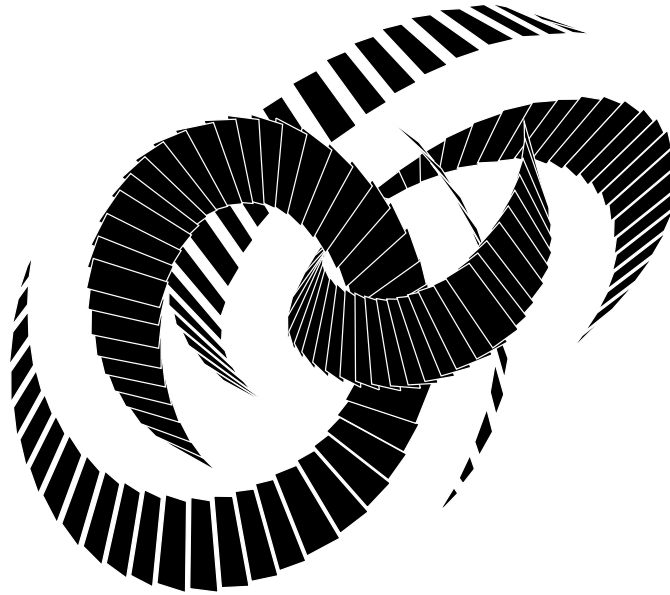


# KnotPlot

A Program for Viewing Mathematical Knots

October 15, 2002



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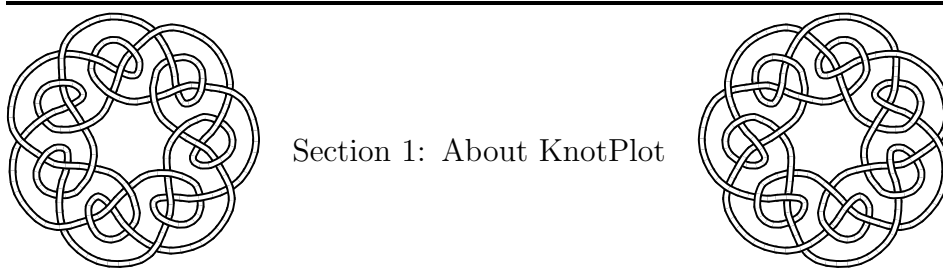
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(WWW: [www.knotplot.com](http://www.knotplot.com))

## Introduction

This highly inadequate manual vaguely describes KnotPlot, a program to display knots and links in three and four dimensions. KnotPlot is probably one of the largest programs ever written which serves no clearly defined purpose whatsoever. However, it is a great deal of fun, mostly because knots are such nice things to look at.



KnotPlot is a program for visualizing and interacting with 3-D and 4-D knots. Over the long years, the program has steadily accreted new features, of which some of the most interesting are the following:

**Knot catalogue** — The complete appendix C of Rolfsen’s book *Knots and Links* [Rol76] is included (about 384 knots and links), as are many other knots of a special nature. This database makes possible many opportunities for experimentation.

**Automatic construction** — Knots and links may be constructed using the notation system developed by Conway’s notation system [Con70]. Conway’s method of plugging tangles into what he called “basic polyhedra” has been extended to allow for arbitrary *tangle holders* used by a *tangle calculator* in KnotPlot. Knots and links such as knot chains, torus knots (and links), and Lissajous knots [BHJS94] can be constructed automatically.

**Sketching** — Knots can be sketched by hand in 3-D, marking the location of individual points along the knot (called *beads*) with the mouse and using the mouse buttons to indicate over and under crossings.

**Knot transformations** — Knots may be transformed into new knots via a number of procedures. This is used to create satellite knots, doubled knots, and cabled knots [Rol76, Kau87]. Mutations [APR89] and (soon) global mutations [Rol94] can also be performed.

**Knot relaxation** — Once a knot is entered into KnotPlot it may be *relaxed* into a smoother configuration by applying a system of forces to it.

**Interactive manipulation** — Knots may be interactively modified by direct manipulation. This can take the form of “dragging” the knot around in three dimensions or by selectively applying forces to local regions of the knot.

**Topological properties** — The Alexander and HOMFLY polynomials, writhe, average crossing number, thickness [Sim96] and Dowker code [DT83, Thi85] of a knot can be computed. The polynomial calculations are an example of the use of KnotPlot in conjunction with other software that acts as a “plugin”.

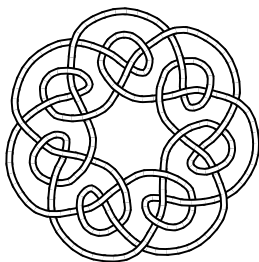
**Experimental knot theory** — KnotPlot has a simple but effective programming model that allows users to search for minimal stick conformations and interesting random knots [Mil96] easily.

**Graphs, open strings, and braids** — Knotted graphs [SW90, Han89] are handled (almost) as easily as normal knots. Also, knots or links don’t have to be closed strings. Commands are available that allow for the easy generation of arbitrary braids.

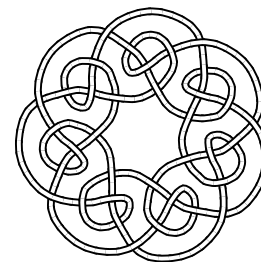
**4D surfaces** — Knotted and linked spheres [AC59, Rol76] in four dimensions can be interactively constructed. The surfaces may be viewed with KnotPlot or exported to other visualizers such as the Geometry Center’s GeomView [PLM93].

**Graphical display** — A very large number of options are available for changing the display, many are bizarre or abstract to the point where they are no longer recognizable as knots [HBK<sup>+</sup>94, New96].

**External support** — KnotPlot can export surface models in a number of different formats, including Wavefront OBJ, AutoCAD DXF, POVray, and METAFONT. Also, Postscript pictures in numerous flavours may be generated. Surface models exported from KnotPlot have been used in various projects [Gib94, Bot94].



Section 2: Installing and running KnotPlot



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## 2.1 Installing KnotPlot

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KnotPlot is freely available from the KnotPlot web site, [www.knotplot.com](http://www.knotplot.com). If you're at one of KnotPlot's "home institutions", it may already be installed on your system.

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## 2.2 Entering commands

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There are three modes of interaction with the program:

**command line** — Many of the features of KnotPlot are available only through this mode. Although the program echos commands in the command line window, the mouse can be positioned in any of the three windows when entering text via the keyboard.

**control panel** — Some commands are only available by using the control panel. Other operations, such as setting various parameters may be easier to do with the control panel.

**menu** — Clicking the right mouse button in either the control panel window or the command line window will bring up a pop-up menu.

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## 2.3 Loading knots

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A complete catalogue of all the knots in appendix C of Dale Rolfsen's book *Knots and Links* [Rol76] is included on line. The coördinates for these knots were kindly provided by Professor Rolfsen and then relaxed using KnotPlot. The file naming convention is as follows:

- For single component knots, the file  $C.n$  contains the knot  $C_n$ .
- For multi-component links, the file  $C.k.n$  contains the link  $C_n^k$ .

So for example, to load the knot  $10_{102}$  you would type the command “**load 10.102**”

For demo purposes, knots can also be selected at random from the data base by using the command “**knot**” (which can be abbreviated to the single letter **k**). To randomly select a knot with a specific number of components use the command “**knot  $n$** ” where  $n$  is the number of components you want (from 1 to 4). To randomly select a knot from the “special collection”, use the command “**knot s**”. This collection of knots contains a number of unusual knots, or knots in non-standard configurations, as well as several composite<sup>1</sup> knots. Typing **zoo** will give you an array of randomly selected knots.

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## 2.4 Changing the view

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The view seen of the knot or link may be changed by using one of the mouse buttons in the view window. Note that these commands affect only the view seen in the view window. PostScript output is affected by only rotations. Changing the view window has no effect on any geometry exported in the form of surface models or knot files.

### 2.4.1 Rotations

The view may be rotated with the **rotate** command (see below). However it is much simpler to use the “virtual trackball” [?] which can be thought of as enclosing the knot. The best way to learn how to use the trackball is to try it out. Once a knot is loaded, move the mouse to the view window and click down with the left mouse button. Now move the mouse and watch how the knot rotates.

### 2.4.2 Translating

To translate the view, use the middle mouse button in the view window. This is the same as changing the values of **trx** and **try**.

### 2.4.3 Scaling

To scale the view, click down in the view window with the middle mouse button. Move the mouse to the right to increase the scale and to the left to decrease. This action is identical to changing the value of the parameter **scale**.

