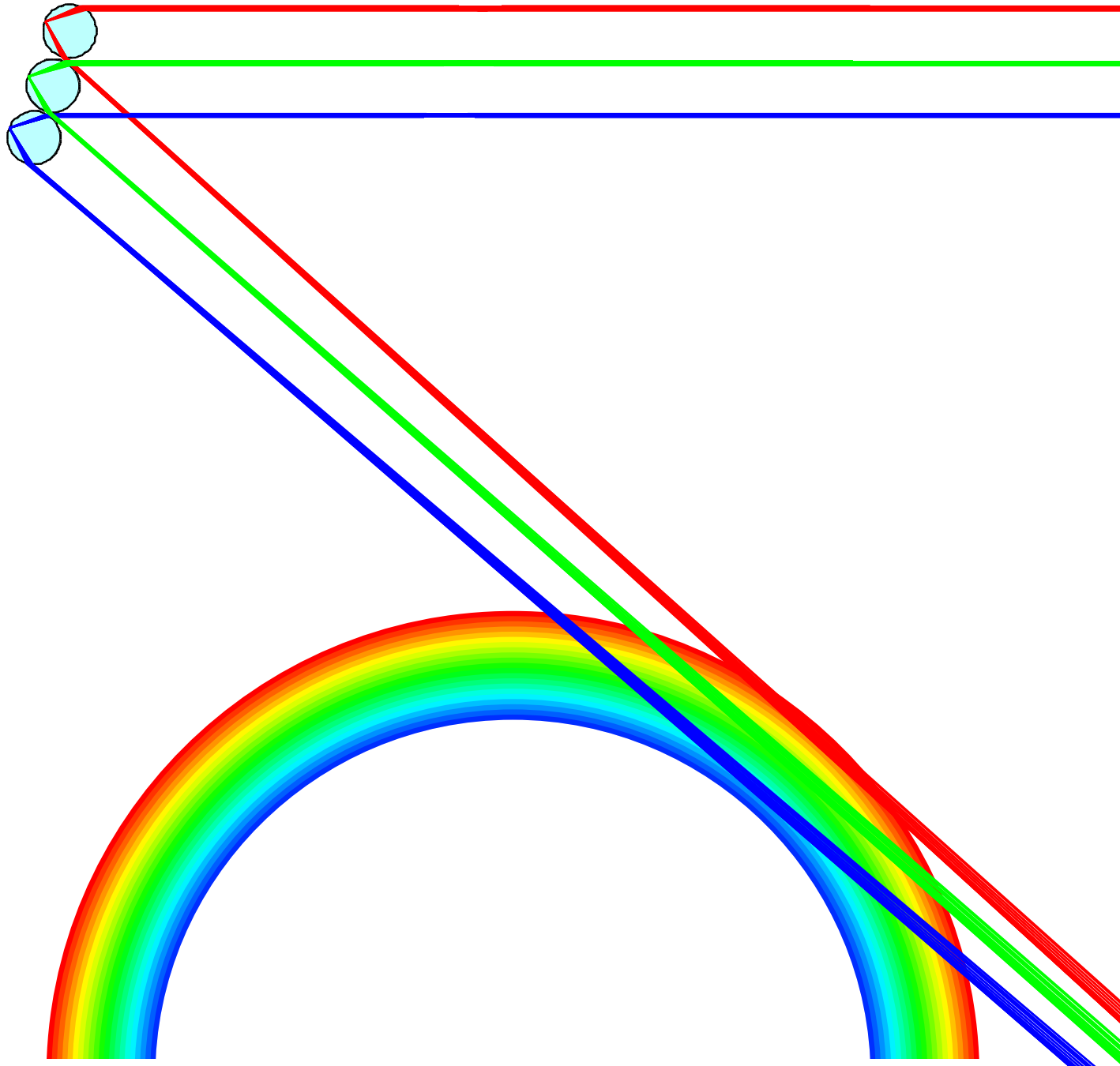
RAYTRACE

Reference Manual



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Contents

Introduction

The purpose of this manual is to provide detailed information on the use of all Raytrace features. The manual is organised in the same way as the Raytrace menu structure. If you don't know which menu might contain a function you are looking for then try the index.

Use this manual for reference once you are familiar with the basic operation of Raytrace. Once you have installed Raytrace or if Raytrace has already been installed for you then read the section **Essential reading** in the tutorial manual.

Conventions used in Raytrace manuals

Menu items are referred to using the notation:

Menu name -- item name

for example: **File -- Save As**.

In the case of further levels of popup menu the notation

Menu name -- popup name > item name

is used, for example: **Edit -- Select All > Rays**

Where examples are given, any actions which you should actually perform are indicated by an asterisk, indentation and a different font, e.g.

* Perform this action

System requirements

Raytrace requires a minimum of an IBM AT compatible 286 PC running Microsoft Windows 3.1 or later with a 3.5" floppy disk and a mouse installed.

Raytrace can be run from a floppy disk if necessary but it is recommended that you install it on your hard-disk. Less than 1.5 Mb of hard-disk space is required for complete installation.

Raytrace works best with a VGA display with 800 x 600 resolution but will function at high or lower resolutions.

Because of the intensive calculations that are involved in animating ray diagrams, it is recommended that you use the fastest computer you can find and preferably one equipped with a maths co-processor. A 486DX-33 or higher is recommended.

If you have purchased a site license then you can install Raytrace on a networked system. Raytrace runs under Windows 95 and Windows NT.

Installing Raytrace

Installing Raytrace is simply a matter of copying all the files supplied on the floppy disk into an appropriate sub-directory on your hard disk and creating a program icon in the Windows Program Manager. Use the following steps as a guide and refer to the Window's Users Guide if you are unsure.

* Using the Windows File manager choose the menu item **File -- Create Directory**, and create a new sub-directory on your hard disk for Raytrace, e.g. C:\RAYTRACE

* Copy all the files supplied on the floppy disk into this new directory.

* In the Windows Program manager, open the group in which you want the Raytrace icon to appear and choose the menu item **File -- New**, choose the **Program Item** option and then the **Browse** option to specify the RAYTRACE.EXE file in the sub-directory you created above.

Installation will then be complete. When Raytrace is run the first time it will automatically perform any remaining set-up that is required.

Un-installing Raytrace

Raytrace does not alter any system files. To remove it from your system simply delete all the files in the Raytrace directory and remove any icons that you may have created for Raytrace from groups in the Program manager.

If you find a bug

Raytrace has undergone several years of testing, upgrading and de-bugging. However, there is always the possibility that something has been missed. If you think you have found a bug then check the documentation carefully - there are some things that Raytrace just cannot do! If you still think it is a bug then please document, as carefully as possible, what you were doing when the problem arose (include any script listings, copies of relevant ray files and any information reported by Windows in the event of a crash) and contact IME Software by email, fax or mail (contact details appear in the opening dialog box which can be also be accessed from **Help -- About**).

The following statements are not a guarantee and in no way extend the statement of warranty contained in the end user licence agreement. However, to demonstrate its high regard for its customers, IME Software will endeavour to rectify any identifiable bug as quickly as possible and supply you with new copies of the relevant files via electronic communications. If you do not have access to email or ftp facilities then IME will attempt to notify you when the problem has been rectified and will supply updated copies of the files on disk for the cost of disk, postage and packaging.

If you have a suggestion

If you have a suggestion for improving Raytrace then please do not hesitate to send it to IME Software. Many of the existing features of Raytrace arose from user feedback. IME Software endeavours to incorporate useful suggestions where-ever possible within the existing framework of the program. If your suggestion is particularly useful then IME Software will try and supply you with an updated copy of the program as stated above.

File menu

File -- New

Choosing this menu item clears the entire contents of the ray diagram and changes some settings to their default values.

Settings that are changed are:

- **Defaults -- Ray settings...** and
- **Defaults -- Child Rays...**
- The **Reflect if no refraction** and **Refract** fertility options are set, all others are cleared.

- All items in the **Options -- Show >** sub menu are checked. This means all object types will be visible.

- **Modify -- Pause Trail update** unchecked.

If you want to clear the ray diagram without resetting these options then use **Clear -- All**.

File -- new also returns the zoom setting to its default value so that one drawing unit is equal to one display pixel and the coordinate origin is set to the centre of the Raytrace window.

You can recover from using this command with **Edit -- Undo**.

File -- Save

Choose this menu item to save the diagram under the current filename (indicated in the Raytrace title bar). The previous copy of the ray diagram is over-written. If the current diagram was created from scratch and there is no filename in the Raytrace title bar then the action is the same as **File -- Save As**.

File -- Save As

Choose this menu item to save your ray diagram to a file of a different name. A standard Windows "Save As" dialog box will appear.

By default the "Save As" dialog box starts with the directory specified by **Work files:** in the **File -- Directories...** dialog box.

Enter the name of the file and click on **Ok** or double click on one of the existing file names displayed in the file list box.

By convention, files should be saved with the extension **.ray** but this is not necessary - you may use any extension or omit the extension.

You will be prompted if you try and overwrite an existing file.

All default settings and options, including the Raytrace window size and position but excluding the settings of **Options -- Update on ray drag** and **Options -- Update on element drag** are saved with the file.

File -- Open

Choose this item to load a ray diagram from a file. A standard Windows "Open" dialog box will appear.

By default the "Open" dialog box starts with the directory specified by **Work files:** in the **File -- Directories...** dialog box.

Enter the name of the file and click on **Ok** or double click on the filename in the file list box.

You must enter the extension if you type in the filename.

If you meant to save the existing ray diagram before opening a new one then you can recover with **Edit -- Undo**. However, if you do this, note that the filename will stay as that of the most recently opened file; it does not revert to the name of the file that was in use before you used File -- Open. Hence you should use **File -- Save As** to save a diagram recovered in this way, not **File -- Save**.

All default settings and options except **Options -- Update on ray drag** and **Options -- Update on element drag** are set to those which were active when the file was saved. This includes the size and position of the Raytrace window.

File -- Directories...

Choosing this menu item starts a dialog box which allows you to change three directories that are important to Raytrace. The usage of these directories is described below. Normally for single user systems you can ignore these settings as they are set to sensible defaults when Raytrace first starts. However, if you install a site license copy of Raytrace on a networked system then you may need to pay some attention to these settings.

If you specify the properties for the Raytrace icon when installing it under Window's Program Manager then you must set the working directory (do not confuse this with Raytrace's "Work files" directory) to the directory which contains the files RAYTRACE.EXE and RAYTRACE.ID.

The **File -- Directories...** settings are saved in a file called RAYTRACE.DIR which is created in this working directory specified by Program Manager the first time Raytrace runs.

System files

This is the directory in which Raytrace expects to find the help file, RAYTRACE.HLP, and the material file, RAYTRACE.MAT and the identity file RAYTRACE.ID. It is also the directory which is used by default when selecting an element library file (extension .ELB) although you can select an element library file from any directory.

Undo file

This is the directory in which Raytrace will store the files associated with the **Edit -- Undo** function. On a networked system the user must have read/write permission for this directory and it should be unique for each user.

Work files

This is the default directory that is used when you save or open a ray diagram; although you can save or open a file in any directory. On a networked system it should be set to the directory in which the user to save their files.

When entering directory names in the **File -- Directories** dialog box the final backslash character must be present. For example, C:\RAYTRACE\ not C:\RAYTRACE

If you leave a directory blank then the Windows working directory discussed above is used by default.

File -- Button bar >

This sub-menu contains items that control Raytrace's button bar. These are listed and discussed below.

On/Off This menu toggles controls whether the button bar is visible or not. If you turn the button bar on without having a button bar loaded then you will get a blank button bar.

Save Saves the current button bar to a file.

Load Loads a button bar from a file. Note that when Raytrace starts it always loads the button bar file that was most recently loaded using this menu item. If you modify the button bar and save it under a new name using the previous menu item, then

exit Raytrace and re-start it, the old button bar will be loaded not the modified version. To overcome this simply load the new version and from then on it will be the default.

Add a button You have two choices when adding a button. You can choose to have the button access a Raytrace menu item or you can have it run a Raytrace script file directly. A dialog box appears for you to make your choice in. After you select one of the options presented, either:

For accessing a menu item - choose the menu item as you would normally
For running a script - select the script file in the dialog box that appears.

In both cases you then have to select the bitmap file that contains the bitmap you want to appear on the button face. This bitmap should be no bigger than 62 pixels wide by 24 pixels high. The best way to make your own bitmaps is to edit one of those supplied with Raytrace.

Delete a button After choosing this menu item, confirm that you want to delete a button by clicking on **Ok** in the dialog box which appears and then click on the button you want to delete. You can scroll up and down to find the button after choosing this menu item if you want.

Move a button Choose this menu item then follow the directions given to you on screen. You can position a button "before" (either above or to the left of depending on the button bar orientation) any other button. To put a button at the end of the button bar you need to move it to second last then move the last button in front of it.

Horizontal/Vertical Controls whether the button bar appears down the left side of the Raytrace window or across the top of the window. You can generally see more buttons at once on a vertical button bar.

File -- Print

Choosing this menu item will cause Raytrace to print the current view of the ray diagram. A standard Windows "Print" dialog box will appear. The diagram will be scaled so that the visible window fits the page. If the **Zoom -- Freeze aspect** option is unchecked then the aspect ratio of the ray diagram will be changed so that the portion visible in the Raytrace window exactly fills the entire printer page.

File -- Create Metafile

Choosing this menu item will cause a Windows metafile called RAYTRACE.WMF to be created in the working directory. The file will contain the meta graphics commands which will draw the ray diagram. You may be able to import this type of file into some drawing or word processing programs or use the file in other ways. You will generally find that using the **Edit -- Copy** command to transfer the ray diagram, or parts of it, to the Windows clipboard is the best way to export to other applications. This menu item is provided as a second avenue for exporting the ray diagram image or in case you need an explicit metafile for some purpose;.

File -- Run Script

This menu item lets you choose and run a Raytrace script file. Script files give you the facility to pre-program demonstrations, student tasks or sequences of complicated operations so that they are readily accessible to those without a full operating knowledge of Raytrace. See the RayScript reference manual for more information on the creation and use of script files.

File -- Quit

You may exit Raytrace at any time simply by choosing this menu item.

If you exit by mistake without saving your work, you can recover the lost work by restarting Raytrace and immediately choosing **Edit -- Undo**.

Edit menu

Edit -- Undo

Choosing this menu item will "undo" the previous modification made to the ray diagram. Up to five operations may be undone. The number of operations that are available for undoing is indicated in the menu.

Zooming cannot be undone; instead, use **Zoom -- Previous**.

A change in the selection of objects cannot be undone.

The undo operation uses a set of files created in the Raytrace undo directory (see **File -- Directories...**). These files are modified whenever you perform some action on the ray diagram. If you are running Raytrace from a floppy disk then the undo directory will default to the floppy disk and you will notice a significant pause while the files are updated. If you need to run Raytrace from a floppy disk, try and set the undo directory to a temporary directory on a hard-disk to increase the operational speed.

