.
   *
   * @note The `override` keyword is very useful: indicates that this method
   *  implements a virtual method of the base class so the compiler is
   *  aware of that intention.
   */
  double Area() override { return fSideLength*fSideLength; }

  /** The **optional** `Perimeter` interface method implementation. */
  double Perimeter() override { return 4.0*fSideLength; }


private:

  // the only data member is the length of the edge
  double  fSideLength;

};

#endif  // SQUARE_HH
```

Also note, that the `VShape2D` base class has an other *virtual* method, the `VShape2D::Perimeter()` that actually has an implementation in the base class so this method is **not pure virtual**. Since this method already has an implementation in the base class, the derived classes might optionally provide their own implementation of this method or not at all. The default implementation, i.e. the one in the base class will be used in the later case.

Tip: The above **dynamic** or **run-time polymorphism**, i.e. the run-time resolution of function calls, is achieved in C++ through the *combination of inheritance and virtual methods*. From the computing performance point of view, in some cases it might be beneficial to make this resolution at **compile time**. **Static** or **compile time** polymorphism can be achieved by the template metaprogramming based Curiously Recurring Template Pattern (CRTP) C++ construct.

2.2 Some useful unix commands

It might be useful to refresh some of the most important unix commands since we will work in the terminal. This can also be used during the course as a cheat sheet.

Command	Meaning / effect
`ls`	list files in the current directly
`ls -l`	same as above in long format (more details)
`.`	the current working directory
`..`	parent directory
`~`	home directly
`cp` *file1 file2*	copy *file1* to *file2*
`mv` *file1 file2*	move/rename *file1* to *file2*
`rm` *file*	remove/delete *file*
`pwd`	print working directory (Where am I?)ß
`cd` *dirname*	change to *dirname* directory (e.g. change to your home directory `cd ~`)
`mkdir` *dirname*	make directory with the name *dirname*
`rmdir` *dirname*	remove/delete directory with the name *dirname*
`rmdir -r` *dirname*	removes even sub-directories recursively
`cat` *file*	show the content of *file*
`more` *file*	shows the file page by page
`ctrl + C`	interrupts the running process
`echo` *string*	write out the string (e.g. write out the value of a shell variable like PATH as `echo $PATH`)
`$`	use the `$` prefix front of shell variables to get their value (e.g. above)

2.3 *Geant4* installation

Building and installing *Geant4* from source will be shown very briefly in this section. This will be the standard way of using the *Geant4* toolkit when you become an experienced *Geant4* application developer (hopefully after this course). Moreover, this will also help to understand better why we decided to use the common *Virtual Machine(VM)* version for this course.

While all the details regarding the installation of the *Geant4* toolkit can be found in the Installation Guide, we will focus here only building and installing from source on unix system. Note, that certain softwares/libraries must be installed on your system in order to be able to build and/or use *Geant4*. These are listed in the System/Software Prerequisites section of the Installation Guide.

Obtain the source

The first step is to obtain the source code of the *Geant4* toolkit that can be downloaded from Downloads (see the screenshot in Fig. 2.1).

It will be assumed in the following that the *Geant4* source code has been downloaded to the `G4DOWNLOAD` directory. After moving to this directory we can see the following when we list the content with the `ls` command:

```
bash-3.2$ ls
geant4-v11.0.1.tar.gz
```

Then we can uncompress the source code by:

```
bash-3.2$ tar -xzvf geant4-v11.0.1.tar.gz
x geant4-v11.0.1/
```

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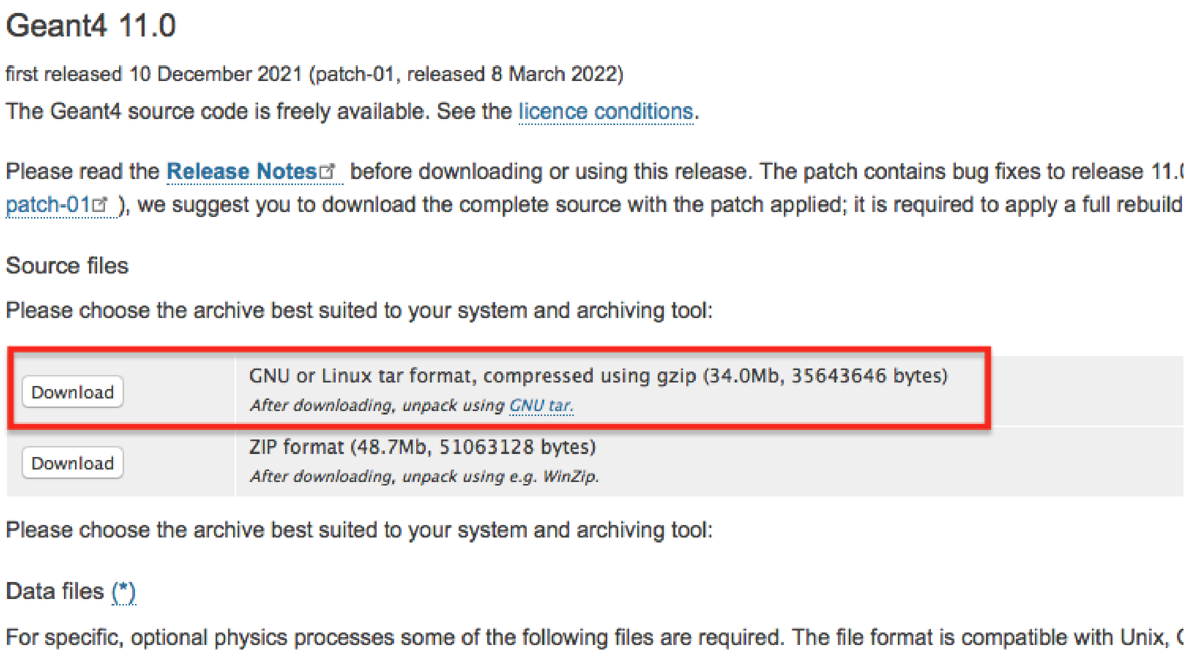
Geant4 11.0

first released 10 December 2021 (patch-01, released 8 March 2022)

The Geant4 source code is freely available. See the licence conditions.

Please read the **Release Notes** before downloading or using this release. The patch contains bug fixes to release 11.(
patch-01), we suggest you to download the complete source with the patch applied; it is required to apply a full rebuild

Source files

Please choose the archive best suited to your system and archiving tool:

Download	GNU or Linux tar format, compressed using gzip (34.0Mb, 35643646 bytes) *After downloading, unpack using GNU tar.*
Download	ZIP format (48.7Mb, 51063128 bytes) *After downloading, unpack using e.g. WinZip.*

Please choose the archive best suited to your system and archiving tool:

Data files (*)

For specific, optional physics processes some of the following files are required. The file format is compatible with Unix, (

Fig. 2.1: *Geant4* page screen shot for downloading the toolkit source code

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```
x geant4-v11.0.1/.github/
x geant4-v11.0.1/.github/CODEOWNERS
x geant4-v11.0.1/.gitignore
x geant4-v11.0.1/CMakeLists.txt
x geant4-v11.0.1/CONTRIBUTING.rst
x geant4-v11.0.1/LICENSE
x geant4-v11.0.1/README.rst
x geant4-v11.0.1/ReleaseNotes/
x geant4-v11.0.1/ReleaseNotes/Beta4.10.0-1.txt
x geant4-v11.0.1/ReleaseNotes/Beta4.10.1-1.txt
x geant4-v11.0.1/ReleaseNotes/Beta4.10.2-1.txt
x geant4-v11.0.1/ReleaseNotes/Beta4.10.3-1.txt
x geant4-v11.0.1/ReleaseNotes/Beta4.10.4-1.txt
...
```

