Using Web Frameworks for Scientific Applications

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Jan 7, 2015

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1 Web frameworks

Computational scientists may want to offer their applications through a web interface, thereby making a *web application*. Basically, this means that users can set input data to the application on a web page, then click on some *Compute* button, and back comes a new web page with the results of the computations. The web interface can either be used as a GUI locally on the scientist's computer, or the interface can be depolyed to a server and made available to the whole world.

Web applications of the mentioned type can be created from scratch using CGI scripts in (e.g.) Python, but the code quickly gets longer and more involved as the complexity of the web interface grows. Nowadays, most web applications are created with the aid of *web frameworks*, which are software packages that simplify the programming tasks of offering services through the Internet. The downside of web frameworks is that there is a significant amount of steps and details to learn before your first simple demo application works. The upside is that advanced applications are within reach, without an overwhelming amount of programming, as soon as you have understood the basic demos.

We shall explore two web frameworks: the very popular Django framework and the more high-level and easy-to-use framework Flask. Our introductory examples were also implemented in the web2py framework, but according to our experience, Flask and Django are easier to explain to scientists. The primary advantage of Django over other web frameworks is the rich set of documentation and examples. Googling for "Django tutorials" gives lots of hits including a list

of web tutorials and a list of YouTube videos. There is also an electronic Django book. At the time of this writing, the Flask documentation is not comparable. The two most important resources are the official web site and the WTForms Documentation. There is, unfortunately, hardly any examples on how Django or Flask can be used to enable typical scientific applications for the web, and that is why we have developed some targeted examples on this topic.

A basic question is, of course, whether you should apply Flask or Django for your web project. Googling for *flask vs django* gives a lot of diverging opinions. The authors' viewpoint is that Flask is much easier to get started with than Django. You can grow your application to a really big one with both frameworks, but some advanced features is easier in one framework than in the other.

The problem for a computational scientist who wants to enable mathematical calculations through the web is that most of the introductory examples on utilizing a particular web framework address web applications of very different nature, e.g., blogs and polls. Therefore, we have made an alternative introduction which explains, in the simplest possible way, how web frameworks can be used to

1. generate a web page with input data to your application,
2. run the application to perform mathematical computations, and
3. generate a web page with the results of the computations.

To work with Django, you need to know about Python packages and modules as well as Python classes. With Flask it is enough to be familiar with functions and modules, though knowledge of classes and a bit of decorators might be an advantage.

All the files associated with this document are available in a GitHub repository. The relevant files for the web applications are located in a subtree `doc/src/web4sa/src-web4sa/apps` of this repository.

1.1 The MVC pattern

The MVC pattern stands for Model-View-Controller and is a way of separating the user's interaction with an application from the inner workings of the application. In a scientific application this usually means separating mathematical computations from the user interface and visualization of results. The Wikipedia definition of the MVC pattern gives a very high-level explanation of what the model, view, and controller do and mentions the fact that different web frameworks interpret the three components differently. Any web application works with a set of data and needs a user interface for the communication of data between the user and some data processing software. The classical MVC pattern introduces

- the model to hold the data
- the view to display the data

- the controller to move the data by gluing the model and the view.

For applications performing mathematical computations we find it convenient to explicitly introduce a fourth component that we call *compute* where the mathematical computations are encapsulated. With the MVC pattern and the compute component we have a clear separation between data (model), the way data is presented (view), the computations (compute), and the way these components communicate (controller). In a small program such a separation may look as overkill, but it pays off in more complicated applications. More importantly, the concepts of the MVC pattern are widely used in web frameworks and their documentation so one should really adapt to the MVC way of thinking.

Web frameworks often have their own way of interpreting the model, view, and controller parts of the MVC pattern. In particular, most frameworks often divide the view into two parts: one software component and one HTML template. The latter takes care of the look and feel of the web page while the former often takes the role of being the controller too. For our scientific applications we shall employ an interpretation of the MVC pattern which is compatible with what we need later on:

- the model contains the data (often only the input data) of the application,
- the view controls the user interface that handles input and output data, and also calls to functionality that computes the output given the input.

The model will be a Python class with static attributes holding the data. The view consists of Python code processing the model's data, calling the compute component, and specifying HTML templates for the design of the web pages.

Flask does not force any MVC pattern on the programmer, but the code needed to build web applications can easily be split into model, view, controller, and compute components, as will be shown later. Django, on the other hand, automatically generates application files with names `views.py` and `models.py` so it is necessary to have some idea what Django means by these terms. The controller functionality in Django lies both in the `views.py` file and in the configuration files (`settings.py` and `urls.py`). The view component of the application consists both of the `views.py` file and template files used to create the HTML code in the web pages.

Forthcoming examples will illustrate how a scientific application is split to meet the requirements of the MVC software design pattern.

1.2 A very simple application

We shall start with the simplest possible application, a "scientific hello world program", where the task is to read a number and write out "Hello, World!" followed by the sine of the number. This application has one input variable and a line of text as output.

Our first implementation reads the input from the command line and writes the results to the terminal window:

```
#!/usr/bin/env python
import sys, math
r = float(sys.argv[1])
s = math.sin(r)
print 'Hello, World! sin(%g)=%g' % (r, s)
```

In the terminal we can exemplify the program

```
Terminal> python hw.py 1.2
Hello, World! sin(1.2)=0.932039
```

The task of the web version of this program is to read the `r` variable from a web page, compute the sine, and write out a new web page with the resulting text.

1.3 Application of the MVC pattern

Before thinking of a web application, we first *refactor* our program such that it fits with the classical MVC pattern and a compute component. The refactoring does not change the functionality of the code, it just distributes the original statements in functions and modules. Here we create four modules: `model`, `view`, `compute`, and `controller`.

- The `compute` module contains a function `compute(r)` that performs the mathematics and returns the value `s`, which equals `sin(r)`.
- The `model` module holds the input data, here `r`.
- The `view` module has two functions, one for reading input data, `get_input`, and one for presenting the output, `present_output`. The latter takes the input, calls `compute` functionalty, and generates the output.
- The `controller` module calls the view to initialize the model's data from the command line. Thereafter, the view is called to present the output.

The `model.py` file contains the `r` variable, which must be declared with a default value in order to create the data object:

```
r = 0.0    # input
s = None   # output
```

The `view.py` file is restricted to the communication with the user and reads

```
import sys
import compute

# Input: float r
# Output: "Hello, World! sin(r)=..."

def get_input():
    """Get input data from the command line."""
    r = float(sys.argv[1])
    return r

def present_output(r):
    """Write results to terminal window."""
    s = compute.compute(r)
    print 'Hello, World! sin(%g)=%g' % (r, s)
```

The mathematics is encapsulated in `compute.py`:

```
import math

def compute(r):
    return math.sin(r)
```

Finally, `controller.py` glues the model and the view:

```
import model, view

model.r = view.get_input()
view.present_output(model.r)
```

Let us try our refactored code:

```
Terminal> python controller.py 1.2
Hello, World! sin(1.2)=0.932039
```

The next step is to create a web interface to our scientific hello world program such that we can fill in the number `r` in a text field, click a *Compute* button and get back a new web page with the output text shown above: "Hello, World! sin(r)=s".

2 Making a Flask application

Not much code or configuration is needed to make a Flask application. Actually one short file is enough. For this file to work you need to install Flask and some corresponding packages. This is easiest performed by

```
Terminal> sudo pip install --upgrade Flask
Terminal> sudo pip install --upgrade Flask-WTF
```

The `--upgrade` option ensures that you upgrade to the latest version in case you already have these packages.

2.1 Programming the Flask application

The user interaction. We want our input page to feature a text field where the user can write the value of `r`, see Figure 1. By clicking on the *equals* button the corresponding `s` value is computed and written out the result page seen in Figure 2.

The Python code. Flask does not require us to use the MVC pattern so there is actually no need to split the original program into model, view, controller, and compute files as already explained (but it will be done later). First we make a `controller.py` file where the view, the model, and the controller parts appear within the same file. The `compute` component is always in a separate file as we like to encapsulate the computations completely from user interfaces.

Figure 1: The input page.

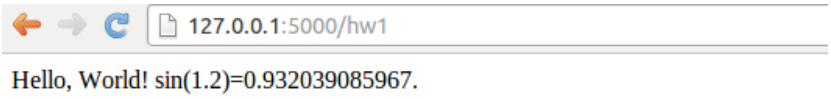


Figure 2: The output page.

The view that the user sees is determined by HTML templates in a subdirectory `templates`, and consequently we name the template files `view*.html`. The model and other parts of the view concept are just parts of the `controller.py` file. The complete file is short and explained in detail below.

```
from flask import Flask, render_template, request
from wtforms import Form, FloatField, validators
from compute import compute

app = Flask(__name__)

# Model
class InputForm(Form):
    r = FloatField(validators=[validators.InputRequired()])

# View
@app.route('/hw1', methods=['GET', 'POST'])
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        r = form.r.data
        s = compute(r)
        return render_template("view_output.html", form=form, s=s)
    else:
        return render_template("view_input.html", form=form)

if __name__ == '__main__':
    app.run(debug=True)
```

Dissection. The web application is the `app` object of class `Flask`, and initialized as shown. The model is a special Flask class derived from `Form` where the input variable in the app is listed as a static class attribute and initialized by a special form field object from the `wtforms` package. Such form field objects

correspond to HTML forms in the input page. For the `r` variable we apply `FloatField` since it is a floating-point variable. A default validator, here checking that the user supplies a real number, is automatically included, but we add another validator, `InputRequired`, to force the user to provide input before clicking on the *equals* button.

The view part of this Python code consists of a URL and a corresponding function to call when the URL is invoked. The function name is here chosen to be `index` (inspired by the standard `index.html` page that is the main page of a web app). The decorator `@app.route('/hw1', ...)` maps the URL `http://127.0.0.1:5000/hw1` to a call to `index`. The `methods` argument must be as shown to allow the user to communicate with the web page.

The `index` function first makes a form object based on the data in the model, here class `InputForm`. Then there are two possibilities: either the user has provided data in the HTML form or the user is to be offered an input form. In the former case, `request.method` equals `'POST'` and we can extract the numerical value of `r` from the `form` object, using `form.r.data`, call up our mathematical computations, and make a web page with the result. In the latter case, we make an input page as displayed in Figure 1.

The template files. Making a web page with Flask is conveniently done by an HTML template. Since the output page is simplest we display the `view_output.html` template first:

```
Hello, World! sin({{ form.r.data }})={{s}}.
```

Keyword arguments sent to `render_template` are available in the HTML template. Here we have `form` and `s`. With the `form` object we extract the value of `r` in the HTML code by `{{ form.r.data }}`. Similarly, the value of `s` is simply `{{ s }}`.

The HTML template for the input page is slightly more complicated as we need to use an HTML form:

```
<form method=post action="">
  Hello, World! The sine of {{ form.r }}
  <input type=submit value=equals>
</form>
```

Testing the application. We collect the files associated with a Flask application (often called just *app*) in a directory, here called `hw1`. All you have to do in order to run this web application is to find this directory and run

```
Terminal> python controller.py
 * Running on http://127.0.0.1:5000/
 * Restarting with reloader
```

Open a new window or tab in your browser and type in the URL `http://127.0.0.1:5000/hw1`.

2.2 Equipping the input page with output results

Our application made two distinct pages for grabbing input from the user and presenting the result. It is often more natural to add the result to the input page. This is particularly the case in the present web application, which is a kind of calculator. Figure 3 shows what the user sees after clicking the *equals* button.

Figure 3: The modified result page.

To let the user stay within the same page, we create a new directory `hw2` for this modified Flask app and copy the files from the previous `hw1` directory. The idea now is to make use of just one template, in `templates/view.html`:

```
<form method=post action="">
  Hello, World! The sine of
  {{( form.r )}}
  <input type=submit value=equals>
{% if s != None %}
{{s}}
{% endif %}
</form>
```

The form is identical to what we used in `view_input.html` in the `hw1` directory, and the only new thing is the output of `s` below the form.

The template language supports some programming with Python objects inside `{%` and `%}` tags. Specifically in this file, we can test on the value of `s`: if it is `None`, we know that the computations are not performed and `s` should not appear on the page, otherwise `s` holds the sine value and we can write it out. Note that, contrary to plain Python, the template language does not rely on indentation of blocks and therefore needs an explicit end statement `{% endif %}` to finish the if-test. The generated HTML code from this template file reads

```
<form method=post action="">
  Hello, World! The sine of
  <input id="r" name="r" type="text" value="1.2">
  <input type=submit value=equals>

0.932039085967

</form>
```

The `index` function of our modified application needs adjustments since we use the same template for the input and the output page:

```
# View
@app.route('/hw2', methods=['GET', 'POST'])
```

```
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        r = form.r.data
        s = compute(r)
    else:
        s = None

    return render_template("view.html", form=form, s=s)
```

It is seen that if the user has given data, `s` is a `float`, otherwise `s` is `None`. You are encouraged to test the app by running

```
Terminal> python controller.py
```

and loading `http://127.0.0.1:5000/hw2` into your browser. A nice little exercise is to control the formatting of the result `s`. To this end, you can simply transform `s` to a string: `s = '%.5f' % s` before sending it to `render_template`.

2.3 Splitting the app into model, view, and controller files

In our previous two Flask apps we have had the view displayed for the user in a separate template file, and the computations as always in `compute.py`, but everything else was placed in one file `controller.py`. For illustration of the MVC concept we may split the `controller.py` into two files: `model.py` and `controller.py`. The view is in `templates/view.html`. These new files are located in a directory `hw3_flask` The contents in the files reflect the splitting introduced in the original scientific hello world program in Section 1.3. The `model.py` file now consists of the input form class:

```
from wtforms import Form, FloatField, validators

class InputForm(Form):
    r = FloatField(validators=[validators.InputRequired()])
```

The file `templates/view.html` is as before, while `controller.py` contains

```
from flask import Flask, render_template, request
from compute import compute

app = Flask(__name__)

@app.route('/hw3', methods=['GET', 'POST'])
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        r = form.r.data
        s = compute(r)
    else:
        s = None

    return render_template("view.html", form=form, s=s)


if __name__ == '__main__':
    app.run(debug=True)
```

The statements are indentical to those in the `hw2` app, only the organization of the statement in files differ.

2.4 Troubleshooting

Address already in use. You can easily kill the Flask application and restart it, but sometimes you will get an error that the address is already in use. To recover from this problem, run the `lsof` program to see which program that applies the 5000 port (Flask runs its server on `http://127.0.0.1:5000`, which means that it uses the 5000 port). Find the PID of the program that occupies the port and force abortion of that program:

```
Terminal> lsof -i :5000
COMMAND   PID USER   FD   TYPE  DEVICE SIZE/OFF NODE NAME
python  48824  hpl    3u  IPv4 1128848      0t0  TCP ...
Terminal> kill -9 48824
```

You are now ready to restart a Flask application.

3 Making a Django application

We recommend to download and istall the latest official version of Django from http://www.djangoproject.com/download/. Pack out the tarfile, go to the directory, and run `setup.py`:

```
Terminal> tar xvzf Django-1.5-tar.gz
Terminal> cd Django-1.5
Terminal> sudo python setup.py install
```

The version in this example, 1.5, may be different at the time you follow these instructions.

3.1 Setting up a Django project

Django applies two concepts: *project* and *application* (or *app*). The app is the program we want to run through a web interface. The project is a Python package containing common settings and configurations for a collection of apps. This means that before we can make a Django app, we must to establish a Django project.