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<sup>1</sup>A composite knot is a knot that can be cut into several simpler knots (this can be defined rigorously). Tying two knots consecutively in the same piece of string corresponds roughly to the idea of a composite knot. If a knot (or link) is not composite, then it is called *prime*.

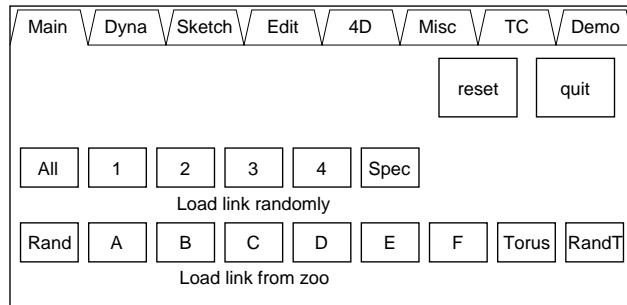
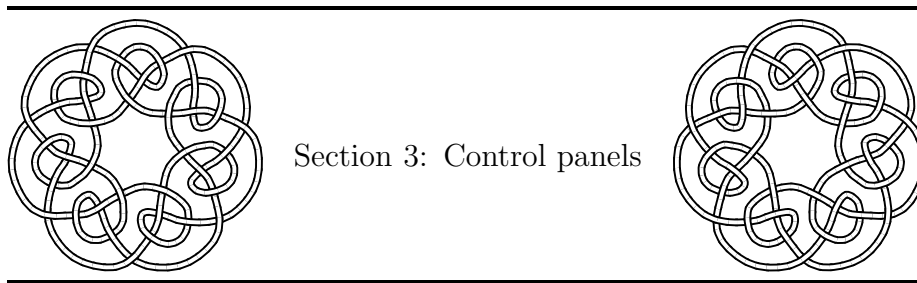


Figure 1: Top part of the main control panel.




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### 3.1 Main control panel

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The top part of the main control panel is shown in Figure 1.

- The tabs at the top of the control panel take you to other control panels, explained later.
- The two buttons in the top row are the most important buttons to know about. If you ever get KnotPlot into a weird state, the **reset** button can usually get back to the startup state.
- Yes, it's true, the **quit** button terminates KnotPlot. You can also do this by typing in the commands 'quit', 'exit', or 'stop', by hitting the ESC-key or by selecting 'exit' from the pop-up menus.
- The next row of buttons loads knots chosen randomly from the knot catalogue. The **All** button chooses a knot from the entire catalogue, the numbered buttons choose a link with that many components. The **Spec** button picks a knot selected at random from the Special Collection.
- A row of nine buttons bring up an assortment of knots in a tabular format. Click on the one you want and it'll be loaded. You can also use the **zoo** command to display the knot catalogue in order, starting from a given point. **Rand** will give you a random selection. The buttons **A** thru **F** display the Rolfsen collection in increasing order. The last two buttons are for torus knots, **Torus** shows torus knots in order of increasing complexity (according to crossing number), **RandT** is a randomly selected collection of torus knots.
- Some of KnotPlot's dynamics may be controlled with the bottom part of this control panel, however, many more options are available on the dynamics control panel. Click on the 'Dyn' button to go there.
- To sketch a knot, click on 'Sketch'. Sketching is explained in a different section.

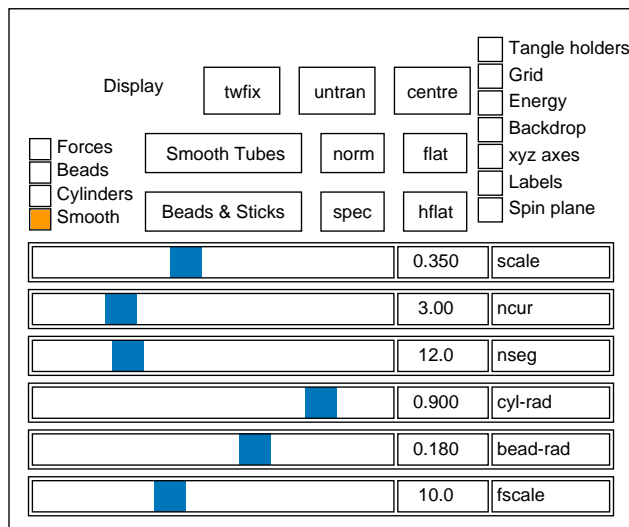


Figure 2: Display part of the main control panel.

- A number of special objects may be drawn along with knots or links. These can be selected using the radio buttons or by using the **special** command.
  - Various kinds of grids, useful when sketching. The parameter **grmode** controls the kind of grid drawn.
  - The knot energy, currently the minimum distance energy as defined by Simon. You can watch the energy change during relaxation. Note that this will slow down relaxation considerably as it is a fairly expensive calculation. It can be useful setting **dstep** to something around 10 to (often greatly) improve performance.
  - A coloured backdrop, just for fun.
  - xyz axes and bead labels.
  - The spin plane. When the spin plane is on it may be moved using the Shift key and the mouse buttons in the view window.

All the buttons and sliders shown in Figure 2 control how the knot is displayed. In addition, some of them will affect any surface geometry exported by KnotPlot. Nothing in this section affects the underlying mathematical object (that is, what is read and written with the **load** and **save** commands).

To get a feel for how things work try loading a knot at random (see above) and then click on the two large buttons labelled **Smooth Tubes** and **Beads & Sticks**. This will show you the two principal methods of displaying knots. The beads and sticks closely approximate the actual mathematical object. KnotPlot starts out in a smooth tube mode, mostly because knots look prettier in this mode.

- You can rotate the view seen in the view window by using a virtual trackball (left mouse) and translate the view by using the right mouse in the view window. These transformations may be undone, and the view restored to the default orientation by clicking on the **untran** button.
- Sometimes, especially if **nseg** is too small, you'll see a funny crimp in the knot or link's surface at the point at which the drawing begins and ends for each component. There are technical reasons for this that are explained elsewhere. For the present you can get rid of this deficit angle by clicking on the **twfix** button (twist fix). There is also a **twfix** command that does the same job (and more).

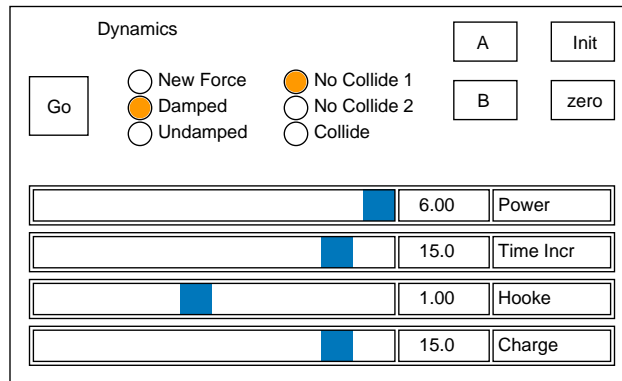


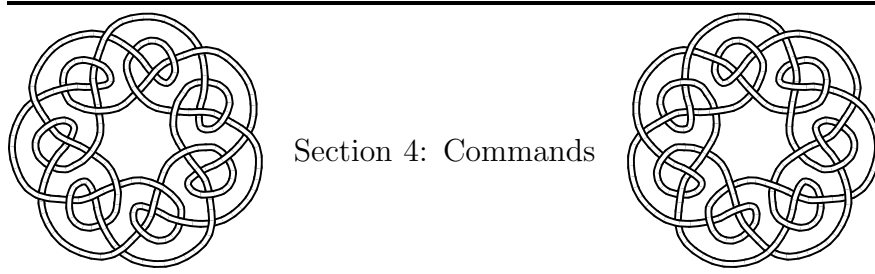
Figure 3: Dynamics part of the main control panel.

- To reset the display, click on the 'reset' button in the right of the display section. This reset button also resets pretty much everything else in the program, including 4D parameters, Postscript output, the dynamics, and what knot.
- Don't ask me why the 'scale' slider is on top all by itself. The drawing scale can also be changed by using the middle mouse button in the view window.
- The **norm**, **spec**, **flat**, and **hflat** buttons need explaining, try them out when you're in 'Smooth Tubes' mode.

The bottom part of the main control panel (Figure 3) allows the dynamical model to be interactively modified.

