# Apex angle-based model of the gravitropic reaction

## Installation

Download the **.msi** file named **apex_only.msi**. Then navigate (in *File Explorer*) to the folder in which this file was saved and double-click on the file name to run the file [*OR* right-click on the **apex_only.msi** file name and choose '**Install**' from the menu that appears].

The installation file will display this announcement in the centre of your screen:
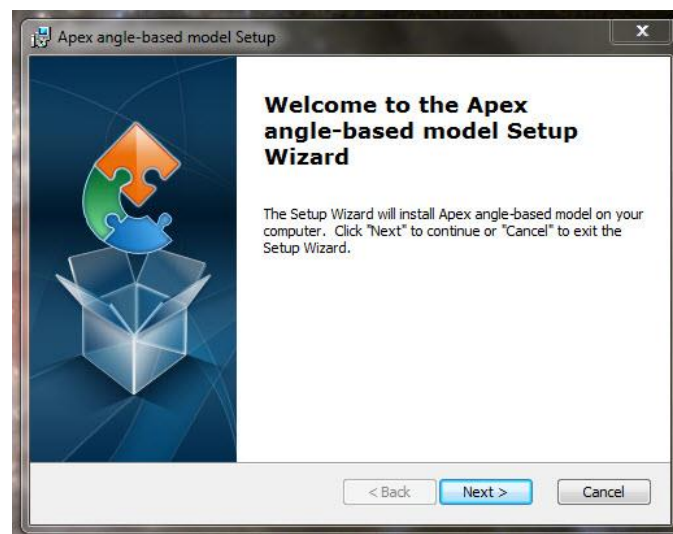
When you click '**Next**', this screen appears:
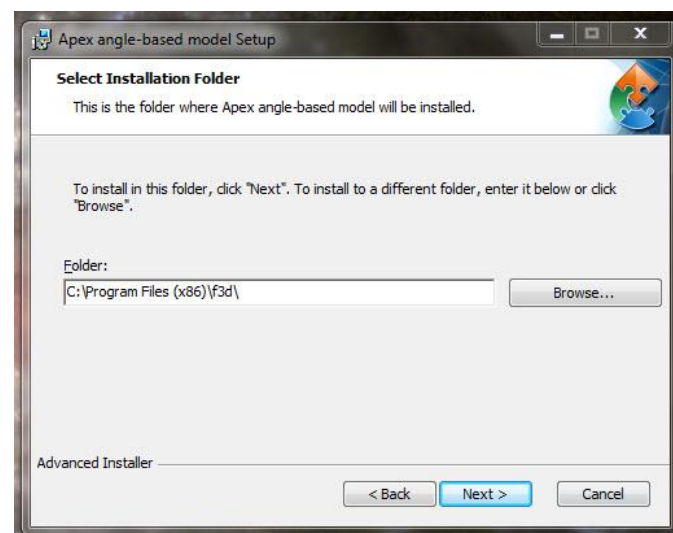
You can accept that offer to install the package into your existing '**C:\Program Files (x86)**' folder, or click on the '**Browse…**' button to find somewhere else. *BUT* as we've suggested already, we recommend downloading and installing on a USB flash drive, so we expect you are running the **apex_only.msi** file from a flash drive in a USB port on your machine. The little

window that currently shows **C:\Program Files (x86)\f3d** is actually a text edit window, so you can position your cursor in it and start typing the address of the place you want to install the ***Apex angle-based modelling program***. I'll assume your USB drive will be drive E: (you may have to **Browse** to use File Explorer to confirm that) and suggest you type **E:\apex-angle-based-model** into that edit window. With that done, click on the '**Next >**' button and the Installer will do everything for you. It will keep you informed of progress and announce when it's finished.

- You'll note that I've not accepted the invitation to install into a folder called **\f3d**, preferring my own name **\apex-angle-based-model**. I've done that for two reasons: one is to show you that the program doesn't mind which folder it's installed into (and will eventually run from), ***but*** don't mess with the names of the other folders the **.msi** file installs! The second reason is that I like to know explicitly what my folders contain.

