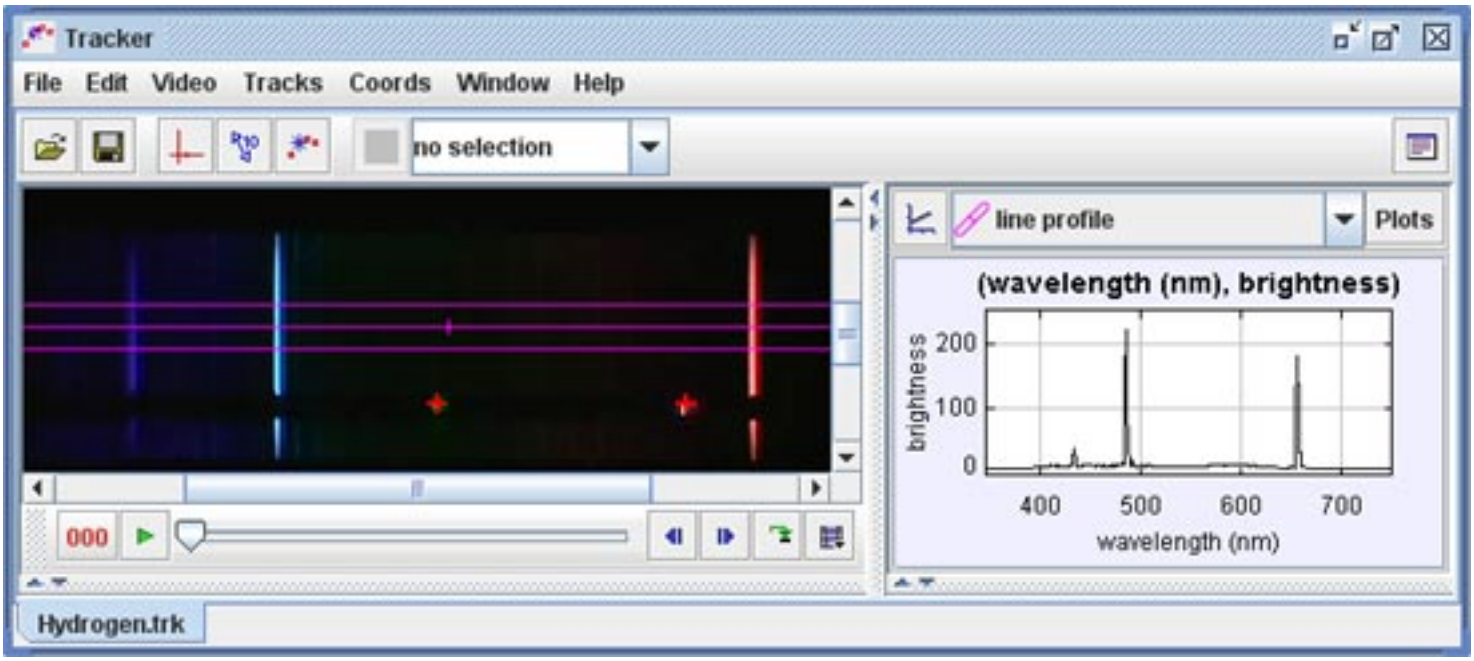
# Tracker Help



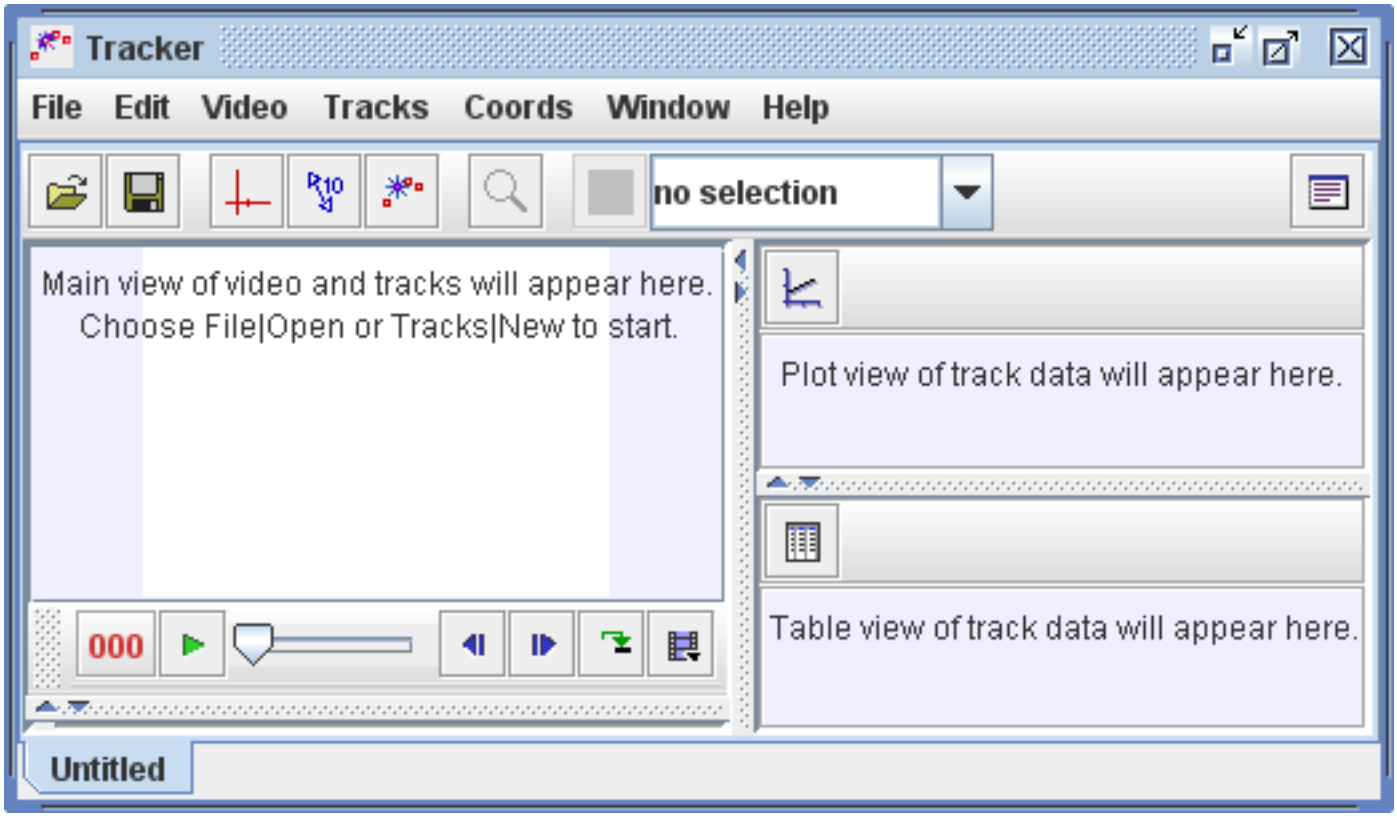

Tracker is a video analysis package built on the **Open Source Physics** (OSP) Java framework. Features include object tracking with position, velocity and acceleration overlays and graphs, special effect filters, multiple reference frames, calibration points, line profiles for analysis of spectra and interference patterns, and dynamic particle models. It is designed to be used in introductory college physics labs and lectures.

To start using Tracker, see getting started.

# Getting Started

When you first open Tracker it appears as shown below. Here's how to start analyzing a video:

1. **Open a video or tracker file.**
2. **Identify the frames ("video clip") you wish to analyze.**
3. **Calibrate the video scale.**
4. **Set the reference frame origin and angle.**
5. **Track objects of interest with the mouse.**
6. **Plot and analyze the tracks.**
7. **Save your work in a tracker file.**
8. **Export track data to a spreadsheet.**
9. **Print or copy/paste images for reports.**



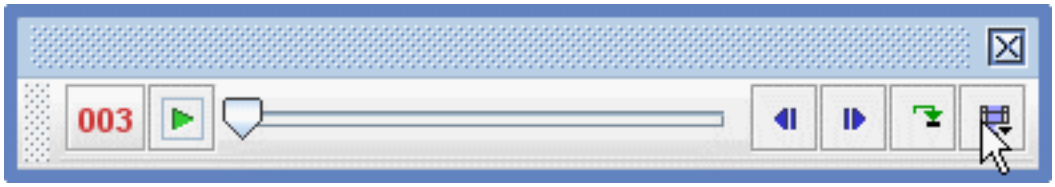

For more information about Tracker's user interface, including user customization, see user interface.

### 1. Open a video or tracker file

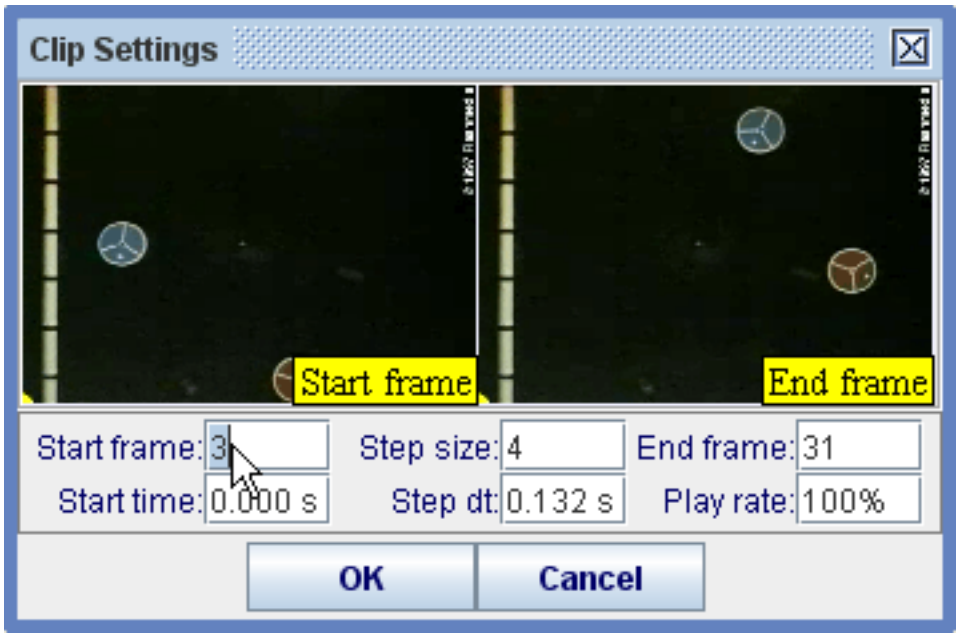
Click the **Open** button  or **File|Open** menu item and select a QuickTime video (.mov) or tracker file (.trk) to open it. Other video types can be opened as long as QuickTime can play them. You can also open image files (.jpg, .gif, .png) or paste an image from the clipboard. For more information see videos.

### 2. Identify the frames ("video clip") you wish to analyze

Display the clip settings by clicking the **clip settings** button at the right end of the player as shown.

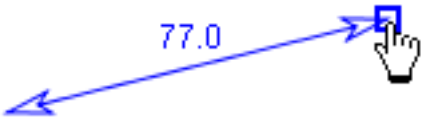



In the clip settings dialog, set the **Start** and **End** frames to define the range you wish to analyze. You can drag the player's slider to scan through the video and quickly find the frames of interest. If the video contains too many frames to analyze (more than 20 or so can become tedious), increase the **Step Size** to automatically skip frames. For more information see video clips.

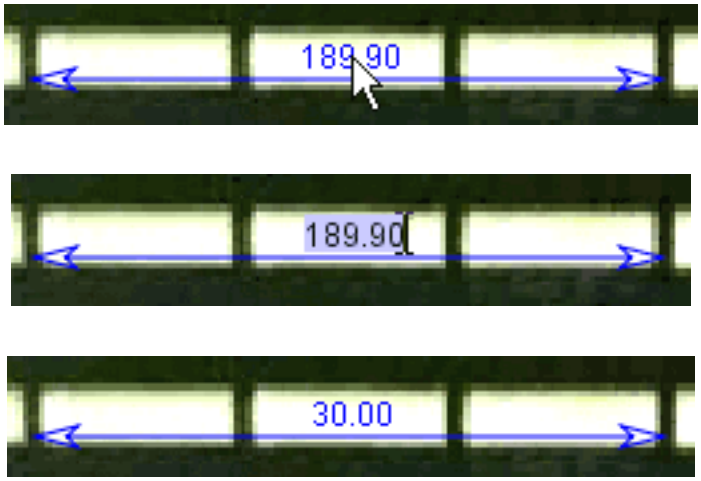



### 3. Calibrate the scale

Click the **Tape Measure** button  to show the tape measure.



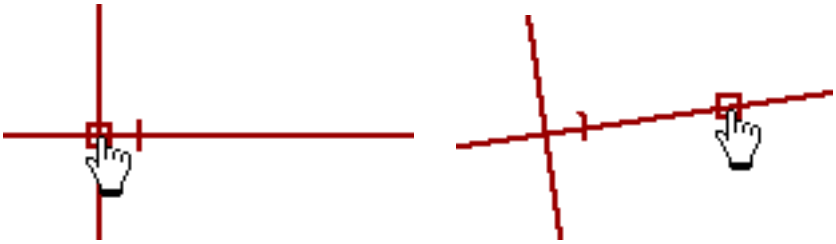

Drag the two ends of the tape to positions that are a known world distance apart (for example, the ends of a meter stick or other object with known dimensions in the video image). Then click the tape readout and enter the known distance. For example, in the figure below the scale is set in cm units using a white meter stick with black stripes every 10 cm.




For more information see tape measure, or for an alternate way to calibrate the video consider a calibration point pair.

### 4. Set the reference frame origin and angle

Click the **Axes** button  to show the coordinate axes. Drag the origin and/or x-axis to set the reference frame origin and angle. A common choice for the origin is the initial position of an object of interest. For more information see axes, or for alternate ways to set the origin and/or angle consider the tape measure, a calibration point pair or an offset origin.

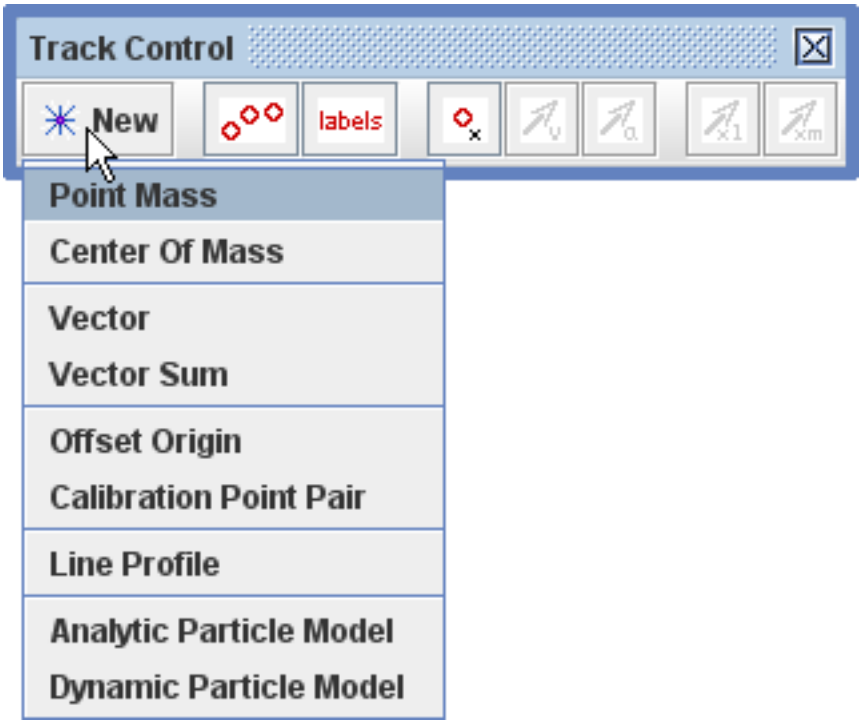


The video scale and reference frame origin and angle uniquely define the **coordinate system** used to convert pixel image positions to scaled world coordinates. In some videos the coordinate system properties may vary from one frame to the next (e.g., if the camera is zoomed the scale will change, or if panned the origin will change). Tracker makes it easy to

handle such videos--see coordinate system for more information.

### 5. Track objects of interest with the mouse or model them with particle models.

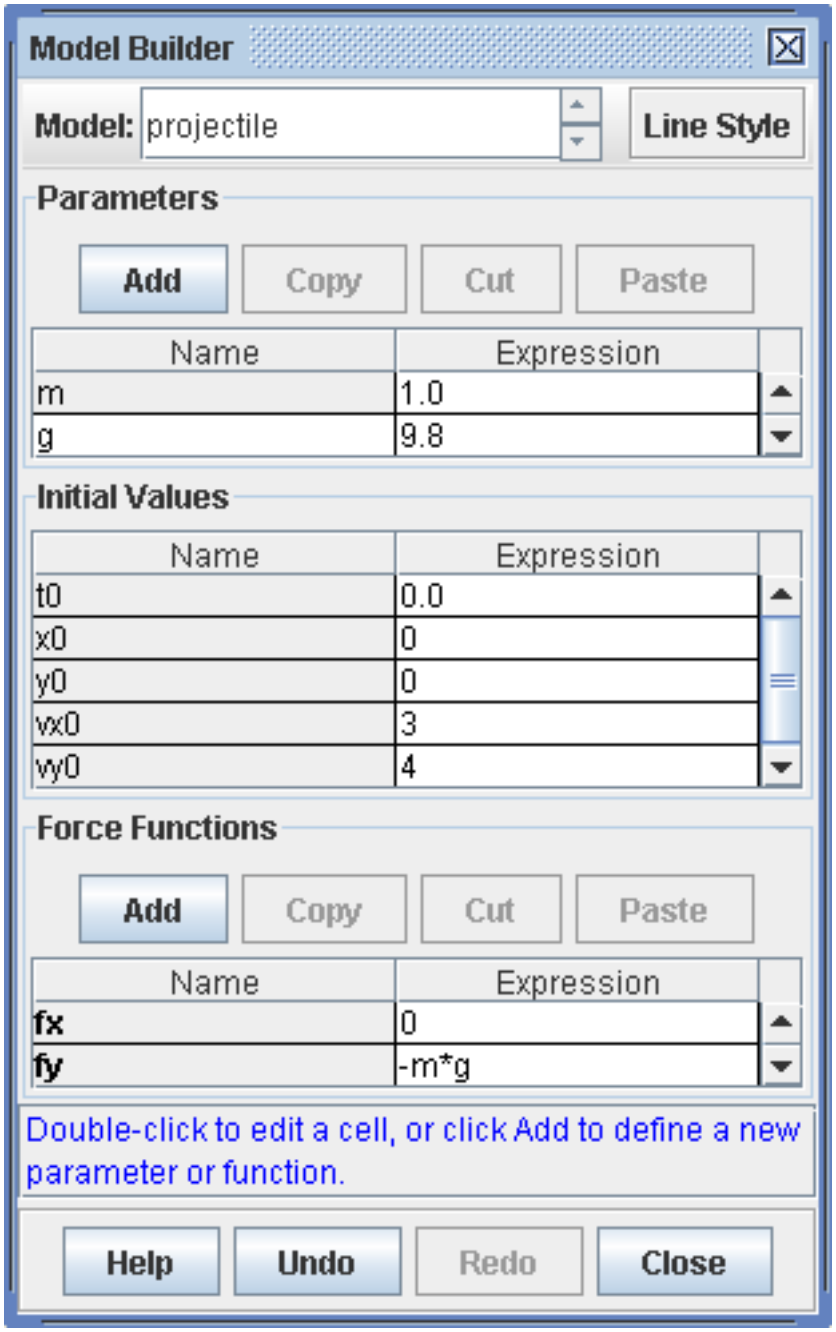
Click the **Track Control** button  to show the track control. Then click the **New** button and choose a track type from the menu of choices. Most moving objects are tracked using a **Point Mass** track or modeled using a **Dynamic Particle Model** track.



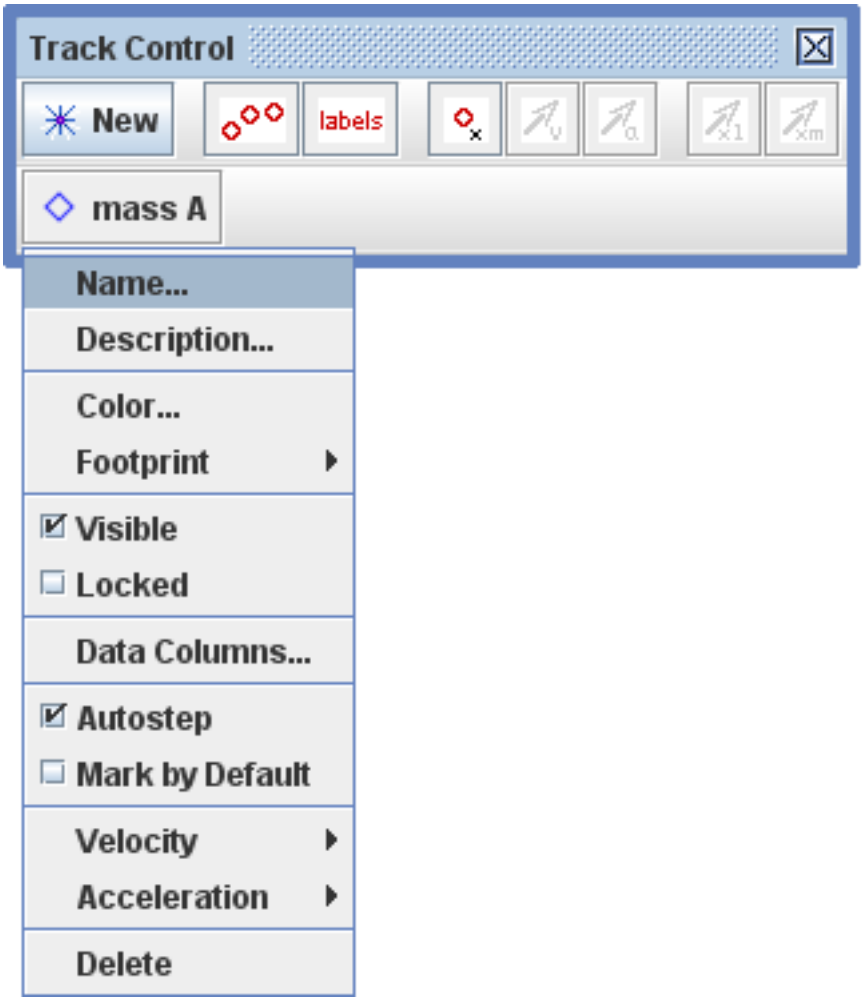

If tracking an object, mark its position on every frame by holding down the **shift key** and clicking the mouse (crosshair cursor) as the video automatically steps through the video clip. **Note**: don't skip frames--if you do, velocities and accelerations cannot be determined.

You can always adjust a marked position by dragging it with the mouse or selecting it and nudging with the arrow keys. Right-click the video to zoom in for sub-pixel accuracy.

If modeling an object, enter values and expressions into the **Model Builder** as shown below. The particle will automatically draw itself on the video when played.



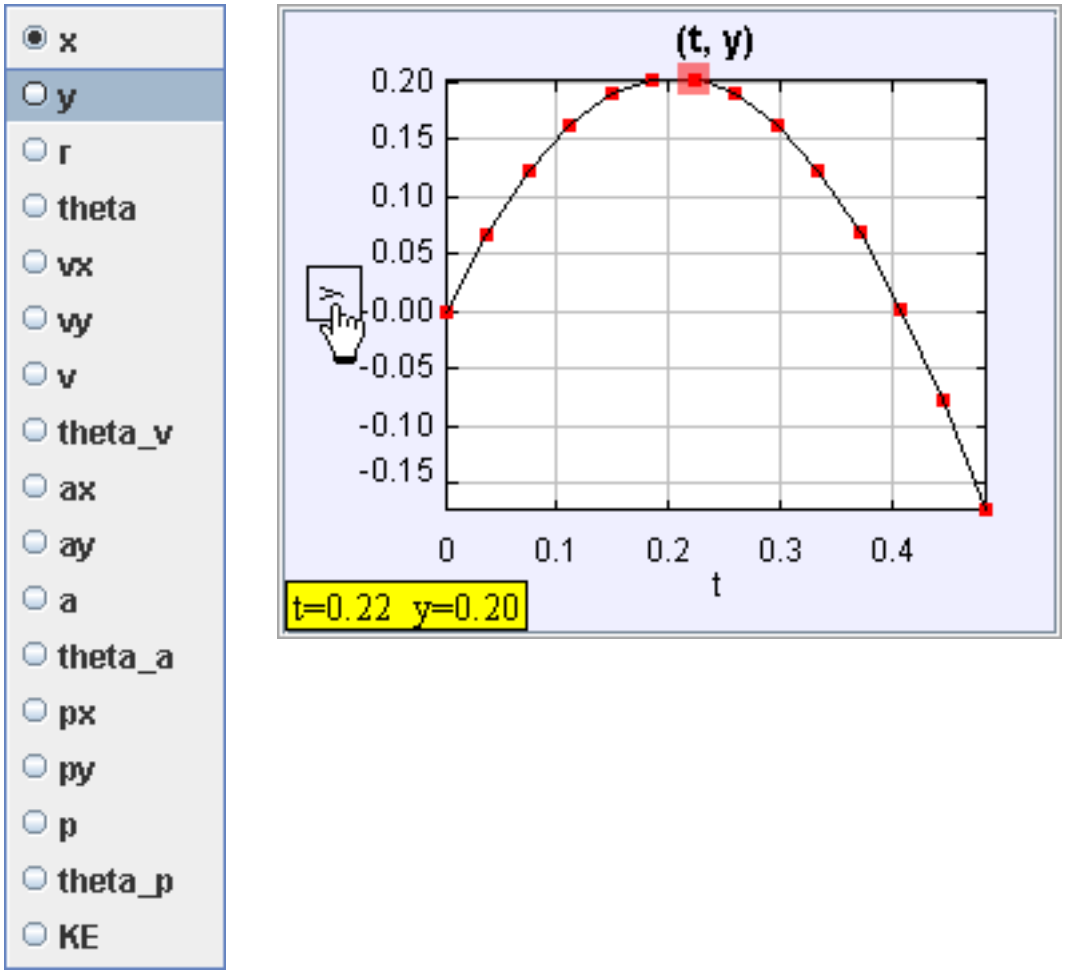

You can change the name and appearance of a track by clicking its button on the track control and choosing from the popup menu. Other track control buttons let you show or hide trails, labels, velocity vectors and acceleration vectors.




For more information on tracks and the track control, see tracks. For detailed information on a specific track type, see point mass, center of mass, vector, vector sum, offset origin, calibration point pair, line profile, rgb region, analytic particle model or dynamic particle model.