Edit -- Delete

Choosing this menu item will delete any selected objects from the ray diagram.

Deleting a ray that you have drawn will delete all the child rays associated with it.

Deleting a child ray will have no effect since it will be regenerated by its parent ray. You must change the parent ray fertility (see **Modify -- Rays...**) to remove any unwanted child rays.

You can press the **Del** key to perform the same operation as this menu item.

Edit -- Select All >

This sub-menu contains six items which are the types of object that can appear in a Raytrace ray diagram, i.e. **Rays**, **Elements**, **Tape measures**, **Protractors**, **Annotations** and **Trails**.

Choosing any of these items does just what it says; it causes all the objects of the specified type to be marked as selected. You might want to select all rays so that you can change their properties (see **Modify -- Rays...**) or you could select all protractors and change the readouts from degrees to radians (see **Modify -- Protractors...)**. **There are** similar operations which you might want to perform on the other types of object.

To delete all objects of a given type use the items in the **Clear** menu rather than selecting them all and using **Edit -- Delete**.

Edit -- Select Child Rays

Choosing this menu item causes all the rays that exist as a result of the currently selected rays to become selected too. This can be useful to calculate path lengths or for copying rays (see **Edit -- Copy**) with their fertility structure.

Edit -- Select Group

Select an element and then use this command to select all other elements associated with the group (see **Modify -- Element > Group**). If the selected element is not part of a group then this has no effect.

Edit -- Select extended

Use this menu item if you want to select a number of elements in a region of the diagram. A shortcut key for this action is **Shift+F3**. This works by selecting all the elements that lie within or cross the borders of a rectangle. You define the rectangle by clicking at diagonally opposite corners after choosing this menu item.

Edit -- Cut

Copies the selected objects to the clipboard and removes them from the ray diagram. The objects can then be pasted into other ray diagrams or at a different position in the current diagram.

You must select a base point which will be mapped onto the point you pick when you paste the objects back into the diagram.

Edit -- Copy

If any objects are selected then this menu item copies them to the clipboard. The objects can then be pasted into other ray diagrams or at a different position in the current diagram.

You must select a base point which will be mapped onto the point you pick when you paste the objects back into the diagram.

If no objects are selected then the visible portion of the ray diagram is copied into the clipboard - this can then be pasted into other drawing packages or word-processing programs. This cannot be pasted into a ray diagram since it is only a copy of the picture not the information about the objects that all calculations for the ray diagram are based on.

Edit -- Paste

Inserts the contents of the clipboard (which must have been set by using either **Edit -- Copy** or **Edit -- Cut** in Raytrace) into the ray diagram. You must select a point onto which the base point picked when cutting or copying will be mapped.

Edit -- Library > Paste from...

An element library contains a list of elements which have been pre-defined. You can paste these into your ray diagram rather than having to draw new elements or cut and paste elements from other ray diagrams. You can save your elements in an element library using **Edit -- Library > Save to...**.

This menu item starts the **Paste from Library** dialog box. To paste an element use the following steps:

* Select a library file by clicking on the **Change Library ...** button and selecting an element library using the "Open" dialog box. Element libraries have an extension of ".ELB" by convention. This step is only necessary the first time you use any of the **Edit -- Library > Paste from...**, **Save to...** or **Manager...** menu commands in a given Raytrace session or when you want to change to a different library file.

* Once a library file has been selected, the file name will appear at the top left corner of the dialog box and a list of the available elements in the library will appear in the list box on the right hand side. Select the element you want either by clicking on the name in the list box or typing the name into the edit box in the top right hand corner.

If the **Show preview** check box is checked then a preview drawing of the element will appear in the space on the left hand side of the dialog box. The "start point" of the element is indicated by a small square box on one of the element vertices. This is the point at which the original construction of the element was started and will be the point which is mapped onto the point you select in the next step.

* Press the **Paste** button or double click on the name of the element in the list box to paste the element into your ray diagram.

Once you have pressed the **Paste** button the dialog box will minimize itself to a small box containing two buttons: **Close** and **Restore**. These are explained later.

* Complete the pasting operation by selecting the point in the ray diagram at which the point discussed above will be positioned.

To change the size of the element when you paste it, check the **Scale on paste** check box before pasting the element. In this case you will be prompted (by the cursor) to select two corners of a rectangle in which

the element will be scaled to fit. The aspect ratio of the rectangle is constrained to be the same as a rectangle which just contains the element being pasted.

When you paste an element, the **Paste from Library** dialog box shrinks to a smaller dialog box containing just two buttons. This allows you to paste the element with a minimum of clutter on the screen. The small dialog box can be moved so that it does not cover important parts of your ray diagram. When you want to paste another element from the library simply click on the **Restore** button to make the complete dialog box reappear. If you have finished all the pasting of elements that you want to do then click on the **Close** button to remove the small version of the dialog box.

If the word **Deleted** appears in the middle of the preview area when an element is selected then this means that the element has been marked to be removed from the element library when next it is purged (see **Edit -- Library > Manager...**). However, you can still paste the element in the manner described above.

Edit -- Library > Save to...

To add an element to an existing element library:

* Select the element in your ray diagram and then choose this menu item. A dialog box will appear.

* If you have not already selected a library file using either the **Paste from Library...** or **Library Manager...** items in this sub-menu then use the **Change library...** button to select a library file.

* Type the name you wish to use to describe the element into the edit box and press the **Save** button. You must select a unique name when saving a new element - you will be prompted if you do not.

A list box containing the names of elements already in the library is shown to help you in choosing a unique name, a preview of an existing element will be displayed if you click on a name in the list and the **Show preview** check box is checked.

Edit -- Library > Manager...

Use this menu item if you want to modify the contents of a library file in some way other than adding a new element.

Within the library manager dialog box:

- Use the **Change library...** button if you have not already selected a library file or want to change to a different library than the one currently in use.

- Use the **Create Library...** button to make a new library file. You might find this useful to keep elements for a particular demonstration or project all together or simply to hold useful elements that you have created yourself. Avoid putting more than a few dozen elements into a single library - you can do it if you want but you will find it easier and quicker to find and paste your elements if they are separated into small logical groups contained in separate files.

- Use the **Delete** button to delete an element from the library; click once on its name in the list box or type the name into the edit box then press the **Delete** button. The element is not deleted at this stage it is simply marked to be removed when the **Purge** button is pressed.

- Rename an element by clicking once on its existing name in the list box (or type the existing name into the edit box) then press the **Rename** button.

At the bottom right side of the dialog box are three radio buttons. You can use these to control which names are displayed in the list box. If **Normal** is selected then only elements which have not been marked for deletion are displayed. If **Deleted** is selected then only the names of elements which have been deleted are shown. Choose **Both** to see the names of all elements regardless of whether they are marked for deletion or not.

Elements that have been deleted still occupy space in the library file, can still be pasted, and prevent you from using their name for a new element. To remove them completely you must press the **Purge** button.

Before the **Purge** button has been pressed you can undelete elements: To recover a deleted element prior to purging, use the following steps.

* Click on either the **Deleted** or **Both** radio buttons
* Click on the element name in the list box or type the name into the edit box.
* Click on the **Undelete** button.

Modify menu

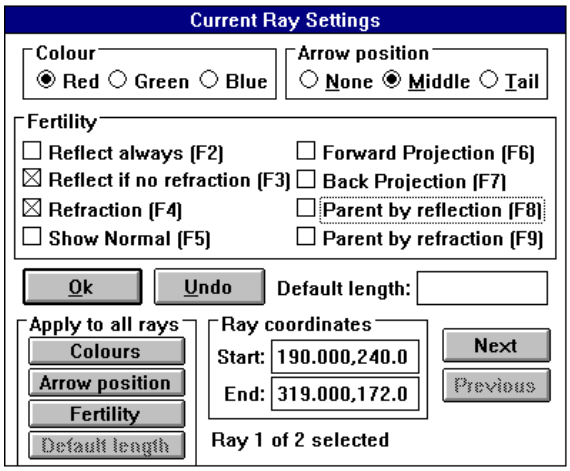
Modify -- Ray...

Choosing this menu item starts a dialog box, which allows you to change the properties of selected rays either individually or all at once.

The controls in the dialog box are divided into a number of groups which are explained below.

Colour

At the top left of the dialog box are three radio buttons which allow you to specify the colour of the ray(s). Choose the colour you want. Rays inherit their colour from their parent ray so this has no effect on child rays. Changing the colour of a parent ray automatically updates the colour of all its children.



Arrow position

At the top right of the dialog box are three radio buttons for options on the arrow position. The arrows perform no function except to indicate the direction of propagation of the ray. The option you use is a matter of personal preference of perhaps clutter in the diagram.

Fertility

A strange name, but the best that occurred to me at the time. A ray's fertility controls which child rays are generated when the ray interacts with an element. There are seven types of child ray which can be generated and eight options:

Reflect Always Checking this option means that a reflected ray will be generated at any intersection between the ray and any refracting region or surface element. This option is mutually exclusive with the next one.

Reflect if no refraction Checking this option means that, if a refracted ray exists, then the reflected ray will not be generated. If a refracted ray does not exist (either because a critical angle is exceeded or because the element is a surface) then the reflected ray will be generated. This option is mutually exclusive with the previous option. The existence (potential or real) of a refracted ray is determined independently of the setting of the **Refraction** option.

Refraction Checking this option will cause a refracted ray to be generated (provided a critical angle is not exceeded) at the intersection between the ray and any region element that it actually hits.

Show Normal Checking this option will cause a dotted "normal" or "perpendicular to the interface" ray to be drawn where-ever the ray intersects with an element. Normals will not be shown where the ray intersects a thin lens or par-axial mirror.

Forward Projection Checking this option will cause a dash-dot ray to be drawn as a continuation of the rays original path wherever the ray interacts with an element. Forward projected rays behave like any other ray and can have their fertility modified to give rise to further rays etc. By default forward projected rays have their fertility set to again forward project so that the projection will automatically extend beyond any elements in the rays path.

Back Projection The same as **Forward Projection** but in the reverse direction. Back projected rays are useful for showing the position of virtual images.

Parent by reflection Checking this option will generate a ray which, if it had been drawn, would have given rise to the existing ray by reflection at a boundary. Useful for back-tracking alternative paths in a ray diagram. A ray generated by this option is still considered a child ray.

This option will have no effect if the ray is itself the child of another ray by means of a reflection.

Parent by refraction Similar to **Parent by reflection** but for refraction instead.

Default length

The length of the ray will be modified to this value by moving its end point only if it does not interact with an element. You can use this control to change the length of some or all of the terminal rays in a diagram. Since this setting has no immediate effect on rays that interact with elements you can change the length of all the terminal rays with the following steps.

* Selecting all rays with Edit -- Select All > Rays...
* Choosing **Modify -- Ray...**, and changing the default length value
* Clicking on the **Default Length** button in the **Apply to all rays** section of the dialog box.

See the example Reflection and refraction by a rectangular prism in the tutorial manual for an example where this is done.

Ray co-ordinates

You can change the end points of the current ray by typing the co-ordinates into the **Start:** and **End:** edit boxes. An alternative which specifies the end co-ordinates exactly is to drag the ray and use an absolute co-ordinate snap to finish the drag.

When more than one ray is selected...

At the bottom of the dialog box the number of rays selected is indicated along with the number of the current ray being modified. The latter number only indicates the order in the set of rays selected, it is not a property of the ray. You can step through all the selected rays (modifying each one as you go) by using the **Next** and **Prev** buttons.

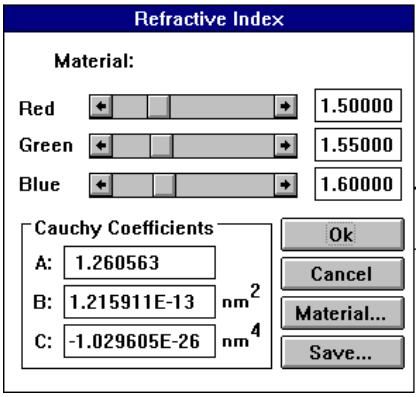
To apply the currently displayed settings to all the selected rays, click on one of the four buttons in the box labeled **Apply to all rays**. These buttons are only enabled if more than one ray was selected when the dialog box started. The **Default Length** button only becomes enabled if you have changed the entry in the default length edit box.

The **Undo** button only undoes changes made to a single ray, it will not undo a change made to more that one ray using one of the **Apply to all rays** buttons or if you have used either of the **Next** or **Prev** buttons to change to a different ray. To undo a change to more that one ray you must exit from the dialog box and use **Edit -- Undo**.

Modify -- Element > Refractive Index...

This menu item starts a dialog box which allows you to vary the refractive indices of all selected elements. Three refractive index values are used for each element; these correspond to the three wavelengths represented by the red, green and blue coloured rays. You can change these wavelengths using **Modify -- Wavelengths...**.

You can use any of the following methods to change the refractive indices:



- Adjust the scroll bars to get the refractive indices that you want.
- Enter the desired refractive indices in the edit boxes next to the scroll bars.
- Enter the coefficients of the Cauchy equation for a particular substance.
- Select a particular material for which the refractive properties have already been set. To do this, click on the **Material...** button and select a material from the list box in the **Select Material** dialog box which appears.

If **Options -- Update on Element Drag** is checked then the ray diagram will update as you change the refractive indices.

The changes affect all selected elements except "thin lenses" and "par-axial mirrors" for which refractive index is meaningless.

Surface, shape and screen elements have latent refractive indices (since they can be turned into regions using **Modify -- Element > Change to > Regions**). These latent refractive indices can be changed using this menu item just like regions.

If you want to define a new material then enter either:

- the Cauchy coefficients or
- the refractive indices at three known wavelengths (see **Modify -- Wavelengths...**)

then click on the **Save...** button and enter a name for the material in the dialog box which appears. If you use a name of a material which is already defined then the new values will over-write the old ones.

Modify -- Element > Lock >

This sub-menu contains four items which can be used to constrain how the selected elements may be dragged. The items and their functions are:

Position	Locks the selected elements so they cannot be dragged at all.
X Position	Locks the selected elements so they can only be dragged vertically.
Y Position	Locks the selected elements so they can only be dragged horizontally.
Unlock position	Removes any constraints placed on the selected elements using the previous three menu items.

The most common use for these menu items is to lock lenses onto an axis to make it easier to move them about without spoiling the transverse alignment.

You can still move locked elements using the **Modify -- Move** menu item. If a locked element is part of a group (see **Modify -- Element > Group**) then dragging the locked element will constrain the dragging of the whole group. If you drag another element in the group which is not locked then the constraints on the locked element are ignored.

