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1 Introduction

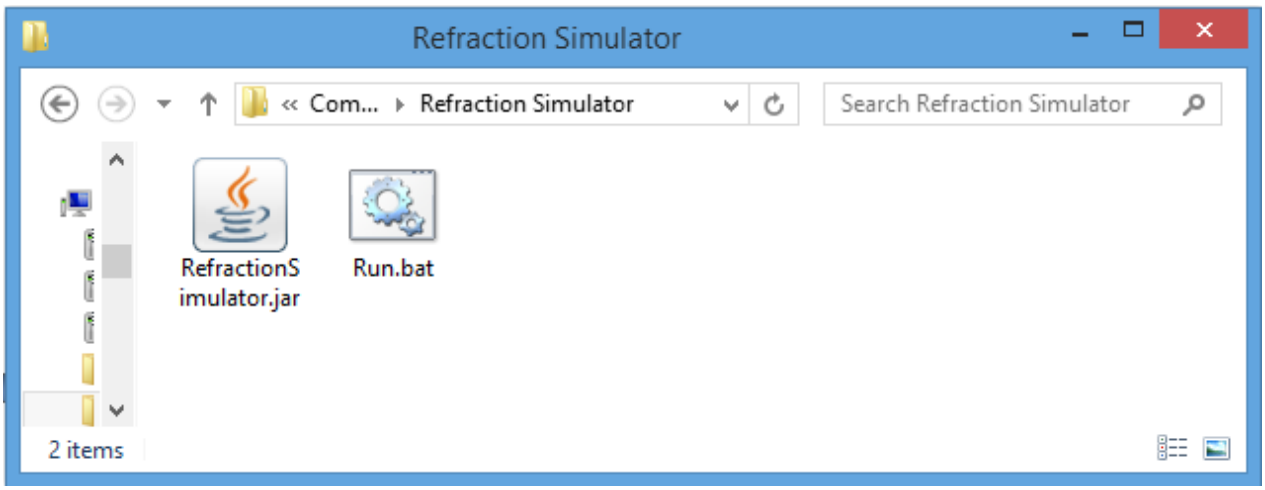
This application is for use by Physics teachers and students to simulate and visualise refraction and total internal reflection in a 3-D environment. There can be multiple light sources which each fire a beam of light. The beams can then be made to pass between materials (or reflect at the boundary) at varying angles and the resulting paths of the beams observed and angles read. This is advantageous to live demonstration because the user can set the material of the surroundings and custom materials can be created which are not limited to existing in reality.

The beams and angles are updated in real-time, making this application suitable for live demonstration in a classroom. It's main purpose here would be to demonstrate how angles of refraction are affected by changes in the angle of incidence, relative refractive indices and general visualisation in 3-D which diagrams do not provide and more specifically how lenses cause divergence and convergence in three dimensions. The application can also save still images which may serve as diagrams that can be shown in a slideshow presentation or printed for students' notes. The application is also useful for setting questions relating to Snell's law and also producing answers to these questions.