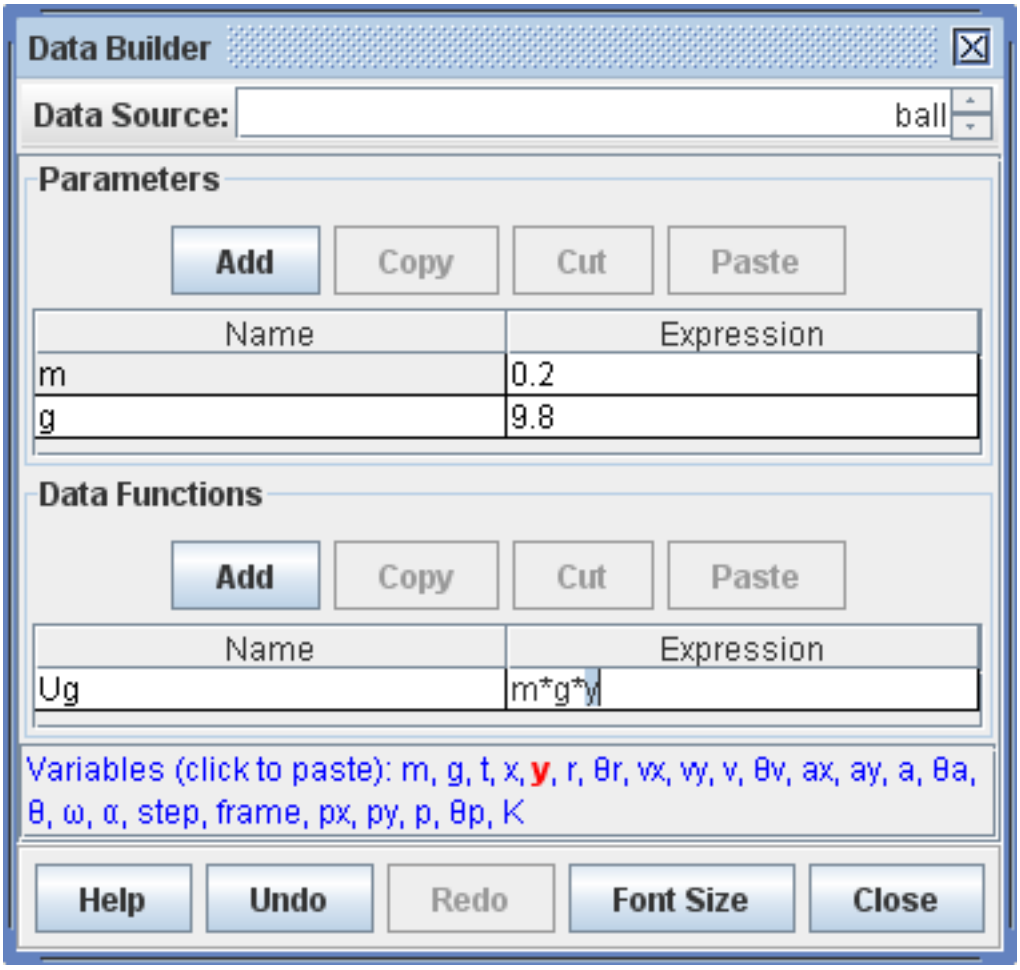
### 6. Plot and analyze the tracks

The **Plot View** displays graphs of track data. Click the x- or y-axis label to change the variable plotted on that axis. To plot multiple graphs, click the **Plots** button and select the desired number. Right-click on a plot to access display and analysis options in a popup menu.

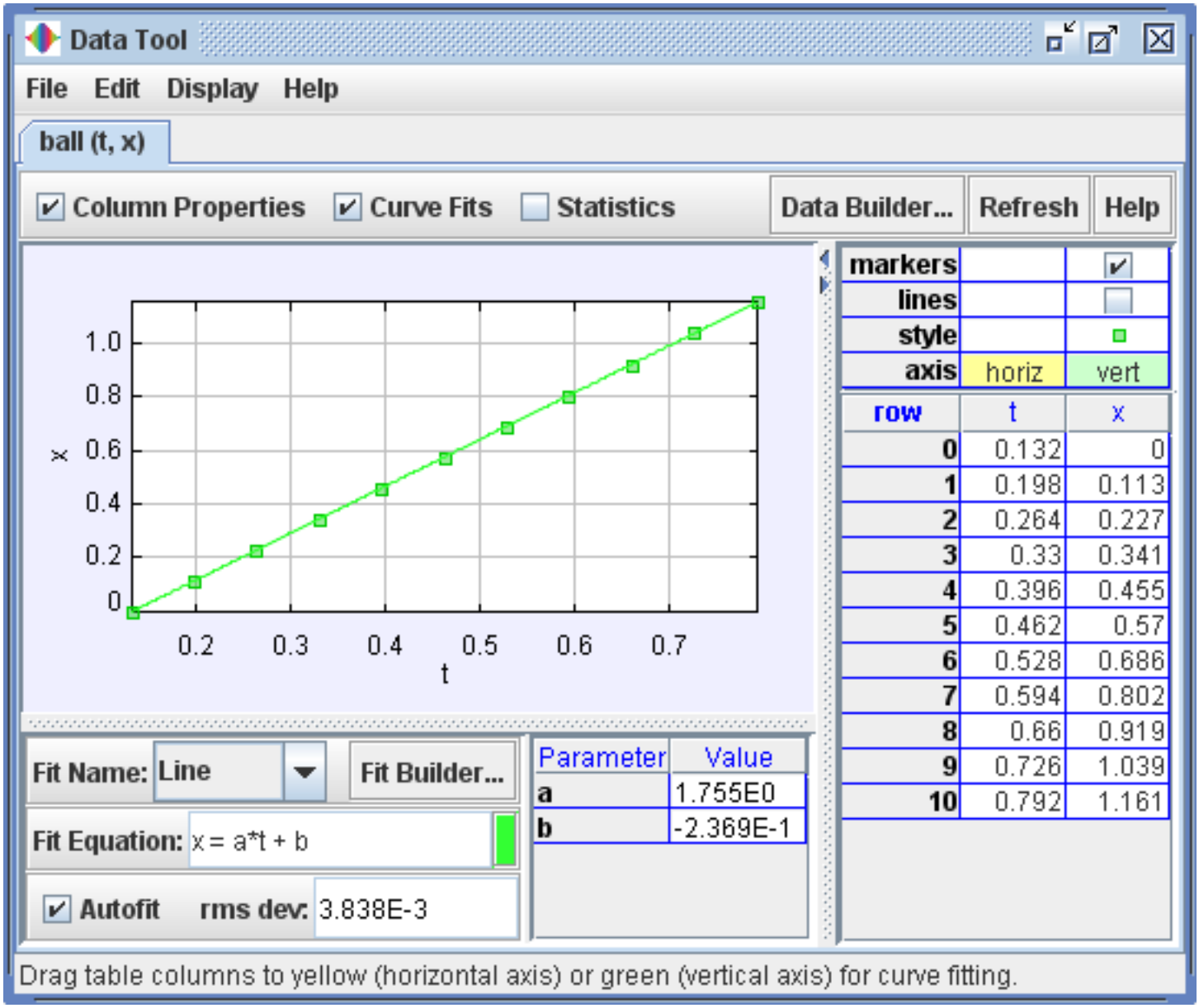



Two of the most powerful analysis options available from the popup menu are **Define...** and **Analyze...**.

- The Define... item displays a **Data Builder** with which you can define custom variables for plots and datatables. Custom variables can be virtually any function of built-in and previously defined custom variables. For help using Data Builder, open Data Builder and click its Help button.




- The Analyze... item displays a **Data Tool** with statistics, curve-fitting and other analysis capabilities. For help using Data Tool, open Data Tool and click its Help button.




## 7. Save your work in a tracker (.trk) file

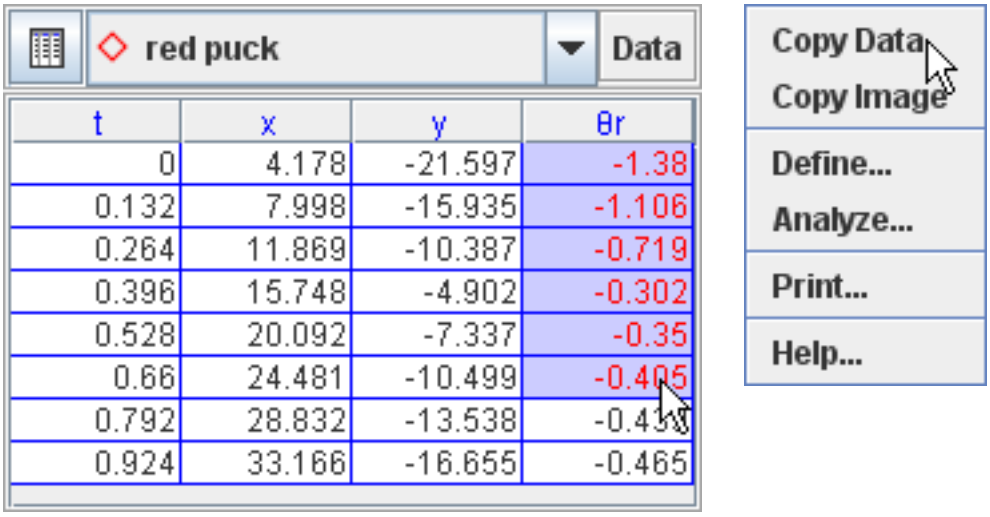
Click the **Save** button  or **File|Save As...** menu item to save your work in an XML-based **tracker file** with the extension ".trk". When a saved tracker file is opened, Tracker loads the video, sets the clip and coordinate system properties, and rebuilds all tracks, custom variables and views. For more information see tracker files.

## 8. Export track data to a spreadsheet

Tracker's **Datatable View** displays track data in a table. To change the variables included in the table, click the **Data** button and select from the list displayed.

Data can be easily exported from the datatable by copying to the clipboard and pasting into a spreadsheet or other application. To copy, select the desired data in the table, then right-click

and choose **Copy Data** from the popup menu. For more information see datatable view.




## 9. Print or copy/paste images for reports

You can print or copy an image of the entire Tracker frame or any individual view (e.g., a plot or datatable). To print the entire frame (all visible views), choose the **File|Print Frame...** menu item. To print an individual view, right-click the view and choose **Print...** from the popup menu. To copy an image, choose the desired view from the **Edit|Copy Image** menu or right-click a view and choose **Copy Image**. Pasting printed or copied images into notes and reports is an excellent way to document your video analysis results.

# Installation

In order to use Tracker you must first download and install (1) *Java* and (2) *QuickTime* or (for Linux users) *FFmpeg*, *Gimp* or other video conversion utility as described below.

### 1. Java

- Download the most recent Java installer (version 5 or higher) from http://java.sun.com/javase/downloads/. The JRE (Java Runtime Environment) is all you need unless you're a Java developer.
- Double-click the installer and follow the instructions.

### 2a. QuickTime (Mac and Windows only)

- Download the most recent standalone QuickTime installer (version 7 or higher) from http://www.apple.com/quicktime/download/. You do not need to purchase QuickTime Pro.
- Double-click the installer and follow the instructions. QuickTime for Java is automatically installed.

### 2b. FFmpeg, Gimp or other video conversion utility (Linux)

- Download FFmpeg from http://ffmpeg.mplayerhq.hu/ and/or Gimp from http://www.gimp.org/unix/.
- See Tracker on Linux for help using Tracker on Linux.

### 3. Tracker

- The easiest way to use Tracker is to **Web Start** it by clicking the link on Tracker's home page at http://www.cabrillo.edu/~dbrown/tracker/. Web Start is recommended because it is always up to date.
- If you prefer, If you prefer, you may download **tracker.jar** by clicking the link on Tracker's home page. Double-click the jar file to start Tracker. If you download, it is wise to update frequently.
- If you wish, you can **download sample video experiments** by clicking the link on Tracker's Home page.

**Congratulations! To start using Tracker, see getting started.**

# Tracker on Linux

Tracker is a Java-based application and will therefore run on Linux as long as Java 5.0 or higher is correctly installed. QuickTime is not available for Linux, however, so Tracker cannot open QuickTime movies directly. Instead, Quicktime and other digital video formats must be converted to either **jpg or png image sequences** or **animated gifs**. If you have access to a Windows or Mac computer, you can use Tracker itself to do the conversion. If not, you can use FFmpeg to convert to an image sequence.

*Note: the animated gif conversion process described below is untested. If you are a Linux user and can recommend any better method(s) please contact me at dobrown at cabrillo dot edu.*

### 1. Converting a video to a numbered image sequence using Tracker on Windows or Mac

- On a Windows or Mac computer, use Tracker to open the video.
- If desired, open the clip inspector and set the start frame, end frame and/or step size.
- If desired, apply one or more video filters to optimize the video image.
- Choose the Video|Save Clip As|Image Sequence menu item, assign a file name and choose an image type (jpg or png). Tracker automatically determines the required number of digits for the numbering.

### 2. Converting a video to a numbered image sequence using FFmpeg on Linux

- Download FFmpeg from **http://ffmpeg.mplayerhq.hu/**.
- On the command line, enter "**ffmpeg -i <movie-file> <image-name>%03d.jpg**" or "**ffmpeg -i <movie-file> <image-name>%03d.png**" to create a numbered sequence of images.
- The %03d format code in the ffmpeg command above produces three-digit numbering ("frame001.jpg, frame002.jpg, ..."). Single-digit numbering ("frame1.jpg, frame2.jpg, ...") will work for sequences up to 9 images and two-digit numbering ("frame01.jpg, frame02. jpg, ...") for up to 99 images. Very long image sequences can require huge amounts of memory and in some cases may cause Tracker to freeze.

### 3. Opening or importing a numbered image sequence into Tracker

- Choose the **File|Open...**, **Video|Import...** or **Video|Replace...** menu item and select the first image in the sequence.
- If a "Load Image Sequence" dialog pops up, click on "Entire Sequence". This will load the entire sequence into a single video in Tracker.
- Very long image sequences can require huge amounts of memory and in some cases

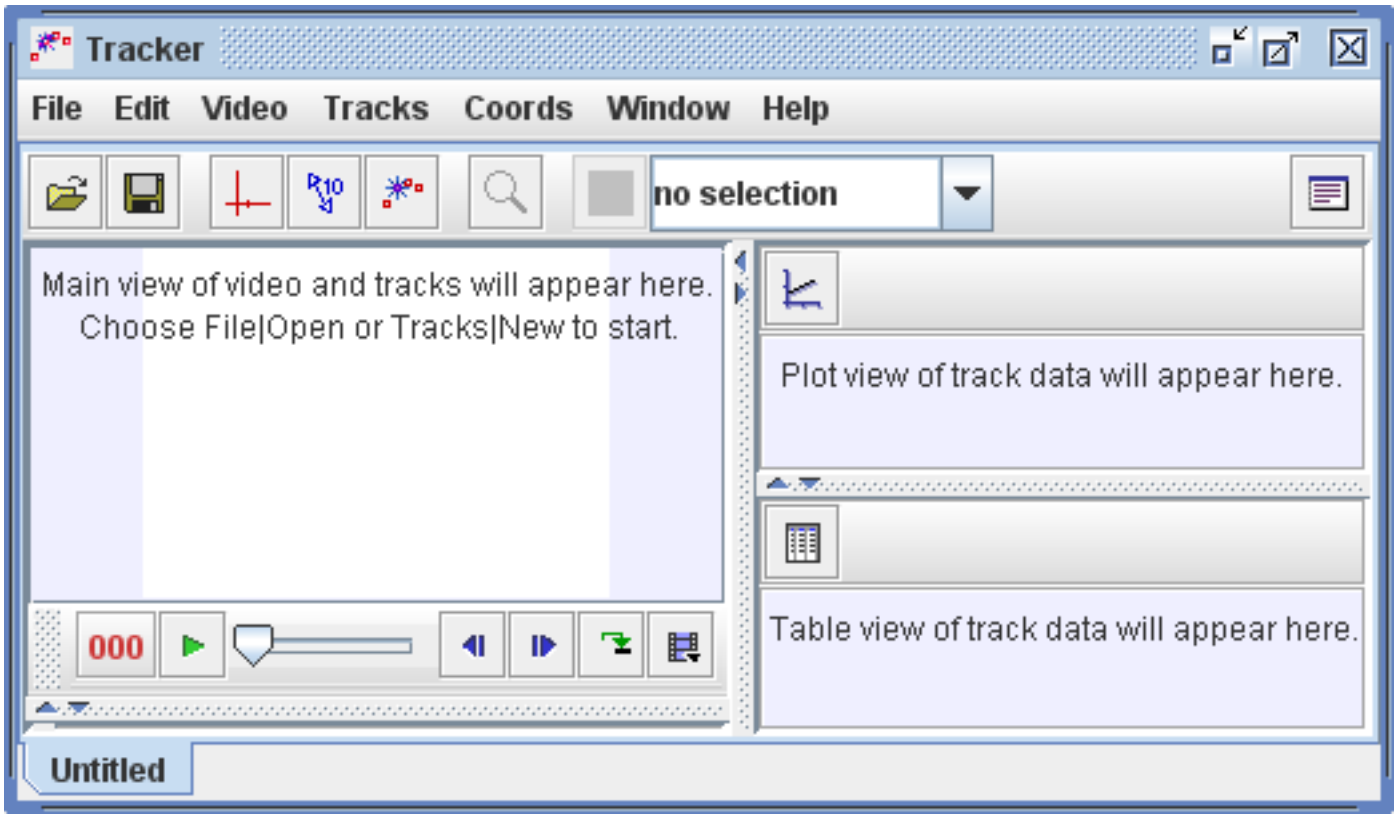
may cause Tracker to freeze.

## 4. Converting a video to an animated gif using Gimp on Linux

- Download Gimp from **http://www.gimp.org/unix/**.
- Convert the video to an image sequence as described above.
- Merge the images into a single animated gif file using Gimp.

# User Interface

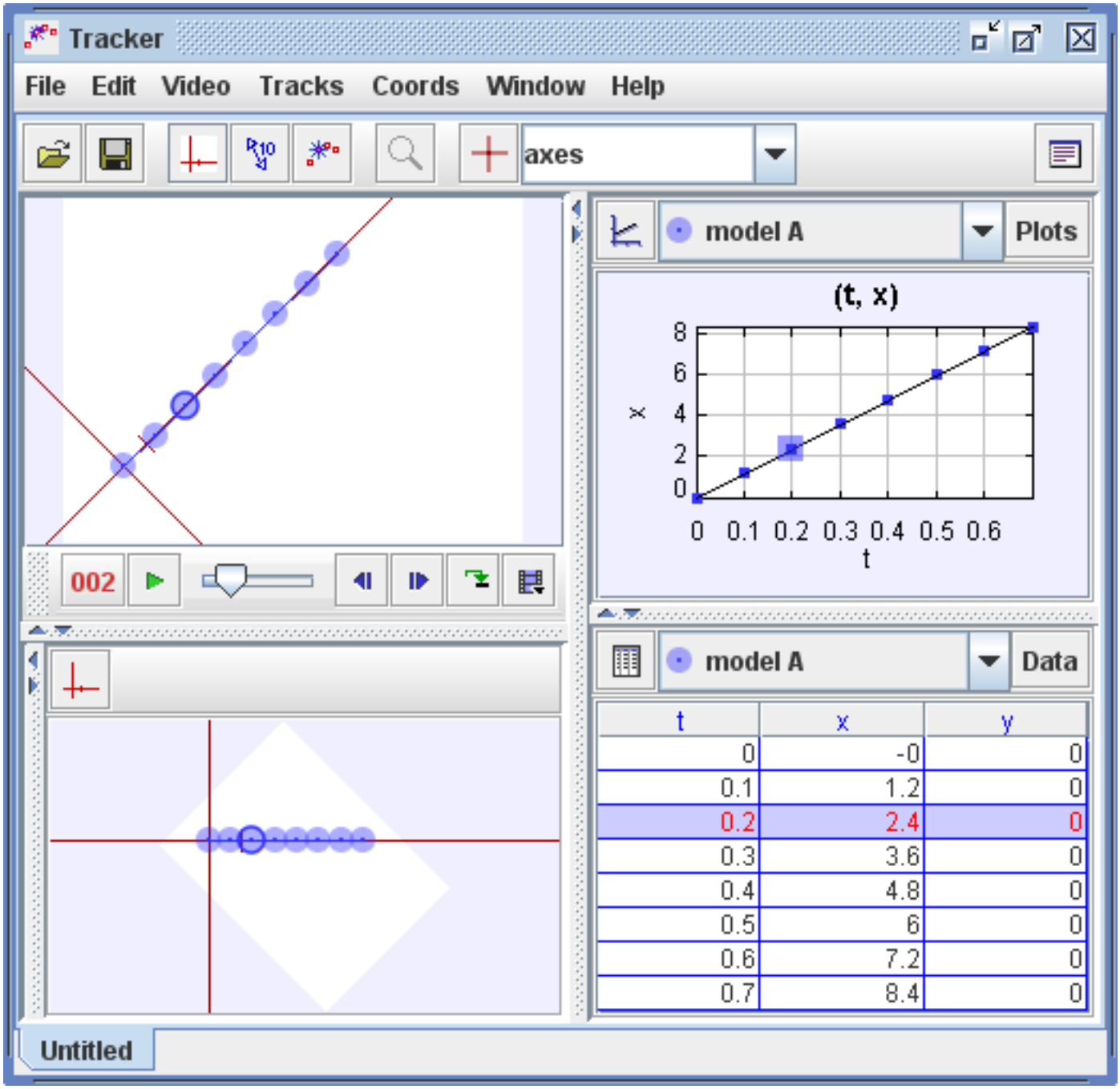
## 1. Main view




Each Tracker tab, like "Untitled" above, displays the following components:

- A **main video view** that displays video images with track overlays. The video view has a fixed, stable video image. Tracks are marked and edited in the video view.
- A **menu bar** that offers access to most program commands and settings. Some menu items include icons showing which toolbar buttons perform identical actions.
- A **toolbar**, displayed directly below the menu bar, that offers quick access to frequently used commands, controls, tools, track settings and data fields.
- A **player** that controls the video and track playback and offers access to video clip settings.
- **Additional views** in attached view panes. Open, close or resize a view by clicking or dragging the thin dividers between panes or by selecting the desired view from the Window menu.

## 2. Additional views



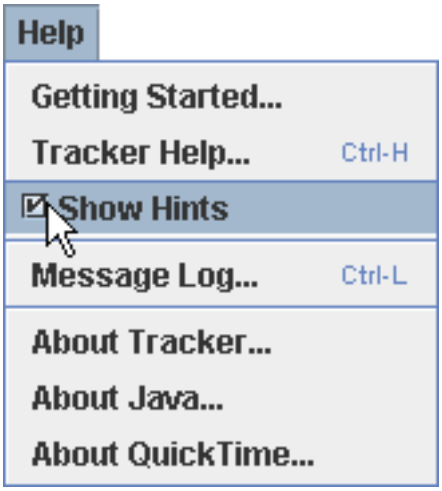

Here a point mass track has been added and the split panes have been opened to display all view types.

- The **main video view** (top left) displays the video and tracks in video space. In this example, the video view keeps the video image (white background) fixed even though the axes are tilted.
- The **plot view** (top right) displays one or more graphs of track-generated data. Multiple graphs are stacked vertically.
- The **table view** (bottom right) displays a data table of track-generated data.
- The **world view** (bottom left) displays the video and tracks in world space. The world view keeps the axes fixed (with the x-axis pointing right), so the video is tilted.

Any view pane can display any type of view. To select a desired view type, click the **view chooser** button on the left side of the view pane toolbar and choose from the drop-down list.

### 3. Hints

By default, Tracker displays **hints** in a yellow box at the bottom right corner of the main view. Hints are very useful for new and occasional users of Tracker. Experienced users can turn off hints by unchecking the **Show Hints** checkbox in the Help menu.




### 4. Background mat

The background mat is a white area normally hidden behind the video. It is never smaller than the video, but may be made larger if desired by choosing from the **Edit|Mat Size** menu. A larger mat size increases the area that is drawn in the video and world views. This is useful when some of a track's steps, or the axes, would otherwise be drawn offscreen--a common situation when using particle model tracks, calibration point pairs or offset origins.

### 5. Languages

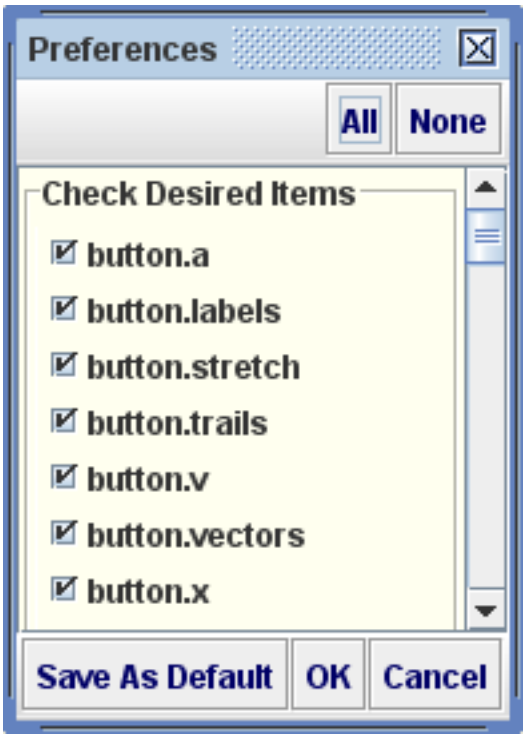
Select a language other than that of the default locale by choosing from the **Edit|Language** menu. If your preferred language is not available, and you wish to provide a translation, please contact Douglas Brown at dobrown at cabrillo dot edu.

### 6. Undo and redo

Many operations in Tracker can be undone and redone using the **Undo** and **Redo** items in the **Edit** menu. There is no limit to the number of undo actions.

### 7. Customizing Tracker

Tracker's user interface can be greatly simplified by hiding unwanted features using the Preferences dialog shown. This is particularly important when introducing students to Tracker for the first time. As they gain familiarity with the program, additional features can be included as needed.




To display the preferences dialog, choose the **Edit|Preferences** menu item. Selected features will be enabled; unselected ones will be hidden.

There are two ways to save your preferences:

1. Click the **Save As Default** button. This will immediately save the currently checked items in a default configuration file named "default config.trk". New Tracker documents automatically load this file to configure themselves. (Note: the Save As Default button is only available when the config.save item is selected in the preferences. If it is hidden and you wish to enable it, select the config.save item and click the OK button, then reopen the preferences dialog.)

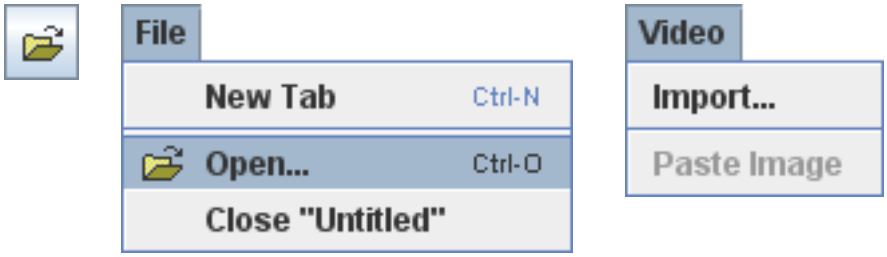
2. Select the config.saveWithData item in the preferences. The preferences will then be included in the xml file whenever the Tracker document is saved. Opening or importing this file will then restore the saved preferences.

# Videos

The term **video** in the discussion below refers to (a) a digital video file recognized by QuickTime (typically .mov or .avi), (b) an animated GIF file (.gif), or (c) a sequence of one or more digital images (.jpg or .png files or images pasted from the clipboard), referred to as an **image video**.

