

15-424/15-624/15-824 Lab 0  
Installing Mathematica and KeYmaera X

## 1 Installation

KeYmaera X is an automated theorem prover that you will use for every lab assignment in this course. KeYmaera X works best when it uses Mathematica as a powerful back-end arithmetic solver, as opposed to the free Z3 solver which is installed automatically. Since you will be using KeYmaera X a lot, we expect you to set it up with Mathematica.

For your convenience, we provide instructions on installing Mathematica and running KeYmaera X from your own computer. However, if you are unable to do this, the lab assignments can be completed using KeYmaera X from any CMU cluster with Mathematica installed (see here for a list of clusters that support Mathematica: [http://www.cmu.edu/computing/clusters/software/cluster\\_software.html](http://www.cmu.edu/computing/clusters/software/cluster_software.html)).

**Note:** Unless you have a very under-powered machine, we suggest you install KeYmaera X locally.

After installing Mathematica, installing KeYmaera X should be straightforward.

**Step 1: Install Mathematica, Download KeYmaera X, and run KeYmaera X** We provide instructions for three settings: CMU Mac Clusters, CMU Linux Clusters, and local installation.

**Option 1:** Run KeYmaera X from a CMU Mac Cluster

Check that Mathematica is installed and has an active license by opening it from the command line:

```
$ mathematica
```

Follow on-screen directions (if any), until the Mathematica welcome screen appears, and then exit. This only needs to be done the first time you use Mathematica.

Next, download and open KeYmaera X here:

```
http://keymaeraX.org/keymaerax.jar
```

Once downloaded, you may also open this file via the terminal with this command:

```
$ java -Xss20M -jar keymaerax.jar
```

Skip to step 2.

### Option 2: Run KeYmaera X from a CMU Linux Cluster

Check that Mathematica is installed and has an active license by opening it from the command line:

```
[user@unix1 ~]$ mathematica
```

Follow on-screen directions (if any), until the Mathematica welcome screen appears, and then exit. This only needs to be done the first time you use Mathematica.

Then run the following from the command line to download and run KeYmaera X:

```
[user@unix1 ~]$ wget http://keymaeraX.org/keymaerax.jar  
[user@unix1 ~]$ java -Xss20M -jar keymaerax.jar
```

Skip to step 2.

### Option 3: Run KeYmaera X from your personal computer.

First, download the CMU student version of Mathematica version **10** from this url:

<http://www.cmu.edu/computing/software/all/mathematica-student/download.html>

NOTE: The installation file is **large**, so the download will take some time.

Follow the detailed installation instructions in the **README** file to install Mathematica and retrieve a license key from the Wolfram website.

**Before proceeding, activate Mathematica** by launching Mathematica and entering the license key that you obtained by following the instructions in the README file included with Mathematica.

#### Is Mathematica Installed?

To check that Mathematica is installed:

- Open a terminal and run the math command. You should get a prompt like "In[1]:= ". Type `1=1` and hit enter. You should see some reasonable output :-) If you see some message about license information, follow the directions in the **README** file that came with Mathematica.
- If you do not know how to open a terminal window, Google “(your operating system) open terminal”. Google will give you some instructions right on the search page.

Next, open KeYmaera X:

Download it here: <http://keymaeraX.org/keymaerax.jar>

**Open** `keymaerax.jar` or run `java -Xss20M -jar keymaerax.jar` from the command line. Double-clicking on `keymaerax.jar` may not work:

- If you are on a Mac, open the folder containing `keymaerax.jar` in Finder, and then right-click on `keymaerax.jar` and select **Run**
- If you are on a Windows machine, try running `java -jar keymaerax.jar` from the command line if double-click does not work.
- If you are on a Linux machine, run `java -Xss20M -jar keymaerax.jar` if double-clicking does not seem to have any effect. You may also need to set the executable bit by running `chmod +x keymaerax.jar`.

You may safely ignore any Java security warnings.