2 Installation Instructions

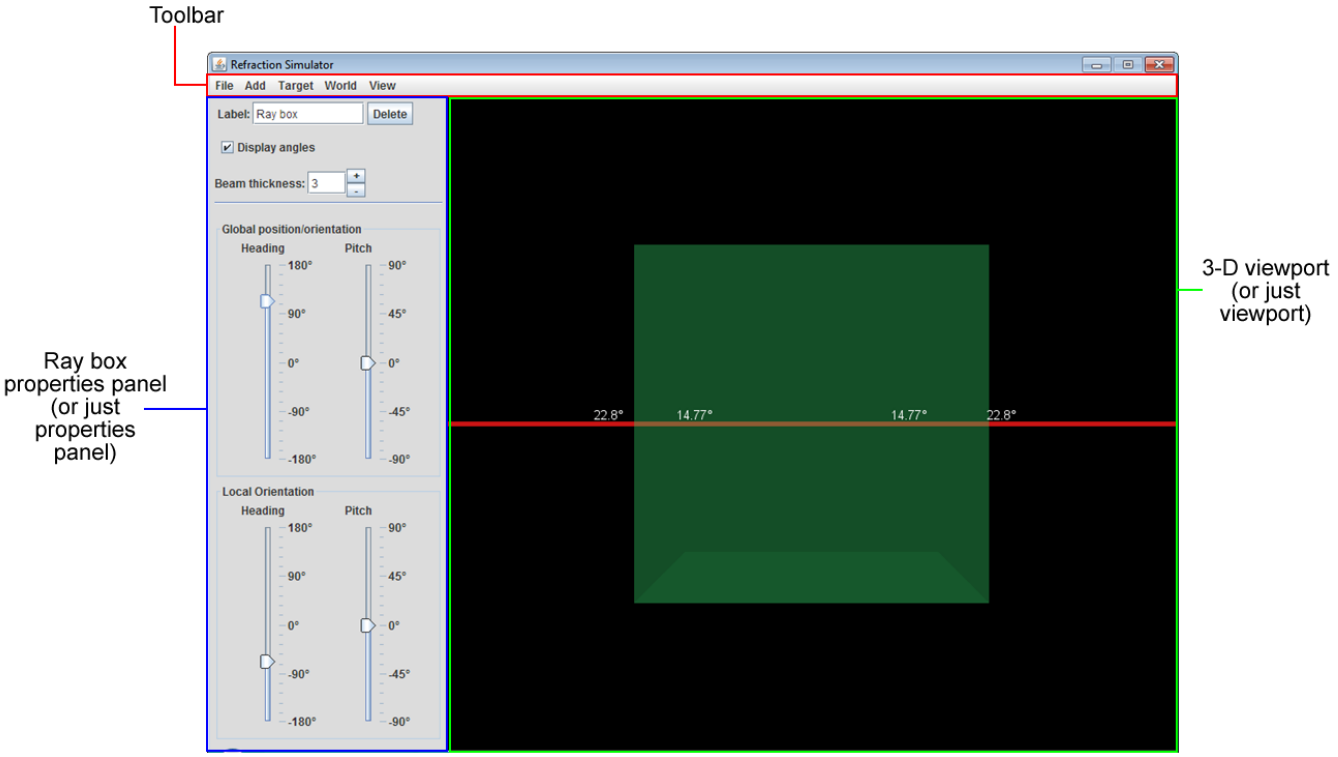
The application can be transferred via any medium with a capacity of at least 76 KB, such as a memory stick, a CD or the Internet. The application consists of a directory (folder) called "Refraction Simulator". This can be copied or moved to anywhere on the machine's secondary storage devices (given that there is enough available space) and even renamed.

The directory contains two files. The program is contained entirely within the executable RefractionSimulator.jar file. If Java runtime environment (JRE) is installed on the machine, the application can be started from a file browser by double-clicking RefractionSimulator.jar or Run.bat (if double-clicking RefractionSimulator.jar did not work – Run.bat must be in the same directory/folder).

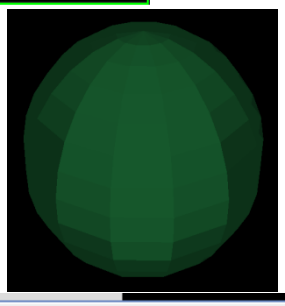


3 How to Use the System

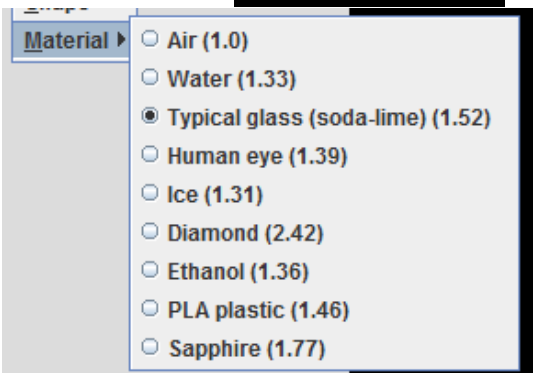
Upon starting the program you will be presented with a default setup such as that shown by the image below which labels the different areas of the user interface.