When the installation is complete, use File Explorer to *Browse* to, and look inside, the folder you've just created (**\apex-angle-based-model**) and you'll find it contains:

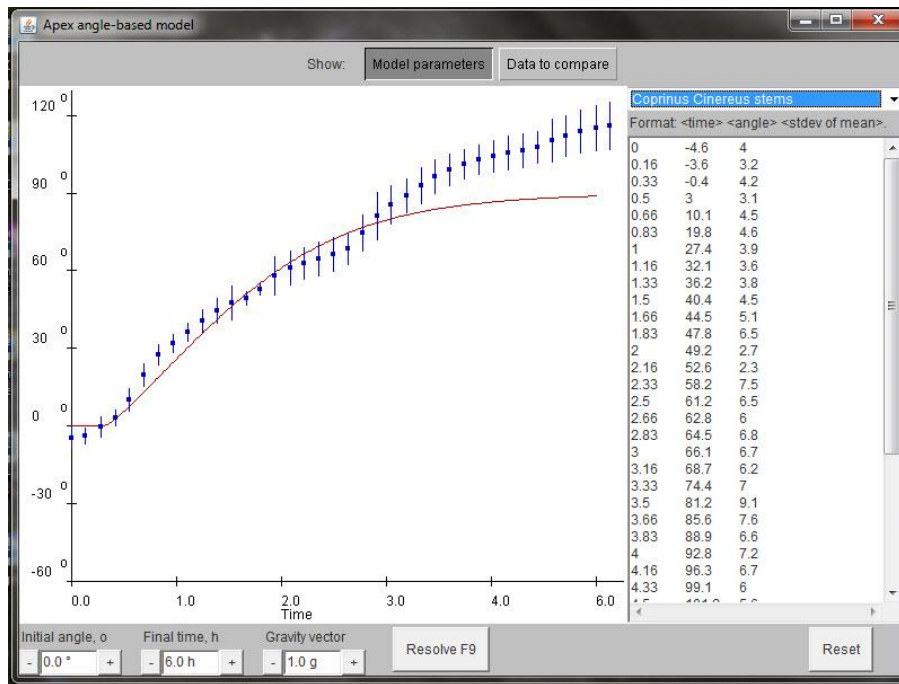| Name	Date modified	Type	Size
jars	14/02/2017 11:04	File folder	
jre_apex	14/02/2017 11:04	File folder	
sources	14/02/2017 11:04	File folder	
regid.1995-09.com.example_c524204d...	01/02/2017 09:46	SWIDTAG File	2 KB

The SWIDTAG (software identification tag) is a management file that need not concern you. It is an XML-format file that identifies the software to Windows. The file folder called **sources** is an archive containing a ZIP file (**apex.zip**), which holds all the .java files for the program, and a **.txt** copy of the **GNU General Public License** [https://www.gnu.org/licenses/gpl.html] under which this software is distributed. The file folder called **jre_apex** contains all the working components of the program.

The folder you need to look at is the one called **jars**; have a look in that and you'll see that it contains a single file called **apex.jar**, which is an 'executable jar file' that will launch the *Apex angle-based modelling program*.

- Before you do launch the program here's another recommendation: create a ***shortcut to apex.jar*** to save yourself the hassle of navigating through all these folders to launch it. Like this: settle your cursor on *apex.jar* to highlight it in the folder window, then **right-click** and choose '**Create shortcut**' from the menu that appears. The shortcut will appear in the same window beneath *apex.jar*, and you can then drag-and-drop the newly created shortcut from that folder window to your ***Desktop***, where it will acquire a snazzy 'cup of steaming java' icon.