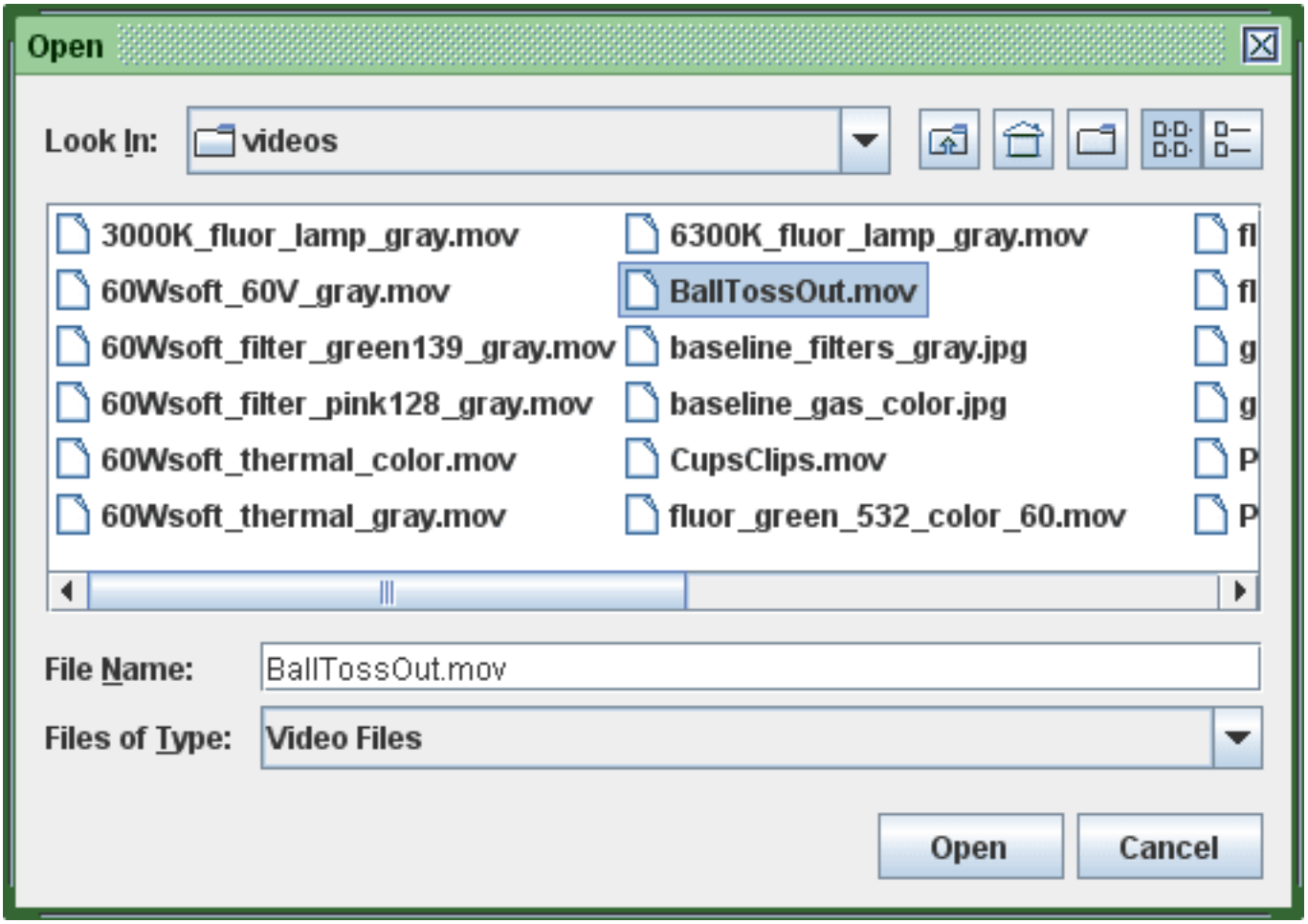
## 1. Opening a video

To open a video into a new tab, use the **Open** button or **File|Open** menu item. To import a video into an existing tab, use the **Video|Import**, **Video|Replace** or **File|Import** menu item.




In the file chooser, set the file type to Video Files and select the desired file. Tracker will open JPG and PNG images and image sequences, animated GIFs, and QuickTime MOV and AVI files.

**Note:** If Tracker cannot open a movie file, you may need to reinstall QuickTime. (Note: QuickTime is not available for Linux. To use Tracker on Linux, please see Tracker on Linux.)



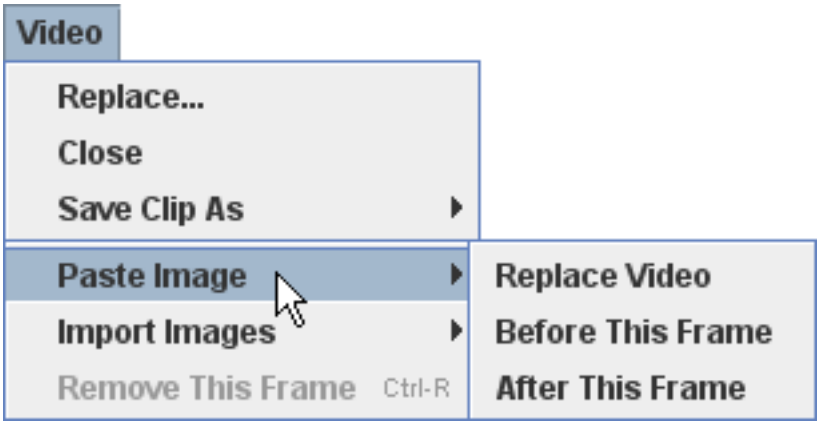

## 2. Opening numbered image sequences

Tracker will automatically open a sequence of up to 1000 JPG or PNG images that are numbered sequentially. To open a sequence, select only the first image in the sequence.

Image sequence numbering must have a fixed format. For example, selecting the first image in a sequence numbered image00.jpg to image14.jpg will open all 15 images, but if the sequence is numbered image0.jpg to image14.jpg then only the first 10 images will be opened (i.e., up to image9.jpg).

## 3. Pasting images from the clipboard

Images that have been copied to the clipboard may be pasted directly into Tracker for analysis. Choose the **Video|Paste Image** or **Video|Paste Image|Replace Video** menu item to create a new image video.

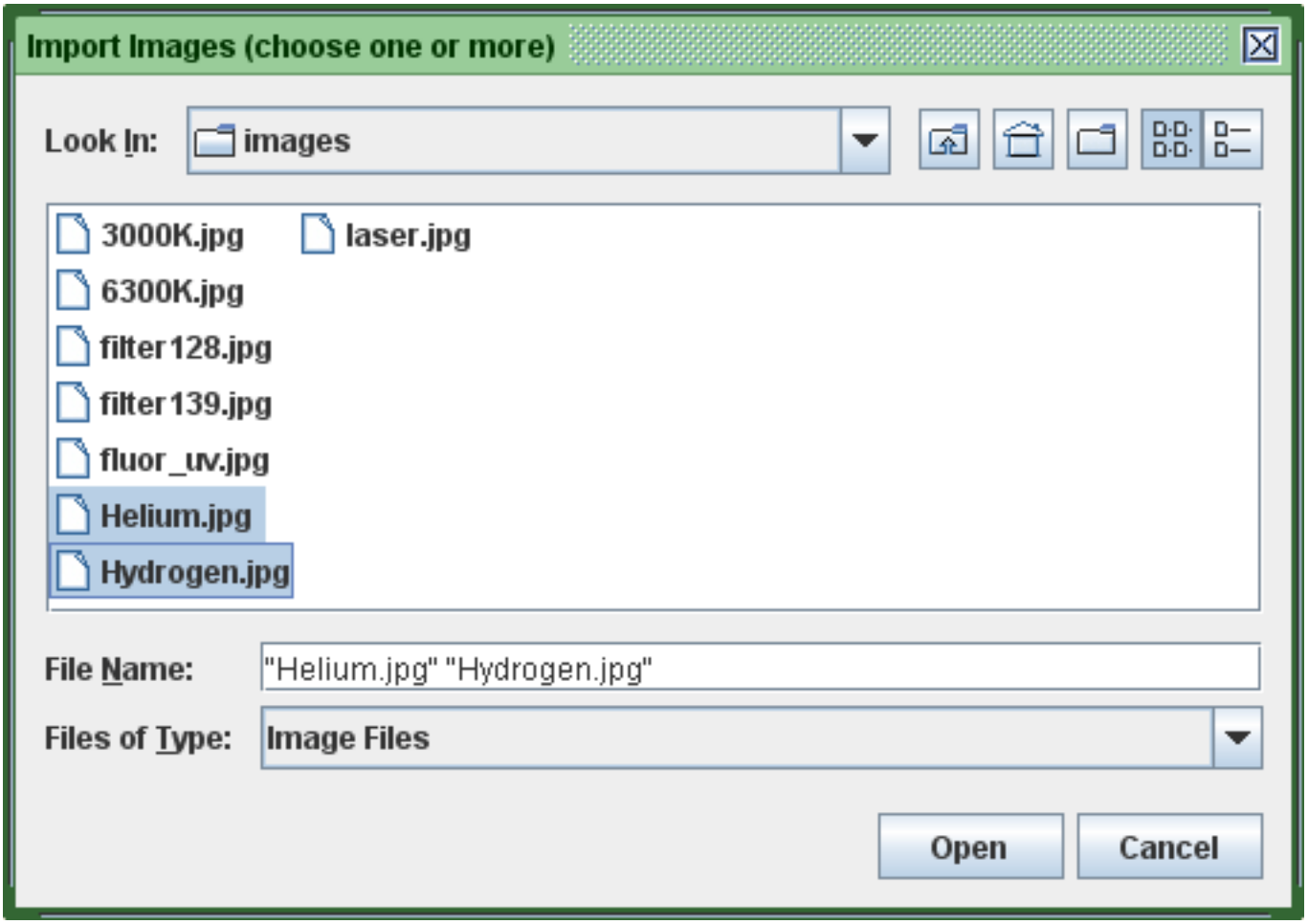



## 4. Adding and removing images from an image video

Once an image video has been created, you can paste or import additional images using the **Video|Paste Image** or **Video|Import Images** menu choices **Before This Frame** or **After This Frame**.

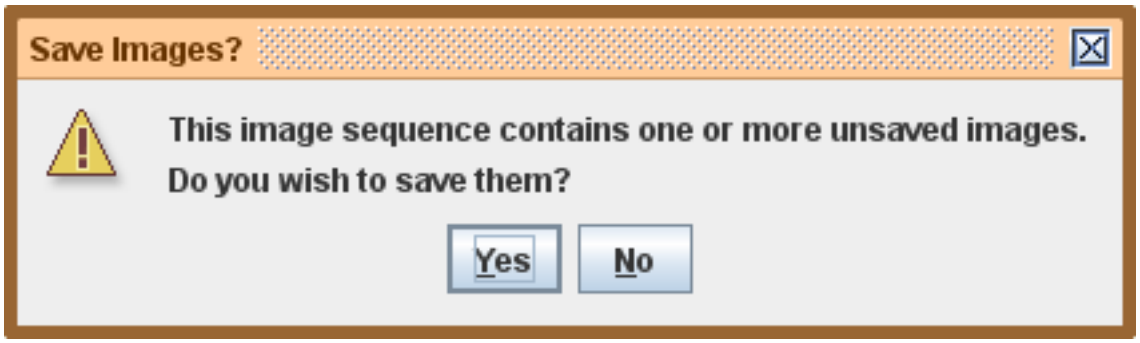
To remove images from an image video use the **Video|Remove This Frame** item.

When importing images you can select multiple images in the file chooser by control-clicking or shift-clicking.



## 5. Saving pasted images

When closing or saving an image video that contains pasted images, a warning dialog prompts you to save the images as files if desired. You must save the images if you wish to reopen them at a later time.

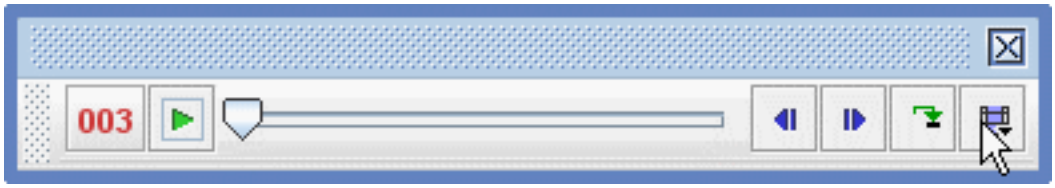



## 6. Video clips

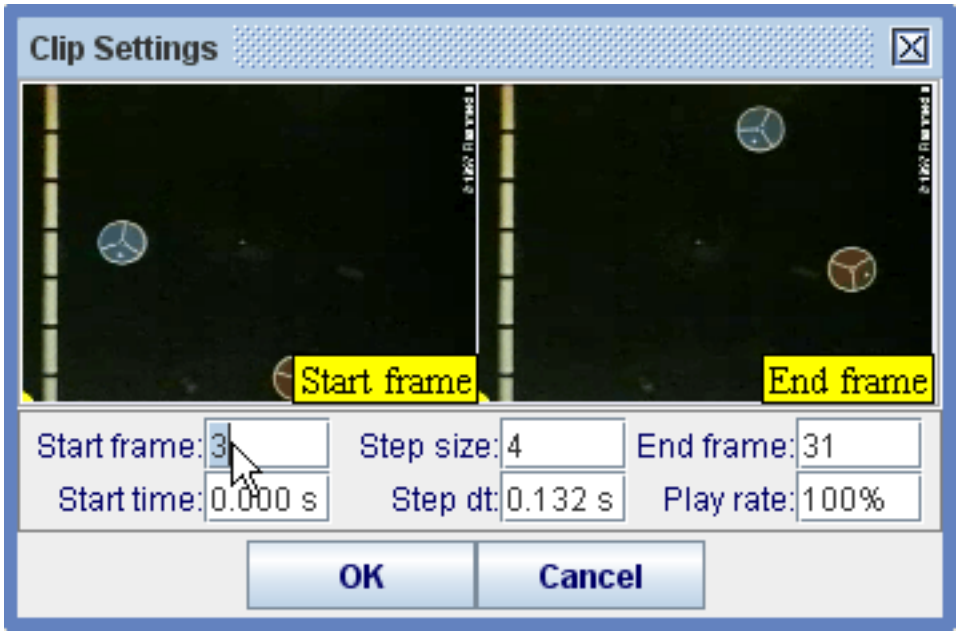
A **video clip** is a subset of frames in a video defined by a start frame, step size (number of frames per step), and end frame. The start frame is the frame number of the first step, the step size is the frame increment between successive steps, and the end frame is the frame number of the last step. For example, a clip with start frame 3, step size 2 and end frame 11 would have step numbers 0, 1, 2, 3 and 4 that map to video frame numbers 3, 5, 7, 9 and 11, respectively.

A clip is defined for every video and even for null videos. For single-frame and null videos the clip settings apply to tracks but every step maps to the same video image.

Video clip properties are set in the **clip inspector**. To display the clip inspector, click the inspector button at the right end of the player.




The clip inspector shows thumbnail images of the start and end frames along with the current video clip settings. In addition, there are fields for setting a start time (time assigned to step 0), the time interval dt between steps (important for high-speed or time-lapse videos) and the play rate as a percent of normal playback speed.



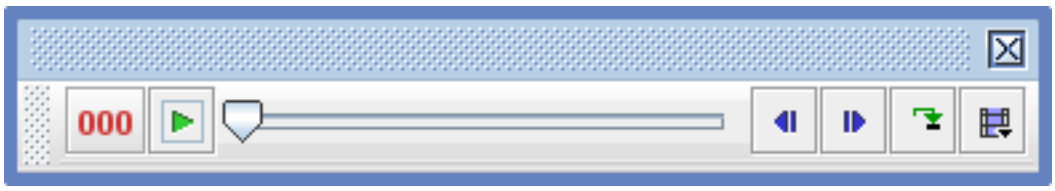

**Note**: since point mass tracks require that you mark their steps for every frame in the clip, it is most efficient to define the clip *before* marking. Clip properties may be changed at any time, but previously unmarked frames will then require marking.

### 7. Using the video player

The player includes (from left to right):

- time/step/frame readout
- play/pause button
- slider
- step forward button
- step back button
- loop button
- clip inspector button.

You can drag the entire player by the left end to convert it to a floating window if desired.

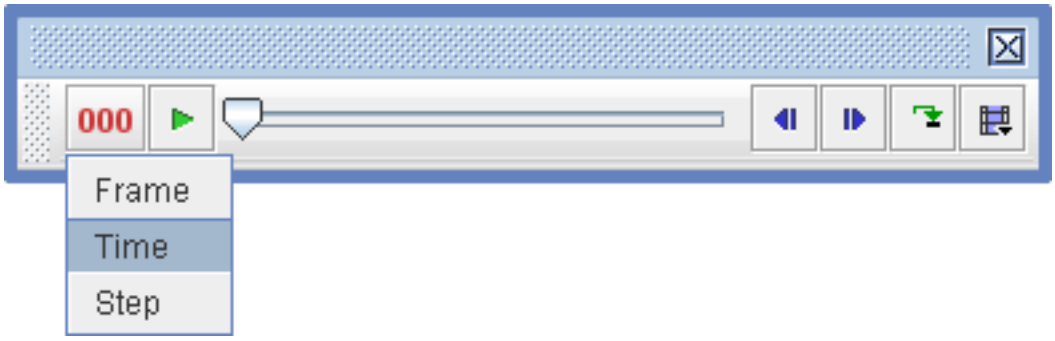



Click the **play/pause** button to play the video at the rate specified in the clip inspector; click again to pause the video. Drag the slider to scan a video or move quickly to a desired frame.

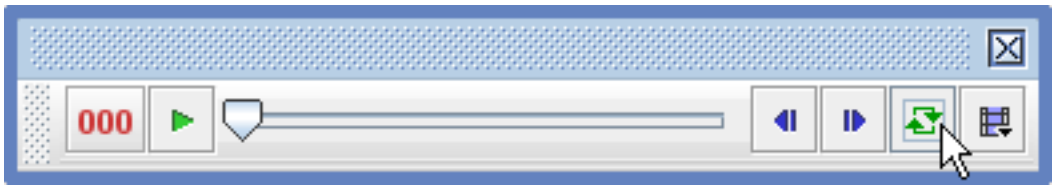
Click the **step** button to step forward one step, or use the keyboard shortcut PageDown. Click

the **back** button to step back one step, or use the keyboard shortcut PageUp.

Click the readout to choose **frame** (number, measured from the beginning of the video), **time** (seconds, measured from the start frame) or **step** (number, measured from the start frame). The readout displays frame number by default.




Click the **loop** button to toggle looping (continuous play).



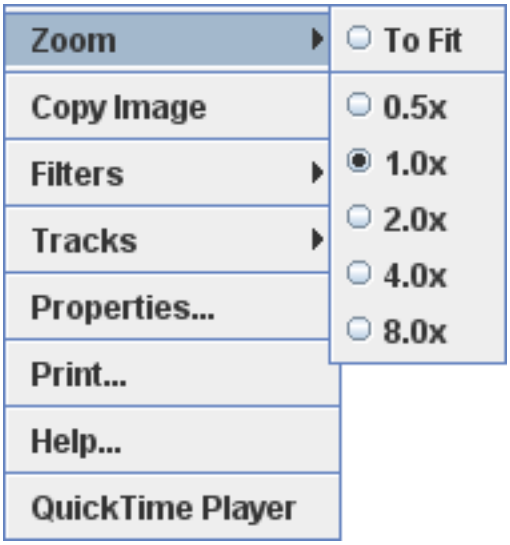

## 8. Magnifying (zooming) a video

Click the **zoom** button on the toolbar (*shortcut*: press the **Z key**) to turn on a zoom tool that can be used to magnify the video image up to 8x. With the zoom tool on, position the zoom cursor over a region of interest and either (a) click the mouse or (b) roll the mouse wheel to zoom. Double-click the mouse to set the zoom level **To Fit** so the video image fits exactly in the main video view.

By default, the tool zooms in (mouse cursor and button display the zoom-in icon). Hold down the **Alt key** to zoom out (mouse cursor and button display the zoom-out icon).

Zoom button with zoom off, zoom-in and zoom-out icons

Another zoom option is to right-click the video and choose the desired zoom level from the popup menu as shown below.




### 9. Video filters

Video filters allow you to modify the video image. See video filters for complete filter descriptions.

### 10. Hiding and closing a video

Uncheck the **Video|Visible** menu item to hide the video image and display the tracks on a white background. Choose **Video|Close** to remove the video permanently.

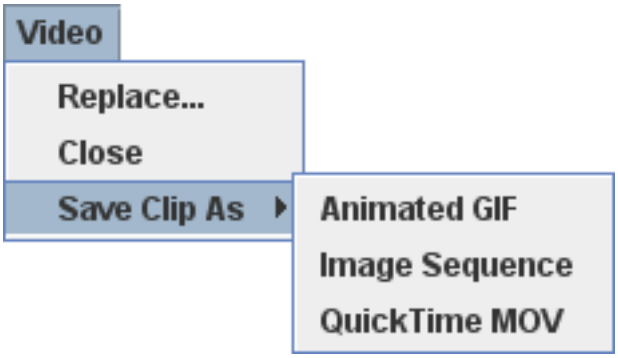
**Note:** when removing or replacing a video, a new video clip is created. This may result in some tracks having existing steps that are no longer included or unmarked steps that are newly included in the clip. If this happens, correct the problem by resetting the start frame, step size and step count for the new clip.

### 11. Saving a video clip as a file

Tracker can save the current video clip, including filters, as a new QuickTime movie, animated gif or image sequence. The new video file(s) will have the same dimensions as the current video.

**Note:** QuickTime movie file sizes can be large since they are not currently compressed! Animated gif files are always compressed, but have only 256 colors.

To save a video clip, select the desired **Video/Save Clip As...** menu choice and use the file chooser to save the file.

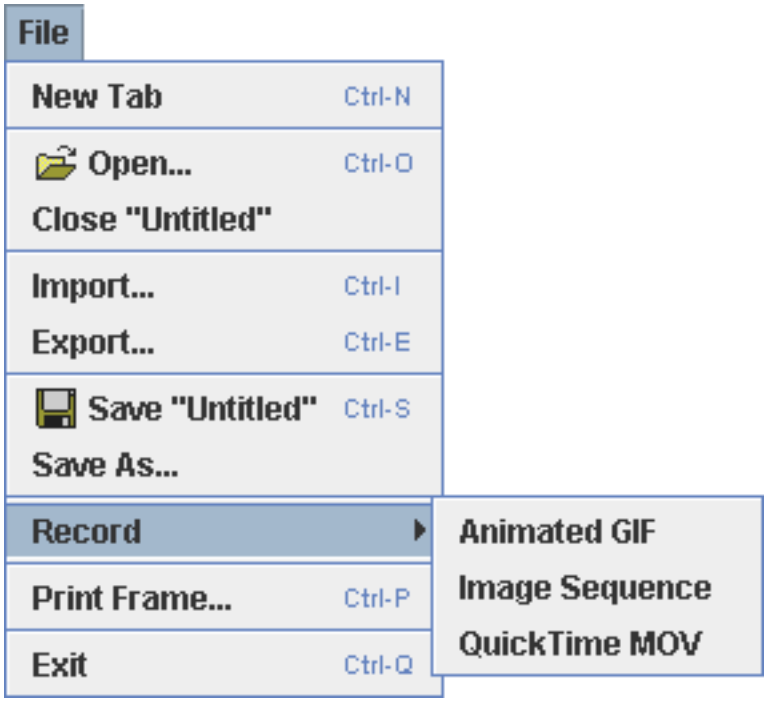


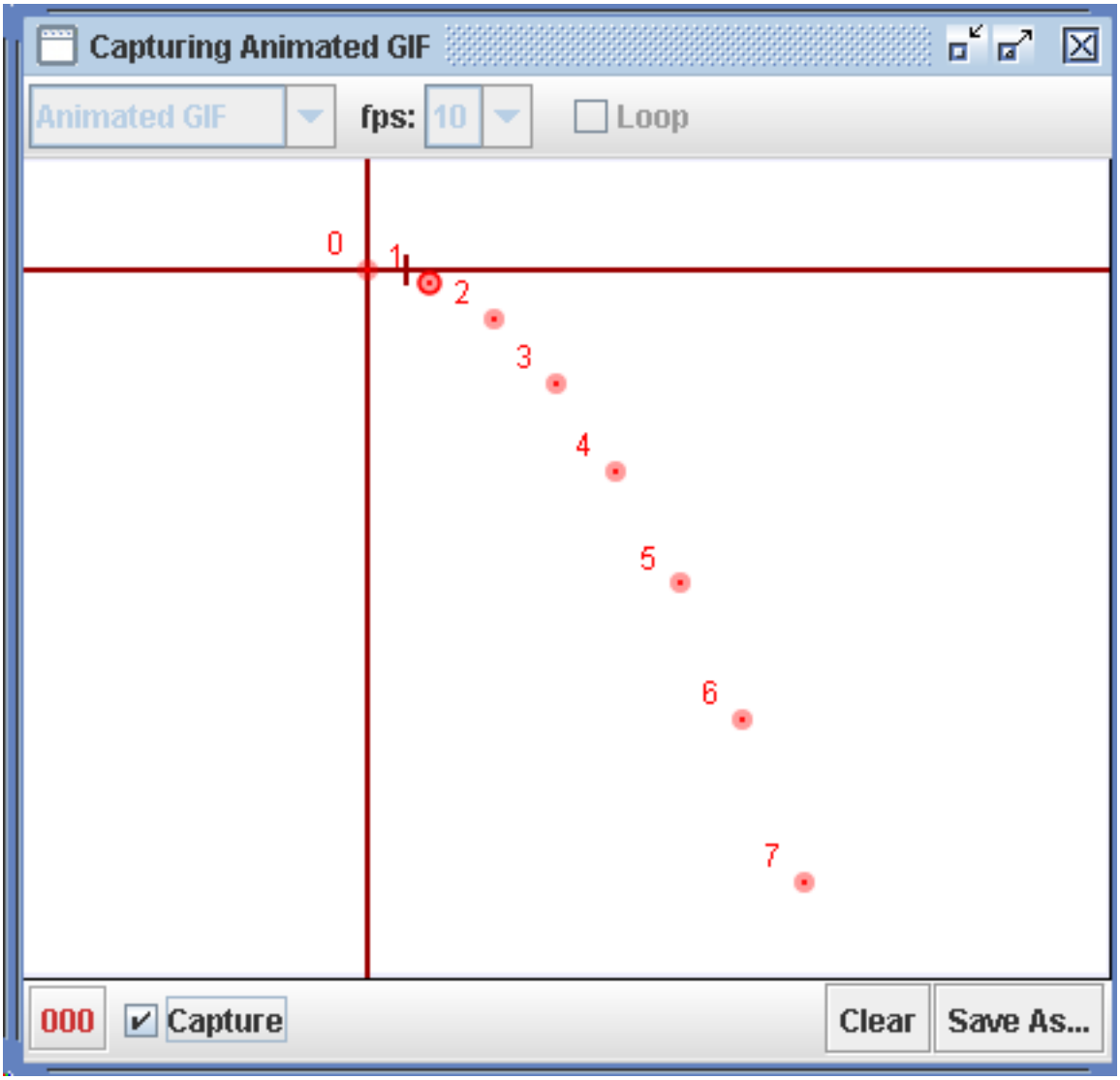

## 12. Recording a video of the main view

Tracker can record any or all frames in the main view (video with filters, zoom level and visible track overlays) as a QuickTime movie, animated gif or image sequence. The recording will have the dimensions of, and record the image within, the current viewport in the main video view.

**Note:** QuickTime movie file sizes can be large since they are not currently compressed! Animated gif files are always compressed, but have only 256 colors.

To record a video, select the **File/Record** menu item. This will bring up the **Video Capture Tool** which allows you to control the frame capture process and preview the video before saving it.






**Note**: the video dimensions are those of the main view. To produce a smaller video, shrink the main view window and set the zoom level "To Fit" before starting the recording process. Any extra white space around the video image will be included in the recorded image (i.e., what you see is what you get!).