3.1 Terminology

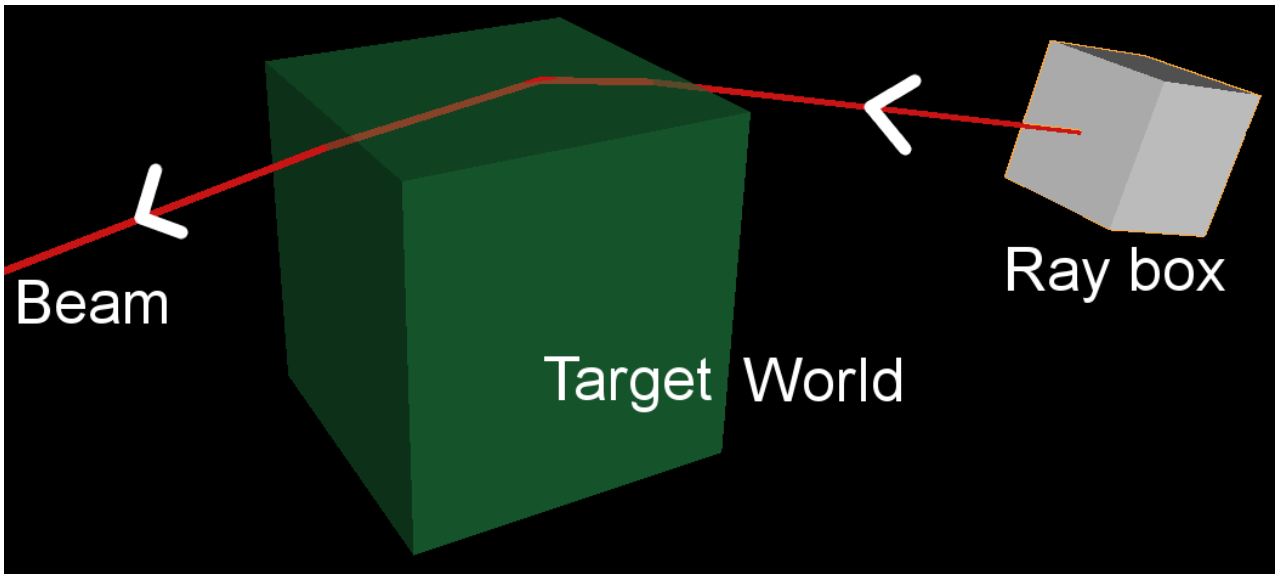


- **Object**: a shape which can be viewed in the viewport and consists of flat faces defined by points in 3-D space. Some examples are cubes, triangular prisms, approximations of spheres and all manner of irregular shapes too.
- **Material**: a virtual model of the refractive properties of a real-world material such as water, glass or diamond. The refractive index given for a material is relative to a vacuum and refractive indices the user inputs will be treated as being relative to a vacuum.

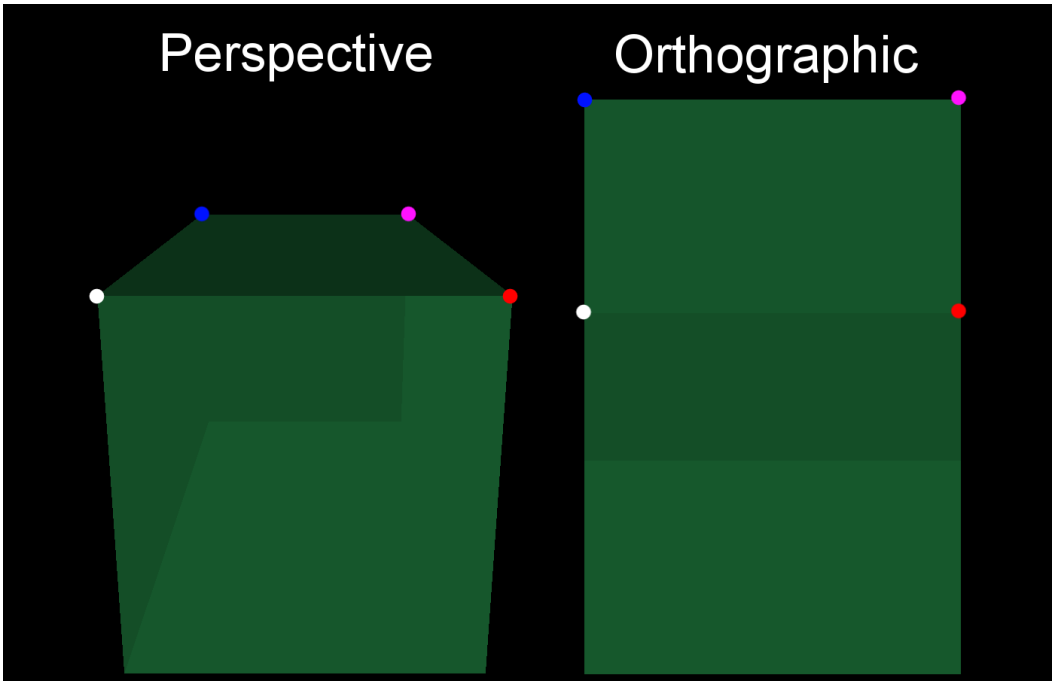


- **Beam**: an object which shows the path that a beam of light would take. The user can change the thickness of the object representing the beam of light.
- **Ray box**: an object which the user can move and rotate to set the initial direction of a beam. Each ray box has a label which allows it to be identified in the viewport. Ray boxes have some other properties and ray boxes can be selected individually in order to edit these properties.
- **Target/Target shape**: the green semi-transparent object at the centre of the viewport through which beams of light can be shone. The user can change the shape and material of this object.

