0.1 Introduction

There are many reasons why one would want to create a graphical user interface for a package or piece of R functionality. For example,

- GUIs can make R's functionality available to the casual R user,
- GUIs can be dynamic, they can direct the user how to fill in arguments, can give feedback on the choice of an argument, they can prevent or allow user input as appropriate,
- Although a command line is usually faster when the commands are known, a GUI can make some less commonly used tasks easier to do.
- GUIs make dealing with large data sets easier both visually and as an alternative to sometimes difficulte command line usage.
- GUIs can tightly integrate with graphics, for example the rggobi interface among others.

Even as R is rapidly gaining interest, especially commercial interest, it lacks a common graphical user interface. This is due to several reasons. (1) The R language is designed for command line usage. (2) The GUI would need to run on all supported R platforms (3) the wide variety of user types means a single interface would be unlikely to satisfy all. Even if it did have a common interface, as much of R's functionality depends on user contributions there will always be a demand for package programmers to provide convenient interfaces to their work.

0.2 A simple GUI in R

We begin with an example showing how one can use R's standard graphics device, as a canvas for drawing a GUI, for playing a game of tic-tac-toe against the computer. Although this example has nothing to do with statistics, it illustrates, in a familiar way, some of the issues that this text will address with using GUIs.

Many GUIs can be thought of as different views of some data model. In this example, the data simply consists of information holding the state of the game. Here we define a global variable, `board`, to store the current state of the game.

```
board <- matrix(rep(0,9), nrow=3)        # a global
```

The GUI provides the representation of the data for the user. This example just uses a canvas for this, but most GUIs have a combination of components to represent the data and allow for user interaction. The layout of the GUI directs the user as to how to interact with it and is an important factor as to whether the GUI will be well received. Here we define a function to layout the game board using the graphics device as a canvas.

```
layoutBoard <- function() {
  plot.new()
  plot.window(xlim=c(1,4), ylim=c(1,4))
  abline(v=2:3);  abline(h=2:3)
  mtext("Tic Tac Toe. Click a square:")
}
```

A GUI is designed to respond to user input typically by the mouse or keyboard. The underlying toolkit allows the programmer to assign functions to be called when some specific event occurs. Typically, the toolkit *signals* that some action has occurred, and then calls *callbacks* or *event handlers* that have been assigned by the programmer. How this is implemented varies from toolkit to toolkit.

R's interactive graphics devices implement the `locator` function which responds to mouse clicks by user. When using this function, one specifies how many mouse clicks to gather and the *control* of the program is suspended until these are gathered (or the process is terminated). The suspension of control makes this a *modal* GUI. This design is common for simple dialogs that require immediate user attention, but not common otherwise. To make non-modal dialogs possible, the writers of the R packages that interface with the GUI toolkits have to interface with R's event loop mechanism.

Here we define a function to collect the player's input.

```
doPlay <- function() {
  iloc <- locator(n=1, type="n")
  clickHandler(iloc)
}
```

In the above function, `clickHandler` is an *event handler*. Its job is to process the output of the `locator` function, checking first if the user terminated `locator` using the keyboard. If not it proceeds to draw the move, and then, if necessary, the computer's move. Afterwards, play is repeated until there is a winner or a "cat's" game.

```
clickHandler <- function(iloc) {
  if(is.null(iloc))
    stop("Game terminated early")
  move <- floor(unlist(iloc))
  drawMove(move,"x")
  board[3*(move[2]-1) + move[1]] <<- 1
  if(!isFinished())
    doComputerMove()
  if(!isFinished())
    doPlay()
}
```

The use of `<<-` in the handler illustrates a typical issue in GUI design within R. After a GUI is created, the state is typically modified within the

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scope of the callback functions. These callbacks need to be able to modify values outside of their scope, yet even if the values are passed in as argument, this is usually not possible while assigning within the scope of the function call, due to R's pass by copy function calls. As such, global variables are often employed along with some strategies to avoid an explosion of variable names.

Validation of user input is an important task for a GUI, especially for Web GUIS. In the above, the `clickHandler` function checks to see if the user terminated the game early and issues a message, more helpful forms of validation are possible in general.

At this point, we have a data model, a view of the model and the logic that connects the two, but we still need to implement some of the functions to tie it together.

This function draws either an "x" or an "o". It does so using the `lines` function. The `z` argument contains the coordinates of the square to draw.

```
drawMove <- function(z,type="x") {
  i <- max(1,min(3,z[1])); j <- max(1,min(3,z[2]))
  if(type == "x") {
    lines(i + c(.1,.9),j + c(.1,.9))
    lines(i + c(.1,.9),j + c(.9,.1))
  } else {
    theta <- seq(0,2*pi,length=100)
    lines(i + 1/2 + .4*cos(theta), j + 1/2 + .4*sin(theta))
  }
}
```

One could use `text` to place a text "x" or "o", but this may not look good if the GUI is resized. Most GUI layouts allow for dynamic resizing. Overall this is a great advantage, for example, it allows translations to just worry about the text and not the layout, which will be different for every language.