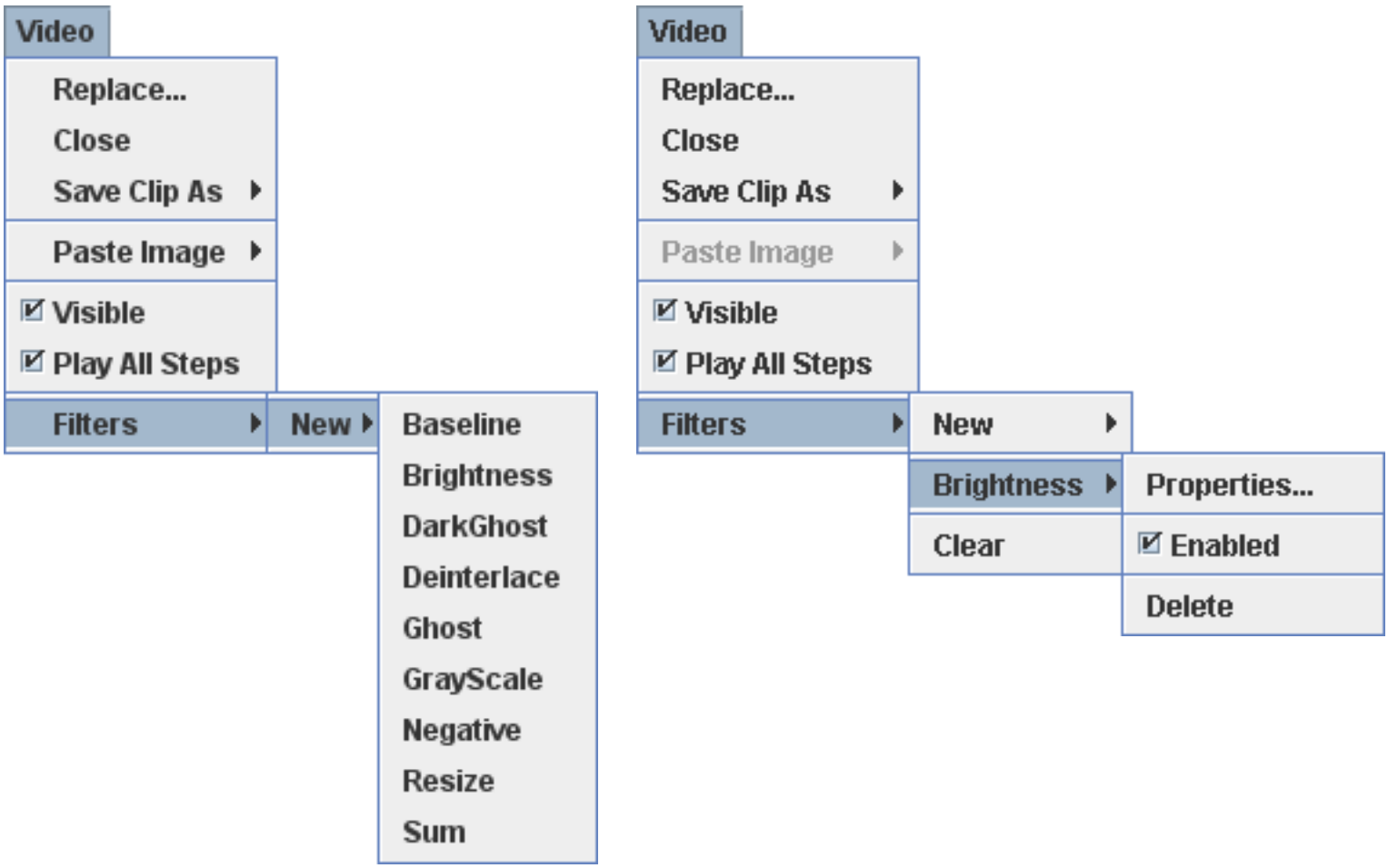
# Video Filters

Video filters allow you to modify the video image for special effects or to improve the quality of data obtained from tracks. Tracker's filters fall into four general categories:

1. Image enhancement: brightness/contrast, deinterlace
2. Special effects: ghost, dark ghost, greyscale, negative
3. Noise reduction: baseline, sum/average
4. Distortion correction: resize

## 1. Applying filters to a video

Create a new filter with the **Video|Filters|New** menu. Multiple filters are applied in the order in which they are created and listed in the **Video|Filters** menu. Existing filters can be temporarily disabled or permanently deleted. Choose **Video|Filters|Clear** to delete all filters.

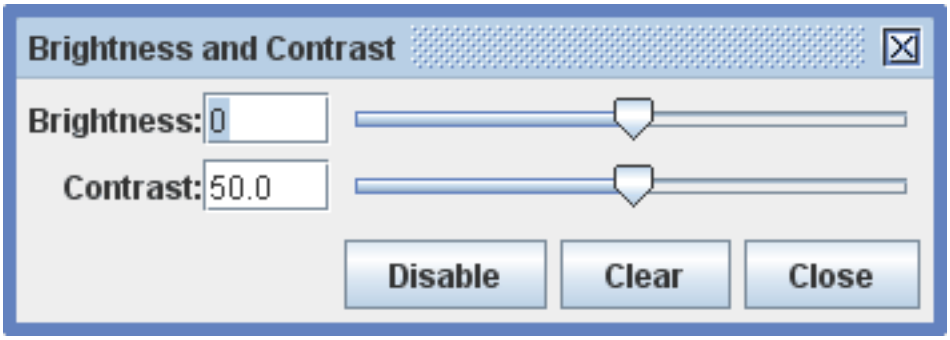



## 2. Setting a filter's properties

Most filters have a properties dialog that enables the user to set filter parameters. The dialog pops up when the filter is created and remains accessible from the **Video/Filters** menu. Every dialog has a **Disable** button that temporarily disables the filter so it has no effect.

### 3. Brightness/contrast filter

The **brightness** filter has adjustments for both brightness (range -128 to +128) and contrast (range 0-100). Changes in brightness affect the RGB components of all pixels equally until minimum (0) or maximum (255) values are reached.




To set a value, use the slider or enter it directly in a field. The **Clear** button resets the brightness and contrast to their default values.

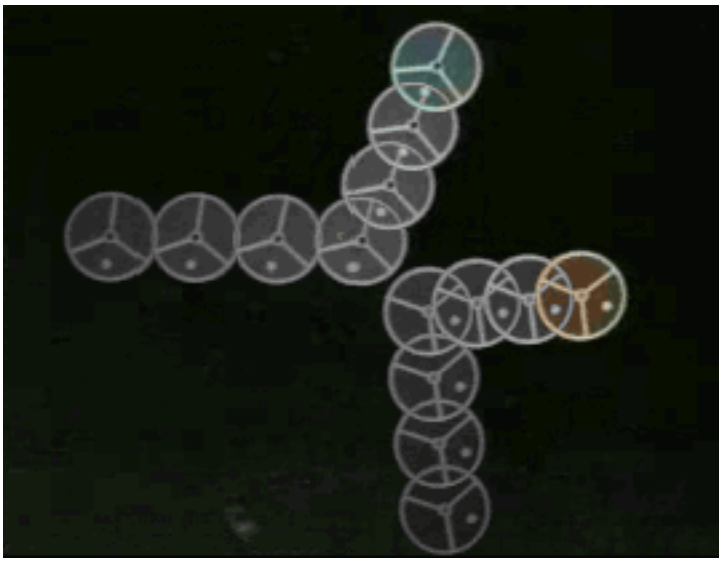
### 4. Deinterlace filter

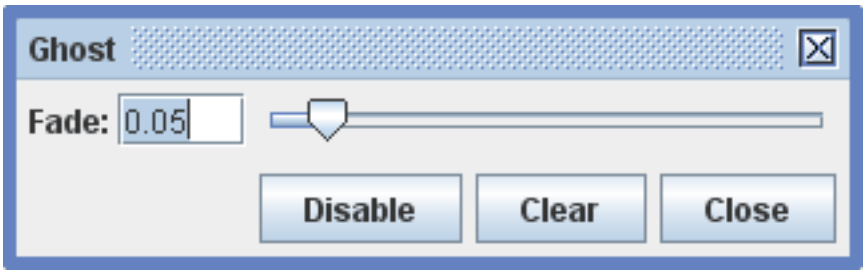
The **deinterlace** filter is used to eliminate double images that appear in interlaced videos.


Each frame of a 30 fps interlaced video consists of two fields, odd and even, that are captured 1/60 s apart. Each field contains a complete image with half the vertical resolution of the frame. When played on an interlaced TV the fields are displayed sequentially so the separate images result in smoother motion, but when viewed one frame at a time in Tracker the fields are combined, resulting in a double image. The interlace filter corrects the problem by displaying only one of the fields. Note that this also reduces the vertical resolution.

### 5. Ghost filter

The **ghost** filter leaves a trail of fading ghost images of a moving bright object against a dark background. The effect is produced only when the video is played or stepped. The "live" motion diagram that results can be a very effective tool for learning the concepts of position, velocity and acceleration.






To set the rate at which the ghosts fade, use the slider or enter a value directly in the field. The **Clear** button clears all current ghosts from the image.

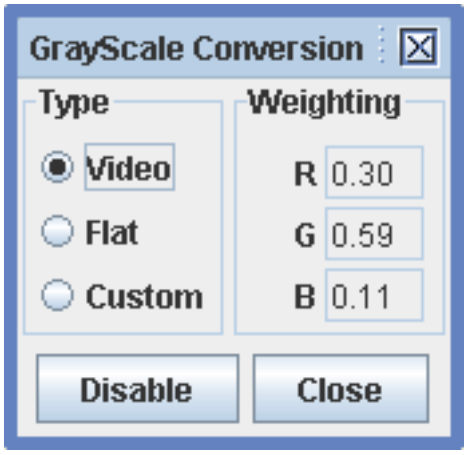
### 6. Dark ghost filter

The **dark ghost** filter is like the ghost filter above except that it works with moving dark object against a bright background.

### 7. Grayscale filter

The **grayscale** filter converts a color image into a grayscale image. This is useful for extracting brightness data (gray level 0-255) from RGB components. The conversion uses separate RGB weighting factors in the equation:

gray level = (R*weightR + G*weightG + B*weightB) / (weightR + weightG + weightB)




The filter includes standard weighting factors for video and flat-response images but also allows advanced users to define custom weighting factors.

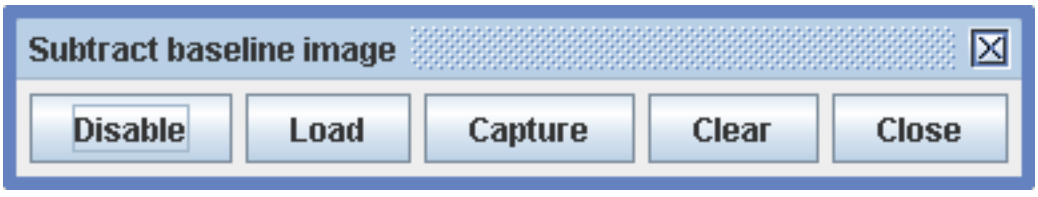
### 8. Negative filter

The **negative** filter produces a negative image in which each pixel RGB component x becomes 255-x. This is often useful when printing, particularly when combined with a brightness filter, since dark features against a light background are often clearer (and use less ink!) than light features against a dark background.

There is no properties dialog for the negative filter since there is nothing to adjust.

### 9. Baseline filter

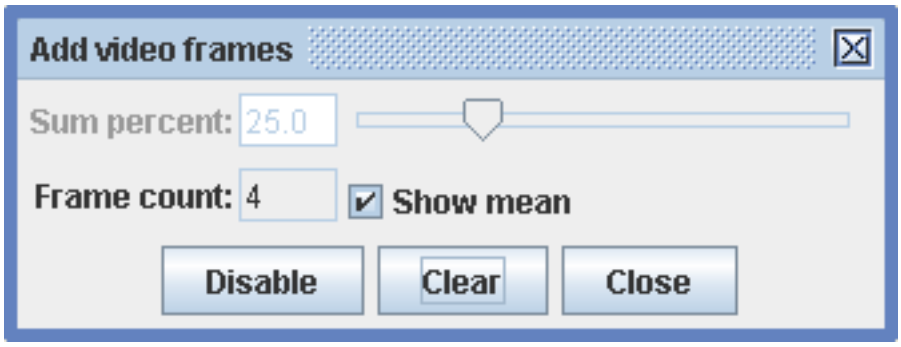
The **baseline** filter subtracts a "baseline" image from the video images. If the baseline is the (unchanging) background in the video scene, the background is eliminated, leaving black. This is particularly useful when using a line profile or rgb region to measure RGB values in spectral or other images contaminated with unwanted background light--simply capture an image or video of the background light alone (i.e., with the spectral light source turned off) and use it as the baseline.




To set a baseline image, use the **Load** button to load the image from a file or the **Capture** button to capture the video image currently displayed in tracker. The **Clear** button removes the current baseline image.

### 10. Sum/average filter

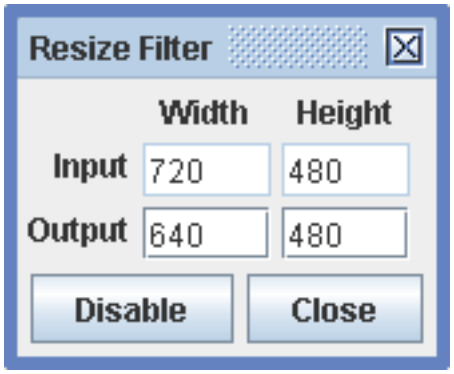
The **sum** filter adds video images together (separate RGB components) and displays a fraction of the result. When the **Show mean** checkbox is selected, the fraction is automatically adjusted to display the mean RGB values of the images. This can significantly reduce the RGB noise in videos of spectra or other optical phonomena.




When the Show mean checkbox is not selected, use the slider or enter a percent directly in the field. The **Clear** button resets the sum to the current image.

### 11. Resize filter

The **resize** filter changes the dimensions of the video image. This is particularly useful for correcting the distortions that result when the non-square pixels in DV-formatted videos are displayed and analyzed in Tracker's square pixel environment. This causes the image to be stretched horizontally. The stretch can be corrected by resizing the image from 720x480 to 640x480 as shown.



# Tracks

A track represents a video feature that evolves over time. All interactive elements in Tracker, including the axes and tape measure, are tracks.

The position or shape of the feature in a single video frame is known as a **Step**; thus, a track is a series of steps. Each step can be selected and manipulated with the mouse or keyboard. Some steps, like those for point mass tracks, have only a single moveable point, but others, like vector steps, have two end points plus a center handle point.

There are nine different types of user-defined tracks. For detailed information on a specific type, see its corresponding help topic: point mass, center of mass, vector, vector sum, offset origin, calibration point pair, line profile, rgb region, analytic particle model or dynamic particle model.

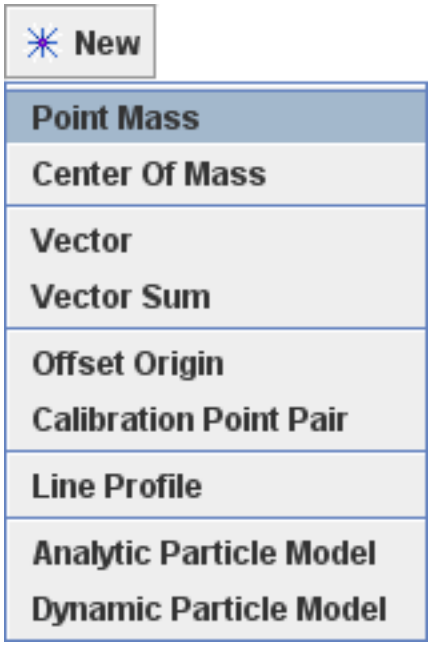
### 1. Track control

The **track control** lets you easily create new tracks and control most display properties of existing tracks. Click the Track Control button on the toolbar to show the track control.

The track control includes (from left to right):

- **New** button lets you create new tracks.
- **Trails** button shows and hides all trails.
- **Labels** button shows and hides all labels.
- **Positions** button shows and hides all point mass positions.
- **Velocities** button shows and hides all point mass velocity vectors.
- **Accelerations** button shows and hides all point mass acceleration vectors.
- **Stretch** button stretches all vectors.
- **Dynamics** button multiplies all motion vectors by mass.


### 2. Creating a track

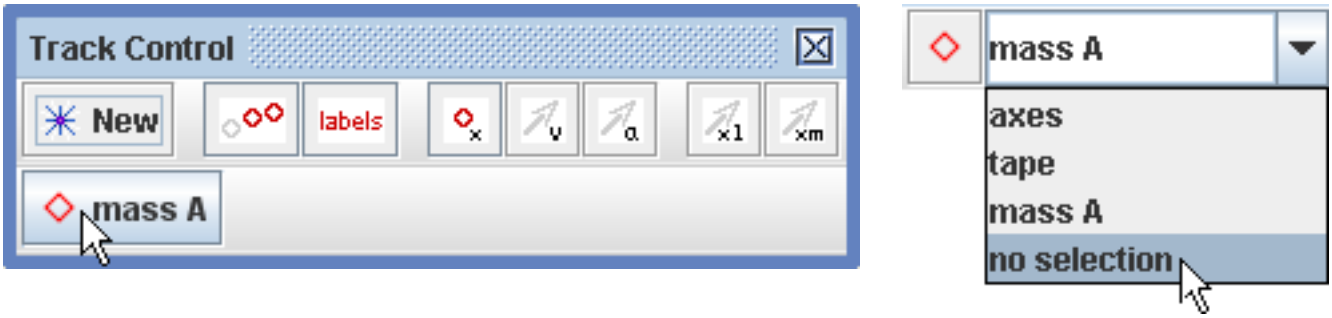



Create a new track by selecting the desired track type from the **New** button menu on the track control or the **Track|New** menu on the menu bar. A newly created track is automatically selected for marking.

### 3. Selecting a track

Tracks can be marked or edited only when they are selected. The name, color and footprint of the currently selected track are displayed on the toolbar.

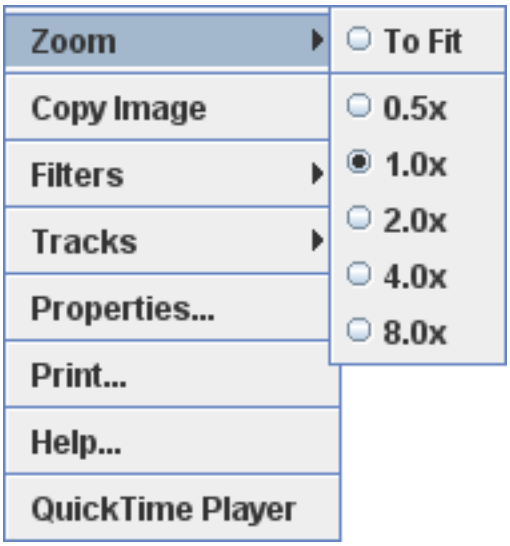

To select a track, click its button on the track control or select its name from the dropdown list on the toolbar. Double-click the background (video) or choose "no selection" to deselect the currently selected track.




### 4. Marking a track

Marking a track refers to the process of defining its position on each frame in the video clip using the **crosshair cursor** (shown above at twice actual size). To mark, hold down the **shift key** and click the mouse on the feature of interest as the video automatically steps through the video clip. Don't skip frames--if you do, velocities and accelerations cannot be determined.

Marking is done in the main video view. For more accurate marking, magnify the image up to 8x using the zoom tool or by right-clicking on the video and choosing the desired zoom level.




There is some variability in marking requirements. Vector and line profile tracks require dragging rather than clicking. Point mass and vector tracks expect every step to be marked, but offset origin, calibration point pair, line profile and rgb region tracks require marking only a single frame. Center of mass, vector sum and particle model tracks are marked automatically.

In rare circumstances you may wish to control the marking process in more detail. You can mark a track without holding down the shift key by checking the **Mark By Default** option in the tracks menu. And if you prefer that the video not automatically step forward while marking you can uncheck the **Autostep** option.

### 5. Duplicating or importing a track

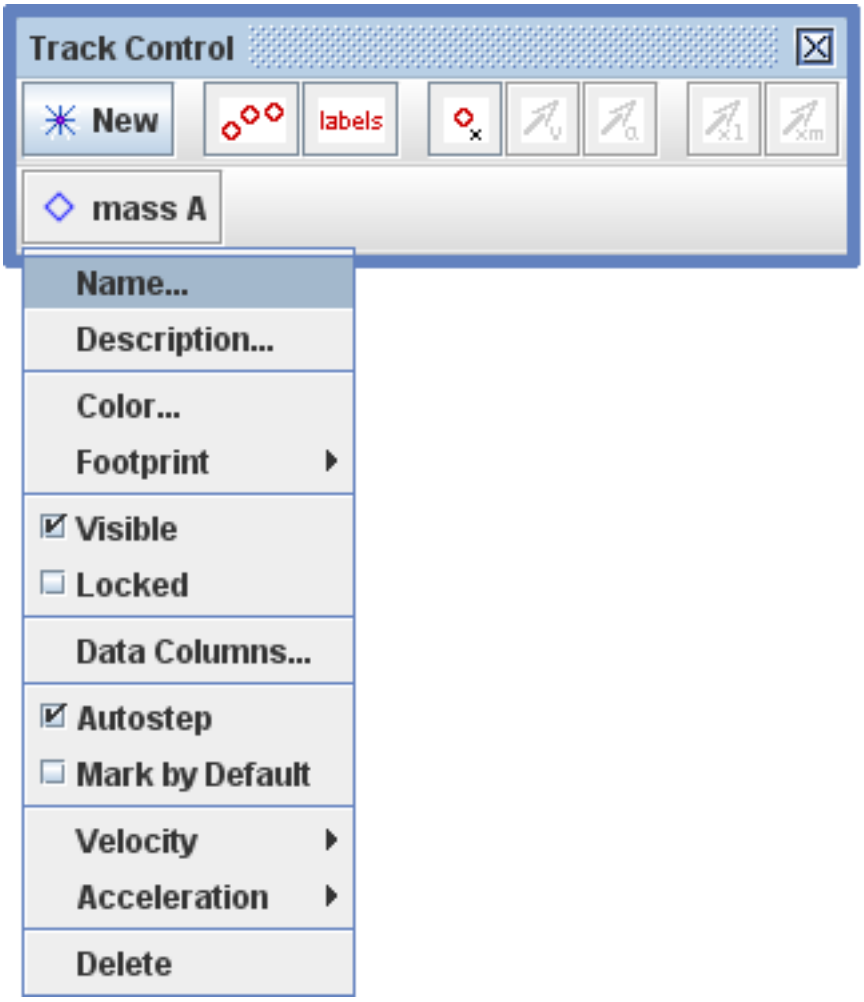
Make a duplicate copy of an existing track by selecting the track and copying it to the clipboard using the **Edit|Copy** menu item, then pasting using the **Edit|Paste** item. You can paste into the same tab or a different one. When pasting into the same tab, you will be prompted to rename the track since tracks must have unique names.

Since the tape measure and axes are tracks, they can also be copied. When pasted, they

replace the existing tape or axes in the tab. When no track is selected, the entire tracker panel (video clip, coordinate system and tracks) is copied.

Tracks can also be imported directly from saved tracker files into an open tab using the **File| Import** menu item. For more information see tracker files.

### 6. Track menus

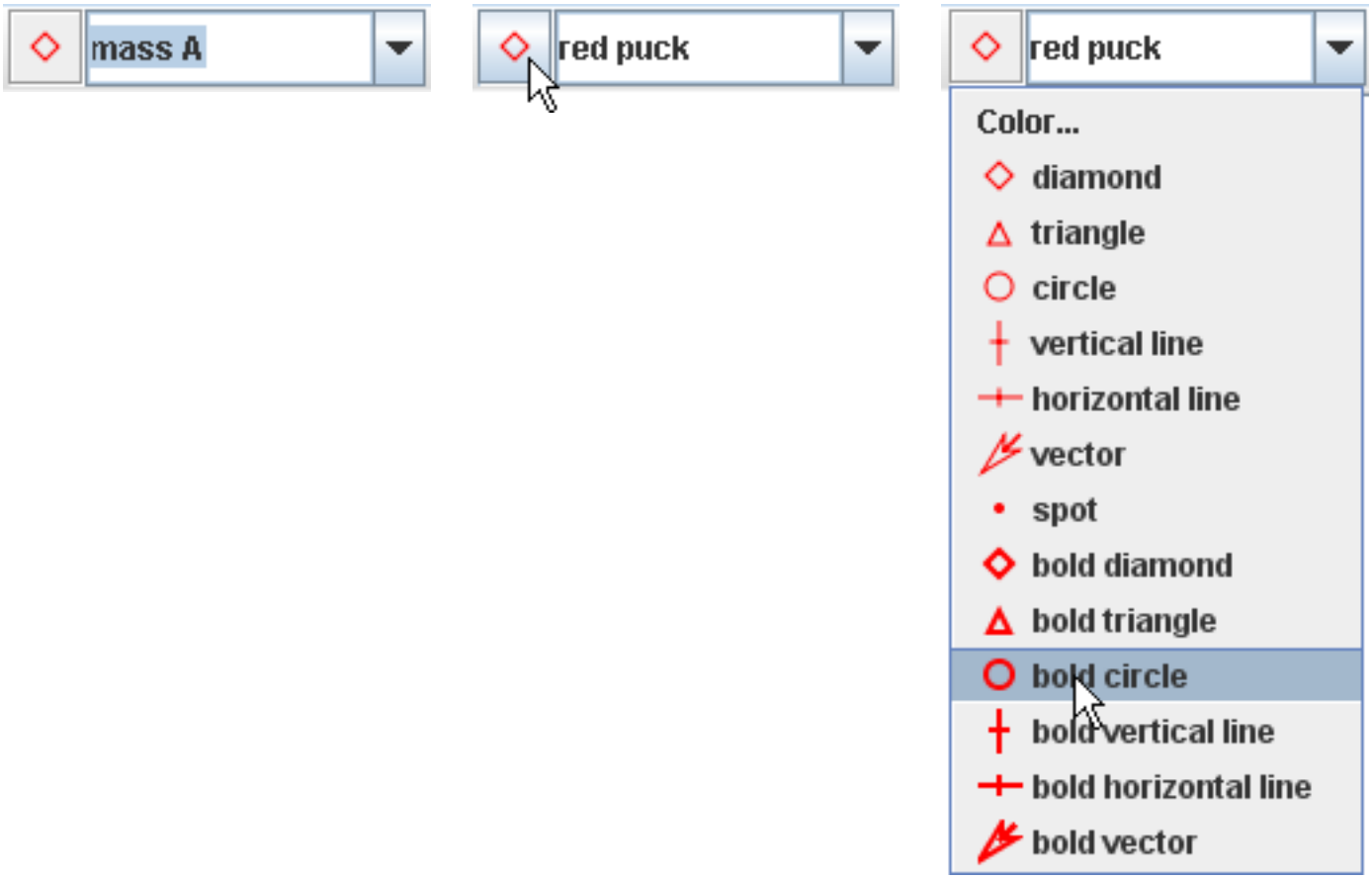



Every track has a menu with items for setting its properties. Track menus can be accessed either from the **Tracks** menu on the menu bar, by right-clicking the main video view, or by clicking the track's button on the track control.