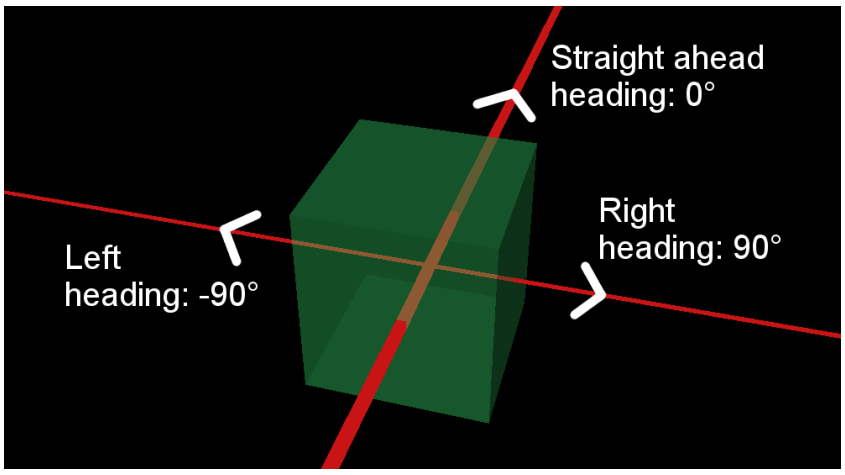
- **World**: the ‘surroundings’ or the virtual 3-D space outside of the target. The user can change the material of the world.



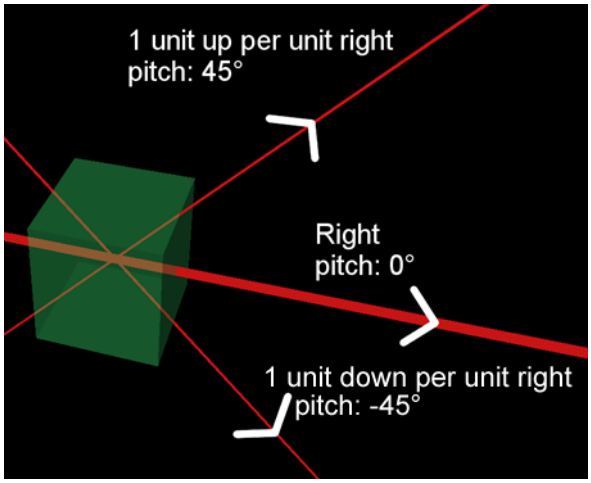
- **Camera**: the position and orientation in space from which the user sees the 3-D space.
- **Perspective**: a method of visualising three dimensions in two dimensions which simulates how we see the world; parallel lines converge towards a vanishing point as they extend away from us and objects become smaller as they move further away. The alternative to perspective visualisation is orthographic visualisation in which parallel lines remain parallel and an object’s size is independent of how far away it is.



- **Heading**: in a horizontal plane, the angle of rotation from straight ahead between $-180°$ and $180°$; clockwise is positive and anti-clockwise is negative.



- **Pitch**: in a vertical plane, the angle of rotation from horizontal between $-90°$ and $90°$; upwards is positive and downwards is negative.



3.2 3-D Viewport

This is where most information is output; three-dimensional objects are rendered here and angles and ray box labels overlaid. The viewport also responds to both keyboard and mouse inputs which allow the user to navigate 3-D space, toggle between perspective and orthographic viewing and select or deselect a ray box.

3.2.1 Navigating 3-D Space

The user/camera is always looking directly towards the centre of the 3-D space, which is roughly the centre of the target.

To orbit around the centre of the space, left-click and drag with the mouse over the viewport; dragging right increases heading, dragging left decreases heading, dragging down increases pitch, dragging up decreases pitch and dragging diagonally affects both the camera's heading and pitch.

To move closer to the centre (zoom in) scroll up or right-click and drag up with the mouse over the viewport. To move further away from the centre (zoom out) scroll down or right-click and drag down.

There are some points of view (camera positions) that the user might find particularly useful which can be switched to through the toolbar (View > Camera position) or by pressing the appropriate key with the viewport in focus (no button or other input component has been clicked or dragged since the viewport was last clicked or dragged in):

- 1 Front: looking in the direction with heading $0°$ and pitch $0°$
- 2 Back: looking in the direction with heading $180°$ and pitch $0°$
- 3 Left: looking in the direction with heading $90°$ and pitch $0°$
- 4 Right: looking in the direction with heading $-90°$ and pitch $0°$
- 5 Top: looking in the direction with heading $0°$ and pitch $-90°$
- 6 Bottom: looking in the direction with heading $0°$ and pitch $90°$

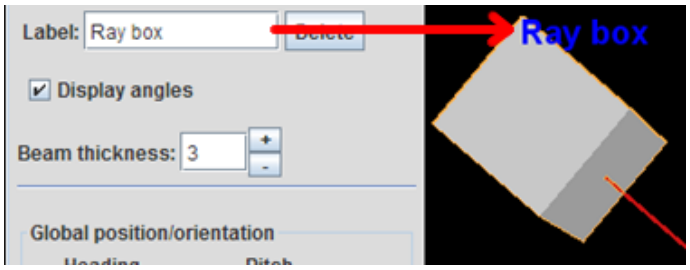
3.2.2 Other Functions

Using the viewport is the only way to select or deselect a specific ray box. No more than one ray box can be selected at a time and the purpose of selecting a ray box is so that its properties can be edited in the properties panel. To select a ray box, click it in the viewport (without dragging) at a point where it is not behind another object such as the target or a beam. Clicking a ray box when another is already selected changes the selection, and clicking anything but a ray box deselects the selected ray box. Deleting a ray box deselects it (it must be selected to be deleted) and adding a ray box makes the new ray box the current selection.