Modify -- Element > Change to >

This sub-menu contains six items. Choosing one of the first four of these: **Region**, **Surface**, **Shape** and **Screen** changes all selected region, surface, shape and screen elements into the type specified in the menu item.

When region elements are changed into one of the other types they are opened by removing the segment which was automatically added to close the region. They also retain their refractive indices in a latent sense so that if they are converted back into elements there is no loss of information.

When surface, shape and screen elements are converted into region elements they are closed automatically by the addition of line segments. They acquire the latent refractive indices which they acquired either when they were created or by use of **Modify -- Element > Refractive index...**.

These menu items have no effect on thin lens, par-axial mirror or iris elements.

The last two items in the menu: **Converging** and **Diverging** change all selected thin lens elements into the type specified in the menu item. The magnitude of the focal length is unchanged in the conversion. Choosing these items has no effect on any of the other types of elements.

See items in the **Create -- Element >** sub menu for an explanation of the different types of element.

Modify -- Element > Turn Off and Turn On

These menu items allow you to turn the selected elements on and off. If an element is turned off then it will still appear unchanged on the screen but rays will not interact with it in any way. You can use this to see what the effect of removing an element is without modifying the drawing in any other way. All types of elements are affected (although it makes no difference to shape elements whether they are on or off).

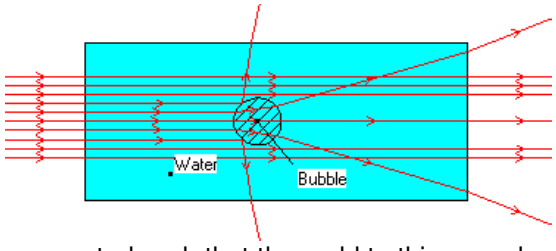
Modify -- Element > Additive refractive index and Subtractive refractive index

When region elements overlap, the refractive indices in the overlapped region is determined by "summing" the refractive indices of all the overlapping elements using the formula:
where N is the number of overlapping elements and, n_i is the refractive index of the ith overlapping element.

$$n = 1 + \sum_{i=1}^{N} (n_i - 1)$$

Raytrace offers you the facility of making some of the elements count negatively towards this sum, i.e. have negative value of n_i. This lets you make voids inside regions very simply as in the example shown below where an air bubble in a tank of water is modelled.

When an element is set to have a subtractive refractive index it is hatched as shown in the diagram above.



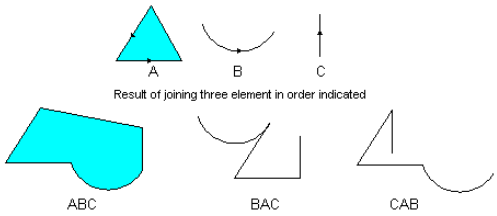
By default all region elements are created such that they add to this sum shown above. If you select an element and choose **Modify -- Element > Subtractive refractive index** then that element will count negatively towards the sum. You still set the magnitude of the element's refractive indices in the same way using **Modify -- Element > Refractive index...**.

You cannot create regions with refractive indices less than 1 using subtractive elements. If the result of the calculation shown above is less than 1 then the refractive index is set to be 1.

Modify -- Element > Join

Choosing this menu item will join all selected region and surface elements into one combined element (any selected shape elements are ignored). The order in which the elements were selected determines the order in which they are joined up. The final element assumes the properties of the first selected element, i.e. region/surface and refractive index properties. Region elements are opened before joining to other elements.

The result of joining three elements is shown on the right for three different orders of selecting the elements. The right hand side of the triangle is the closing segment and is ignored when joining takes place.



Use this menu item in conjunction with **Modify -- Element > Explode** to add and delete or modify individual segments within an existing element.

Modify -- Element > Explode

Choosing this menu item will break apart all selected region, surface, shape and screen elements into their individual segments. The positions of the segments are not changed; so no immediate effect is obvious for surface elements. Region element will not be filled and will no longer refract rays since they become a collection of surfaces positioned end to end. All segments become surface elements after exploding.

Modify -- Element > Group

If elements are "grouped" then moving any one of the group by dragging will cause the whole group to move. Grouped elements do not share any properties and are not operated on as a group in any other way.

To group elements simply select the elements you want and then choose this menu item.

To move one element in the group without moving the others, use **Modify -- Move**.

To add an element to a group:

* De-select everything then select one of the elements in the group and the element which is to be added.
* Choose **Edit -- Select Group** to select all the elements already in the group.
* Choose **Modify -- Element > Ungroup** to destroy the old grouping.
* While all the elements are still selected use **Modify -- Element > Group** to form the new group which includes the extra element.

Modify -- Element > Ungroup

To remove the grouping of elements, select any member of the group and choose this menu item.

Modify -- Element > Remove from group

To remove an element from any group with which it is associated select the element then choose this menu item. See **Modify -- Element > Group** for information on how to add an element to a group.

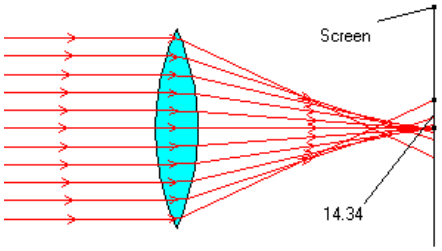
Modify -- Element > Link to snap and Unlink from snap

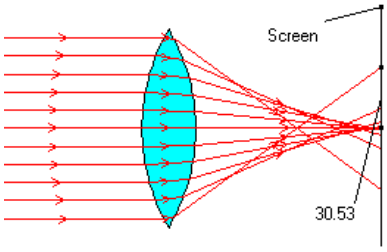
You can link the selected elements to an object snap using **Modify -- Element > Link to snap**. If you do, then the elements will be moved so that they always retain the same relative position to the snap point as that which existed when the link was established. You destroy the link by selecting the elements and using **Modify -- Element > Unlink from snap**.

This feature is intended to let you move screen or shape elements around as ray intersections change

An example where this might be of use is in determining the lateral spherical aberration of a lens using a screen linked to the par-axial focal point of a lens. This is illustrated below.

The screen element in the diagram shown above was positioned to coincide with the intersection of two of the rays passing close to the centre of the lens and then linked to the same ray intersection. A tape measure shows the extent of the lateral spherical aberration. As the shape of the lens was changed the





screen moved and the new value for the spherical aberration was shown automatically.

When linking an element to a ray intersection snap use the following steps:

* De-select all rays.

* Select the element you want to link.

* Hold down the control when you select the first ray (or both rays at once).

* Hold down the control key when you select the second ray if necessary.

If you do not hold down the control key when selecting the first ray the link will not be established.

You can link any type of element to any type of snap but be careful some combinations are not logical when the element itself controls the snap point - e.g. a lens linked to the intersection of rays that have passed through itself.

Modify -- Source > Ray count

Select a source by selecting a ray emanating from it then choose this menu item. Enter the new number of rays for this source in the dialog box which appears.

This command operates on all sources (point and plane) which have one or more of their rays selected.

Beware that if you have created an "image" by anchoring a trail, tape measure or annotation to an intersection of two rays which result from the source's existence then this command will have one of two effects.

- If you reduce the number of rays and one (or both) of the rays that led to the image is removed as a consequence then the intersection will cease to exist and the "image" position will no longer update.

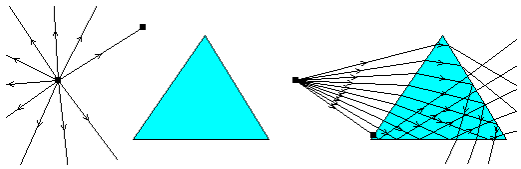
- If you increase the number of rays then the ray intersection will still exist but its position may move because of the repositioning of the rays which takes place when the new ray spacing comes into effect.

Modify -- Source > Flip point sources

Select a point source by selecting a ray emanating from it then choose this menu item. The aperture points defining the source will be swapped. Shown below on the left is a point source whose aperture has been linked to the vertices of the prism but in the wrong sense. The source has been flipped over on the right by using this menu item.

This command operates on all point sources which have one or more of their rays selected.

Modify -- Source > Unlink snaps



Use this menu item to detach the links between a source and any object snaps used when it was created. This will stop the source moving as you adjust the elements or whatever it was linked to. A link is established whenever you:

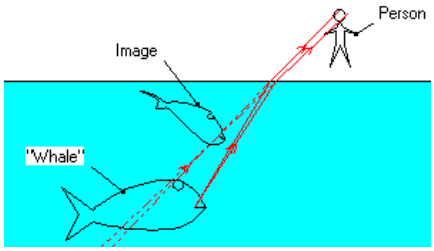
- use an element snap during creation of a source or
- you drag one of the three defining points of the source and end the drag operation with a snap

If you don't want the link then you must remove it with this menu item. To keep only some of the links for a source, you must create the source without the links (or remove the links) and drag the appropriate points and finish the drag with the desired snap.

Modify -- Source > Link point source via child rays

This menu item lets you use Raytrace to solve for the ray paths between a source point and a specified aperture. It allows you to trace out the cross section of images as seen by the eye.

An example is shown on the right. In this case the point source has been linked to two points on the head of the "person" via its refracted child rays. The cross section of the image seen by the person was traced out by the intersection of the refracted rays - the back projected rays indicate the intersection point. (This example was constructed using the script MANSVIEW.RSC which is supplied with Raytrace.)



To use this facility follow these steps:

* Create the point source so that its child rays pass close to where you want them.

* Select the source by selecting one or more of its rays

* Select the two child rays of the extreme rays of the source that you want to pass through a given aperture.

* Choose **Modify -- Source > Link point source via child rays**.

* Specify the two aperture points.

The source should then orient itself so that the selected child rays pass exactly through the two points that you selected. This involves a numerical search which may not succeed if the rays must follow a complicated path or a path which passes close to the vertices of an element such that the child rays can cease to exist during the search process. You should check that a possible path exists before using this facility and that when the source is rotated to either side of the expected path by a few degrees that the selected
child rays continue to exist.

When you drag the source or object to which the child rays are linked, Raytrace will continuously search for new ray paths to the aperture points. This may be slow, depending on the complexity of the path and ray diagram, because the numerical search involves calculating the ray paths many times. If you have anything slower than a 486DX-33 machine then drag with caution and be patient!

You can remove the link between the child rays and aperture by selecting one of the source rays and choosing the menu item **Modify -- Source > Unlink snaps**.

Modify -- Tape Measure...

This item starts a dialog box which presents you with a set of options for how the distance measured by the tape measure is displayed.

These are explained below.

Distance Only the length of the tape measure is displayed - units are drawing units.

Polar (Degrees) The distance, and the direction in degrees, are displayed. 0° is horizontal and to the right, increasing positively in the anti-clockwise direction. The ° symbol shows that the angle is measured in degrees. This is the default option.

Polar (Radians) The distance and the direction in radians are displayed. Angles measured as for the previous option. The abbreviation **rad** shows that the angle is in radians.

Cartesian The x and y displacements of the tape measure are displayed, separated by a comma.

None No readout is displayed. You can use this option to "de-clutter" the display or to create "images" by anchoring a tape measure to two ray intersections - this is how the image is created in the file PLNMIRR.RAY. If the **Info -- Readouts** menu item is used to copy the readouts of selected tape measures which have this option set then they default to Cartesian. A leader will still be displayed if the **Use Leader** option is checked.

Decimal places You can change the number of decimal places displayed in the readout independently for distance and angle by clicking in the + and - buttons.

Use Leader If this option is checked then a line is drawn from the middle of the tape measure to some point where the text of the readout is displayed. You can drag the end of the leader to the position that you want. This option is on by default.

Leader fixed If this option is checked then the end of the leader will remain fixed at the position it was created in or dragged to. This can be useful if the ends of the tape measure are moving large distances (for example if an image position goes off screen) since you will still be able to see the readout.

Modify -- Protractor...

This item starts a dialog box which presents you with a set of options for how the angle measured by the protractor is displayed.

Degrees The angle is displayed in degrees. 0° is horizontal and to the right, positively increasing in anti-clockwise direction. This is the default option. The ° symbol is used to indicate the angle is in degrees.

Radians The angle is displayed in radians. Angles measured as for the previous option. The abbreviation **rad** is used to indicate the angle is in radians.

None No readout is displayed. You can use this option to "de-clutter" the display. If the **Info -- Readouts** menu item is used to copy the readouts of protractors with this option selected then they default to degrees. A leader will still be displayed if the **Use Leader** option is checked.

Decimal places You can change the number of decimal places displayed in the readout by clicking in the + and - buttons.

Use Leader If this option is checked then a line is drawn from the centre point of the protractor to some point where the text of the readout is displayed. You can drag the end of the leader to the position that you want. This option is on by default.

Leader fixed If this option is checked then the end of the leader will remain fixed at the position it was created in or dragged to. This can be useful if the centre point of the protractor is moving large distances or goes outside the visible window since you will still be able to see the readout.

Modify -- Wavelengths

This menu item starts a dialog box which allows you to specify the wavelengths represented by the three colours used in Raytrace. Note that the colours Red, Green and Blue refer only to the colours as they are drawn on the screen; the wavelength may represent a different colour in the physical world. The default values when Raytrace starts are: Red = 632.8 nm, Green = 550.0 nm and Blue = 470.0 nm. The red wavelength is that of a common helium-neon laser, the green and blue wavelengths are approximately in the centre of the waveband corresponding to the colour. You can specify wavelengths anywhere in the range from 50 nm to 20000 nm - that should be a big enough range enough for anyone!

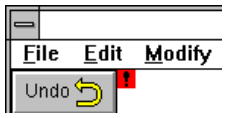
The **Change refractive indices** option controls whether Raytrace changes the refractive properties of elements in response to a change in the wavelengths. The refractive properties of an element are defined either by the combination of its three refractive index values and the red, green and blue wavelengths or by its Cauchy coefficients, independent of the three wavelengths.

If the **Change refractive indices** option is checked then Raytrace will use the existing Cauchy coefficients of each element to re-calculate the refractive indices appropriate for the new wavelengths - thus the element "material" stays the same. If the option is not checked then the three existing values of refractive index and the three wavelengths are used to re-calculate the Cauchy coefficients of the element - thus the element "material" changes.

Uncheck the **Change refractive indices** option if you have already set known values of the refractive indices and are setting the corresponding wavelengths. Check the option if you simply want to change the wavelengths without changing the refractive properties of any elements.

Modify -- Background refractive index...

With this menu item you can set the refractive index of the background area in Raytrace to any value just as you can with a region element. When a background refractive index other than 1 is set for any colour you will see a small red square with an exclamation mark in it in the top left corner of the Raytrace window as shown on the right. This is a reminder that the background refractive index is not 1. If you click on this reminder square you can clear the background refractive index without having to go through this menu item.



Using this facility you can easily demonstrate the effect of putting a lens under water. Don't change the lens, just change the background.