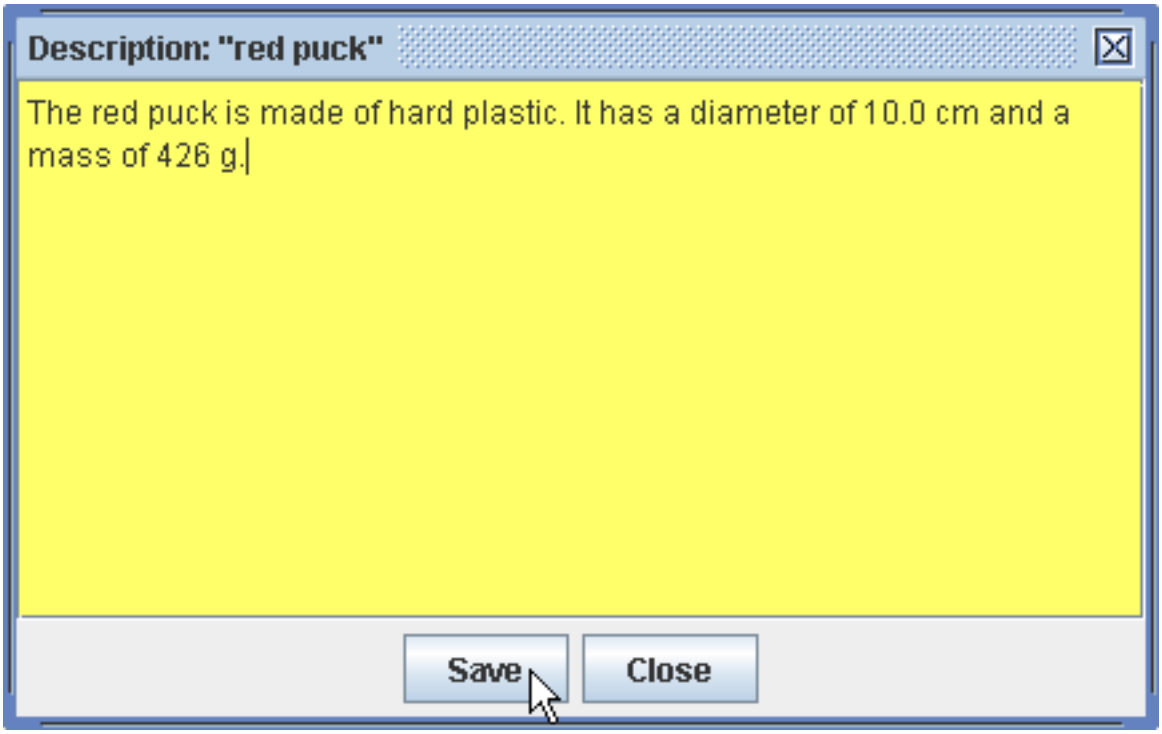
### 7. Customizing and documenting a track

Every track is identified by its **name**, **color**, **footprint** (visible shape) and **description**. Newly created tracks are assigned default values for the first three properties that depend on the type of track. For example, a point mass might initially be named ”mass A” and be drawn as a red diamond.


A track's name, footprint and color are displayed on the toolbar when the track is selected. To change the default values, select the track and enter a new name in the editable name field or click the footprint button and choose a new footprint or color. These properties can also be set from the track menu.



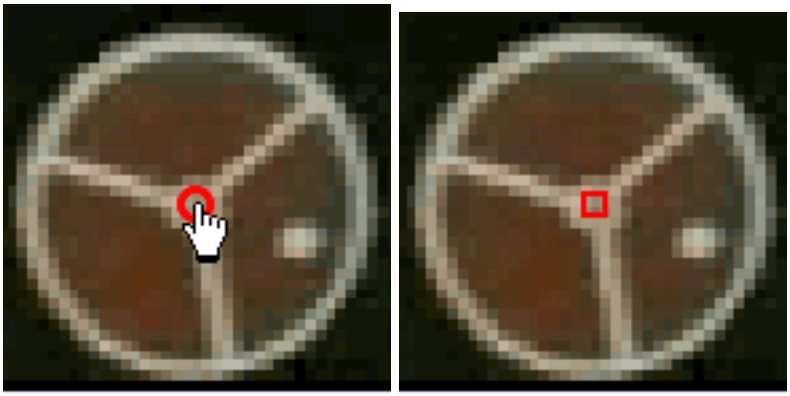

To enter a description for a track, open the **description window** by clicking the  button at the right end of the toolbar. As you enter the description, the field turns yellow to indicate the changes have not been saved. To save the description, click the Save button.




## 8. Controlling visibility

Hide a track by turning off the **Visible** property in the track's menu. Or use the **trails**, **labels**, **positions**, **velocities** and **accelerations** buttons on the track control to toggle the visibility of these features on all tracks.


## 9. Selecting and identifying points



To select a point, move the mouse cursor over it in the main video view. The cursor will become a hand pointer and the point will be identified in the bottom right message box. Click to

select it. **Note:** To select a point while marking, release the shift key.

When a point is selected, its track is selected, its editable properties (position, etc) are displayed on the toolbar, and it is identified with a square selection icon.

### 10. Editing a step

To edit a step, select and drag one of its points. A selected point can also be nudged one pixel at a time with the arrow keys on the keyboard. Holding down the shift key increases the nudge distance.

Many tracks also provide input fields on the toolbar for setting positions or other properties of the selected step.

### 11. Deleting

Delete a single step by selecting it and hitting the **delete key** on the keyboard. Delete an entire track by name or clear all tracks in the **Edit** menu.


A track can also be deleted by choosing the **Delete** item in its track menu.

### 12. Locking a track

Locking a track prevents any changes to its steps. Lock a track by turning on the **Locked** property in the track's menu.

# Coordinate System

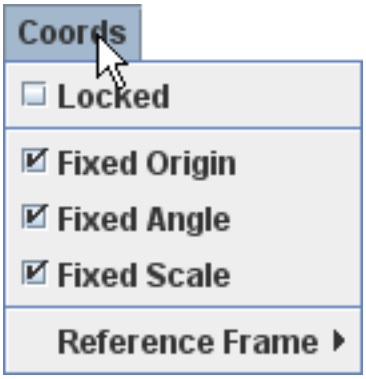
When you mark a point in Tracker's main video view, you are defining its **image position**. Image positions are measured in pixel units relative to the top left corner of the video image. In a 320 x 240 pixel image the upper left corner is at image position (0.0, 0.0) and the lower right is at (320.0, 240.0).

Since a video image is a camera view of the real world, a physical object within that image also has **world coordinates**. World coordinates are measured in scaled world units (e.g., meters) relative to a specified reference frame. The origin of the reference frame may be anywhere on or off the image.

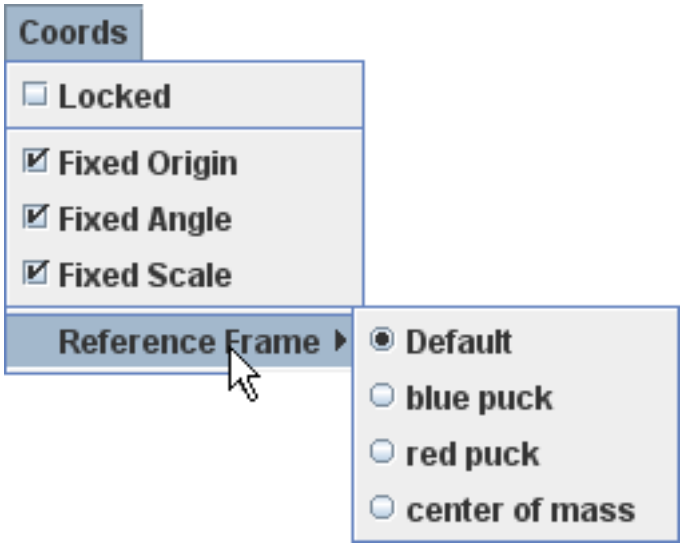
The **coordinate system** is a set of transformations used to convert image positions into world coordinates. The coordinate system defines for each frame of the video:

- **scale** (image units per world unit)
- **origin** (image position of the reference frame origin)
- **angle** (counterclockwise angle from the image x-axis to the world x-axis.

### 1. Setting coordinate system properties




By default, the scale, origin and angle of the coordinate system are **fixed**--that is, they do not vary from frame to frame. However, any or all of these may be allowed to vary by turning off the appropriate Fixed property in the **Coords** menu on the menu bar. When the scale, origin and angle is not fixed, it must be set for every step in the video clip; when it is fixed, setting it once is sufficient.




The positions and properties of the origin that you set are those of the **default reference frame**. The **Coords/Reference Frame** menu enables you to select other reference frames in which the origin moves along with a point mass, center of mass or particle model track. Center of mass reference frames are particularly useful when studying collisions.

### 2. Setting the scale (calibrating)

Set the scale using the **tape measure** or **calibration points**.

### 3. Setting the origin

Set the position of the origin using the **axes**, an **offset origin** or **calibration points**.

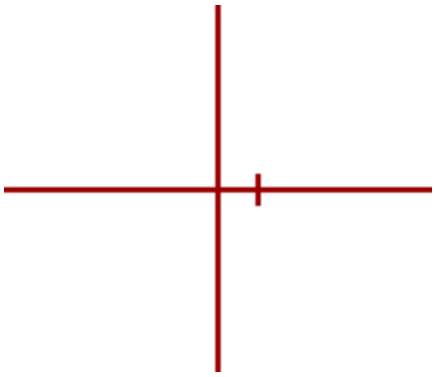
### 4. Setting the angle

Set the angle of the x-axis using the **axes**, **tape measure** or **calibration points**.

### 5. Locking the coordinate system

Locking the coordinate system prevents any changes to the scale, origin and angle. Lock it by turning on the **Locked** property in the **Coords** menu.

# Coordinate Axes



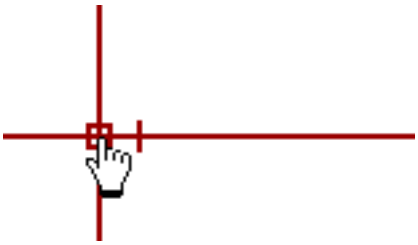
The **coordinate axes** show the location of the origin and direction of the positive x-axis of the coordinate system. The origin is at the intersection of the axes and the positive x-axis is indicated by a tick mark near the origin. The positive y-axis is always 90 degrees counter-clockwise from the positive x-axis.

Since the axes is a track, it has a menu that is accessible in the Tracks menu on the menu bar or by right-clicking the main video view.

### 1. Displaying the axes

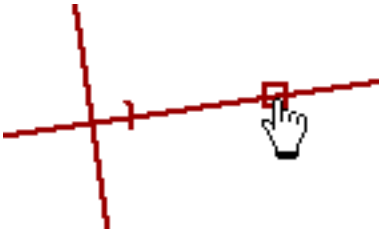
Display the axes by clicking the **axes button**  on the toolbar.

### 2. Moving the default origin



Select and drag or nudge the origin to a desired location in the main video view.

### 3. Setting the angle



Select and drag or nudge the positive x-axis to rotate the axes about the origin. Hold down the shift key to restrict angles to 5 degree increments.


The angle is displayed in the angle field on the toolbar. A desired angle may be entered directly in this field.

### 4. Locking the axes

Locking the axes prevents it from making any changes to the origin or angle. Lock the axes by turning on the **Locked** property in its track menu.

# Tape Measure


The **tape measure** is used to measure distances and angles, to calibrate the video scale, and to correct for tilt in the video image. To display the tape, clicking the tape measure button on the toolbar.

Since a tape measure is a track, it has a menu that is accessible in the Tracks menu on the menu bar or by right-clicking the main video view.

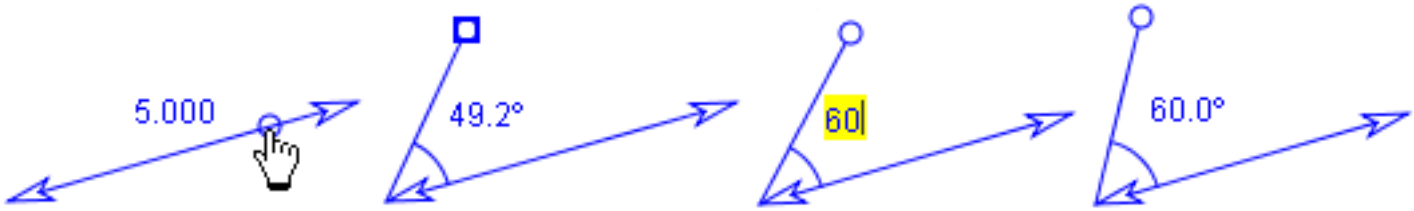
### 1. Measuring distances and angles

You can use the tape to measure both the distance between any two points (tape length) and the angle relative to the +x-axis of a line connecting the points (tape angle) by dragging the ends of the tape. The length is displayed on the **tape readout** and both the length and angle are displayed on the toolbar.


To move the tape without changing its length or angle, drag the middle.

### 2. Measuring angular arcs

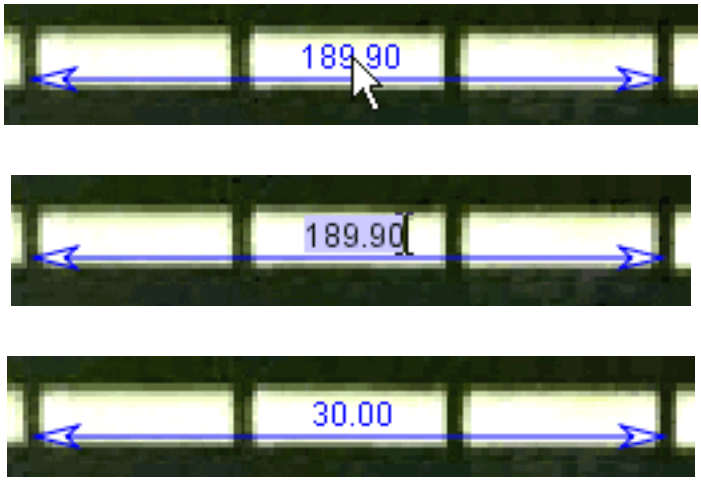
You can use the tape to measure angular arcs using a jackknife-like **arm**. To select the arm, move the cursor along the tape to a point about midway between the center and the end until a small circle is displayed. Click and drag the circle to open the arm. The tape readout and the angle field on the toolbar will display the angular arc between the tape and arm. Set the arc to a specific angle by clicking either the angle field on the toolbar or the tape readout itself and entering the desired angle in degrees.




To close the arm, drag the circle toward the hinge end of the tape until it disappears.

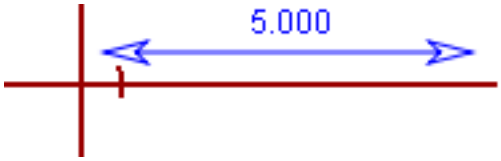
### 3. Setting the scale (calibrating the video)

To calibrate a video image, drag the ends of the tape to positions that are a known world distance apart (for example, the ends of a meter stick or other object with known dimensions in the video image). Then click either the length field on the toolbar or the **tape readout** itself and enter the known distance. For example, in the figure below the scale is set in cm units using a white meter stick with black stripes every 10 cm.




### 4. Setting the angle (correcting tilt in the video image)

The tape angle can be used to correct for camera tilt when shooting a video. Drag the ends of the tape so that it is parallel to a video feature that is horizontal or at some other known angle. Then enter the known angle into the tape angle field on the toolbar. This will rotate the coordinate system so the +x-axis is correctly oriented to horizontal in the video image. Note that it does NOT rotate the tape itself.



### 5. Unfixing the tape

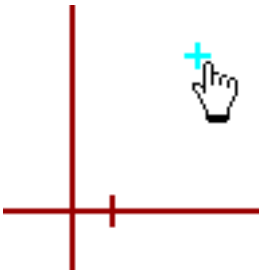
By default, the tape measure is **fixed**--that is, its end positions do not vary from frame to frame. Uncheck the **Fixed** checkbox in its track menu to allow the end positions to vary.

Note that fixing the tape measure is not the same as fixing the scale of the coordinate system!

### 6. Locking the tape measure

Locking the tape measure prevents it from making any changes to the scale. Lock the tape by turning on the **Locked** property in its track menu.

# Offset Origin



An **offset origin** track has fixed assigned world coordinates that, for a given coordinate system, uniquely determine its image position at each step in a video clip. When an offset origin is dragged in the main video view, the origin of the coordinate system moves with it in order to maintain the offset origin's assigned world coordinates. This makes it useful for remotely setting the position of the origin, particularly when the origin is outside the video image.

### 1. Marking an offset origin

After creating an offset origin, click on a feature in the video image that has known world coordinates. Marking a single frame is all that's required. The offset origin is initially assigned the current world coordinates of the clicked image feature. The x- and y-components of the world coordinates are displayed on the toolbar when the offset origin is selected.

### 2. Changing the world coordinates (moves the origin)


Select the offset origin and enter the desired values in the x and y fields on the toolbar to change its world coordinates.

**Note:** changing the world coordinates of an offset origin moves the coordinate system origin so that the offset origin's image position remains unchanged.

### 3. Moving the offset origin (moves the origin)

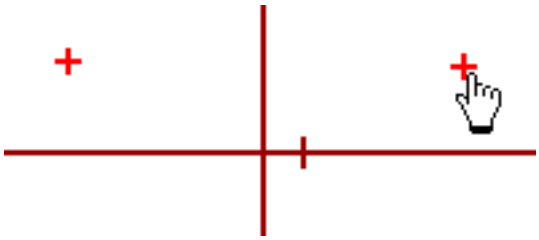
Select and drag or nudge the offset origin to a desired location in the main video view.

**Note:** moving an offset origin moves the actual coordinate system origin with it so that the offset origin's world coordinates remain unchanged.

## 4. Locking the offset origin

Locking the offset origin prevents it from making any changes to the origin. Lock the offset origin by turning on the **Locked** property in its track menu.

# Calibration Point Pair



A **calibration point pair** track is similar to an offset origin except that it defines **two points** with fixed assigned world coordinates. World coordinates may consist of an x-component, y-component or both. For a given coordinate system, these world coordinates uniquely determine the scale, origin, and/or angle at each step. When either of the calibration points is dragged in the main video view, the properties of the coordinate system are modified in order to maintain the assigned world coordinates. Calibration points are the easiest way to set coordinate system properties when two features with known world coordinates are visible in all video frames.

**Note:** Calibration points are very powerful. It is strongly recommended to "play" with some calibration points while both the axes and tape measure are visible to see how they work together to control the coordinate system.

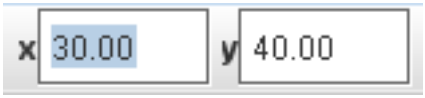
### 1. Marking calibration points

After creating a calibration points track, click on a feature in the video image that has known world coordinates. Then click on a second feature in the same image. Marking a single frame is all that's required. The calibration points are initially assigned the current world coordinates of the clicked image features.

### 2. Axis options


The "Axes" spinner determines whether the calibration points control both x- and y-axes or only a single axis. When a single axis is selected (here "X only"), moving a calibration point along that axis changes the scale and translates the origin without changing the angle. Moving a calibration point perpendicular to the selected axis has no effect. This is very useful when one axis is unknown or unimportant--for example, with vertical motion studies or optical spectrum analysis using a line profile track.

### 3. Changing the world coordinates of a calibration point




The world coordinates of either calibration point are displayed on the toolbar when it is selected. A point that is "X Only" will display only the x-component.

Enter the desired values in the x and/or y fields on the toolbar to change the world coordinates of the selected calibration point.

**Note:** Changing the world coordinates changes the coordinate system scale, origin and/or angle so that the image positions of both points remain unchanged.

### 4. Moving a calibration point

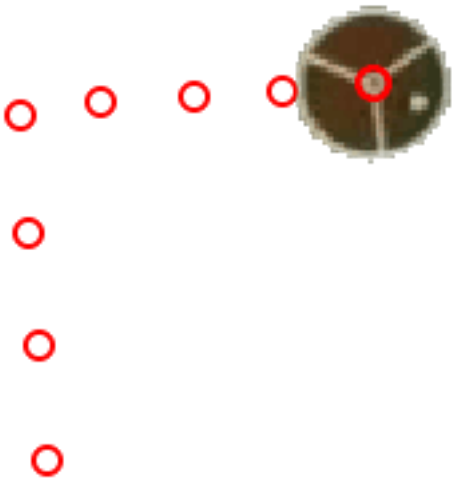
Select and drag or nudge either calibration point to a desired location in the main video view.

**Note:** Moving a calibration point changes the coordinate system scale, origin and/or angle so that the world coordinates of both points and the image position of the unselected point remain unchanged.

### 5. Locking the calibration points

Locking the calibration points track prevents it from making any changes to the coordinate system. Lock the calibration points track by turning on the **Locked** property in its track menu.

# Point Mass



A **point mass** track represents a mass moving as a point-like object. It is the most fundamental model of a moving inertial object. Point masses are the building blocks with which more complex and realistic models of physical systems are constructed in classical physics.

### 1. Marking and editing the steps

Click once to mark each step.

A point mass marks by default (i.e. immediately upon creation) and autoadvances the video for easy and fast marking. It is wise to set the video clip first so you don't mark unnecessary video frames. Zoom in for accuracy.

Point masses have visible trails by default. Hide the trails if desired using the trails button on the track control.

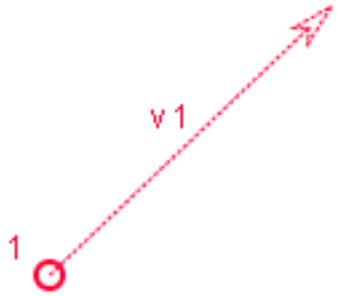
To edit a marked step, select it and drag or use the arrow keys on the keyboard to nudge it one pixel at a time. Very fine control is possible at a high zoom level. You can also enter world coordinates directly in the toolbar fields to assign a known position.


### 2. Setting the mass


A newly created point mass is given a default mass of 1.0 (arbitrary units). Enter a new mass (m >= 0) in the mass field on the toolbar to change it.

### 3. Displaying motion vectors

Toggle the vector visibility for all point masses by clicking the velocity or acceleration button on the track control. The vectors are drawn with dotted lines and are initially **attached** to their positions (i.e. the tail of the velocity vector for step n is at the step n position).




**Note:** Some motion vectors, especially accelerations, may be very short. You can artificially "stretch" them by a factor of 2 or 4 by clicking on the stretch vectors button on the track control.

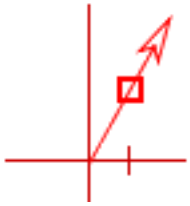

You can change the footprint of a vector by first selecting it, then clicking the footprint button on the toolbar and choosing from the list. The ”big arrow” footprint is particularly useful for large classroom presentations.

### 4. Analyzing motion vectors

Select a vector by clicking near its center to display its components on the toolbar.


Drag a vector to detach it from its position and move it around. Drop the vector with its tail near its position to reattach--it will **snap** to the position.

A vector will also snap and attach to the origin when the axes are visible. This is useful for estimating and visualizing its components.



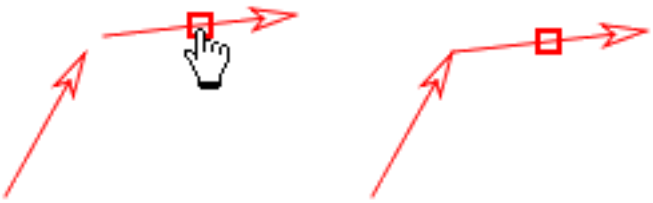
Attach all vectors quickly to the origin or positions with the **Tails to Origin** or **Tails to Position** items in the point mass track menu.

### 5. Displaying momentum and net force vectors


Click the dynamics button on the toolbar to multiply all velocity and acceleration vectors by their mass. This changes them to momentum and net force vectors, respectively.

Tracker always draws momentum and net force vectors with dashed lines to distinguish them from motion vectors (dotted lines) and independent vector tracks (solid lines).

### 6. Linking motion vectors



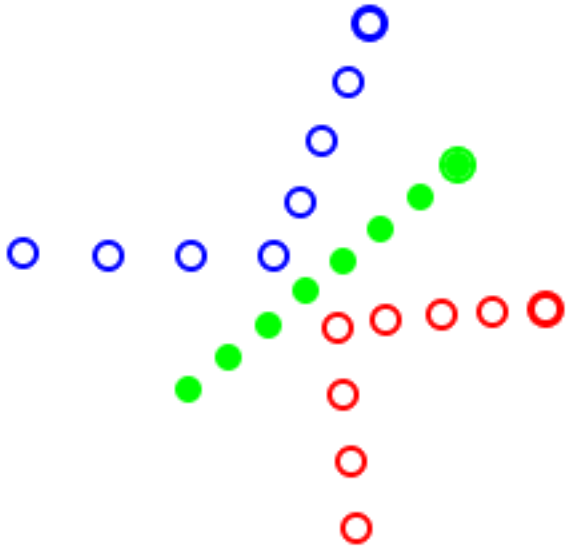
Vectors can be linked tip-to-tail to visually determine their vector sum. To link vectors, drag and drop one with its tail near the tip of the other. The dropped vector will snap to the tip when it

links. You may continue to link additional vectors in the same way to form a chain.

**Note:** Tracker makes no attempt to check whether it is mathematically appropriate or physically meaningful to link a given set of vectors--it simply makes it possible.

When you drag the first vector (i.e. the vector with the unlinked tail) in a chain, the chain moves as a unit and the vectors remain linked. When you drag any vector further up the chain, however, it detaches and "breaks" the chain.

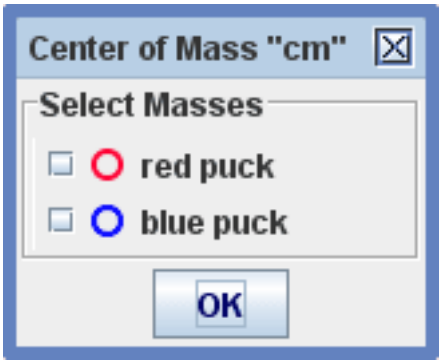
# Center of Mass



A **center of mass** (cm) track represents the center of mass of a collection of point masses. It's mass is not settable, but instead is the sum of its point masses. Similarly, it's steps are not marked but instead are determined by the positions and masses of its point masses. Center of mass footprints are always solid to distinguish them from independent point masses.

A cm is itself a point mass with the usual motion vectors. See point mass for additional information.

### 1. Adding point masses to a cm




Select the point masses to include in a cm by checking them in the dialog shown. The dialog is displayed when the center of mass is initially created or by choosing **Select Masses** in the cm's track menu.

# Vector

A **vector** track can represent any vector but is commonly used as a force in a force diagram. Since it is a track, the force may vary with time (i.e. with step number).

**Note:** Many introductory physics topics involve constant forces or forces at a single instant of time. By defining a video clip with a single frame and using vector and vector sum tracks, these situations can be modeled and analyzed visually using Tracker. The background video can be a single frame of a movie, a still image or a blank white screen.

### 1. Marking the steps

Click the crosshair cursor at the tail and drag the tip with the pointer hand to mark a vector step. Vectors are drawn with solid lines to distinguish them from motion vectors.

Vectors have visible trails by default. Hide the trails if desired using the trails button on the track control.

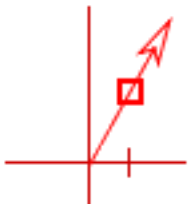
### 2. Editing a vector

Select any point on a vector to display its components on the toolbar. Enter a desired value in the appropriate field or select and drag/nudge the tip to change the components.


Drag or nudge the center of a vector to move it without changing its components.

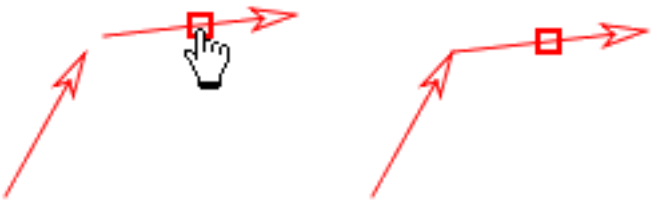
### 3. Analyzing vectors

When the axes are visible you can drop a vector with its tail near the origin and it will **snap** and attach to the origin. This is useful for estimating and visualizing its components.



Attach all vectors quickly to the origin with the **Tails to Origin** menu item in the vector track menu.

### 4. Linking vectors (see also vector sum)

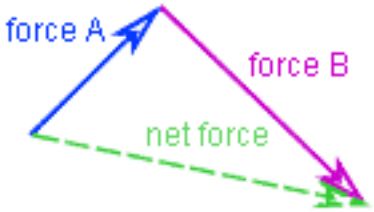


Vectors can be linked tip-to-tail to visually determine their vector sum. To link vectors, drag and drop one with its tail near the tip of the other. The dropped vector will snap to the tip when it links. You may continue to link additional vectors in the same way to form a chain.

