Grasshopper Documentation

Release 0.0.1

J. Miske, A. Danagoulian

Apr 08, 2020

Contents

CHAPTER 1

Motivation

Current particle physics simulations take place largely within small communities developing limited tools for specific areas of study. These particle simulations are essential to evaluating environments outside of the realm of experimentation in the radiation sciences. While multi-use toolkits exist for particles simulation (such as MCNP or SRIM), these computational tools are often difficult for untrained users to adapt into their projects. Geant4 is one such toolkit used widely by physicists in radiology, fission reactor work, and space irradiation studies among many other fields [1]. Geant4 can be adapted for use in other programs using the methods supplied by the open source code provided. In addition, Geant4 relies on various databases shared by institutes such as NIST. Unfortunately, Geant4 and the related libraries are not a common program to install and use for scientific simulation users or the general public interested in this work [2]. However, a widely applicable simulation engine using Geant4, called Grasshopper, has been developed to allow for generating straightforward Monte Carlo simulations for engineers and scientists in a wide range of fields.

CHAPTER 2

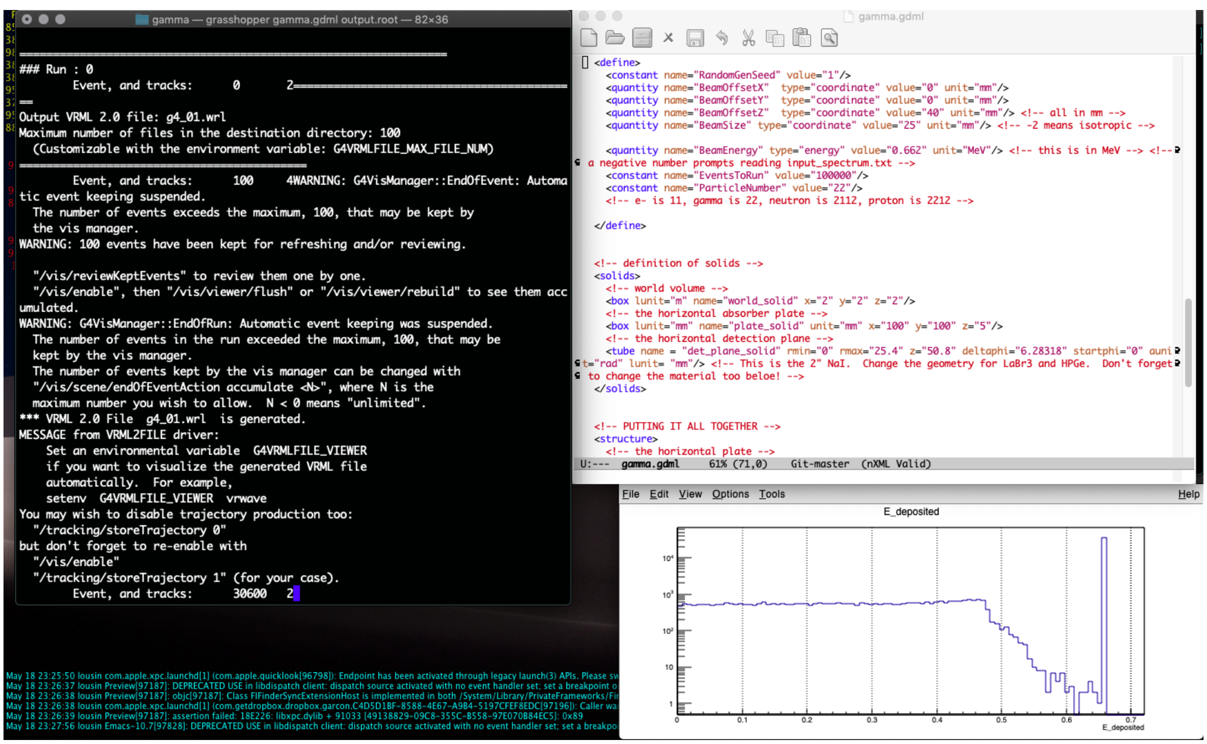
Current Work

Grasshopper is currently being benchmarked against other particle simulation tools. By comparing results of major databases of particle physics constants, we can evaluate the real world simularity of the simulation.