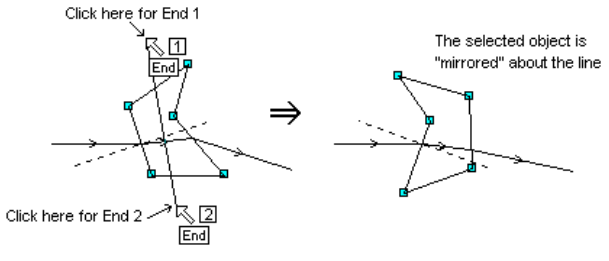
Modify -- Thin lenses with background

This menu item is checked by default. It controls how thin lens elements are treated when a background refractive index (for the red wavelength) is set or modified. When checked the focal length of all thin lens elements is modified by the same factor that the background refractive index is changed. So for example if this item is checked and you create a thin lens element then change the background red index from 1 to 2, the focal length of the lens will be doubled. If this menu item is unchecked then the focal lengths of thin lens elements remains unchanged no matter how the background refractive index is varied.

Modify -- Mirror

This menu item allows you to mirror (reflect or flip - call it what you will) the selected objects about some line. After choosing this menu item, the cursor changes to the "End 1" form; select one end of the "mirror line". The cursor will then change to the "End 2" form; select the second end of the mirror line. The effect is illustrated on the right.

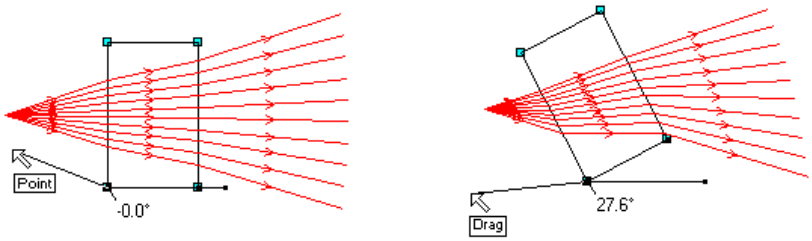
You can use snaps to specify the end points and the ortho drag mode can be useful for quickly mirroring



objects about horizontal or vertical lines. Note that Trail objects are unaffected by the mirror function.

Modify -- Rotate

This menu item allows you to rotate the selected objects about some point. After choosing this menu item you will be given the choice of either rotating the objects through a specific angle (in degrees) or controlling the rotation by dragging the mouse. In both cases you must select the point about which the rotation is to take place use a snap if necessary. The diagram below illustrates the points selected for a rotation controlled by mouse dragging and its effect.
In the illustration above, the rectangular element was selected and then **Modify -- Rotate** used to initiate the rotate operation. The **Rotate by dragging** option was chosen and, in response to the “centre point” cursor an end snap was used to specify the lower left corner of the rectangle. An arbitrary point (shown in the diagram on the left) was then selected in response to the “point” cursor - note the rubberband that extends from the selected centre point.



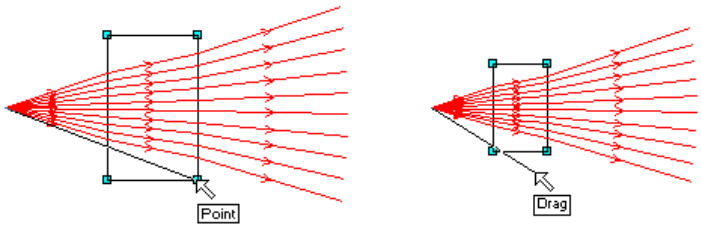
As the mouse was moved the line joining the selected centre point and the arbitrary point was rotated to track the new mouse position as shown in the right-hand diagram. The point that is selected in response to the “point” cursor does not have to be arbitrary, for example a specific point on the rectangle could have been selected with a snap and rotated to line up with another specific position.

Note that Trail objects are unaffected by the rotate function.

Modify -- Scale

This menu item allows you to scale the selected objects. After choosing this menu item you will be given the choice of either scaling the objects by a specific numerical factor or controlling the scale operation by dragging the mouse. In both cases you must select a point which will act as the centre of the dilation (scaling). The point you select will not be moved by the scale operation. The diagram below illustrates the points chosen for a mouse controlled scaling operation.

In the illustration above, the rectangular element was selected and then **Modify -- Scale** used to initiate the scaling operation. The **Scale by dragging** option was chosen and, in response to the “base point” cursor an end snap was used to specify the start of the source rays. An point close to the lower right vertex of the rectangle was then selected in response to the “point” cursor - note the rubberband that extends from the



selected centre point. A snap could have been used to specify a point exactly on the corner of the rectangle.

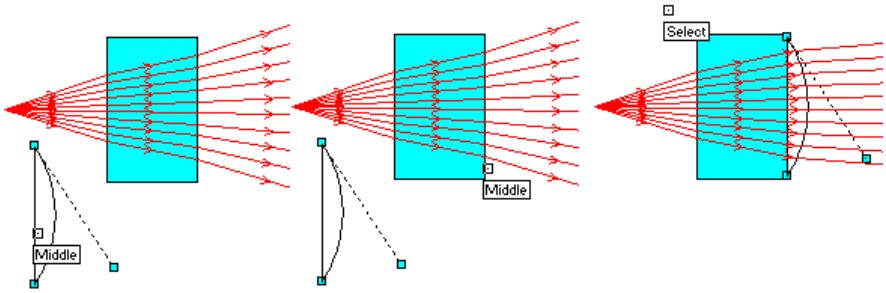
As the mouse was moved the rectangle was scaled so that the line joining the selected base point and the point near the corner of the rectangle was the same length as the line joining the base point and the new mouse position as shown on the right in the diagram above.

Note that Trail objects are unaffected by the scale function.

Modify -- Move

This menu item allows you to move the selected objects through as specified displacement. After choosing this menu item you must select two points; the first in response to the "base point" cursor and the second in response to the "point" cursor. The selected objects are moved through a displacement that maps the first point onto the second. This is illustrated below.

In the diagram above, the lens shape was selected and then Modify -- Move used to initiate the move operation. In response to the “base point” cursor, a mid point snap was used to select the middle of the



plane face of the lens (on the left above). In response to the “point” cursor another mid point snap was used to select the middle of the right hand face of the rectangle (in the middle above). The result is that the lens was placed up against the side of the rectangle as shown on the right above. Note that the points selected for the move operation can be arbitrary if you just want to move one or more objects out of the way.

The move function can be used as an alternative to dragging or when you want to move more than one object through the same displacement.

To use a specific displacement, select an arbitrary first point and then a **Rel coords** snap using the **Base = Previous point** option for the second point. You can then specify the displacement in either Cartesian or polar form.

Note that Trail objects are unaffected by the move function.

Modify -- Pause Trail update

Checking this menu item causes the updating of all trails to be suspended. When the option is subsequently unchecked the trails continue from the new positions of their points. You can toggle this option simple by pressing the **P** key; you don't need to stop dragging to generate trails with separate segments.

Trails will appear as separated segments if this option is used repeatedly during a drag operation. If you select a trail affected in such a way, only the first segment is highlighted by a drag handle.

Modify -- Reset Trails

Choosing this menu item erases all trails. It does not delete them. When you subsequently drag the ray diagram the trails will continue to update from the points where they were reset. If you want to delete a trail then select it and use **Edit -- Delete**. A fixed amount of memory is allocated to storing the information for each trail. If this memory is filled up then trail will no longer update; using this menu item will allow the trail to start afresh.

Modify -- Auto trace

Raytrace allows you to move or drag any point along a pre-defined path using the **Auto drag** function. However, this menu item is specifically for moving either a source or ray along a specified path.

To use **Auto trace,** select either a source (by selecting one or more of the rays coming from the source) or a single ray that does not come from a source, as well as an element which defines the path you want. It is best (but not essential) to select a "shape" element so that the ray(s) that will be moved do not interact with the element

Once you have selected the source/ray and element, choose this menu item. You will be given some options in a dialog box which depends upon whether you selected a single ray or a source. These are explained below.

The dialog box which gives you the three options also contains an option: **Press space to step.** If this is checked then you must press the space bar to proceed from one point to the next along the path. If this option is not checked then Raytrace will recalculate and step along the path as fast as possible.

In all cases, when the **Auto trace** function finishes the selected source or ray is returned to its original position. Press the **Esc** key to abort the auto trace function at the next point.

The number of steps that are made along the segments of the path element is controlled using **Defaults -- Auto drag settings...**.

The readouts of any tape measures and protractors will be copied into the clipboard for each point at which the ray diagram is updated along the path. You can, for example, generate object and image distances for a particular lens and paste the data into a spread sheet for analysis.

See also the **Auto Drag** function.

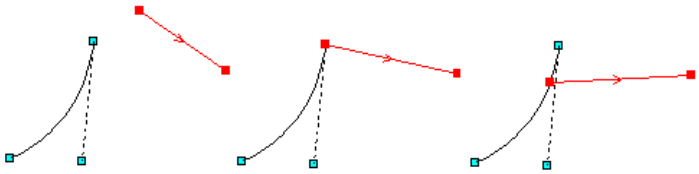
If a single ray is selected

The three options you are presented with are: **Start**, **End**, **Whole ray**. These are described below. Note that for simplicity no interactions between the other elements and the ray have been shown in these examples. If the ray did intercept another active element then it would interact normally; just as if it had been created manually with the end points specified by the auto trace function.

Start

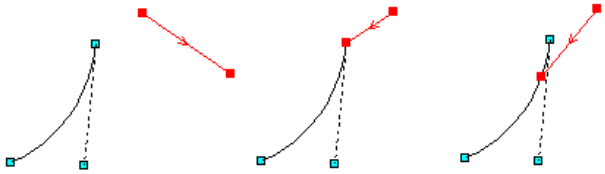
The start of the selected ray is stepped along the path element. The diagram on the right shows a selected ray and element, the first step after the **Start** option was chosen and a subsequent step.

End



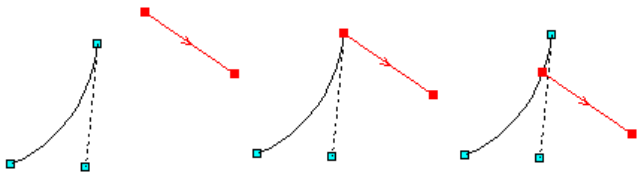
The end of the selected ray is stepped along the path element. The diagram on the right shows a selected ray and element, the first step after the **End** option was chosen and a subsequent step.

Whole ray



The whole ray is stepped along the path element while maintaining its original orientation. The diagram on the right shows a selected ray and element, the first step after the **Whole ray** option was chosen and a subsequent step.

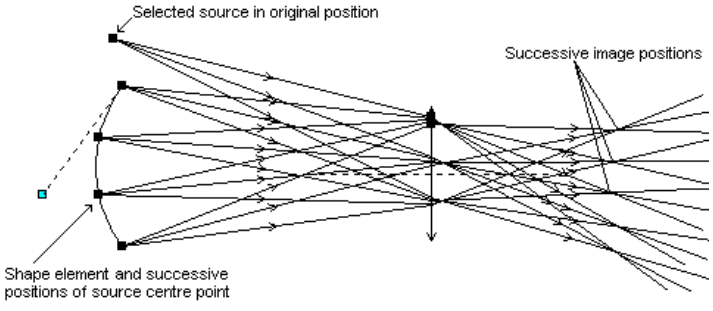
If a source is selected



The three options you are presented with are: **Centre/Base**, **Aperture Pnt 1** and **Aperture Pnt 2**.

Centre/Base

This is illustrated in the following diagram where the point source is moved from its original position to four points along the circular arc. Note that all positions are shown for illustration in this diagram; only one position at a time is actually shown when using Raytrace.



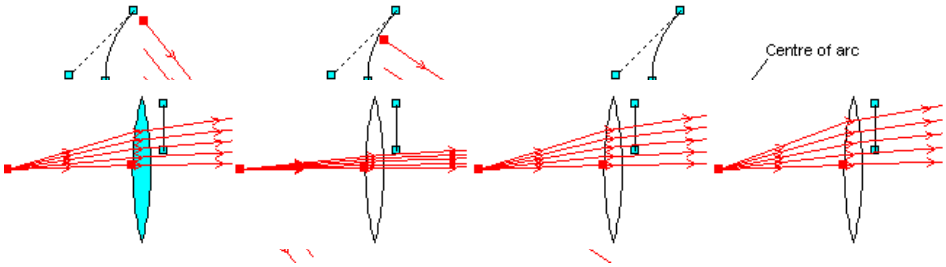
Attach a trail to some ray intersections and use this option to trace out the image cross sections corresponding to complex objects or to trace out focal surfaces of optical systems.

The diagram below shows the same option applied to a plane source.

The arc shape that is selected in the diagram above was centred on the upper left vertex of the prism, the same point as the first aperture point that the plane source. The diagram shows the position of the source before the auto trace began, at one point in the middle of the operation and the final position of the source before the operation ends. You could use this to tabulate values for say sunlight striking an optical system from different elevations.

Aperture Pnt 1 and Aperture Pnt 2

These functions of these options are the same, they just operate on the different aperture points of a source. The diagram below shows a point source which has had its upper aperture point traced along the vertical line. Basically, these options let you vary the position of one of the aperture points for either point or plane sources.



Modify -- Link segments

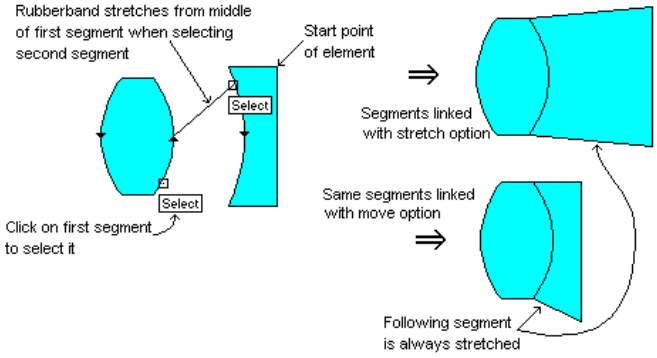
Sometimes you will need to create two elements which match up along one segment exactly. An example of this is a doublet lens (see the tutorial example **Creating a cemented doublet lens**) or a lens lying on the interface between two different media. While you can construct elements which match along a segment exactly, dragging one element will generally spoil the match between the two elements. If you link the matching segments then dragging one of them will cause the other segment to be modified to maintain the exact match. See the tutorial example for an illustration of the use of this facility.

When Raytrace matches the two segments it will usually need to change the shape of, or move, one of the elements. After selecting the two segments you will be given two options in a dialog box:

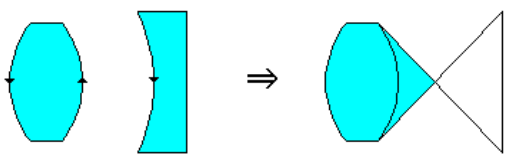
Stretch If you choose this option then Raytrace will modify the shape of the element containing the second segment by stretching the preceding segment. If the second segment was the first one created within its element then the action is the same as the **Move** option.