**Note:** Tracker makes no attempt to check whether it is mathematically appropriate or physically meaningful to link a given set of vectors--it simply makes it possible.

When you drag the first vector in a chain of linked vectors, the chain moves as a unit and the vectors remain linked. When you drag any vector further up the chain, however, it detaches and "breaks" the chain.

# Vector Sum

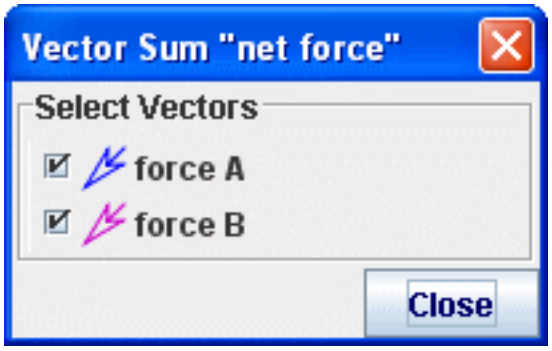



A **vector sum** track represents the vector sum of a collection of vector tracks. It's steps are not marked but instead are determined by the components of the vectors in the sum.

A vector sum is drawn with a dashed line to distinguish it from vector tracks and motion vectors. See vector and point mass for additional information.

**Note**: adding vectors with a vector sum is not the same as linking vectors tip-to-tail. Any two vectors can be linked, including vectors that are different steps in the same track. But adding vectors in a vector sum requires two or more separate vector tracks. The vector sum track consists of a vector at each step that is the sum of the corresponding steps in the vector tracks being added. In the image above, the force A and force B vectors have been linked tip-to-tail to illustrate graphically how the net force vector is determined, but the net force would be the same even if the two force vectors were dragged apart to unlink them as long as their components were not changed.

### 1. Adding vectors to a vector sum




Select the vectors to include in a sum by checking them in the vector sum dialog shown. The dialog is displayed when the vector sum is initially created or by choosing **Select Vectors** in the vector sum's track menu.

# Line Profile

A **line profile** track is a tool for measuring brightness and rgb data along a line on a video image. If the line width is increased by adding **spread**, image pixels above and below the line are averaged in order to reduce noise and/or increase sensitivity.

### 1. Marking the line

Click and drag the mouse (crosshair cursor) to mark a line profile. The line is drawn as a narrow rectangle that surrounds the pixel points analyzed by the line profile tool.

Drag either end of the line to change its length. Drag the center of the line to position it.

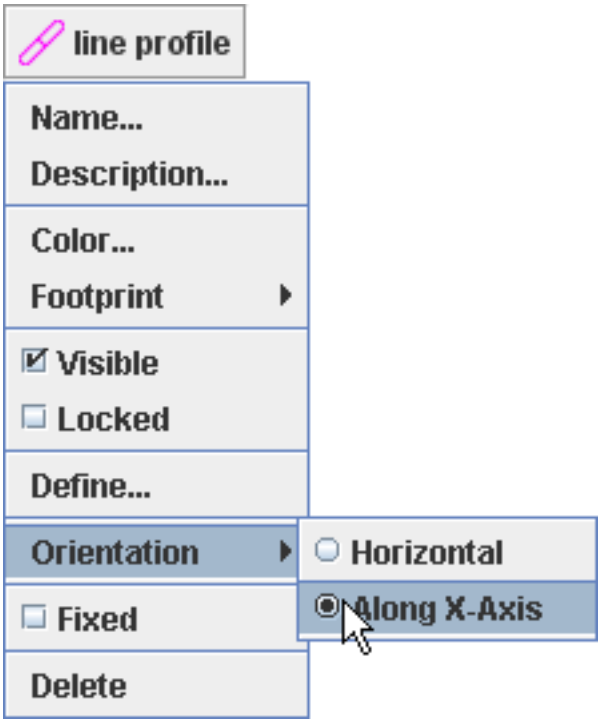
### 2. Adding spread

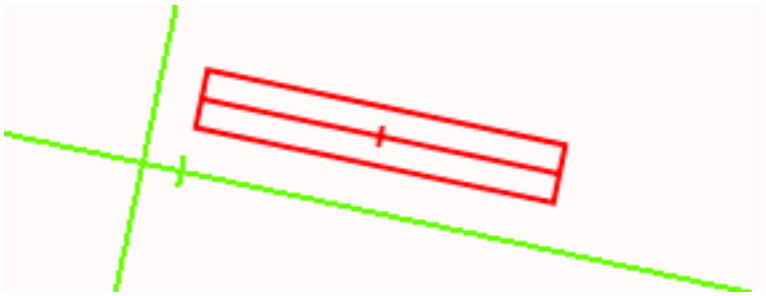

To increase the number of pixels sampled for a smoother average you can give the line profile a **spread**. Select the line and enter the desired spread in pixels in the field on the toolbar.

The spread pixels extend to both sides of the line. Thus, for a given data point on the line, the total number of pixels sampled (i.e., width of the line profile) is 1 + 2*spread. The outline of the line profile shows all pixels included in the average.

### 3. Line orientation

By default, a line profile has a **horizontal orientation**--that is, parallel to the top or bottom edge of the video image. Setting an **x-axis orientation** by selecting the **Along X-Axis** item in its track menu will instead cause the line to remain parallel to the x-axis. This is useful when measuring spectra that have been inadvertently captured with a tilted camera, for example.



### 4. Unfixing the line

By default, the line profile is **fixed**--that is, its center position and length do not vary from frame to frame. Uncheck the **Fixed** checkbox in its track menu to allow these properties to vary.

# RGB Region

An **rgb region** track measures the mean brightness and rgb data as a function of time in a circular region of a video image.

### 1. Marking the rgb region

Click the mouse (crosshair cursor) to mark the center of the rgb region. The region is drawn as a circle around a center cross. Drag the center of the region or select it and enter the desired world coordinates in the toolbar fields to position it.

If the position of the rgb region is **unfixed** so that it varies from frame to frame (see below), then the video will autostep forward so the region can be marked independently on every frame.

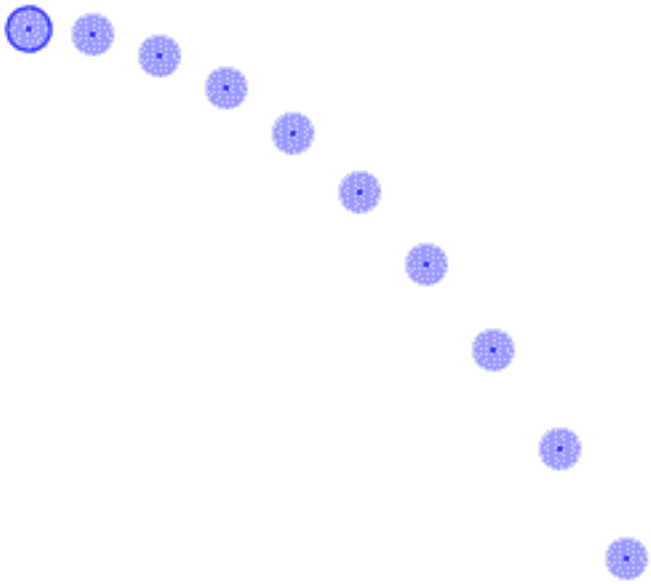
### 2. Unfixing the position and/or radius

By default, the rgb region has both a **fixed position** and a **fixed radius**--that is, its position and radius do not vary from frame to frame. Uncheck the appropriate checkbox in its track menu to allow these properties to vary.

### 3. Setting the radius


Select the region and enter the radius in pixels in the field on the toolbar. The outline of the region shows the pixels included in the average. If the region's radius is unfixed, you can set a different radius in every frame.

# Particle Models



A **particle model** track is a mathematical model of a point mass. The step positions of the particle are determined by the parameters of the model rather than being marked with the mouse.

There are two types of models: **analytic** and **dynamic**. An analytic model defines position functions of time, while a dynamic model defines force functions and initial conditions for numerical ODE solvers.

A particle model has a settable mass and generates motion data and vectors just like any other point mass. See point mass for additional information.

### 1. Building models

Particle model properties are displayed and edited using the Model Builder tool. To use the builder, choose **Model Builder...** from the model's track menu.

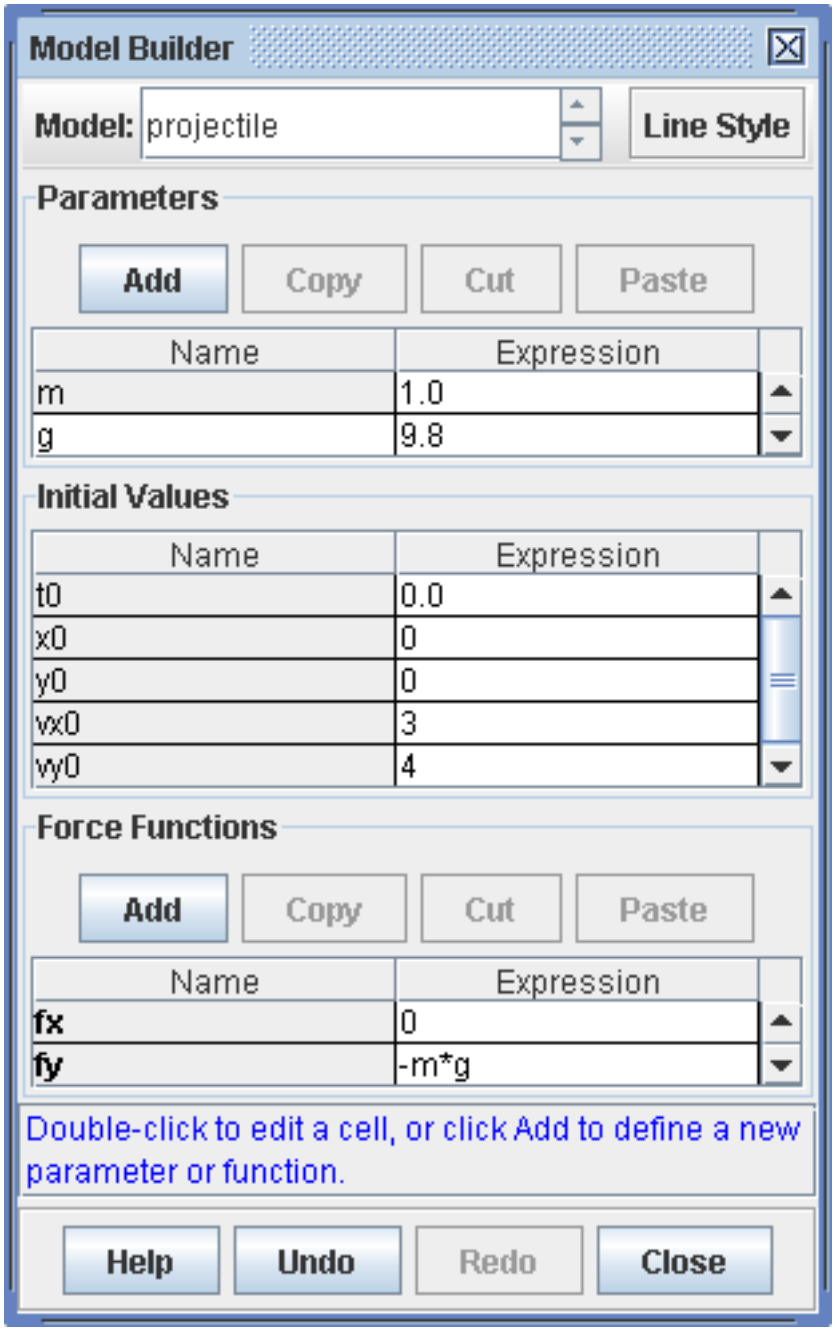



**Fig. 1 Model Builder with a dynamic model of a simple projectile**

Functions and parameters are defined by entering expressions that are "parsed" (interpreted) by the OSP parser. The values of parameters are constants while those of functions depend on input variables such as x, y, t, etc. The parser recognizes the following elements:

- **Numbers** in decimal or scientific notation (e.g., 1.0E-3)
- **Names** of parameters, functions and other input variables
- **Constants** e and pi
- **Arithmetic operators** + - * / ^
- **Boolean operators** = > < <= >= <> & | !
- **Parentheses** to control order of operation

- **Mathematical functions** shown in Table 1
- **If statements** in the form *if(conditional statement, expression1, expression2)*. Expression1 is evaluated if the conditional statement is true and expression2 is evaluated if it is false. For example, if (x < 0, x^2, -x^2) is a valid function expression.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| abs (x) | acos (x) | acosh (x) | asin (x) | asinh (x) | atan (x) | atanh (x) | atan2 (x,y) | ceil (x) | cos(x) |
| cosh (x) | exp (x) | frac (x) | floor (x) | int(x) | log (x) | max (x,y) | min (x,y) | mod (x,y) | random (x) |
| round (x) | sign (x) | sin(x) | sinh (x) | sqr (x) | sqrt (x) | step (x) | tan(x) | tanh (x) | |

**Table 1 Mathematical functions recognized by the OSP Parser**

Model Builder displays model functions along with associated parameters and initial conditions in tables with **Name** and **Expression** columns as shown in Fig. 1. The name of the fit is shown in bold font in the function table.

To edit a name or expression, double-click its table cell (gray cells cannot be edited). Names must be unique and can contain no spaces or mathematical symbols. Expressions must be valid mathematical expressions parsable by the OSP parser.

To create a new parameter or function, click the appropriate **Add** button.

When editing an expression, the names of all available variables are listed in blue in the status bar as shown in Fig. 2. To insert a variable directly from the list, move the mouse cursor over it until it turns red and then click.

Variables for parameter expressions include only other parameters, while variables for function expressions include independent variables (e.g., x, y, t, etc), parameters and support function names. In the example shown, the "fy" function may depend on any or all of the variables x, vx, y, vy, t, m, g. The entry "-m*g" is thus a valid expression.

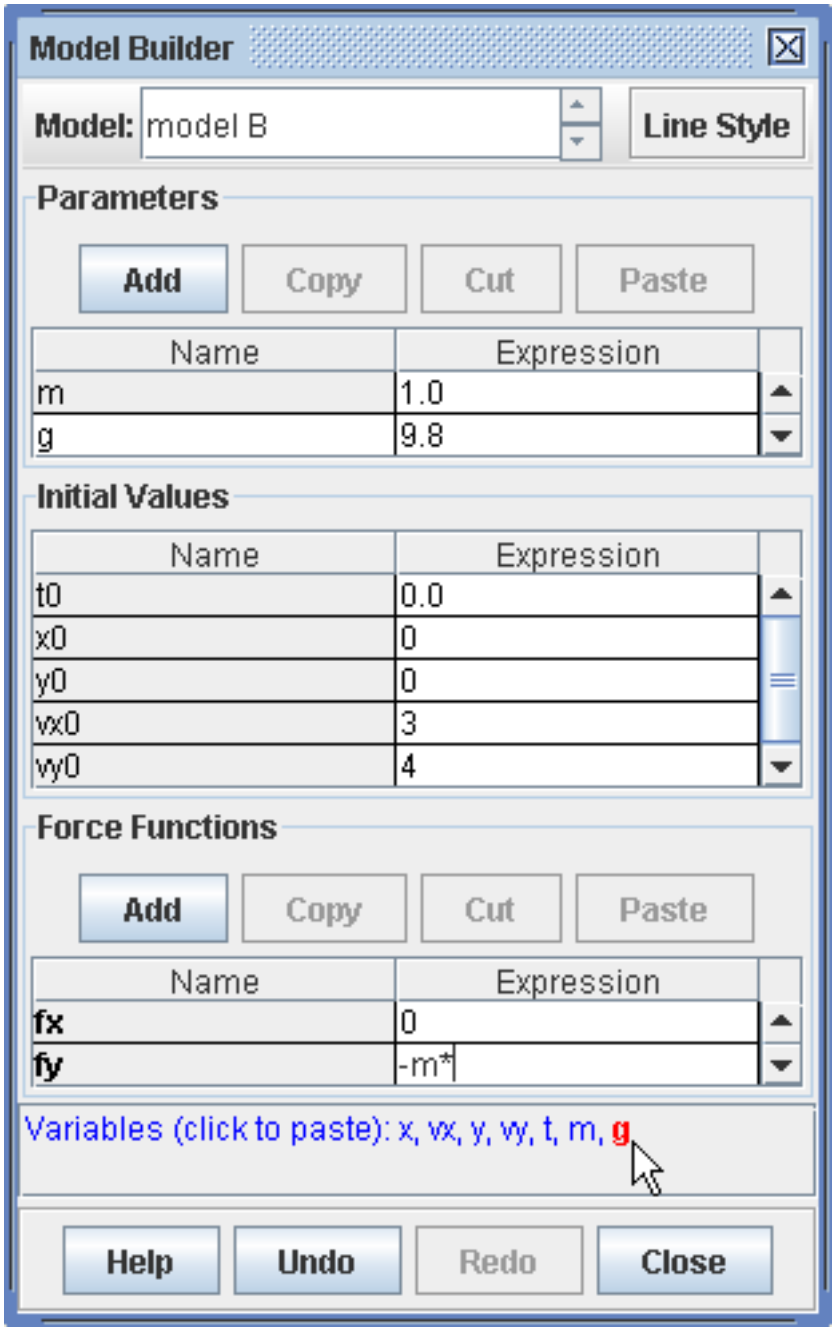



**Fig. 2 Editing an expression**

If an invalid expression is entered into a cell the cell turns red and an error message is displayed in the status bar. In Figure 3, the expression "-mg" is invalid since the multiplication operator (*) has been omitted. Circular references also result in an error condition.

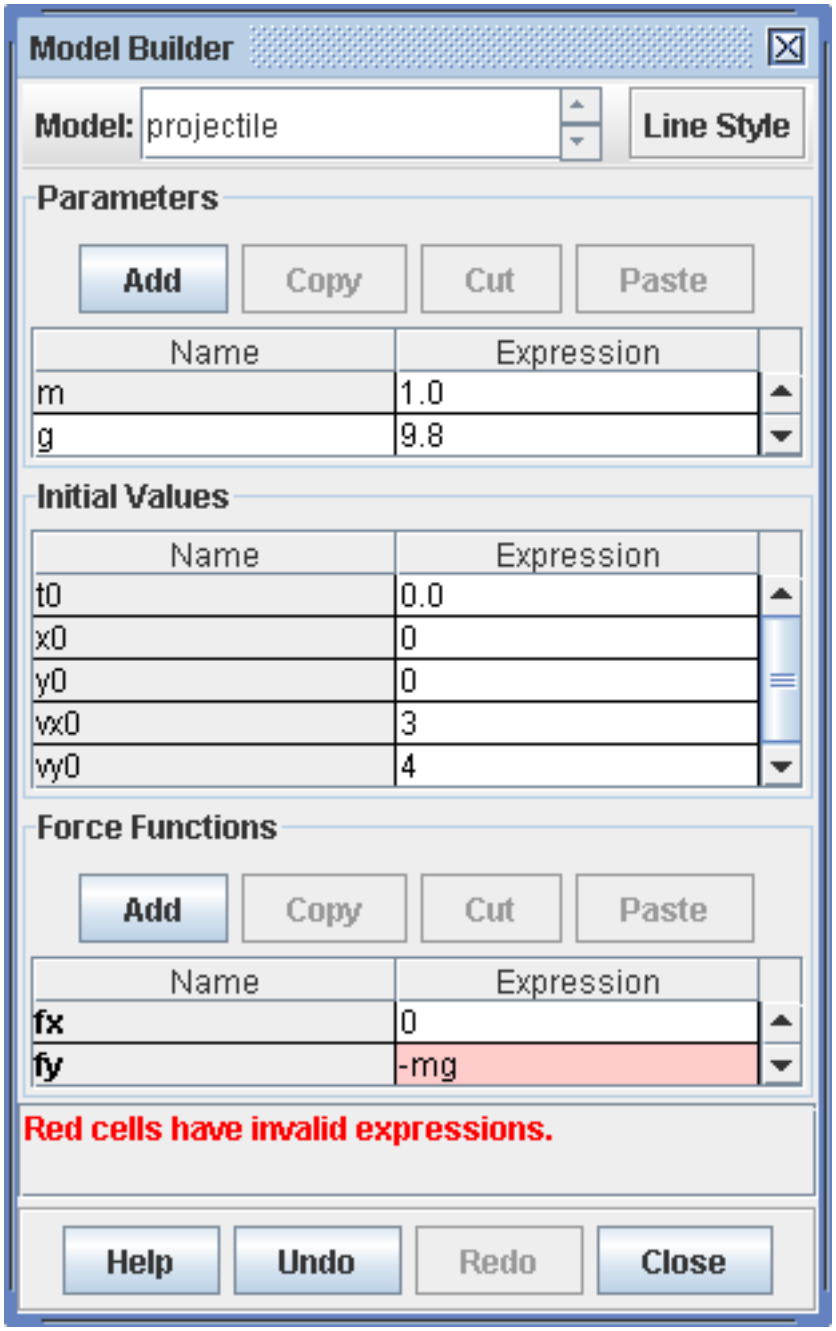



**Fig. 3 Invalid expression**

Model Builder includes several features designed to help build, modify and compare models quickly:

1. Complex expressions can be simplified by defining one or more **support functions**. For example, the analytic model of a damped oscillator shown in Fig. 4 defines the support function "amp" that represents the exponentially decaying amplitude. This makes the y position function easier to write and understand.
2. All edits are **undoable** and **redoable** making it easy to quickly flip back and forth between two function expressions or parameter values.
3. Single or multiple table rows can be copied or cut to the clipboard for **pasting** into other

tables.

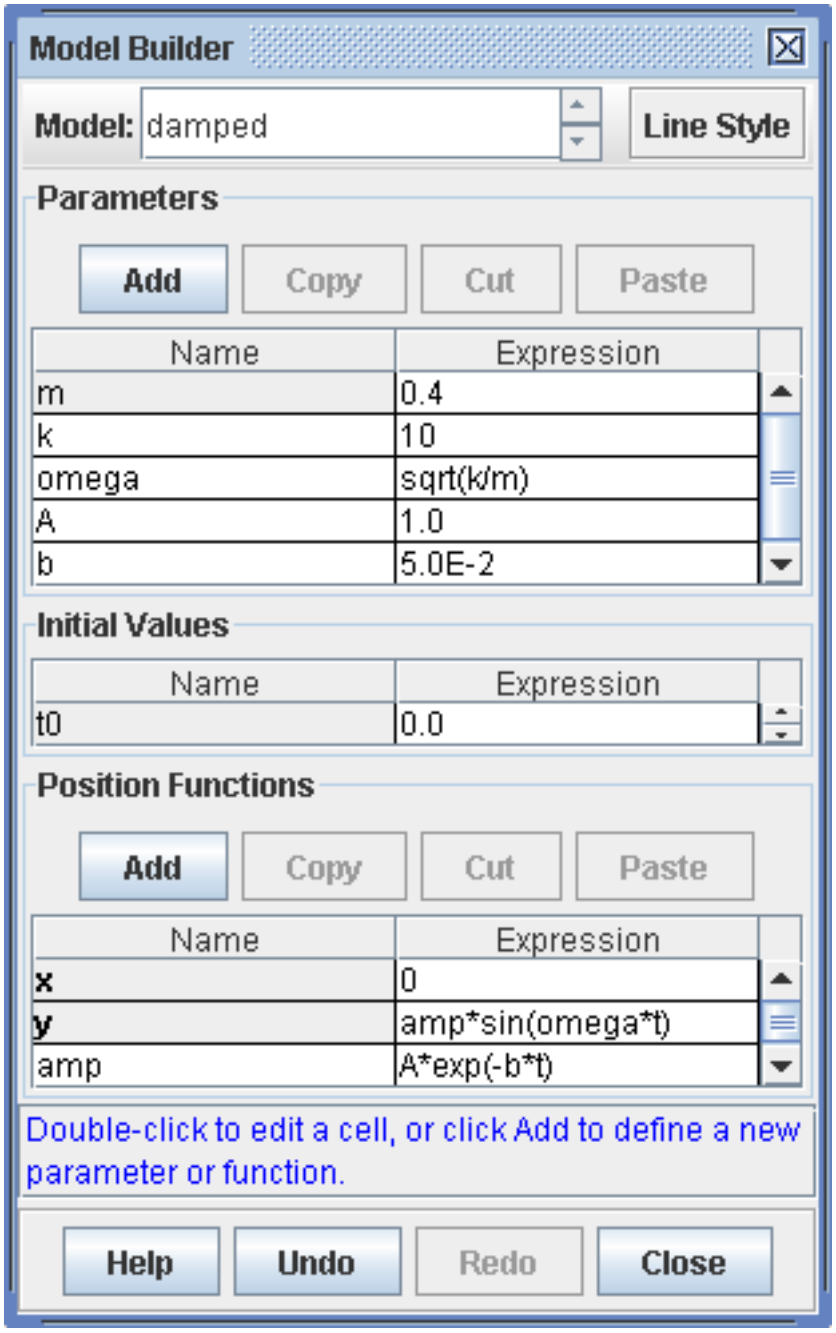
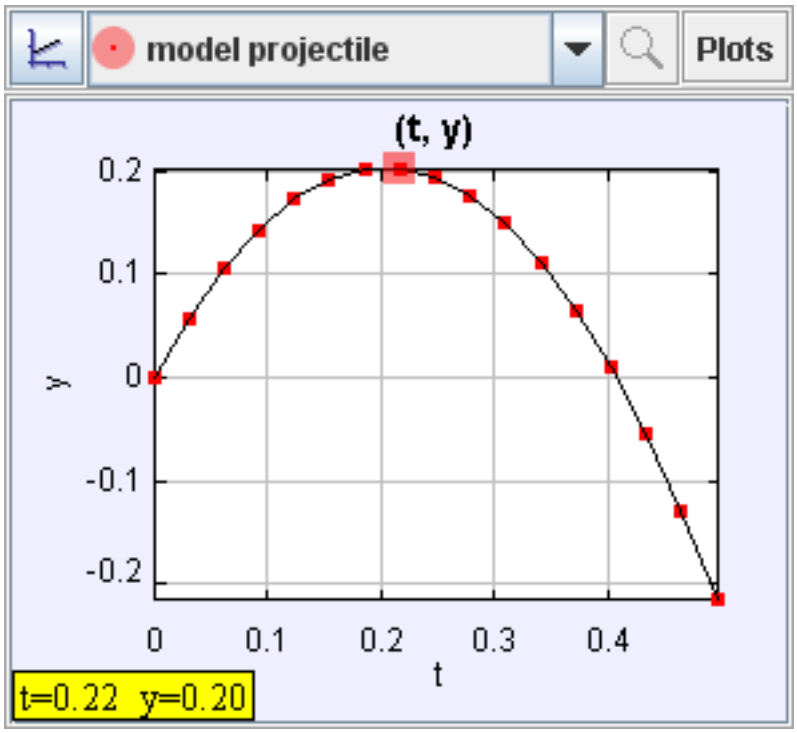



**Fig. 4 Using a support function to simplify expressions**

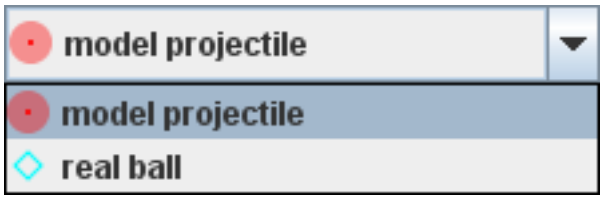
# Plot View




The **plot view** displays plots of a track's data. It has its own toolbar for selecting tracks, displaying multiple plots, and zooming in. The color of the plot markers is the same as that of the selected track. The data point associated with the current video frame or currently selected step is highlighted in the plot and its coordinates are displayed in the lower left corner.