A Django project for managing a set of Django apps is created by the command

```
Terminal> django-admin.py startproject django_project
```

The result in this example is a directory `django_project` whose content can be explored by some `ls` and `cd` commands:

```
Terminal> ls django_project
manage.py django_project
Terminal> cd django_project/django_project
Terminal> ls
__init__.py settings.py urls.py wsgi.py
```

The meaning of the generated files is briefly listed below.

- The outer `django_project/` directory is just a container for your project. Its name does not matter to Django.
- `manage.py` is a command-line utility that lets you interact with this Django project in various ways. You will typically run `manage.py` to launch a Django application.
- The inner `django_project/` directory is a Python package for the Django project. Its name is used in import statements in Python code (e.g., `import django_project.settings`).
- `django_project/__init__.py` is an empty file that just tells Python that this directory should be considered a Python package.
- `django_project/settings.py` contains the settings and configurations for this Django project.
- `django_project/urls.py` maps URLs to specific functions and thereby defines that actions that various URLs imply.
- `django_project/wsgi.py` is not needed in our examples.

Django comes with a web server for developing and debugging applications. The server is started by running

```
Terminal> python manage.py runserver
Validating models...

0 errors found
March 34, 201x - 01:09:24
Django version 1.5, using settings 'django_project.settings'
Development server is running at http://127.0.0.1:8000/
Quit the server with CONTROL-C.
```

The output from starting the server tells that the server runs on the URL `http://127.0.0.1:8000/`. Load this URL into your browser to see a welcome message from Django, meaning that the server is working.

Despite the fact that our introductory web applications do not need a database, you have to register a database with any Django project. To this end, open the `django_project/settings.py` file in a text editor, locate the `DATABASES` dictionary and type in the following code:

```
import os

def relative2absolute_path(relative_path):
    """Return the absolute path correspodning to relative_path."""
    dir_of_this_file = os.path.dirname(os.path.abspath(__file__))
    return dir_of_this_file + '/' + relative_path

DATABASES = {
   'default' : {
```

```
        'ENGINE': 'django.db.backends.sqlite3',
        'NAME': relative2absolute_path('../database.db')
    }
}
```

The `settings.py` file needs absolute paths to files, while it is more convenient for us to specify relative paths. Therefore, we made a function that figures out the absolute path to the `settings.py` file and then combines this absolute path with the relative path. The location and name of the database file can be chosen as desired. Note that one should *not* use `os.path.join` to create paths as Django always applies the forward slash between directories, also on Windows.

3.2 Setting up a Django application

The next step is to create a Django app for our scientific hello world program. We can place the app in any directory, but here we utilize the following organization. As neighbor to `django_project` we have a directory `apps` containing our various scientific applications. Under `apps` we create a directory `django_apps` with our different versions of Django applications. The directory `py_apps` contains the original `hw.py` program in the subdirectory `orig`, while split of this program according to the MVC pattern appears in the `mvc` directory.

The directory `django_apps/hw1` is our first attempt to write a Django-based web interface for the `hw.py` program. The directory structure is laid out by

```
Terminal> cd ..
Terminal> mkdir apps
Terminal> cd apps
Terminal> mkdir py_apps
Terminal> cd py
Terminal> mkdir orig mvc
Terminal> cd ../..
Terminal> mkdir django_apps
Terminal> cd django_apps
```

The file `hw.py` is moved to `orig` while `mvc` contains the MVC refactored version with the files `model.py`, `view.py`, `compute.py`, and `controller.py`.

The `hw1` directory, containing our first Django application, must be made with

```
Terminal> python ../../django_project/manage.py startapp hw1
```

The command creates a directory `hw1` with four empty files:

```
Terminal> cd hw1
Terminal> ls
__init__.py models.py tests.py views.py
```

The `__init__.py` file will remain empty to just indicate that the Django application is a Python package. The other files need to be filled with the right content, which happens in the next section.

At this point, we need to register some information about our application in the `django_project/settings.py` and `django_project/urls.py` files.

Step 1: Add the app. Locate the `INSTALLED_APPS` tuple in `settings.py` and add your Django application as a Python package:

```
INSTALLED_APPS = (
    'django.contrib.auth',
    'django.contrib.contenttypes',
    ...
    'hw1',
)
```

Unfortunately, Django will not be able to find the package `hw1` unless we register the parent directory in `sys.path`:

```
import sys
sys.path.insert(0, relative2absolute_path('../../apps/django_apps'))
```

Note here that the relative path is given with respect to the location of the `settings.py` script.

Step 2: Add a template directory. Make a subdirectory `templates` under `hw1`,

```
Terminal> mkdir templates
```

and add the absolute path of this directory to the `TEMPLATE_DIRS` tuple:

```
TEMPLATE_DIRS = (
    relative2absolute_path('../../apps/django_apps/hw1/templates'),
)
```

The `templates` directory will hold templates for the HTML code applied in the web interfaces. The trailing comma is important as this is a tuple with only one element.

Step 3: Define the URL. We need to connect the Django app with an URL. Our app will be associated with a Python function `index` in the `views` module within the `hw1` package. Say we want the corresponding URL to be named `hw1` relative to the server URL. This information is registered in the `django_project/urls.py` file by the syntax

```
urlpatterns = patterns('',
    url(r'^hw1/', 'django_apps.hw1.views.index'),
```

The first argument to the `url` function is a regular expression for the URL and the second argument is the name of the function to call, using Python's syntax for a function `index` in a module `views` in a package `hw1`. The function name `index` resembles the `index.html` main page associated with an URL, but any other name than `index` can be used.

3.3 Programming the Django application

The Django application is about filling the files `views.py` and `models.py` with content. The mathematical computations are performed in `compute.py` so we copy this file from the `mvc` directory to the `hw1` directory for convenience (we could alternatively add `../mvc` to `sys.path` such that `import compute` would work from the `hw1` directory).

The user interaction. The web application offers a text field where the user can write the value of `r`, see Figure 4. After clicking on the *equals* button, the mathematics is performed and a new page as seen in Figure 5 appears.

Figure 4: The input page.

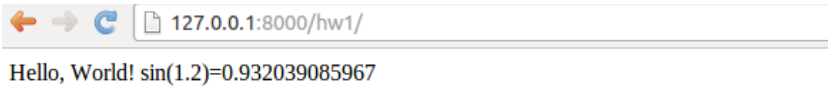


Figure 5: The result page.

The model. The `models.py` file contains the model, which consists of the data we need in the application, stored in Django's data types. Our data consists of one number, called `r`, and `models.py` then look like

```
from django.db import models
from django.forms import ModelForm

class Input(models.Model):
    r = models.FloatField()

class InputForm(ModelForm):
    class Meta:
        model = Input
```

The `Input` class lists variables representing data as static class attributes. The `django.db.models` module contains various classes for different types of data, here we use `FloatField` to represent a floating-point number. The `InputForm` class has a the shown generic form across applications if we by convention apply the name `Input` for the class holding the data.

The view. The `views.py` file contains a function `index` which defines the actions we want to perform when invoking the URL (here `http://127.0.0.1:8000/hw1/`). In addition, `views.py` has the `present_output` function from the `view.py` file in the `mvc` directory.

```
from django.shortcuts import render_to_response
from django.template import RequestContext
from django.http import HttpResponse
from models import InputForm
from compute import compute

def index(request):
    if request.method == 'POST':
        form = InputForm(request.POST)
        if form.is_valid():
            form = form.save(commit=False)
            return present_output(form)
    else:
        form = InputForm()

    return render_to_response('hw1.html',
            {'form': form}, context_instance=RequestContext(request))

def present_output(form):
    r = form.r
    s = compute(r)
    return HttpResponse('Hello, World! sin(%s)=%s' % (r, s))
```

The `index` function deserves some explanation. It must take one argument, usually called `request`. There are two modes in the function. Either the user has provided input on the web page, which means that `request.method` equals `'POST'`, or we show a new web page with which the user is supposed to interact.

Making the input page. The input consists of a web form with one field where we can fill in our `r` variable. This page is realized by the two central statements

```
# Make info needed in the web form
form = InputForm()
# Make HTML code
render_to_response('hw1.html',
    {'form': form}, context_instance=RequestContext(request))
```

The `hw1.html` file resides in the `templates` subdirectory and contains a template for the HTML code:

```
<form method="post" action="">{% csrf_token %}
    Hello, World! The sine of {{ form.r }}
    <input type="submit" value="equals" />
</form>
```

This is a *template file* because it contains instructions like `{% csrf_token %}` and variables like `{{ form.r }}`. Django will replace the former by some appropriate HTML statements, while the latter simply extracts the numerical value of the variable `r` in our form (specified in the `Input` class in `models.py`). Typically, this `hw1.html` file results in the HTML code

```
<form method="post" action="">
<div style='display:none'>
<input type='hidden' name='csrfmiddlewaretoken'
value='oPWMuuy1gLlXm9GvUZINv49eVUYnux5Q' /></div>
    Hello, World! The sine of <input type="text" name="r" id="id_r" />
    <input type="submit" value="equals" />
</form>
```

Making the results page. When then user has filled in a value in the text field on the input page, the `index` function is called again and `request.method` equals `'POST'`. A new form object is made, this time with user info (`request.POST`). We can check that the form is valid and if so, proceed with computations followed by presenting the results in a new web page (see Figure 5):

```
def index(request):
    if request.method == 'POST':
        form = InputForm(request.POST)
        if form.is_valid():
            form = form.save(commit=False)
            return present_output(form)

def present_output(form):
    r = form.r
    s = compute(r)
    return HttpResponse('Hello, World! sin(%s)=%s' % (r, s))
```

The numerical value of `r` as given by the user is available as `form.r`. Instead of using a template for the output page, which is natural to do in more advanced cases, we here illustrate the possibility to send raw HTML to the output page by returning an `HttpResponse` object initialized by a string containing the desired HTML code.

Launch this application by filling in the address `http://127.0.0.1:8000/hw1/` in your web browser. Make sure the Django development server is running, and if not, restart it by

```
Terminal> python ../../../django_project/manage.py runserver
```

Fill in some number on the input page and view the output. To show how easy it is to change the application, invoke the `views.py` file in an editor and add some color to the output HTML code from the `present_output` function:

```
    return HttpResponse("""
<font color='blue'>Hello</font>, World!
sin(%s)=%s
"""% (r, s))
```

Go back to the input page, provide a new number, and observe how the "Hello" word now has a blue color.

3.4 Equipping the input page with output results

Instead of making a separate output page with the result, we can simply add the sine value to the input page. This makes the user feel that she interacts with

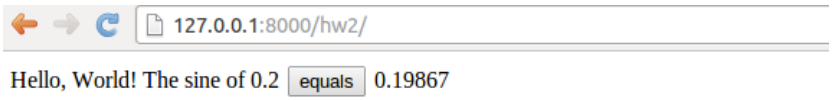


Figure 6: The modified result page.

the same page, as when operating a calculator. The output page should then look as shown in Figure 6.

We need to make a new Django application, now called `hw2`. Instead of running the standard `manage.py startapp hw2` command, we can simply copy the `hw1` directory to `hw2`. We need, of course, to add information about this new application in `settings.py` and `urls.py`. In the former file we must have

```
TEMPLATE_DIRS = (
    relative2absolute_path('../../apps/django_apps/hw1/templates'),
    relative2absolute_path('../../apps/django_apps/hw2/templates'),
)

INSTALLED_APPS = (
    'django.contrib.auth',
    'django.contrib.contenttypes',
    'django.contrib.sessions',
    'django.contrib.sites',
    'django.contrib.messages',
    'django.contrib.staticfiles',
    # Uncomment the next line to enable the admin:
    # 'django.contrib.admin',
    # Uncomment the next line to enable admin documentation:
    # 'django.contrib.admindocs',
    'hw1',
    'hw2',
)
```

In `urls.py` we add the URL `hw2` which is to call our `index` function in the `views.py` file of the `hw2` app:

```
urlpatterns = patterns('',
    url(r'^hw1/', 'django_apps.hw1.views.index'),
    url(r'^hw2/', 'django_apps.hw2.views.index'),
```

The `views.py` file changes a bit since we shall generate almost the same web page on input and output. This makes the `present_output` function unnatural, and everything is done within the `index` function:

```
def index(request):
    s = None  # initial value of result
    if request.method == 'POST':
        form = InputForm(request.POST)
        if form.is_valid():
            form = form.save(commit=False)
            r = form.r
            s = compute(r)
```

```
    else:
        form = InputForm()

    return render_to_response('hw2.html',
            {'form': form,
             's': '%.5f' % s if isinstance(s, float) else ''
             }, context_instance=RequestContext(request))
```

Note that the output variable `s` is computed within the `index` function and defaults to `None`. The template file `hw2.html` looks like

```
<form method="post" action="">{% csrf_token %}
    Hello, World! The sine of {{ form.r }}
    <input type="submit" value="equals" />
{% if s != '' %}
{{ s }}
{% endif %}
</form>
```

The difference from `hw1.html` is that we right after the *equals* button write out the value of `s`. However, we make a test that the value is only written if it is computed, here recognized by being a non-empty string. The `s` in the template file is substituted by the value of the object corresponding to the key `'s'` in the dictionary we pass to the `render_to_response`. As seen, we pass a string where `s` is formatted with five digits if `s` is a float, i.e., if `s` is computed. Otherwise, `s` has the default value `None` and we send an empty string to the template. The template language allows tests using Python syntax, but the if-block must be explicitly ended by `{% endif %}`.

4 Handling multiple input variables in Flask

The scientific hello world example shows how to work with one input variable and one output variable. We can easily derive an extensible recipe for apps with a collection of input variables and some associated HTML code as result. Multiple input variables are listed in the `InputForm` class using different types for different forms (text field, float field, integer field, check box field for boolean values, etc.). The value of these variables will be available in a `form` object for computation. It is then a matter of setting up a template code where the various variables if the `form` object are formatted in HTML code as desired.

Our sample web application addresses the task of plotting the function $u(t) = Ae^{-bt}\sin(wt)$ for $t \in [0, T]$. The web application must have fields for the numbers A, b, w, and T, and a *Compute* button, as shown in Figure 7. Filling in values, say 0.1 for b and 20 for T, results in what we see in Figure 8, i.e., a plot of $u(t)$ is added after the input fields and the *Compute* button.

We shall make a series of different versions of this app:

1. `vib1` for the basic set-up and illustration of tailoring the HTML code.
2. `vib2` for custom validation of input, governed by the programmer, and inlined graphics in the HTML code.

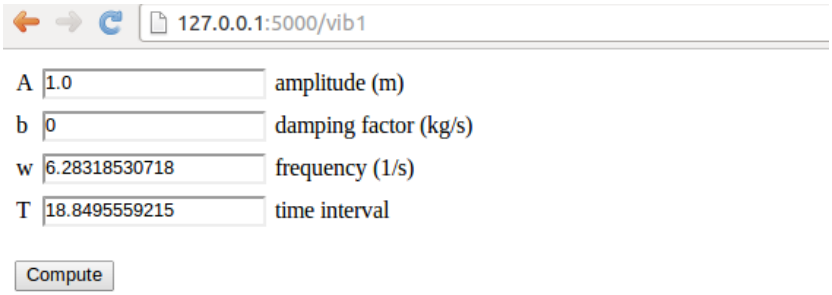


Figure 7: The input page.