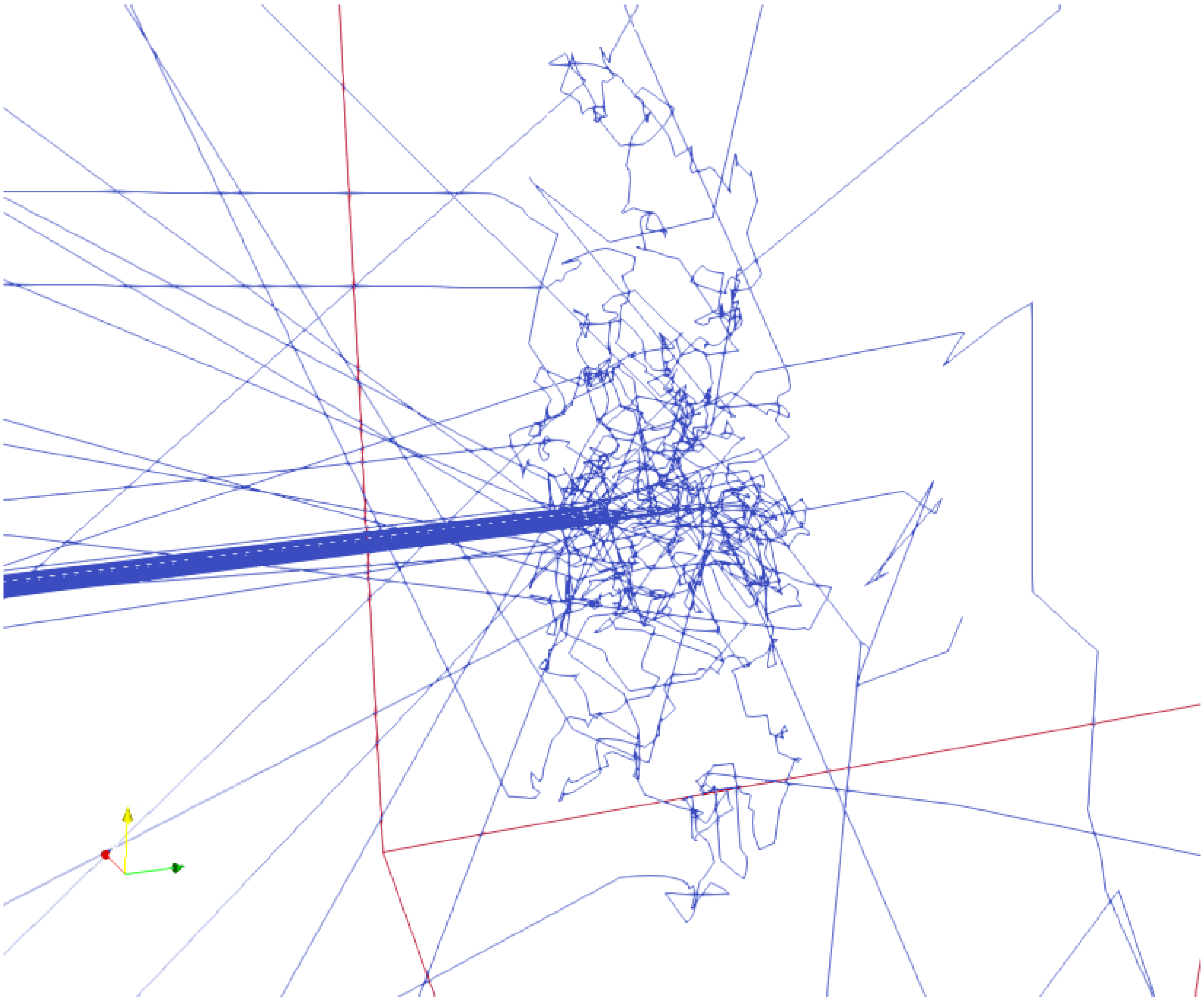
CHAPTER 3

Screenshots from Grasshopper

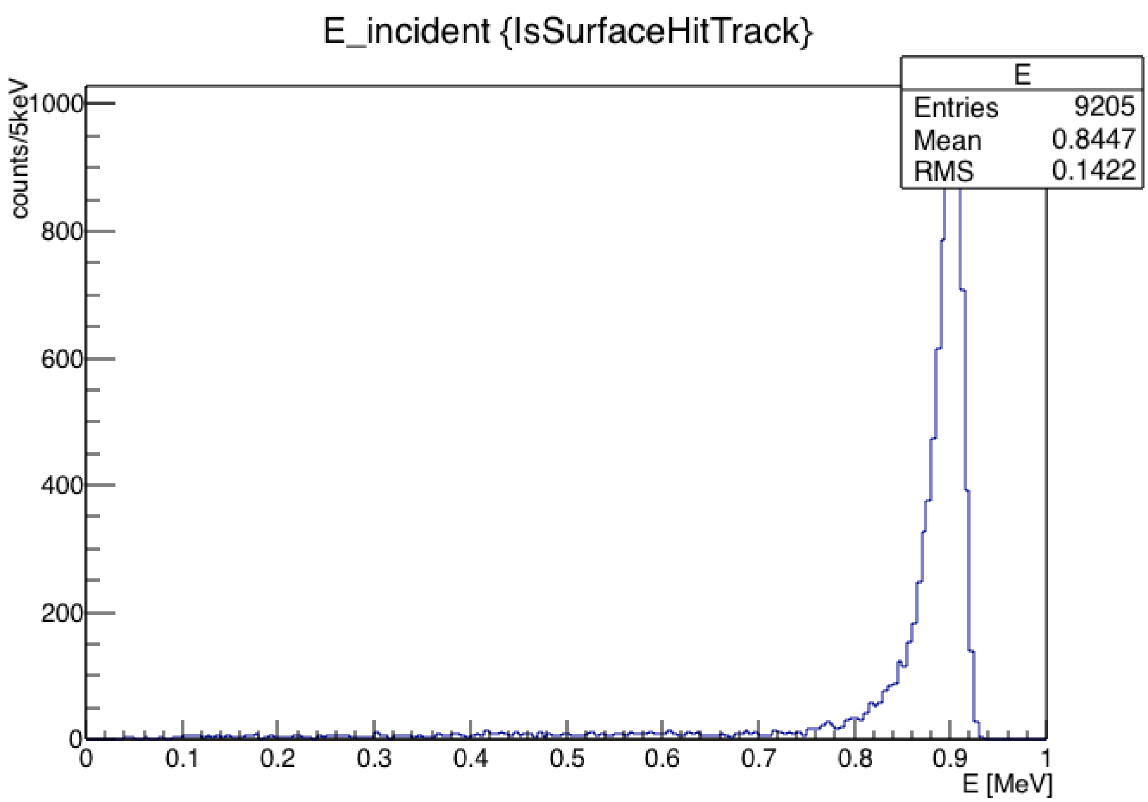
A view of your workspace:



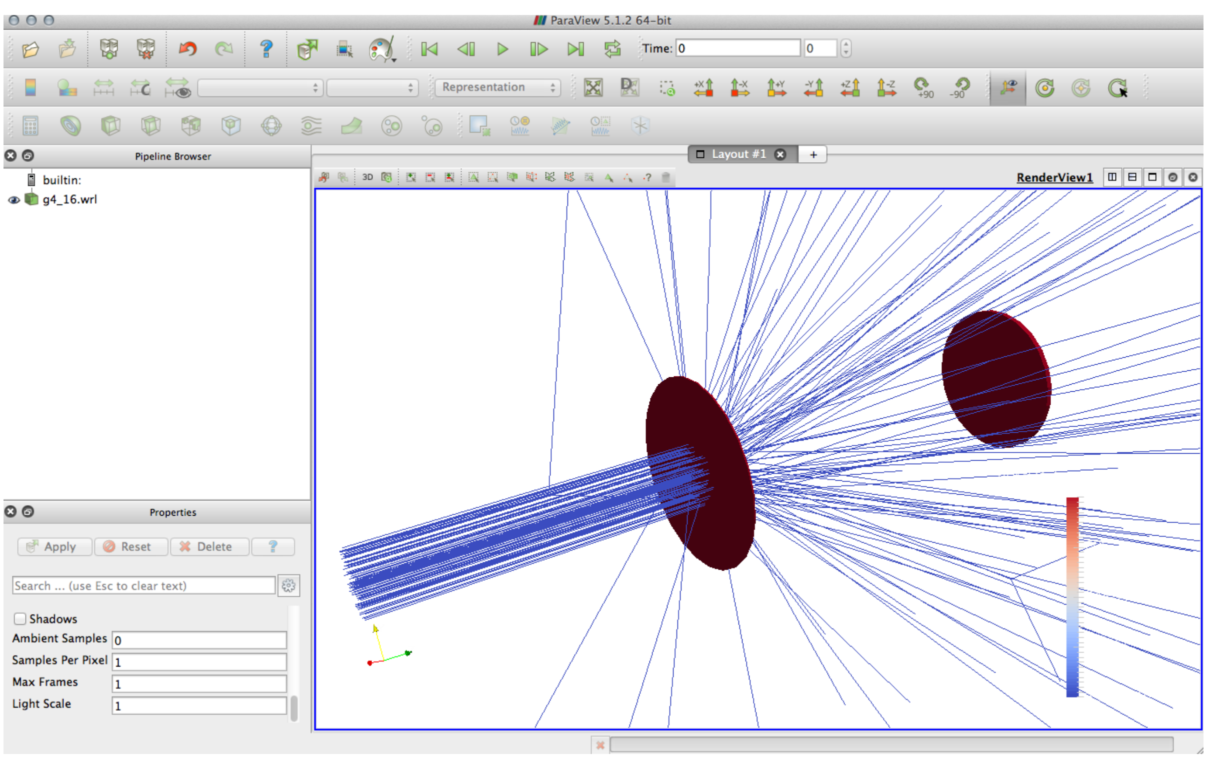
A visualization of a 1 MeV neutron beam entering a water volume, undergoing thermalization.



