Using SIMIND Monte-Carlo Software with STIR Software for SPECT simulations

Instructions for those familiar with the use of STIR

Version 1.0 [10/11/2022]

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Contents

Useful links

SIMIND Manual v7.0
http://www2.msf.lu.se/simind/download/simind_manual.pdf

Note: some parts of the manual may still refer to v6.2 (e.g. description of Main page in change)

STIR User's Guide v5.0
http://stir.sourceforge.net/documentation/STIR-UsersGuide.pdf

STIR Developer's Overview
http://stir.sourceforge.net/documentation/STIR-developers-overview.pdf

STIR_SIMIND Tutorial Repo (includes Jupyter notebook demo and example STIR and SIMIND files)[1]
https://github.com/samdporter/STIR_SIMIND

[1] These should soon be added to STIR examples

Getting started with SIMIND

Follow the instructions for download and install from https://simind.blogg.lu.se/downloads/
(*V7.0 available at 06/09/2022*)

There are two key programs within SIMIND:

- **change** (defines SPECT system and other simulation parameters)
- **simind** (performs the Monte Carlo simulation)

more detail on each will be given below

Minimum required input files for SIMIND

- Emission data (extension *.smi)
  - Must be in 16 bit integer form
- Density data (extension *.dmi)
  - Must be in 16 bit integer form
  - Units of 1000*density (e.g. water density = 1.0 g/cm^3, pixel value should be 1000)
- *.smc file
  - File created in/edited with the **change** program
  - Contains parameters used to define the imaging system

Basic SIMIND instructions; defining parameters for the system (change)

change is the program that allows configuration of simulation (i.e. defines the system)

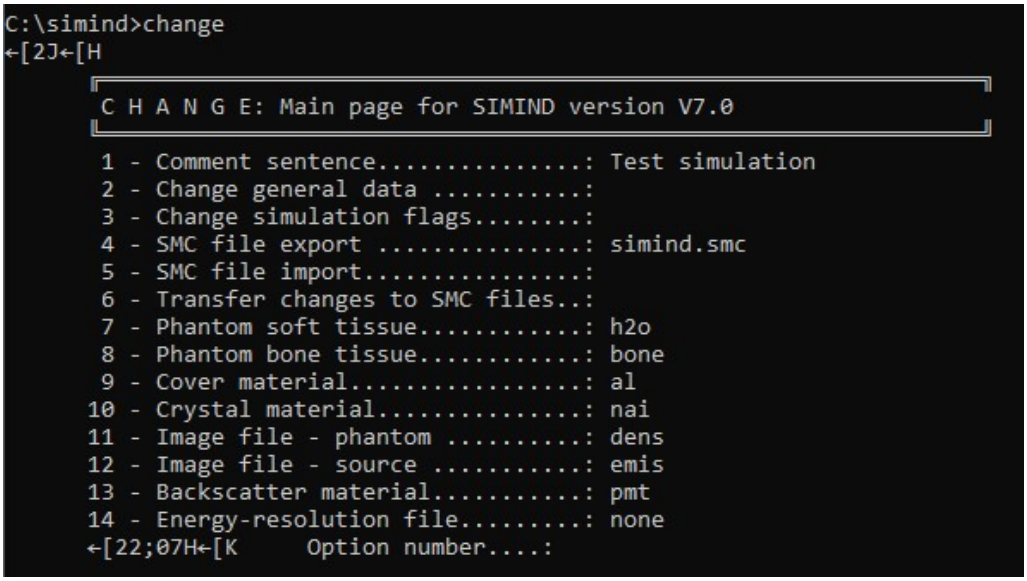
change is an interface for editing the *.smc file