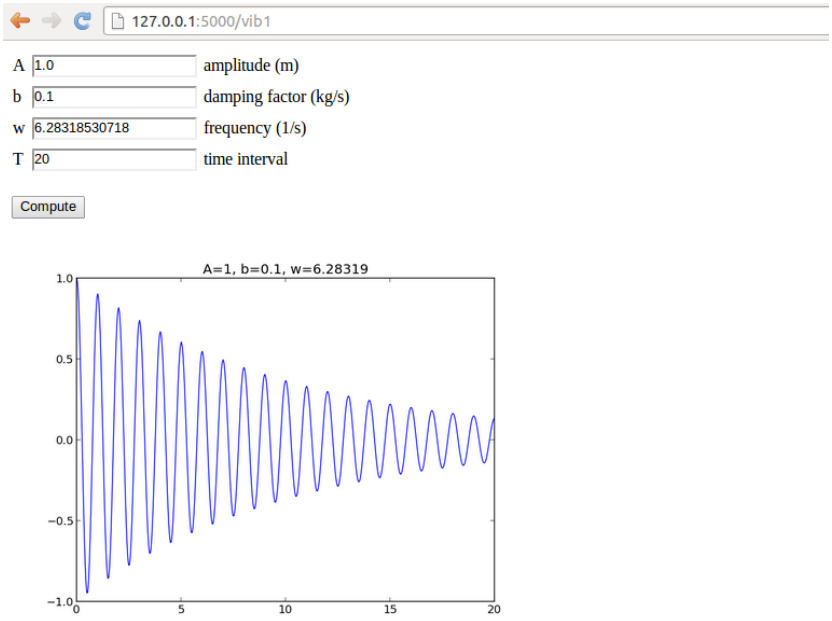


Figure 8: The result page.

3. `gen` for automatic generation of the Flask app (!).
4. `login` for storing computed results in user accounts.

4.1 Programming the Flask application

The forthcoming text explains the necessary steps to realize a Flask app that behaves as depicted in Figures 7 and 8. We start with the `compute.py` module

since it contains only the computation of $u(t)$ and the making of the plot, without any interaction with Flask.

The files associated with this app are found in the `vib1` directory.

The compute part. More specifically, inside `compute.py`, we have a function for evaluating $u(t)$ and a `compute` function for making the plot. The return value of the latter is the name of the plot file, which should get a unique name every time the `compute` function is called such that the browser cannot reuse an already cached image when displaying the plot. Flask applications must have all extra files (CSS, images, etc.) in a subdirectory `static`.

```
from numpy import exp, cos, linspace
import matplotlib.pyplot as plt
import os, time, glob

def damped_vibrations(t, A, b, w):
    return A*exp(-b*t)*cos(w*t)

def compute(A, b, w, T, resolution=500):
    """Return filename of plot of the damped_vibration function."""
    t = linspace(0, T, resolution+1)
    y = damped_vibrations(t, A, b, w)
    plt.figure()  # needed to avoid adding curves in plot
    plt.plot(t, y)
    plt.title('A=%g, b=%g, w=%g' % (A, b, w))
    if not os.path.isdir('static'):
        os.mkdir('static')
    else:
        # Remove old plot files
        for filename in glob.glob(os.path.join('static', '*.png')):
            os.remove(filename)
    # Use time since Jan 1, 1970 in filename in order make
    # a unique filename that the browser has not chached
    plotfile = os.path.join('static', str(time.time()) + '.png')
    plt.savefig(plotfile)
    return plotfile

if __name__ == '__main__':
    print compute(1, 0.1, 1, 20)
```

Avoid file writing.

It is in general not a good idea to write plots to file or let a web app write to file. If this app is deployed at some web site and multiple users are running the app, the `os.remove` statements may remove plots created by all other users. However, the app is useful as a graphical user interface run locally on a machine. Later, we shall avoid writing plot files and instead store plots in strings and embed the strings in the `img` tag in the HTML code.

We organize the model, view, and controller as three separate files, as illustrated in Section 2.3. This more complicated app involves more code and especially the model will soon be handy to isolate in its own file.

The model. Our first version of `model.py` reads

```
from wtforms import Form, FloatField, validators
from math import pi

class InputForm(Form):
    A = FloatField(
        label='amplitude (m)', default=1.0,
        validators=[validators.InputRequired()])
    b = FloatField(
        label='damping factor (kg/s)', default=0,
        validators=[validators.InputRequired()])
    w = FloatField(
        label='frequency (1/s)', default=2*pi,
        validators=[validators.InputRequired()])
    T = FloatField(
        label='time interval (s)', default=18,
        validators=[validators.InputRequired()])
```

As seen, the field classes can take a `label` argument for a longer description, here also including the units in which the variable is measured. It is also possible to add a `description` argument with some help message. Furthermore, we include a `default` value, which will appear in the text field such that the user does not need to fill in all values.

The view. The view component will of course make use of templates, and we shall experiment with different templates. Therefore, we allow a command-line argument to this Flask app for choosing which template we want. The rest of the `controller.py` file follows much the same set up as for the scientific hello world app:

```
from model import InputForm
from flask import Flask, render_template, request
from compute import compute
import sys

try:
    template_name = sys.argv[1]
except IndexError:
    template_name = 'view_plain'

app = Flask(__name__)

if template_name == 'view_flask_bootstrap':
    from flask_bootstrap import Bootstrap
    Bootstrap(app)

@app.route('/vib1', methods=['GET', 'POST'])
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
```

```
            result = compute(form.A.data, form.b.data,
                             form.w.data, form.T.data)
        else:
            result = None

        return render_template(template_name + '.html',
                               form=form, result=result)

if __name__ == '__main__':
    app.run(debug=True)
```

The HTML template. The details governing how the web page really looks like lie in the template file. Since we have several fields and want them nicely align in a tabular fashion, we place the field name, text areas, and labels inside an HTML table in our first attempt to write a template, `view_plain.html`:

```
<form method=post action="">
<table>
  {% for field in form %}
    <tr>
    <td>{{ field.name }}</td><td>{{ field }}</td>
    <td>{{ field.label }}</td>
    </tr>
  {% endfor %}
</table>
<p><input type=submit value=Compute></form></p>

<p>
{% if result != None %}
<img src="{{ result }}" width="500">
{% endif %}
</p>
```

Observe how easy it is to iterate over the `form` object and grab data for each field: `field.name` is the name of the variable in the `InputForm` class, `field.label` is the full name with units as given through the `label` keyword when constructing the field object, and writing the field object itself generates the text area for input (i.e., the HTML input form). The control statements we can use in the template are part of the Jinja2 templating language. For now, the if-test, for-loop and output of values (`{{ object }}`) are enough to generate the HTML code we want.

Recall that the objects we need in the template, like `result` and `form` in the present case, are transferred to the template via keyword arguments to the `render_template` function. We can easily pass on any object in our application to the template. Debugging of the template is done by viewing the HTML source of the web page in the browser.

You are encouraged to go to the `vib` directory, run `python controller.py`, and load

`‘http://127.0.0.1:5000/vib1‘`

into your web browser for testing.

4.2 Implementing error checking in the template

What happens if the user gives wrong input, for instance the letters `asd` instead of a number? Actually nothing! The `FloatField` object checks that the input is compatible with a real number in the `form.validate()` call, but returns just `False` if this is not the case. Looking at the code in `controller.py`,

```
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        result = compute(form.A.data, form.b.data,
                         form.w.data, form.T.data)
    else:
        result = None
```

we realize that wrong input implies `result = None` and no computations and no plot! Fortunately, each field object gets an attribute `error` with information on errors that occur on input. We can write out this information on the web page, as exemplified in the template `view_errcheck.html`:

```
<form method=post action="">
<table>
  {% for field in form %}
    <tr>
    <td>{{ field.name }}</td><td>{{ field(size=12) }}</td>
    <td>{{ field.label }}</td>
    {% if field.errors %}
      <td><ul class=errors>
      {% for error in field.errors %}
        <li><font color="red">{{ error }}</font></li>
      {% endfor %}</ul></td>
    {% endif %}
    </tr>
  {% endfor %}
</table>
<p><input type=submit value=Compute></form></p>
<p>
{% if result != None %}
<img src="{{ result }}" width="500">
{% endif %}
</p>
```

Two things are worth noticing here:

1. We can control the width of the text field where the user writes the numbers, here set to 12 characters.
2. We can make an extra column in the HTML table with a list of possible errors for each field object.

Let us test the error handling of the `A` field by writing `asd` instead of a number. This input triggers an error, whose message is written in red to the right of the label, see Figure 9.

It is possible to use the additional HTML5 fields for input in a Flask context. Instead of explaining how here, we recommend to use the Parampool package to automatically generate Flask files with HTML5 fields.

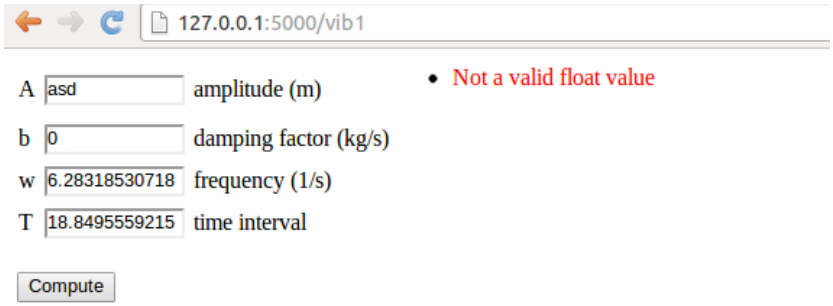


Figure 9: Error message because of wrong input.

4.3 Using style sheets

Web developers make heavy use of CSS style sheets to control the look and feel of web pages. Templates can utilize style sheets as any other standard HTML code. Here is a very simple example where we introduce a class `name` for the HTML table's column with the field name and set the foreground color of the text in this column to blue. The style sheet is called `basic.css` and *must* reside in the `static` subdirectory of the Flask application directory. The content of `basic.css` is just the line

```
td.name { color: blue; }
```

The `view_css.html` file using this style sheet features a `link` tag to the style sheet in the HTML header, and the column containing the field name has the HTML tag `<td class="name">` to trigger the specification in the style sheet:

```
<html>
<head>
<link rel="stylesheet" href="static/basic.css" type="text/css">
</head>
<body>

<form method=post action="">
<table>
  {% for field in form %}
    <tr>
    <td class="name">{{ field.name }}</td>
    <td>{{ field(size=12) }}</td>
    <td>{{ field.label }}</td>
```

Just run `python controller.py view_css` to see that the names of the variables to set in the web page are blue.

4.4 Using LaTeX mathematics

Scientific applications frequently have many input data that are defined through mathematics and where the typesetting on the web page should be as close as

possible to the typesetting where the mathematics is documented. In the present example we would like to typeset A, b, w, and T with italic font as done in LaTeX. Fortunately, native LaTeX typesetting is available in HTML through the tool MathJax. Our template `view_tex.html` enables MathJax. Formulas are written with standard LaTeX inside `\(` and `\)`, while equations are surrounded by `$$`. Here we use formulas only:

```
<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js", "color.js"]
  }
});
</script>
<script type="text/javascript"
 src="http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>

This web page visualizes the function \(
u(t) = Ae^{-bt}\sin (w t), \hbox{ for } t\in [0,T]
\).

<form method=post action="">
<table>
  {% for field in form %}
    <tr>
    <td>\( {{ field.name }} \)</td><td>{{ field(size=12) }}</td>
    <td>{{ field.label }}</td>
```

Figure 10 displays how the LaTeX rendering looks like in the browser.

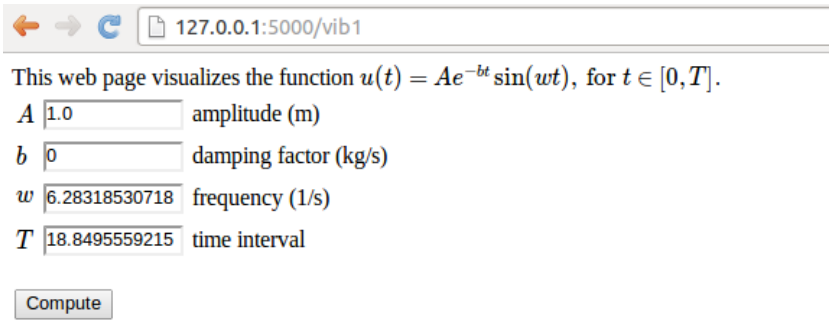


Figure 10: LaTeX typesetting of mathematical symbols.

4.5 Rearranging the elements in the HTML template

Now we want to place the plot to the right of the input forms in the web page, see Figure 11. This can be accomplished by having an outer table with two rows.

The first row contains the table with the input forms in the first column and the plot in the second column, while the second row features the *Compute* button in the first column.

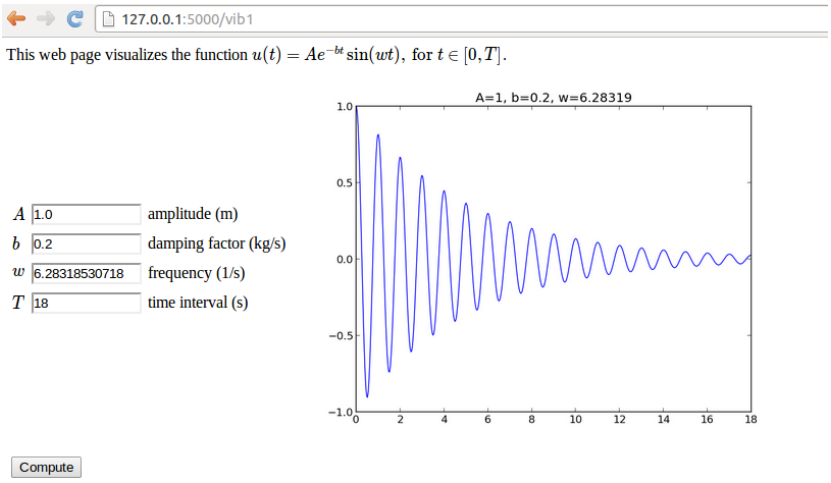


Figure 11: New design with input and output side by side.

The enabling template file is `view_table.html`:

```
<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js"]
  }
});
</script>
<script type="text/javascript"
 src="http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>

This web page visualizes the function \(
u(t) = Ae^{-bt}\sin (w t), \hbox{ for } t\in [0,T]
\).

<form method=post action="">
<table> <!-- table with forms to the left and plot to the right -->
<tr><td>
<table>
  {% for field in form %}
    <tr>
    <td>\( {{ field.name }} \)</td><td>{{ field(size=12) }}</td>
    <td>{{ field.label }}</td>
    {% if field.errors %}
      <td><ul class=errors>
      {% for error in field.errors %}
```

```
        <li><font color="red">{{ error }}</font></li>
      {% endfor %}</ul></td>
    {% endif %}
    </tr>
  {% endfor %}
</table>
</td>

<td>
<p>
{% if result != None %}
<img src="{{ result }}" width="500">
{% endif %}
</p>
</td></tr>
<tr>
<td><p><input type=submit value=Compute></p></td>
</tr>
</table>
</form>
```

4.6 Bootstrap HTML style

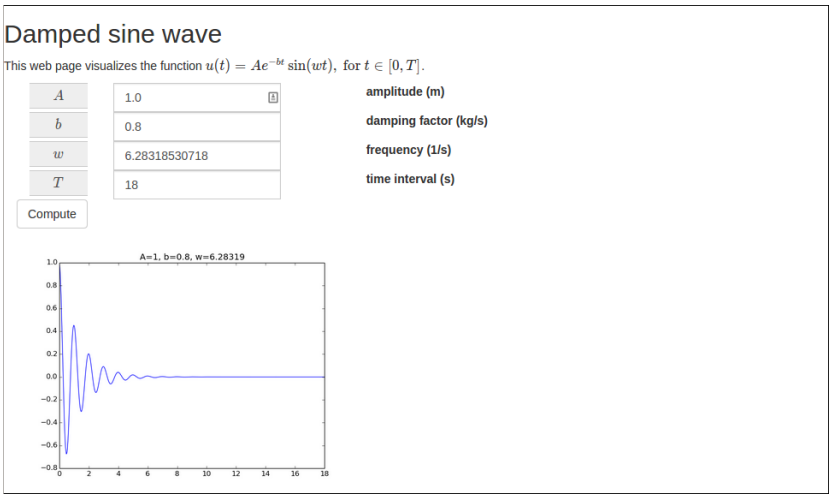
The Bootstrap framework for creating web pages has been very popular in recent years, both because of the design and the automatic support for responsive pages on all sorts of devices. Bootstrap can easily be used in combination with Flask. The template file `view_bootstrap.html` is identical to the former `view_table.html`, except that we load the Bootstrap CSS file and include in comments how to add the typical navigation bar found in many Bootstrap-based web pages. Moreover, we use the grid layout functionality of Bootstrap to control the placement of elements (name, input field, label, and error message) in the input form.