that eventually will create a subdirectory in the `G4DOWNLOAD` directory containing all the source codes:

```
bash-3.2$ ls
geant4-v11.0.1                geant4-v11.0.1.tar.gz
```

It will be assumed in the following that the created subdirectory, with all the uncompressed *Geant4* source code, is G4SRC. This means G4SRC = `full/path/to/geant4-v11.0.1` in the above example (please note, that you need to replace `/full/path/to` with your actual path to the uncompressed source directory), that can be set as an environment variable as:

```
bash-3.2$ export G4SRC=/full/path/to/geant4-v11.0.1
```

Then we can check if everything set properly by writing the value of the newly created environment variable as:

```
bash-3.2$ echo $G4SRC
/full/path/to/geant4-v11.0.1
```

and eventually move to the source code directory and list the content as:

```
bash-3.2$ cd $G4SRC
bash-3.2$ ls
CMakeLists.txt          LICENSE             ReleaseNotes          config    ␣
↪           examples
CONTRIBUTING.rst      README.rst          cmake             environments    ␣
↪     source
```

Configure, build and install

We will create a `build` subdirectory here that will be used then to store our build configuration and `Makefiles` generated by using `CMake` (see some reasons later *why we use it*). So we crate the `build` subdirectory inside the `G4SRC` and change to that:

```
bash-3.2$ mkdir $G4SRC/build
bash-3.2$ cd $G4SRC/build
```

Then we will use `CMake` to configure the build and generate the corresponding unix `Makefiles`. Note, that having the appropriate version of `CMake` installed and available on your system is part of the Prerequisites for building and/or using *Geant4*.

There are several configuration options to set how *Geant4* is built, installed and what optional components of the toolkit are enabled. Some of them are provided by `CMake` itself while there are several *Geant4* specific configuration options. All of them are listed and described in the Build Option section of the Installation Guide.

One very useful `CMake` option is `CMAKE_INSTALL_PREFIX`. This can be used to set the required installation location. Suppose that we want to install *Geant4* under a `path/to/install/dir`, that actually we also set to be stored in a new environment variable `G4INSTALL` (by `export`-ing it similarly to `G4SRC` above), we can configure the build as `-DCMAKE_INSTALL_PREFIX=$G4INSTALL`. An other, already *Geant4* specific `CMake` configuration option, is `GEANT4_INSTALL_DATA` with the possible values of `ON/OFF(default)`. Turning this `ON` results in downloading and installing all the datasets that *Geant4* requires. Please note, that all the *Geant4* configuration and build options starts with the `GEANT4_` prefix. Beyond the *optional* configuration options mentioned so far, `CMake` has a *required* input argument. This is the *top level* `CMakeLists.txt` `CMake` input file location, that is usually located in the main directory of the projects. In our case, this is the parent directory of our current `$G4SRC/build`. Therefore, configuring our current *Geant4* build from the `$G4SRC/build` subdirectory, such that we require

- to install the toolkit under `$G4INSTALL` : `-DCMAKE_INSTALL_PREFIX=$G4INSTALL`
- downloading and installing all *Geant4* datasets: `-DGEANT4_INSTALL_DATA=ON`

can be down as:

```
bash-3.2$ cmake ../ -DCMAKE_INSTALL_PREFIX=$G4INSTALL -DGEANT4_INSTALL_DATA=ON
-- The C compiler identification is GNU 10.2.0
-- The CXX compiler identification is GNU 10.2.0
-- Checking whether C compiler has -isysroot
-- Checking whether C compiler has -isysroot - yes
-- Checking whether C compiler supports OSX deployment target flag
-- Checking whether C compiler supports OSX deployment target flag - yes
-- Detecting C compiler ABI info
```

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```
-- Detecting C compiler ABI info - done

...

-- Found Threads: TRUE
-- The following Geant4 features are enabled:
CMAKE_CXX_STANDARD: Compiling against C++ Standard '17'
GEANT4_BUILD_MULTITHREADED: Build multithread enabled libraries
GEANT4_BUILD_TLS_MODEL: Building with TLS model 'initial-exec'
GEANT4_USE_SYSTEM_EXPAT: Using system EXPAT library

-- Configuring done
-- Generating done
-- Build files have been written to: ...
```

Tip: After the configuration, still inside the `G4SRC/build` subdirectory, one can inspect/change the configuration options before the build by `bash-3.2$ ccmake .` that will open the configuration settings and offers the possibility to e.g. change values. Try this out, especially its advanced mode using the `t` key to see the large number of configuration options that *Geant4* provides.

After the successful configuration (i.e. receiving no configuration errors above), one can easily build and install the *Geant4* toolkit now as (`-j6` building parallel with 6 threads):

```
bash-3.2$ make -j6
[  0%] Creating directories for 'G4INCL'
[  0%] Creating directories for 'G4SAIDDATA'
[  0%] Creating directories for 'G4ENSDFSTATE'
[  1%] Creating directories for 'G4PII'
[  1%] Creating directories for 'RealSurface'
[  1%] Creating directories for 'G4ABLA'
[  1%] Performing download step (download, verify and extract) for 'G4SAIDDATA'
[  1%] Performing download step (download, verify and extract) for 'G4PII'
[  1%] Performing download step (download, verify and extract) for 'G4ENSDFSTATE'
[  1%] Performing download step (download, verify and extract) for 'G4ABLA'
[  1%] Performing download step (download, verify and extract) for 'G4INCL'
[  1%] Performing download step (download, verify and extract) for 'RealSurface'
-- Downloading...