For this particular simulation, you can see the energy distribution of the electrons hitting the detector in the plot below (from ROOT):



Here is the view of a '.wrl' file in Paraview:



Important: Recommended publication for citing A. Danagoulian, J. Miske "*Grasshopper: A Geant4 code for*

Research and Development of Radiation Transport"

CHAPTER 4

Indices and tables

- genindex
- modindex
- search

4.1 Getting Started

This section details how to start using Grasshopper to generate simulations that utilize Geant4.

4.1.1 Requirements

4.1.2 For MIT Nuclear Science Students

At a minimum you will need to login to nsecluster.mit.edu. From a terminal run ssh -Y yourusername@nsecluster.mit.edu the windows users can either use cygwin, PUTTY or some ssh client for additional (good, detailed, recommended) instructions, please see here and here. you will also need to have some minimum ability of working in linux environment. See here for a brief tutorial. Optional, but highly recommended – install paraview on your laptop. This will allow you to inspect the visualization VRML files generated by grasshopper (one picture's worth a thousand words, a 3D rendering is worth a billion).

Installing Geant4 on your own machine

If you are not a MIT NSE student with access to the pre-existing Grasshopper cluster. You can install Grasshopper and the necessary dependencies on your own computational machine of choice.

Please start by installing the main dependency, Geant4 itself, at the following link.

http://geant4-userdoc.web.cern.ch/geant4-userdoc/UsersGuides/InstallationGuide/html/index.html

4.1.3 On Linux (Ubuntu)

In addition:

The Grasshopper program is offered through Launchpad as a personnel package archive (PPA).

4.1.4 On Mac

1) Unpack the source and create a build directory next to it as suggested by the build instructions.

```
$ tar xzf geant4.10.00.tgz
$ mkdir geant4.10.00-build
$ cd geant4.10.00-build
```

Run cmake with appropriate flags to turn on GDML use.

The GDML is so it can read geometry converted from HDDS to GDML using the ROOT TGeoManager->Export() utility. Note that GDML requires xerces and that it be given explicitly.

```
> cmake -DCMAKE_INSTALL_PREFIX=/usr/local/geant4/geant4.10.00.$BMS_OSNAME
-DGEANT4_USE_GDML=ON
-DXERCESC_ROOT_DIR=$XERCESCROOT
-DXERCESC_INCLUDE_DIR=/usr/local/include/
-DXERCESC_LIBRARY=/usr/local/lib/libxerces-c.so
-DGEANT4_BUILD_MULTITHREADED=ON
-DCMAKE_BUILD_TYPE=RelWithDebInfo
-DCMAKE_C_COMPILER=clang
-DCMAKE_CXX_COMPILER=clang++
/Users/"Fill in for your machine"/"Desktop"/"GEANT4"/geant4.xx.xx
```

Note the last line where you must specific your path to where Geant4 is downloaded and the version.

4.1.5 On PC

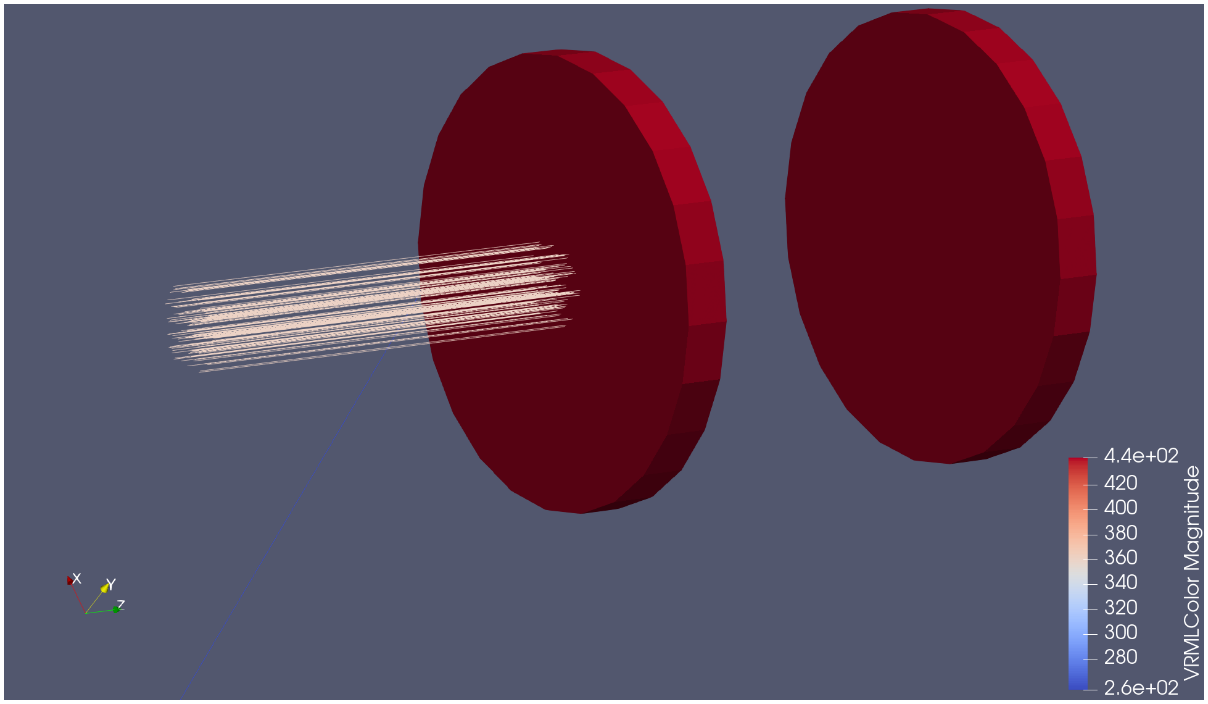
Coming later. The Geant4 website has details on installing Geant4 through PC, which can be done via Cygwin.

4.2 Examples

This page shows some examples of a Grasshopper GDML input file.