Move If you choose this option then Raytrace will move the entire element containing the second segment so that the starting point of the segments overlay.

For both options the segment following the second segment will be stretched to allow matching of the end points of the two selected segments. The effects of these options are illustrated on the right.



Note that the direction in which the segments are drawn is important. Raytrace will flip a segment around to make the match exact in every sense - including direction. This can lead to results like that shown below where the two arc segments were drawn in opposite senses.



Linking segments whose direction does not match leads to "bow tie" type shapes

To avoid this, plan ahead when drawing the elements or undo the linking and flip one of the elements over using **Modify -- Mirror** before linking the segments again.

When linking segments, both segments must be of the same type, i.e. both line, both arc or both conic segments. Thin lens and par-axial mirror elements cannot be linked. Also, the closing line of a region element cannot be linked as a segment.

The first segment you select when linking segments is the controlling segment. If you drag it in any way then the second segment will change to match it. If you try and drag the second segment nothing will happen since it is always re-matched to the shape of the first segment.

Segment links are not copied by the **Edit -- Copy** or **Edit -- Cut** commands and therefore cannot be pasted. If you want to copy two elements that are linked then you can do so but you will need to establish the link between the elements if you paste them back into a ray diagram.

Modify -- Unlink segments

To destroy a link between segments simply select one of the elements involved in the link and choose this menu item. The linked segment retains its current shape it does not revert to the shape it had before being linked.

Clear menu

Clear -- All

Choosing this menu item clears everything from the ray diagram. Unlike **File -- New,** this command does not change any of the current options or settings.

Clear -- Void rays

A void ray is one which no longer exists, but still occupies space in the ray diagram database. A record of such a ray is kept because it (and its child rays) may come into existence again.

An example of why this is useful:

Suppose you trace a ray through a prism and then through some subsequent optics, e.g. a lens. You then drag the incident ray and at some angle of incidence on the prism the ray is totally internally reflected and no longer emerges to pass through the subsequent optics. When you return the ray to its original angle of incidence you would like the ray to propagate as it did before - through the prism and the subsequent optics. Raytrace does not delete the rays that propagated through the subsequent optics when the ray totally internally reflects - instead it makes them void and you never see them unless the ray again emerges from the prism. When this happens all the void rays come back - along with all the information about their fertility etc.

You may want to delete void rays using this menu item when you run out of ray space so that more useful rays can be created.

Clear -- Rays, Elements, Tape measures, Protractors, Annotations, Trails

Each of these menu items clears all of one type of object from the ray diagram database. The operations are un-affected by any of the **Options -- Show > xxx** menu settings. To delete only a sub-set of the objects of any type, select the objects and use **Edit -- Delete** or press the **Del** key.

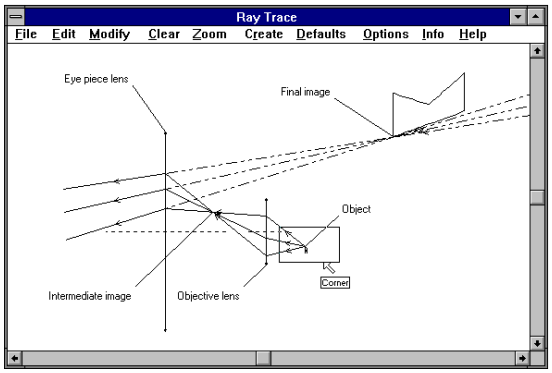
Zoom menu

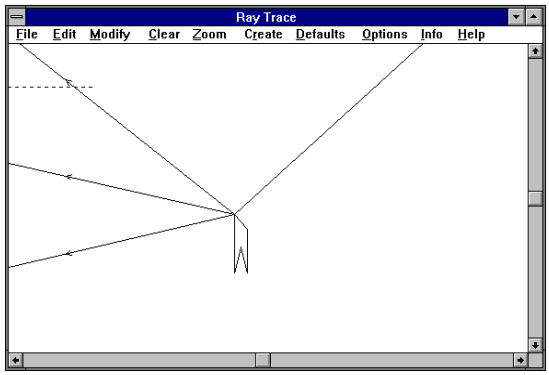
Raytrace does not limit the size of the ray diagram to the visible window. This menu contains items which allow you to scale and move the window about in the ray diagram. You can also pan the ray diagram by using the scroll bars on the side and bottom of the Raytrace window.

Zoom -- In

This menu item allows you to specify a rectangular region which will expand to fill the Raytrace window. After choosing **Zoom -- In** the cursor will be in the "corner point" form, click the primary mouse button where you want the top left (or bottom right) corner of the new display to be. Move the cursor until the rectangular zoom box is the size you want it then click the primary mouse button again. This is illustrated below where the area around the small object shape has been zoomed to see greater detail:

The aspect ratio of the zoom box is normally constrained to be the same as the Raytrace window but this may be changed by unchecking the menu item **Zoom -- Freeze Aspect** (see below).

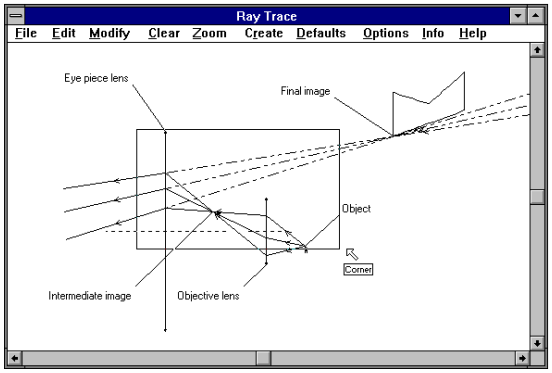


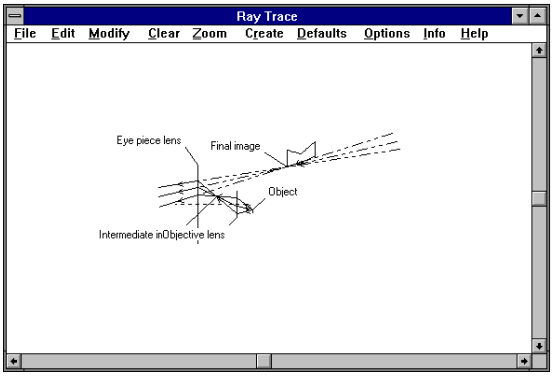


Zoom -- Out

After choosing this menu item, select a rectangular area in the same manner as for **Zoom -- In.** The view will be scaled such that the contents of the current window will fit inside the rectangular area you select. as illustrated below.

As for **Zoom -- In**, the aspect ratio of the zoom box is normally constrained to be the same as the Raytrace window but this may be changed by unchecking **Zoom -- Freeze Aspect**.





Zoom -- Extents

Choosing this menu item adjusts the scale of the diagram so that all objects fit within the current Raytrace window. Objects that are not visible because of the state of items in the **Options -- Show >** sub-menu are not included when determining the extents of the diagram.

Zoom -- Previous

Reverts to the previous zoom scale if there was one. Only works on one level of zoom.

Zoom -- Reset

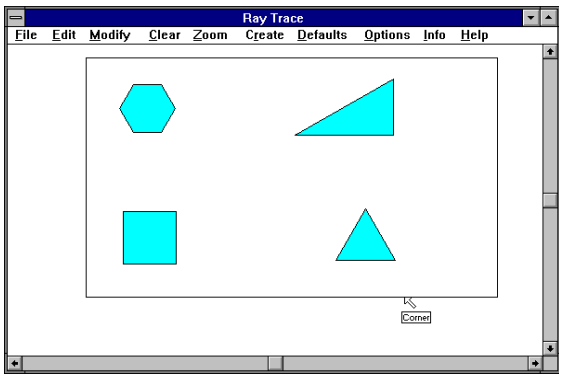
Zooms to the same scale as that used by default when Raytrace starts. The aspect ratio is 1, the coordinate origin is in the centre of the Window and the viewing scale is 1 drawing unit = 1 display pixel. If you get lost or confused when zooming or panning the diagram then use this menu item to get back to a fixed starting point.

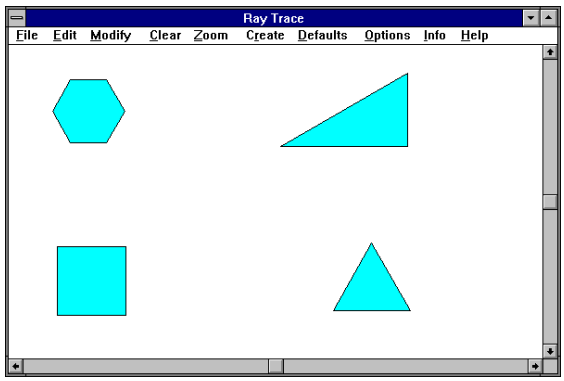
Zoom -- Freeze Aspect

Sometimes ray diagrams can become very "long and narrow" so Raytrace allows the option of changing the horizontal and vertical viewing scales independently (changing the aspect ratio). This lets you see both vertical and horizontal details of the diagram without panning or zooming.

Zooming in with **Zoom -- Freeze Aspect** checked is illustrated below. On the left the zoom box is constrained to have the same aspect ratio as the Raytrace window and the corner may not track the cursor exact cursor position (it is only aligned with the cursor along one axis). When zooming is completed, as shown on the right, the x and y scales have both changed by the same factor.

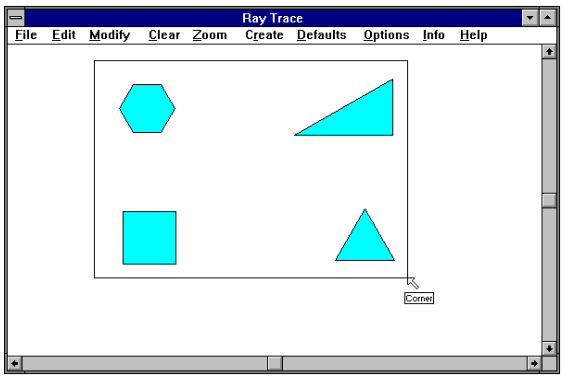
Zooming in with **Zoom -- Freeze Aspect** unchecked is illustrated below. On the left the zoom box tracks the cursor position exactly. When zooming is completed, as shown on the right, the x and y scales are different

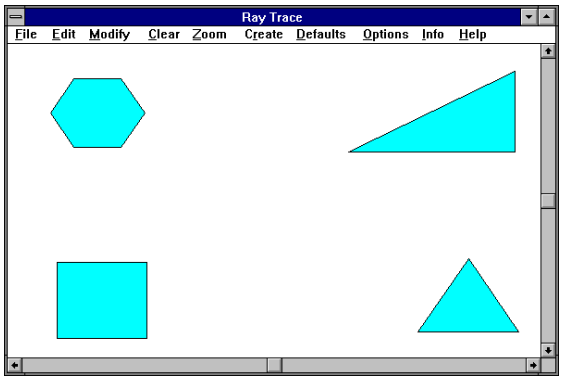




so objects appear to have changed shape.

The **Zoom -- Freeze Aspect** setting affects **Zoom -- In**, **Zoom -- Out** and **Zoom -- Extents** operations. **Zoom -- Previous** restores the previous scales regardless of the **Zoom -- Freeze Aspect** setting. **Zoom --**





Reset will always return you to an aspect ratio of 1 regardless of this setting.

The aspect ratio is 1 when Raytrace starts. If you uncheck **Zoom -- Freeze Aspect** and change the aspect ratio by zooming then re-check this option, the aspect ratio will stay fixed at the new value.

Create menu

Create -- Ray

Choose this menu item to begin drawing rays.

The cursor will change to the start point form - position the cursor where you want the ray to start and click once on the primary mouse button or use a snap. The cursor will then change to the end point form and a rubberband with an arrow head will stretch between the selected starting point and the cursor position. Move the cursor to where you want the ray to end and click the primary mouse button again. The ray will then be drawn using the current default settings (See **Defaults -- Ray settings**).

The cursor returns to the start point form and you can continue to draw rays in the same manner. Once you have drawn all the rays you want, click on the secondary mouse button and choose **Finished** from the popup menu or simply press **Esc**. Raytrace will then calculate and display the paths of all resulting rays.

Note:

- You do not have to hold the primary mouse button down while dragging to the end point.
- You do not have to make rays stop exactly on the edge of any elements that you expect them to interact with, Raytrace will lengthen or shorten rays automatically when they interact with elements.
- If you want to create several rays with different colours or fertility settings then it is probably better not to change the default settings for each one but rather use **Modify -- Rays...** to change the rays after you have drawn them.
- To create a number of rays coming from a common point, use **Create -- Source > Point** or, for parallel rays, **Create -- Source > Plane**.
- Use the ortho drag mode to create rays which are either horizontal or vertical.
- You can use snaps when creating or dragging rays to specify the position relative to parts of the ray diagram but the rays cannot be linked to the snap points as sources can.

Create -- Element > Region, Surface, Shape, Screen

Choose one of these menu item to start drawing a new element.

After choosing any of these menu items the cursor always changes to the start point form. Select a starting point on the basis of giving yourself enough room to draw the element in the window. It is easier not to try drawing the element in the final position - move it there after you finish creating it.

Region elements will be closed automatically by a line segment added between the last vertex that you specify and the starting point.

After drawing the element you complete it either by choosing the menu item **Create -- Element > Finish element** or by clicking on the secondary mouse button and choosing **Finished** from the popup menu.

Undoing a mistake

If you make a mistake on any segment when creating one of these elements either:

- Press the **U** key to undo the last segment. Repeatedly pressing **U** will undo all the way back to the first segment if you want.
- Choose **Create -- Element > Undo segment**.
- Click on the secondary mouse button and choose **Undo segment** from the popup menu.

Changing the type of segment

By default Raytrace starts creating elements with line segments.

You change between drawing line, arc and conic segments while creating an element by clicking on the secondary mouse button and choosing the type of segment you want from the popup menu. The current type of segment is indicated by a check mark next to the item in the popup menu. A region element is always closed by a line segment regardless of the current type of segment being drawn.

You cannot change the segment type until after you have selected the starting point for the element.

Creating arcs

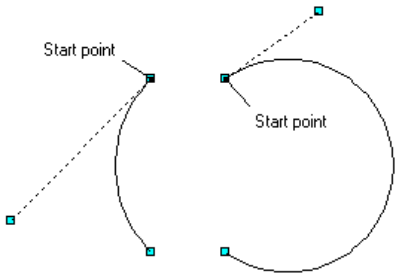
There are three different methods of specifying circular arcs. These are described below. Before you can change the method of creating arcs you must be drawing an element and have selected **Circular Arc** from the popup menu as described above. Once you have selected circular arcs as the current segment type, click on the secondary mouse button and re-choose the **Circular Arc** item (it should have a check mark beside it) to bring up another level of popup menu. The current method is indicated by having a check mark beside it - select the method that you want. If either of the **Centre**/**End** or **Radius**/**End** items is checked then a fourth item, **Clockwise arc,** also appears in the menu.