**Step 2: Access the KeYmaera X Web User Interface** By now, you should have run `java -Xss20M -jar keymaerax.jar` or otherwise launched KeYmaera X. When doing so, you should have seen a loading screen with a progress bar. After a few moments, a web browser window should automatically open the KeYmaera X web-based user interface. If this does not happen, open a web browser and go to `http://127.0.0.1:8090`.

#### Is KeYmaera X Running?

KeYmaera X runs in the background. To check if KeYmaera X is running, simply access the web page `http://127.0.0.1:8090` from you web-browser.

**Step 3: Register an Account and Log In to KeYmaera X** Enter a username and password and press "Register". Accept the license agreement and you will be logged in automatically.

**Password Security Note:** We take standard security precautions with passwords, such as storing them only as a salted hash and using timing attack-resistant hash comparisons. That being said, we do store the salted hash in the home directory of the machine where you ran `keymaerax.jar`. If you do not like this, we recommend using a throwaway username and password, such as "guest" and "guest".

**Step 4: Configure KeYmaera X to use Mathematica** Click "Help" and then "Backend Configuration". Now set "Selected tool:" to "Mathematica" If you are running KeYmaera X on your own machine, click `Use _ default` (where `_` is the name of your operating system) next to each of the input boxes. Then, click **Save Configuration**. Wait for a dialog to appear indicating that KeYmaera X has been reconfigured. When the dialog appears, close the dialog and **restart** KeYmaera X by clicking the power button in the top right-hand corner of the web UI.

**Note: The clusters use a non-default path for Mathematica. For the clusters, use the following paths:**

- MathKernel: `/usr/local/depot/mathematica-10.1/Executables/MathKernel`
- JLink: `/usr/local/depot/mathematica-10.1/Executables/MathKernel`

We tell you to use Mathematica by default because it usually works better than Z3. However, Z3 may also work better once in a while. You can return to this page and select Z3 later if you wish to experiment with it.

### Updating KeYmaera X

KeYmaera X is constantly being updated. The current version status is displayed on the footer of any page. Currently, you should see the text

```
KeYmaera X version 4.3.1 (latest release)
```

Sometimes you will see the text

```
(version _ is now available from keymaeraX.org)
```

instead of (latest release). This indicates that your keymaerax.jar is out of date. To update, delete your current keymaerax.jar and download the latest release of KeYmaera X from <http://keymaeraX.org/keymaerax.jar>.

## 2 Playing around

Here are a couple of exercises so that you can start getting familiar with KeYmaera X.

- **Exercise 1: Prove a property using KeYmaera X and Mathematica.**

Load lab0.kyx (included in lab0.zip) into KeYmaera X:

- Click on **Models** in the menu bar at the top of the page.
- Enter a Model Name (anything will do; e.g., Lab 0 Part 1).
- Click the "Select File" button and locate the lab0.kyx file.
- Click **Upload**.
- The new model should appear in the list of models. Find the model and click the **Start New Proof** button (⚙️) in the **Actions** column.
- In the **Proof Programming** box, delete `nil` and enter:

```
master
```

and click **Execute**. Wait while the Master proof search procedure executes. This took 1-2 minutes on the TA's laptop.

