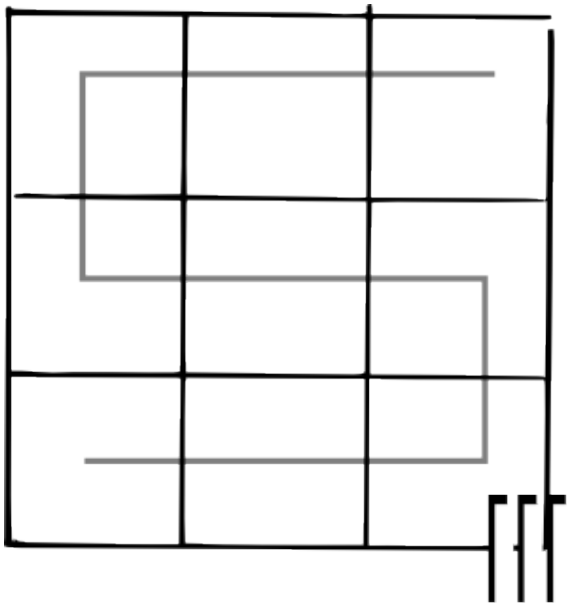

Peano Cookbook

www.peano-framework.org

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1 Preamble

Peano is an open source C++ solver framework. It is based upon the fact that spacetrees, a generalisation of the classical octree concept, yield a cascade of adaptive Cartesian grids. Consequently, any spacetree traversal is equivalent to an element-wise traversal of the hierarchy of the adaptive Cartesian grids. The software Peano realises such a grid traversal and storage algorithm, and it provides hook-in points for applications performing per-element, per-vertex, and so forth operations on the grid. It also provides interfaces for dynamic load balancing, sophisticated geometry representations, and other features. Some properties are enlisted below.

Peano is currently available in its third generation. The development of the original set of Peano codes started around 2002. 2005-2009, we merged these codes into one Peano kernel (2nd generation). In 2009, I started a complete reimplementation of the kernel with special emphasis on reusability, application-independent design and the support for rapid prototyping. This third generation of the code is subject of the present cookbook.

Dependencies and prerequisites

Peano is plain C++ code and depends only on MPI and Intel's TBB or OpenMP if you want to run it with distributed or shared memory support. There are no further dependencies or libraries required. C++ 11 is used. GCC 4.2 and Intel 12 should be sufficient to follow all examples presented in this document. If you intend to use Peano, we provide a small Java tool to facilitate rapid prototyping and to get rid of writing glue code. This Peano Development Toolkit (PDT) is pure Java and uses DaStGen. While we provide the PDT's sources, there's also a jar file available that comprises all required Java libraries and runs stand alone. To be able to use DaStGen—we use this tool frequently throughout the cookbook—you need a recently new Java version.

We recommend to use Peano in combination with

- Paraview (`www.paraview.org`) or VisIt (`https://wci.llnl.gov/simulation/computer-codes/visit/`) as our default toolboxes create vtk files.
- make and `awk`.

But these software tools are not mandatory.

The whole cookbook assumes that you use a Linux system. It all should work on Windows and Mac as well, but we haven't tested it in detail.

Who should read this document

This cookbook is written similar to a tutorial in a hands-on style. Therefore, it also contains lots of source code snippets. If you read through a chapter, you should immediately be able to re-program the presented details in your code and use the ideas.

Therefore, this cookbook is written for people that have a decent programming background as well as scientific computing knowledge. Some background in the particular application area's algorithms for some chapters also is required. If you read about the particle handling in Peano, e.g., the text requires you to know at least some basics such as linked-cell methods. The text does not discuss mathematical, numerical or algorithmic background. It is a cookbook after all.

What is contained in this document

This book covers a variety of problems I have tackled with Peano when I wrote scientific papers. There is no overall read thread through the document. I recommend to start reading some chapters and then jump into chapters that are of particular interest. Whenever something comes to my mind that should be added, I will add it. If you feel something is urgently missing and deserves a chapter or things remain unclear, please write me an email and I'll see whether I can provide some additional text or extend the cookbook.