For all of the methods the starting point of the arc is already defined, either by virtue of the fact that it must be the same as the end point of the previous segment of because it is the original starting point of the element.

End/Tangent

This is the initial default method for specifying arcs and is the easiest to use: Select the end point of the chord of the arc then select the “tangent” point. This point indicates the direction of the tangent to the arc at the start point. Using the initial tangent direction allows you to define any arc with the specified chord.

The diagram on the right shows two arcs which has been selected. The tangent points are indicated by the drag handles connected to the start points by the dashed line. The distance of the tangent point from the start point is irrelevant although the further away from the start point the finer control you have in specifying the tangent direction.

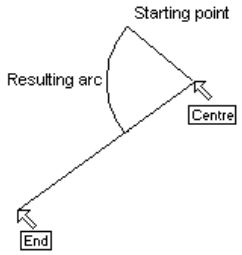


Although this is the easiest way to create arcs it does not let you specify a radius directly. You can specify a radius after the element has been completed by selecting the arc and dragging its tangent control point - click on the secondary mouse button and select **Set arc radius** from the popup menu.

Centre/End

In this case you specify the centre and end points of the arc. The direction of the arc depends on whether the **Clockwise arc** discussed above is checked.

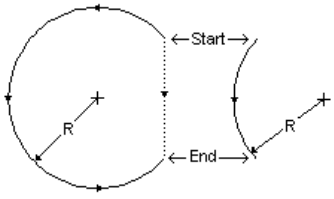
With this option the end point of the arc will probably not coincide with the end point that you specify. The arc will end where it intersects a line drawn between the centre point and the selected end point. This is illustrated on the right.



Radius/End

In this case the radius of the arc is specified as the distance between the starting point of the arc and the point you select in response to the “radius“ cursor (the direction is irrelevant). You select the end point of the arc normally. The direction of the arc is again determined by the check state of the **Clockwise arc** menu item. The easiest way to specify an exact radius is to use a **Rel Coords** snap with the **Base = Previous point** option to specify a point the required distance from the arc start point.

With this method there is still an ambiguity about the final arc shape. This is illustrated on the right; both arcs have the same chord and radii and both are drawn in a clockwise sense. Raytrace will always put the centre of the arc to the right of the chord when looking from the start towards the end point. The arc that would be produced is the one shown on the left. If you end up with the wrong result then you can use **Modify -- Mirror** to flip the resulting arc or redraw the arc in the opposite sense with start and end points reversed.



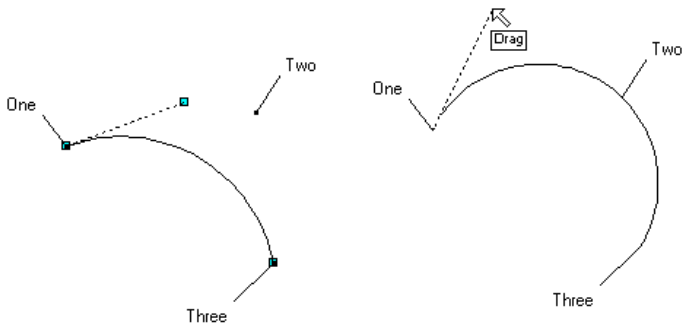
Arcs through three points

You might want to draw an arc through three points in order to determine the radius of curvature of something that has been traced out, e.g. a focal surface. There are two methods you can use, one is exact but cumbersome, the other is easier but only approximate.

The exact method To draw an arc through three points use a conic segment (see below) with the **Vertex, End, Eccentricity** option set and an eccentricity of 0. This will create a "circular" conic with the focus being the centre of the arc. You can then draw a normal circular arc over the top using the **Centre**/**End** option (and snaps) if you want or simply use the conic. This method is only worth considering if the three points can be specified exactly using snaps.

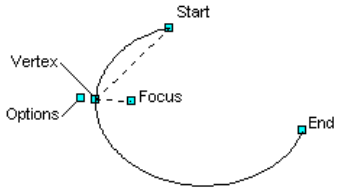
The easy method In this case start by creating an arc segment with the **End**/**Tangent** method and select the start and end as the two points most distant from each other. Specify an arbitrary tangent point. Once the arc is created, select it and drag the tangent control point until the arc passes through the third point. This is illustrated below.

Drawing conics



For conics you must specify three points in addition to the start point. The four points specified (start, focus, vertex and end) over-determine the shape of the segment and one of the points must be adjusted to fit. You can change the way Raytrace adjusts the four points to be consistent.

When a conic segment is selected you will see five drag handles, four at the start, focus, end and vertex points and one positioned near the vertex point on the opposite side of the curve to the focus; this is labeled "Options" in the example shown on the right.



You can change the way the four points define the shape of the conic segment after it has been created by selecting the element containing the conic segment and clicking on the options drag handle or you can set the options in advance using the **Defaults -- Conic Settings...** menu item.

Which-ever method you use, a dialog box containing the options will appear. There are five options available and these are described below.

Focus, End, Axis The start, focus and end points are used as specified. The vertex is used in conjunction with the focus point to define the direction of the axis of the conic and will be moved to lie on the conic.

Focus, Vertex, End Angle The start, focus and vertex points are used as specified. The end point specifies the direction from the focus at which the conic ends. The end point is moved to lie on the conic.

Vertex, Axis, Eccentricity The start and vertex points are used as specified. In addition the eccentricity is held fixed (see below). The focus point only specifies the direction of the axis relative to the vertex point and the end point only specifies a direction relative to the focus.

Vertex, End, Eccentricity The start, vertex and end points are used as specified. The eccentricity is held fixed (see below). The focus point (and hence axis direction) are determined to fit these constraints.

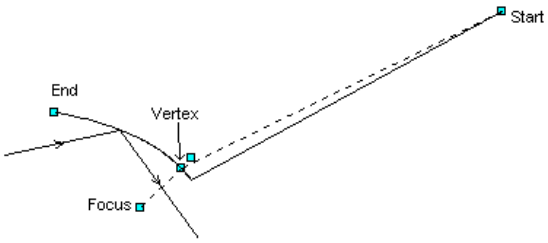
Focus, End, Eccentricity The start, focus and end points are used as specified. The eccentricity is held fixed (see below). The vertex (and hence axis direction) are determined to fit these constraints.

Eccentricity For the last three options you need to specify the eccentricity by entering a value in this box.

- An eccentricity of 0 will give a circular arc.
- Values between -1 and +1 (exclusive) will give rise to an ellipse. The sign of the eccentricity determines which focus is shown with the drag handle when the segment is selected.
- A value of 1 will give you a parabola; a value of -1 is converted to a value of +1.
- A value greater than 1 will give you a hyperbola.
- If a value less than -1 is entered then it is ignored and the current value is retained.

Care with conics

Be careful how you define parabolic and hyperbolic shaped segments. In both cases it is fairly easy to drag one of the defining points to a position which cannot be reconciled with the other defining points. You may end up with a parabola or hyperbola which extends off to "infinity", a result which then makes it difficult to control. Alternatively with a hyperbola, you may end up with a strange looking result as shown on the right.



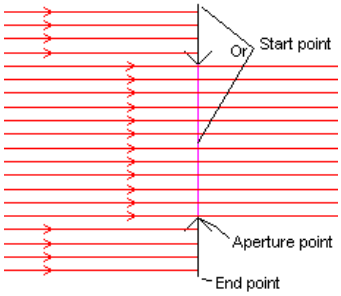
This sort of result stems from the fact that a hyperbola has two branches on opposite sides of the directrix. In the case shown above the selected start and end points lie on opposite branches and cannot be reconciled. The curved portion of the segment still functions correctly but the line joining the start and end points is an artifact and will not interact with rays.

Deleting, adding or modifying a single segment

To delete a segment from an element, break the element up into individual segments using **Modify -- Element > Explode**, delete the segment that you don't want, select the remaining segments in the order that they should be joined and use **Modify -- Element > Join** to put them back together again. You can insert or modify (rotate, flip or scale) a segment using the same technique.

Create -- Element > Iris

An iris element is like a screen with a hole in it. You can adjust the overall size of the screen as well as the size of the hole. An example is shown on the right. Rays can pass through the central section of the iris between the arrow heads. Rays striking the iris outside this section are blocked.



After choosing **Create -- Element > Iris** you must select three points:

- The start point
- An end point
- An aperture point

The use of the start and end points is affected by the **Create -- Par-axials on centre** menu item. If this item is checked then the start point is the centre of the iris, otherwise it is one end of the iris. The end point defines the orientation and extent of the iris. The aperture point defines the size of

the opening within the extent of the iris. The size of the opening is set to the distance between the mid-point of the iris and the aperture point you select. The points are illustrated in the preceding diagram.

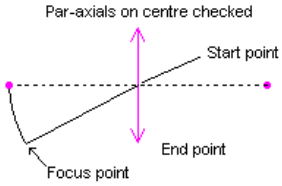
Create -- Element > Converging thin lens and Diverging thin lens

An thin lens element in Raytrace is one which obeys the familiar rules: rays striking the lens parallel to the axis are refracted through the focus, rays passing through the centre of the lens are un-deviated and rays coming from (or passing through) the focus are refracted parallel to the axis. You can create either converging or diverging thin lenses using these two menu items.

After choosing the appropriate **Create -- Element >** menu item you must select three points:

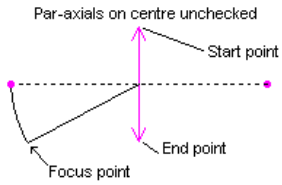
- The starting point
- An end point, which defines the orientation and size of the element's aperture (height of the lens)
- A focus point which defines the focal length of the lens.

How the starting point is used depends on the on whether the menu item **Create -- Par-axials on centre** is checked or not. If it is checked, the starting point will be the centre of the lens and the end point will be one end of the lens aperture. If it is not checked then the starting point will be one end of the lens aperture and the end point will be the other end. In both cases the relative orientation of the start and end points sets the plane of the lens aperture.



The focal length is set to the distance between the mid point of the aperture and the point you choose as the focus point regardless of the orientation of where you select the focus point with respect to the lens aperture.

The principle axis between the focal points is shown by a dashed line with dots at either end. The aperture is shown by a single line with arrow-heads at either end. The arrowheads point out for a converging lens and in for a diverging lens.



You can change a lens from converging to diverging and vice-versa with the menu items **Modify -- Element > Change to > Converging** and **Modify -- Element > Change to > Diverging**.

Create -- Element > Par-axial mirror

You make a par-axial mirror element in a similar manner as a thin lens element. Like thin lens elements their creation is affected by the state of the menu item **Create -- Par-axials on centre**.

When a par-axial mirror element is drawn, a dashed line connects the focal point of the mirror to the middle of the aperture. The aperture is indicated by a single line.

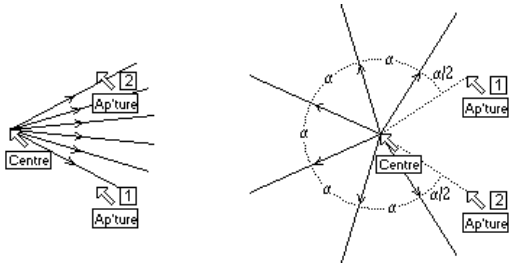
The direction in which you specify the focal length is irrelevant, Raytrace always positions the focal point to the right of the aperture when looking from the starting point along the aperture towards the end point. Hence to flip a par-axial mirror over you must either rotate it through 180° using **Modify -- Rotate** or mirror it (using **Modify -- Mirror**) about a line parallel to its axis, not its aperture.

Create -- Source > Point

This menu item creates a group of rays that come from the same point. To define the source you specify a number of rays followed by a centre point and two aperture points which define the aperture through which the rays will pass. The rays will be spaced in an anti-clockwise direction starting near the first aperture point you select and stopping near the second aperture point. The angular spacing of the rays will be even and offset from the aperture end points by half their angular spacing.

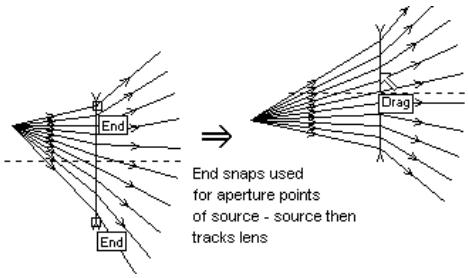
The point sources shown on the right were created using the same relative positioning of the three defining points but with the order of the aperture points reversed.

If you make a mistake in specifying the order of the aperture points then select one of the rays coming from the source and choose the menu item **Modify -- Source > Flip point sources** to correct it. Alternatively, delete it and start again.



Rays from sources all carry the same attributes when created. However, once the source is created the individual rays may be modified independently so has to have different colour etc. The length of the rays coming from the source is controlled by the default length setting in **Defaults -- Ray settings...** not by the position of the aperture points.

You can use snaps when creating a source; if you snap to some part of an element then the source defining points will be linked to the snap points. This means that if you move the element, or drag it, the source will track the new position of the snap points. For example if the aperture points of the source are snapped to the ends of a lens and the lens is dragged then the source always strikes the lens as illustrated on the right.



If you specify the same point for both aperture points then the rays will all be overlaid. This can be useful for generating what looks like a white ray by creating a source with 3 rays and changing the colours of the rays to red, green and blue. See the tutorial on **Dispersion by a triangular prism** for an example using this technique.
If you try and drag one of the rays from a source then you will be given two options in a dialog box.

The first of these, **Drag only this ray,** will mean that the dragging affects only the one ray; just as would be the case for a ray not coming from a source . While you can drag an individual ray from a source to any position, it will be re-positioned when the source is next updated; for example when some part of the ray diagram is dragged.

The second option, **Drag all rays from this source,** causes the dragging to effect the entire source. This depends on which ray you are dragging:

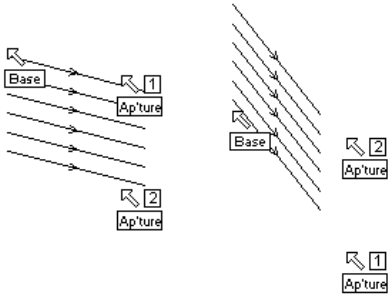
- If you drag the start of any ray and use this option then you will drag the centre of the source and all the source rays will move accordingly.
- If you drag any of the rays as a whole then the source will be dragged as a whole as if all three defining points were moved by the same amount.
- If you drag the end point of either extreme ray then the corresponding aperture point will be moved and the ray spacing will be modified accordingly.

Beware that when you drag any of the source points in this manner then any links to objects created with snaps will be lost; you can create a new link by using a snap to finish dragging. See also **Modify -- Source > Unlink snaps**.

You can delete a source by deleting any one of the rays emanating from it.