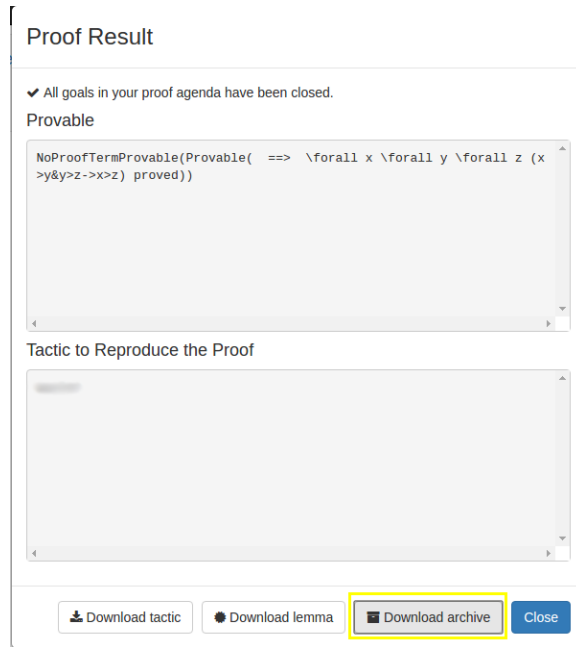


Figure 1: How to Download a Finished Proof

- Eventually a **Proof Found** dialog should appear. From here you can download your work by pressing **Download archive**, which will give you the `.kya` file for your proof. Do this for every KeYmaera X proof you submit this semester. Do not confuse this with the `Download tactic` and `Download lemma` which only give you partial information in the form of `.kyt` `.kyp` files. **If you submit only the `.kyp` and `.kyt` we will not be able to grade your assignment.** If for some reason your `.kya` file will not download, see Appendix A for another way to submit assignments in case of emergency. However, that method is harder to grade, so please only do it when absolutely necessary.

If you forget to download the archive when you finish the proof, the same functionality is also available from the Proofs screen as `Download (partial) proof`.

- If Master finishes but the proof isn't done yet (and the Proof Found dialog doesn't appear), this probably means Mathematica is not configured correctly. Make sure Steps 1 and 4 were completely correctly.

- **Exercise 2: Finding Counter-examples using KeYmaera X.**

Let's interact with KeYmaera X a little bit more now by using examples from assignment 0 (which you should have completed by now, right?) Think of the formula  $\forall x(x > 0 \wedge x < 1)$ , i.e., for all real numbers  $x$ ,  $x$  is greater than 0 and  $x$  is smaller than 1. Is this formula valid? If not, why? Can you find a counter-example?

Counterexamples are assignments of variables that falsify the formula, and therefore the existence of a counterexample implies the formula is false. KeYmaera X prefers to

check whether formulas are true, so it won't try to find a counterexample unless we ask for it explicitly.

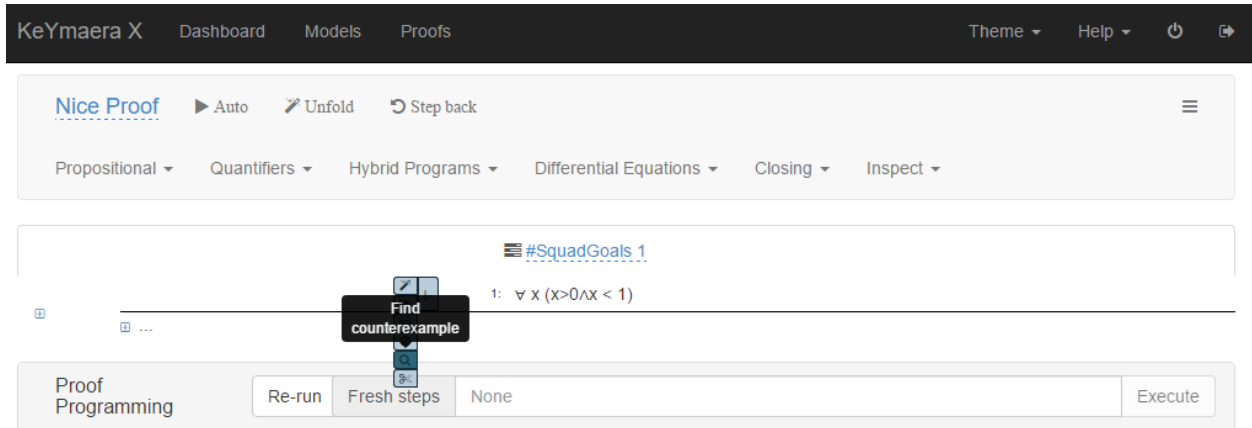


Figure 2: Trying to find a counterexample for the formula.