The template looks like

```
<!DOCTYPE html>
<html lang="en">


<link href=
"http://netdna.bootstrapcdn.com/bootstrap/3.1.1/css/bootstrap.min.css"
rel="stylesheet">

<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js", "color.js"]
  }
});
</script>
<script type="text/javascript" src=
"http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>
<!--
<nav class="navbar navbar-default" role="navigation">
<div class="collapse navbar-collapse" id="bs-example-navbar-collapse-1">
    <ul class="nav navbar-nav">
```

```
        {% for text, url in some_sequence %}
        <li><a href="/{{url}}">{{ text }}</a></li>
        {% endfor %}
        </ul>
</div>
</nav>
-->

<h2>Damped sine wave</h2>

This web page visualizes the function \(
u(t) = Ae^{-bt}\sin (w t), \hbox{ for } t\in [0,T]
\).

<p>
<form class="navbar-form navbar-top" method="post" action="">
  <div class="form-group">
  {% for field in form %}
    <div class="row">
     <div class="input-group">
      <label class="col-xs-1 control-label">
      <span class="input-group-addon"> \( {{ field.name }} \) </span>
      </label>
      <div class="col-xs-2">
      {{ field(class_="form-control") }}
      </div>
      <div class="col-xs-3">
        {{ field.label }}
      </div>
      {% if field.errors %}
        {% for error in field.errors %}
          <div class="col-xs-3">
            <div style="color: red;">{{ error }}</div>
          </div>
        {% endfor %}
      {% endif %}
     </div>
    </div>
  {% endfor %}
<br/>
<input type="submit" value="Compute" class="btn btn-default">
</form>

<p>
{% if result != None %}
<img src="{{ result }}" width="400">
{% endif %}
</html>
```

The input fields and fonts now get the typical Bootstrap look and feel:

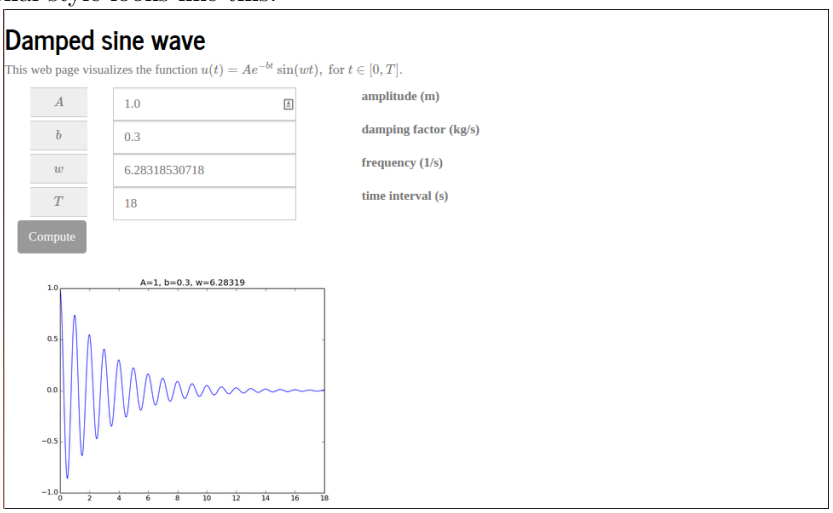


The only special feature in this template is the need to pass a CSS class `form-control` to the field object in the part that defines the input field. We also use the standard `input-group-addon` style in the name part of the Bootstrap form. A heading *Damped sine wave* was added to demonstrate the Bootstrap fonts.

It is easy to switch to other Bootstrap styles, e.g., those in the "Bootswatch family": "http:bootswatch.com":

```
<link href=
"http://netdna.bootstrapcdn.com/bootswatch/3.1.1/X/bootstrap.min.css"
rel="stylesheet">
```

where `X` can be `journal`, `cosmo`, `flatly`, and other legal Bootswatch styles. The journal style looks like this:



While `view_bootstrap.html` makes use of plain Bootstrap HTML code, there is also a higher-level framework, called Flask-Bootstrap that combines Flask and Bootstrap. Installation of this extension is done by `sudo pip install flask-bootstrap`.

After `app = Flask(__name__)` we need to do

```
from flask_bootstrap import Bootstrap
Bootstrap(app)
```

The template employs new keywords `extends` and `block`:

```
{% extends "bootstrap/base.html" %}

{% block styles %}
{{super()}}
<style>
    .appsize { width: 800px }
</style>

<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js", "color.js"]
  }
});
</script>
<script type="text/javascript" src=
"http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>
{% endblock %}

<!--
{% block navbar %}
<nav class="navbar navbar-default" role="navigation">
<div class="collapse navbar-collapse" id="bs-example-navbar-collapse-1">
    <ul class="nav navbar-nav">
       {% for f in some_sequence %}
       <li><a href="/{{f}}">{{f}}</a></li>
       {% endfor %}
       </ul>
</div>
</nav>
{% endblock %}
-->

{% block content %}

<h2>Damped sine wave</h2>

This web page visualizes the function \(
u(t) = Ae^{-bt}\sin (w t), \hbox{ for } t\in [0,T]
\).

<p>
<form class="navbar-form navbar-top" method="post" action="">
  <div class="form-group">
  {% for field in form %}
    <div class="row">
     <div class="input-group appsize">
```

```
      <label class="col-sm-1 control-label">
      <span class="input-group-addon"> \( {{ field.name }} \) </span>
      </label>
      <div class="col-sm-4">
      {{ field(class_="form-control") }}
      </div>
      <div class="col-sm-4">
        {{ field.label }}
      </div>
      {% if field.errors %}
        {% for error in field.errors %}
          <div class="col-sm-3">
            <div style="color: red;">{{ error }}</div>
          </div>
        {% endfor %}
      {% endif %}
     </div>
    </div>
  {% endfor %}
<br/>
<input type="submit" value="Compute" class="btn btn-default">
</form>

<p>
{% if result != None %}
<img src="{{ result }}" width="500">
{% endif %}
</html>
{% endblock %}
```

It is important to have the MathJax script declaration and all styles within `{% block styles %}`.

It seems easier to apply plain Bootstrap HTML code than the functionality in the Flask-Bootstrap layer.

4.7 Custom validation

The `FloatField` objects can check that the input is compatible with a number, but what if we want to control that $A > 0$, $b > 0$, and T is not greater than 30 periods (otherwise the plot gets cluttered)? We can write functions for checking appropriate conditions and supply the function to the list of validator functions in the call to the `FloatField` constructor or other field constructors. The extra code is a part of the `model.py` and the presented extensions appear in the directory `vib2`.

Using Flask validators. The simplest approach to validation is to use existing functionality in the web framework. Checking that $A > 0$ can be done by the `NumberRange` validator which checks that the value is inside a prescribed interval:

```
from wtforms import Form, FloatField, validators

class InputForm(Form):
    A = FloatField(
        label='amplitude (m)', default=1.0,
        validators=[validators.NumberRange(0, 1E+20)])
```

Tailored validation. We can also easily provide our own more tailored validators. As an example, let us explain how we can check that T is less than 30 periods. One period is $2\pi/w$ so we need to check if $T > 30 \cdot 2\pi/w$ and raise an exception in that case. A validation function takes two arguments: the whole `form` and the specific `field` to test:

```
def check_T(form, field):
    """Form validation: failure if T > 30 periods."""
    w = form.w.data
    T = field.data
    period = 2*pi/w
    if T > 30*period:
        num_periods = int(round(T/period))
        raise validators.ValidationError(
            'Cannot plot as much as %d periods! T<%.2f' %
            (num_periods, 30*period))
```

The appropriate exception is of type `validators.ValidationError`. Observe that through `form` we have in fact access to all the input data so we can easily use the value of w when checking the validity of the value of T. The `check_T` function is easy to add to the list of validator functions in the call to the `FloatField` constructor for `T`:

```
class InputForm(Form):
    ...
    T = FloatField(
        label='time interval', default=6*pi,
        validators=[validators.InputRequired(), check_T])
```

The validator objects are tested one by one as they appear in the list, and if one fails, the others are not invoked. We therefore add `check_T` after the check of input such that we know we have a value for all data when we run the computations and test in `check_T`.

Tailored validation of intervals. Although there is already a `NumberRange` validator for checking whether a value is inside an interval, we can write our own version with some improved functionality for open intervals where the maximum or minimum value can be infinite. The infinite value can on input be represented by `None`. A general such function may take the form

```
def check_interval(form, field, min_value=None, max_value=None):
    """For validation: failure if value is outside an interval."""
    failure = False
    if min_value is not None:
        if field.data < min_value:
            failure = True
    if max_value is not None:
        if field.data > max_value:
            failure = True
    if failure:
        raise validators.ValidationError(
            '%s=%s not in [%s, %s]' %
            (field.name, field.data,
             '-infty' if min_value is None else str(min_value),
             'infty'  if max_value is None else str(max_value)))
```

The problem is that `check_interval` takes four arguments, not only the `form` and `field` arguments that a validator function in the Flask framework can accept. The way out of this difficulty is to use a Python tool `functools.partial` which allows us to call a function with some of the arguments set beforehand. Here, we want to create a new function that calls `check_interval` with some prescribed values of `min_value` and `max_value`. This function looks like it does not have these arguments, only `form` and `field`. The following function produces this function, which we can use as a valid Flask validator function:

```
import functools

def interval(min_value=None, max_value=None):
    return functools.partial(
        check_interval, min_value=min_value, max_value=max_value)
```

We can now in any field constructor just add `interval(a, b)` as a validator function, here checking that $b \in [0, \infty)$:

```
class InputForm(Form):
    ...
    b = FloatField(
        label='damping factor (kg/s)', default=0,
        validators=[validators.InputRequired(), interval(0,None)])
```

Demo. Let us test our tailored error checking. Run `python controller.py` in the `vib2` directory and fill in -1.0 in the b field. Pressing *Compute* invokes our `interval(0,None)` function, which is nothing but a call to `check_interval` with the arguments `field`, `form`, `0`, and `None`. Inside this function, the test `if field.data < min_value` becomes true, `failure` is set, and the exception is raised. The message in the exception is available in the `field.errors` attribute so our template will write it out in red, see Figure 12. The template used in `vib2` is basically the same as `view_tex.html` in `vib1`, i.e., it feaures LaTeX mathematics and checking of `field.errors`.

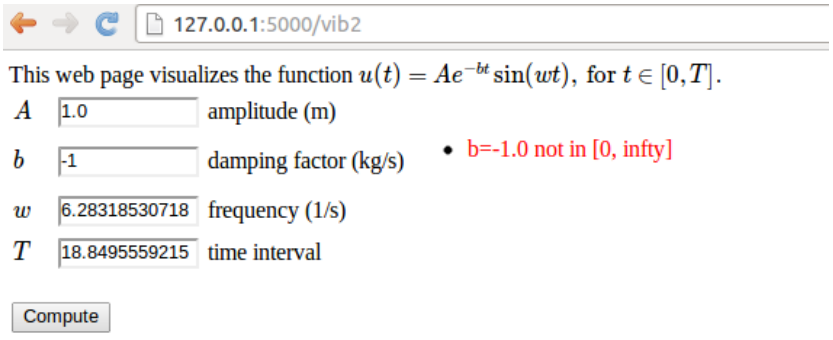


Figure 12: Triggering of a user-defined error check.

Finally, we mention a detail in the `controller.py` file in the `vib2` app: instead of sending `form.var.data` to the `compute` function we may automatically generate a set of local variables such that the application of data from the web page, here in the `compute` call, looks nicer:

```
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        for field in form:
            # Make local variable (name field.name)
            exec('%s = %s' % (field.name, field.data))
        result = compute(A, b, w, T)
    else:
        result = None

    return render_template(template, form=form, result=result)

if __name__ == '__main__':
    app.run(debug=True)
```

The idea is just to run `exec` on a declaration of a local variable with name `field.name` for each field in the form. This trick is often neat if web variables are buried in objects (`form.T.data`) and you want these variables in your code to look like they do in mathematical writing (`T` for T).

4.8 Avoiding plot files

Files with plots are easy to deal with as long as they are in the `static` subdirectory of the Flask application directory. However, as already pointed out, the previous `vib1` app, which writes plot files, is not suited for multiple simultaneous users since every user will destroy *all* existing plot files before making a new one. Therefore, we need a robust solution for multiple users of the app.

The idea is to not write plot files, but instead return the plot as a string and embed that string directly in the HTML code. This is relatively straightforward with Matplotlib and Python. The relevant code is found in the `compute.py` file of the `vib2` app.

PNG plots. Python has the `StringIO` object that is a string buffer with the look and behavior of a file. The idea is to let Matplotlib write to a `StringIO` object and afterwards extract the string from this object:

```
import matplotlib.pyplot as plot
from StringIO import StringIO
# run plt.plot, plt.title, etc.
figfile = StringIO()
plt.savefig(figfile, format='png')
figfile.seek(0)  # rewind to beginning of file
figdata_png = figfile.buf  # extract string
```

Before the PNG data can be embedded in HTML we need to convert the data to base64 format:

```
import base64
figdata_png = base64.b64encode(figdata_png)
```

Now we can embed the PNG data in HTML by

```
<img src="" width="500">
```

where `PLOTSTR` is the content of the string `figdata_png`.

The complete `compute.py` function takes the form

```
def compute(A, b, w, T, resolution=500):
    """Return filename of plot of the damped_vibration function."""
    t = linspace(0, T, resolution+1)
    y = damped_vibrations(t, A, b, w)
    plt.figure()  # needed to avoid adding curves in plot
    plt.plot(t, y)
    plt.title('A=%g, b=%g, w=%g' % (A, b, w))

    # Make Matplotlib write to StringIO file object and grab
    # return the object's string
    from StringIO import StringIO
    figfile = StringIO()
    plt.savefig(figfile, format='png')
    figfile.seek(0)  # rewind to beginning of file
    import base64
    figdata_png = base64.b64encode(figfile.buf)
    return figdata_png
```

The relevant syntax in an HTML template is

```
<img src="{{ results }}" width="500">
```

if `results` holds the returned object from the `compute` function above.

SVG plots. Inline figures in HTML, instead of using files, are most often realized by XML code with the figure data in SVG format. Plot strings in the SVG format are created very similarly to the PNG example:

```
figfile = StringIO()
plt.savefig(figfile, format='svg')
figdata_svg = figfile.buf
```

The `figdata_svg` string contains XML code text can almost be directly embedded in HTML5. However, the beginning of the text contains information before the `svg` tag that we want to remove:

```
<?xml version="1.0" encoding="utf-8" standalone="no"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.1//EN"
  "http://www.w3.org/Graphics/SVG/1.1/DTD/svg11.dtd">
<!-- Created with matplotlib (http://matplotlib.sourceforge.net/) -->
<svg height="441pt" version="1.1" viewBox="0 0 585 441" ...
```

The removal is done with a little string manipulation:

```
figdata_svg = '<svg' + figfile.buf.split('<svg')[1]
```

Now, `figdata_svg` can be directly inserted in HTML code without any surrounding tags (because it is perfectly valid HTML code in itself).