Create -- Source > Plane

This menu item creates a group of parallel rays. You specify a number of rays, a base point and two aperture points as for a point source. In this case the rays are drawn evenly spaced and parallel to a line joining the base point with the first aperture point. This is illustrated on the right.



These two plane sources were created with the same relative position of the three defining points but with the order of the aperture points reversed.

You can drag and modify the rays of a plane source in the same way as described for a point source, see **Create -- Source > Point**.

Create -- Tape measure

A tape measure is an object which displays the distance between two points in the ray diagram. To create a tape measure, choose **Create -- Tape measure** then select the two points you want the tape measure to stretch between.

Tape measures are drawn as a straight lines with small dots at either end. The readout is positioned either over the middle of the line or at the end of a leader attached to the middle of the line. Various options can be set by selecting the tape measure and using **Modify -- Tape measure...**. See **Modify -- Tape measure** for the available options.

To select a tape measure you must click somewhere on either the tape measure line or the leader; clicking on the readout has no effect. Once selected, tape measures can be dragged like other objects. Tape measures can be linked to snaps either at creation or at the end of dragging so that they change automatically as the ray diagram is dragged or modified.

The readouts of all selected tape measures can be copied to the clipboard using **Info -- Readouts** and all tape measure readouts are copied to the clipboard for each step in either an **Auto drag** or **Auto trace** operation.

Create -- Protractor

A protractor is an object which displays the angle subtended by two "end" points relative to a third "centre" point. To create a protractor, choose **Create -- Protractor** then select the centre and two end points you want to define the protractor.

A protractor is drawn as two lines joining the centre point to the end points with small dots at the ends of the lines. The angle is displayed either close to the centre point or at the end of a leader attached to the centre point. Various options can be set by selecting the protractor and using **Modify -- Protractor...**. See **Modify -- Protractor** for the available options.

To select a protractor you must click somewhere on one of the "arms" of the protractor or the leader; clicking on the readout has no effect. Once selected, protractors can be dragged like other objects. Protractors can be linked to snaps either at creation or at the end of dragging so that they change automatically as the ray diagram is dragged or modified.

The readouts of selected protractors can be copied to the clipboard using **Info -- Readouts** and all protractor readouts are copied to the clipboard for each step in either an **Auto drag** or **Auto trace** operation.

Create -- Annotation

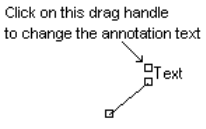
When you choose this menu item a dialog box will appear with space to type in the annotation text. The text must be less than 32 characters long and will appear as a single line of text in the diagram.

Once you have entered the desired text, click on **Ok**. You must then select the base point to which the annotation will be anchored. This may be a snap to an object; if so then the annotation will be moved to maintain its relationship with the object whenever the object is moved.

After selecting the base point you must specify the leader offset. The annotation will be placed at this point and a leader line will join the text to the base point. You may select the same point for the base and leader points, in which case a small dot will appear at the base point; if you do this then you must click on this dot to select the annotation.

To select an annotation you must click somewhere on the leader line; clicking on the text has no effect. Once selected, you can drag an annotation as you do other objects.

To change the annotation text, first select the annotation. A third drag handle will be displayed near the start of the text; click on this drag handle to bring up the dialog box for entering the annotation text. Type in the new text and click on **Ok**.



Create -- Trail

A trail is an object consisting of a series of line segments joining a sequence of points defined by the movement of some point in the ray diagram.

When you choose this menu item you will be prompted by the cursor to select the point which you want the trail to follow. The point must be an object snap which you must invoke either with the secondary mouse button's popup menu or with a shortcut key. If you do not invoke a snap when selecting the point then the trail will not be created. When the selected point moves as a result of dragging some part of the ray diagram a trail will be drawn - joining the positions occupied by the point as it moves. You can use trails to:

- simply indicate where you have dragged a point
- trace out cross sections of images
- trace out the locus of a point as some parameter of the ray diagram is changed.

There are several examples of the use of trails in the tutorial manual.

You can select a trail by clicking on it somewhere, however you cannot drag a trail or modify it. See also **Modify -- Reset trails** and **Modify -- Pause Trail update**.

Create -- Par-axials on centre

The state of this menu affects how thin lens, par-axial mirrors and iris elements are created. See **Create -- Converging thin lens** etc. for information on its effect. Whether you check this menu item or not is largely a matter of personal preference although sometimes it is easier to create a thin lens one way rather than the other. The state of this menu item is saved when you exit Raytrace and restored when next you run Raytrace.

Defaults menu

Defaults -- Ray settings...

Choosing this menu item brings up a dialog box which allows you to set the default colour, arrow position and fertility of rays before you create them. To change these settings for rays that have already been created use **Modify -- Ray...**. These settings do not apply to rays that Raytrace generates; see **Defaults -- Child rays...**.

If you enter a value in the default length edit box this will only apply to rays that are generated when you create a source. Rays that you create manually retain the length that you create them with unless they interact with an element.

The available options are explained under **Modify -- Rays...**.

Defaults -- Child Rays...

Choosing this menu item brings up a dialog box which allows you to set the default colour, arrow position, fertility and length of rays that are created by Raytrace. These settings do not apply to rays that you draw; see **Defaults -- Ray settings...**.

The available options are explained under **Modify -- Rays...**.

Defaults -- Refractive Indices...

Choosing this menu item brings up a dialog box which allows you to set the refractive indices for elements before you create them. It does not alter the properties of elements that have already been created - to do this select the element and use **Modify -- Element > Refractive Index...**.

The methods of setting the refractive index, choosing materials etc. are explained under **Modify -- Element > Refractive Index...**.

Since surface, shape and screen elements can be turned into regions, they have latent refractive indices which are set to these default values when they are created.

Defaults -- Auto drag settings...

Choosing this menu item brings up a dialog box which allows you to set the number of points per segment at which the ray paths are re-calculated during either a **Modify -- Auto trace** or **Auto drag** function. The number of points can be adjusted independently for line, arc and conic segments.

The number of steps per segment must be between 1 and 1000. Note that these are steps per segment and the path element that is used in conjunction may have as many segments as you like. However because the readouts of all tape measures and protractors are copied into the clipboard at each step there is effectively a limit to the total number of steps that can be used in any one auto drag/trace operation set by the clipboard reaching its 64 kb limit.

If the **Press space to step** option is checked then Raytrace will pause after calculating the ray paths at each step until the space bar is pressed.

Defaults -- Conic Settings...

This menu item allows you to change the default manner in which conic segments are defined. It starts the Conic Segment Options dialog box, the various settings are described fully in the section **Drawing Element - Conics.** These settings apply only to newly created conics and not to already existing segments. You can change the constraints on a conic after it is created by clicking on its fifth drag handle. See the tutorial **Introduction to conics** for some examples. More information is also given under the sub-menu **Create -- Element >** in this manual.

Options menu

Options -- Colours

This menu item brings up a dialog box which allows you to set the colours used by Raytrace to draw elements and the background colour. A thumbnail sketch allows you to see the effect of choosing a combination before accepting the settings with **Ok** or abandoning any selection and using the current colour scheme with **Cancel**.

Red, green and blue are missing from the colour items because these are reserved for the three ray colours.

To change the colour scheme first select one of the **Background**, **Outlines**, **Fill** or **Par-axials** options then choose the colour that you want for that option. The thumbnail sketch will update automatically.

Tape measures, protractors and annotation leaders and trails are always drawn in black unless black is the current background colour in which case they are drawn in white. Tape measure and protractor readouts and annotation text are drawn in the current outline colour.

Options -- Show >

This sub menu contains seven items. The first three of these, **Red Rays**, **Green Rays** and **Blue Rays** control whether the rays of the specified colour are visible or not.

Even when rays are not visible their positions are still calculated so that tape measures and protractors which depend upon the rays for position information are updated correctly. The main purpose of these options is to allow you to simplify the ray diagram by hiding rays which you are not interested in at the time. Turning off some rays may also make it easier to select other objects.

Rays are deselected if their colour is turned off; for example if you have rays of all three colours in a diagram, use the **Edit -- Select All > Rays** command, turn the green rays off then on by using **Options -- Show > Green Rays** twice, then only the red and blue rays will remain selected.

The next four items in this sub-menu affect the visibility of **Tape Measures**, **Protractors**, **Annotations** and **Trails** respectively.

Not showing objects that are not of immediate interest can make a ray diagram much easier to work with. Selection of objects is sometimes simplified when extraneous objects in close proximity are not displayed.

Any selected objects are deselected if they are of a type which is not shown; they are not re-selected when they are made visible again.

Using **File -- New** to clear a ray diagram sets all these option so that the objects are visible. Remember if you use **Clear -- All** to clear the ray diagram then this options are not affected.

These options are saved with the ray diagram. So, if you create an object in a ray diagram that you have loaded and it does not become visible, check these items - they may have been turned off when the ray diagram was saved.

Options -- Show Grid

Raytrace allows you to display a grid as an aid in drawing objects. Check this menu item to display a grid. If the current grid size is unsuitable for the scale to which you have zoomed then the grid will not display - it will display if you later change the zoom scale to one where the grid size is appropriate.

You can toggle the display of the grid simply by hitting the **G** key at any time.

You should use **Options -- Snap to grid** to snap to grid intersections rather than trying to align the cursor with a grid intersection manually.

Options -- Grid size

You can specify the x and y spacing of the drawing aid grid using this menu item. The grid size is specified in drawing units. The default grid size when Raytrace starts is 20 drawing units in both x and y directions.

If you choose a grid spacing which is too small or too large to be displayed meaningfully at the current zoom setting then you will be prompted that the grid will not be displayed. However the grid will still be active at the selected size for snapping purposes. The grid spacings in X and Y directions are independent and it is possible to display only the horizontal or vertical lines if one of the spacings is inappropriate.

You can see the effect of a particular grid size before exiting the dialog box by using the **Grid On/Off** button to toggle the display of the grid.

Options -- Snap to grid

If this option is checked then Raytrace will always snap to the nearest grid intersection. This option can be over-ridden by selecting another snap type. This can make selecting objects difficult unless they lie on a grid intersection or line so it is recommended that you turn off the snap to grid option when selecting objects.

When you drag an element the grid display is suppressed for the sake of speed but the snap to grid will still function.

You can toggle this option simply by pressing the **S** key at any time.

Options -- Update on Ray Drag

If this item is checked then Raytrace will "animate" the ray diagram as you drag rays or sources around. If this is slow on your computer then you might like to uncheck this item - in this case Raytrace waits until you finish dragging the rays before it completes the ray paths. If you want to make good use of trails and the **Modify -- Auto trace** features of Raytrace then you must have this item checked.

Options -- Update on Element Drag

If this item is checked then Raytrace will "animate" the ray diagram as you drag elements around. If this is slow on your computer then you might like to uncheck this item - in this case Raytrace waits until you finish dragging the element before it completes the ray paths.

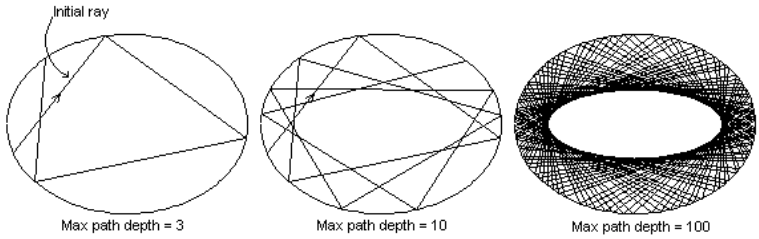
If you plan to use the **Auto drag** facility to change the shape of an element and want to record the effects then this item must be checked.

This item also controls whether Raytrace updates the diagram while you change the refractive index of an element or after you have finished changing the refractive index.

Options -- Maximum path depth...

This menu item brings up a dialog box which allows you to control the maximum number of generations of child rays that can spring from any ray. This option is useful for limiting the number of total internal reflections that can occur. For example if you start a ray inside a closed reflector then this setting limits the number of reflections that can occur inside the reflector. The effect of this setting is illustrated in the diagram below.

Different child paths are independent as far as this setting is concerned - it is the number of ray generations



along any path that is limited not the total number of child rays.

If you set this value to a large number and encounter an internal reflection then be prepared for the sometimes long calculation times involved. The absolute limit on this number is determined by the amount of memory allocated to ray information - at this stage 400 rays.

Info menu

Info -- Identify Point

After choosing this menu item, select a point in the ray diagram (you may use a snap). After selecting the point a message box will appear containing the coordinates of the point as well as the refractive index at that point.

This information is also copied to the clipboard.

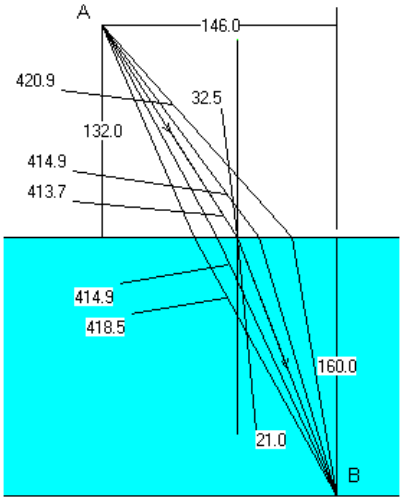
Info -- Physical Length

This menu item causes the physical path length (expressed in drawing units) of all selected rays to be summed and displayed in a message box as well as being copied to the clipboard.

Info -- Optical Length

This menu item causes the optical path length (physical path multiplied by refractive index) of all selected rays to be summed and displayed in a message box as well as being copied to the clipboard.

An example which used this function to demonstrate Fermat's principle is illustrated here. Alternative paths connecting A and B have been generated manually and compared to the actual path (indicated by the rays with arrow heads). The optical path lengths have been calculated and are shown for each path. The refractive index of the medium is 1.5 and the angles of incidence and refraction which obeys Snell's law are shown. The optical path length for the rays obeying Snell's law is a minimum in accordance with Fermat's principle.



Info -- Readouts

This menu item causes the readouts of all selected tape measures and protractors to be copied to the clipboard. If the tape measures or protractors have the **None** option set then they are treated as if the **Cartesian** or **Degrees** options are set.

Help menu

Help -- Contents

This menu item starts the Windows help facility at the Raytrace help contents page. It is the entry point for information relating to Raytrace.

Help -- Quick Tour

This menu item starts the Quick Tour which is offered at when Raytrace first starts.

Help -- Helper scripts

This menu item runs the Raytrace script file called HELPER.RSC. As supplied this script gives you access to most of the other scripts that are supplied with Raytrace. These include many examples as well as some assistant type scripts which perform useful tasks.

Help -- Using Help

This menu item starts the help facility on topics related to using the Windows help facility. Only use this if you are unfamiliar with using Windows help and are not searching for information relating to Raytrace.

Help -- About

This menu item brings up a dialog box containing information about the version number and release date of Raytrace and the licensee of the particular copy of the program. This is the same dialog box which appears when you first start Raytrace. To return to Raytrace click on the **Run RAYTRACE** button.