Perspective visualisation can be toggled on and off through the toolbar (View > Perspective) or by pressing P with the viewport in focus (no button or other input component has been clicked or dragged since the viewport was last clicked or dragged in).

3.3 Properties Panel

The properties panel allows the user to edit some properties of the selected ray box or delete it. If no ray box is selected then the properties panel is blank.



The label of a ray box is printed in blue text within the viewport next to the ray box and can be set in the text field at the top of the properties panel. The default label is ‘Ray box’, but the label can be blank or contain symbols and special characters. The label in the viewport is updated when the user presses enter or clicks another input component such as the viewport.

A ray box can be removed by pressing the ‘Delete’ button at the top of the properties panel. This cannot be reversed and the selection is cleared.

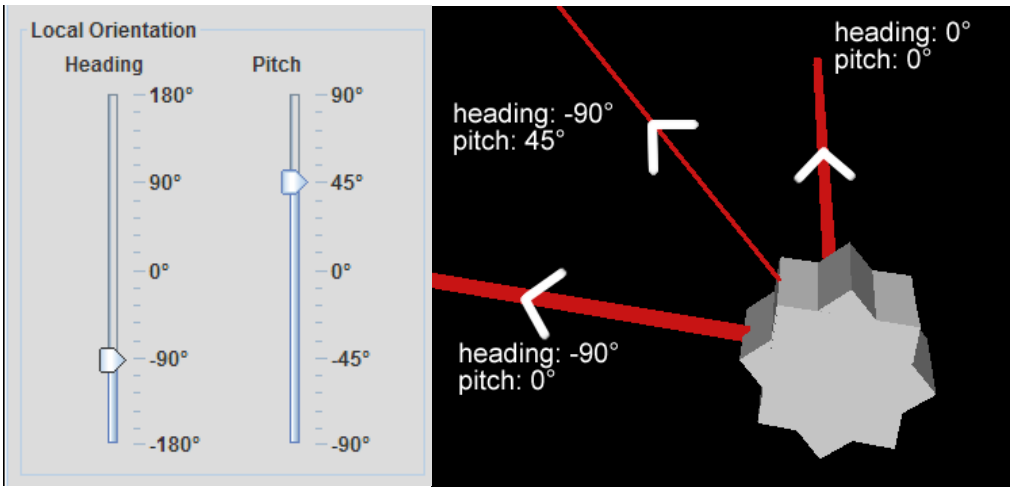
The ‘Display angles’ checkbox toggles the printing of all angles for the beam of the selected ray box. The default setting is on.

The ‘Beam thickness’ field is used to set the width of the beam associated with the selected ray box in arbitrary units. The beam is updated in the viewport when the user presses enter or clicks another

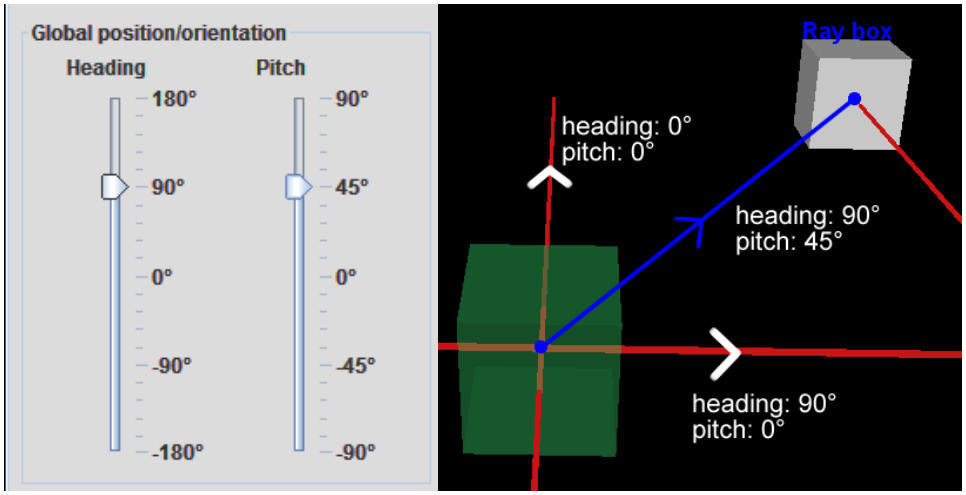
input component. The value of this field is an integer between 1 and 10 inclusive; an invalid number will be rounded to the nearest integer in this range and non-numerical input will not change the value. The '+' button next to the text field increments the thickness by 1 and the '-' button decrements it by 1. The default beam thickness is 3.