Launch the Apex angle-based modelling program

Launch the program with a double-click either on your new shortcut to apex.jar or directly on apex.jar in its own folder. The following view will appear in a new window (which you may want to resize to suit your preferences):

Now, let's get back to that start-up screen. It's actually showing you the results of the modelling exercise represented by the real experimental observations recorded in the table at the right-hand side of the window (this is a text-edit box, so you can play around with the numbers if you want to).

In the main window, the data in the side table are plotted on a graph of angle *versus* time (as blue squares with standard deviation error bars attached), and the Java simulation *predicts* how the mathematics on which it is based expect the apex angle to change during the process of the gravitropic reaction, and plots that as well (as the red line). Reasonable correspondence between the two plots, especially over the first three hours, suggests that the mathematical assumptions made in the model are reasonably accurate.

These (built-in) data describe the gravitropic reaction of stems (= mushroom stipes) of the small ink cap mushroom *Coprinopsis cinerea*, though when the program was written this organism was called Coprinus cinereus and this is the name that appears here.

Notice the following points about this screen:
- The plot in the main window is a graph with vertical axis graduated in angular degrees; note that 0° = **horizontal**, 90° = **vertical**.

- The horizontal axis of the plot is **time in hours**.
- The standard experiment (see below) starts with re-orienting the stems to the horizontal; so, the initial angle (see the box in the bottom left corner?) is **zero**. You can change that. Try changing the initial angle, then press (click) the button ***Resolve*** (bottom middle) [or press function key F9] and the program will plot its prediction.
- You can also change the time span (remember, change it then press ***Resolve***).
- More challenging for the experimental scientist is a change of the gravity vector (the third little window). You might like to find out, for example, how a fruit body would react to being placed horizontal on the surface of **Mars** ($g = 0.38$), **Saturn** ($g = 0.92$) or **Jupiter** ($g = 2.36$). ***The model will predict*** how the *Coprinopsis* stem will respond in each of these circumstances. You might have to speak to NASA to arrange tests of those predictions, but it should be a fun project and, hey, nothing ventured – nothing gained.

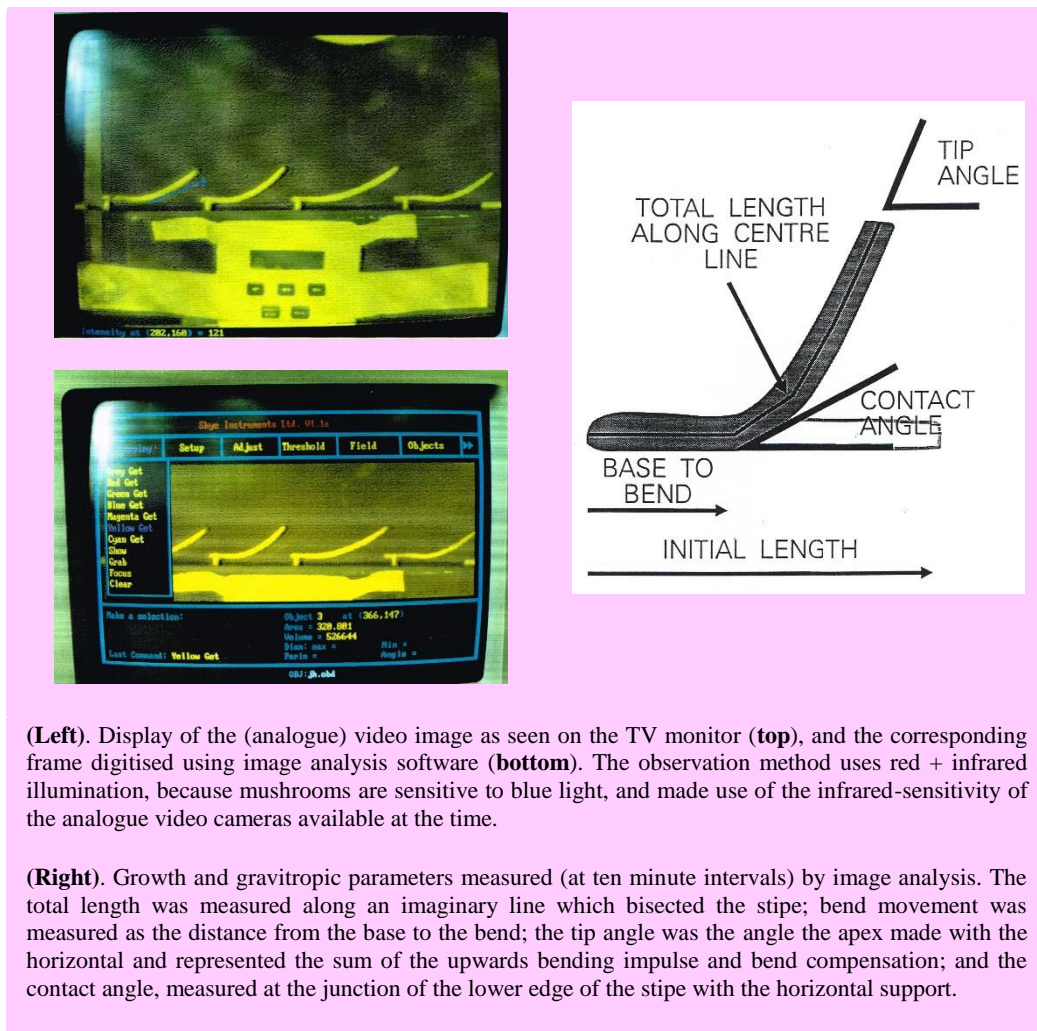Let's now examine the top of the start-up screen:

- At far right is a drop-down menu that allows you to choose between a (small) number of built-in experimental models. Click on the triangle and the menu will show you (after the default 'Coprinus Cinereus stems'): *Triticum aestivum* coleoptiles, *Triticum aestivum* roots, *Zea mays* roots, and 'New object'. Click on the wheat or maize choices and you'll get a set of experimental data (which will be plotted) and the model's predictions for that experimental subject (again, reasonable correspondence implies reasonable accuracy). Click on ***New object*** and you will get a blank data entry screen (and the model will plot its **default (that is, purely theoretical) predictions**. If you do enter data remember to enter them in the form 'time: angle: standard deviation'.
- If you change subject, the mathematical model will have to change the parameters it uses to make its predictions. To inspect these, click on the button (top, centre) called ***Model parameters***. This will change the contents of the right-hand data window to show the parameters used for the currently-selected experimental subject. For example, the *Coprinus Cinereus stems* parameters look like this:
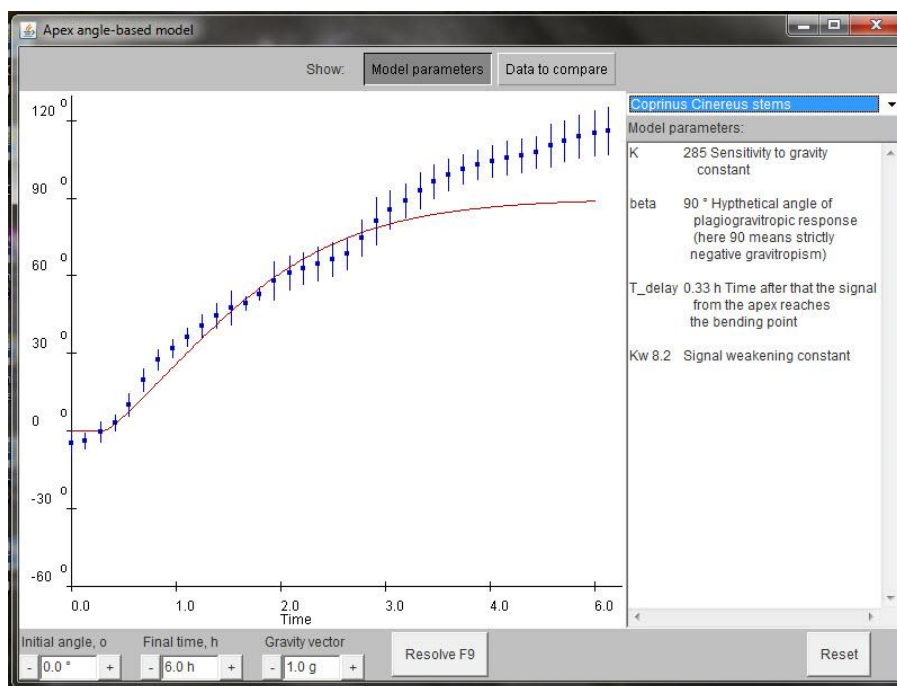
Again, this **Model parameters** window is a *text editing window*; so, you can change the numerical values just by typing in new ones. Remember, make the change then press (click) the button ***Resolve***. The program will then make a new prediction for the revised parameter set and plot it (as a red line with the *same* set of experimental data).