...

[100%] Building CXX object source/CMakeFiles/G4physicslists.dir/physics_lists/util/src/
↪G4HadProcesses.cc.o
[100%] Building CXX object source/CMakeFiles/G4physicslists.dir/physics_lists/util/src/
↪G4PhysListUtil.cc.o
[100%] Building CXX object source/CMakeFiles/G4physicslists.dir/physics_lists/util/src/
↪G4WarnPLStatus.cc.o
[100%] Linking CXX shared library ../BuildProducts/lib/libG4physicslists.dylib
[100%] Built target G4physicslists
```

then after the successful build, install the *Geant4* toolkit under the previously set `$G4INSTALL` location as:

```
bash-3.2$ make install
[  0%] Built target G4ENSDFSTATE
[  0%] Built target G4INCL
[  0%] Built target G4ABLA
[  1%] Built target G4SAIDDATA
[  2%] Built target G4PII
[  2%] Built target RealSurface
[  2%] Built target G4NDL
[  2%] Built target G4PARTICLEXS

...

-- Installing: ...
```

This last step above only makes all the headers, configuration files, libraries that have been just built to the location specified during the configuration. Before starting to use the freshly installed *Geant4* toolkit on our system, one needs to make sure that all the related environment settings are done (e.g. setting `PATH`, `*_LIBRARY_PATH` or other *Geant4* specific environment variables such as data set location, etc.). All the details are given in the Postinstall Setup of the Installation Guide. This can be done by using the script provided after the installation under `$G4INSTALL/bin` as:

```
bash-3.2$ source $G4INSTALL/bin/geant4.sh
bash-3.2$ echo $G4LEDATA
/what/you/set/as/install/location/share/Geant4-11.0.1/data/G4EMLOW8.0
```

This above includes writing out one of the *Geant4* specific environment variable value just for cross checking that everything is set as we expect.

Try an example application

As an example, we can build and execute one of the *Geant4* example applications that are delivered by the toolkit. They can be found under the `$G4SRC/examples`. We can try one of the *basic* examples like `/basic/B1`. So first change the directory to this location and create a `build` subdirectory there and entering:

```
bash-3.2$ cd $G4SRC/examples
bash-3.2$ ls
CMakeLists.txt              README                  advanced                novice
GNUmakefile         README.HowToRun         basic
History                     README.HowToRunMT       extended
bash-3.2$ cd basic/
bash-3.2$ ls
B1          B3              B5              GNUmakefile     README
B2          B4              CMakeLists.txt  History
bash-3.2$ cd B1
bash-3.2$ ls
CMakeLists.txt      History         exampleB1.cc    exampleB1.out   init_vis.mac    run2.
↪mac        vis.mac
GNUmakefile README          exampleB1.in    include         run1.mac        src
bash-3.2$ mkdir build
bash-3.2$ cd build/
```

Then the build of the example can be configured by using `CMake` as:

```
bash-3.2$ cmake ../ -DGeant4_DIR=$G4INSTALL/lib/Geant4-11.0.1/
-- The C compiler identification is GNU 10.2.0
-- The CXX compiler identification is GNU 10.2.0
-- Checking whether C compiler has -isysroot
-- Checking whether C compiler has -isysroot - yes

...

-- Generating done
-- Build files have been written to: ...
```

Note, that as before, `CMake` requires the location of the top level `CMakeLists.txt` of the project and the location of the *Geant4* toolkit `CMake` configuration file, that has been installed under the `$G4INSTALL/lib/Geant4-11.0.1/` location. This latter must be provided through the *Geant4_DIR* `CMake` configuration option as shown above. One can export this location into an environmental variable (e.g. `export G4COMP=$G4INSTALL/lib/Geant4-11.0.1/`) then the above configuration can be shorten as `-DGeant4_DIR=$G4COMP`. This latter is done in the provided Virtual Machine that we will discuss below.

Following the successful configuration phase, the example can be built as:

```
bash-3.2$ make -j6
Scanning dependencies of target exampleB1
[ 37%] Building CXX object CMakeFiles/exampleB1.dir/src/DetectorConstruction.cc.o
[ 37%] Building CXX object CMakeFiles/exampleB1.dir/exampleB1.cc.o
[ 37%] Building CXX object CMakeFiles/exampleB1.dir/src/ActionInitialization.cc.o
[ 75%] Building CXX object CMakeFiles/exampleB1.dir/src/EventAction.cc.o
[ 75%] Building CXX object CMakeFiles/exampleB1.dir/src/RunAction.cc.o
[ 75%] Building CXX object CMakeFiles/exampleB1.dir/src/PrimaryGeneratorAction.cc.o
[ 87%] Building CXX object CMakeFiles/exampleB1.dir/src/SteppingAction.cc.o
[100%] Linking CXX executable exampleB1
[100%] Built target exampleB1
```

then execute the simulation by using one of the provided *Geant4* macro file (don't care about the details now, we will become familiar will all the details during this week):

```
bash-3.2$ ./exampleB1 run1.mac


          ################################
          !!! G4Backtrace is activated !!!
          ################################


**************************************************************
 Geant4 version Name: geant4-11-00-patch-01 [MT]   (8-March-2022)
  << in Multi-threaded mode >>
                      Copyright : Geant4 Collaboration
                     References : NIM A 506 (2003), 250-303
                                : IEEE-TNS 53 (2006), 270-278
                                : NIM A 835 (2016), 186-225
                            WWW : http://geant4.org/
**************************************************************


<<< Reference Physics List QBBC
```
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```
Visualization Manager instantiating with verbosity "warnings (3)"...
Visualization Manager initialising...
Registering graphics systems...

You have successfully registered the following graphics systems.

...

Pool ID '15G4CountedObjectIvE', size : 0.000961 MB
Number of memory pools allocated: 5; of which, static: 0
Dynamic pools deleted: 5 / Total memory freed: 0.0067 MB
============================================================
G4Allocator objects are deleted.
UImanager deleted.
StateManager deleted.
RunManagerKernel is deleted. Good bye :)
RunManager is deleted.
```

So we can conclude that everything works fine!