September 14, 2015
Tobias Weinzierl

Contents

2 Quickstart

Time: Should take you around 15 minutes to get the code up and running. Then another 15 minutes to have the first static adaptive Cartesian grid.
Required: No previous knowledge, but some experience with the Linux command line and Paraview is advantageous.

2.1 Download and install

To start work with Peano, you need at least two things.

1. The Peano source code. Today, the source code consists of two important directories. The `peano` directory holds the actual Peano code. An additional `tarch` directory holds Peano's technical architecture.
2. The Peano Development Toolkit (PDT). The PDT is a small Java archive. It takes away the cumbersome work to write lots of glue code, i.e. empty interface implementations, default routines, ..., so we use it quite frequently.

For advanced features, you might want to use some **toolboxes**. A toolbox in Peano is a small collection of files that you store in a directory and adopt all pathes accordingly. From a user's point of view, when we use the term toolbox we actually mean this directory with all its content.

> **Remark:** Originally, we hoped that Peano's technical architecture (`tarch`) might become of value for several projects, i.e. projects appreciate that they do not have to re-develop things such as logging, writing of output files, writing support for OpenMP and TBB, and so forth. To the best of our knowledge, the tarch however is not really used by someone else, so we cannot really claim that it is independent of Peano. Nevertheless, we try to keep it separate and not to add anyting AMR or grid-specific to the tarch.

There are two ways to get hold of Peano's sources and tools. You either *download the archives from the website* or you *access the repository directly*. Both variants are fine. We recommend to access the respository directly.

2.1.1 Download the archives from the website

If you don't want to download Peano's whole archive, change to Peano's webpage `http://www.peano-framework.org` and grab the files

- `peano.tar.gz` and
- `pdt.jar`

from there. If you do so, please skip the first two lines from the script before. Otherwise, load down the important files with `wget`. Independent of which variant you follow, please unpack the `peano.tar.gz` archive. It holds all required C++ sources.

```
> wget http://sourceforge.net/projects/peano/files/peano.tar.gz
> wget http://sourceforge.net/projects/peano/files/pdt.jar
> tar -xzvf peano.tar.gz
```

There's a couple of helper files that we use IN the cookbook. They are not necessarily required for each Peano project, but for our examples here they are very useful. So, please create an additional directory `usrtemplates` and grap these files

```
> mkdir usrtemplates
> cd usrtemplates
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTKMultilevelGridVisualiserImplementation.template
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTKMultilevelGridVisualiserHeader.template
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTKGridVisualiserImplementation.template
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTKGridVisualiserHeader.template
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTK2dTreeVisualiserImplementation.template
> wget http://sourceforge.net/projects/peano/files/ \
  usrtemplates/VTK2dTreeVisualiserHeader.template
```

2.1.2 Access the repository directly

Instead of a manual download, you might also decide to download a copy of the whole Peano repository. This also has the advantage that you can do a simple `svn update` anytime later throughout your development to immediately obtain all kernel modifications.

```
> svn checkout http://svn.code.sf.net/p/peano/code/trunk peano
```

Your directory structure will be slightly different than in the example above, but this way you can be sure you grabbed everything that has been released for Peano through the webpage ever.

The archive `pdt.jar` will be contained in `pdt`, while the two source folders will be held by `src`. The directory `usrtemplates` is contained in `pdt`.