Obviously, there are quite a few parameter changes you could make, so there's a lot of experimentation you can do here. But remember that this (our first) model of gravitropism deals only with the angle of the apex. To understand this better, let me show you how the experimental data were obtained.

When we set out to establish the exact kinetics and mechanics of gravitropism in the mushroom *Coprinopsis cinerea* one of the first things we developed was a standardised, simple experiment in which fruit body stipes were placed horizontally (fixed with a mapping pin through their basal bulb or with a piece of adhesive tape wrapped around the basal bulb) on a balsa wood support in an environmental chamber to be observed continuously using video recordings, followed by computer analysis of the videotaped images to analyse the kinetics of the gravitropic response.

(Left). Display of the (analogue) video image as seen on the TV monitor (**top**), and the corresponding frame digitised using image analysis software (**bottom**). The observation method uses red + infrared illumination, because mushrooms are sensitive to blue light, and made use of the infrared-sensitivity of the analogue video cameras available at the time.

(Right). Growth and gravitropic parameters measured (at ten minute intervals) by image analysis. The total length was measured along an imaginary line which bisected the stipe; bend movement was measured as the distance from the base to the bend; the tip angle was the angle the apex made with the horizontal and represented the sum of the upwards bending impulse and bend compensation; and the contact angle, measured at the junction of the lower edge of the stipe with the horizontal support.

We found that the stipe became gravireceptive after the cap had completed meiosis, beginning to bend within 30 minutes of being placed horizontal. Stipe bending first occurred in the apical 15% of its length, and then the position of the bend moved rapidly towards the base, traversing

40% of stipe length in 2.5 h. Meanwhile, the stipe elongated by 25%, mostly in its upper half but also in basal regions. If the **apex** was pinned in the horizontal position the stipe base was elevated but overshot the vertical, often curling through more than 300°. When the **base** was pinned to the horizontal (considered analogous to the normal situation of a fruit body disturbed by the action of animals in the environment), 90% of the initial bend was compensated as the stipe brought its apex accurately upright, rarely overshooting the vertical. The **apex** had to be free to move for this *curvature compensation* to occur.

These experiments were done in the early 1990s; in those almost prehistoric days before digital cameras, digital TV and digital computer monitors. Our video images were digitised with a PC computer using the Skye S1733 video digitising card and Skye S1730 image analysis software [Skye Instruments Ltd still prospers (http://www.skyeinstruments.com/) although 'video digitiser' no longer features on the website]; the (analogue) video images being sampled at 10 min intervals. For photographic illustrations, analogue video frames were digitised with a '*Screen Machine*' real-time video digitiser card and software, and transferred to film (Ilford 100 ASA black & white) with a Polaroid Image Recorder (for traditional wet development!).

You will appreciate that, interesting though it is, modelling the apex angle is a gross over-simplification of the gravitropic behaviour of the mushroom stem. And that's why we went on to investigate *curvature compensation* in more detail and develop the **spatial organisation model** of the gravitropic reaction.