2.4 Some notes on the Virtual Machine

As it was shown in the previous section, the *Geant4* toolkit offers a large variety of configuration options. Some of these options enables optional components or makes possible to select the preferred solution from the available set of alternatives. The different configurations results in *Geant4* installations with different functionalities and characteristics. Moreover, some of the components that can be enabled or selected by such configuration options requires extra libraries to be installed and available on the system as prerequisites. One good example is the visualisation option offered by the toolkit. *Geant4* provides several alternative Visualization Drivers from which the user can select the preferred one at the configuration time of the toolkit build. However, the different drivers require different graphics systems being available (e.g. `OpenGL`, `X11`, `Qt`, etc.). These are not only platform dependent but very often not trivial to set.

Using the Virtual Machine(VM) ensures, that we all have access to a *Geant4* toolkit installation with exactly the same build and environmental configuration on the same platform. This greatly simplifies the common setup problem and ensures that we are all on the same page. The *Geant4* VM, that will be used throughout this course, is kindly provided by the Laboratoire de Physique des Deux Infinis Bordeaux (LP2i Bordeaux), CNRS/IN2P3/Bordeaux University. Please see the corresponding README for more information.

There is a default `local1` user account created on your linux VM with the `local1` password (the root password is `rocky8.5`). The `/home/local1` home directory location is set in the `HOME` environmental variable. There are several *Geant4* specific environmental variables set in the system. You can see them by:

```
localhost.localdomain:/local1 < 63 >printenv | grep G4
G4INSTALL=/usr/local/geant4.11.0.1
G4BUILD=/usr/local/src/build
G4ALPHAHPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4TENDL1.4/Alpha
G4UI_USE_TCSH=1
G4SAIDXSDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4SAIDDATA2.0
G4INCL=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4INCL1.0
G4REALSURFACEDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/RealSurface2.2
G4VIS_USE=1
G4LEVELGAMMADATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/PhotonEvaporation5.7
```

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```
G4UI_USE_QT=1
G4LIB_USE_GDML=1
G4EXAMPLES=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/examples
G4LIB=/usr/local/geant4.11.0.1/lib64
G4NEUTRONXSDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4PARTICLEXS4.0
G4COMP=/usr/local/geant4.11.0.1/lib64/Geant4-11.0.1
G4SRC=/usr/local/src/geant4-v11.0.1
G4VIS_BUILD_OPENGLX_DRIVER=1
G4ANALYSIS_USE=1
G4LIB_BUILD_GDML=1
G4TRITONHPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4TENDL1.4/Triton
G4VIS_USE_OPENGLX=1
G4RADIOACTIVEDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/RadioactiveDecay5.6
G4NEUTRONHPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4NDL4.6
G4ABALDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4ABLA3.1
G4ENSDFSTATEDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4ENSDFSTATE2.3
G4INCLUDE=/usr/local/geant4.11.0.1/include/Geant4
G4PIIDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4PII1.3
G4SYSTEM=Linux-g++
G4DEUTERONHPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4TENDL1.4/Deuteron
G4PARTICLEXSDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4PARTICLEXS4.0
G4WORKDIR=/home/local1/geant4/work
G4HE3HPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4TENDL1.4/He3
G4PROTONHPDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4TENDL1.4/Proton
G4LEDATA=/usr/local/geant4.11.0.1/share/Geant4-11.0.1/data/G4EMLOW8.0
```

in a terminal window. You can open a `Terminal` window in your system by clicking `Activities -> Terminal`. Some of these, e.g. the *Geant4* data set location related variables like the `G4LEDATA` that points to the low energy EM physics data set location, are **required** to be set for the operation of *Geant4*. These required environmental variables are usually set in the post-install procedure (see at the end of the *Configure, build and install,* part above). Other *Geant4*, **optional** environmental variables are set in your VM system simply for convenience. These can be grouped to *Geant4* (build) configuration and some location related environmental variables. The first set was used during the production of the VM build of the toolkit to turn `ON/OFF` some of the *Geant4* optional `CMake` configuration option e.g.

- `G4VIS_USE_OPENGLX`: that was used to turn `ON/OFF` the `GEANT4_USE_OPENGL_X11` *Geant4* optional `CMake` configuration option for enabling the visualization component with `OpenGL-Xlib` driver (i.e. `OpenGL` with the `X11 X Window System`).
- `G4UI_USE_QT`: that was used to turn `ON/OFF` the `GEANT4_USE_QT` *Geant4* optional `CMake` configuration option for enabling the `Qt` based Graphical User Interface (GUI)

The second set contains those variables that makes easy the locate the directories of the *Geant4* source code (`G4SRC`), install (`G4INSTALL`) or the configuration location (`G4COMP`) that needs to be provided in the required `Geant4_DIR` `CMake` input variable when compiling any *Geant4* applications. You can print any of these variable values just before by:

```
localhost.localdomain:/local1 < 67 >echo $G4SRC
/usr/local/src/geant4-v11.0.1
```

Note, that (some of) the location related variables are the same as above when the *Geant4* toolkit was *built and installed from source*. Therefore, we can follow exactly the same steps (and commands but now on the VM) to configure, build and execute the `/examples/basic/B1` example application. The only difference is, that now we (the `local1` user) has nor right to modify the system. We can overcome this by simple copying the example to somewhere our user area.

We will use the G4WORKDIR=/home/local1/geant4/work directory throughout this course that first we make sure that it exists, then copy the /examples/basic/B1 example application codes:

```
localhost.localdomain:/work < 84 >mkdir -p ~/geant4/work/
localhost.localdomain:/work < 85 >cd ~/geant4/work/
localhost.localdomain:/work < 86 >cp -r $G4SRC/examples/basic/B1 .
localhost.localdomain:/work < 87 >ls
/home/local1/geant4/work
B1/
```

Then we can create the build directory, configure and build the application as:

```
localhost.localdomain:/work < 88 >cd B1
localhost.localdomain:/B1 < 89 >mkdir build
localhost.localdomain:/B1 < 90 >cd build/
localhost.localdomain:/build < 91 >cmake ../ -DGeant4_DIR=$G4COMP
-- The C compiler identification is GNU 8.5.0
-- The CXX compiler identification is GNU 8.5.0
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done

...