- The default dynamical model is a damped force law with collision avoidance. This is what you get if you click the **A** button in the dynamics section. The other main force law of interest is an undamped force law without collision checking. You can get this by clicking **B**. Another interesting combination is 'Damped' with 'Collide'. This speeds up the relaxation but allows for possible change of knot type. The 'Init' button initializes the dynamical model to the default setting (including all the slider positions).
- Click on the **Go** button to watch the knot relax. This button will turn green while the knot is relaxing.
- The **zero** button zeros the velocities of all the beads. This is only applicable to undamped relaxations.

All of the parameters for the dynamics may be changed while relaxation is taking place. The same thing applies to any display parameters. Just remember you may have to click and hold down the left mouse button over the control panel until you see some visual feedback in the case where a large knot is being relaxed.



This is a description of some of the commands available in KnotPlot. Commands may be abbreviated to any length. However it is safer to never abbreviate a command to *less than four characters*. Commands are guaranteed to be unambiguous if this general rule is followed. Command arguments that take on numerical values may be set in the same way as parameters (except without an equal sign). See the explanation at the beginning of that section.

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#### 4.1 General purpose commands

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< *filename* — Reads the file *filename* and executes the commands found there. Same as the **read** command.

! *shell-command* — Sends the string *shell-command* to the shell to be executed there.

**alert** *message text1 [text2]* — Pops up an alert box with *message* written in it, and two buttons *text1* and *text2*.

**animate** *parameter start stop steps [linear | log]* — Animates *parameter* from *start* to *stop* in *steps* increments. Defaults to **linear**. The demos directory has several examples of the use of **animate**.

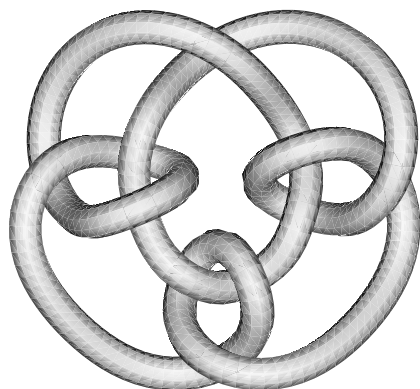


Figure 4: Example picture with **psout** command and **psmode** = 0

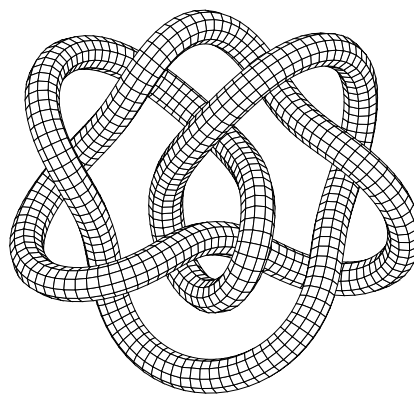


Figure 5: Example picture with **psout** command and **psmode** = 1 (the default).

**exit** — Same as the **quit** command.

**function** *number action* — With no arguments, prints the current binding of the function keys. With one argument, prints the binding for that key. Otherwise the function key *number* is bound to *action*. See the demo files and the knotplotrc file for examples of use.

**information** — Prints out some useful information about the current knot, such as the number of beads and components, and the extent in the three orthogonal directions.

**nap** *number* — Same as **pause** except on SGIs, where there is a difference but not a very interesting one.

**nop** — This command does *nothing at all*.

**panel psout** [*filename*] — Outputs a PostScript representation of the current control panel to the file *filename.eps*. If *filename* is omitted, the output is written to the file *cpanel.eps*.

**panel set** *which* — Sets the control panel to *which*. The same effect can be achieved using the pop-up menus.

**parameters** — Prints the current settings of all parameters.

**parameters** *name* — Prints the value of any parameters starting with the string *name*. For example, **parameters** will print out the values of all parameters starting with 's'.

**path** [*directory*] — If *directory* is omitted, this command prints the current read and write paths.

**pause** *number* — Pauses execution for *number* seconds. This is only useful for sessions run from a script.

**quit** — Same as the **stop** command.

**read** *filename* — Reads the file *filename* and executes the commands found there. Same as the **j** command. It is useful because there are certain contexts where **read** will work but **j** will not.

**rsfunction** — Similar to the **function** command except uses shifted function keys (using the right shift key).

**seed** *value* — Sets the random number seed to *value*.

**sfunction** — Similar to the **function** command except uses shifted function keys (using the left shift key).

**special** *what* — Without an argument, turns off drawing of all specials. Otherwise, *what* may be one of the following:

- **axes** — Turns on drawing of 3D coordinate axes.
- **backdrop** — Turns on backdrop.
- **command** — To be explained elsewhere.
- **intro** — Draws the intro screen.
- **labels** — Turns on drawing of bead labels.
- **monitor** — Draws the text normally seen in the monitor window in the view window as well (doesn't really work at all).
- **sphere** — Turns on drawing of utility sphere.
- **spin** — Turns on drawing of spin plane (see the **spin** command).

If you want to draw more than one special at a time, append the keywords with a '+' sign. Appending a '-' sign will turn off that special without affecting the drawing of other specials. Appending a '' sign will toggle the special without affecting other specials. The spin plane, labels, and axes may also be turned on and off with the radio button in the main control panel and the utility sphere via the pop-up menu.

**statistics** — Prints out some execution info.

**stop** — Same as the **exit** command.

**version** — Prints out some useful information, including how to find the KnotPlot home directory (the root of the KnotPlot distribution) and the resource directory.

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## 4.2 Loading and saving knots and links

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**allocate** *nbeads* — Allocates enough memory for *nbeads* number of beads.

**coords** — Prints out the coordinates of every bead in the current knot.

**coords** *filename* — Same as the above command except this outputs to the file *filename*. These files are made for easy reading by other software. A knot file written with this command may be read by using the **load** command.

**knot** — Loads a knot or link from the catalogue, selected at random. Very useful for demos.

**knot** *n* — Same as above, but loads a knot with *n* components.

**knot number** *n* — Loads the *n*<sup>th</sup> knot or link from the tables. The valid range for *n* is from 1 to 384.

**knot special** — Loads a knot at random from the “special collection” The special collection contains several oddities as well as a few composite knots.

**load** *filename* — Loads a knot from the file *filename*. Note that *filename* may be in any of the formats that the **save** command can write.

**load combine** *filename* — Same as above except a new link is created by combining the current knot and the knot in the file *filename* (*i.e.* creates the union of the two knots or links).

**load sum** *filename* — Same as above except a new knot is formed by creating the direct sum of the current knot and the knot in file *filename*. This command uses the **shift**, **revbeads**, and **translate to** commands to move everything into the correct position. If you find you don’t like the results it gives, you may have to do these operations as well as **cut** and **join** yourself. One limitation is that KnotPlot expects both summands to be *proper knots*.

**save** *filename* [*format*] — Saves the current knot or link to the file *filename*. If *format* is omitted, the file is saved in the format given by the current value of **sformat**. If *format* is an integer, then that value is used as the save format and **sformat** is ignored. Otherwise, if *format* is **float** (or **LOCF**), **short** (or **LOCS**), **char** (or **LOCC**), **ascii** (or **raw**), **ked**, or **ming** then the file is saved with that format instead of the format specified by **sformat** (see the description of **sformat**). Including the second parameter is useful for temporarily overriding the default save format.

**zoo** *start size* — Generates a “knot zoo” of size *size*×*size* starting with the knot number *start* in the standard catalogue. If *size* is omitted, it will default to 5. If *start* is 0, a random selection of knots is loaded. This command uses singlebuffer mode so that the knots can be seen while they are being loaded. Clicking with the left mouse on an image in the zoo will load that knot or link.

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### 4.3 Creating new knots and links

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These commands will create something from scratch. In addition you could load a knot or link from the catalogues with the **load** command or sketch one yourself. See also the **construct** command below, which can be used to construct user-defined things. The commands **chain**, **lissajous**, **2lissajous**, **torus**, and **unknot** are affected by the **new** parameter.

**chain** *ncomp* [*nbeads* *htwists*] — Creates a linked chain with *ncomp* components (which may be either even or odd) of *nbeads* each. If *nbeads* is omitted or zero, it defaults to 9. The parameters **D-chain** and **d-chain** control the geometry of the chain. *htwists* specifies the number of half twists in the knot chain.

**conway** *n* — Constructs the knot with Conway number *n*. Non-rational knots require the appropriate tangle templates to be resident in the KnotPlot distribution.