### 1. Selecting a track

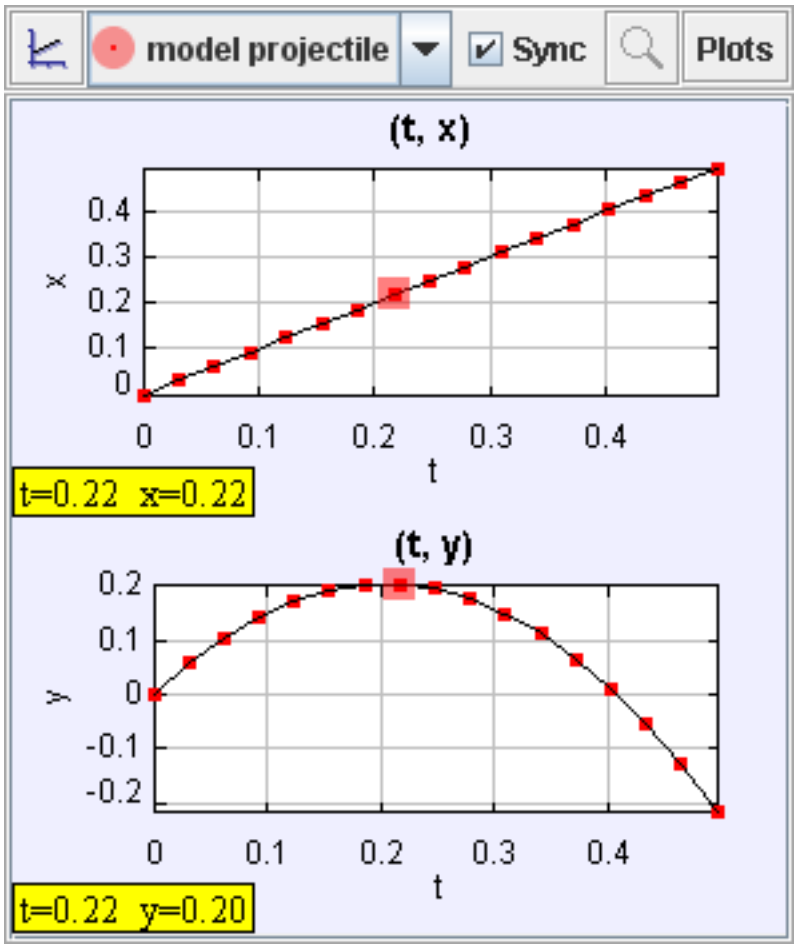
Select the track of interest from the dropdown list on the plot view's toolbar.




### 2. Multiple plots and synchronized x-axes

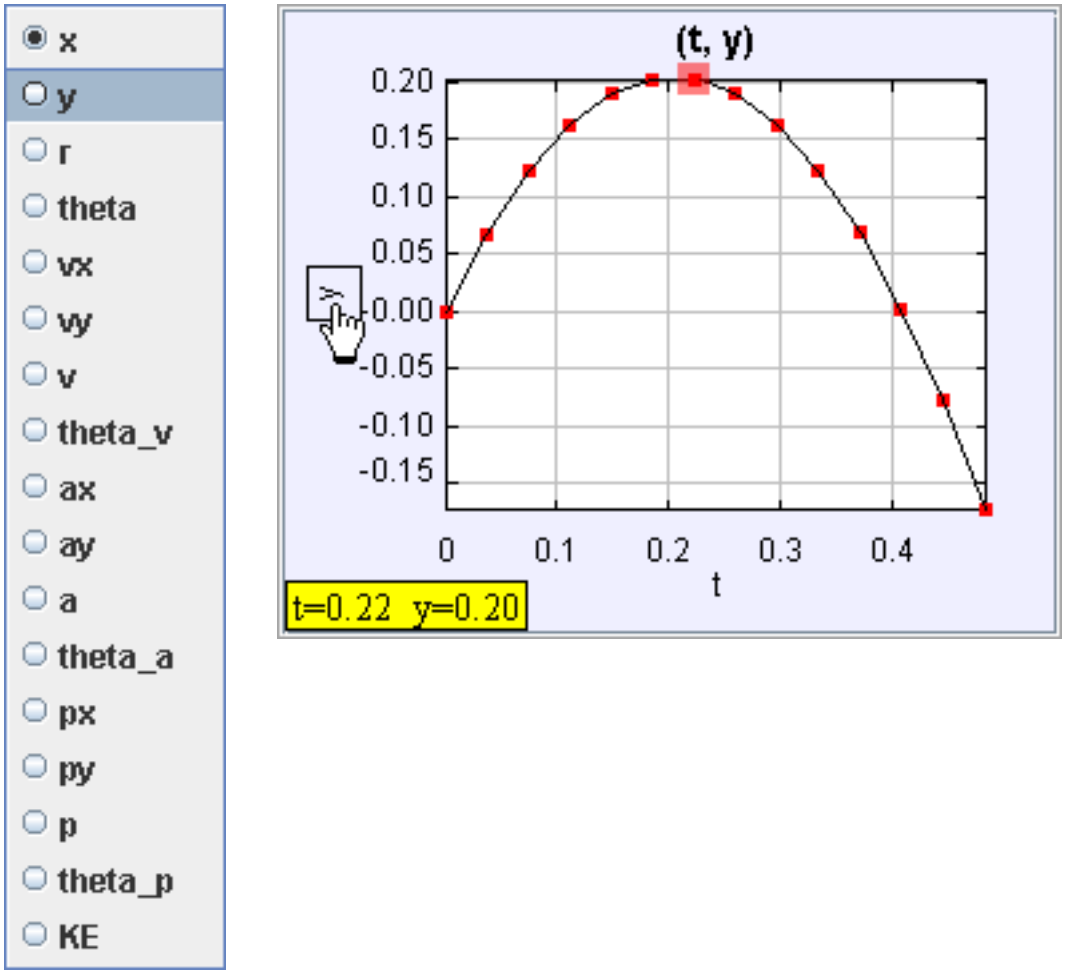
Click the **Plots** button and choose the number of plots desired. Multiple plots are stacked vertically.


Check the **Sync** checkbox to synchronize the horizontal axes of the plots so that they all share the same variable and scale. Unchecking this box enables the horizontal variables and scales to be set independently. Vertical variables and scales are always independent.



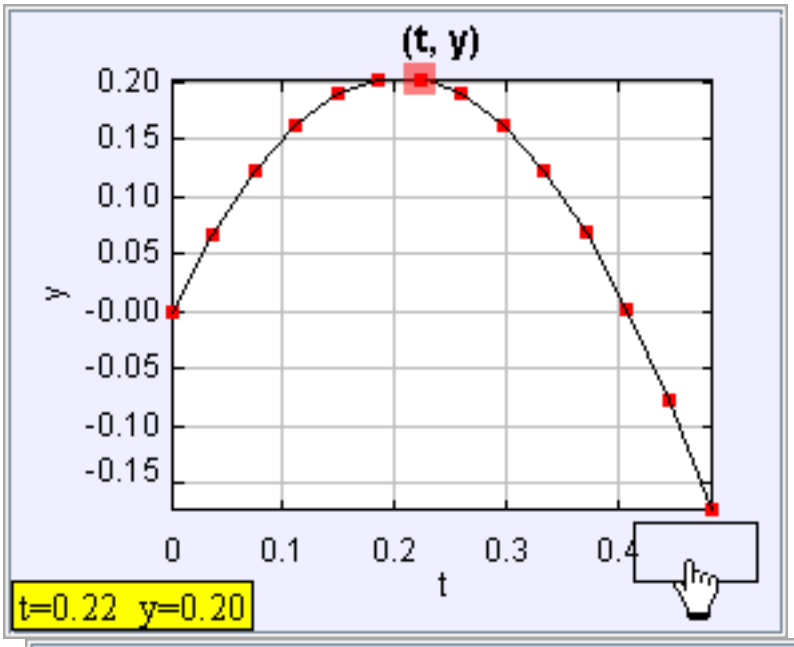

### 3. Setting plot axis variables

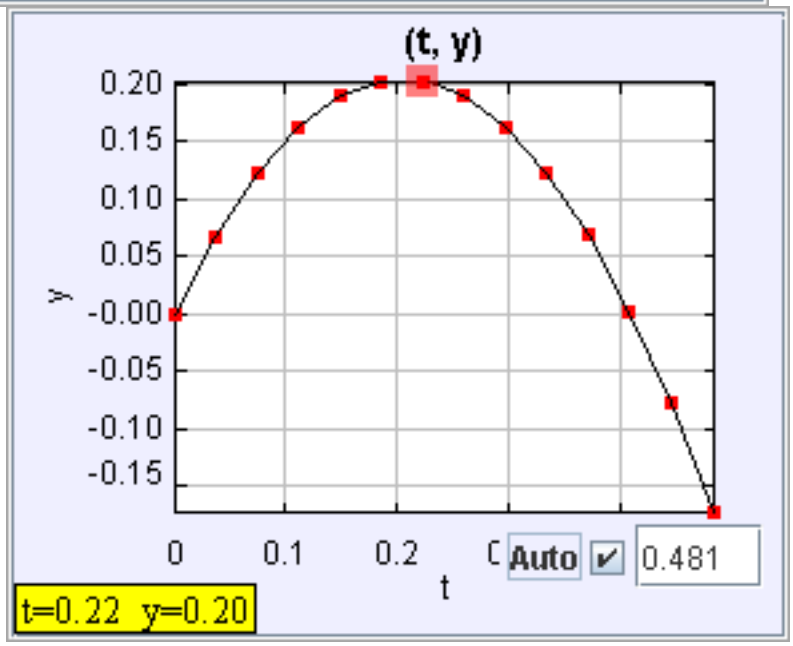
Move the mouse over an axis label until a box appears, then click on the box and choose the desired variable from the resulting popup list.

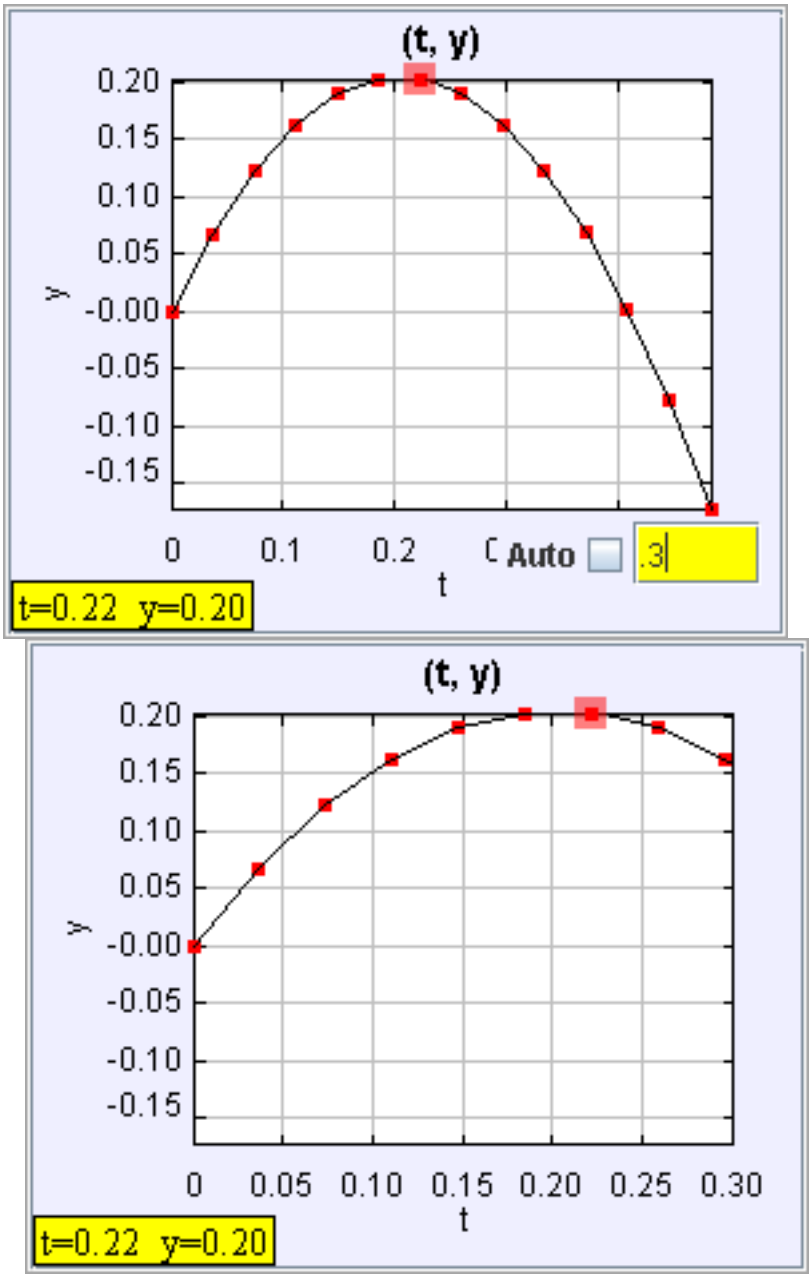



## 4. Setting the scale

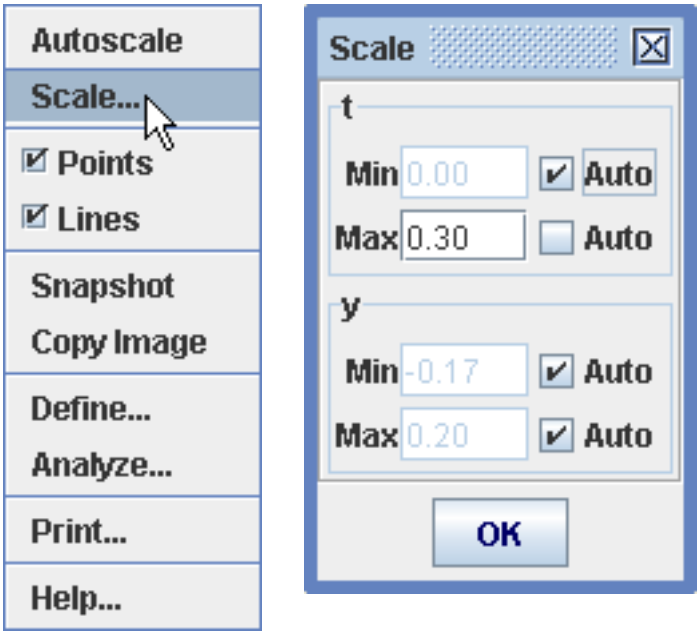
All plots initially autoscale by default. To manually set a fixed minimum or maximum on either axis, move the mouse over the upper or lower end of the axis until a box appears, then click on the box and enter a value. Select the **Auto** checkbox to turn on autoscaling again. Note that each minimum or maximum can be independently set or autoscaled.


(t, y)
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
y
0
0.1
0.2
0.3
0.4
t
t=0.22 y=0.20


(t, y)
0.20
0.15
0.10
0.05
-0.00
-0.05
-0.10
-0.15
y
0
0.1
0.2
Auto
0.481
t
t=0.22 y=0.20

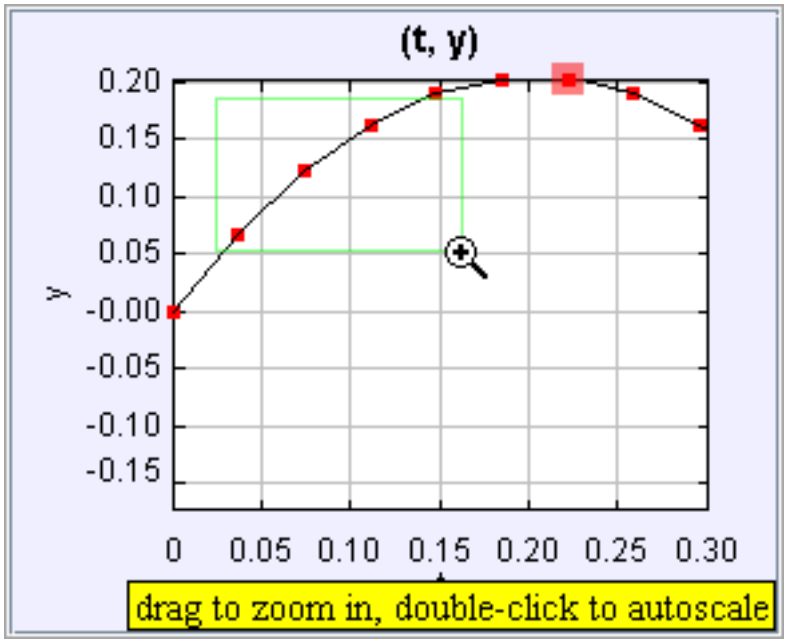



Additional scaling options are available by right-clicking the plot and choosing from the popup menu. The **Scale...** item displays a dialog where all four axis limits can be set. The **Autoscale** item autoscales all four axes so all data is visible.




## 4. Using the zoom tool

Click the **zoom** button on the toolbar (*shortcut*: press the **Z key**) to turn on the zoom tool. To zoom to a region of interest, drag the mouse to define its rectangular limits, or click the mouse to zoom in by 2x. Double-click the mouse to autoscale all four axes so all data is visible.

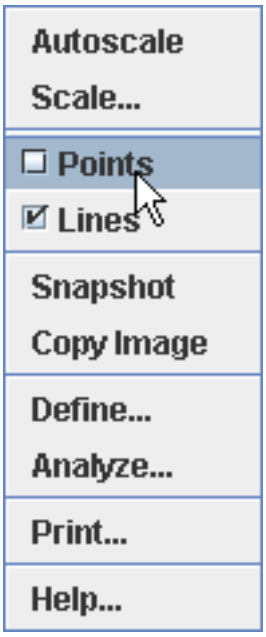



By default, the tool zooms in (mouse cursor and button display the zoom-in icon). Hold down the **Alt key** and click the mouse to zoom out by 2x (mouse cursor and button display the zoom-out icon).

Zoom button with zoom off, zoom-in and zoom-out icons

## 5. Hiding data point and lines

Right-click the plot and uncheck the appropriate box to hide the data points or connecting lines.

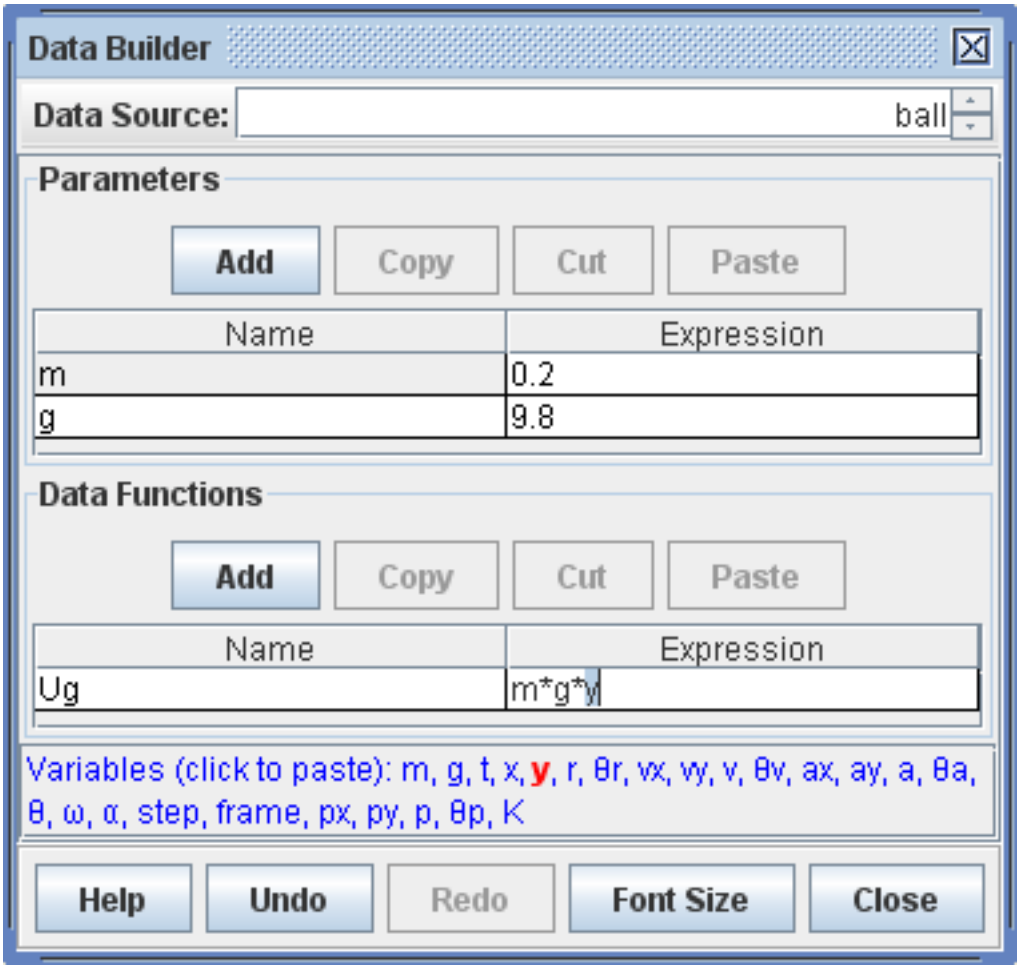



## 6. Defining new data columns with Data Builder

Right-click a plot and choose **Define...** to display a **Data Builder** with which you can define custom variables for plots and datatables.


Custom variables can be virtually any function of built-in and previously defined custom

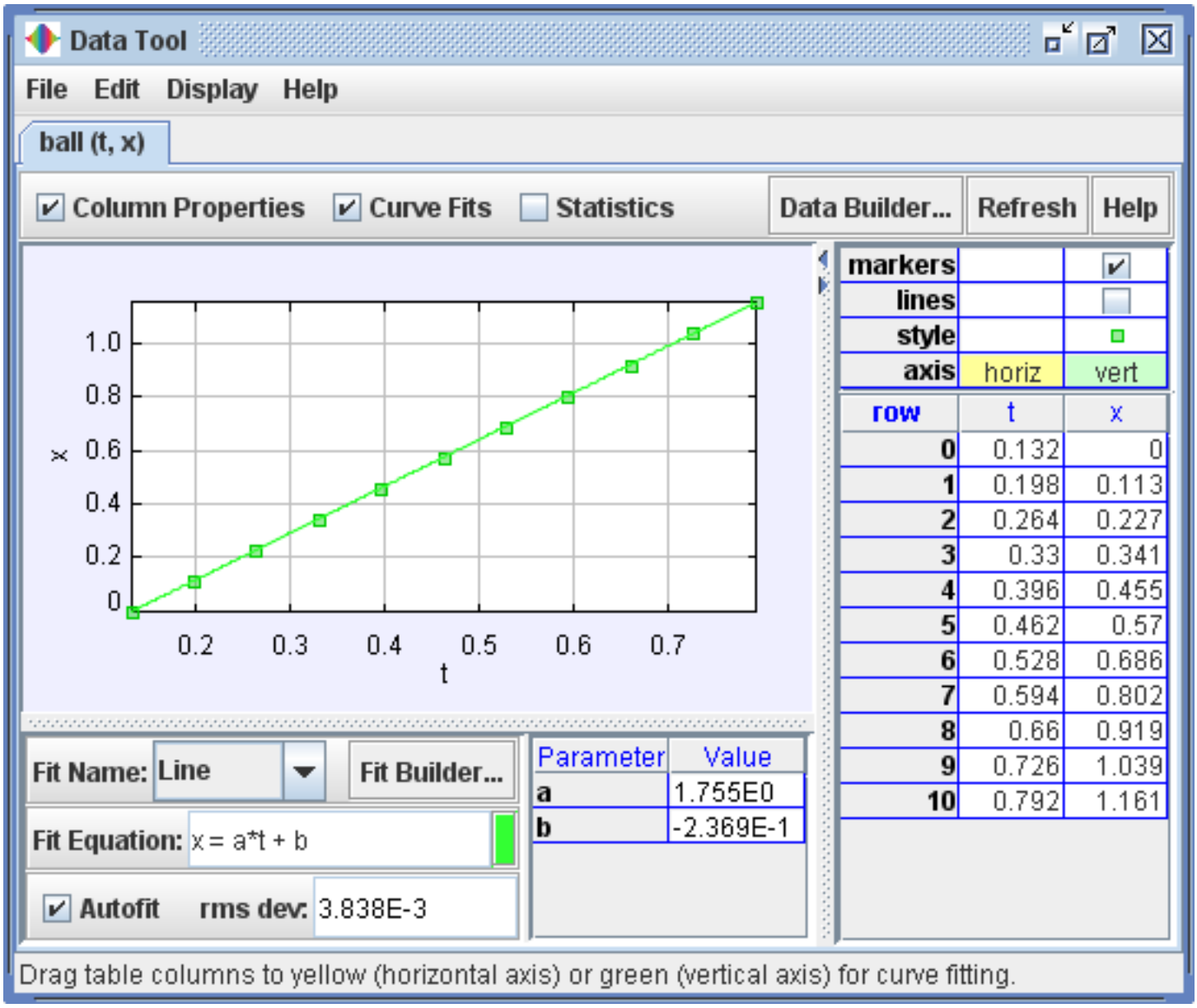
variables. For help using Data Builder, open Data Builder and click its Help button.



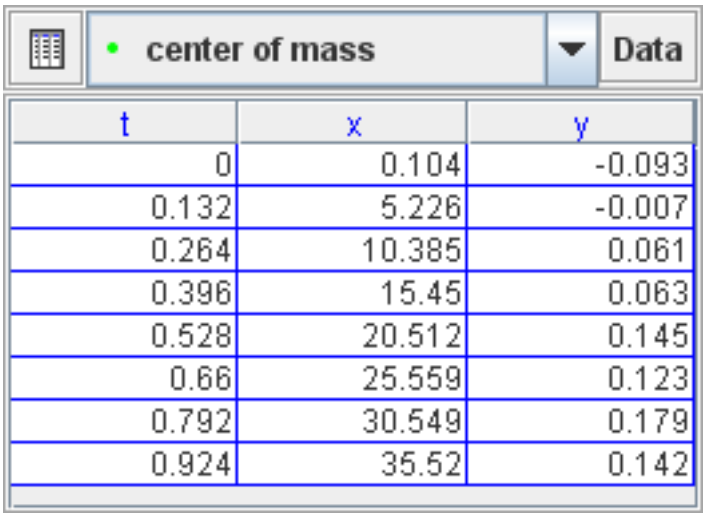

## 6. Analyzing data with Data Tool

Right-click a plot and choose **Analyze...** to open its data in the **Data Tool** for analysis.

The Data Tool provides statistical analysis including automatic and manual curve fitting of all or any selected subset of the data. For help using Data Tool, open Data Tool and click its Help button.



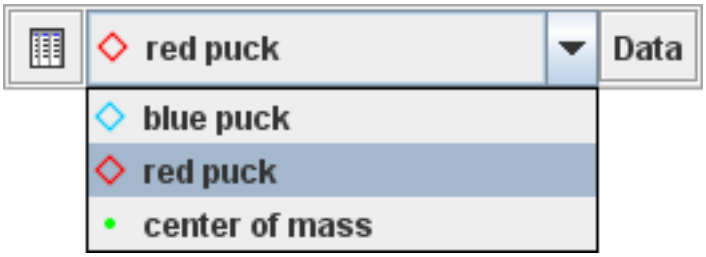
# Datatable View




The **datatable view** displays a table of a track's data. It has its own toolbar for selecting the track and visible data columns. The data displayed in the table can be analyzed with the Data Tool or copied to the clipboard and pasted into a spreadsheet or other application.