Find a counterexample for the above formula:

- Open the **lab0-forall.kyx** file in a text editor and look at the syntax. Now create a new model from the lab0-forall.kyx in KeYmaera X and start a new proof for the model.
  - Explore the interface. Select the whole formula by hovering the mouse over the  $\forall x$ . Notice how different parts of the formula are highlighted depending on what you mouse over.
  - To find a counter-example, hold your mouse over the **turnstile** ( $\vdash$ ) symbol. A menu will appear with various options that apply to the current goal. Click the magnifying glass icon to find a counter-example to this formula. A window should pop up with a counter-example. Make sure that the counter-example that KeYmaera X found is indeed a counter-example.
- **Exercise 3: Write a formula yourself.** Create a new file called **lab0-transitivity.kyx** (a template is included). Using KeYmaera's syntax from the cheatsheet<sup>1</sup> and the **lab0-forall.kyx** example, write down the formula for transitivity of the real numbers.

$$\forall x (\forall y (\forall z ((x > y \wedge y > z) \rightarrow x > z)))$$

There is a template file included with the code handout for this assignment in **lab0-transitivity.kyx**. After filling out the template with your answer, load your new **lab0-transitivity.kyx** file into KeYmaera X and make sure that it parses correctly.

<sup>1</sup><http://keymaeraX.org/KeYmaeraX-sheet.pdf>

- **Exercise 4: Semantics for First-Order Logic.** For each of the formulas below, write in `lab0.txt` whether the formula is unsatisfiable, (just) satisfiable, or valid, and briefly explain why. If you wish, think about how you can check your work in KeYmaera X using the features you just learned, then do it.

1.  $\exists y xy = 1$
2.  $\forall x \exists y xy = 1$

### 3 Submission Instructions

For lab submissions in this course, we will use Autolab (<https://autolab.andrew.cmu.edu/courses/15424-s17>). When submitting a lab, you will receive a preliminary binary grade (0/1). If you receive a score of 0, it means there was some error in your submission – a missing file, a file that KeYmaera X could not parse, etc. If you receive a score of 1, then your submission is in valid form. The AutoLab binary score indicates whether your submission is valid and does not necessarily indicate your final grade on the lab!

Your final submission for Lab 0 should be in the form of a **single .zip file** containing exactly and only 3 files:

**lab0.kya** – The archive for the model `lab0.kyx` distributed with this lab. This contains the model and proof from Exercise 1.

**lab0-transitivity.kyx** – A file containing your answer to Exercise 3. A template is provided in the code handout associated with this lab. In this case you just submit the `.kyx` because you didn't have to do a proof. When you do a proof, submit the `.kya`!

**lab0.txt** – A text file containing answers to written questions.

Create a comment on the top of each model file that says how long the tactic for your proof takes to run and whether the proof closes. For example:

```
/**
 * Running time (in minutes, estimate): 2 mins
 * Proved?(Y/N): yes
 * KeYmaera X Version:
 * ...more comments here...
 */
```

should be the first 4 lines of any `.kyx` file you submit in this course.

Please do not include any personally identifiable information in your submission. This way it is easier for us to grade anonymously and reduce implicit grading bias. Autolab already knows who you are so there is no need to say so in your submission.

## 4 Installation FAQ

We know this is new software, and all new software has bugs. We want you to be able to spend as much of your time as possible focusing on the assignment instead of dealing with bugs, so please reach out to us when something seems broken and we will respond as quickly as possible.

Finally, please ask for help from your TA during installation! You may also share tips on installing and upgrading KeYmaera X with (and ask for help from) your fellow students. (However, remember that sharing the specifics of lab solutions with other students does violate the academic integrity policies of the course.)

### A Database Extraction

Submitting your archive should work fine, but in case of bugs, here is an alternate, older method. Please only use this if the prior method does not work because this is harder to grade.

The entirety of every proof you do in KeYmaera X, including all your intermediate scratch work, is stored in an SQLite database, which is located in a subdirectory of your home directory: `~/.keymaerax/keymaerax.sqlite`

Submit this file in case of emergency, though of course don't forget to submit any other files that aren't a `.kya`: those are not in the database. Autolab will tell you that your submission is bad because this is not the intended submission format, but we will have your file on our Autolab and be able to grade it.