The SVG code generated by Matplotlib may contain UTF-8 characters so it is necessary to make a unicode string out of the text: `unicode(figdata_svg, 'utf-8')`, otherwise the HTML template will lead to an encoding exception.

We have made an alternative compute function `compute_png_svg` that returns both a PNG and an SVG plot:

```
def compute_png_svg(A, b, w, T, resolution=500):
    ...
    figfile = StringIO()
    plt.savefig(figfile, format='svg')
    figfile.seek(0)
    figdata_svg = '<svg' + figfile.buf.split('<svg')[1]
    figdata_svg = unicode(figdata_svg,'utf-8')
    return figdata_png, figdata_svg
```

The relevant syntax for inserting an SVG plot in the HTML template is now

```
{{ result[1]|safe }}
```

The use of `safe` is essential here.

Important: use `safe` for verbatim HTML code:

Special HTML characters like `<`, `>`, `&`, `"`, and `'` are escaped in a template string like `{{ str }}` (i.e., `&` is replaced by `&` '<' is replaced by `<`, etc.). We need to avoid this manipulation of the string content because `result[1]` contains XML code where the mentioned characters are essential part of the syntax. Writing `{{str|safe}}` ensures that the contents of the string `str` are not altered before being embedded in the HTML text.

An alternative template, `view_svg.html` applies the SVG plot instead of the PNG plot. We use the command-line argument `svg` for indicating that we want an SVG instead of a PNG plot:

```
# SVG or PNG plot?
svg = False
try:
    if sys.argv[1] == 'svg':
        svg = True
except IndexError:
    pass
if svg:
    from compute import compute_png_svg as compute
    template = 'view_svg.html'
else:
    from compute import compute
    template = 'view.html'
```

4.9 Autogenerating the code

We shall now present generic `model.py` and `controller.py` files that work with *any* `compute` function (!). This example will demonstrate some advanced, powerful features of Python. The source code is found in the `gen` directory.

Inspecting function signatures. The basic idea is that the Python module `inspect` can be used to retrieve the names of the arguments and the default values of keyword arguments of *any* given `compute` function. Say we have some

```
def mycompute(A, m=0, s=1, w=1, x_range=[-3,3]):
    ...
    return result
```

Running

```
import inspect
arg_names = inspect.getargspec(mycompute).args
defaults  = inspect.getargspec(mycompute).defaults
```

leads to

```
arg_names = ['A', 'm', 's', 'w', 'x_range']
defaults = (0, 1, 1, [-3, 3])
```

We have all the argument names in `arg_names` and `defaults[i]` is the default value of keyword argument `arg_names[j]`, where `j = len(arg_names) - len(defaults) + i`.

Generating the model. Knowing the name `name` of some argument in the `compute` function, we can make the corresponding class attribute in the `InputForm` class by

```
setattr(InputForm, name, FloatForm())
```

For name equal to `'A'` this is the same as hardcoding

```
class InputForm:
    A = FloatForm()
```

Assuming that all arguments in `compute` are floats, we could do

```
class InputForm:
    pass  # Empty class

arg_names = inspect.getargspec(mycompute).args
for name in arg_names:
    setattr(InputForm, name, FloatForm())
```

However, we can do better than this: for keyword arguments the type of the default value can be used to select the appropriate form class. The complete `model.py` file then goes as follows:

```
"""
Example on generic model.py file which inspects the arguments
of the compute function and automatically generates a relevant
InputForm class.
"""

import wtforms
from math import pi

from compute import compute_gamma as compute
import inspect
arg_names = inspect.getargspec(compute).args
defaults  = inspect.getargspec(compute).defaults

class InputForm(wtforms.Form):
    pass

# Augment defaults with None elements for the positional
# arguments
defaults = [None]*(len(arg_names)-len(defaults)) + list(defaults)
# Map type of default to right form field
type2form = {type(1.0): wtforms.FloatField,
             type(1):   wtforms.IntegerField,
             type(''):  wtforms.TextField,
             }

for name, value in zip(arg_names, defaults):
    if value is None:
        setattr(InputForm, name, wtforms.FloatField(
            validators=[wtforms.validators.InputRequired()]))
    else:
        if type(value) in type2form:
            setattr(InputForm, name, type2form[type(value)](
                default=value,
                validators=[wtforms.validators.InputRequired()]))
        else:
            raise TypeError('argument %s %s not supported' %
                            name, type(value))

if __name__ == '__main__':
    for item in dir(InputForm):
        if item in arg_names:
            print item, getattr(InputForm, item)
```

(The `compute_gamma` function imported from `compute` is the only application-specific statement in this code and will be explained later.)

Generating the view. The call to `compute` in the `controller.py` file must also be expressed in a general way such that the call handles any type and number of parameters. This can be done in two ways, using either positional or keyword arguments.

The technique with positional arguments is explained first. It consists of collecting all parameters in a list or tuple, called `args`, and then calling `compute(*args)` (which is equivalent to `compute(args[0], args[1], ..., args[n])` if `n` is `len(args)-1`). The elements of `args` are the values of the form variables. We know the name of a form variable as a string `name` (from `arg_names`), and if

`form` is the form object, the construction `getattr(form, name).data` extracts the value that the user provided (`getattr(obj, attr)` gets the attribute, with name available as a string in `attr`, in the object `obj`). For exampe, if `name` is `'A'`, `getattr(form, name).data` is the same as `form.A.data`. Collecting all form variables, placing them in a list, and calling `compute` are done with

```
arg_names = inspect.getargspec(compute).args
args = [getattr(form, name).data for name in arg_names]
result = compute(*args)
```

Our `InputForm` class guarantees that all arguments in `compute` are present in the form, but to be absolutely safe we can test if `name` is present in the `form` object:

```
args = [getattr(form, name).data for name in arg_names
        if hasattr(form, name)]
```

A potential problem with the `args` list is that the values might be in wrong order. It appears, fortunately, that the order we assign attributes to the form class is preserved when iterating over the form. Nevertheless, using keyword arguments instead of positional arguments provides a completely safe solution to calling `compute` with the correct arguments. Keyword arguments are placed in a dictionary `kwargs` and `compute` is called as `compute(**kwargs)`. The generic solution is

```
kwargs = {name: getattr(form, name).data for name in arg_names
          if hasattr(form, name)}
result = compute(**kwargs)
```

The `compute(**kwargs)` call is equivalent to `compute(A=1, b=3, w=0.5)` in case `kwargs = {'w'=0.5, 'A':1, 'b':3}` (recall that the order of the keys in a Python dictionary is undetermined).

Generating the template. It remains to generate the right HTML template. The HTML code depends on what the returned `result` object from `compute` contains. Only a human who has read the `compute` code knows the details of the returned result. Therefore, we leave it to a human to provide the part of the HTML template that renders the result. The file `templates/view_results.html` contains this human-provided code, while `templates/view.html` is a completely generic template for the forms:

```
<form method=post action="">
<table>
  {% for field in form %}
    <tr><td>{{ field.name }}</td> <td>{{ field }}</td>
    <td>{% if field.errors %}
      <ul class=errors>
      {% for error in field.errors %}
        <li>{{ error }}</li>
      {% endfor %}</ul>
    {% endif %}</td></tr>
  {% endfor %}
```

```
</table>
<p><input type=submit value=Compute></form></p>

{% if result != None %}
{{ result|safe }}
{% endif %}
```

At the end of this code, an HTML text `result` (string) is to be inserted. This text is typically generated by calling Flask's `render_template` function, which uses `templates/view_results.html` to turn the return object `result` from the compute function into the desired HTML code:

```
def index():
    ...
    if result:
        result = render_template('view_results.html', result=result)
        # result is now rendered HTML text
    return render_template('view.html', form=form, result=result)
```

Notice.

A perhaps simpler alternative would be to have a generic `view_forms.html` file and a user-specific `view_results.html` and explicitly combining them into a new file. This requires file writing by the app, which one normally wants to avoid. Especially if the web app gets multiple users, the file writing may lead to corrupt files.

The complete, generic form of the `index` function becomes

```
def index():
    form = InputForm(request.form)
    if request.method == 'POST' and form.validate():
        arg_names = inspect.getargspec(compute).args
        kwargs = {name: getattr(form, name).data
                  for name in arg_names if hasattr(form, name)}
        result = compute(**kwargs)
    else:
        result = None
    if result:
        # result must be transformed to HTML and inserted as a
        # string in the generic view.html file
        result = render_template('view_results.html', result=result)
    return render_template('view.html', form=form, result=result)

if __name__ == '__main__':
    app.run(debug=True)
```

Application. Let us apply the files above to plot the gamma probability density function

$$g(x;a,h,A) = \frac{|h|}{\Gamma(a)A}\left(\frac{x}{A}\right)^{ah-1} e^{-\left(\frac{x}{A}\right)^h},$$

and its cumulative density

$$G(x; a, h, A) = \int_0^x g(\tau; a, h, A) d\tau,$$

computed by numerically the Trapezoidal rule, for instance. We also want to compute and display the mean value $A\Gamma(a + 1/h)/\Gamma(a)$ and standard deviation

$$\sigma = \frac{A}{\Gamma(a)} \sqrt{\Gamma(a + 2/h)\Gamma(a) - \Gamma(a + 1/h)^2}.$$

Here, $\Gamma(a)$ is the gamma function, which can be computed by `math.gamma(a)` in Python. Below is a `compute.py` file with the relevant implementations of $g(x; a, h, A)$ (`gamma_density`), $G(x; a, h, A)$ (`gamma_cumulative`), and a function `compute_gamma` for making a plot of g og G for $x \in [0, 7\sigma]$.

```
def gamma_density(x, a, h, A):
    # http://en.wikipedia.org/wiki/Gamma_distribution
    xA = x/float(A)
    return abs(h)/(math.gamma(a)*A)*(xA)**(a*h-1)*exp(-xA**h)

def gamma_cumulative(x, a, h, A):
    # Integrate gamma_density using the Trapezoidal rule.
    # Assume x is array.
    g = gamma_density(x, a, h, A)
    r = zeros_like(x)
    for i in range(len(r)-1):
        r[i+1] = r[i] + 0.5*(g[i] + g[i+1])*(x[i+1] - x[i])
    return r

def compute_gamma(a=0.5, h=2.0, A=math.sqrt(2), resolution=500):
    """Return plot and mean/st.dev. value of the gamma density."""
    gah = math.gamma(a + 1./h)
    mean = A*gah/math.gamma(a)
    stdev = A/math.gamma(a)*math.sqrt(
        math.gamma(a + 2./h)*math.gamma(a) - gah**2)
    x = linspace(0, 7*stdev, resolution+1)
    y = gamma_density(x, a, h, A)
    plt.figure()  # needed to avoid adding curves in plot
    plt.plot(x, y)
    plt.title('a=%g, h=%g, A=%g' % (a, h, A))
    # Make Matplotlib write to StringIO file object and grab
    # return the object's string
    from StringIO import StringIO
    figfile = StringIO()
    plt.savefig(figfile, format='png')
    figfile.seek(0)  # rewind to beginning of file
    import base64
    figdata_density_png = base64.b64encode(figfile.buf)
    figfile = StringIO()
    plt.savefig(figfile, format='svg')
    figfile.seek(0)
    figdata_density_svg = '<svg' + figfile.buf.split('<svg')[1]
    figdata_density_svg = unicode(figdata_density_svg,'utf-8')

    y = gamma_cumulative(x, a, h, A)
    plt.figure()
    plt.plot(x, y)
```

```
plt.grid(True)
figfile = StringIO()
plt.savefig(figfile, format='png')
figfile.seek(0)
figdata_cumulative_png = base64.b64encode(figfile.buf)
figfile = StringIO()
plt.savefig(figfile, format='svg')
figfile.seek(0)
figdata_cumulative_svg = '<svg' + figfile.buf.split('<svg')[1]
figdata_cumulative_svg = unicode(figdata_cumulative_svg,'utf-8')
return figdata_density_png, figdata_cumulative_png, \
       figdata_density_svg, figdata_cumulative_svg, \
       '%.2f' % mean, '%.2f' % stdev
```

The `compute_gamma` function returns a tuple of six values. We want output as displayed in Figure 13.

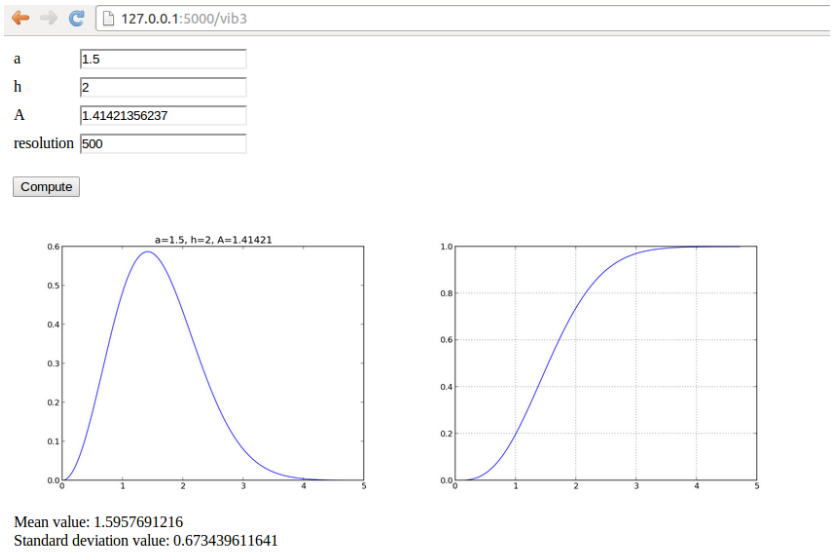


Figure 13: Design of a web page illustrating the gamma probability functions.

The design is realized in the file `view_results.html` shown below.

```
<p>
<table>
<tr>
<td>
<img src="{{ result[0] }}" width="400">
</td><td>
<img src="{{ result[1] }}" width="400">
</td></tr>
<tr>
<td>{{ result[2]|safe }}</td>
<td>{{ result[3]|safe }}</td>
</tr>
<tr><td>
```

```
Mean value: {{ result[4] }} <br>
Standard deviation value: {{ result[5] }}
</td></tr>
</table>
</p>
```

To create the web application, we just perform the following steps:

1. copy the generic `controller.py` and `model.py` files to a new directory
2. write the compute function in a file `compute.py`
3. edit `controller.py` and `model.py` to use the right name of the compute function (`from compute import name as compute`)
4. add an appropriate `templates/view_forms.html` file that visualizes the returned value `results` from the compute function

4.10 User login and storage of computed results

We now want to make an app where the computed results can be stored in a database. To this end, each user must create an account and login to this account for archiving results and for browsing previous runs of the application. More files are needed for this purpose, compared to the previous apps, and the files are located in the `login` directory.