Usage:

```
> change
```

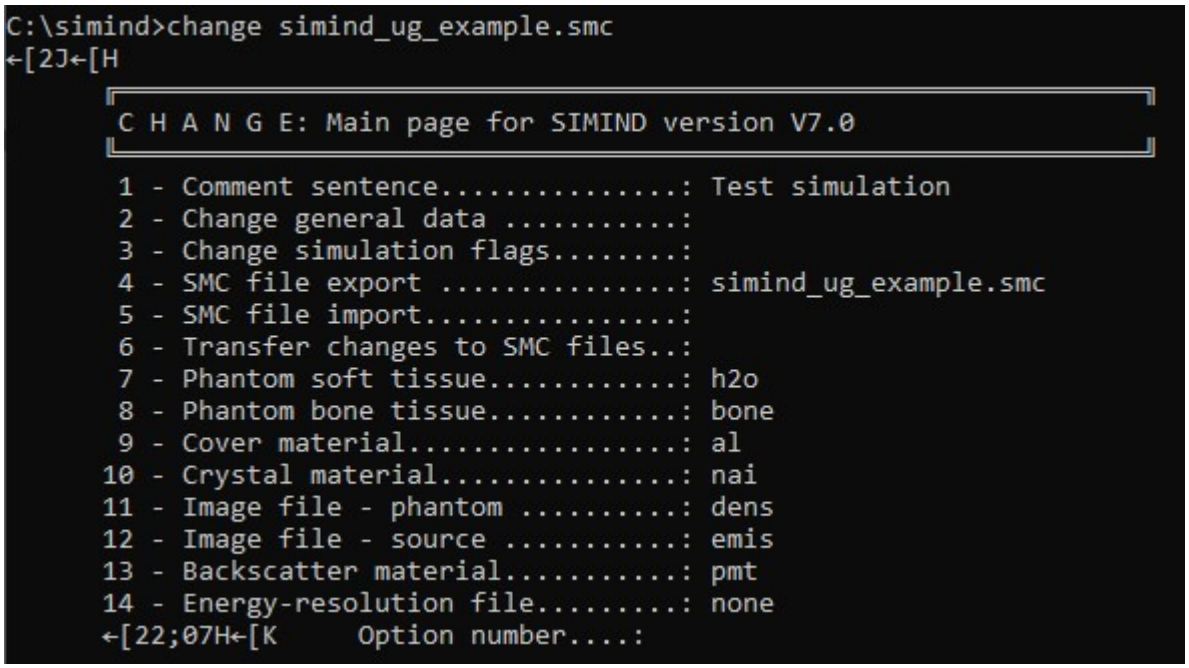
Opens “Main” page in order to edit simind.smc file

- simind.smc initially holds all the default parameters, but is updated whenever you close the “change” program after making changes, even if you output to a different *.smc file
- Should be considered a temporary file



> change filename.smc

Opens “Main” page in order to edit a specific *.smc file



Once this menu is opened, you can:

- review and edit system and simulation parameters (option 2)
- review simulation flags [T/F] (option 3)
- choose to export changes to a different *.smc file (option 4)
  This creates a new file, but be aware that changes will ALSO be made to whatever *.smc file that **change** was initially opened with
- load in a different previously saved .smc file (option 5)

Note that if you pick option 1, this will force you to enter a value for all 101 parameters (and if you keep hitting return, it will overwrite each parameter with zero) .[2]

- In this case, to exit out of the **change** programme without saving, use CTRL+C

Usually best to pick **option 2** – change general data

This allows you to specify which parameters you want to edit

A series of pages with 10-15 parameters on each page is displayed as follows:

- Indices 1 - 15: Scintillation Camera Parameters
- Indices 16 - 30: Scintillation Camera Parameters
- Indices 31 – 45: Non-homogeneous phantom and SPECT parameters
- Indices 46 – 60: Collimator parameters
- Indices 76 – 85: Imaging parameters and other settings
- Indices 91 – 101: Solid-state detector settings

[2] In v6.2, it was possible to update comment sentence, but don’t seem to be able to do this with V7 (manual says you can change using Index-9 of the main menu. On v6.2 it was option 7: see appendix)

If you're happy with the parameters on one page, hit return to move on to the next page

On the relevant page, enter the index number of the parameter you want to change and hit return

Enter the value you want to change that parameter to and hit return

The new value should be displayed for the relevant parameter

See SIMIND manual for detailed descriptions of all parameters for each index number.

See section below for specific parameters required to configure your simulation with voxelwise input from STIR.

When satisfied with all parameters, exit the **change** program (by hitting return on the 'home' page), then the *.smc file will be overwritten by the parameters you've just used.

Note certain parameters can also be specified using switches when you run your simind simulation (see below)

To exit **change** at any time, without saving, use CTRL+C

Parameters required to configure simulation to be compatible with voxelwise input (generated in STIR)

- Set **Index-14** (type of phantom) to -1
  - density distribution map
- Set **Index-15** (type of source distribution to be simulated) to -1
  - source distribution map
- Set **Index-41** (SPECT: Starting angle) to 90 degrees
  - This corresponds with a STIR simulation start angle of 180 degrees
- Index 12 corresponds to radius of rotation
  - Note that units are in cm throughout (important for defining pixel sizes and radius of rotation)

Note that indices 79 and 82 (source map dimensions) must be equal

To test: do density map dimensions need to be isotropic/match source map dimensions? (indices 34, 78, 81)
Recommend setting indices 34, 76, 77, 78, 79, 81 and 82 the same (await results of test above)