2.1.3 Prepare your own project

From hereon, we recommend that you do not make any changes within Peano repositories but use your own directory `peano-projects` for your own projects. We refer to one of these projects generically from hereon as `myproject`. Within `peano-projects`, we will need to access the directories `peano` and `tarch`. It is most convenient to create symbolic links to these files. Alternatively, you also might want to copy files around or adopt makefiles, scripts, and so forth. I'm too lazy to do so and rely on OS links.

```
> mkdir peano-projects
> cd peano-projects
> ln -s <mypath>/peano peano
> ln -s <mypath>/tarch tarch
> ls
```

```
  peano tarch
```

2.2 Create an empty Peano project

Peano projects require four files from the very beginning:

- A **specification** file is kind of the central point of contact. It defines which data models are used and which operations (algorithmic phases) do exist in your project. And it also specifies the project name, namespace, and so forth.
- A **vertex definition** file specifies which data is assigned to vertices in your grid.
- A **cell definition** file specifies which data is assigned to cells in your grid.
- A **state definition** file specifies which data is held in your solver globally.

We will use these files and modify them all the time. For our first step, they are basically empty. As mentioned before, we suggest to have one directory per project. Rather than creating the files as well as the directory manually, we can use the PDT for this:

```
> java -jar <mypath>/pdt.jar --create-project myproject myproject
> ls
  myproject peano tarch
```

If you are interested in the semantics of the magic arguments, call jar file without any argument and you will obtain a brief description. A quick check shows that the aforementioned four files now have been created:

```
> ls -al myproject
drwxr-xr-x 2 ... .
drwxr-xr-x 5 ... ..
-rw-r--r-- 1 ... Cell.def
-rw-r--r-- 1 ... project.peano-specification
-rw-r--r-- 1 ... State.def
-rw-r--r-- 1 ... Vertex.def
```

The PDT typically is used only once with the `--create-project` argument. From hereon, it serves different purposes. That is ...

2.3 A first spacetree code

... it helps us to write all the type of code parts that we don't want to write: **glue code** that does nothing besides gluing the different parts of Peano together.

We postpone a discussion of the content of the generated files to Chapter 3 and continue to run a first AMR example. For this, we call the PDT again. However, this time, we use the generated specification file as input and tell the tool to create all glue code.

```
> java -jar <mypath>/pdt.jar --generate-gluecode \
  myproject/project.peano-specification myproject \
  <mypath>/usrtemplates
```

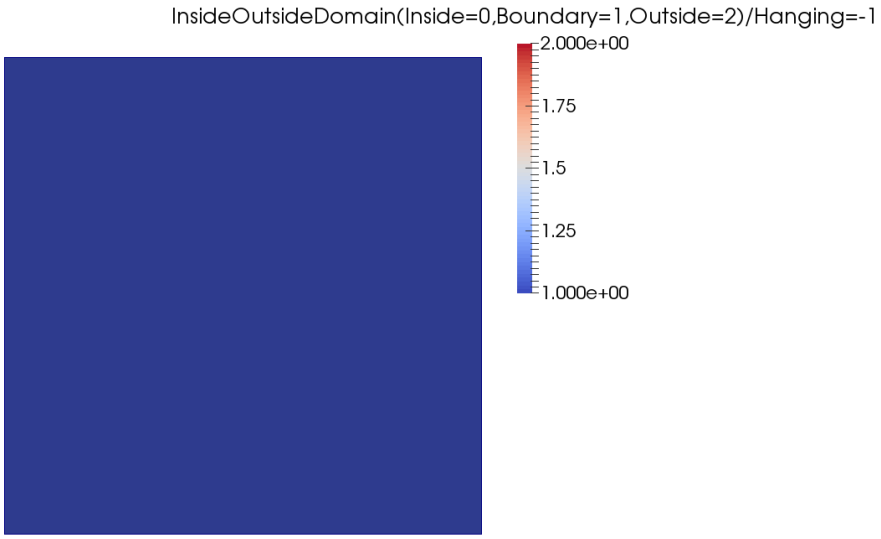
By default, the autogenerated, (almost) empty four files require the `usrtemplates`. We reiterate that many projects later won't need them. If we again study the content of our directory, we see that lots of files have been generated. For the time being, the `makefile` is subject of our interest. Depending on your compiler, you should be able to call `make` straight away. If it doesn't work, open your favourite text editor and adopt the makefile accordingly.

```
> ls myproject
  adapters Cell.cpp Cell.def
  Cell.h dastgen main.cpp
  makefile mappings project.peano-specification
  records repositories runners
  State.cpp State.def State.h
  tests Vertex.cpp Vertex.def
  Vertex.h VertexOperations.cpp VertexOperations.h
> make -f myproject/makefile
> ls
  files.mk myproject peano peano-YourProjectName-debug tarch
```

