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A user-guide for running SpaceEx verification tool

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1 Introduction

This serves as a tutorial on how to use SpaceEx¹ from the terminal. There are two ways to do so: (i) running directly the executable file, and (ii) compiling the source code and then running the executable. Note that this tutorial does not present the compilation procedure. The example files can found at Github².

2 Steps

The necessary steps are as follows.

1. **Set up Virtual Machine (necessary only for Window users)**. There are executable files for Linux and macOS but not for Windows. Our recommendation for Windows users is to create a new Virtual Machine and install Linux (also possible with macOS).
 - **Download OS**. The first step is to download a 32- or 64-bit Linux distribution (e.g. Ubuntu³ or Debian⁴). We recommend the 64-bit version as it supports the latest SpaceEx version.
 - **Download VM**. There are several options, notably Oracle Virtual-Box⁵ or VMware Player⁶. Our recommendation would be the former.
 - **Set up new VM**. Once the VM application is downloaded, a new VM should be created and set up. For VirtualBox, simply open the application, navigate to option “new” (on top-left), select Linux and version (e.g. 64-debian), memory size (over 2 GB is typically enough), “create a virtual machine now”, “VDI”, “dynamically allocated” and size over “8 GB”.

¹<http://spaceex.imag.fr/>

²<https://github.com/nikos-kekatos/SpaceEx-tutorials>

³<https://www.ubuntu.com/download/desktop>

⁴<https://www.debian.org/distrib/>

⁵<https://www.virtualbox.org/wiki/Downloads> (1st option for Windows host)

⁶<https://my.vmware.com/en/web/vmware/downloads>

- **Install OS.** Now, a new virtual machine should be created (appears on the left) and you shall select “start”. The option “Select Start-up disk” pops up and you should add the location of the downloaded ISO file (64-bit Linux). Now, it is possible to install Linux⁷.

- **Set up Linux.** There are numerous tutorials on how to use Linux⁸. The necessary actions to setup your Linux for SpaceEx use follow.

- Open terminal (Ubuntu: press Dash, Debian: press Activities, and then search for Terminal).
- Gain root access by `$ su` (`$` is used for clarity, it should not be added) and insert your password.
- `$ apt-get install sudo`
- `$ sudo apt-get install build-essential`
- `$ sudo apt-get update`

2. **Download SpaceEx.** Depending on the OS you have downloaded, select the corresponding executable file from SpaceEx website⁹. That is `SpaceEx command line executable v0.9.8f` for 64 bit Linux or `SpaceEx command line executable v0.9.8e` (64 bit Mac OS X)

3. **Run SpaceEx.**

- use command `cd` to change directory (to the folder you saved the spaceex files). For example, `$ cd /home/user/Downloads/spaceex_exe`
If you cannot `cd` with root privilege, press `exit` (to leave root) and then write the aforementioned command.
- until you get familiar with paths and directories, save the `xml` and `cfg` files at the same path, e.g. `/home/user/Downloads/spaceex_exe`
- now, you are ready to run spaceex by writing in the terminal:
`./spaceex -g config.cfg -m model.xml -o output`
- Spaceex will run, show the steps on the terminal screen and save the results in the output file. The results could be numbers (representing the vertices of the reachable sets) or text. More information can be found at the FAQ¹⁰.

⁷There will be several questions but they are similar to a Windows installation.

⁸<http://www.makeuseof.com/tag/an-a-z-of-linux-40-essential-commands-you-should-know/> for the basic commands

⁹<http://spaceex.imag.fr/download-6>

¹⁰<http://spaceex.imag.fr/documentation/user-documentation/frequently-asked-questions-21>

3 SpaceEx Options

- All the options can be displayed by writing the command `$./spaceex --help` in the terminal.
- Note that the options given in the command line (like “output” or “initially”) override the options written in the CFG file.
- To obtain the flattened/composed hybrid automaton in XML format, you can add the argument `-output-system-file new_name`

4 Example

We illustrate the necessary commands on the *Timed bouncing ball* example from the SpaceEx website. The model (XML & CFG) are enclosed in the accompanied zip file. They can also be found at the SpaceEx website¹¹.

- `$./spaceex -g bball_timed.cfg -m bball_timed.xml -o out.gen`. This command creates and saves the reachability results to a GEN file (the name of the file is *out*).
- `$./spaceex -g bball_timed.cfg -m bball_timed.xml -o out2.gen -v D6 --flowpipe-tolerance 0.01`. This command creates the *out2* GEN file, while specifying the accuracy of the computations and the verbosity level.
- `$./spaceex -g bball_timed.cfg -m bball_timed.xml -o out3.gen --initially "12<=x<=12.2 & v==0 & t==0"`. This command conducts reachability analysis for the specified initial conditions (overriding the initial conditions declared in the CFG file) and creates the *out3* GEN file.
- `$./sspaceex -g bball_timed.cfg -m bball_timed.xml --output-system-file bball_timed_flattened.xml`. This command performs flattening of the original model and saves the flattened/composed hybrid automaton as *bball_timed_flattened.xml*. The composed automaton can be visualized with the SpaceEx Model Editor^{??}.

5 Plotting

The easiest option to plot from the terminal is to use the `graph` utility from the *Plotutils* package¹². This package is available for all major Linux distributions and for MacOS. If not installed, follow online instructions¹³. MacOS users could write in the command line `$ brew install wget` (to install Homebrew) and `$ brew install plotutils` (to install Plotutils).

¹¹<http://spaceex.imag.fr/download-6/>

¹²<https://www.gnu.org/software/plotutils>

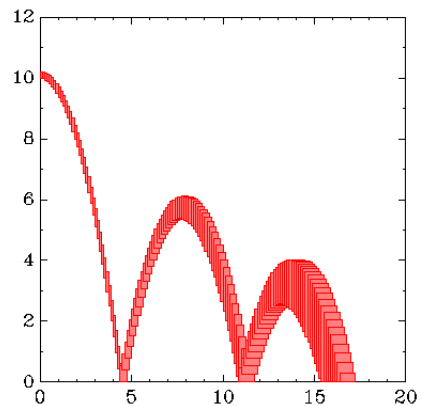
¹³<https://www.gnu.org/software/plotutils/manual/en/plotutils.html>

To generate a PNG bitmap, write in the terminal `$ graph -T png -C -B -q0.5 myfile.gen > myfile.png`. To generate a PDF file, write `$ graph -T ai -C -B -q0.5 myfile.gen > myfile.pdf`

Returning to the timed bouncing ball example, we select the output variables and run SpaceEx.

```
$ ./spaceex -g bball_timed.cfg -m bball_timed.xml -o out4.gen -a "t,x"
```

For plotting, we write `$ graph -T png -C -B -q0.5 out4.gen > bball.png` and `$ open bball.png`. The plot is shown in the following figure.



A guide with further plotting methods is available on the SpaceEx website.

6 Run multiple configurations

There are two ways to run multiple reachable computations, either by creating new CFG files with multiple configurations (e.g. different initial conditions) or running SpaceEx with different arguments in the terminal.

If you want to automatically run different configurations, you can run a bash file. A practical option is to have a parametrized bash file that concerns different configurations.

One way to automatically create several CFG files with different initial conditions and names is provided by `$./run_spaceex.sh`. It employs the *timed bouncing ball* example and can be found in the zip file.

The file can be executed by writing in the terminal the following command `$./run_spaceex.sh`. If you have problem with permissions, try the command `$ sh run_spaceex.sh`.