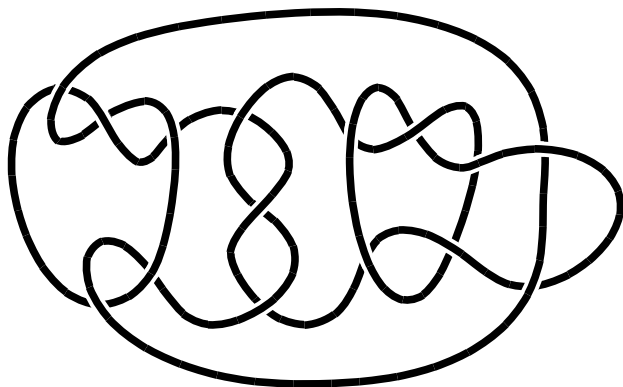


Figure 6: 15 crossing mutant of a 13 crossing knot created with the tangle calculator.

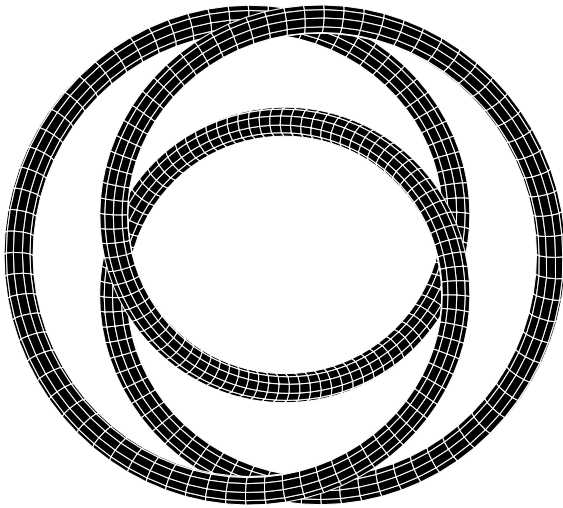
**lissajous** *nx ny nz* [*phix phiy nbeads*] — Constructs a Lissajous knot [BHJS94] of type  $(nx, ny, nz)$  and phase  $(phix, phiy)$  with *nbeads* number of beads. If *nbeads* is omitted, the number of beads defaults to **N-torus**. *phix* and *phiy* both default to 0 if omitted, and that's not too interesting. For best results they should have different values.

**2lissajous** *nx ny nz nk* [*phix phiy phiz nbeads*] — Similar to the **lissajous** command except constructs a 2-mode Lissajous knot.

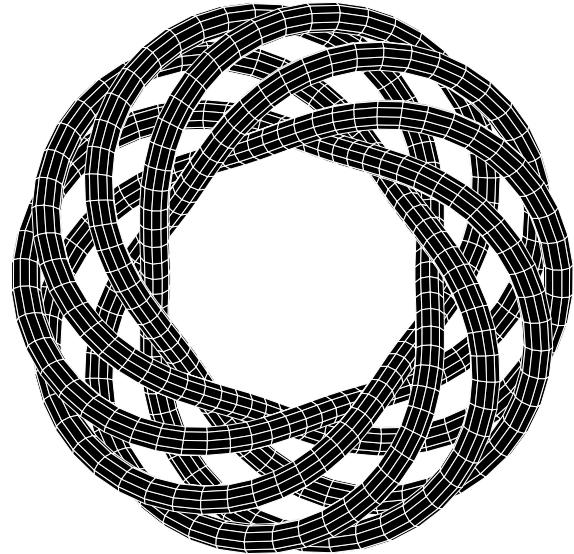
**random tangle** — Creates a random tangle using the tangle calculator. This is one of several methods of creating random knots.

**tangle** *tangle-string* — Uses the tangle calculator to execute the commands in *tangle-string*. See Figure 6 for an example of a knot created with the tangle calculator (this example from a paper by Morwen Thistlethwaite [Thi85]). An interactive version of the tangle calculator can be accessed using the control panel.

**torus** *n m* [*beads*] — Produces the *torus knot*  $K_{n,m}$ . If *beads* is omitted, the number of beads defaults to **N-torus**. If *beads* is zero, then KnotPlot attempts to choose an appropriate number of beads given the values of *n* and *m*. Other parameters controlling how the knot is constructed are **R-torus** and **d-torus**. If too few beads are used, the results can be bizarre. If *n* and *m* are not relatively prime, then a torus link with  $\gcd(n, m)$  components is created. You can also omit *n* and/or *m* to have values chosen randomly. Figure 7 shows a few nice torus knots.



The torus knot  $K_{3,2}$  (the trefoil)



The torus link  $K_{6,10}$

Figure 7: Some nice torus knots.

**unknot** [ $B$  [ $R$ ]] — Creates an unknot with  $B$  beads of radius  $R$ . in the  $xy$ -plane. If  $B$  is omitted, the number of beads defaults to **N-torus**. If  $R$  is omitted, the radius defaults to **R-torus**.

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#### 4.4 Transformation tools

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Knots or links can be transformed into new knots or links using the commands in this section. Other commands that could belong in this section are the **jitter**, **mangle**, and **split** commands as some of these may change the knot type.

**cable** — Takes the current knot and *cables* it. The use of this command is not recommended.

**close** *compA* [**to** *compB*] — With one argument, closes component *compA* if it is open, otherwise closes all components in the range *compA* to *compB*. Without any arguments, prints out information on all components. See the **open** command.

**close all** — Closes all components.

**companion** — Transforms the current knot (one component only) into its “companion” knot. The use of this command is not recommended.

**cut** *bead* — Cuts a component at location *bead*. If the component is closed, it becomes open. Otherwise two open components result. Small components (less than four beads) are automatically reaped. See the **join** command.

**delete**  $n$  — Deletes component  $n$  of the current link. Components are numbered starting at 0. See the **keep** command.

**delete all** — Deletes the current knot or link.

**delete downto**  $N$  — Attempts to remove beads randomly until there only  $N$  left. Will not change knot type.

**double** — Takes the current knot and *doubles* it. The use of this command is not recommended.

**join**  $a\ b$  — Joins together beads  $a$  and  $b$ . Both  $a$  and  $b$  must be the endpoints of an open component. See the **cut** command.

**identify**  $a\ b$  — Identifies bead  $a$  and bead  $b$ . This is how knotted graphs are implemented.

**identify init** — Initializes (unidentifies) all bead identifications. Use this whenever specifying new identifications.

**keep** *component* — Deletes all knot components except *component*. Components are numbered starting at 0. Only makes sense for links. See the **delete** command.

**nbeads** *value* — If *value* begins with a '+' or a '-' sign then the number of beads is incremented or decremented by *value*, otherwise the number of beads is changed to *value*.

**nbeads mult** *fraction* — The number of beads is multiplied by *fraction*. Note that this command may change the knot type.

**open** *compA* [**to** *compB*] — With one argument, opens component *compA* if it is closed, otherwise opens all components in the range *compA* to *compB*. Without any arguments, prints out information on all components. See the **close** command.

**open all** — Opens all components.

**refine** [ $N$ ] — Refines the knot, increasing the number of beads by a factor of  $N$ . If  $N$  is omitted, it defaults to 3.

**revbeads** [*comp*] — Reverses the beads in component *comp*. If *comp* is omitted all beads in each component are reversed. Useful in combination with the **shift** command.

**shift** *distance* [*comp*] — Shifts the bead numbering in component *comp* by *distance*, which may be positive or negative. If *comp* is omitted, all components are affected. Use the **special** command to turn on bead labels.

**swap** *compa compb* — Swaps components *compa* and *compb*.

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## 4.5 Relaxing knots and links

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If you're running in an interactive mode, you should almost never need to enter any of these commands, since everything can be controlled using the main control panel.

**charge** *value* — Sets the charge to *value*.

**collision** [**allow** | **none** | **fast**] — If the argument is omitted, prints the current collision constraint. If set to **allow** collision checking is disabled. Mode **none** is obsolete and should not be used. Defaults to **fast**.

**go** *niter* — Performs *niter* iterations of the knot relaxation. This command immediately returns and other commands (such as **save** and **load** may be used while the knot is relaxing.

**hooke** *value* — Sets the spring constant to *value*.

**power** *value* — Sets the exponent in the dynamical simulation to *value*.

**timeincr** *value* — Sets the time increment to *value*.

---

## 4.6 Graphics display

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These commands affect the display of the knot or link. It is possible that they will also affect any output geometry in the cases where the type of surface (broken, smooth) or quality is changed.