Required additional software. Three more packages are needed for this more advanced application:

- Flask-Login
- Flask-SQLAlchemy
- Flask-Mail

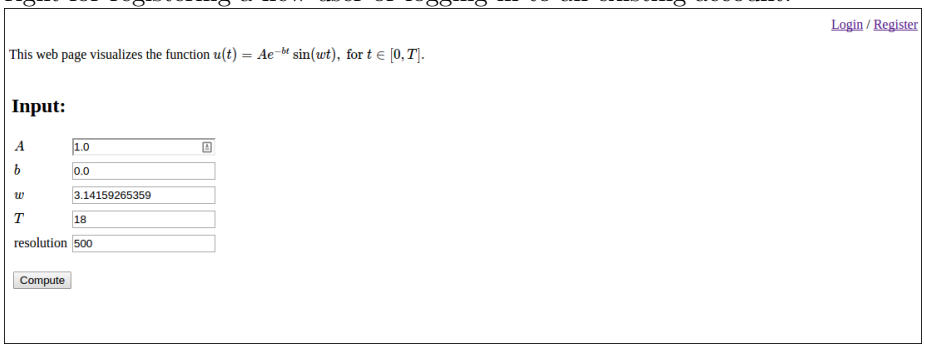
Installation is done by

```
sudo pip install --upgrade flask-login
sudo pip install --upgrade flask-sqlalchemy
sudo pip install --upgrade flask-mail
```

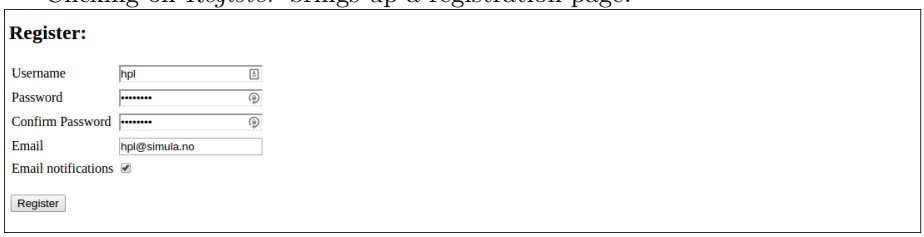
The compute part. The `compute.py` file contains the `compute` function from the `vib2` app in Section 4.8.

There is quite much Flask code required for user accounts and login. The files here were generated by the Parampool package and then edited and specialized to the present application. In general, it is not recommended to hack further on the example given here, but rather utilize Parampool to generate web apps with user accounts and login.

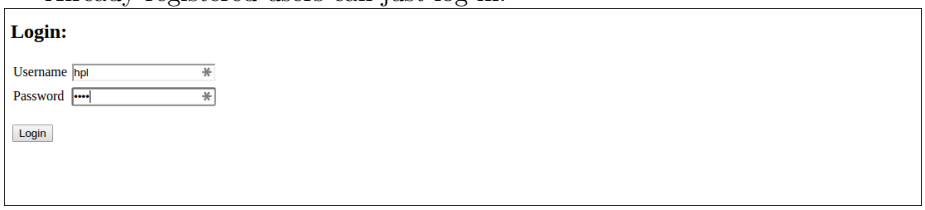
The interfaces of the app. The first page after starting the app (`python controller.py`) shows input fields for the numerical parameters, but there are also links to the right for registering a new user or logging in to an existing account:



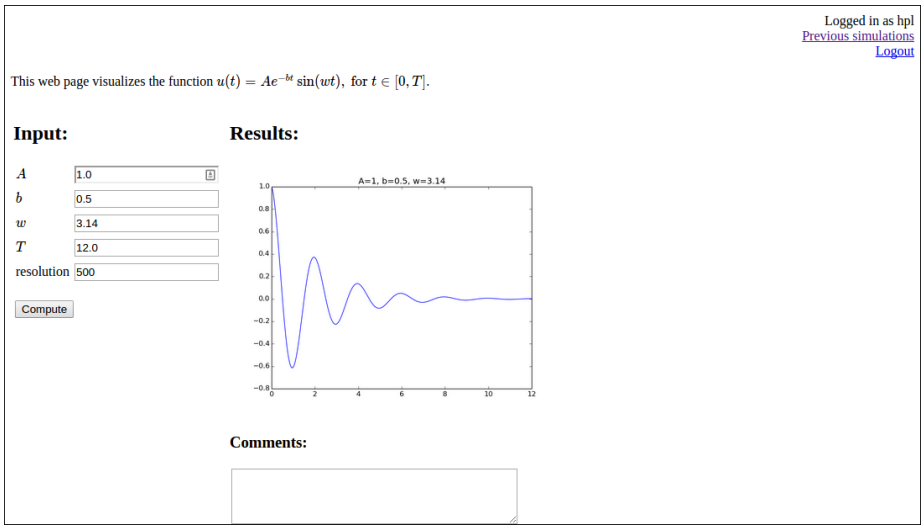
Clicking on *Register* brings up a registration page:



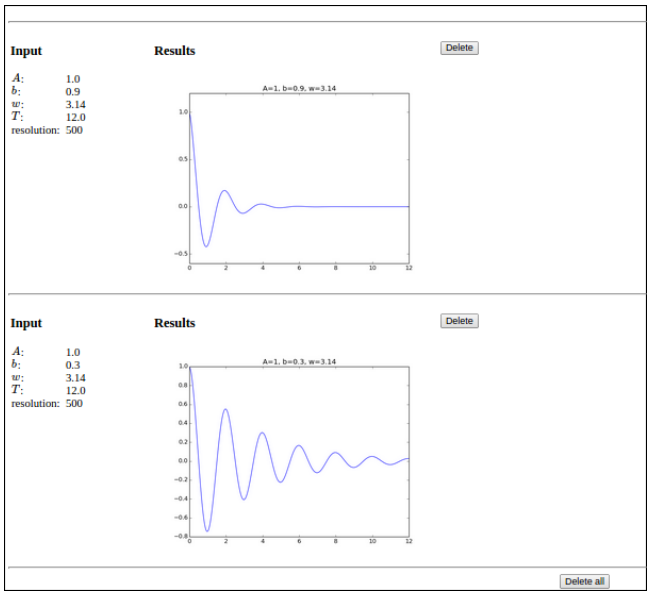
Already registered users can just log in:



Then the fields with input parameters are shown again. After pressing *Compute* we are left with a combination of input and results, plus a field where the user can write a comment about this simulation:



All simulations (input data, results, and comment) are stored in a database. Clicking on *Previous simulation* brings us to an overview of what is in the database:



Here, one can browse previous results, remove entries, or erase the whole database.

The source code. Rather than explaining everything about the source code in detail, we primarily list the various code files below. A starting point is the central `controller.py` file, which is now quite lengthy and involves four different URLs (the input page, the login page, the registration page, and the previous results page).

```
import os
from compute import compute as compute_function

from flask import Flask, render_template, request, redirect, url_for
from forms import ComputeForm
from db_models import db, User, Compute
from flask.ext.login import LoginManager, current_user, \
     login_user, logout_user, login_required
from app import app

login_manager = LoginManager()
login_manager.init_app(app)

@login_manager.user_loader
def load_user(user_id):
    return db.session.query(User).get(user_id)

# Path to the web application
@app.route('/', methods=['GET', 'POST'])
def index():
    result = None
    user = current_user
    form = ComputeForm(request.form)
    if request.method == "POST":
        if form.validate():

            result = compute_function(form.A.data, form.b.data,
                                      form.w.data, form.T.data)
            if user.is_authenticated():
                object = Compute()
                form.populate_obj(object)
                object.result = result
                object.user = user
                db.session.add(object)
                db.session.commit()

                # Send email notification
                if user.notify and user.email:
                    send_email(user)
    else:
        if user.is_authenticated():
            if user.Compute.count() > 0:
                instance = user.Compute.order_by('-id').first()
                result = instance.result
                form = populate_form_from_instance(instance)

    return render_template("view.html", form=form,
                           result=result, user=user)


def populate_form_from_instance(instance):
    """Repopulate form with previous values"""
    form = ComputeForm()
    for field in form:
        field.data = getattr(instance, field.name)
    return form

def send_email(user):
    from flask.ext.mail import Mail, Message
    mail = Mail(app)
    msg = Message("Compute Computations Complete",
```

```
                  recipients=[user.email])
    msg.body = """
A simulation has been completed by the Flask Compute app.
Please log in at

http://localhost:5000/login

to see the results.

---
If you don't want email notifications when a result is found,
please register a new user and leave the 'notify' field
unchecked.
"""
    mail.send(msg)

@app.route('/reg', methods=['GET', 'POST'])
def create_login():
    from forms import register_form
    form = register_form(request.form)
    if request.method == 'POST' and form.validate():
        user = User()
        form.populate_obj(user)
        user.set_password(form.password.data)

        db.session.add(user)
        db.session.commit()

        login_user(user)
        return redirect(url_for('index'))
    return render_template("reg.html", form=form)

@app.route('/login', methods=['GET', 'POST'])
def login():
    from forms import login_form
    form = login_form(request.form)
    if request.method == 'POST' and form.validate():
        user = form.get_user()
        login_user(user)
        return redirect(url_for('index'))
    return render_template("login.html", form=form)

@app.route('/logout')
@login_required
def logout():
    logout_user()
    return redirect(url_for('index'))

@app.route('/old')
@login_required
def old():
    data = []
    user = current_user
    if user.is_authenticated():
        instances = user.Compute.order_by('-id').all()
        for instance in instances:
            form = populate_form_from_instance(instance)

            result = instance.result
            if instance.comments:
                comments = "<h3>Comments</h3>" + instance.comments
```

```
            else:
                comments = ''
            data.append(
                {'form':form, 'result':result,
                 'id':instance.id, 'comments': comments})

    return render_template("old.html", data=data)

@app.route('/add_comment', methods=['GET', 'POST'])
@login_required
def add_comment():
    user = current_user
    if request.method == 'POST' and user.is_authenticated():
        instance = user.Compute.order_by('-id').first()
        instance.comments = request.form.get("comments", None)
        db.session.commit()
    return redirect(url_for('index'))

@app.route('/delete/<id>', methods=['GET', 'POST'])
@login_required
def delete_post(id):
    id = int(id)
    user = current_user
    if user.is_authenticated():
        if id == -1:
            instances = user.Compute.delete()
        else:
            try:
                instance = user.Compute.filter_by(id=id).first()
                db.session.delete(instance)
            except:
                pass

        db.session.commit()
    return redirect(url_for('old'))


if __name__ == '__main__':
    if not os.path.isfile(os.path.join(
        os.path.dirname(__file__), 'sqlite.db')):
        db.create_all()
    app.run(debug=True)
```

Creation of the app object is put in a separate file app.py:

```
import os
from flask import Flask

app = Flask(__name__)
app.config['SQLALCHEMY_DATABASE_URI'] = 'sqlite:///sqlite.db'
app.secret_key = os.urandom(24)

# Email settings
import base64
app.config.update(
        MAIL_SERVER='smtp.gmail.com',
        MAIL_PORT=587,
        MAIL_USE_TLS=True,
        MAIL_USERNAME = 'cbcwebsolvermail@gmail.com',
        MAIL_PASSWORD = base64.decodestring('WGlmZmljdox0UFch'),
```

```
        MAIL_DEFAULT_SENDER = 'Some name <name@gmail.com>'
        )
```

The forms for the compute function and for the login is stored in a file called `forms.py`:

```
import wtforms as wtf
from math import pi

class ComputeForm(wtf.Form):
    A = wtf.FloatField(label='\( A \)', default=1.0,
        validators=[wtf.validators.InputRequired()])
    b = wtf.FloatField(label='\( b \)', default=0.0,
        validators=[wtf.validators.InputRequired()])
    w = wtf.FloatField(label='\( w \)', default=pi,
        validators=[wtf.validators.InputRequired()])
    T = wtf.FloatField(label='\( T \)', default=18,
        validators=[wtf.validators.InputRequired()])
    resolution = wtf.IntegerField(label='resolution', default=500,
        validators=[wtf.validators.InputRequired()])

from db_models import db, User
import flask.ext.wtf.html5 as html5

# Standard Forms
class register_form(wtf.Form):
    username = wtf.TextField(
        label='Username', validators=[wtf.validators.Required()])
    password = wtf.PasswordField(
        label='Password', validators=[
            wtf.validators.Required(),
            wtf.validators.EqualTo(
                'confirm', message='Passwords must match')])
    confirm  = wtf.PasswordField(
        label='Confirm Password',
        validators=[wtf.validators.Required()])
    email    = html5.EmailField(label='Email')
    notify   = wtf.BooleanField(label='Email notifications')

    def validate(self):
        if not wtf.Form.validate(self):
            return False

        if self.notify.data and not self.email.data:
            self.notify.errors.append(
        'Cannot send notifications without a valid email address')
            return False

        if db.session.query(User).filter_by(
            username=self.username.data).count() > 0:
            self.username.errors.append('User already exists')
            return False

        return True

class login_form(wtf.Form):
    username = wtf.TextField(
        label='Username', validators=[wtf.validators.Required()])
    password = wtf.PasswordField(
        label='Password', validators=[wtf.validators.Required()])
```

```
    def validate(self):
        if not wtf.Form.validate(self):
            return False

        user = self.get_user()

        if user is None:
            self.username.errors.append('Unknown username')
            return False

        if not user.check_password(self.password.data):
            self.password.errors.append('Invalid password')
            return False

        return True

    def get_user(self):
        return db.session.query(User).filter_by(
            username=self.username.data).first()
```

Database-related code for the SQLAlchemy database is collected in `db_models.py`:

```
from flask.ext.sqlalchemy import SQLAlchemy
from werkzeug import generate_password_hash, check_password_hash
from app import app

db = SQLAlchemy(app)

class User(db.Model):
    id = db.Column(db.Integer, primary_key=True)
    username = db.Column(db.String(50), unique=True)
    pwhash = db.Column(db.String())
    email = db.Column(db.String(120), nullable=True)
    notify = db.Column(db.Boolean())

    def __repr__(self):
        return '<User %r>' % (self.username)

    def check_password(self, pw):
        return check_password_hash(self.pwhash, pw)

    def set_password(self, pw):
        self.pwhash = generate_password_hash(pw)

    def is_authenticated(self):
        return True

    def is_active(self):
        return True

    def is_anonymous(self):
        return False

    def get_id(self):
        return self.id

class Compute(db.Model):
    id = db.Column(db.Integer, primary_key=True)

    A = db.Column(db.String())
```

```
    b = db.Column(db.String())
    w = db.Column(db.String())
    T = db.Column(db.String())
    resolution = db.Column(db.Integer)

    result = db.Column(db.String())
    comments = db.Column(db.String(), nullable=True)
    user_id = db.Column(db.Integer, db.ForeignKey('user.id'))
    user = db.relationship('User',
           backref=db.backref('Compute', lazy='dynamic'))
```

Finally, we need views. For the results of the computation we have a `view.html` file that is very similar to `view_table.html` in the `vib1` app:

```
<!DOCTYPE html>
<html lang="en">
  <head>
    <meta charset="utf-8" />
    <title>Flask Vib app</title>
  </head>
  <body>

<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js", "color.js"]
  }
});
</script>
<script type="text/javascript" src=
"http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>

{% if user.is_anonymous() %}
  <p align="right"><a href="/login">Login</a>
  / <a href="/reg">Register</a></p>
{% else %}
  <p align="right">Logged in as {{user.username}}<br>
    <a href="/old">Previous simulations<a/><br>
    <a href="/logout">Logout</a></p>
{% endif %}

This web page visualizes the function \(
u(t) = Ae^{-bt}\sin (w t), \hbox{ for } t\in [0,T]
\).

<p>
<!-- Input and Results are typeset as a two-column table -->
<table>
<tr>
<td valign="top">
<h2>Input:</h2>

<form method=post action="" enctype=multipart/form-data>
<table>
  {% for field in form %}
    <tr>
      <td>{{ field.label }}</td>
      <td>{{ field(size=20) }}</td>
```

```
      <td>
      {% if field.errors %}
        <ul class=errors>
        {% for error in field.errors %}
          <li>{{ error }}</li>
        {% endfor %}</ul>
      {% endif %}
      </td></tr>
  {% endfor %}
</table>
<p>
<input type="submit" value="Compute">
</p>
</form>
</td>

<td valign="top">
  {% if result != None %}
    <h2>Results:</h2>
    <img src="{{ result|safe }}" width="400">
    {% if not user.is_anonymous() %}
      <h3>Comments:</h3>
      <form method="post" action="/add_comment">
          <textarea name="comments" rows="4" cols="40"></textarea>
          <p><input type="submit" value="Add">
      </form>
      {% endif %}

  {% endif %}
</td></tr>
</table>
</body>
</html>
```