This function is used to test if a game is finished. The matrix `m` allows us to easily check all the possible ways to get three in a row.

```
isFinished <- function() {
  if(sum(abs(board)) >= 9)
    return(TRUE)
  m <- matrix(1:9,nrow=3)
  ways <- list(m[,1], m[,2], m[,3],
               m[1,], m[2,], m[3,],
               diag(m),diag(apply(m,2,rev)))
  sums <- sapply(ways, function(i) abs(sum(board[i])))
  if(any(sums == 3))
    return(TRUE)
  return(FALSE)
}
```

This function picks a move for the computer. The move is converted into coordinates using %% to get the remainder and %/% to get the quotient when dividing an integer by an integer. This function just chooses at random from the left over positions; we leave implementing a better strategy to the interested reader.

```
doComputerMove <- function() {
  newMove <- sample(which(board == 0),1) # random !
  board[newMove] <<- -1
  z <- c((newMove-1) %% 3, (newMove-1) %/% 3) + 1
  drawMove(z,"o")
}
```

This function provides the main entry point for our GUI. To play a game it first lays out the board and then calls `doPlay`. When this function terminates, a message is written on the screen.

```
playGame <- function() {
  layoutBoard()
  doPlay()
  mtext("All done\n",1)
}
```

This example adheres to the model-view-controller design pattern that is implemented by virtually every complex GUI. We will encounter this pattern throughout this book, although it is not always explicit.

A final point, the above example illustrates a common issue when designing software that is particularly true of GUIs – feature creep is an endless temptation. In this case, there are many obvious improvements: localizing the text messages so different languages can be used, implementing a better logic for the computer's moves, drawing a line connecting three in a row when there is a win, indicating who won when there is a win, etc. For many GUIs there is a necessary trade-off between usability and complexity.

0.3 GUI Design Principles

The most prevalent pattern of user interface design is denoted WIMP, which stands for Window, Icon, Menu and Pointer (i.e., mouse). The WIMP approach was developed at Xerox PARC in the 1970's and later popularized by the Apple Macintosh in 1984. This is particularly evident in the separation of the window from the menubar on the Mac desktop. Other graphical operating systems, such as Microsoft Windows, later adapted the WIMP paradigm, and libraries of reusable GUI components emerged to support development of applications in such environments. Thus, GUI development in R adheres to WIMP approach.

The primary WIMP component from our perspective is the window. A typical interface design consists of a top-level window referred to as the *doc-*

ument window that shows the current state of a "document", whatever that is taken to be. In R it could be a data frame, a command line, a function editor, a graphic or an arbitrarily complex form containing an assortment of such elements.

Abstractly, WIMP is a command language, where the user executes commands, often called actions, on a document by interacting with graphical controls. Every control in a window belongs to some abstract menu. Two common ways of organizing controls into menus are the menubar and toolbar.

The parameters of an action call, if any, are controlled in sub-windows. These sub-windows are termed *application windows* by Apple (**?**), but we prefer the term *dialogs*, or *dialog boxes*. These terms may also refer to smaller sub-windows that are used for alerts or confirmation. The program often needs to wait for user input before continuing with an action, in which case the window is modal. We refer to these as *modal dialog boxes*.

Each window or dialog typically consists of numerous controls laid out in some manner to facilitate the user interaction. Each window and control is a type of *widget*, the basic element of a GUI. Every GUI is constituted by its widgets. Not all widgets are directly visible by the user; for example, many GUI frameworks employ invisible widgets to lay out the other widgets in a window.

There is a wide variety of available widget types, and widgets may be combined in an infinite number of ways. Thus, there are often numerous means to achieve the same goals. For example, Figures 0.1 and 0.2 show three dialogs that perform the same task – collect arguments from the user to customize the printing of a document. Although all were designed to do the same thing, there are many differences in implementation.

In some cases, typical usage suggests one control over another. The choice of printer for each is specified through a combo box. However, for other choices a variety of widgets are employed. For example, the control to indicate the number of copies for the Mac is a simple text entry window, whereas for the KDE and R dialog it is a spinbutton. The latter minimizes user error, say through entering a non-positive integer. The KDE and Mac dialogs have icons to compactly represent actions, whereas the R example has none. The landscape icon for the Mac is very clear and provides this feature without having to use a sub dialog.