-- Build files have been written to: /home/local1/geant4/work/B1/build
localhost.localdomain:/build < 92 >make
[ 12%] Building CXX object CMakeFiles/exampleB1.dir/exampleB1.cc.o
[ 25%] Building CXX object CMakeFiles/exampleB1.dir/src/ActionInitialization.cc.o
[ 37%] Building CXX object CMakeFiles/exampleB1.dir/src/DetectorConstruction.cc.o
[ 50%] Building CXX object CMakeFiles/exampleB1.dir/src/EventAction.cc.o
[ 62%] Building CXX object CMakeFiles/exampleB1.dir/src/PrimaryGeneratorAction.cc.o
[ 75%] Building CXX object CMakeFiles/exampleB1.dir/src/RunAction.cc.o
[ 87%] Building CXX object CMakeFiles/exampleB1.dir/src/SteppingAction.cc.o
[100%] Linking CXX executable exampleB1
[100%] Built target exampleB1
```

We can run the example application just as before by ./exampleB1 run1.mac but now we also have the possibility to execute the application with visualisation. This can be achieved by executing the application without providing any input macro file as ./exampleB1.

Note: All above was just to become familiar with the provided VM so you are not expected to understand much about what's happening in the *Geant4* application. Concentrate only to keep in mind some of the useful location related environmental variables as G4SRC or G4COMP and the way they are used. You will become familiar with all the remaining technical and toolkit related details during this course.

Tip: You might want to make sure at this point that one of your preferred editor for coding is available on the VM system. I will use the atom editor during the course that you can install by opening the internet browser (Activities -> Firefox or from the terminal as firefox) and typing atom.

2.5 Some notes on using CMake

Let me demonstrate here with a single example how CMake helps us when building a *Geant4* simulation application. Consider the following simple *"Hello World!"* C++ code, created and saved to our VM $HOME/geant4/work/preli_cmake directory area into the simple ourmain.cc (that can be created by either the cat > ourmain.cc or tee main.cc):

```
localhost.localdomain:/geant4-v11.0.1 < 108 >mkdir -p $HOME/geant4/work/preli_cmake
localhost.localdomain:/geant4-v11.0.1 < 109 >cd $HOME/geant4/work/preli_cmake/
localhost.localdomain:/preli_cmake < 110 >cat > ourmain.cc
```

```
#include <iostream>

int main() {

  std::cout << " Hello World! " << std::endl;

  return 0;
}
```

that we can compile and run as:

```
localhost.localdomain:/preli_cmake < 115 >g++ -o ourmain ourmain.cc
localhost.localdomain:/preli_cmake < 116 >./ourmain
 Hello World!
```

Now try to use something in this simple application from the *Geant4* toolkit installed on the system under the G4INSTALL. Keeping it simple, we can declare a variable but using a *Geant4* defined type, e.g. G4double from $G4SRC/source/global/management/include/G4Types.hh, instead of the standard C++ one e.g.

```
#include <iostream>

// include the Geant4 header where the G4double variable defined
#include "G4Types.hh"

int main() {

  // a Geant4 defined variable type (form $G4SRC/source/global/management/include/
↪G4Types.hh)
  G4double x = 1.23;

  std::cout << " Hello World! " << std::endl;

  return 0;
}
```

when we try to compile now as before, we get an error:

```
localhost.localdomain:/preli_cmake < 117 >g++ -o ourmain ourmain.cc
ourmain.cc:4:10: fatal error: G4Types.hh: No such file or directory
 #include "G4Types.hh"
          ^~~~~~~~~~~~
compilation terminated.
```

simply because the compiler doesn't know where the look for the `G4Types.hh` header file. We can resolve this by simply adding the `$G4INSTALL/include/Geant4` directory to the locations where the compiler looks for include files. This can be done with the `-I` flag as:

```
localhost.localdomain:/preli_cmake < 123 >g++ -I $G4INSTALL/include/Geant4 -o ourmain␣
↪ourmain.cc
localhost.localdomain:/preli_cmake < 124 >./ourmain
 Hello World!
```

Cool. But what if I want to use now something that needs more than the declaration (more than the header) i.e. the library as well? A simply example is `G4cout, G4endl` from the `$G4SRC/source/global/management/include/globals.hh` (actually deeper but never mind, this include works fine) that is the *Geant4* version of `std::cout, std::endl`

```
#include <iostream>

// include the Geant4 header for G4cout and G4endl (also includes G4Types.hh)
#include "globals.hh"

int main() {

  // a Geant4 defined variable type (form $G4SRC/source/global/management/include/
↪G4Types.hh)
  G4double x = 1.23;

  // write out the variable value using G4cout
  G4cout << " x = " << x << G4endl;

  std::cout << " Hello World! " << std::endl;

  return 0;
}
```

However, when compiling this like before we get an error:

```
localhost.localdomain:/preli_cmake < 138 >g++ -I $G4INSTALL/include/Geant4 -o ourmain␣
↪ourmain.cc
In file included from /usr/local/geant4.11.0.1/include/Geant4/globals.hh:50,
                 from ourmain.cc:4:
/usr/local/geant4.11.0.1/include/Geant4/G4String.hh:117:31: error: ‘std::string_view’␣
↪has not been declared
   inline G4int compareTo(std::string_view, caseCompare mode = exact) const;
```

We need to make sure now that the application is linked with the required libraries, located `libG4global` and `libG4ptl` that are under the `G4INSTALL/lib64` directory. The library location can be specified as `-L$G4INSTALL/lib64` then linked as `-lG4global -lG4ptl`. We also need to specify the C++ standard, since *Geant4* requires now C++ standard 17, that can be done by `-std=c++17`. (Moreover, for some reasons having the `LD_LIBRARY_PATH` set is not enough on the VM but we need to set the run-time linker path as well with `-Wl,-rpath,$G4INSTALL/lib64`) So eventually all these would lead to:

```
localhost.localdomain:/preli_cmake < 172 >g++ -std=c++17 -I $G4INSTALL/include/Geant4 -o␣
↪ourmain ourmain.cc -L$G4INSTALL/lib64 -Wl,-rpath,$G4INSTALL/lib64 -lG4global -lG4ptl
localhost.localdomain:/preli_cmake < 173 >./ourmain
 x = 1.23
```

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```
Hello World!
```

Not negligible details, but have a look how many different libraries are under `$G4INSTALL/lib64`!