The `login.html` template for the login page takes the form

```
<!DOCTYPE html>
<html lang="en">
<head>
  <meta charset="utf-8" />
  <title>Flask Vib app</title>
</head>
<body>
<h2>Login:</h2>
<form method=post action="">
  <table>
    {% for field in form %}
      <tr><td>{{ field.label }}</td>
          <td>{{ field(size=20) }}</td>
          <td>
            {% if field.errors %}
              <ul class=errors>
              {% for error in field.errors %}
                <li>{{ error }}</li>
              {% endfor %}</ul>
            {% endif %}</td></tr>
    {% endfor %}
  </table>
  <p><input type="submit" value="Login">
</form>
```

```
</body>
</html>
```

The page for registering a new user has a simple template `reg.html`:

```
<!DOCTYPE html>
<html lang="en">
<head>
  <meta charset="utf-8" />
  <title>Flask Vib app</title>
</head>
<body>
<h2>Register:</h2>
<form method=post action="">
<table>
   {% for field in form %}
     <tr><td>{{ field.label }}</td>
         <td>{{ field(size=20) }}</td>
          <td>
            {% if field.errors %}
              <ul class=errors>
              {% for error in field.errors %}
                <li>{{ error }}</li>
              {% endfor %}</ul>
            {% endif %}</td></tr>
   {% endfor %}
</table>
<p><input type=submit value=Register>
</form>
</body>
</html>
```

The final file is `old.html` for retrieving old simulations:

```
<!DOCTYPE html>
<html lang="en">
<head>
  <meta charset="utf-8" />
  <title>Flask Vib app</title>
</head>
<body>

<script type="text/x-mathjax-config">
MathJax.Hub.Config({
  TeX: {
     equationNumbers: {  autoNumber: "AMS"  },
     extensions: ["AMSmath.js", "AMSsymbols.js", "autobold.js", "color.js"]
  }
});
</script>
<script type="text/javascript"
 src="http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
</script>

<h2>Previous simulations</h2>
<p align="right"><a href="/">Back to index</a></p>
{% if data %}
  {% for post in data %}
    <hr>
    <table>
```

```
    <tr>
    <td valign="top" width="30%">
    <h3>Input</h3>
      <table>
      {% for field in post.form %}
        <tr><td>{{ field.label }}: </td>
            <td>{{ field.data }}</td></tr>
      {% endfor %}
      </table>
    </td><td valign="top" width="60%">
    <h3>Results</h3>
    <img src="{{ post.result|safe }}" width="400">
    {% if True %}
      <p>
      {{ comments }}
    {% endif %}
    </td><td valign="top" width="60%">
    <p>
    <form method="POST" action="/delete/{{ post.id }}">
      <input type=submit value="Delete"
       title="Delete this post from database">
    </form>
    </td></tr>
    </table>
   {% endfor %}
   <hr>
   <center>
   <form method="POST" action="/delete/-1">
     <input type=submit value="Delete all">
   </form>
   </center>
{% else %}
  No previous simulations
{% endif %}
</body>
</html>
```

Warning.

- Sending email from the app does not work.
- Storing comments does not work.

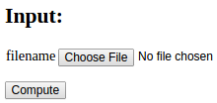
hpl 1: Check if an autogenerated app from `_generate_app.py` can send mail and store comments. Need a `compute` function that returns full HTML text then.

Resources. Working with a database in Flask is described here:

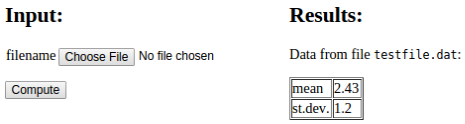
- `http://pythonhosted.org/Flask-SQLAlchemy/quickstart.html`,
- `http://blog.miguelgrinberg.com/post/the-flask-mega-tutorial-part-iv-database`,
- The Flask login extension

4.11 Uploading of files

Overview of the application. Many user interfaces need the user to provide data files. A minimalistic application is to have a button for uploading a single file. As example we use a file with a series of numbers, and the application's purpose is to compute the mean and standard deviation of the numbers. The first user interface just has the *Choose File* and *Compute* buttons:



Clicking on *Choose File* brings up a file browser where the user can choose the file to uploaded to the application. Say this is a file `testfile.dat`. Pressing thereafter *Compute* leads to storage of the `testfile.dat` on the server in a subdirectory `uploads` and computation of basic statistics of the numbers in the file. The resulting output looks like



The model class. The widget `FieldField` is used for an input field with a *Choose File* button:

```
import wtforms as wtf

class Average(wtf.Form):
    filename   = wtf.FileField(validators=
                               [wtf.validators.InputRequired()])
```

The controller file. The controller file needs some special code to specify a directory to store uploaded files. We also include some code to check that the file has a name with the right extension.

```
# Relative path of directory for uploaded files
UPLOAD_DIR = 'uploads/'

app.config['UPLOAD_FOLDER'] = UPLOAD_DIR
app.secret_key = 'MySecretKey'

if not os.path.isdir(UPLOAD_DIR):
    os.mkdir(UPLOAD_DIR)

# Allowed file types for file upload
ALLOWED_EXTENSIONS = set(['txt', 'dat', 'npy'])

def allowed_file(filename):
    """Does filename have the right extension?"""
    return '.' in filename and \
           filename.rsplit('.', 1)[1] in ALLOWED_EXTENSIONS
```

The `index` function must have code for saving the file, and as usual, calling the compute function and rendering a new page:

```
def index():
    form = Average(request.form)
    filename = None  # default
    if request.method == 'POST':

        # Save uploaded file on server if it exists and is valid
        if request.files:
            file = request.files[form.filename.name]
            if file and allowed_file(file.filename):
                # Make a valid version of filename for any file ystem
                filename = secure_filename(file.filename)
                file.save(os.path.join(app.config['UPLOAD_FOLDER'],
                                       filename))

        result = compute_function(filename)
    else:
        result = None

    return render_template("view.html", form=form, result=result)
```

The compute function. We assume that the uploaded file is available in the `uploads` subdirectory, so the compute function needs to open this file, read the numbers, and compute statistics. The file reading and computations are easily done by `numpy` functions. The results are presented in an HTML table.

```
import numpy as np
import os

def compute_average(filename=None):
    data = np.loadtxt(os.path.join('uploads', filename))
    return """
Data from file <tt>%s</tt>:
<p>
<table border=1>
<tr><td> mean    </td><td> %.3g </td></tr>
<tr><td> st.dev. </td><td> %.3g </td></tr>
""" % (filename, np.mean(data), np.std(data))
```

The HTML template. Although the present minimalistic application only needs a very simple HTML template, we reuse a quite generic template known from previous examples, where the input variables are listed to the left and the output of the compute function is presented to the right. Such a template looks like

```
<!DOCTYPE html>
<html>
  <head>
    <meta charset="utf-8" />
    <title>Flask Average app</title>
  </head>
  <body>

  <!-- Input and Results are typeset as a two-column table -->
```

```
<table>
<tr>
<td valign="top">
  <h2>Input:</h2>

    <form method=post action="" enctype="multipart/form-data">
      <table>
        {% for field in form %}
          <tr><td>{{ field.name }}</td>
              <td>{{ field(size=20) }}</td>
              <td>{% if field.errors %}
                <ul class=errors>
                {% for error in field.errors %}
                  <li>{{ error }}</li>
                {% endfor %}</ul>
              {% endif %}</td></tr>
        {% endfor %}
      </table>
      <p><input type="submit" value="Compute">
  </form></p>
</td>

<td valign="top">
  {% if result != None %}
    <h2>Results:</h2>
      {{ result|safe }}

  {% endif %}
</td>
</tr>
</table>
</body>
</html>
```

5 Handling multiple input variables in Django

We shall briefly how to work with multi-variable input in Django. The text is the Django counterpart to Section 4. There are four float input variables: A, b, w, and T. A function `compute` in the file `compute.py` makes a plot of the function $u(t) = Ae^{-bt}\sin(wt)$ depending on these four parameters and returns the name of the plot file. Our task is to define four input fields, execute the `compute` function and show the input fields together with the resulting plot, cf. Figures 7 and 8.

5.1 Programming the Django application

Adding the app to a project. Any Django app needs a project, but here we reuse the project we set up for the scientific hello world examples. We go to the directory `apps/django_apps` and create the Django app `vib1`:

```
Terminal> python ../../django_project/manage.py startapp vib1
```

Then we

1. add `relative2absolute_path('../../apps/django_apps/vib1/templates'),` to the `TEMPLATE_DIRS` tuple in `settings.py`,
2. add `vib1` to the `INSTALLED_APPS` tuple, and
3. add `url(r'^vib1/', 'django_apps.vib1.views.index')` to the `patterns` call in `urls.py`.

These steps ensure that Django can find our application as a module/package, that Django can find our templates associated with this application, and that the URL address applies the name `vib1` to reach the application.

The compute part. The computations in our application are put in a file `compute.py` and explained in detail in Section 4.1.

The model. We can now write `models.py` and the `Input` class that defines the form fields for the four input variables:

```
from django.db import models
from django.forms import ModelForm
from math import pi

class Input(models.Model):
    A = models.FloatField(
        verbose_name=' amplitude (m)', default=1.0)
    b = models.FloatField(
        verbose_name=' damping coefficient (kg/s)', default=0.0)
    w = models.FloatField(
        verbose_name=' frequency (1/s)', default=2*pi)
    T = models.FloatField(
        verbose_name=' time interval (s)', default=18)

class InputForm(ModelForm):
    class Meta:
        model = Input
```

Note here that we can provide a more explanatory name than just the variable name, e.g., `' amplitude (m)'` for `A`. However, Django will always capitalize these descriptions, so if one really needs lower case names (e.g., to be compatible with a mathematical notation or when just listing the unit), one must start the text with a space, as we have demonstrated above. We also provide a default value such that all fields have a value when the user sees the page.

The view. The `views.py` file looks as follows:

```
from django.shortcuts import render_to_response
from django.template import RequestContext
from django.http import HttpResponse
from models import InputForm
from compute import compute
import os

def index(request):
```

```
    os.chdir(os.path.dirname(__file__))
    result = None
    if request.method == 'POST':
        form = InputForm(request.POST)
        if form.is_valid():
            form2 = form.save(commit=False)
            result = compute(form2.A, form2.b, form2.w, form2.T)
            result = result.replace('static/', '')
    else:
        form = InputForm()

    return render_to_response('vib1.html',
            {'form': form,
             'result': result,
             }, context_instance=RequestContext(request))
```

Some remarks are necessary:

1. Doing an `os.chdir` to the current working directory is necessary as Django may be left back in another working directory if you have tested other apps.

2. The `form2` object from `form.save` is the object we extract data from and send to `compute`, but the original `form` object is needed when making the HTML page through the template.

3. Images, media files, style sheets, javascript files, etc. must reside in a subdirectory `static`. The specifications of the URL applies tools to find this `static` directory and then the `static` prefix in the `result` filename must be removed.

The template for rendering the page is listed next.

```
<form method=post action="">{% csrf_token %}
<table>
  {% for field in form %}
    <tr>
    <td>{{ field.name }}</td>
    <td>{{ field }}</td>
    <td>{{ field.label }}</td>
    <td>{{ field.errors }}</td>
    <td></td>
    </tr>
  {% endfor %}
</table>
<p><input type=submit value=Compute></form></p>

<p>
{% if result != None %}
{% load static %}
<img src="{% get_static_prefix %}{{ result }}" width=500>
{% endif %}
</p>
```

The tricky part is the syntax for displaying *static content*, such as the plot file made in the `compute` function.

5.2 Custom validation

Django has a series of methods available for user-provided validation of form data. These are exemplified in the app `vib2`, which is an extension of the `vib1` app with additional code. (This other app needs of course registrations in `settings.py` and `urls.py`, similar to what we did for the `vib1` app.)

Making sure that $A > 0$ is easiest done with a built-in Django validator for minimum value checking:

```
class Input(models.Model):
    A = models.FloatField(
        verbose_name=' amplitude (m)', default=1.0,
        validators=[MinValueValidator(0)])
```

We can write our own validators, which are functions taking the value is the only argument and raising a `ValidationError` exception if the value is wrong. Checking that a value is inside an interval can first be implemented by

```
def check_interval(value, min_value=None, max_value=None):
    """Validate that a value is inside an interval."""
    failure = False
    if min_value is not None:
        if value < min_value:
            failure = True
    if max_value is not None:
        if value > max_value:
            failure = True
    if failure:
        raise ValidationError(
            'value=%s not in [%s, %s]' %
            (value,
             '-infty' if min_value is None else str(min_value),
             'infty' if max_value is None else str(max_value)))
```

However, this function takes more than the value as argument. We therefore need to wrap it by a function with `value` as the only argument. The following utility returns such a function (see Section 4.7 for more explanation):

```
import functools

def interval(min_value=None, max_value=None):
    """Django-compatible interface to check_interval."""
    return functools.partial(
        check_interval, min_value=min_value, max_value=max_value)
```

Now, `interval(0, 1)` returns a function that takes `value` as its only argument and checks if it is inside $[0, 1]$. Such a function can be inserted in the `validators` list in the field constructor, here to tell that b must be in $[0, \infty)$:

```
class Input(models.Model):
    ...
    b = models.FloatField(
        verbose_name=' damping coefficient (kg/s)', default=0.0,
        validators=[interval(0,None)])
```

A final example on custom validation is to avoid plotting more than 30 periods of the oscillating function u. This translates to checking that T is geater than 30 periods, i.e., $T > 30 \cdot 2\pi/w$. The task is done in the `InputForm` class, where any method `clean_name` can do validation and adjustment of the field name `name`. The code for a `clean_T` method goes as follows:

```
class InputForm(ModelForm):
    class Meta:
        model = Input

    def clean_T(self):
        T = self.cleaned_data['T']
        w = self.cleaned_data['w']
        period = 2*pi/w
        if T > 30*period:
            num_periods = int(round(T/period))
            raise ValidationError(
                'Cannot plot as much as %d periods! T < %.2f' %
                (num_periods, 30*period))
        return T
```

We refer to the vast Django documentation for many other ways of validating forms. The reader is encouraged to run the `vib2` application and test out the validations we have implemented.

5.3 Customizing widgets

One will occasionally have full control of the layout of the individual elements in a web form. These are typeset inside `input` tags in HTML. Django associates the term *widget* with an HTML form field. To set the size (width) of the field and other properties, one must in Django specify a `widgets` dictionary in the form class. The key is the name of the parameter in the model class, while the value is a widget class name. Standard input fields for numbers and text apply the `TextInput` widget. An example on setting the size of the `T` field to a width of 10 characters goes like

```
from django.forms import TextInput

class InputForm(ModelForm):
    class Meta:
        model = Input
        widgets = {
            'T': TextInput(attrs={'size': 10}),
        }
```

At the time of this writing, Django does not yet support the many additional HTML5 input fields. Nevertheless, the `parampool` package gives access to HTML5 widgets in a Django context. We recommend to use `parampool` to automatically generate the necessary Django files, and then one can view the form class in the `models.py` file for how HTML5 widgets can be used in the definition of the `widgets` dictionary.