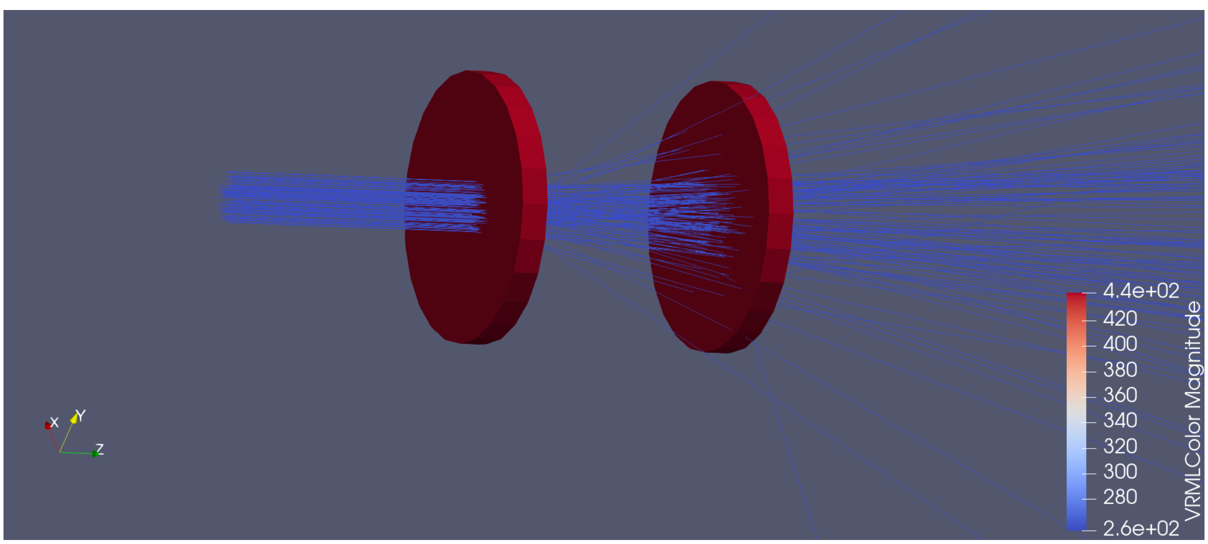
4.2.1 Example Alpha Particle Energy Loss

The world volume consists of Air at 1e-4 atm of pressure. The first red disk is Air at 1 atm and the second red disk is the detector volume made of G4_Si.



4.2.2 Example Beta Particles in Water Transmission

The world volume consists of Air at 1e-4 atm of pressure. The first red disk is G4_WATER and the second red disk is the detector volume made of G4_Si.



4.2.3 Example Hand Calculations for 20 Situations

5 particles, 2 shields, 2 energies

ID	Particle	Shield	Energy
01	Proton	Water 1cm	1 MeV
02	Proton	Water 1cm	10 MeV
03	Proton	G4_Fe 1cm	1 MeV
04	Proton	G4_Fe 1cm	10 MeV
05	Neutron	Water 1cm	1 MeV
06	Neutron	Water 1cm	10 MeV
07	Neutron	G4_Fe 1cm	1 MeV
08	Neutron	G4_Fe 1cm	10 MeV
09	Electron	0.5 Air 1cm	1 MeV
10	Electron	0.5 Air 1cm	10 MeV
11	Electron	1.0 Air 1cm	1 MeV
12	Electron	1.0 Air 1cm	10 MeV
13	Alpha	0.5 Air 1cm	1 MeV
14	Alpha	0.5 Air 1cm	10 MeV
15	Alpha	1.0 Air 1cm	1 MeV
16	Alpha	1.0 Air 1cm	10 MeV
17	Gamma	Water 1cm	1 MeV
18	Gamma	Water 1cm	10 MeV
19	Gamma	G4_Fe 1cm	1 MeV
20	Gamma	G4_Fe 1cm	10 MeV

4.2.4 Equations used

Transmission (Differential Cross Section):

$I = I_0 e^{-\Sigma(E)x}$

Use tables,

Parameters:

- c: speed of light
- ϵ_0: Vacuum permittivity
- beta: the ratio of v to c
- e: electron charge
- m_e: electron mass

ID	Particle	Shield*	Energy	Stopping Power	Transmission
01	Proton	Water 1cm	100 MeV	7.289e0 cm2/g	6.8e-4
02	Proton	Water 1cm	1 GeV	2.211e0 cm2/g	1.1e-1
03	Proton	G4_Fe 1cm	100 MeV	0.05043 cm2/g	6.7e-1
04	Proton	G4_Fe 1cm	1 GeV	0.00157 cm2/g	9.88e-1
05	Neutron	Water 1cm	1 MeV		
06	Neutron	Water 1cm	10 MeV		
07	Neutron	G4_Fe 1cm	1 MeV		
08	Neutron	G4_Fe 1cm	10 MeV		
09	Electron	0.5 Air 1cm	100 MeV	2.41e0 cm2/g	9.97e-1
10	Electron	0.5 Air 1cm	1 GeV	1.46e1 cm2/g	9.82e-1
11	Electron	1.0 Air 1cm	100 MeV	4.82e0 cm2/g	9.94e-1
12	Electron	1.0 Air 1cm	1 GeV	2.91e1 cm2/g	9.65e-1
13	Alpha	0.5 Air 1cm	1 MeV	9.62e2 cm2/g	3.08e-1
14	Alpha	0.5 Air 1cm	10 MeV	2.32e2 cm2/g	7.53e-1
15	Alpha	1.0 Air 1cm	1 MeV	1.92e3 cm2/g	9.47e-2
16	Alpha	1.0 Air 1cm	10 MeV	4.64e2 cm2/g	5.67e-1
17	Gamma	Water 1cm	1 MeV		
18	Gamma	Water 1cm	10 MeV		
19	Gamma	G4_Fe 1cm	1 MeV		
20	Gamma	G4_Fe 1cm	10 MeV		

- water is liquid state

Additionally the following formula could be used but is unnecessary for these high level estimates.

Energy Loss (Bethe Block Formula)

$$-<\frac{dE}{dx}>=\frac{4\pi}{m_ec^2}\frac{nz^2}{\beta^2}(\frac{e^2}{4\pi\epsilon_0})^2[ln(\frac{2m_ec^2\beta^2}{I(1-\beta^2)})-\beta^2]$$

4.3 Release Notes

Release Notes

4.4 Theory and Methodology

4.4.1 Theory

Grasshopper utilizes tools in Geant4 to generate Monte Carlo (MC) particle simultions. In computing, a Monte Carlo algorithm is a randomized algorithm whose output can be incorrect to a certain range in probability. One such examples of an MC algorithm is the Karger–Stein algorithm.

The name refers to the grand casino in the Principality of Monaco at Monte Carlo, which is famous around the world as an icon of gambling. The term "Monte Carlo" was first introduced in 1947 by Nicholas Metropolis.

Las Vegas algorithms are the subset of Monte Carlo algorithms that can always produce the correct answer. Because they make random choices as part of their working, the time taken might vary between runs even with the same input.