How the interfaces are laid out also varies. All panels are read top to bottom, although the Mac interface also has a very nice preview feature on the left side. The KDE dialog uses frames to separate out the printer arguments from the arguments that specify how the print job is to proceed. The Mac uses a vertical arrangement to guide the user through this. For the Mac, horizontal separators are used instead of frames to break up the areas, although a frame is used towards the bottom. Apple uses a center balance for

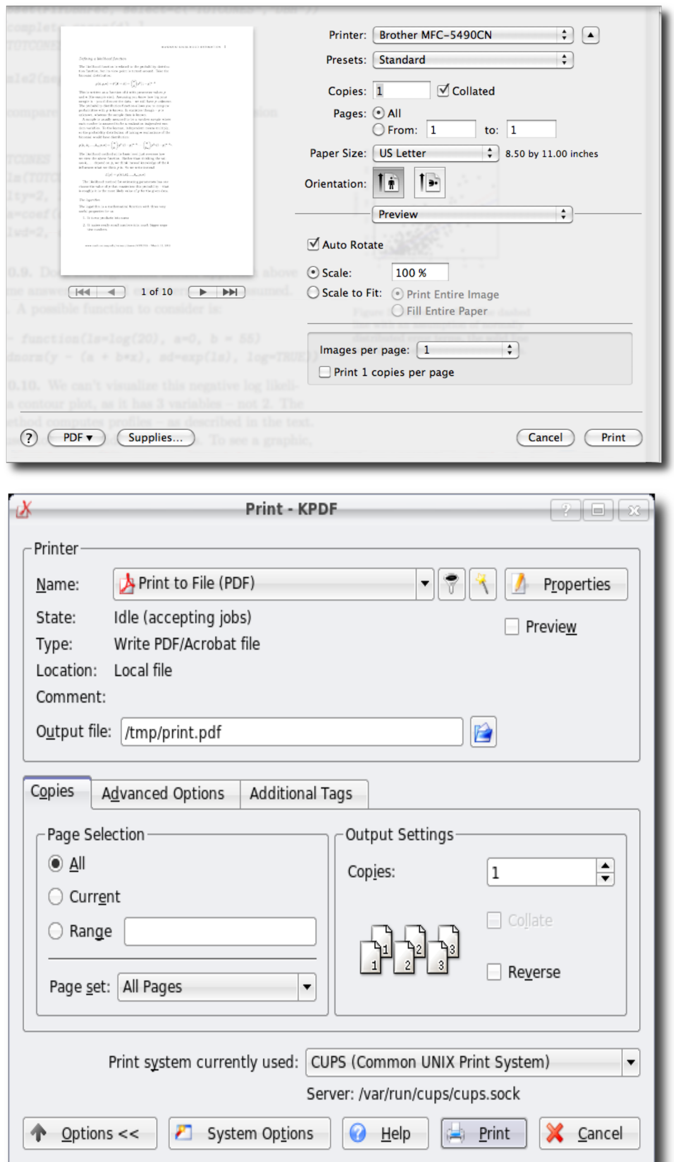

Figure 0.1: Two print dialogs. One from Mac OS X 10.6 and one from KDE 3.5.

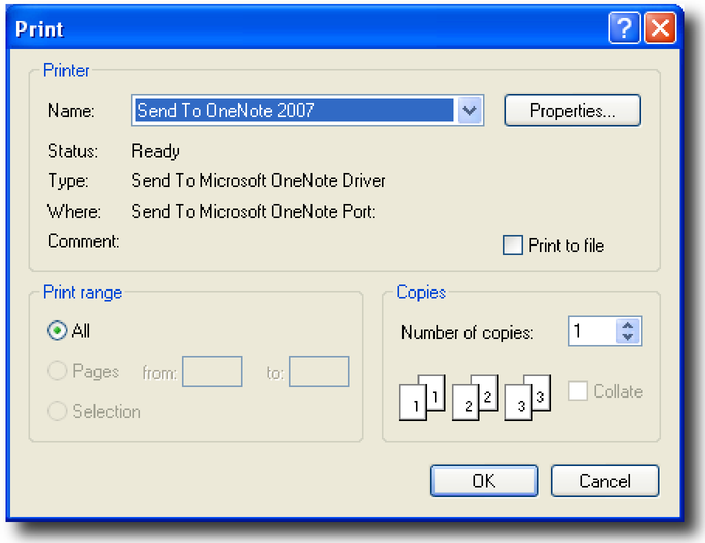

Figure 0.2: R's print dialog under windows XP using XP's native dialog.

its controls. They are not left justified as are the KDE and Windows dialogs. Apple has strict user-interface guidelines and this center balance is a design decision.