5.4 Resources

Below are some resources for accounts and login with Django as well as utilization of Bootstrap styles in the views.

- Django: make user
- Django: read and write database
- http://stackoverflow.com/questions/11821116/django-and-bootstrap-what-app-is-recommended
- https://github.com/dyve/django-bootstrap3
- https://www.youtube.com/watch?v=3Bwl5CYa5Uc

6 Exercises

Exercise 1: Add two numbers

Make a web application that reads two numbers from a web page, adds the numbers, and prints the sum in a new web page. Package the necessary files that constitute the application in a tar file. Filename: `add2.tar.gz`.

Exercise 2: Upload data file and visualize curves

Suppose you have tabular data in a file:

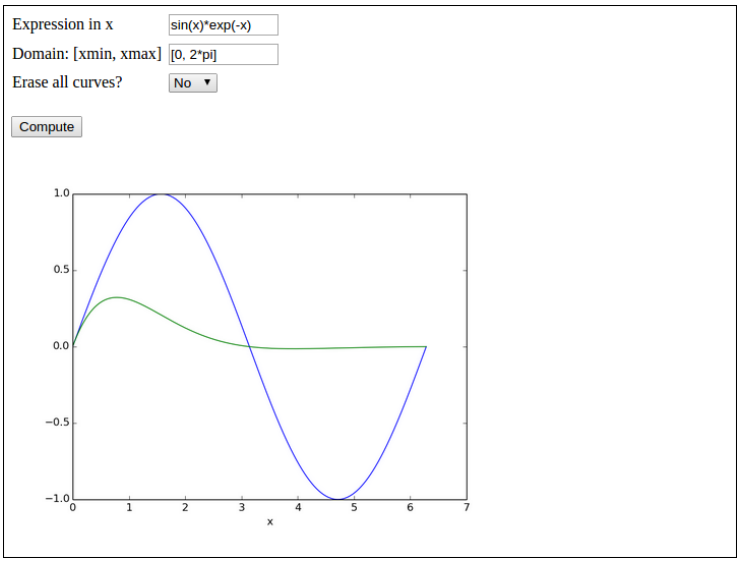
```
#  t        y       error
0.0000    1.2345   1.4E-4
1.0000    0.9871  -4.9E-3
1.2300    0.5545   8.2E-3
```

That is, there is a comment line with headings for the various columns, and then floating-point values are listed with an arbitrary number of columns and rows. You want to upload such a data file to a web application and have the each column, from the second one, plotted against the the values in the first column. In the particular example, `y` and `error` should be plotted against `t`, yielding two curves.

The web application may have one field: the name of the file to upload. Search for constructions on how to upload a files and write this application. Generate a suitable data file for testing purposes. Filename: `upload.tar.gz`.

Exercise 3: Plot a user-specified formula

The purpose of this exercise is to write a web application that can visualize any user-given formula. For example, in the interface below,



the user has

- specified a curve $\sin(x)$ (`sin(x)`) to be plotted
- specified the x interval to be $[0, 2\pi]$ (`[0, 2*pi]`)
- clicked *Compute* to get a blue line with the sine curve
- specified a new formula $\sin(x)e^{-x}$ (`sin(x)*exp(-x)`)
- chosen *No* as the answer to *Erase all curves?*
- clicked *Compute* to have the $\sin(x)e^{-x}$ drawn with green line without erasing the previous curve

That is, the user can fill in any expression in x, specify the domain for plotting, and choose whether new curves should be added to the plot or if all curves should be erased prior to drawing a new one.

Hint 1. You may use the `vib1` app from Section 4.1 with the `view_errcheck.html` template as starting point. Preferably, let plots be created as strings, as explained for the `vib2` app in Section 4.8.

The *Formula* and *Domain* fields need to be `TextField` objects, and the compute function must perform an `eval` on the user's input. The *Erase* field is a `SelectField` object with selections *Yes* and *No*. The former means that the compute function calls the `figure` function in Matplotlib before creating a new plot. If this is not done, a new formula will be plotting in the same figure as the last one. With the Yes/No selection, it is possible either plot individual curves or compare curves in the same plot.

Hint 2. Performing `eval` on the user's input requires that names like `sin`, `exp`, and `pi` are defined. The simplest approach is to do a

```
from numpy import *
```

in the top of the file containing the compute function. All the names from `numpy` are then available as global variables and one can simply do `domain = eval(domain)` to turn the string `domain` coming from the *Domain* text field into a Python list with two elements.

A better approach is not to rely on global variables, but run `eval` in the `numpy` namespace:

```
import numpy
domain = eval(domain, numpy.__dict__)
```

The evaluation of the formula is slightly more complicated if `eval` is to be run with the `numpy` namespace. One first needs to create x coordinates:

```
x = numpy.linspace(domain[0], domain[1], 10001)
```

Now, `eval(formula, numpy.__dict__)` will not work because a formula like `sin(x)` needs both `sin` and `x` in the namespace. The latter is not in the namespace and must be explicitly included. A new namespace can be made:

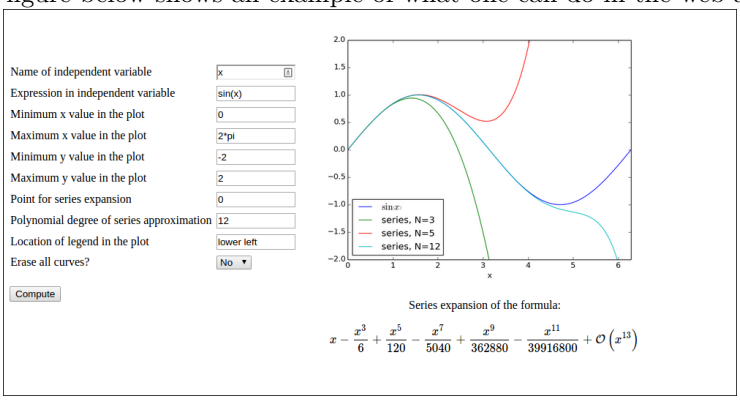
```
namespace = numpy.__dict__.copy()
namespace.update({'x': x})
formula = eval(formula, namespace)
```

Hint 3. You should add tests when evaluating and using the strings from input as these may have wrong syntax.
Filename: `plot_formula.tar.gz`.

Exercise 4: Visualize Taylor polynomial approximations

This exercise develops a web application that can plot Taylor polynomial approximations of *any* degree to *any* user-given formula. You should do Exercise 3 first as many of the techniques there must be used and even further developed in the present exercise.

The figure below shows an example of what one can do in the web app:



Here, the user has

- filled in the formula $\sin(x)$ (`sin(x)`)
- specified N to be 3
- clicked *Compute* to get the formula $\sin(x)$ plotted together with the Taylor polynomial approximation of degree 3, expanded around $x = 0$
- changed N to 5
- chosen *No* for the question *Erase all curves?*
- clicked *Compute* to have the series expansion of degree 5 plotted in the same plot
- changed N to 10
- clicked *Compute* to have the series expansion of degree 10 plotted in the same plot

We can use `sympy` to produce Taylor polynomial expansions of arbitrary expressions. Here is a session demonstrating how to obtain the series expansion of $e^{-x}\sin(\pi x)$ to 2nd degree.

```
>>> import sympy as sp
>>> x = sp.symbols('x')
>>> f = sp.exp(-x)*sp.sin(sp.pi*x)
>>> f.series(x, 0, 3)
pi*x - pi*x**2 + O(x**3)
>>> sp.latex(f.series(x, 0, 3))
'\\pi x - \\pi x^{2} + \\mathcal{O}\\left(x^{3}\\right)'
>>> fs = f.series(x, 0, 3).removeO()  # get rid of O() term
>>> fs
-pi*x**2 + pi*x
>>> f_func = sp.lambdify([x], fs)     # make Python function
>>> f_func(1)
0.0
>>> f_func(2)
-6.283185307179586
```

Basically, the steps above must be carried out to create a Python function for the series expansion such that it can be plotted. A similar `sp.lambdify` call on the original formula is also necessary to plot that one.

However, the challenge is that the formula is available only as a string, and it may contain an independent variable whose name is also only available through a string from the web interface. That is, we may give formulas like `exp(-t)` if `t` is chosen as independent variable. Also, the expression does not contain function names prefixed with `sympy` or `sp`, just plain names like `sin`, `cos`, `exp`, etc. An example on `formula` is `cos(pi*x) + log(x)`.

a) Write a function

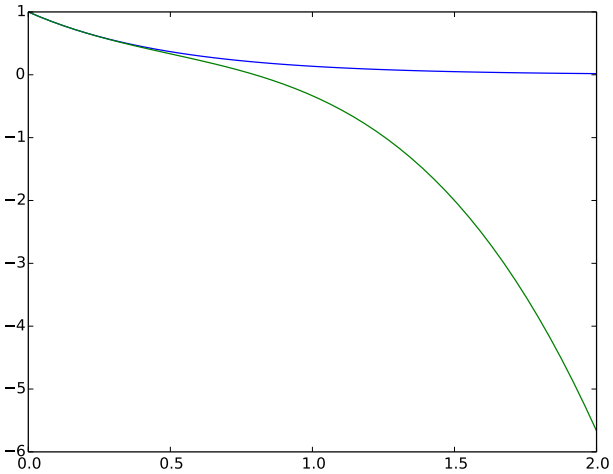
```
def formula2series2pyfunc(formula, N, x, x0=0):
```

that takes a `sympy` formula, and integer `N`, a `sympy` symbol `x` and another `sympy` symbol `x0` and returns 1) a Python function for `formula`, 2) a Python function for the series expansion of degree `N` of the formula around `x0`, and 3) a LaTeX string containing the formula for the series expansion.

Put the function in a file `compute.py`. You should thereafter be able to run the following session:

```
>>> import compute
>>> import sympy as sp
>>> from sympy import *
>>> t = symbols('t')
>>> formula = exp(-2*t)
>>> f, s, latex = compute.formula2series2pyfunc(formula, 3, t)
>>> latex
'- \\frac{4 t^{3}}{3} + 2 t^{2} - 2 t + 1'
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> t = np.linspace(0, 2)
>>> plt.plot(t, f(t), t, s(t))
[<matplotlib.lines.Line2D at 0x7fc6c020f350>,
 <matplotlib.lines.Line2D at 0x7fc6c020f5d0>]
>>> plt.show()
```

The resulting plot is displayed below.



Hint. The series expansion is obtained by `formula.series(x, x0, N)`, but the output contains an `O()` term which makes it impossible to convert the expression to a Python function via `sympy.lambify`. Use

```
series = formula.series(x, x0, N+1).removeO()
```

to get an expression that can be used as argument to `sympy.lambdify`. We use `N+1` since `N` in the `series` function refers to the degree of the `O()` term, which is now removed.

For the LaTeX expression it is natural to have the `O()` term:

```
latex = sympy.latex(formula.series(x, x0, N+1))
```

because then the terms start with the lowest order (and not the highest order as is the case when `removeO()` is used).

b) Write the compute function:

```
def visualize_series(
    formula,                    # string: formula
    independent_variable,       # string: name of independent var.
    N,                          # int: degree of polynomial approx.
    xmin, xmax, ymin, ymax,     # strings: extent of axes
    legend_loc,                 # string: upper left, etc.
    x0='0',                     # string: point of expansion
    erase='yes',                # string: 'yes' or 'no'
    ):
```

Hint 1. Converting the string `formula` to a valid `sympy` expression is challenging. First, create a local variable for a `sympy` symbol with the content of `independent_variable` as name, since such a variable is needed with performing `eval` on `formula`. Also introduce a variable `x` to point to the same `sympy` symbol. Relevant code is

```
# Turn independent variable into sympy symbol, stored in x
import sympy as sp
exec('x = %s = sp.symbols("%s")' %
     (independent_variable, independent_variable))
```

Hint 2. Evaluating `formula` in the namespace of `sympy` (so that all the `sin`, `exp`, `pi`, and similar symbols are defined properly as `sympy` objects) needs a merge of the `sympy` namespace and the variable for the `sympy` symbol representing the independent variable:

```
namespace = sp.__dict__.copy()
local = {}
local[independent_variable] = x
namespace.update(local)
formula = eval(formula, namespace)
```

Turning `x0` into a valid `sympy` expression is easier: `x0 = eval(x0, sp.__dict__)`.

Hint 3. Note that in the web interface, the minimum and maximum values on the axis can be mathematical expressions such as `2*pi`. This means that these quantities must be strings that are evaluated in the `numpy` namespace, e.g.,

```
import numpy as np
xmin = eval(xmin, np.__dict__)
```

Hint 4. Getting the legends right when plotting multiple curves in the same plot is a bit tricky. One solution is to have a global variable `legends` that is initialized to `[]` and do the following inside the compute function:

```
import matplotlib.pyplot as plt
global legends
if erase == 'yes':   # Start new figure?
    plt.figure()
    legends = []
if not legends:
    # We come here every time the figure is empty so
    # we need to draw the formula
    legends.append('$%s$' % sp.latex(formula))
    plt.plot(x, f(x))
```

Here, `f` is the Python function for computing the `numpy` variant of the expression in `formula`.

Hint 5. Use the test block in the file to call the compute function several times with different values of the `erase` parameter to test that the erase functionality is correct.

c) Write the remaining files. These have straightforward content if Exercise 3 is done and understood.
Filename: `Taylor_approx.tar.gz`.

Exercise 5: Extend the gen app

Add a new argument `x_axis` to the `compute` function in the `gen` application from Section 4.9. The `x_axis` argument measures the extent of the x axis in the plots in terms of the number of standard deviations (default may be 7). Observe how the web interface automatically adds the new argument and how the plots adapt!

Exercise 6: Equip the gen app with more data types

In the `gen` application from Section 4.9, use the `label` argument in the form field objects to add an information of the type of data that is to be supplied in the text field. Extend the `model.py` file to also handle lists, tuples, and Numerical Python arrays. For these three new data types, use a `TextField` object and run `eval` on the text in the `view.py` file. A simple test is to extend the `compute` function with an argument `x_range` for the range of the x axis, specified as an interval (2-list or 2-tuple). Filename: `gen_ext.tar.gz`.

Exercise 7: Auto-generate code from function signature

Given a `compute` with a set of positional and keyword arguments, the purpose of this exercise is to *automatically* generate the Flask files `model.py` and `controller.py`. Use the Python `inspect` module, see Section 4.9, to extract

the positional and keyword arguments in `compute`, and use this information to construct the relevant Python code in strings. Write the strings to `model.py` and `controller.py` files. Assume as in Section 4.9 that the user provides a file `view_results.html` for defining how the returned object from the `compute` function is to be rendered.

Test the code generator on the `compute` function in the `vib1` application to check that the generated `model.py` and `controller.py` files are correct. Filename: `generate_flask.py`.

7 Resources

7.1 Flask resources

- Flask website
- The Flask Mega-Tutorial by Miguel Grinberg
- WTForms Documentation
- The Jinja2 templating language
- The Werkzeug library

7.2 Django resources

- Django webpage
- Web tutorials
- YouTube videos

8 Remaining

- apply (generated apps) to simviz (make py simviz too and describe that)
- store data in database
- discuss list values read as text and use of eval, perhaps exercise
- avoid Flask or Django in exercises, just do not specify and have common exercises at the very end
- app: username, TextAreaField, store in database and retrieve for admin

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