Given a procedure for verifying whether the answer given by a Monte Carlo algorithm is correct, and that the analyical probability of a correct answer is bounded above zero, then with probability one running the algorithm repeatedly while testing the answers will eventually give a correct answer. Whether this process is a Las Vegas algorithm depends on whether halting with probability one is considered to satisfy the definition. [1]

4.4.2 GDML

<?xml version="1.0" encoding="UTF-8" standalone="no" ?>

xmlns:xsi

xsi:noNamespaceSchemaLocation

Materials section

Consists of objects that are materials, isotopes, elements, etc.

Define section

Solids section

Structure section

Setup

References

[1] https://en.wikipedia.org/wiki/Monte_Carlo_algorithm

4.5 User's Guide

Welcome to the Grasshopper User's Guide!

This tutorial will guide you through the essential aspects of using OpenMC to perform simulations.

4.6 Developer's Guide

4.6.1 Bugs

Grasshoppers hate bugs. The code has been tested fairly well, however there are probably still some bugs in it. If you run against a strange behavior, please prepare a brief report with the following information

- the platform you are running it on
- the gdml file (attach it)
- a description of the symptoms, along with the relevant part of the screen output

Email the bug report to mailto:aregjan@mit.edu.

Please generate a GitHub pull request if you believe that you have source code changes to make in order to avoid the bug.

4.6.2 Grasshopper Specific Files

The base of Grasshopper which interacts with G4 is written in C++.

The files included in the src/ and include/ directories from root are as follows.

src/

Analysis.cc

AnalysisManager.cc

DADEphysicsList.cc

DMXMaxTimeCuts.cc

DMXMinEkineCuts.cc

DMXPhysicsList.cc

EventAction.cc

EventActionMessenger.cc

GammaNuclearPhysics.cc

PhysicsList.cc

PrimaryGeneratorAction.cc

RunAction.cc

StackingAction.cc

SteppingAction.cc

VisManager.cc

src/

Analysis.hh

AnalysisManager.hh

DADEphysicsList.hh

DetectorConstruction.hh

DMXMaxTimeCuts.hh

DMXMinEkineCuts.hh

DMXPhysicsList.hh

DMXSpecialCuts.hh

EventAction.hh

EventActionMessenger.hh

GammaNuclearPhysics.hh

PhysicsList.hh

PhysicsListLowEnergy.hh

PrimaryGeneratorAction.hh

RunAction.hh

StackingAction.hh

SteppingAction.hh

VisManager.hh

4.6.3 Contributing to Grasshopper

Thank you for considering contributing to Grasshopper! We look forward to welcoming new members to the community and will do our best to help you get up to speed. The purpose of this section is to document how the project is managed: how contributions (bug fixes, enhancements, new features) are made, how they are evaluated, who is permitted to merge pull requests, and what happens in the event of disagreements. Once you have read through this section, the workflow section outlines the actual mechanics of making a contribution (forking, submitting a pull request, etc.).

The goal of our governance model is to:

- Encourage new contributions.
- Encourage contributors to remain involved.
- Avoid unnecessary processes and bureaucracy whenever possible.
- Create a transparent decision making process which makes it clear how contributors can be involved in decision making.

Overview

Grasshopper uses a liberal contribution model for project governance. Anyone involved in development in a non-trivial capacity is given an opportunity to influence the direction of the project. Students working with the project head Areg have supplied code. Project decisions are made through a consensus-seeking process rather than by voting.

Docs

Documentation is managed through ReadTheDocs. This platform allows us to use the Sphinx documentation engine. While the Sphinx library is designed for use with Python projects, ReadTheDocs has extensions for many sorts of code bases.

The RTD getting started page (Link)[https://docs.readthedocs.io/en/stable/index.html].

Terminology

- A *Contributor* is any individual creating or commenting on an issue or pull request.
- A *Committer* is a subset of contributors who are authorized to review and merge pull requests.
- The *TC* (Technical Committee) is a group of committers who have the authority to make decisions on behalf of the project team in order to resolve disputes.
- The *Project Lead* is a single individual who has the authority to make a final decision when the TC is unable to reach consensus.

Contribution Process

Any change to the Grasshopper repository must be made through a pull request (PR). This applies to all changes to documentation, code, binary files, etc. Even long term committers and TC members must use pull requests.

No pull request may be merged without being independently reviewed.

For non-trivial contributions, pull requests should not be merged for at least 36 hours to ensure that contributors in other timezones have time to review. Consideration should be given to weekends and other holiday periods to ensure active committers have reasonable time to become involved in the discussion and review process if they wish. Any committer may request that the review period be extended if they are unable to review the change within 36 hours.

During review, a committer may request that a specific contributor who is most versed in a particular area review the PR before it can be merged.

A pull request can be merged by any committer, but only if no objections are raised by any other committer. In the case of an objection being raised, all involved committers should seek consensus through discussion and compromise.

In the case of an objection being raised in a pull request by another committer, all involved committers should seek to arrive at a consensus by way of addressing concerns being expressed through discussion, compromise on the proposed change, or withdrawal of the proposed change.

If objections to a PR are made and committers cannot reach a consensus on how to proceed, the decision is escalated to the TC. TC members should regularly discuss pending contributions in order to find a resolution. It is expected that only a small minority of issues be brought to the TC for resolution and that discussion and compromise among committers be the default resolution mechanism.

Becoming a Committer

All contributors who make a non-trivial contribution will be added as a committer in a timely manner. Committers are expected to follow this policy.

TC Process

Any issues brought to the TC will be addressed among the committee with a consensus-seeking process. The group tries to find a resolution that has no objections among TC members. If a consensus cannot be reached, the Project Lead has the ultimate authority to make a final decision. It is expected that the majority of decisions made by the TC are via a consensus seeking process and that the Project Lead intercedes only as a last resort.

Resolution may involve returning the issue to committers with suggestions on how to move forward towards a consensus.

Members can be added to the TC at any time. Any committer can nominate another committer to the TC and the TC uses its standard consensus seeking process to evaluate whether or not to add this new member. Members who do not participate consistently at the level of a majority of the other members are expected to resign.

In the event that the Project Lead resigns or otherwise steps down, the TC uses a consensus seeking process to choose a new Project Lead.

Team

The team consists of the following individuals:

- Areg Danagoulian
- Jacob Miske

4.6.4 Style Guide

In developing C++ code, please follow the standards of the C++ linter.

In developing Python code, please follow the standards of the PyLint linter.

Welcome to the Grasshopper Developer's Guide!

This guide documents how contributions are made to Grasshopper, what style rules exist for the code, how to run tests, and other related topics.

In addition, the Dev Guide serves to brief Grasshopper users on the functionality of each file in the codebase of the Grasshopper program. For devs, the shorthand for Grasshopper can be GRSHPR, a recursive acronym for "Grasshopper Realistically Simulates High-Energy Particles & Radiation".