3.3.1 Ray Box Position and Orientation

The local orientation of a ray box refers to the heading and pitch of the direction it is facing (the initial direction of its beam). Modifying the heading or pitch of a ray box's local orientation doesn't change its position in space. The local heading and pitch of the selected ray box can be changed with the bottom two sliders in the properties panel.



The global position/orientation of a ray box refers to the heading and pitch of a line from the centre of the 3-D space to the centre of the ray box. Modifying a ray box's global heading or pitch orbits it around the centre of the 3-D space, meaning both its position in space and its local orientation are changed. The global heading and pitch of the selected ray box can be changed with the top two sliders in the properties panel.

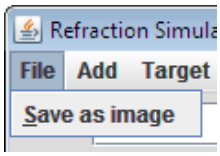


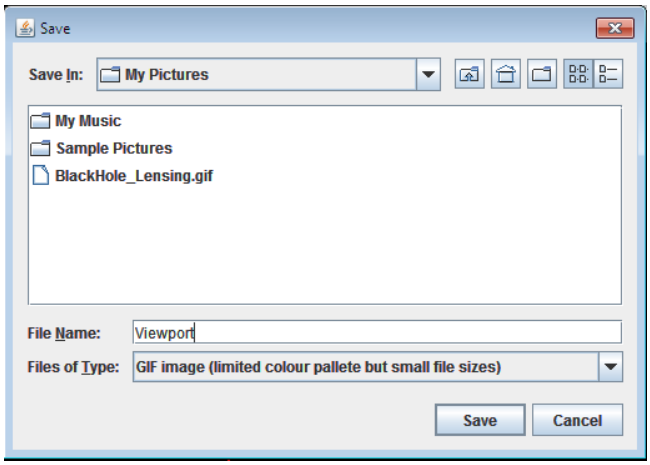
3.4 Toolbar

The toolbar allows the user to change more general settings than the properties panel via several drop-down menus and dialog boxes.

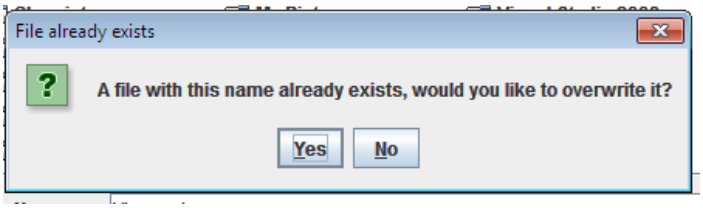
3.4.1 File Menu

This menu has only one item, which is allows the user to save the contents of the viewport to a common image file format. Clicking File > Save as image opens a dialog box which lets the user browse to a folder/directory to save the image in and the user can type a name for the file and choose between GIF, PNG and JPEG file formats. GIF format should give the most compression without loss of information because only a few colours are present in the viewport. However, other applications may prefer another file format.



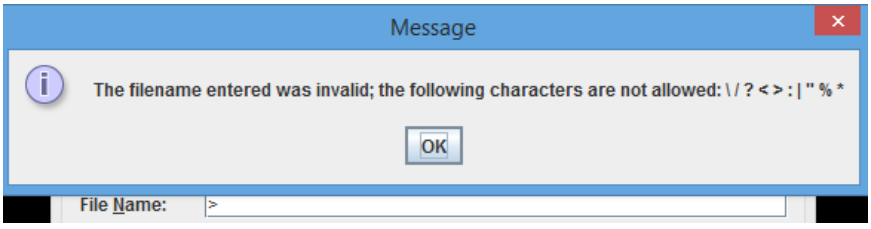


The name of the file doesn't have to include the file extension as the application will append that if the user omits it. If the user attempts to save an image in the same directory as another with the same name (automatically appended file extensions included), then another dialog box will open to alert the user of the issue and ask if they want to overwrite the file. Nothing will happen and the dialog box will remain open if the user tries to save a file without a name.