So just copy now the `$G4SRC/examples/basic/B1/CMakeLists.txt` as:

```
localhost.localdomain:/preli_cmake < 178 >cp $G4SRC/examples/basic/B1/CMakeLists.txt .
```

and edit to replace `exampleB1 -> ourmain`, `B1 -> ours` and remove the complete part copying scripts (that we don't have)

```
#----------------------------------------------------------------------------
# Setup the project
cmake_minimum_required(VERSION 3.16...3.21)
project(ours)

#----------------------------------------------------------------------------
# Find Geant4 package, activating all available UI and Vis drivers by default
# You can set WITH_GEANT4_UIVIS to OFF via the command line or ccmake/cmake-gui
# to build a batch mode only executable
#
option(WITH_GEANT4_UIVIS "Build example with Geant4 UI and Vis drivers" ON)
if(WITH_GEANT4_UIVIS)
  find_package(Geant4 REQUIRED ui_all vis_all)
else()
  find_package(Geant4 REQUIRED)
endif()

#----------------------------------------------------------------------------
# Setup Geant4 include directories and compile definitions
# Setup include directory for this project
#
include(${Geant4_USE_FILE})
include_directories(${PROJECT_SOURCE_DIR}/include)

#----------------------------------------------------------------------------
# Locate sources and headers for this project
# NB: headers are included so they will show up in IDEs
#
file(GLOB sources ${PROJECT_SOURCE_DIR}/src/*.cc)
file(GLOB headers ${PROJECT_SOURCE_DIR}/include/*.hh)

#----------------------------------------------------------------------------
# Add the executable, and link it to the Geant4 libraries
#
add_executable(ourmain ourmain.cc ${sources} ${headers})
target_link_libraries(ourmain ${Geant4_LIBRARIES})

#----------------------------------------------------------------------------
# For internal Geant4 use - but has no effect if you build this
# example standalone
#
add_custom_target(ours DEPENDS ourmain)
```

Then we can use this, to compile now our example easily as:

```
localhost.localdomain:/preli_cmake < 183 >mkdir build
localhost.localdomain:/preli_cmake < 184 >cd build
localhost.localdomain:/build < 185 >cmake ../ -DGeant4_DIR=$G4COMP
-- The C compiler identification is GNU 8.5.0
-- The CXX compiler identification is GNU 8.5.0

...

-- Build files have been written to: /home/local1/geant4/work/preli_cmake/build
```

then we can simply compile and run our application as:

```
localhost.localdomain:/build < 188 >make
[ 50%] Building CXX object CMakeFiles/ourmain.dir/ourmain.cc.o
[100%] Linking CXX executable ourmain
[100%] Built target ourmain
localhost.localdomain:/build < 189 >./ourmain
 x = 1.23
 Hello World!
```

Just so much simpler since CMake (and the *Geant4* CMake configuration file) can help us. We can inspect the $G4INSTALL/lib64/Geant4-11.0.1/Geant4Config.cmake *Geant4* CMake configuration file especially the top to see what will be set:

```
localhost.localdomain:/geant4 < 194 >less $G4INSTALL/lib64/Geant4-11.0.1/Geant4Config.
↪cmake
```

and we can even write out the content of Geant4_LIBRARIES from our new CMakeLists.txt file, after the *Geant4* libraries are already found (since that will be the point when the *Geant4* configuration file will be processed):

```
...

  find_package(Geant4 REQUIRED)
endif()

message("---> Look at me, we print out the value of Geant4_LIBRARIES: ${Geant4_LIBRARIES}
↪")
```

Then reconfiguring our build prints (at a point):

```
localhost.localdomain:/build < 211 >cmake ../ -DGeant4_DIR=$G4COMP
---> Look at me, we print out the value of Geant4_LIBRARIES: Geant4::G4Tree;Geant4::G4FR;
↪Geant4::G4GMocren;Geant4::G4visHepRep;Geant4::G4RayTracer;Geant4::G4VRML;Geant4::
↪G4OpenGL;Geant4::G4gl2ps;Geant4::G4visQt3D;Geant4::G4vis_management;Geant4::G4modeling;
↪Geant4::G4interfaces;Geant4::G4persistency;Geant4::G4analysis;Geant4::G4error_
↪propagation;Geant4::G4readout;Geant4::G4physicslists;Geant4::G4run;Geant4::G4event;
↪Geant4::G4tasking;Geant4::G4tracking;Geant4::G4parmodels;Geant4::G4processes;Geant4::
↪G4digits_hits;Geant4::G4track;Geant4::G4particles;Geant4::G4geometry;Geant4::
↪G4materials;Geant4::G4graphics_reps;Geant4::G4intercoms;Geant4::G4global;Geant4::
↪G4tools;Geant4::G4zlib;Geant4::G4ptl;Geant4::G4UIVisDefinitions
-- Configuring done
-- Generating done
-- Build files have been written to: /home/local1/geant4/work/preli_cmake/build
```

I hope this helps to understand how using `CMake` can help us to configure and build our applications especially using such complex softwares as the *Geant4* toolkit.

Part II

Application Documentation

3 C++ interface demonstrator

Code documentation of the simply C++ interface demonstrator. You can find the corresponding codes under the `applications/preliminaries/cpp-interface`.

class **`VShape2D`**

Interface, i.e. base class with a **pure virtual** method, for 2D shape area computations.