There it is: the first Peano executable. We can run it straight away:

```
> ./peano-YourProjectName-debug
> ls
  files.mk grid-0.vtk myproject peano
  peano-YourProjectName-debug tarch
```

We see that it has produced a vtk file. So it is time to startup Paraview or VisIt and see what is inside.



Congratulations: We have created the simplest adaptive Cartesian grid in 2d that does exist. A single square!

2.4 Some real AMR

We now set up something slightly more complicated. First of all, we switch to a 3d setup rather than 2d. For this, open the makefile (`myproject/makefile`) and alter the content of the `DIM` variable.

```
# Set Dimension
# -------------
#DIM=-DDim2
```

```
DIM=-DDim3
#DIM=-DDim4
```

If you clean your project (`make -f myproject/makefile clean`) and rebuild your code, you see that the individual files are translated with the compile switch

```
g++ ... -DDim3 ....
```

Indeed, this is all that's required for Peano to run a 3d experiment rather than a 2d setup.

> **Remark:** We do support currently up to 10-dimensional setups. If you require higher dimensions, you might even be able to extend Peano accordingly by changing solely the file `peano/utils/Dimensions.h`. But have fun with your memory requirements exploding.

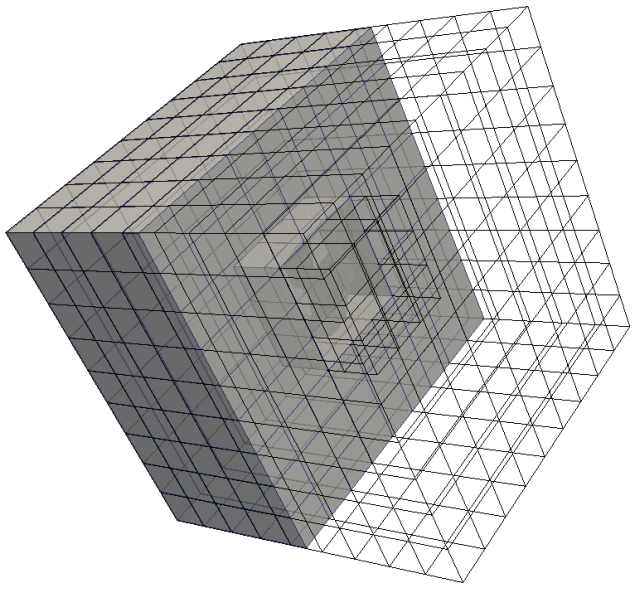
Next, we will edit the file `myproject/mappings/CreateGrid.cpp`. Open it with your favourite text editor and search for the operation `createBoundaryVertex`. Change it into the code below:

```
void myproject::mappings::CreateGrid::createBoundaryVertex(
 myproject::Vertex& fineGridVertex,
 const tarch::la::Vector<DIMENSIONS,double>& fineGridX,
 const tarch::la::Vector<DIMENSIONS,double>& fineGridH,
 myproject::Vertex *const coarseGridVertices,
 const peano::grid::VertexEnumerator& coarseGridVerticesEnumerator,
 myproject::Cell& coarseGridCell,
 const tarch::la::Vector<DIMENSIONS,int>& fineGridPositionOfVertex
) {
  logTraceInWith6Arguments("createBoundaryVertex(...)", ...);
    // leave this first line as it is

  if (coarseGridVerticesEnumerator.getLevel()<2) {
    fineGridVertex.refine();
  }

  logTraceOutWith1Argument("createBoundaryVertex(...)",fineGridVertex);
}
```

If you compile this code and run the executable, you will (besides lots of debug output) obtain a way bigger vtk file. If you visualise it this time, we observe that the code refines towards the cube's boundary. You may want to play around with magic `2` in the operation above. Or you might want to continue to our final example.