**backface** [**true** | **false**] — Enables or disables removal of backfacing polygons.

**blendfunction** *sfactor dfactor* — Sets the blendfunction (see the GL manual). The parameters must be one of **zero one dc mdc sa msa da mda min-sa-mda sc msc**. This command is an exception to most commands in that abbreviations are not allowed for the parameters. The default is **blendfunction sa msa**.

**cheapo** — Sets **nsegments** to **chnseg** and **ncurve** to **chncurve**. This is useful if a cheaper quality rendering is desired in exchange for a faster drawing time. See **luxo** command.

**clrfun** [*what*] — Sets the clear functions used each time something is drawn. The value supplied for *what* should be one of the following:

- **fz** | **zf** The frame buffer and z-buffer will be cleared (this is the default).
- **z** Only the z-buffer will be cleared.
- **f** Only the frame buffer will be cleared.
- **n** Neither the frame buffer nor the z-buffer will be cleared.

This function is useful for several neat tricks, include painting and getting beads to leave traces during relaxation. Enter the command without an argument to see the buffers which are currently being cleared.

**display** — Forces display to be updated, even if nothing has changed.

**display true** — Forces the display to be updated, even if the parameter **Drawing** is set to **off**.

**dbuffer** — Switches to doublebuffer mode. In this mode, all drawing takes place in an off-screen buffer.

**draw** *what* — Changes the way the knot is drawn. Currently only five settings are of interest:

- **normal** Sets the drawing to its normal setting.
- **spectrum** Draws the knot as a “spectrum”.
- **flat** Draws the knot flat shaded.
- **broken** Draw the knot as a broken surface. Controlled by the **broff** parameter.
- **sbroken** Combines the **broken** and **spectrum** options above.

**luxo** — Similar to **cheapo** above except produces high quality rendering. Sets **nsegments** to **lxnseg** and **ncurve** to **lxncurve**. May be very slow on some machines.

**makeobj** — Makes the current knot loaded into a graphical object. Can greatly speed up the rendering time on some machines. Must be used in conjunction with **mode o** (see below). This command is not needed if a knot is loaded when **mode o** is already in effect.

**mathsv** *material hue saturation value* — Sets the colour of the indicated material. *material* must be one of the following:

**knot** The knot material.

**bead** The bead material.

**arrow** The arrow material.

**4D** The 4D knot material.

*hue*, *saturation*, and *value* must be in the range from 0 to 1.

**matrgb** *material red green blue* — Similar to **mat-hsv** but uses RGB space instead of HSV space.

**mode** *mode* — Sets the drawing mode. *mode* may be one of the following:

**s** Draws the knot as a smooth tube, interpolating between beads depending on the setting of **ncurve**.

**c** Draws cylinders between beads.

**b** Draws the beads.

**f** Draws the force vectors.

**a** Draws the anchors.

**C** Draws identification clusters (for knotted graphs).

**o** Draws the knot as a graphical object. This setting is mutually exclusive of the others.

These settings may be OR'd together, for example **mode cfb** will draw cylinders, beads, and force vectors. Use **mode sc** in conjunction with **draw spectrum** for bizarre effects.

**nonprop** *xs ys zs* — Modifies the current view matrix by a non-proportional scaling factor. Useful for special effects.

**ortho** [*x<sub>s</sub> y<sub>s</sub> z<sub>s</sub>* — ] Sets the view to an orthographic projection with clipping volume  $x \in (-x_s, x_s)$ ,  $y \in (-y_s, y_s)$ , and  $z \in (-z_s, z_s)$ . If the parameters are omitted, appropriate values given the shape of the viewport are chosen.

**rotate** [**x** | **y** | **z**] *angle* — Rotates the current view about the indicated axis by an amount of *angle* degrees. Note this is not the same as the **about** command.

**rotate fix** — Uses the current rotation matrix to modify the embedding of the knot and then resets the view matrix to the unit matrix.

**rotate unit** — Resets the rotation matrix to the unit matrix.

**sbuffer** — Switches to singlebuffer mode. In this mode, all drawing takes place in the on-screen buffer. This way the knot may be viewed as it is drawn. The command **zoo** uses singlebuffer mode.

**twfix** — A command that will automatically adjust **twist** to eliminate the deficit angle seen when **nsegments** is too small. A demo script is available in the demos directory that illustrates the use of this command.

**zbuffer** [**true** | **false**] — Enables or disables z-buffering.

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## 4.7 Geometry commands

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These commands affect the embedding of the knot or link in space. They have no effect on the viewing transform but will affect any surface models exported or anything saved with the **save** command.

**about**  $[x \mid y \mid z]$  *angle* [*comp*] — Rotates component *comp* of the current link about the indicated axis by *angle* degrees. This may appear to be identical to the **rotate** command, but there is a difference. This command modifies the coordinate values of the link, thus affecting any geometric data that might be written out in a file. The **rotate** command simply modifies the viewing transformation. If *comp* is omitted, all components in the link are modified. If *comp* is the keyword **last** then only the last component is rotated. Rotating only one of several components is likely to change knot type.

**breakup** —

**centre** — Translates the knot or link so its bounding is centered at the origin.

**centre mass** — Translates the knot or link so its centre of mass is at the origin.

**fitto** *size* — Fits the knot to a radius of *size*.

**jitter** *distance* — Displaces each bead by a random distance, in a random direction.

**length** — Displays information about the length of each component.

**mangle** *niters*  $\alpha$  *redraw* *centre* — *Mangles* the knot (single component) *niters* times. Each time the knot is mangled two beads are chosen at random and one of the two arcs connecting the beads is rotated about the line through the beads by a random angle<sup>2</sup>. The angle rotated is chosen uniformly between  $-\alpha$  and  $+\alpha$ . If *redraw* or *centre* are omitted then all mangling is done and then the mangled knot is displayed. Otherwise if *redraw* is non-zero the knot is redrawn every *redraw* manglings. The *centre* parameter is used in a similar fashion.

**reflect** *axis* [*comp*] — Reflects component *comp* of the current link about axis *axis* which must be one of **x**, **y**, or **z**. Reflections can be concatenated, for example **refl xyz** will perform an inversion through the origin. If *comp* is omitted, all components are reflected. If *comp* is the keyword **last** then only the last component is reflected.

**scale** *xs ys zs* [*comp*] — Scales component *comp* of the current link by the factors *xs*, *ys*, and *zs* in the obvious directions. Not to be confused with the **scale** parameter. If *comp* is omitted, all components are scaled. If *comp* is the keyword **last** then only the last component is scaled.

**split** — Splits every cylinder in two. Doubles the number of beads.

**split cylinder** *n* — Splits the *n*<sup>th</sup> cylinder in two.

**split** *value* — Splits any cylinder with a length greater than *value*.

**swirl** *angle*  $[x \mid y \mid z \mid r]$  — “Swirls” the knot by the *angle* degrees about the indicated axis. If the second parameter is omitted, it defaults to **y**. Use **r** to have a axis chosen at random. The best way to see how this command works is to try it. May change knot type if too much swirling is done.

**translate** *x y z* [*comp*] — Translates component *comp* of the current link by the vector  $(x, y, z)$ . This is a translation relative to the current location. If *comp* is omitted, all components are translated. If *comp* is the keyword **last** then only the last component is translated.

---

<sup>2</sup>This function was inspired by a talk given by K. C. Millett at the 1993 meeting of the American Mathematical Society in Vancouver.

**translate to**  $x\ y\ z$  [*comp*] — Translates component *comp* of the current link so that its initial bead is located at the position  $(x, y, z)$ . Unlike the above command, this is an absolute translation. If *comp* is omitted, all components are translated so that bead 0 is at the indicated location.

**writhe** — Computes the writhe of the current knot.

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## 4.8 Producing pictures

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These commands produce pictures of one form or another.

**ascii** [*xsize* [*ysize*]] — Makes a cheapo ascii picture of the knot or link. Most useful when running without the command window or without graphics at all (for example over a modem on a VT100 terminal). Assumes that the knot fits into a bounding box of  $(-10, 10)$ . You can use the **fitto** command to ensure this. If *ysize* is omitted, it defaults to  $11/25$  of *xsize*. If *xsize* is omitted, it defaults to 50.

**ppmout** *name* [*squish*] — Outputs what is currently seen in the view window as a *PPM*<sup>3</sup> file. The output is written to the file *name.ppm*. Normally the frame buffer is squished by the factor *squish* in both directions. If *squish* is omitted, it defaults to the current value of **ppm-reduce**. Use a *squish* of 1 to output the frame buffer at full resolution. PPM files are a good, simple, and useful file format for colour images. There are many tools installed on most platforms that can manipulate PPM images.