Author M. Novak

Date May 2022

This base class is an **interface** for 2D shape area computations. It has its **pure virtual** *Area()* method. Therefore, this method **must be implemented by each derived** classes. This ensures, that whatever type of an actuall 2D shape is (derived from this base class) the *Area()* interface method will be available. Therefore, the rest of the code can be developed without knowing what 2D shapes will be eventually there: they will be all *`VShape2D`* types providing their own implementation of the *Area()* interface method defined in this base class.

Note, that the **pure virtual** method makes this base class **abstract**, i.e. objects cannot be instantiated directly form this base class.

Subclassed by *Circle*, *Square*

Public Functions

virtual double **`Area`**`()` = 0

The area computation *interface* method.

Example of a **pure virtual** method that makes this base class **abstract**.

Each 2D shape has an area but all computed differently depending on the actual type of the shape. This is why it's a **pure virtual method**, i.e. **each derived class must implement**.

inline virtual double **`Perimeter`**`()`

Optional perimeter computation method.

Example of a **virtual** method with defult implementation in the base class.

Each 2D shape has its own way of computing the perimeter just like the area. However, we decided that actually the perimeter is not important for our algorithm in most cases of shapes. Therefore, this default implementation is available for each derived class and will be invoked unless the concrete derived class provides its own implementation. The derived *`Square`* class implements this method while *`Circle`* relyes on this defult base class implementation.

class `Square` : public *VShape2D*

Derived class that implements the *VShape2D* interface for Square-s.

Author M. Novak

Date May 2022

Public Functions

inline virtual double `Area()` override

Actual implementation of the area computation interface method of the base class.

Square **must implement** the *VShape2D::Area* base class method since that's a **pure virtual method**.

Note: The `override` keyword is very useful: indicates that this method implements a virtual method of the base class so the compiler is aware of that intention.

---

inline virtual double `Perimeter()` override

The **optional** `Perimeter` interface method implementation.

class `Circle` : public *VShape2D*

Derived class that implements the *VShape2D* interface for Circle-s.

Author M. Novak

Date May 2022

Public Functions

inline virtual double `Area()` override

Actual implementation of the area computation interface method of the base class.

Circle **must implement** the *VShape2D::Area* base class method since that's a **pure virtual method**.

4 Introduction

Bals lashd

Let's ciete here the final application dosucmentaion as *final application* ...

---

5 Application description

The `Geant4` application, that is developed during this course, is a very simple … bala bal

- add image
- explain
- show the results comapring ti experiegst

6 Code documentation of `yourMainApplication` of the application

This section contains the automatic code documentation of the `main` of the application developed during the course. Reference the main file as *yourMainApplication* and the main funtion as `main()`

This is how to reference some code documentation part now e.g. the *Detector Construction* and this is how to reference a class now `YourDetectorConstruction`.

6.1 Code documentation: *yourMainApplication*

The main function of this user application.

Author M. Novak

Date December 2019

Functions

int **`main`**(int argc, char **argv)

The `main` function of the user application.

7 Code documentation of `YourDetectorConstruction` of the application

This section contains the code documentation of the `detector construction` of the application developed during the course.

7.1 The `YourDetectorConstruction` class

class **`YourDetectorConstruction`** : public G4VUserDetectorConstruction

Implementation of the `Geant4` `G4VUserDetectorConstruction` **mandatory interface** for this user application.

Author M. Novak

Date December 2019

The description of the application detector geometry must be implemented in the *Construct()* interface.

Public Functions

`YourDetectorConstruction()`

Constructor.

`~YourDetectorConstruction()` override

Destructor.

G4VPhysicalVolume *`Construct()` override

It's interface method to construct the detector.

The base class has the *Construct()* (only one) pure virtual method which is invoked by the G4RunManager when it's Initialize() method is invoked. The *Construct()* method must return the G4VPhysicalVolume pointer which represents the world volume.

Your entire detector description must be implemented here in this method.

8 Code documentation of the user action part of the application

This section contains the code documentation of all the user actions of the application developed during the course.

8.1 The mandatory interface implementations

This is the **mandatory** action initialization (that includes the construction and registration of the primary generator action). An object form the action initialization implementation class must be registered in the run manager inside the main (e.g. `main()` in *yourMainApplication*) of each application.

class `YourActionInitialization` : public G4VUserActionInitialization

Implementation of the `Geant4` `G4VUserActionInitialization` **mandatory interface** for this user application.

Author M. Novak

Date December 2019

All user actions (i.e. at least your implementation of the `G4VUserPrimaryGeneratorAction` ,that is *YourPrimaryGeneratorAction* in our case, but all optional actions) objects must be constructed and registered in the `G4RunManager` through a single user action initialization object from this class.

The *construction* and *registration* of all user action objects must be implemented in the *Build()* interface (pure virtual) method that is invoked by all worker threads before starting the run. The additional *BuildForMaster()* virtual method of the base class is invoked by only the master thread. No other user actions than implementation of the `G4UserRunAction` should be constructed here!

According to the above, we construct and register only *YourRunAction* object in the *BuildForMaster()* interface method while all the user actions are constructed and created in the *Build()* method. This is because, the master run action object *YourRunAction::GenerateRun()* method is invoked by the master at the beginning of the run to create its own *YourRun* object. The same is done for each workers. Hoever, unlike the individual worker *YourRun* objects, that are used during the simulatio to collect thread-local infomation, the single master *YourRun* object is untouched till the end of the run. It will be used only to collect/merge the individual thread-local run infomation into one global *YourRun* obejct after all worker finished the simulation.

Public Functions

void **Build**() const override

(Pure) Virtual method to be implemented by the user to instantiate User Action class objects.

Each application **must implemnted** this method. It is invoked by all workers at the beginning of the run to instantiate all (worker) thread-local user action objects. At least the construction and registration of the primary generation action must be implemented in this method.

void **BuildForMaster**() const override

Virtual method to be implemented by the user to instantiate User RunAction.

This method is invoked only by the master and only your implementation of the `G4VUserRunAction` should be constructed and registered here (see the class description why).

class **YourPrimaryGeneratorAction** : public G4VUserPrimaryGeneratorAction

Implementation of the `Geant4 G4VUserPrimaryGeneratorAction` **mandatory interface** for this user application.