The layout also determines how many features and choices are visible to the user at a given time. For example, the Mac GUI uses "disclosure buttons" to allow access to printer properties and the PDF settings, whereas KDE uses a notebook container to show only a subset of the options at once.

The Mac GUI provides a very nice preview of the current document indicating to the user clearly what is to be printed and how much. Adjusting GUIs to the possible state is an important user interface property. GUI areas that are not currently sensitive to user input are grayed out. For example, the "collate" feature of the GUI only makes sense when multiple copies are selected, so the designers have it grayed out until then. A common element of GUI design is to only enable controls when their associated action is possible, given the state of the application.

The Mac GUI has the number of pages in focus, whereas Windows places the printer in focus. This allows the user to interact with the GUI without the mouse. Typically the tab key is used to step through the controls. GUI's often have keyboard accelerators that allow power users to shift the focus directly to a specific widget. Examples are found in the KDE dialog, where the underlined letters indicate the accelerator key. Most dialogs also have a default button, which will initiate the dialog action when the return key is pressed. The KDE dialog, for example, indicates that the "print" button is

Table 0.1: Table of possible selection widgets by data type and size

Type of data	Single	Multiple
Boolean	Checkbox	
Small list	radiogroup	checkboxgroup
	combobox	list box
	list box	
Moderate list	combobox	list box
	list box	
Large list	list box	list box
Sequential	slider spinbutton	
Tabular	table	table
Heirarchical	tree	tree

the default button through special shading.

Each dialog presents the user with a range of buttons to initiate or cancel the printing. The Windows ones are set on the right and consist of the standard "OK" and "Cancel" buttons. The Mac interface uses a spring to push some buttons to the left, and some to the right to keep separate their level of importance. The KDE buttons do so as well, although one can't tell from this. However, one can see the use of stock icons on the buttons to guide the user.

Choice of widget

A GUI is comprised of one or more widgets or controls. The appropriate choice of widget depends on a balance of condiderations. For example, many widgets offer the user a selection from one or more possible choices. An appropriate choice depends on the type and size of the information being displayed, the constraints on the user input, and on the space available in the GUI layout. As an example, Table 0.3 lists suggestes different types of widgets used for this purpose depending on the type and size of data and the number of items to select.

Figure 0.3 shows several such controls in a single GUI. A checkbox enables an intercept, a radio group selects either full factorial or a custom model, a combobox selects the "sum of squares" type, and a list box allows for multiple selection from the available variables in the data set.

For many R object types there are natural choices of widget. For example, values from a sequence map naturally to a slider or spin button; a data frame maps naturally to a table widget; or a list with similar structure can map naturally to a tree widget. However, certain R types have less common metaphors. For instance, a formula object can be fairly complex. Figure 0.3 shows an SPSS dialog to build terms in a model. R power users may be

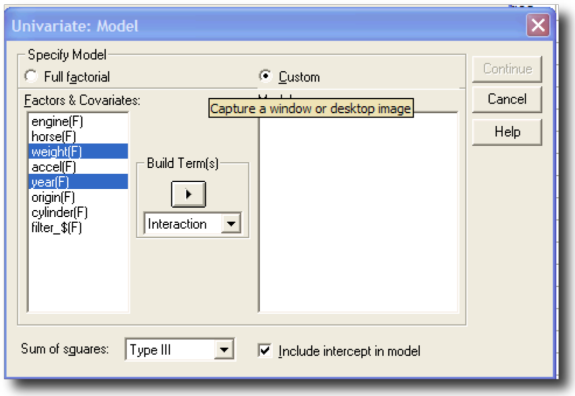

Figure 0.3: A dialog box from SPSS version 11 for specifying terms for a linear model. The graphic shows a dialog that allows the user to specify individual terms in the model using several types of widgets for selection of values, such as a radio group, a checkbox, combo boxes, and list boxes.

much faster specifying the formula through a text entry box, but beginning R users coming to grips with the command line and the concept of a formula may benefit from the assistance of a well designed GUI. One might desire an interface that balances the needs of both types of user, or the SPSS interface may be appropriate. Knowing the potential user base is important.

0.4 Controls

This section provides an overview of many common controls, i.e., widgets that represent the actions to be performed on a document. Each displays some information, and most accept user input.

Selection

A common task for a GUI is the selection of a value. In the context of R, there are many different types of values the user may need to select. For example, selecting a data frame from a list of data frames, selecting a variable in a data frame, selecting certain cases in a data frame, selecting a logical value for a function argument, selecting a numeric value for a confidence level or selecting a string to specify an alternative hypothesis. Clearly there can be no one-size-fits-all widget to handle the selection of a value. We describe some standard selection widgets next.