2.5 A tree within the spacetree

In the final example we create a slightly more interesting setup. We solely edit the operation `createInnerVertex` within the file `myproject/mappings/CreateGrid.cpp`, recompile it and have a look at the result. When you study source code, please note the similarity to Matlab when we work with vectors in Peano; as well as that the indices start with 0. If your want to get rid of all the debug statements and are sick of long waiting times, remove the `-DDebug` statement in the line `PROJECT_CFLAGS = -DDebug -DAsserts` within the makefile. There are more elegant ways to filter out log statements that we will discuss later.

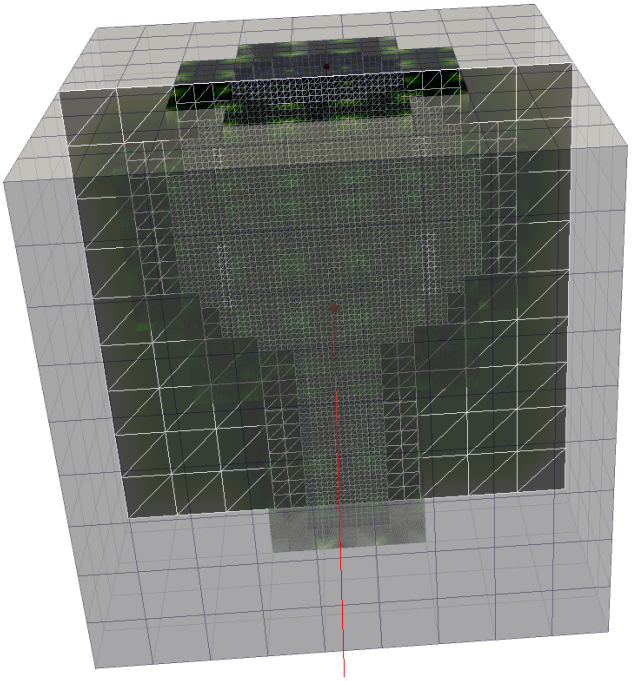
```
void myproject::mappings::CreateGrid::createInnerVertex(
 myproject::Vertex& fineGridVertex,
 const tarch::la::Vector<DIMENSIONS,double>& fineGridX,
 const tarch::la::Vector<DIMENSIONS,double>& fineGridH,
 myproject::Vertex *const coarseGridVertices,
 const peano::grid::VertexEnumerator& coarseGridVerticesEnumerator,
 myproject::Cell& coarseGridCell,
 const tarch::la::Vector<DIMENSIONS,int>& fineGridPositionOfVertex
) {
 logTraceInWith6Arguments("createInnerVertex(...)",fineGridVertex,...);

 if (
   fineGridVertex.getRefinementControl()==Vertex::Records::Unrefined
   &&
   coarseGridVerticesEnumerator.getLevel()<4
 ) {
   bool trunk = (fineGridX(0)-0.5)*(fineGridX(0)-0.5)
              + (fineGridX(2)-0.5)*(fineGridX(2)-0.5)<0.008;
   bool treeTop = (fineGridX(0)-0.5)*(fineGridX(0)-0.5)
                + (fineGridX(1)-0.7)*(fineGridX(1)-0.7)
                + (fineGridX(2)-0.5)*(fineGridX(2)-0.5)<0.3*0.3;
   if (trunk | treeTop) {
     fineGridVertex.refine();
```

```
    }
  }

  logTraceOutWith1Argument("createInnerVertex(...)",fineGridVertex);
}
```

So here's what I get. Feel free to create better pics:



3 The basics explained