4.7 Python API

Python API

Grasshoppers base functionality can be accessed with a python library.

ESTAR API

https://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

PSTAR API

https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

APSTAR API

https://physics.nist.gov/PhysRefData/Star/Text/ASTAR.html

4.8 Grasshopper Formats

Grasshopper is built to accept an input file in the form of a GDML file. Use of other interfaces to generate the GDML input are available.

4.9 Publications

4.9.1 Overviews

4.9.2 Benchmarking

A thesis project to benchmark the Grasshopper program against other physics simulations tools is currently in progress.

4.10 License Agreement

The Grasshopper software uses the GPL 3.

GNU GENERAL PUBLIC LICENSE

Version 3, 29 June 2007

Preamble

The GNU General Public License is a free, copyleft license for software and other kinds of works.

The licenses for most software and other practical works are designed to take away your freedom to share and change the works. By contrast, the GNU General Public License is intended to guarantee your freedom to share and change all versions of a program–to make sure it remains free software for all its users. We, the Free Software Foundation, use the GNU General Public License for most of our software; it applies also to any other work released this way by its authors. You can apply it to your programs, too.

When we speak of free software, we are referring to freedom, not price. Our General Public Licenses are designed to make sure that you have the freedom to distribute copies of free software (and charge for them if you wish), that you receive source code or can get it if you want it, that you can change the software or use pieces of it in new free programs, and that you know you can do these things.

To protect your rights, we need to prevent others from denying you these rights or asking you to surrender the rights. Therefore, you have certain responsibilities if you distribute copies of the software, or if you modify it: responsibilities to respect the freedom of others.

For example, if you distribute copies of such a program, whether gratis or for a fee, you must pass on to the recipients the same freedoms that you received. You must make sure that they, too, receive or can get the source code. And you must show them these terms so they know their rights.

Developers that use the GNU GPL protect your rights with two steps: (1) assert copyright on the software, and (2) offer you this License giving you legal permission to copy, distribute and/or modify it.

For the developers' and authors' protection, the GPL clearly explains that there is no warranty for this free software. For both users' and authors' sake, the GPL requires that modified versions be marked as changed, so that their problems will not be attributed erroneously to authors of previous versions.

Some devices are designed to deny users access to install or run modified versions of the software inside them, although the manufacturer can do so. This is fundamentally incompatible with the aim of protecting users' freedom to change the software. The systematic pattern of such abuse occurs in the area of products for individuals to use, which is precisely where it is most unacceptable. Therefore, we have designed this version of the GPL to prohibit the practice for those products. If such problems arise substantially in other domains, we stand ready to extend this provision to those domains in future versions of the GPL, as needed to protect the freedom of users.

Finally, every program is threatened constantly by software patents. States should not allow patents to restrict development and use of software on general-purpose computers, but in those that do, we wish to avoid the special danger that patents applied to a free program could make it effectively proprietary. To prevent this, the GPL assures that patents cannot be used to render the program non-free.

The precise terms and conditions for copying, distribution and modification follow.

TERMS AND CONDITIONS

0. Definitions.

"This License" refers to version 3 of the GNU General Public License.

"Copyright" also means copyright-like laws that apply to other kinds of works, such as semiconductor masks.

"The Program" refers to any copyrightable work licensed under this License. Each licensee is addressed as "you". "Licensees" and "recipients" may be individuals or organizations.

To "modify" a work means to copy from or adapt all or part of the work in a fashion requiring copyright permission, other than the making of an exact copy. The resulting work is called a "modified version" of the earlier work or a work "based on" the earlier work.

A "covered work" means either the unmodified Program or a work based on the Program.

To "propagate" a work means to do anything with it that, without permission, would make you directly or secondarily liable for infringement under applicable copyright law, except executing it on a computer or modifying a private copy.

Propagation includes copying, distribution (with or without modification), making available to the public, and in some countries other activities as well.

To "convey" a work means any kind of propagation that enables other parties to make or receive copies. Mere interaction with a user through a computer network, with no transfer of a copy, is not conveying.

An interactive user interface displays "Appropriate Legal Notices" to the extent that it includes a convenient and prominently visible feature that (1) displays an appropriate copyright notice, and (2) tells the user that there is no warranty for the work (except to the extent that warranties are provided), that licensees may convey the work under this License, and how to view a copy of this License. If the interface presents a list of user commands or options, such as a menu, a prominent item in the list meets this criterion.

1. Source Code.

The "source code" for a work means the preferred form of the work for making modifications to it. "Object code" means any non-source form of a work.

A "Standard Interface" means an interface that either is an official standard defined by a recognized standards body, or, in the case of interfaces specified for a particular programming language, one that is widely used among developers working in that language.

The "System Libraries" of an executable work include anything, other than the work as a whole, that (a) is included in the normal form of packaging a Major Component, but which is not part of that Major Component, and (b) serves only to enable use of the work with that Major Component, or to implement a Standard Interface for which an implementation is available to the public in source code form. A "Major Component", in this context, means a major essential component (kernel, window system, and so on) of the specific operating system (if any) on which the executable work runs, or a compiler used to produce the work, or an object code interpreter used to run it.

The "Corresponding Source" for a work in object code form means all the source code needed to generate, install, and (for an executable work) run the object code and to modify the work, including scripts to control those activities. However, it does not include the work's System Libraries, or general-purpose tools or generally available free programs which are used unmodified in performing those activities but which are not part of the work. For example, Corresponding Source includes interface definition files associated with source files for the work, and the source code for shared libraries and dynamically linked subprograms that the work is specifically designed to require, such as by intimate data communication or control flow between those subprograms and other parts of the work.

The Corresponding Source need not include anything that users can regenerate automatically from other parts of the Corresponding Source.

The Corresponding Source for a work in source code form is that same work.

2. Basic Permissions.

All rights granted under this License are granted for the term of copyright on the Program, and are irrevocable provided the stated conditions are met. This License explicitly affirms your unlimited permission to run the unmodified Program. The output from running a covered work is covered by this License only if the output, given its content, constitutes a covered work. This License acknowledges your rights of fair use or other equivalent, as provided by copyright law.

You may make, run and propagate covered works that you do not convey, without conditions so long as your license otherwise remains in force. You may convey covered works to others for the sole purpose of having them make modifications exclusively for you, or provide you with facilities for running those works, provided that you comply with the terms of this License in conveying all material for which you do not control copyright. Those thus making or running the covered works for you must do so exclusively on your behalf, under your direction and control, on terms that prohibit them from making any copies of your copyrighted material outside their relationship with you.

Conveying under any other circumstances is permitted solely under the conditions stated below. Sublicensing is not allowed; section 10 makes it unnecessary.

3. Protecting Users' Legal Rights From Anti-Circumvention Law.

No covered work shall be deemed part of an effective technological measure under any applicable law fulfilling obligations under article 11 of the WIPO copyright treaty adopted on 20 December 1996, or similar laws prohibiting or restricting circumvention of such measures.