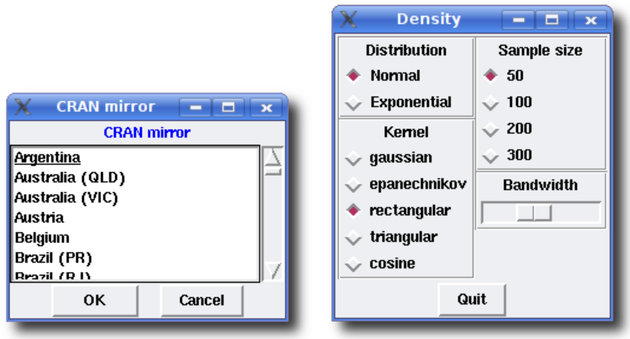

Figure 0.4: Two applications of the `tcltk` package. The left graphic is produced by `chooseCRANmirror` and uses a list box to allow selection from a long list of possibiulities. The right graphic is the `tkdensity` demo from the package. It uses radio buttons and a slider to select the parameter values for a density plot.

Checkboxes

A *checkbox* allows the user to select a logical value for a variable. Checkboxes have labels to indicate which variable is being selected. Combining multiple checkboxes into a group allows for the selection of one or more values at a time.

Radio Button Groups

A *radio button group* allows a user to select exactly one value from a vector of possible values. The analogy dates back to old car radios where there were a handful of buttons to press to select a preset channel. When a new button was pushed in, the old button popped up. This safety feature allowed drivers to keep their eyes on the road. Radio button groups are useful, provided there are not too many values to choose from, as all the values are shown. These values can be arranged in a row, a column or both rows and columns to better use screen space.

Sliders and spinbuttons

A *slider* is a widget that selects a value from a sequence of possible values (typically) through the manipulation of a knob that can visually range over the possible values. Some toolkits (e.g. Java/Swing) only allow for the sequence to have integer values. The slider is a good choice for offering the user a selection of parameter values. The `tkdensity` demo of the `tcltk` package (Figure 0.4) uses a slider to dynamically adjust the bandwith of a density estimate.

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A *spin button* also allows the user to specify a value from a possible sequence of values. Typically, this widget is is drawn with a text box displaying the current value and two arrows to increment or decrement the selection. The text box can usually be edited. Some toolkits generalize beyond a numeric sequence. For example, the letters of the alphabet could be a sequence. A spin button has the advantage of using less screen space, but is less usable if the sequence is long, although often the user can enter in the choice using the keyboard. A spin button is used in the KDE print dialog of Figure 0.1 to adjust the number of copies.

Combo boxes

A *combo box* is a widget that allows the selection of one of several fixed values, while displaying just the currently selected one. Comboboxes may also offer the user the ability to specify a value, in which case they are combined with a text entry area. From a screen-space perspective, they can efficiently allow the selection of a value from many values, although a choice from too many values can be annoying to the user, such as when a web form requests the selection of a country from hundreds of choices.

List boxes

A *list box* is a widget that displays in a column the list of possible choices. A scrollbar is used when the list is too long to show in the allocated space. Some toolkits have list boxes that allow the values to spread out over several columns. Selection typically occurs with a right mouse click or through the keyboad, whereas a double-click will typically be programmed to initiate some action. Unlike comboboxes, list boxes can be used for multiple selection. This is typically done by holding down either the shift or ctrl keys. Figure 0.4 shows a list box created by R that is called from the function `chooseCRANmirror`.

Displaying data

Table and tree widgets support the display and manipulation of tabular and hierarchical data, respectively. More arbitrary data visualization, such as statistical plots, can be drawn within a GUI window, but such is beyond the scope of this section.

Tabular display

A *table widget* shows tabular data, such as a data frame, where each column has a specific data type and cell rendering strategy. Table widgets handle the display, sorting and selection of records from a dataset, and may support editing. Figure 0.5 shows a table widget being used in a Spotfire web player