Author M. Novak

Date December 2019

Generation of primary particles of the application must be implemented in the *GeneratePrimaries()* interface. This interface method is invoked by the G4RunManager::GenerateEvent() whenever a new event is needed.

The construction and registration of the primary generator interface of the application is done in the implementation of the **mandatory** G4VUserActionInitialization (*YourActionInitialization*).

An instance of this primary generator object **must be** created and set in the implementation of the G4VUserActionInitialization::Build() interface method. This is done in *YourActionInitialization::Build()* in this application.

Note: each worker thread has their own object form this primary generator since *YourActionInitialization::Build()* interface method is invoked by each thread.

Note: we keep the pointer to the detector object in order to be able to set the primary generator gun position dynamically. This can be done anytime by invoking the *UpdatePosition()* method.

Public Functions

void **GeneratePrimaries**(G4Event *evt) override

It's interface method to generate primary particles.

(Pure) virtual method to generata primary events. This method will be invoked from the G4RunManager whenever a new event is required.

Parameters **`[in:out]`** – evt Pointer to the `G4Event` object to be filled with primaries.

void **UpdatePosition**()

Public method to set the position of the particle gun.

The detector might be resized by the user between its construction and the start of the run. This method can be invoked (form *YourRunAction::BeginOfRunAction()*) at the begin of the run in order to ensure the proper position of the gun.

8.2 Some of the optional interface implementations

class **`YourRun`** : public G4Run

Implementation of `Geant4` `G4Run` for this user application.

Author M. Novak

Date December 2019

The run of your application usually encapsulates all infomation that you would like to collect during the simulation. Each thread will have their own object form this run class that is generated before the simulation by the individual threads itself simply calling the `G4RunAction::GenerateRun()` (i.e. *YourRunAction::GenerateRun()*) method of the `G4RunAction` (i.e. *YourRunAction*) object that was constructed and registered for the given thread (in *YourActionInitialization::Build()* or *YourActionInitialization::BuildForMaster()* methods for the workers or for the master respecively).

While the run objects of the worker threads are used during the simulation to collect thread-local data, the run object generated by the master, is not used during the simulation. This latter is used only at the end of the run and only to collect all thread-local run data into one gloabl run object. This is done, by calling the *Merge()* method of this class that should contain the implementation how run data can be added/merged.

Note: for this application we will implement a simple histogram class. The only reason why we do this is to demonstrait the good practice regarding the implementation of objects, that are used inside the run object, shoudl follow (e.g. easily `"mergable"`).

Public Functions

void **`Merge`**(const G4Run *run) override

Virtual method to be implemented to define the way of merging the underlying (thread local) Run global data structures into one global instance.

This method will be invoked by the master on its own run object (*YourRun*) on each of the worker, i.e. thread local, run (*YourRun*) objects passing by their pointer as the input argument.

Parameters **`run`** – **[in]** Pointer to a run (*YourRun*) obejct that needs to be merged to this run object.

class **`YourRunAction`** : public G4UserRunAction

Implementation of the `Geant4` `G4UserRunAction` **optional interface** for this user application.

Author M. Novak

Date December 2019

This interface gives the possibility for interacting with the simulation before the simulation of the first (*BeginOfRunAction()*) and after the last (*EndOfRunAction()*) event. The additional *GenerateRun()* virtual method can be used to generate *YourRun* object, i.e. your implementation of `G4Run`, both for the master and for the individual worker threads.

Note: this is the only user action that can be constructed and registered in *YourActionInitialization::BuildForMaster()*.

Public Functions

G4Run ***GenerateRun**() override

Virtual method to generate *YourRun* for each threads.

void **BeginOfRunAction**(const G4Run *run) override

Virtial method that is called by the RunManager before the first event starts.

This is the point where we usually perfrom some final actions needed to be done before the simulation, constructing some run global objects (e.g. for analysis) or we will ensure here that the primary generator gun position is correct.

Parameters **run** – **[in]** Pointer to the G4Run (*YourRun*) object that has been generated for this thread.

void **EndOfRunAction**(const G4Run *run) override

Virtial method that is called by the RunManager after the last event simulation is completed.

This is the point where we usually perfrom some actions needed to be done when the simulation is completed, performing final computation and writing the simulation results usually happens here (we do this here by calling the corresponding method of *YourRun*).

Parameters **run** – **[in]** Pointer to the G4Run (*YourRun*) object that has been generated for this thread.

class **YourEventAction** : public G4UserEventAction

Implementation of the `Geant4` `G4UserEventAction` **optional interface** for this user application.

Author M. Novak

Date December 2019

This interface gives the possibility for interacting with the simulation before (*BeginOfEventAction()*) and after (*EndOfEventAction()*) the simulation of each event.

Public Functions

void **BeginOfEventAction**(const G4Event *evt) override

Virtial method that is called by the RunManager before the start of each event.

This is the point where we usually reset some local variables that are used to accumulate information during the simnulation of a given event.

Parameters **evt** – **[in]** Pointer to the `G4Event` object that will be simulated now.

void **EndOfEventAction**(const G4Event *evt) override

Virtial method that is called by the RunManager after the end of each event.

This is the point where we usually propagate to upper level (i.e. usualy to the run (*YourRun*) obejct) local infomation, that has been collected during the simnulation of a given event.

Parameters **evt** – **[in]** Pointer to the `G4Event` object that simulated has just been completed.

class **YourSteppingAction** : public G4UserSteppingAction

Implementation of the `Geant4` `G4UserSteppingAction` **optional interface** for this user application.

Author M. Novak

Date December 2019

This interface gives the possibility for interacting with the simulation after the complition of the individual simulation steps in its *UserSteppingAction()* method.

Public Functions

void `UserSteppingAction`(const G4Step *step) override

Interface metho dthat is called after each simulation steps.

We do all the fine grane infomation collection in this method that infomation are usually propagated to an auuper elevel, e.g. *YourEventAction*.

> **Warning:** You need to be careful here! Since this method is invoked after each individual simulation step, this is a very perfomance critical point.

Parameters `step` – **[in]** Pointer to the `G4Step` object that has just been completed.

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