Additional functions not covered by a menu item

Auto drag

Auto dragging is very similar to Auto trace except that you can move any point that you can drag along the path not just points associated with sources or rays.

To make use of the auto drag function:

* Start dragging the point you want to move in the normal way

* Once dragging is initiated, click on the secondary mouse button and select Auto drag from the popup menu.

Dragging will then stop and the cursor will return to the select form.

* Select the element you want to use as the path. (Preferably a shape element)

Raytrace will then take over the drag operation and move the point along the path. When it has finished it will return you to manual dragging of the same point.

As in the case of **Modify --Auto trace** the readouts of all tape measures and protractors will be copied to the clipboard at each step along the path.

You control the number of steps taken using and whether the dragging waits at each step for you to press the space bar using **Defaults -- Auto drag settings...**.

Snaps

Snaps will be familiar to anyone who has used a computer aided design package. In Raytrace they serve two purposes:

- To enable you to precisely specify a point relative to some part of the ray diagram.
- To allow “linking” of some objects (sources, tape measures, protractors annotations, etc.) to points within the diagram so that when the diagram changes the linked objects are automatically moved or updated based on the new position of the specified points.

To make use of a snap, click the secondary mouse button once. For some operations this immediately presents you with a menu containing various types of snap. For other operations the snaps are listed in a second level popup which is accessible from the **Snaps >** item. Alternatively, snaps can be selected by a single key press, see the last page of this manual which lists the shortcut keys that can be used in Raytrace.

Snaps only act upon rays and elements and tape measures. You cannot snap to points on protractors, annotations or trails.

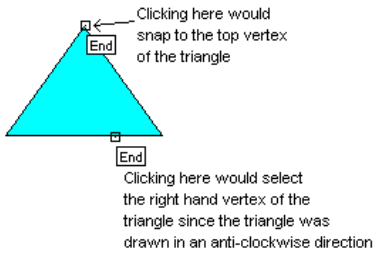
When a snap is active the cursor will change to a select box and a word indicating the type of snap. You position the select box over the point or object that you want to snap to. If more than one object crosses the select box then the snap will act on the object that was drawn or created first. Try and ensure that you position the cursor over only one object when using a snap to avoid any confusion.

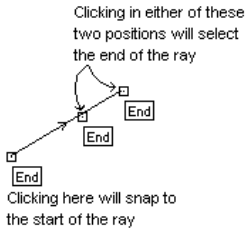
The object does not need to be selected for the snap to function; in some of the following illustrations the objects are shown as selected simply to indicate the position of some of the control points with the drag handles.

End snap

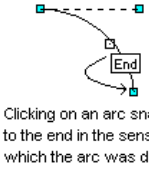
This snaps to either the end point that lies within the select box or to the end of the ray or segment that passes through the select box.

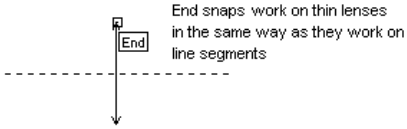
The end snap works on any type of segment: line, arc or conic and on the apertures of thin lens, par-axial mirrors and irises.





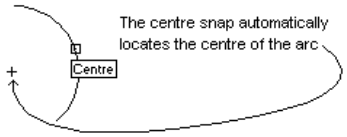
If you are not sure of the direction in which a segment was drawn then it is best to position the end select box over the end point that you want rather than over any part of the segment.





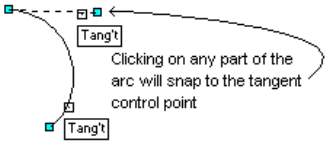
Centre snap

This snaps to the centre of an arc segment. You can position the centre select box over any part of the arc. If the tangent control point is co-linear with the start and end points of the arc then the centre snap will locate the mid-point of the line between the start and end points.



Tangent snap

This snaps to the tangent control point of the arc. The arc need not be selected, it is just shown that way here to indicate the position of the tangent control point.

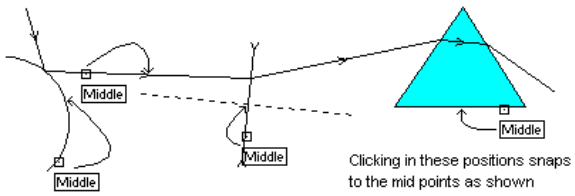


Mid point snap

This snaps to the middle of the ray, line or arc segment that is chosen.

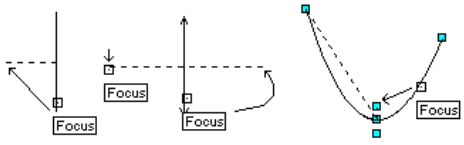
The mid point snap works on thin lens, par-axial mirror elements, irises and tape measures but does not work on conic segments.

Focus snap



This snaps to the focal point of thin lens, par-axial mirrors and conic segments.

If you position the focus select box over a thin lens element then there is some ambiguity about which focus will be used. Raytrace resolves this by looking at the order in which the points defining the lens were specified. However you cannot tell how this will work by looking at the lens. To avoid confusion, position the focus select box over the actual focus point of the thin lens. There is no ambiguity with par-axial mirrors or conic segments so you can position the focus select box anywhere on these types of object.

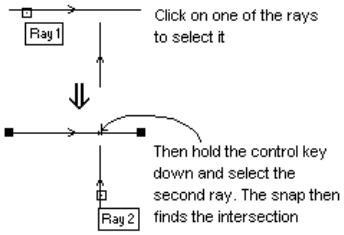


Conic Vertex snap

This snaps to the vertex of the conic segment (where the axis of the conic crosses the curve; indicated by a drag handle when the conic is selected). The vertex need not lie on the part of the segment that is drawn.

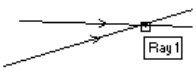
Ray Intersect snap

When you choose this type of snap you must specify the two rays whose intersection you want. When the cursor changes to the Ray 1 select form, select one of the rays. The cursor will then change to the Ray 2 select form. You must hold the control key down when you select the second ray. If you do not, then the ray you select with the Ray 2 cursor is taken as the first ray and the cursor will stay in the Ray 2 select form waiting for you to select another ray.



You can select both rays in the one operation if you position the Ray 1 select box so that it crosses both rays. However it must cross only two rays for this to work.

Ray intersections are the best way to locate image positions in a ray diagram.



Clicking here would select the intersection of the rays in one operation

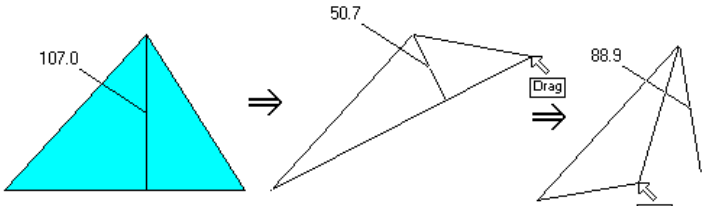
Clicking here would not succeed in finding the ray intersection because more than two rays would be selected

Perpendicular snap

Using this snap, you can make a tape measure or a protractor arm remain perpendicular to a line segment. For example, one end of the tape measure shown on the right has been linked to the upper vertex of the triangle and the other end to a perpendicular snap on the lower edge:

Perpendicular snaps work only on line segments of elements, rays or tape measures and not on arcs, protractors or conic segments.

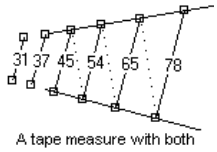
A perpendicular snap obviously requires a point of reference in addition to the line segment to which it finds the perpendicular. When a perpendicular snap is used, it bases the perpendicular on the last point at which the primary mouse button was clicked. However, when defining the end point of the second arm of a protractor or the second aperture point of a point source, Raytrace bases the perpendicular on the centre point of the protractor (or source) rather than the last mouse click.



A perpendicular snap was used to link the lower end of the tape measure to the bottom edge of the triangle.

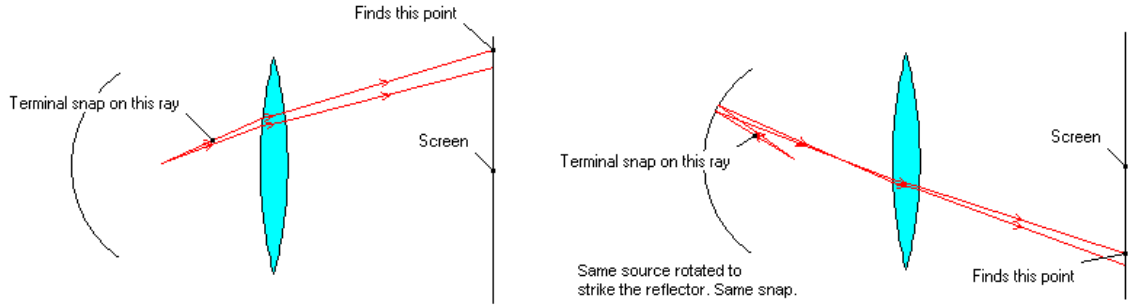
It is possible to create a tape measure with one end linked to a perpendicular snap and then drag the other end of the tape measure and link it to another perpendicular snap. This will lead to a tape measure that shrinks with each update of the ray diagram as shown on the right. Eventually it will have zero length at the intersection of the two line segments involved in the perpendicular snaps. Avoid doing this!

Terminal snap



A tape measure with both ends linked to perpendicular snaps

A terminal snap acts on a ray and finds the end point of the final ray in its propagation path. In determining the final ray, Raytrace follows refractions and reflections from the selected ray (in that order of priority) at each boundary. This snap can be used to find where light finally strikes a screen regardless of the actual path taken to get there. For example, a ray might pass directly from a source through a lens to a screen or if the source is rotated, it might be reflected off a mirror then pass through the lens and strike the screen as shown in the two diagrams below. A terminal snap used on the ray will always find the end of the last generation of its child rays which, in this case, is the point where the light would strike the screen.



Abs Coords snap

When you choose this type of snap a dialog box appears in which you can enter the Cartesian co-ordinates of the point you want. When Raytrace starts, the co-ordinate origin is in the centre of the Raytrace window and one drawing unit is equivalent to one pixel spacing.

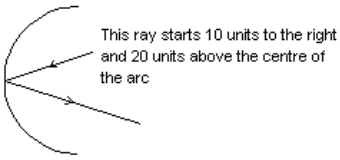
Rel Coords

This option allows you to specify a point as a displacement relative to some base point. When you choose this item the cursor changes to the base point form and you must select the base point - you can use a snap to do this if you want.

Once you have selected the base point, a dialog box appears and you enter either the Cartesian or polar displacement from the base point to the point you want to specify.
For example to specify the start point of the ray 10 units to the right and 20 units above the centre of the arc in the diagram at the right follow these steps:

* Choose **Create -- Ray** to start drawing the ray.

* Press **R** or click on the secondary mouse button and select **Rel Coords** to specify a relative coords snap.



* Press **C** or use the secondary mouse button to specify a centre snap.

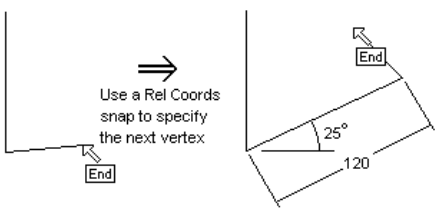
* Position the centre select box over the arc and click the primary mouse button.

* In the resulting dialog box, enter the relative displacement as either x,y coordinates or a radius and angle then click on **Ok**.

For polar displacements the angle is specified in degrees. Whenever you move between the edit boxes in this dialog box the x,y and radius,angle numbers are updated to be consistent.

The **Base = Previous point** button allows you to use the previous point at which the primary mouse button was clicked as the base point - over-riding the base point specified just before the dialog box started. You can use this, among other things, to draw elements where the co-ordinates of the vertices are specified relative to the previous vertex.

For example if you have drawn the first side of an element as shown on the right and want the second side to be 120 units long extending at an angle of 25 degrees to the horizontal you can use a relative coords snap.



After specifying the relative coords snap you must still select a base point to bring up the **Relative Displacement Entry** dialog but the point you pick is irrelevant - in response to the base point cursor simply click somewhere in the Raytrace window. When the dialog box appears press the **Base = Previous point** button and the base point co-ordinates in the dialog box will change to those of the last primary mouse button click (ignoring the click in response to the base point cursor), i.e. the last vertex specified. Enter the relative displacement and click on **Ok** to complete the operation.

Grid Snap

This snap option is slightly different to the others in that it does not specify a point relative to an object. A small cross is displayed in the cursor rather than a box. The point chosen is the grid intersection closest to the point at the centre of the small cross in the cursor. Using grid snap from the popup menu is the same as checking **Options -- Snap to grid** but it applies for only one point. A grid snap will always succeed; the grid does not have to be displayed. See: **Options -- Grid**, **Options -- Grid size...** and **Options -- Snap to grid** in the Raytrace Reference Manual for more information.

None

This is included to allow you to cancel an unwanted snap. If you select a snap and then decide that you want to choose the point freehand either press the **N** key or click on the secondary mouse button and select **None** to cancel the snap.

When snaps don't succeed...

When you specify a snap, Raytrace does not accept the selected point unless the snap is successful. For example, if you specify a centre snap and do not position the cursor over an arc segment when you click the primary mouse button then the snap is unsuccessful and the cursor remains in the centre select form. You can change to another type of snap or you can select **None** from the snap menu to return to freehand pointing.

Shortcut keys

Snap actions

These keys allow you to select a snap without having to click the secondary mouse button.

E	---	End snap
C	---	Centre snap
T	---	Tangent snap
M	---	Mid point snap
F	---	Focus point snap
V	---	Conic Vertex snap
I	---	Ray intersection snap
L	---	Perpendicular snap
Z	---	Terminal snap
A	---	Absolute coords entry
R	---	Relative coords entry
N	---	None (Cancels an unwanted snap if you change your mind)

Grid actions

G	---	Toggles the display of the grid on and off
S	---	Toggles the snap to grid option on and off

Fertility actions

Pressing these keys changes the setting of the fertility option indicated for all selected rays.

F2	---	Reflect always
F3	---	Reflect if no refraction
F4	---	Refract
F5	---	Show normal
F6	---	Forward project
F7	---	Back project
F8	---	Parent by reflection
F9	---	Parent by refraction

Ray colour change

Shift + F2	---	Change the colour of all selected rays in the cyclic order of Red → Green → Blue → Red

Selecting

Shift + F3	---	Starts an extended select operation (Same as menu item **Edit -- Select extended**)
Shift + F4	---	Fine select - toggles a pixel level zoom box centred on the current cursor position so that you can select at the pixel resolution

Miscellaneous

P	---	Toggles the pause state for trail updating. (Same as menu item **Modify -- Pause Trail update**)
ESC	---	Aborts most operations
Del	---	Same as choosing **Edit -- Delete**.