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.
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 similarity 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
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.

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.$BMS_OSNAME
-DCMAKE_USE_GDML=ON
-DXERCESC_ROOT_DIR=$XERCESCROOT
-DXERCESC_INCLUDE_DIR=/usr/local/include/
-DXERCESC_LIBRARY=/usr/local/lib/libxerces-c.so
-GEANT4_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
<table>
<thead>
<tr>
<th>ID</th>
<th>Particle</th>
<th>Shield</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Proton</td>
<td>Water 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>02</td>
<td>Proton</td>
<td>Water 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>03</td>
<td>Proton</td>
<td>G4_Fe 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>04</td>
<td>Proton</td>
<td>G4_Fe 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>05</td>
<td>Neutron</td>
<td>Water 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>06</td>
<td>Neutron</td>
<td>Water 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>07</td>
<td>Neutron</td>
<td>G4_Fe 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>08</td>
<td>Neutron</td>
<td>G4_Fe 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>09</td>
<td>Electron</td>
<td>0.5 Air 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>10</td>
<td>Electron</td>
<td>0.5 Air 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>11</td>
<td>Electron</td>
<td>1.0 Air 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>12</td>
<td>Electron</td>
<td>1.0 Air 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>13</td>
<td>Alpha</td>
<td>0.5 Air 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>14</td>
<td>Alpha</td>
<td>0.5 Air 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>15</td>
<td>Alpha</td>
<td>1.0 Air 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>16</td>
<td>Alpha</td>
<td>1.0 Air 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>17</td>
<td>Gamma</td>
<td>Water 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>18</td>
<td>Gamma</td>
<td>Water 1 cm</td>
<td>10 MeV</td>
</tr>
<tr>
<td>19</td>
<td>Gamma</td>
<td>G4_Fe 1 cm</td>
<td>1 MeV</td>
</tr>
<tr>
<td>20</td>
<td>Gamma</td>
<td>G4_Fe 1 cm</td>
<td>10 MeV</td>
</tr>
</tbody>
</table>

### 4.2.4 Equations used

Transmission (Differential Cross Section):

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

Use tables,

Parameters:

- \( c \): speed of light
- \( \epsilon_0 \): Vacuum permittivity
- \( \beta \): the ratio of \( v \) to \( c \)
- \( e \): electron charge
- \( m_e \): electron mass
<table>
<thead>
<tr>
<th>ID</th>
<th>Particle</th>
<th>Shield*</th>
<th>Energy</th>
<th>Stopping Power</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Proton</td>
<td>Water 1cm</td>
<td>100 MeV</td>
<td>7.289e0 cm²/g</td>
<td>6.8e-4</td>
</tr>
<tr>
<td>02</td>
<td>Proton</td>
<td>Water 1cm</td>
<td>1 GeV</td>
<td>2.211e0 cm²/g</td>
<td>1.1e-1</td>
</tr>
<tr>
<td>03</td>
<td>Proton</td>
<td>G4_Fe 1cm</td>
<td>100 MeV</td>
<td>0.05043 cm²/g</td>
<td>6.7e-1</td>
</tr>
<tr>
<td>04</td>
<td>Proton</td>
<td>G4_Fe 1cm</td>
<td>1 GeV</td>
<td>0.00157 cm²/g</td>
<td>9.88e-1</td>
</tr>
<tr>
<td>05</td>
<td>Neutron</td>
<td>Water 1cm</td>
<td>1 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>Neutron</td>
<td>Water 1cm</td>
<td>10 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>Neutron</td>
<td>G4_Fe 1cm</td>
<td>1 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>Neutron</td>
<td>G4_Fe 1cm</td>
<td>10 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>Electron</td>
<td>0.5 Air 1cm</td>
<td>100 MeV</td>
<td>2.41e0 cm²/g</td>
<td>9.97e-1</td>
</tr>
<tr>
<td>10</td>
<td>Electron</td>
<td>0.5 Air 1cm</td>
<td>1 GeV</td>
<td>1.46e1 cm²/g</td>
<td>9.82e-1</td>
</tr>
<tr>
<td>11</td>
<td>Electron</td>
<td>1.0 Air 1cm</td>
<td>100 MeV</td>
<td>4.82e0 cm²/g</td>
<td>9.94e-1</td>
</tr>
<tr>
<td>12</td>
<td>Electron</td>
<td>1.0 Air 1cm</td>
<td>1 GeV</td>
<td>2.91e1 cm²/g</td>
<td>9.65e-1</td>
</tr>
<tr>
<td>13</td>
<td>Alpha</td>
<td>0.5 Air 1cm</td>
<td>1 MeV</td>
<td>9.62e2 cm²/g</td>
<td>3.08e-1</td>
</tr>
<tr>
<td>14</td>
<td>Alpha</td>
<td>0.5 Air 1cm</td>
<td>10 MeV</td>
<td>2.32e2 cm²/g</td>
<td>7.53e-1</td>
</tr>
<tr>
<td>15</td>
<td>Alpha</td>
<td>1.0 Air 1cm</td>
<td>1 MeV</td>
<td>1.92e3 cm²/g</td>
<td>9.74e-2</td>
</tr>
<tr>
<td>16</td>
<td>Alpha</td>
<td>1.0 Air 1cm</td>
<td>10 MeV</td>
<td>4.64e2 cm²/g</td>
<td>5.67e-1</td>
</tr>
<tr>
<td>17</td>
<td>Gamma</td>
<td>Water 1cm</td>
<td>1 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Gamma</td>
<td>Water 1cm</td>
<td>10 MeV</td>
<td></td>
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</tr>
<tr>
<td>19</td>
<td>Gamma</td>
<td>G4_Fe 1cm</td>
<td>1 MeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Gamma</td>
<td>G4_Fe 1cm</td>
<td>10 MeV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- water is liquid state

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

Energy Loss (Bethe Block Formula)

\[- \frac{dE}{dx} = \frac{4\pi}{m_e c^2} \frac{n z^2}{\beta^2} \left( \frac{e^2}{4\pi\epsilon_0} \right)^2 \ln \left( \frac{2m_e c^2 \beta^2}{I(1 - \beta^2)} \right) - \beta^2 \]

### 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 simulations. 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 analytical 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
<?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


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
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.


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.

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**GNU GENERAL PUBLIC LICENSE**

Version 3, 29 June 2007

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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.


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.

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