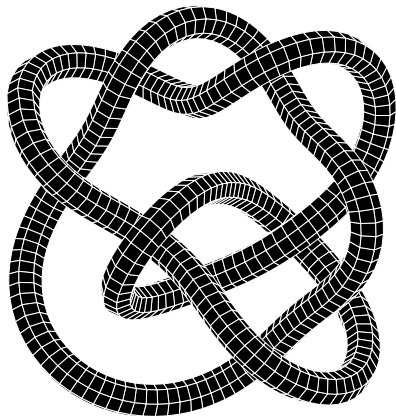


Figure 8: Example picture with **psout** command and **psmode** = 2.

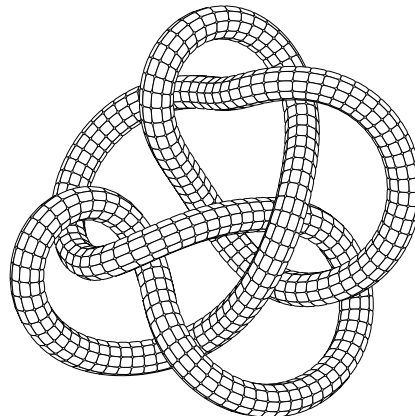


Figure 9: Example picture with **psout** command and **psmode** = 3.

**psoption** *keyword setting* — Sets several options for Postscript output via the **psout** command. Currently, *keyword* can be one of the following:

- **bbox** Changes the kind of bounding box written to the Postscript file. Here, *setting* can be one of
  - **fullpage** Bounding box will be the full page.
  - **smallest** Bounding box will just enclose the figure.
  - **square** Bounding box will be square (this is the default).
- **extension** Sets the file name extension (defaults to .eps)

---

<sup>3</sup>Portable Pix Map.

- **font** Sets the font used for Postscript output. Default is `kbdi/Times-Romani/kbdi`.
- **format**
- **texture** Sets the file used for Postscript textures (applies to `psmode = 30`)

Enter the command without any arguments to see the current settings.

**psout** *name* — Outputs the current knot as a Encapsulated Postscript file (EPSF). This command may be used to produce pictures of the of the type seen in Figure 4. For this command to work properly, the program should be set to **mode s** and **cyl-rad** should be around 1.0. Also, **nsegments** and **ncurve** should not be too high or enormous output files will be produced. Different effects may be achieved by changing the value of **psmode**. Figures 5 and 8 show the results with **psmode** equal to 1 and 2 respectively. The command **twfix** should be used first to eliminate any deficit angle.

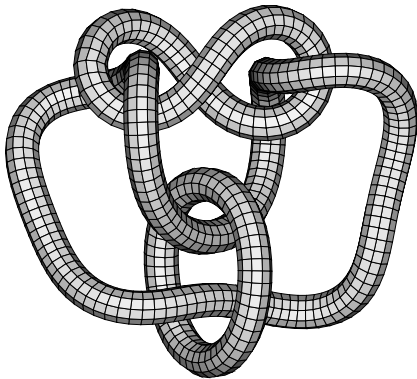


Figure 10: Example picture with **psout** command and **psmode = 4**.

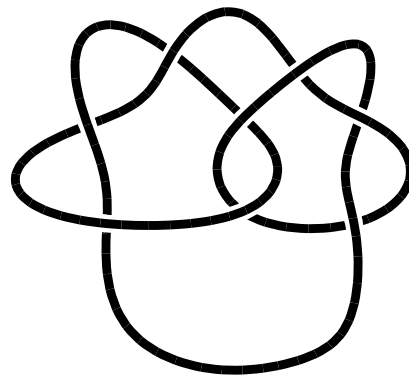


Figure 11: Example picture with **psout** command and **psmode = 40**.

**rawout** *name* — Exactly like the **ppmout** command, except that it omits the header. Use this command instead if you are loading into Photoshop. Outputs to *name.raw*.

---

## 4.9 Exporting surface models

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KnotPlot can export surface descriptions to several other software platforms. **Note that all these commands assume that drawing mode 's' is currently in effect (see the mode command)**. Bizarre effects will occur if this is not the case. Also they work only for one component knots (except for the **objout** command). This is a minor limitation because separate models can be can be exported for each component of a multi-component link (just use the **save**, **load**, and **keep** commands in the right order).

**dxf** *filename* — Outputs a AutoCAD DXF NURBS<sup>4</sup> description to the file *filename.dxf*. The surface is written as a b-spline patch, *which most DXF readers do not implement*.

**objout** *filename* — Outputs a Wavefront OBJ polygon mesh description of the current knot to the file *filename.obj*. If you have a multicomponent link, each component will be written to separate files, with names *filename0.obj*, *filename1.obj*, *filename2.obj*, ...

---

<sup>4</sup>Non-Uniform Rational B-Spline. The surfaces output are actually uniform and non-rational, but that would make them BS surfaces.

**pdfxf** *filename* [*option*] — Outputs a DXF polygonal face description of the current knot to the file *filename.dxf*. If *option* is present and equal to **broken** or if the current drawing function (see the **draw** command) is **broken** the knot is output as a broken surface.

**povray** *filename* — Outputs the current knot as a collection of bézier patches in a format suitable for input into the raytracing program POV-Ray.

**psdl** — Outputs a Alias SDL polygonal face description and model of the current knot to the files *knotD.sdl* and *knotM.sdl*.

**sdl** *filename patchname shadername* — Outputs a NURBS representation of the knot in a format suitable for input into the Alias renderer or raytracer. The NURBS patch is given the name *patchname* and is assigned to the shader *shadername* (defaults are **Knot** and **KnotShader** respectively). The output is written to the file *filename.sdl*. The parameter **atw** should be set to **on** before this command is used.

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## 4.10 Topology commands

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Most of the commands in this section will be of interest to mathematicians. They may or may not be interesting to other people.

**alexander** — Computes the Alexander polynomial for the knot (single component only). Needs Maple somewhere on the system.

**dowker** — Computes the Dowker code [DT83, Thi85] of the current knot (single component only).

**homfly** — Computes the HOMFLY polynomial [FYH<sup>+</sup>85] using an auxiliary program written by Bob Jenkins [?].

**energy** — Computes Simon's minimum distance energy [Sim94] of the current knot or link.

**lnknum** — Computes the linking number.

---

## 4.11 4D commands

---

These commands all deal with four-dimensional knots. Many of these were broken when KnotPlot was ported from IrisGL to OpenGL. Use them at your own risk.

**smovie** *frames*  $i_1$   $i_2$   $i_3$  — Spin the knot in 4D.

**spactivate**  $L_b$   $L_e$  [**on** | **off**] — Enables or disables the drawing of a spun knot in the latitude range  $L_b$  to  $L_e$ . The default is to enable. For example the following script causes only the polar caps and a band 10° around the equator to be displayed.

```
spact -90 90 off           % Turns everything off.
spact -90 -80             % Turns south polar cap on.
spact 90 80               % Turns north polar cap on.
spact -10 10 on          % Turns equatorial band on.
```

Notice that the order of the arguments  $L_b$  and  $L_e$  is irrelevant.

**spdx** *filename* — Outputs a DXF NURBS description of the currently spun knot to the file *filename.dxf*.

**spface** *filename* — Outputs a polygonal DXF description of the currently spun knot to the file *filename.dxf*.

**spsdl** *filename* — Outputs a Alias SDL description of the currently spun knot to the file *filename.sdl*.

**spin**  $\theta \phi \chi$  — First spins the knot about the spin plane. Then performs three rotations in 4-space by the given angles about the planes specified by the **saxes** command. Final result is a knotted 2-sphere in 4-space (see figure 12).