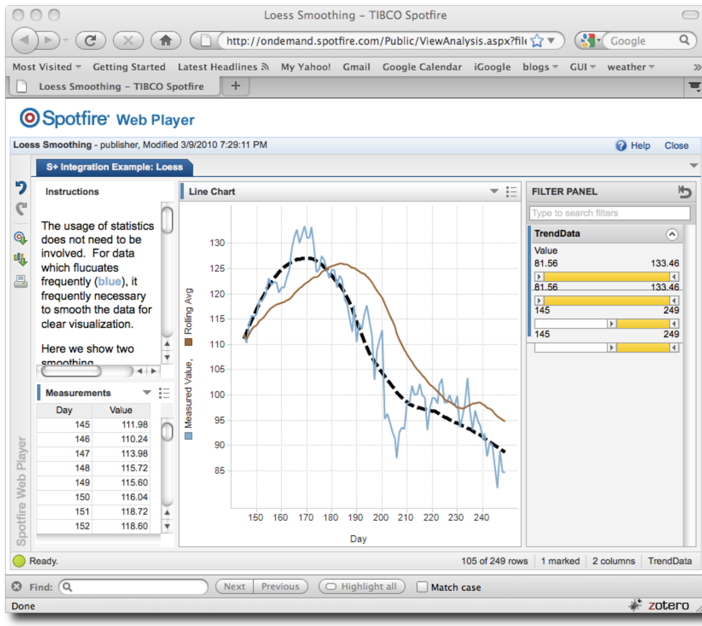


Figure 0.5: A screen shot from Tibco's Spotfire web player illustrating a table widget (lower left) being used to display the selected cases that are summarized in the graphic. The right bar provides a means to filter the cases under consideration.

demonstration to display the cases that a user selects through the filtering controls.

Tree widgets

So far, we have seen how list boxes display homogeneous vectors of data, and how table widgets display tabular data, like that in a data frame. Other widgets support the display of more complex data structures. If the data has a heirarchical structure, then a *tree widget* may be appropriate for its display. Examples of heirarchical data in R, are directory structures, the components of a list, or class hierarchies. The object browser in `JGR` uses a tree widget to show the components of the objects in a users session (the left graphic of Figure 0.6). The root node of the tree is the "data" folder, and each data object in the global workspace is treated as an offspring of this root node. For the data frame `iraq`, its variables are considered as offspring of the data frame. In this case these variables have no further offspring, as indicated by the "page" icon.

Inititiating an action

After the user has specified the parameters of an action, typically through the selection widgets presented above, it comes time to execute the action. Widgets that execute actions include the familiar buttons, menubars and toolbars.

Buttons

A *button* is typically used to give the user a place to click the mouse in order to initiate some immediate action. The "Properties" button, when clicked, opens a dialog for setting printer properties. The button with the wizard icon also opens a dialog. As buttons typically lead to an action, they often are labeled with a verb. (**?**) In Figure 0.3 we see how SPSS uses buttons in its dialogs: buttons which are not valid in the current state are disabled; buttons which are designed to open subsequent dialogs have trailing dots; and the standard actions of resetting the data, canceling the dialog or requesting help are given their own buttons on the right edge of the dialog box.

To speed the user through a dialog, a button may be singled out as the default button, so its action will be called if the user presses the return key. As well, buttons may be given accelerator key bindings, so as their actions are accesible by typing the proper key combination. The KDE print dialog in Figure 0.1 has these bindings indicated through the underlined letter on the button label's.

Icons

In the WIMP paradigm, an *icon* is a pictorial representation of a resource, such as a document or program, or, more generally, a concept, such as a type of file. An application GUI typically adopts the more general definition, where an icon is used to augment or replace a text label on a button, a toolbar, in a list box, etc. When icons are used on toolbars and buttons, they are associated with actions, so the icons should have some visual implication of an action. Well chosen icons make a big visual difference in a GUI.

Menubars

Xerox Parc's revolutionary idea of a `WIMP` GUI added windows, icons, menubars, and pointing devices to the desktop computing environment. The central role of menu bars has not diminished. For a GUI, the *menubar* gives access to the full range of functionality available. Each common action should have a corresponding menu item. Menubars are traditionally associated with a top-level window. This is enforced by the toolkit in wxWidgets and Java but not Tcl/Tk and GTK+. In Mac OS X, the menubar appears on the top line of the display, but otherwise they typically appear at the top of the main window. In most modern applications, standard document-based design is used to organize a GUI and its actions, with a main window showing the document and its menu bar calling actions on the document, some of which may need to open subsequent application windows or dialogs for gathering additional user input. In this model, only the main window has a menu bar, not the application windows or dialogs. In a statistics application, the "document" may be viewed as the active data frame, a report, or a graphic.

The styles used for menubars are fairly standardized, as this allows new users to quickly orient themselves with a GUI. The visible menu names are often in the order `File`, `Edit`, `View`, `Tools`, then application specific menus, and finally a `Help` menu. Each visible menu item when clicked opens a menu of possible actions. The text for these actions traditionally use a `...` to indicate that a subsequent dialog will open so that more information can be gathered to complete the action, as opposed to some immediate action being taken. The text may also indicate a key-board accelerator, such as `Find Next F3` indicating that both "N" as a keyboard accelerator and F3 as a shortcut will initiate this same action.

Not all actions will be applicable at any given time. It is recommended that rather than deleting these menu items, they be disabled, or greyed out, instead.

Menus can get very long. To help the user navigate, menu items are usually grouped together, first by being under the appropriate menu title, then with either horizontal separators to define subsequent groupings, or hierarchical submenus. The latter are indicated with an arrow. Several different levels are possible, but navigating through too many can be tedious.