To test: do pixel sizes need to be isotropic in density maps? (index 31)

To test: do pixel sizes need to be isotropic in source maps? (index 28(?))
Recommend setting indices 31 and 28 the same (await results of tests above)

To test: do parameters on page 1 defining source and phantom length/width/height have any impact when simulating voxelwise data? (indices 2, 3, 4, 5, 6, 7)
Recommend setting indices 2, 3, 4, 5, 6, and 7 as appropriate to encompass entire relevant part of the data (note that units are in cm)

Basic SIMIND instructions; performing the Monte Carlo simulation (simind)

Basic usage:

```
> simind param_filename.smc output_filename
```

Usage including switches (example):

```
> simind param_filename.smc output_filename/FD:dens_file/FS:emiss_file/PX:0.4
```

Switches are useful for performing multiple simulations using the same basic *.smc file, but varying one parameter at a time

For example, the number of photons simulated (i.e. statistical noise) can be controlled with switch /NN

The larger number chosen for switch /NN, the longer the simulation will take and the better the image statistics will be (note that total sum of events in the image will remain the same)

In addition, when using voxelwise phantoms, a switch specifying pixel size must be used /PX

We recommend that the input files for density and emission maps are specified using switches rather than in **change** since there is a character limit of 11 characters stored using **change**

See simind manual for full list of possible runtime switches.

Output files from SIMIND

- Output files comparable to those produced with STIR:
    - *.h00 (header file)
    - * .a00 (data)
- If setting Index 84 (scoring routine) to 1 (“scattwin”)
    - 3 different sets of *.h00 and *.a00 files are produced for each energy window defined: air, scatter and “total”
    - “Total” data takes attenuation and other interactions into account
    - “Air” data is simulation without interactions in the phantom (no attenuation or scatter). Useful for comparing corrections as this corresponds to perfect corrections.
- .res file summarises simulation (how it was set up, energy windows, time taken, sensitivity etc. and all the information that is output to terminal while simind is running)

See simind manual for full list of possible output files.

Reconstructing SIMIND Data using STIR

SIMIND output data can be reconstructed with STIR. First, a few tweaks need to be made to the header file to convert it to a STIR-friendly form. Steps are included below, but note that this can be done quickly and efficiently using the convertSIMINDToSTIR.sh script (available here https://github.com/samdporter/STIR_SIMIND, also need the corresponding .awk file)

- make a copy of the .h00 file, and rename it with extension *.hs
- Edit *.hs file as follows:
    - Comment out, or delete the following:
        - Program author
        - Program version
        - Original institution
        - Contact person
        - Patient name
        - Study ID
        - Data description
        - Exam type
        - Patient ID
        - Total number of images
        - Number of detector heads
        - Number of images/energy window
        - Energy window upper and lower level
        - Time per projection (sec)
        - Image duration (sec) [throws STIR error]
    - Change number format from “short float” to “float”
    - Ensure !matrix size [2] := value corresponds to number of STIR z-slices (it probably won’t by default)
    - Change radius value to mm (currently in cm) and uncomment Radius line

For attenuation correction; use STIR-appropriate attenuation values in the reconstruction (ie. Values of approx. 0.15 rather than 1000 for water)

Data Types

- SIMIND requires 16-bit integer data when dealing with voxelwise inputs
    - Can specify this filetype in the generate image .par file in STIR
    - When using voxelwise input (e.g. as generated in STIR), SIMIND expects the activity file to have extension *.smi, and the density map to have extension *.dmi
        - Rename the binary (*.v) files generated by STIR with the relevant extension
- SIMIND outputs results of simulated SPECT projections as a binary file, consisting of projection data in 32-bit float format (*.a00 files). Header files in interfile format are also produced (*.h00)
- STIR uses Interfile version 3.3 “(with a few small changes)”
- SIMIND also uses Interfile type headers but note that units are in cm rather than mm
- Naming data types: STIR is OK with reference to “integer”, but SIMIND needs “signed integer”[3]

[3] RG to look into this to clarify which files this is important for; think it throws up an error or warning

Defining attenuation maps

- STIR uses attenuation coefficient values (e.g. 0.15cm^{-1} for water)
- SIMIND uses density x 1000 (e.g. 1000 for water, where density of water = 1.0 g/cm^3)
- Remember when simulating in SIMIND to use SIMIND attenuation map
    - If reconstructing in STIR, remember to use STIR-appropriate attenuation values