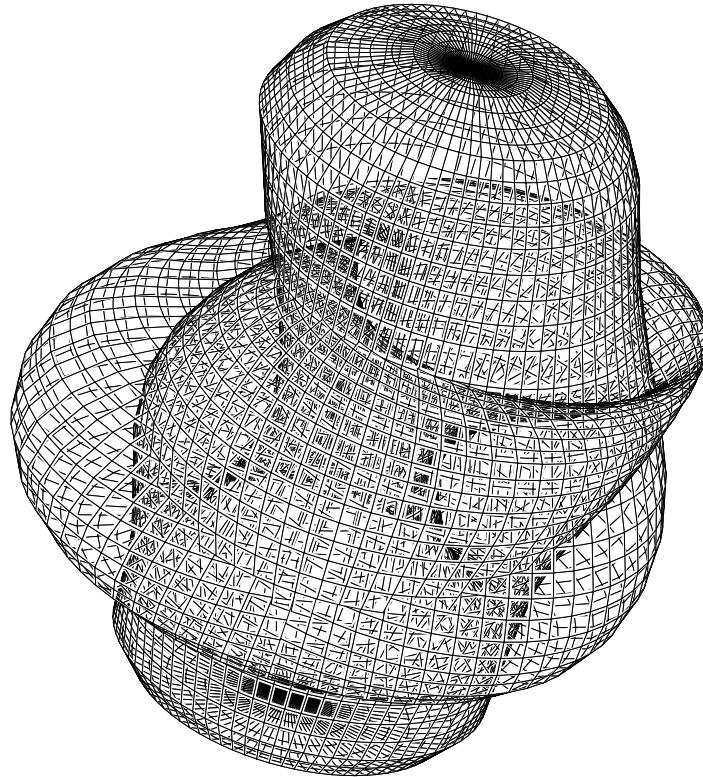


Figure 12: +1-twist spun trefoil. Although not apparent here, this 2-sphere is unknotted in 4-D.

**splane** [*bead1 bead2 [angle]*] — Without any arguments, prints out the current settings for the spin plane. Otherwise draws the spin plane between beads *bead1* and *bead2* and sets the spin plane angle to *angle* degrees. This command will turn on the drawing of the spin plane. You can also turn the spin plane on and off with the **special** command or by using the radio button in the main control panel.

**4dplane** *plane axis1 axis2* — Sets a plane in which four dimensional rotations are performed. With no arguments prints the current settings of the rotation planes.

**4dto3d** *projection* — Sets the method of projection from 4D to 3D for the higher dimensional surfaces. Currently *projection* must be one of the following:

**ortho** uses an orthographic projection.

**persp** uses a perspective projection. The distance of the 4D-eye from the origin is set via the parameter **4deye**.

**hopf** this uses the Hopf mapping from 4D to 3D. Can be expected to produce weird results.



- `\rra` A real number chosen uniformly in the range 0 to  $a$  (inclusive). For example, `\rr1` will choose a number from 0 to 1.
- `\rr+-a` A real number chosen uniformly in the range  $-a$  to  $a$  (inclusive).
- `\ri[a/b]` An integer chosen uniformly in the range  $a$  to  $b$  (inclusive).
- `\ria` An integer chosen uniformly in the range 0 to  $a$  (inclusive).
- `\ri+-a` An integer chosen uniformly in the range  $-a$  to  $a$  (inclusive).

An example using all of the above is in the demos directory.

---

## 5.2 Changing the display

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All the parameters in this section affect only the display as seen on the screen. They have absolutely no effect on the actual surface geometry.

**auto-colour** — If **auto-colour** is **true**, the parameter **hincr** is automatically set when loading a knot or creating a new one, the value of **hincr** depending on the number of components. Set **auto-colour** to **false** to turn off this action (default is true).

**background** — The background colour of the view window. Normally set by specifying a hex value (see the note above, default is 0x444444).

**Drawing** — Turns on or off drawing (default is on).

**drecaps** — Controls whether or not end-caps are drawn for open components. End-caps are not properly drawn in KnotPlot currently, set this parameter to **false** to turn off the drawing. This problem should be fixed in upcoming versions of the software, eliminating the need for this parameter (default is true).

**grmode** — Grid mode, 1 is a rectangular grid, 2 is a pie grid. Use the **3doptions** command to change the colours used to draw the grid.

**grsize** — Size of the grid (default is 10).

**grspace** — Minor spacing between lines on the grid (default is 1). Set to 0 to turn off minor spacing.

**grSpace** — Major spacing between lines on the grid (default is 5). Set to 0 to turn off major spacing.

**hstart** — 'Hue start', the hue of component 0 in smooth tubes mode. Valid range is from 0 to 360 (default is 250).

**hincr** — 'Hue increment', the difference in hue between consecutive components in smooth tubes mode (default depends on number of components).

**saturation** — The colour saturation of the surface while in smooth tubes mode. Valid range is from 0 (no saturation, colours are grey) to 1 (maximum saturation, this is the default).

**scale** — The drawing scale (default is 0.35). Not to be confused with the **scale** command.

**trx try trz** — The offset in the three directions of the displayed knot. Using the right mouse button in the view window is the same as changing **trx** and **try**.

**value** — The 'value' or brightness of the surface while in smooth tubes mode. Valid range is from 0 to 1 (default is 1).

---

### 5.3 Surface geometry

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All of the parameters in this section affect both the display seen on the screen and any surface description output to another program (DXF, SDL, etc.).

**cyl-rad** — The radius of the cylinders or smooth tubes when drawn (0.35). This parameter may also be set using the 'cyl-rad' slider on the main control panel.

**nsegments** — The number of sides of the drawn cylinders. Increase this for better rendering, decrease for faster rendering (default is 12). This parameter is changed by the **luxo** and **cheapo** commands. This parameter may also be set using the 'nseg' slider on the main control panel.

**ncurve** — The number of interpolations (segments) drawn between each bead using **mode s** (default is 3). This parameter is changed by the **luxo** and **cheapo** commands. This parameter may also be set using the 'ncur' slider on the main control panel.

**broff** — The size of the 'broken offset' when in drawing modes 'brok' or 'sbro' (default is 0.1).

---

### 5.4 Creating new knots and links

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These parameters control various settings related to the creation of new knots and links.

**D-chain** — The radius of the entire link created with the **chain** command (default is 10).

**d-chain** — The radius of individual components in a link created with the **chain** command (default is 0.75).

**d-torus** — The smaller radius used in constructing a knot with the **torus** command (default is 2.75).

**new** — If **true**, everything is deleted when new knots or links are created with commands such as **chain** or others (see the section on creating new knots and links to see which commands are affected by this parameter). Set to **false** if you want to keep the old knot or link while adding a new one (default is **true**).

**N-torus** — Number of beads in knots constructed with the **lissajous**, **torus** or **unknot** commands.

**R-torus** — The larger radius used in constructing a knot with the **torus** or **unknot** commands (default is 8.25).

---

### 5.5 Relaxation of knots

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These parameters affect the dynamical system run on the knot or link during the relaxation simulation.

**bencon** — Parameter controlling the magnitude of bending forces (default is 1.0).

**bendforce** — Sets bending forces on or off (default is off).

**close** — The closest distance that the cylinders are allowed to approach in the dynamical simulation (default is 0.12).

**dstep** — Normally when KnotPlot is relaxing a knot, the knot is displayed at each iteration step. On some machines, especially those with slow graphics but fast CPUs, it is often preferable to draw after several iterations. Setting this parameter to a value greater than one will cause KnotPlot to draw every **dstep** iterations during knot relaxation.

**elecforce** — Sets the 'electrical' force on or off (default is on).

**iteration** — Current iteration count (the number of relaxation steps).

**max-dr** — The maximum distance beads are allowed to move each relaxation step. In order for the relaxation to preserve knot type, this parameter should be less than **close** above (default is 0.1).

**mechforce** — Sets the 'mechanical force' on or off (default is on).

---

## 5.6 Four dimensional knots

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These are the relevant parameters for four dimensional knot construction and display.

### 5.6.1 Constructing the knot

These parameters are used to define the surface constructed in the spinning or suspension process.

**4dss** — the number of spin sections created (the number of vertices along a line of latitude) (default is 30).

**4dspangle** — the angle of the spin plane (can also be set with the **splane** command).

**4dw** — suspended knots are constructed "hanging" from the points  $(0, 0, 0, w)$  and  $(0, 0, 0, -w)$  where  $w$  is the value of this parameter.

### 5.6.2 Displaying the knot

These parameters control the display of the knot (or related objects).

**4deye** — this sets the distance of the 4D eye point. Only relevant to the perspective projection.

**4dw** — this controls the length of the coördinate axes and the size of the bounding hyper-cube.

**4dda** — (**true** or **false**) display the four coördinate axes (**false**).

**4ddc** — (**true** or **false**) display a bounding hyper-cube (**false**).

**4ddk** — (**true** or **false**) display the knot itself (**true**).

**4dsm** — the way the knot surface is displayed. The possible values are

**0** — draw as a shaded surface.

**1** — draw as a wire frame coloured according to latitude on the sphere.

**2** — same as 1 except draw latitude lines only.

**3** — same as 1 except draw longitude lines only.

- 11 — draw as a wire frame but colour according to the value of the dimension lost in the projection from 4D to 3D.