The use of menus has evolved to also allow the user to set properties or attributes of current state of the GUI. There may be checkboxes drawn next to the menu item or some icon indicating the current state.

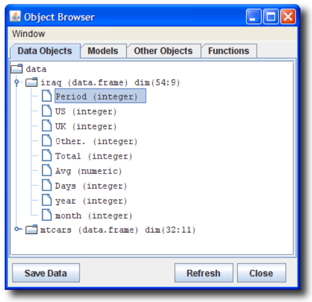
Another use of menus is to bind contextual menus (popup menus) to certain mouse clicks on GUI elements. Typically right mouse clicks will pop up a menu that lists often-used commands that are appropriate for that widget and the current state of the GUI. In Mac OS X one-button users, these menus are bound to a control-click.

Toolbars

Toolbars are used to give immediate access to the frequently used actions defined in the menubar. Toolbars typically have icons representing the action and perhaps accompanying text. They traditionally appear on the top of a window, but sometimes are used along the edges.

Displaying and editing text

As much as possible, WIMP GUIs are designed around using the pointing device to select values for user input. Perhaps this is because it is difficult



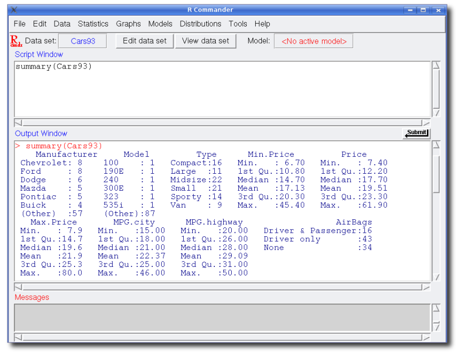


Figure 0.6: Some windows from R GUIs. The left graphic shows the object browser in the JGR GUI using a tree widget to display the possibly heirarchical nature of R objects. The right graphic shows the main Rcmdr (1.3-11) window illustrating the use of multi-line text entry areas for a command area, an output area and a message area.

to both type and move the mouse at the same time. For statistical GUIs, especially for R with its powerful command line, the flexibity afforded by arbitrary text entry is essential for any moderately complex GUI. There is a distinction made between widgets for handling just single lines versus multiple lines of text.

Single line text

A text entry widget for editing a single line of text is used in the KDE print dialog (Figure 0.1) to specify the page range. As range's can be complex to specify, the command line has an advantage. A disadvantage of using this type of widget is the need to validate the user's input, as the input must conform to some specfication.

Text edit boxes

Multi-line text entry areas are used in many GUIs. The right graphic of Figure 0.6 shows a text entry area used by `Rcmdr` to enter R commands, to show the output of the commands and to provide a message area (in lieu of a status bar). The "Output Window" demonstrates the utility of formatting attributes. In this case, attributes are used to specify the color of the commands, so that the input can be distinguished from the output.

Display of information

Some widgets are typically used to just display information and often do not respond to mouse clicks. These are called static controls in wxWidgets.

Labels

A label is a widget for placing text into a GUI that is typically not intended for editing, or even selecting with a mouse. This widget is used to label other controls, so the user understands what will happen when that control is changed.

A Label's text can be marked up in some toolkits. Figure **??** shows labels marked in red and blue in `tcltk`.

Statusbars

A typical top-level window will have a menubar and toolbar for access to the possible actions, an area to display the document being worked on, and at the bottom of the window a statusbar for giving the user immediated feedback on the actions that have been initiated.

Progress bars

A progress bar is used to indicate the percentage of a particular task that has been completed. They are often used during software installation.

Tooltips

A tooltip is a small window that pops up when a user hovers their mouse over a tooltip-enabled widget. These are useful for providing extra information about a particular piece of content displayed by a widget. A common use-case is to guide new users of a GUI. Many toolkits support the display of interactive hypertext in a tooltip, which allows the user to request additional details.

Modal dialog boxes

A *modal dialog box* is a dialog box that keeps the focus until the user takes an action to dismiss the box. They are used to notify the user of some action, perhaps asking for confirmation in case the action is destructive, such as overwriting of a file name. Modal dialog boxes can be disruptive to the flow of interaction, so they should be used sparingly. As the flow essentially stops until the window is dismissed, functions that call modal dialogs can return a value when an event occurs, rather than have a handler respond to the dismiss event. The `file.choose` function, mentioned below, is a good example. When used during an interactive R session, the user is unable to interact with the command line until a file has been specified and the dialog dismissed.

File choosers

A file chooser allows for the selection of existing files, existing directories, or specifying the name of a new file. They are familiar to any user of a GUI. A typical R installation has the functions `file.choose` and `tkchooseDirectory` (in the `tcltk` package) to select files and directories.