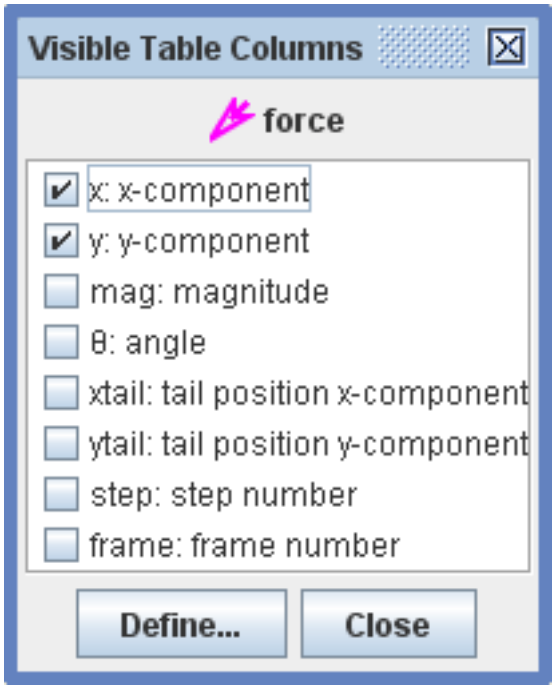
### 1. Selecting a track

Select a track from the dropdown list on the datatable view's toolbar.



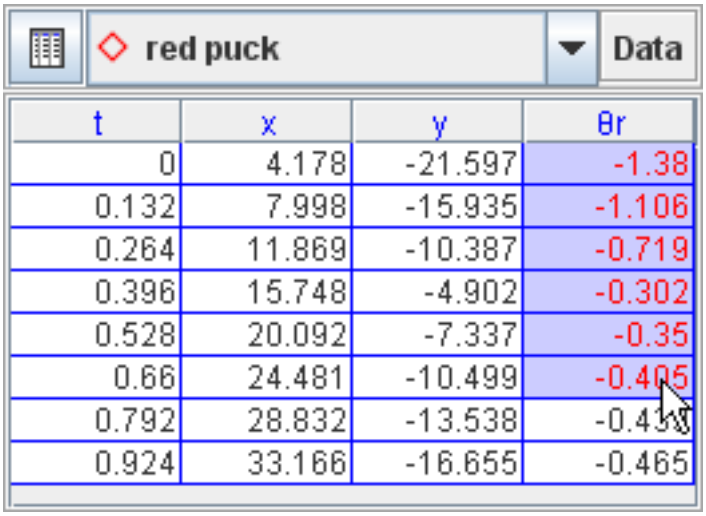

### 2. Selecting visible data columns

Select the data columns displayed in the table by clicking the **Data** button and checking those of interest. The time column is always displayed.



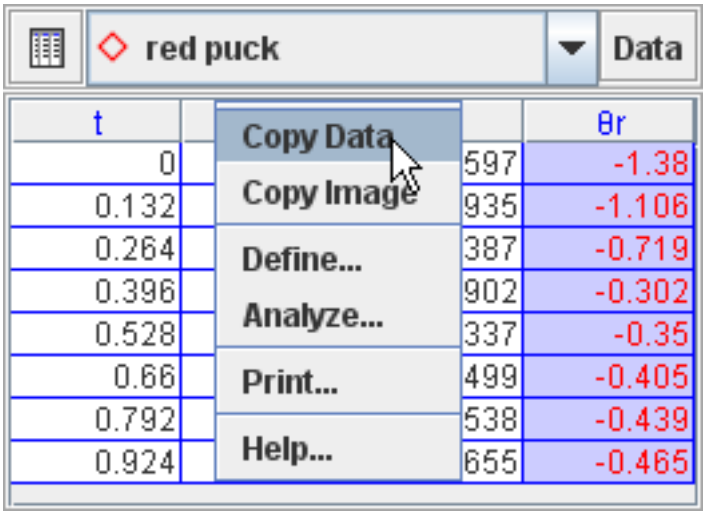

### 3. Selecting data cells

Click and drag in the table to select cells. Double-click to select all cells, or click on a column header to unselect all cells. Note that clicking a column header also sorts all data in that column's ascending order.

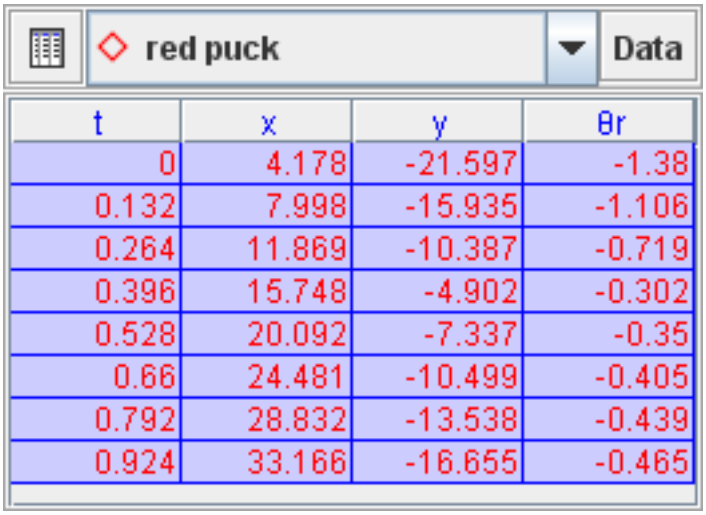



### 4. Copying data

Right-click the table and select **Copy** from the popup menu to copy the selected cells to the clipboard. On Mac, select one cell, then hold down both the shift and control keys while clicking on a second cell to select the enclosed range and pop up the Copy menu.



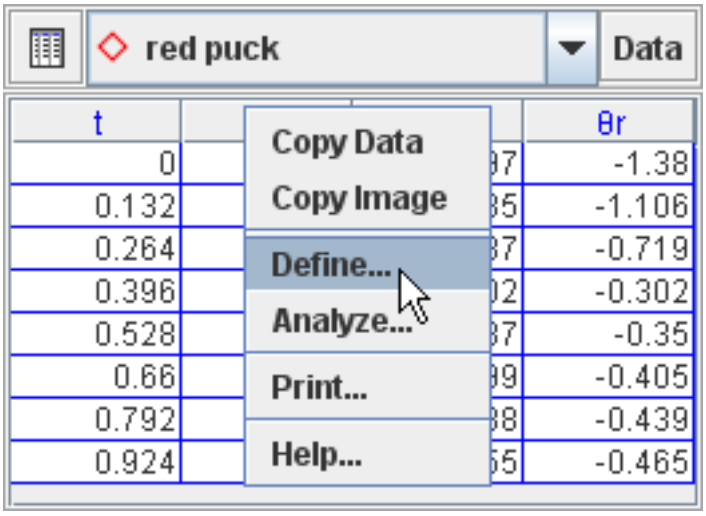

If no cells are selected, the entire datatable will be copied.



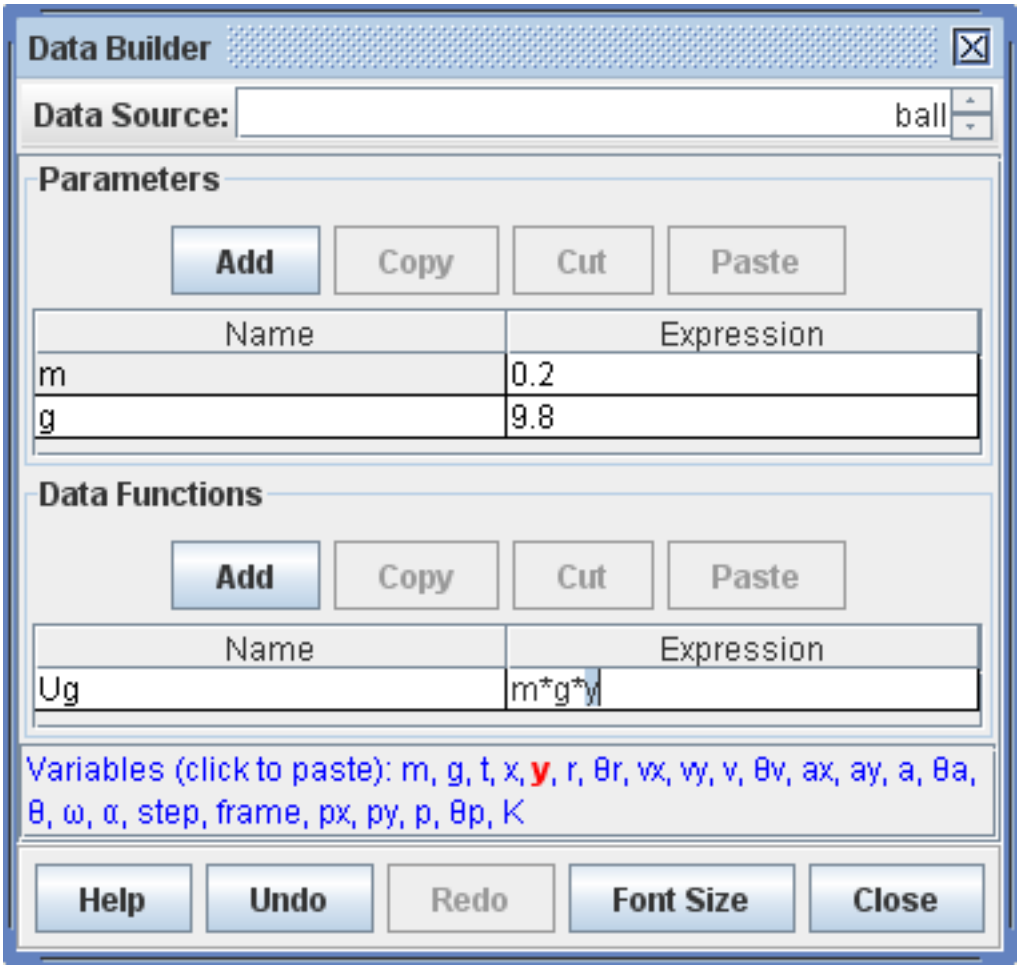

| t | x | y | θr |
|---|---|---|---|
| 0 | 4.178 | -21.597 | -1.38 |
| 0.132 | 7.998 | -15.935 | -1.106 |
| 0.264 | 11.869 | -10.387 | -0.719 |
| 0.396 | 15.748 | -4.902 | -0.302 |
| 0.528 | 20.092 | -7.337 | -0.35 |
| 0.66 | 24.481 | -10.499 | -0.405 |
| 0.792 | 28.832 | -13.538 | -0.439 |
| 0.924 | 33.166 | -16.655 | -0.465 |

## 5. Defining new data columns with Data Builder

Right-click the table and choose **Define...** to display a **Data Builder** with which you can define custom variables for plots and datatables.

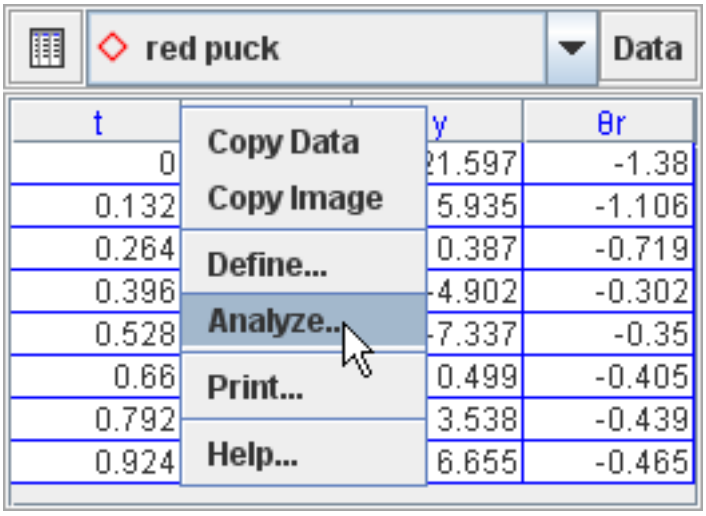



Custom variables can be virtually any function of built-in and previously defined custom variables. For help using Data Builder, open Data Builder and click its Help button.

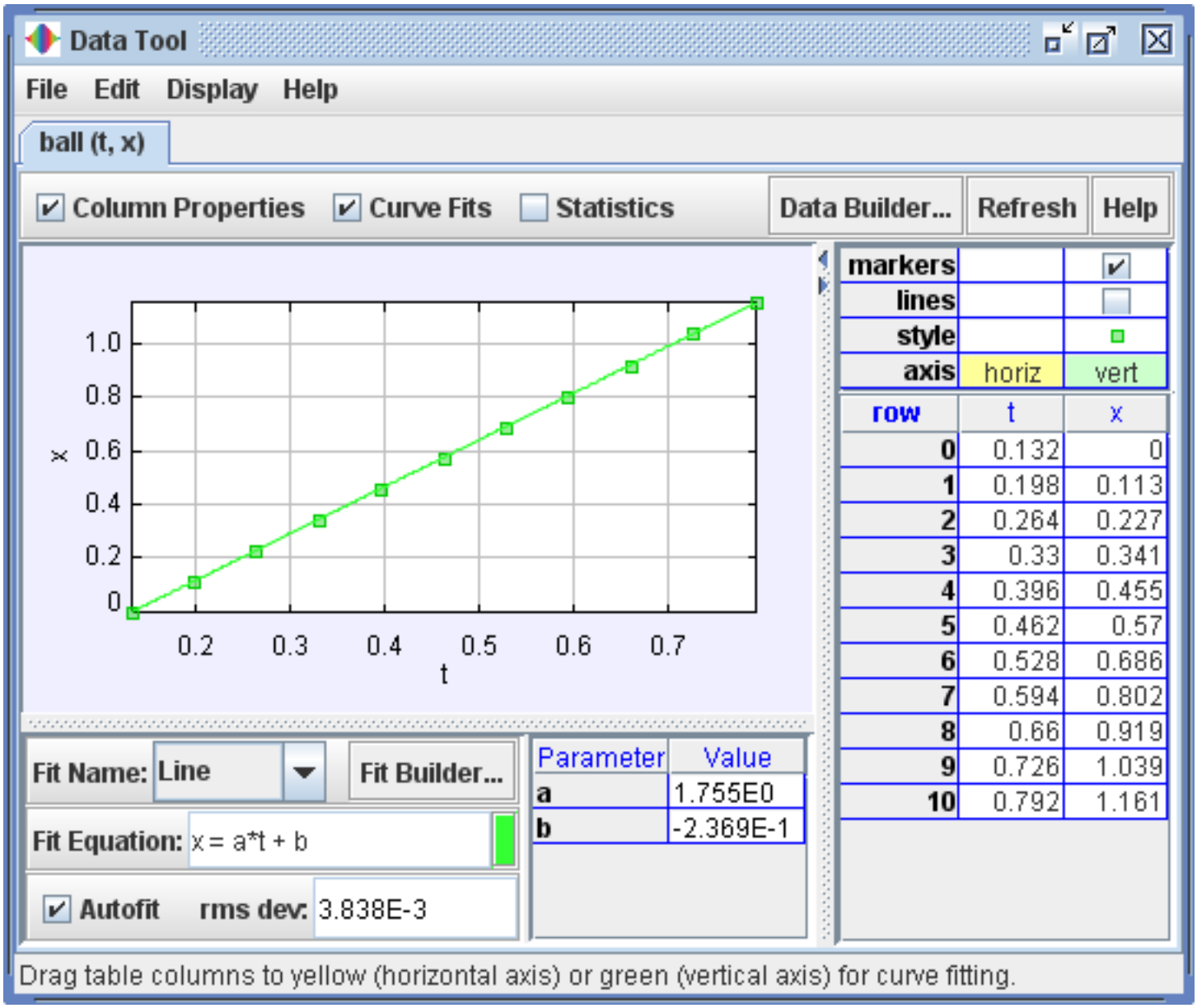



## 6. Analyzing data with Data Tool

Right-click the table and choose **Analyze...** to open all visible columns in the **Data Tool** for analysis.




The Data Tool provides statistical analysis including automatic and manual curve fitting of all or any selected subset of the data. For help using Data Tool, open Data Tool and click its Help button.



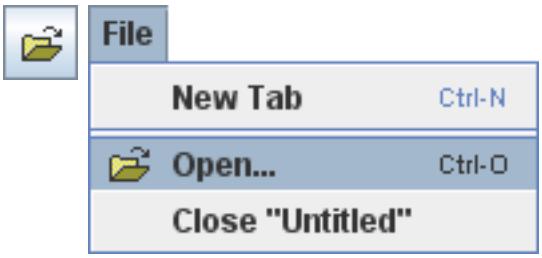
# Tracker Files

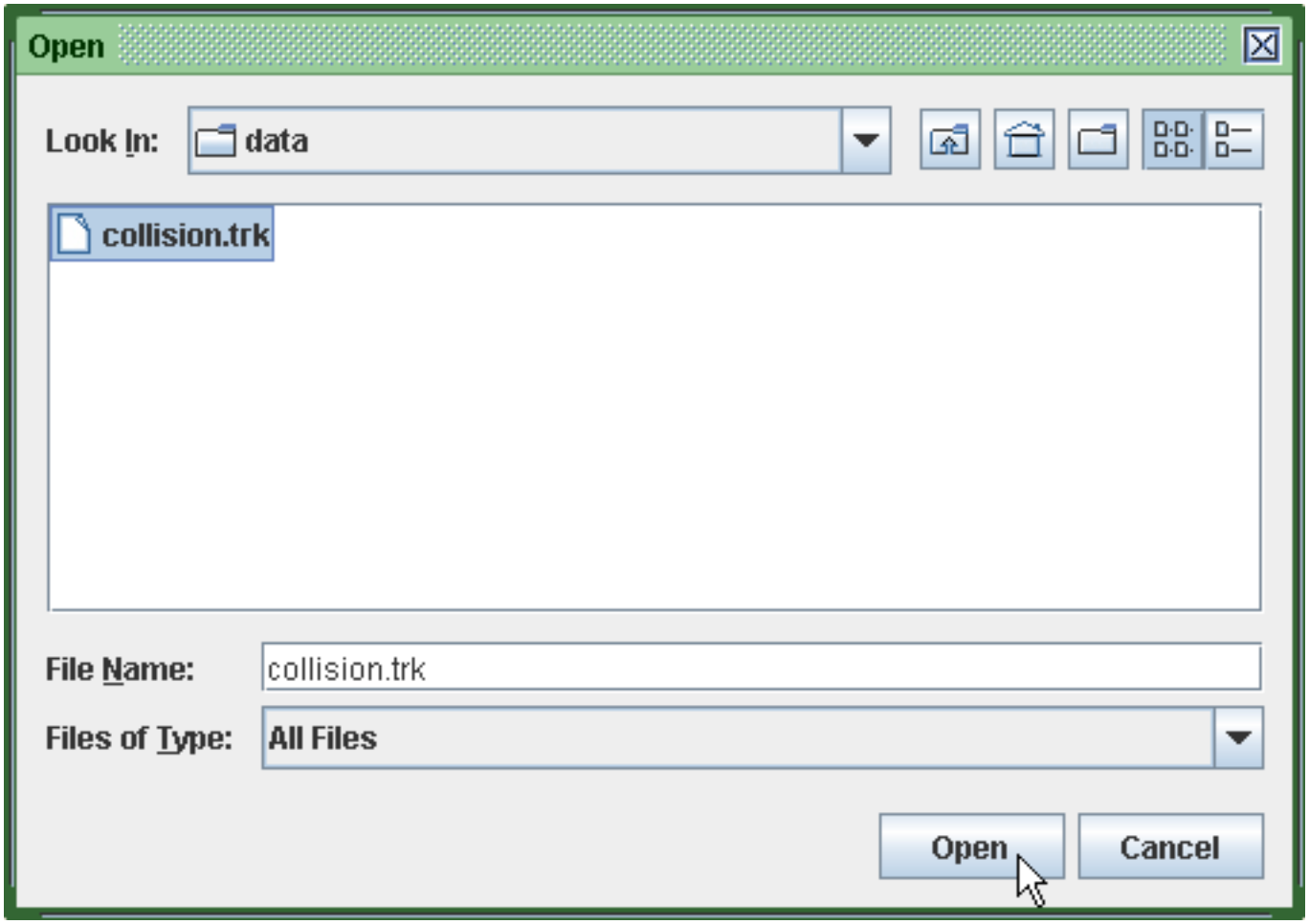
Tracker saves properties of the video clip, coordinate system and tracks in xml-based **tracker files** with the extension "**trk**". When a saved tracker file is opened, Tracker loads the specified video, sets the clip and coordinate system properties, and creates new tracks with the specified identification and step positions.

Step positions are saved in image (pixel) coordinates, so they are not suitable for direct analysis. To access the world data associated with a track, use a datatable view.

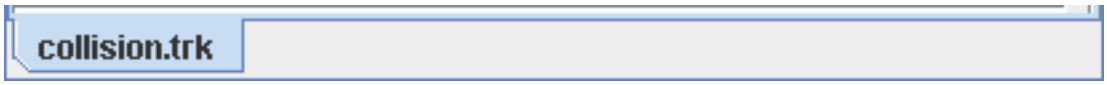
### 1. Opening a tracker file

Bring up the open dialog with the **Open** button or menu item, select the desired file, and click Open.





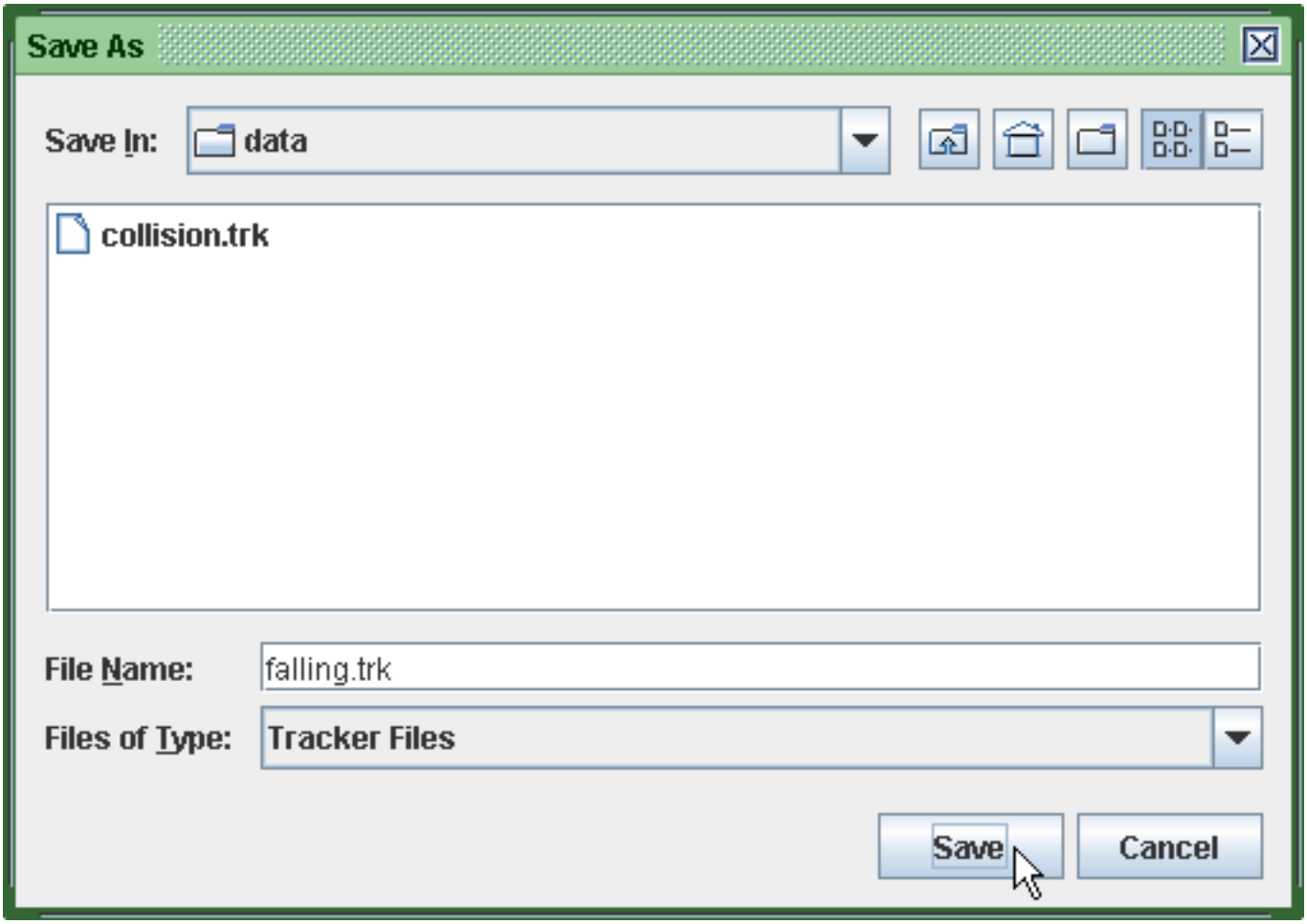

Tracker opens the file in a new tab that displays the file name.




## 2. Saving a tracker file

Save changes to an open tracker file by clicking the **Save** button  or **File|Save** menu item.

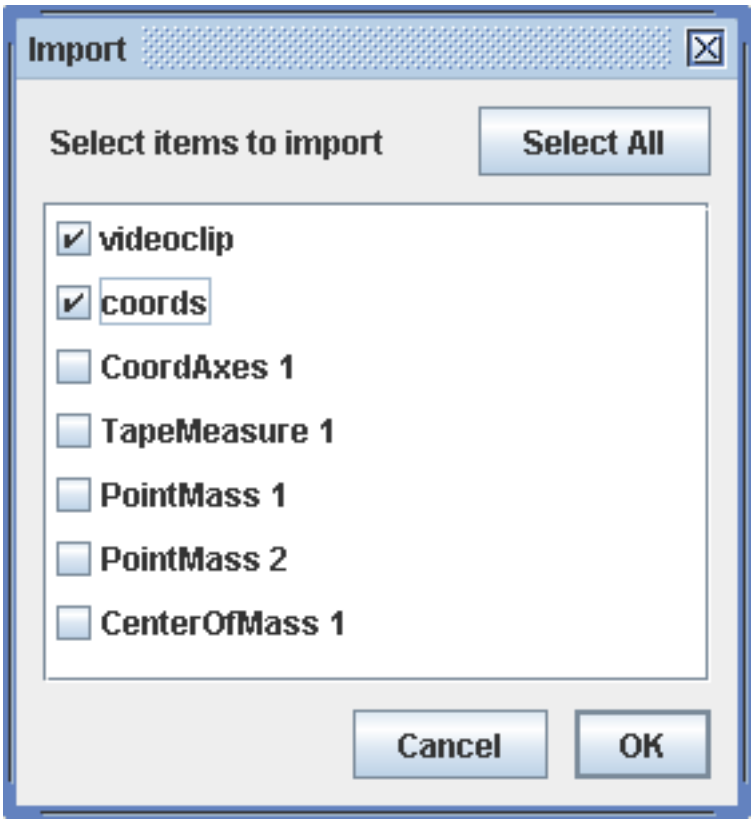
Save a new tracker file by choosing the **File|Save As...** menu item. Tracker will automatically assign the file a "**trk**" extension.




### 3. Importing from and exporting to a tracker file

Videos, tracks and/or the coordinate system from a tracker file can be imported into an existing tab using the **Import** menu item from the File menu. Selected tab elements can also be exported to a tracker file using the **Export** menu item.


When importing or exporting a tracker file, the available elements are displayed in a dialog that allows the user to select those desired.




## 4. Editing a tracker file directly

A tracker file is easily human-read and edited with any text editor. The xml format conforms to the doctype specification defined in osp10.dtd.