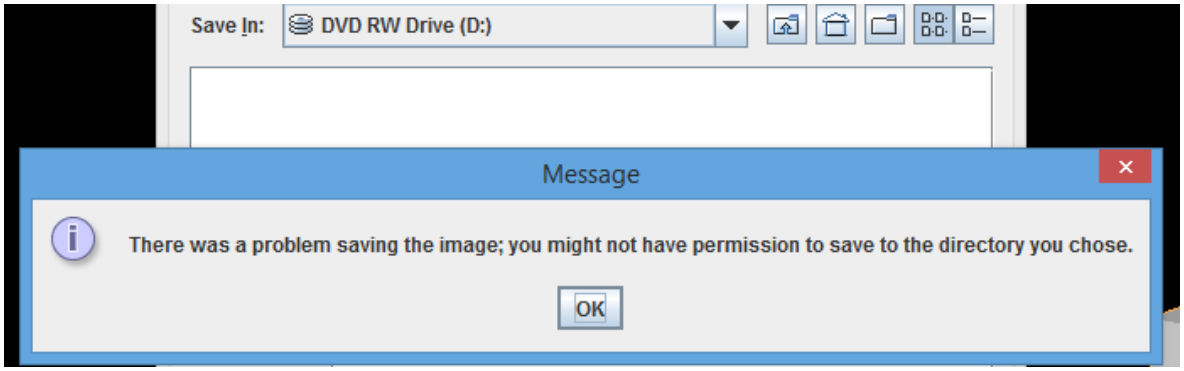
An invalid filename is one which includes any of the following characters:

- \ (backslash)
- / (forward slash)
- | (pipe or bar)
- ? (question mark)
- < (less than)
- > (greater than)
- : (colon)
- " (quotation mark)
- % (percentage)
- * (asterisk)



A dialog box will alert the user if they try to save a file with an invalid name and closing this dialog will return the user to the save dialog with same directory and filename as before. The user can then edit the filename so that it no longer contains any of the listed special characters and attempt to save again.

If the user tries to save where they do not have permission, a dialog box will alert them that they cannot write here and closing this dialog will return the user to the save dialog. The user can then change directory and attempt to save again.

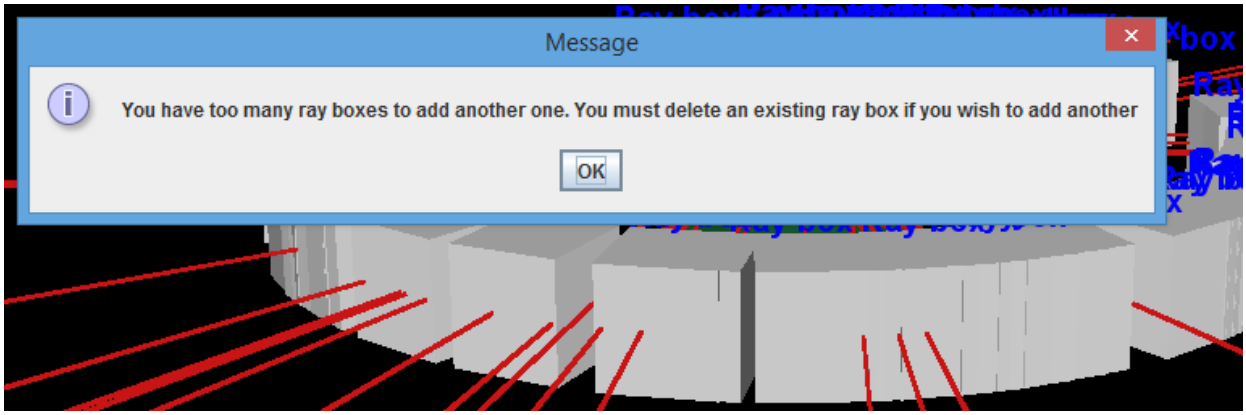


If the user tries to save where there is insufficient storage space, the save dialog will close and another dialog will alert the user that the file couldn't be saved. The user must then use the toolbar to attempt another save.

Clicking the 'Cancel' button will not save the file and will close the dialog box.

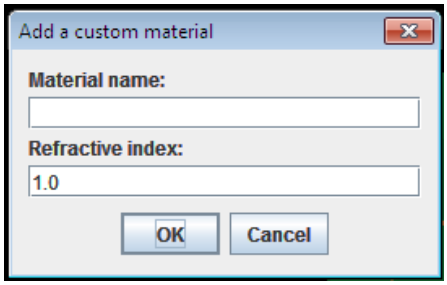
3.4.2 Add Menu

Clicking Add > Ray box will create a new ray box with a random global heading and zero pitch (the local heading is set so that it directly faces the centre of the 3-D space) and make the new ray box the current selection. However, the application only supports the use of up to 49 ray boxes at once, so a message dialog will notify the user if a 50th ray box cannot be added and that some ray boxes should be deleted before more can be added.



3.4.2.1 Custom Material

Clicking Add > Custom material will open a dialog box with an input field for the name of the new material and an input field for the material's refractive index.



The material name is blank by default, but a blank name is replaced with the name 'Custom material' when the user clicks 'OK' or removes focus from the text field. Special characters and symbols are allowed in the name.