When you convey a covered work, you waive any legal power to forbid circumvention of technological measures to the extent such circumvention is effected by exercising rights under this License with respect to the covered work, and you disclaim any intention to limit operation or modification of the work as a means of enforcing, against the work's users, your or third parties' legal rights to forbid circumvention of technological measures.

4. Conveying Verbatim Copies.

You may convey verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice; keep intact all notices stating that this License and any non-permissive terms added in accord with section 7 apply to the code; keep intact all notices of the absence of any warranty; and give all recipients a copy of this License along with the Program.

You may charge any price or no price for each copy that you convey, and you may offer support or warranty protection for a fee.

5. Conveying Modified Source Versions.

You may convey a work based on the Program, or the modifications to produce it from the Program, in the form of source code under the terms of section 4, provided that you also meet all of these conditions:

a) The work must carry prominent notices stating that you modified it, and giving a relevant date.

b) The work must carry prominent notices stating that it is released under this License and any conditions added under section 7. This requirement modifies the requirement in section 4 to "keep intact all notices".

c) You must license the entire work, as a whole, under this License to anyone who comes into possession of a copy. This License will therefore apply, along with any applicable section 7 additional terms, to the whole of the work, and all its parts, regardless of how they are packaged. This License gives no permission to license the work in any other way, but it does not invalidate such permission if you have separately received it.

d) If the work has interactive user interfaces, each must display Appropriate Legal Notices; however, if the Program has interactive interfaces that do not display Appropriate Legal Notices, your work need not make them do so.

A compilation of a covered work with other separate and independent works, which are not by their nature extensions of the covered work, and which are not combined with it such as to form a larger program, in or on a volume of a storage or distribution medium, is called an "aggregate" if the compilation and its resulting copyright are not used to limit the access or legal rights of the compilation's users beyond what the individual works permit. Inclusion of a covered work in an aggregate does not cause this License to apply to the other parts of the aggregate.

6. Conveying Non-Source Forms.

You may convey a covered work in object code form under the terms of sections 4 and 5, provided that you also convey the machine-readable Corresponding Source under the terms of this License, in one of these ways:

a) Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by the Corresponding Source fixed on a durable physical medium customarily used for software interchange.

b) Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by a written offer, valid for at least three years and valid for as long as you offer spare parts or customer support for that product model, to give anyone who possesses the object code either (1) a copy of the Corresponding Source for all the software in the product that is covered by this License, on a durable physical medium customarily used for software interchange, for a price no more than your reasonable cost of physically performing this conveying of source, or (2) access to copy the Corresponding Source from a network server at no charge.

c) Convey individual copies of the object code with a copy of the written offer to provide the Corresponding Source. This alternative is allowed only occasionally and noncommercially, and only if you received the object code with such an offer, in accord with subsection 6b.

d) Convey the object code by offering access from a designated place (gratis or for a charge), and offer equivalent access to the Corresponding Source in the same way through the same place at no further charge. You need not require recipients to copy the Corresponding Source along with the object code. If the place to copy the object code is a network server, the Corresponding Source may be on a different server (operated by you or a third party) that supports equivalent copying facilities, provided you maintain clear directions next to the object code saying where to find the Corresponding Source. Regardless of what server hosts the Corresponding Source, you remain obligated to ensure that it is available for as long as needed to satisfy these requirements.

e) Convey the object code using peer-to-peer transmission, provided you inform other peers where the object code and Corresponding Source of the work are being offered to the general public at no charge under subsection 6d.

A separable portion of the object code, whose source code is excluded from the Corresponding Source as a System Library, need not be included in conveying the object code work.

A “User Product” is either (1) a “consumer product”, which means any tangible personal property which is normally used for personal, family, or household purposes, or (2) anything designed or sold for incorporation into a dwelling. In determining whether a product is a consumer product, doubtful cases shall be resolved in favor of coverage. For a particular product received by a particular user, “normally used” refers to a typical or common use of that class of product, regardless of the status of the particular user or of the way in which the particular user actually uses, or expects or is expected to use, the product. A product is a consumer product regardless of whether the product has substantial commercial, industrial or non-consumer uses, unless such uses represent the only significant mode of use of the product.

“Installation Information” for a User Product means any methods, procedures, authorization keys, or other information required to install and execute modified versions of a covered work in that User Product from a modified version of its Corresponding Source. The information must suffice to ensure that the continued functioning of the modified object code is in no case prevented or interfered with solely because modification has been made.

If you convey an object code work under this section in, or with, or specifically for use in, a User Product, and the conveying occurs as part of a transaction in which the right of possession and use of the User Product is transferred to the recipient in perpetuity or for a fixed term (regardless of how the transaction is characterized), the Corresponding Source conveyed under this section must be accompanied by the Installation Information. But this requirement does not apply if neither you nor any third party retains the ability to install modified object code on the User Product (for example, the work has been installed in ROM).

The requirement to provide Installation Information does not include a requirement to continue to provide support service, warranty, or updates for a work that has been modified or installed by the recipient, or for the User Product in which it has been modified or installed. Access to a network may be denied when the modification itself materially and adversely affects the operation of the network or violates the rules and protocols for communication across the network.

Corresponding Source conveyed, and Installation Information provided, in accord with this section must be in a format that is publicly documented (and with an implementation available to the public in source code form), and must require no special password or key for unpacking, reading or copying.

7. Additional Terms.

“Additional permissions” are terms that supplement the terms of this License by making exceptions from one or more of its conditions. Additional permissions that are applicable to the entire Program shall be treated as though they were included in this License, to the extent that they are valid under applicable law. If additional permissions apply only to part of the Program, that part may be used separately under those permissions, but the entire Program remains governed by this License without regard to the additional permissions.

When you convey a copy of a covered work, you may at your option remove any additional permissions from that copy, or from any part of it. (Additional permissions may be written to require their own removal in certain cases when you modify the work.) You may place additional permissions on material, added by you to a covered work, for which you have or can give appropriate copyright permission.

Notwithstanding any other provision of this License, for material you add to a covered work, you may (if authorized by the copyright holders of that material) supplement the terms of this License with terms:

a) Disclaiming warranty or limiting liability differently from the terms of sections 15 and 16 of this License; or

b) Requiring preservation of specified reasonable legal notices or author attributions in that material or in the Appropriate Legal Notices displayed by works containing it; or

c) Prohibiting misrepresentation of the origin of that material, or requiring that modified versions of such material be marked in reasonable ways as different from the original version; or

d) Limiting the use for publicity purposes of names of licensors or authors of the material; or

e) Declining to grant rights under trademark law for use of some trade names, trademarks, or service marks; or

f) Requiring indemnification of licensors and authors of that material by anyone who conveys the material (or modified versions of it) with contractual assumptions of liability to the recipient, for any liability that these contractual assumptions directly impose on those licensors and authors.