Other key differences & things to be aware of

- An apparent limitation of SIMIND is that the dimensions of the input datasets should be equal (i.e. x=y=z)
    - If, for example z=/= x or y, the simulation will run, but the .h00 file will not contain any information regarding the number of z-slices
- If specifying input emission and attenuation filenames via the main menu (options 11 and 12, there is a character limit (not including the file extension) of 11 characters
    - Suggested workaround: specifying filenames as switches OR editing the .smc file in a text editor after using the **change** program
- Due to the use of switches in SIMIND, referring to files in different directories does not seem to be possible – recommend that all input data files are stored in the same directory as simind is run from
- Units of ROR
    - SIMIND = cm
        - Note that this applies to both setting parameters, and in the interfile header
    - STIR = mm [as per interfile standard]
- Coordinate systems
    - STIR

      x-axis : horizontal axis, pointing right when looking from the bed into the gantry

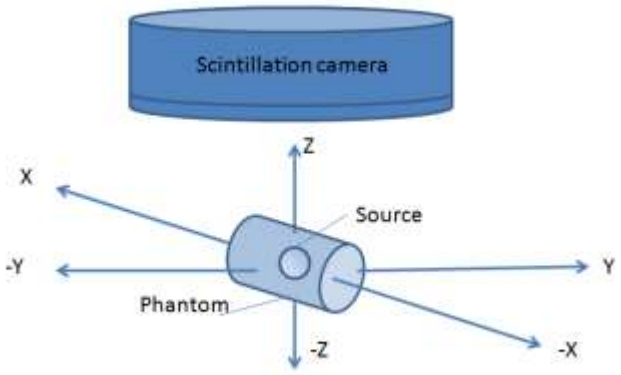
      y-axis : vertical axis, pointing downwards

      z-axis : the scanner axis, pointing from the gantry towards the bed

      The origin of the X and Y axes are located on the central axis of the PET scanner and the Z origin (z=0) is located in the middle of the first ring (i.e at the opposite side of the bed). Note that for images with an even size in x and y, the axis of the scanner *does* coincide with the centre of a pixel. In particular, for range of $2n$, the (internal) image coordinates would run from $-n$ to $(n-1)$.

      http://stir.sourceforge.net/wiki/index.php/STIR_FAQ#How_does_the_STIR_coordinate_system_work_.28e.g._for_generate_image.29

        - Coordinates relate to the scanner (not the patient/phantom)
        - STIR coordinates are ordered (z,y,x) (with z along the scanner axis, y vertical and x horizontal)
        - Recommend to use odd-sided images in all directions
    - SIMIND
        - When simulating voxel-based phantoms, the first density/activity image is located towards +X and the last one is located towards –X. When simulating SPECT, the camera rotates in the ZY plane either clockwise or counter-clockwise (controlled by index 30)



Disclaimer:

This crib sheet and associated test data/tutorials/Jupyter notebook is a work in progress and does not claim to be entirely complete or accurate.

The authors welcome any additions/corrections.

Appendix 1 – old Main page in change for SIMIND v6.1

Main page in Change

```
1. change

*------------------------------------------------------------*
| C H A N G E: MAIN PAGE FOR SIMIND                   V6.1|
*------------------------------------------------------------*
 1 - ..............................>
 2 - Change some general data ......>
 3 - Change simulation flags........>
 4 - Export to   a SMC file.........> simind.smc
 5 - Import from a SMC file.........>
 6 - Clear all SMC data.............>
 7 - Comment sentence................
 8 - Transfer changes to other files>
 9 - Phantom soft tissue........file> h2o
10 - Phantom bone tissue........file> h2o
11 - Cover material.............file> al
12 - Crystal material...........file> nai
13 - Density map................file> alders
14 - Source  map................file> none
15 - Backscatter material.......file> lucite


Option Number....>
```

Appendix 2– outstanding tests/checks to perform

To test: do density map dimensions need to be isotropic/match source map dimensions? (indices 34, 78, 81)

To test: do pixel sizes need to be isotropic in density maps? (index 31)

To test: do pixel sizes need to be isotropic in source maps? (index 28(?))

To test: do parameters on page 1 defining source and phantom length/width/height have any impact when simulating voxelwise data? (indices 2, 3, 4, 5, 6, 7)

To test: non-circular orbits (elliptical orbit, or orbit based on density map –index 42)

To test: Does SIMIND require Uint16 [0 to 65535] or signed int 16 [-32768 to +32767]

To do: RG to check where “signed integer” vs “integer” makes a difference (one is OK for STIR, but not for SIMIND)