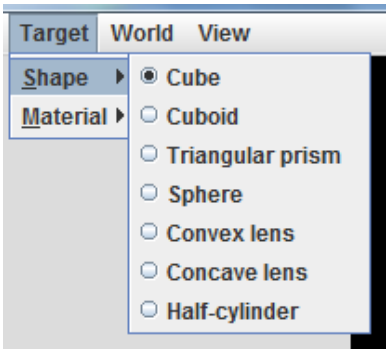
The refractive index is 1.0 by default and all decimals in the range 1 to 100 inclusive are acceptable. A value above 100 will be changed to 100 and anything below 1 will be changed to 1. Non-numerical input will be reverted back to the last valid value.

Closing the dialog box or clicking 'Cancel' will not create a new material.

3.4.3 Target Menu

Clicking Target reveals two submenus which each show a list of items when hovered over.

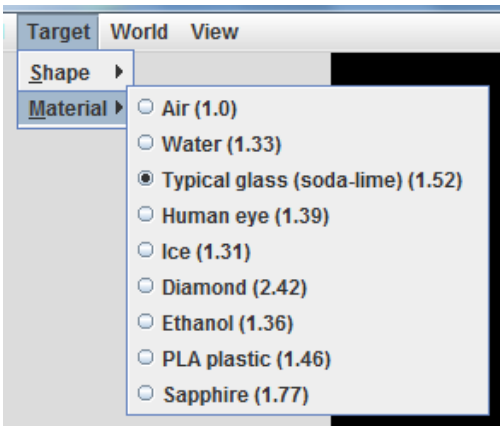
3.4.3.1 Shape Submenu



This submenu contains a list of shapes that the target can take with a radio button next to each. The selected radio button indicates the current shape of the target and clicking an item in the list sets the shape of the target to that shape. The default shape is a cube.

In reality, a sphere, a lens and a half-cylinder have curved faces, but the application can only approximate these shapes with many flat faces, meaning that beams passing the target will not behave exactly as they would with an exact sphere, lens or half-cylinder. Also, because many faces are needed to approximate these shapes, the calculation of the paths of beams takes longer with one of these shapes set, so there will usually be latency in moving or rotating a ray box.

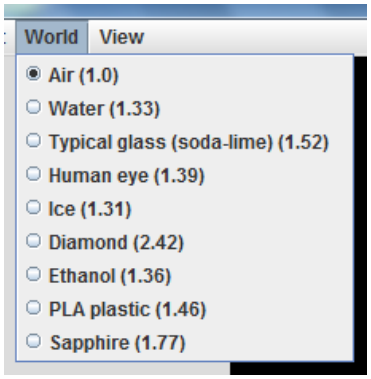
3.4.3.2 Material Submenu



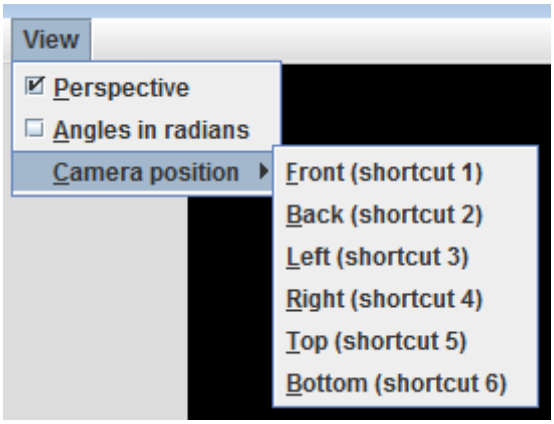
This submenu contains a list of all preset materials and custom materials with a radio button next to each. After each material name the absolute refractive index is given in brackets. The selected radio button indicates the current material of the target and clicking an item in the list sets the material of the target to that material. The default material is soda-lime glass with absolute refractive index 1.52.

3.4.4 World Menu

Clicking World reveals a list of all preset materials and custom materials that works in the same way as the Target > Material submenu, but these materials apply to the world rather than the target. The default material is air with absolute refractive index 1.0.



3.4.5 View Menu



The 'Perspective' checkbox is checked if perspective visualisation is turned on. Clicking this item in the menu toggles between perspective and orthographic visualisation. Perspective visualisation is on by default.

The 'Angles in radians' checkbox is checked if all angles in the viewport and user interface are given in radians. Clicking this item in the menu toggles between degrees and radians. This is unchecked by default.

The 'Camera position' submenu contains a list of camera views which the user may find particularly useful. Clicking one of these menu items positions and orientates the camera accordingly. After the name of the camera position is the keyboard shortcut for that position – these can only be used with the viewport in focus. For details of each of the camera positions, see the bulleted list in the '3-D Viewport' section under the subheading of 'Navigating 3-D Space'.