All other non-permissive additional terms are considered "further restrictions" within the meaning of section 10. If the Program as you received it, or any part of it, contains a notice stating that it is governed by this License along with a term that is a further restriction, you may remove that term. If a license document contains a further restriction but permits relicensing or conveying under this License, you may add to a covered work material governed by the terms of that license document, provided that the further restriction does not survive such relicensing or conveying.

If you add terms to a covered work in accord with this section, you must place, in the relevant source files, a statement of the additional terms that apply to those files, or a notice indicating where to find the applicable terms.

Additional terms, permissive or non-permissive, may be stated in the form of a separately written license, or stated as exceptions; the above requirements apply either way.

8. Termination.

You may not propagate or modify a covered work except as expressly provided under this License. Any attempt otherwise to propagate or modify it is void, and will automatically terminate your rights under this License (including any patent licenses granted under the third paragraph of section 11).

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, you do not qualify to receive new licenses for the same material under section 10.

9. Acceptance Not Required for Having Copies.

You are not required to accept this License in order to receive or run a copy of the Program. Ancillary propagation of a covered work occurring solely as a consequence of using peer-to-peer transmission to receive a copy likewise does not require acceptance. However, nothing other than this License grants you permission to propagate or modify any covered work. These actions infringe copyright if you do not accept this License. Therefore, by modifying or propagating a covered work, you indicate your acceptance of this License to do so.

10. Automatic Licensing of Downstream Recipients.

Each time you convey a covered work, the recipient automatically receives a license from the original licensors, to run, modify and propagate that work, subject to this License. You are not responsible for enforcing compliance by third parties with this License.

An "entity transaction" is a transaction transferring control of an organization, or substantially all assets of one, or subdividing an organization, or merging organizations. If propagation of a covered work results from an entity transaction, each party to that transaction who receives a copy of the work also receives whatever licenses to the work the party's predecessor in interest had or could give under the previous paragraph, plus a right to possession of the Corresponding Source of the work from the predecessor in interest, if the predecessor has it or can get it with reasonable efforts.

You may not impose any further restrictions on the exercise of the rights granted or affirmed under this License. For example, you may not impose a license fee, royalty, or other charge for exercise of rights granted under this License, and you may not initiate litigation (including a cross-claim or counterclaim in a lawsuit) alleging that any patent claim is infringed by making, using, selling, offering for sale, or importing the Program or any portion of it.

11. Patents.

A "contributor" is a copyright holder who authorizes use under this License of the Program or a work on which the Program is based. The work thus licensed is called the contributor's "contributor version".

A contributor's "essential patent claims" are all patent claims owned or controlled by the contributor, whether already acquired or hereafter acquired, that would be infringed by some manner, permitted by this License, of making, using, or selling its contributor version, but do not include claims that would be infringed only as a consequence of further modification of the contributor version. For purposes of this definition, "control" includes the right to grant patent sublicenses in a manner consistent with the requirements of this License.

Each contributor grants you a non-exclusive, worldwide, royalty-free patent license under the contributor's essential patent claims, to make, use, sell, offer for sale, import and otherwise run, modify and propagate the contents of its contributor version.

In the following three paragraphs, a "patent license" is any express agreement or commitment, however denominated, not to enforce a patent (such as an express permission to practice a patent or covenant not to sue for patent infringement). To "grant" such a patent license to a party means to make such an agreement or commitment not to enforce a patent against the party.

If you convey a covered work, knowingly relying on a patent license, and the Corresponding Source of the work is not available for anyone to copy, free of charge and under the terms of this License, through a publicly available network server or other readily accessible means, then you must either (1) cause the Corresponding Source to be so available, or (2) arrange to deprive yourself of the benefit of the patent license for this particular work, or (3) arrange, in a manner consistent with the requirements of this License, to extend the patent license to downstream recipients. "Knowingly relying" means you have actual knowledge that, but for the patent license, your conveying the covered work in a country, or your recipient's use of the covered work in a country, would infringe one or more identifiable patents in that country that you have reason to believe are valid.

If, pursuant to or in connection with a single transaction or arrangement, you convey, or propagate by procuring conveyance of, a covered work, and grant a patent license to some of the parties receiving the covered work authorizing them to use, propagate, modify or convey a specific copy of the covered work, then the patent license you grant is automatically extended to all recipients of the covered work and works based on it.

A patent license is "discriminatory" if it does not include within the scope of its coverage, prohibits the exercise of, or is conditioned on the non-exercise of one or more of the rights that are specifically granted under this License. You may not convey a covered work if you are a party to an arrangement with a third party that is in the business of distributing software, under which you make payment to the third party based on the extent of your activity of conveying the work, and under which the third party grants, to any of the parties who would receive the covered work from you, a discriminatory patent license (a) in connection with copies of the covered work conveyed by you (or copies made from those copies), or (b) primarily for and in connection with specific products or compilations that contain the covered work, unless you entered into that arrangement, or that patent license was granted, prior to 28 March 2007.

Nothing in this License shall be construed as excluding or limiting any implied license or other defenses to infringement that may otherwise be available to you under applicable patent law.

12. No Surrender of Others' Freedom.

If conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot convey a covered work so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not convey it at all. For example, if you agree to terms that obligate you to collect a royalty for further conveying from those to whom you convey the Program, the only way you could satisfy both those terms and this License would be to refrain entirely from conveying the Program.

13. Use with the GNU Affero General Public License.

Notwithstanding any other provision of this License, you have permission to link or combine any covered work with a work licensed under version 3 of the GNU Affero General Public License into a single combined work, and to convey the resulting work. The terms of this License will continue to apply to the part which is the covered work, but the special requirements of the GNU Affero General Public License, section 13, concerning interaction through a network will apply to the combination as such.

14. Revised Versions of this License.

The Free Software Foundation may publish revised and/or new versions of the GNU General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies that a certain numbered version of the GNU General Public License "or any later version" applies to it, you have the option of following the terms and conditions either of that numbered version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of the GNU General Public License, you may choose any version ever published by the Free Software Foundation.

If the Program specifies that a proxy can decide which future versions of the GNU General Public License can be used, that proxy's public statement of acceptance of a version permanently authorizes you to choose that version for the Program.

Later license versions may give you additional or different permissions. However, no additional obligations are imposed on any author or copyright holder as a result of your choosing to follow a later version.

15. Disclaimer of Warranty.

THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.

16. Limitation of Liability.

IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MODIFIES AND/OR CONVEYS THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

17. Interpretation of Sections 15 and 16.

If the disclaimer of warranty and limitation of liability provided above cannot be given local legal effect according to their terms, reviewing courts shall apply local law that most closely approximates an absolute waiver of all civil