Portions of the knot's surface can be selectively enabled or disabled using the **spactivate** command (for example, to view the northern hemisphere only).

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## 5.7 Postscript pictures

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There are several parameters controlling how Postscript pictures are generated. Also, provision is made in the Postscript file for easy editing if something unusual is required.

**psbackface** — If **true**, backfacing polygons are removed when outputting a Postscript file. In certain situations, such as when using a 'broken' drawing function, you might want to see backfacing polygons. If so, set this parameter to **false** (default is **true**).

**psmode** — Will affect the type of Postscript output generated. Defaults to 1. Modes 1 and 2 generally produce smaller files and print faster than mode 0. Modes in the "forties" produce the smallest files of all, and print much faster too. Possible values for **psmode** are:

- 0 — smoothly shaded surface (see Figure 4).
- 1 — white polygons with black outline (see Figure 5).
- 2 — black polygons with white outline (see Figure 8).
- 3 — same as mode 1 except the polygons are slightly rounded (see Figure 9).
- 4 — flat shaded (see Figure 10).
- 5 — similar to mode 0 except a pattern can be specified.
- 10 — output colour Postscript with colours similar to those seen with the drawing mode set to **draw norm**.
- 11 — same as mode 10 except use colours as in drawing mode **draw spec**.
- 30 — Allows a texture map in the form of a *PGM*<sup>5</sup> file to be specified.
- 40 — Simple rendering with a black curve (see Figure 11).
- 41 — Same as mode 40 except black and white are swapped. This gives a similar rendering to the knots and links found in Appendix C of *Knots and Links* (the links in the section headings are in this format, as well as the "infinity" symbol at the end of this manual)
- 42 — Intended to be an improvement over mode 40 but I'm not quite sure. All these modes need some minor improvements. Note that you'll have to make **cyl-rad** smaller with this mode to get similar results to using mode 40.
- 43 — The mode corresponding to mode 42 with black and white swapped.
- 104 — Maps a random Truchet pattern on the surface.

**psN** —

**psM** —

**pssort** — Hidden surfaces are handled in the Postscript rendering by using the 'Painter's algorithm', that is by drawing the polygons back to front. In order to do this, the set of polygons is normally sorted. Set this parameter to **false** to override this default behaviour.

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<sup>5</sup>Portable Grey Map

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## 5.8 Miscellaneous parameters

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### 5.8.1 That twisting stuff

A demo script is available in the demos directory that illustrates the use of the following.

**aftwist** — Usually **off**, set to **on** if you want knots to be automatically **twfixed** when they are loaded. Note that **twfixing** is done when using the buttons on the control panel are used to load something at random.

**atw** — A flag normally set to **off**, but some commands such as **dx** and **sdl** will set it to **on** because they require that the coordinate frame of the smooth tube match up exactly.

**twdefault** — The twisting value used upon loading if **aftwist** is **on**.

**twist** — The amount of twist in milli-radians per segment (best see me for an explanation). Default is 0. Basically, this is a way to eliminate the deficit angle seen at the tie-point in the knot. To eliminate the deficit angle, first set **twist** and then enter the command **twfix** (or just give the value as an argument to **twfix**). Interesting effects can be produced by setting **nseg** = **3** and using a **twist** of around 100.

### 5.8.2 Other parameters

**silent** — KnotPlot will not print anything if this parameter is **true** (default is **false**).

**sformat** — Format used to save knots or links with the **save** command. See the documentation on file formats.

**0** — KnotPlot LOCF **float** format.

**1** — KnotPlot LOCS **short** format. Files saved with this format are about half the size of those saved with the LOCF format. However, a small amount of noise is introduced to the limited precision of short integers. Users should beware of accumulated errors if files are repeatedly loaded and saved with this save format in effect. Most of the knot and link files distributed with KnotPlot are stored in this format.

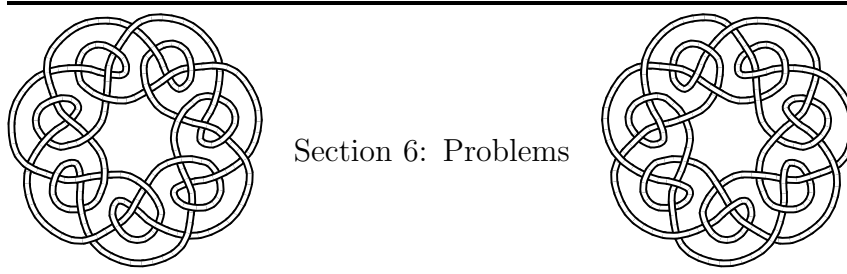
**2** — KnotPlot LOCC **char** format. Files saved with the LOCC are only half the size the equivalent LOCS file and a quarter the size of an equivalent LOCF file. However, the same warning applies to the use of this file format as was given for the LOCS format, only more so. This format is very useful, however, for large animation databases.

**3** — Raw ascii (same format as used by the **coords** command).

**4** — Ascii format suitable for input into Kenny Hunt's KED program. Cannot be used for multi-component links.

**5** — Similar to KED format except suitable for input into Ming. Cannot be used for multi-component links.

**14** — KnotPlot LOCD **double** format. Useful if you need to retain the full precision of KnotPlot's internal representation.



This section documents some problems associated with the operation of KnotPlot and possible solutions. Problems with KnotPlot can be described as caveats, limitations, or just plain bugs.

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## 6.1 Caveats

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These are problems that may occur because of various design flaws in KnotPlot. Unlike true bugs, however, I have no intention of fixing them. They are listed here hopefully to prevent confusion.

**Problem:** Some commands and parameters have the same four letter abbreviation, an example is **backface** and **background**. This is not really a problem, even when they are abbreviated to four letters because commands and parameters are used in different ways.

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## 6.2 Limitations

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Problems in this section are just the way KnotPlot normally behaves, for better or for worse.

**Problem:** Knot components don't join up properly, an ugly crimp is seen.

**Solution:** Use the **twfix** command or the 'twfix' button on the main control panel.

**Problem:** Ugly bends seen when in Smooth Tubes mode.

**Solution:** Relax the knot a bit.

**Problem:** Knot takes forever to draw.

**Solution:** Reduce the value of **nsegments** or **ncurve**.

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## 6.3 Bugs

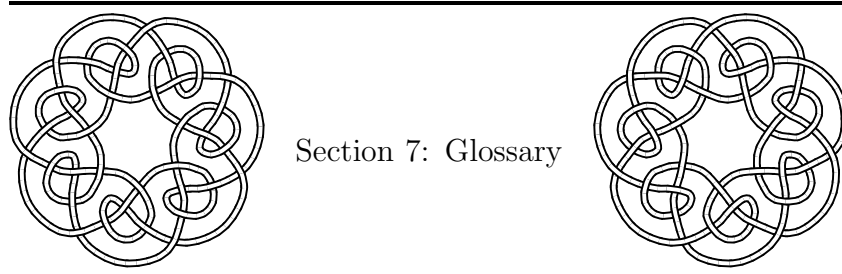
---

**Problem:** **psout** sometimes produces poor output when **psmode** is in the "forties".

**Solution:** Use the **refine** command before exporting to PostScript.

**Problem:** Lack of many problems in this section, other problems encountered with KnotPlot, getting KnotPlot to export models to raytracers....

**Solution:** See me!



**knot** — An embedding of the unit circle into three dimensions. Be warned that I often refer to *links* as knots in this manual.

**link** — A collection of (more-than-one) disjoint embeddings of the unit circle into three dimensions. Sometimes I call one component links knots in this manual.

**PGM** — **P**ortable **G**rey **M**ap file format. This is the grey-scale version of the **PNM** format.

**PNM** — **P**ortable **a**Ny **M**ap file format. Actually a collection of file formats. **PNM** files (the raw versions) are good, simple, and useful file formats for colour, grey scale, and binary images. There are many tools installed on most platforms that can manipulate **PNM** images.

**PPM** — **P**ortable **P**ix **M**ap file format. The colour version of the **PNM** format. The view window can be output as a PPM file using the **ppmout** command.

**proper knot** — Following Conway [Con70] a proper knot consists of exactly one component.

**torus knot** — A torus knot is a knot that can be drawn on the surface of a standard torus without self-intersections. Use the **torus** command to generate one. See Figure 7.

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