Other common choosers are color choosers and font choosers.

Message dialogs

A *message dialog* is a high-level dialog widget for communicating a message to the user. Generally, it has a standard form. There is a small rectangular box that appears in the middle of the screen with an icon on the left and a message on the right. At the bottom is a button to dismiss the dialog, often labeled "OK." The *confirmation dialog* variant would add a "Cancel" button which invalidates the proposed action.

0.5 Containers

Widgets in a GUI are organized in a *widget heirarchy*, where some widgets are parents and some children (which may in turn be parents). The top-level window may play a special role here, as a parent but not a child. This organization offers the toolkit writers the chance to treat each object as a standalone component. For example, when a GUI is resized the typical algorithm is for the parent to be resized, then to send a signal to the children to resize themselves. Another example is when a window is closed, prior to closing the window will signal its children that they will be destroyed, and they should in turn signal their children, if any. A means to traverse the widget heirarchy is provided by each toolkit. In `tcltk` this heirarchical relationship is explicit, as a widget constructor – except for top-level windows – requires a parent widget when be constructed. In the other toolkits, it may be implicit.

In the widget heirarchy, the parents play a different role as those widgets that are just children. The parents play the role of *containers*. Sometimes the word *widget* is reserved for GUI components which are not-containers. Having containers makes it possible to organize GUIs into indivividual components – again, a desirable design feature.

The children of the GUI must be organized in some manner. In GTK+(`gWidgets`), this is done through the choice of container with parameters being set to adjust the placement within the container when the child is added. In Qt and Tcl/Tk there is an added abstraction of a layout. A layout decouples the heirarchy from the layout and offers much more flexibility. In Qt this allows for a richer set of default layout options, and the ability to create ones specialized layouts.

Top level windows

The top-level window of a GUI is typically decorated with a title and buttons to iconify, maximize, or close. Besides the text of the title, the decorations are generally the domain of the window manager, often part of the operating system. The application controls the contents of the window. Generally, a top-level window will consist of a menu bar, a tool bar and a status bar. In between these is the area referred to as the *client area* or *content pane* where other containers or widgets are placed.

The title is a property of the window and may be specified at the time of construction or afterwards.

On a desktop, only one window may have the focus at a time. It may or may not be desired that a new window receive the focus so some means to specify the focus at construction or later is provided by the toolkit.

The initial placement of the window also may be specified at the time of construction. The top-level window of a GUI may generally be placed whereever it is convenient for the user, but sub-windows are often drawn on top of their parent window, as are modal dialog boxes.

The window manager usually decorates a top-level window with a close button. It may be necessary or desirable to specify some action to take place when this button is clicked. For instance, a user might be prompted if they wish to save changes to their work when the close button is pressed.

it may take some time to initially layout a top-level window. Rather than have the window drawn and then have a blank window while this time passes, it is preferable to not make the window visible until the window is ready to draw.

We now describe some of the main containers.

Box containers

A box container places its children in it from left to right or from top to bottom. If each child is viewed as a box, then this container holds them by packing them next to each other. The upper left figure in Figure 0.7 illustrates this.

When the boxes have different sizes, then some means to align them must be decided on. Several possibilities exists. The alignment could be around some center, aligned at a baseline, the top line, or each child can specify where to anchor itself within the allotted space (the upper right graphic in Figure 0.7).

If the space allocated for a box is larger than the space requested by a child component then a decision as to how that component gets placed needs to be made. If the component is not enlarged, then there are nine reasonable places – the center and the 8 compass directions N, NW, W, ... Otherwise, it may be desirable for the component to expand horizontally, vertically or

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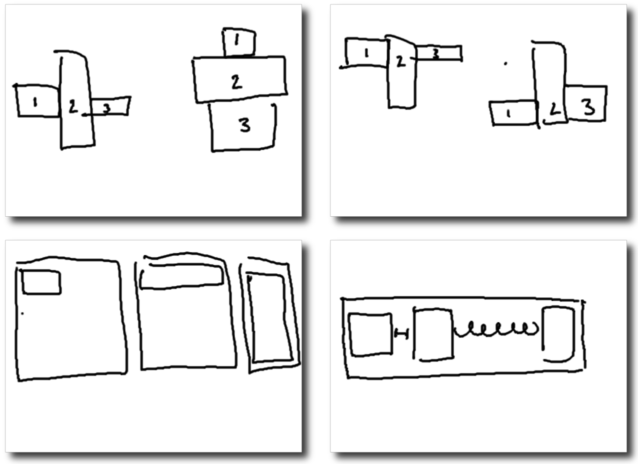

Figure 0.7: XXX REPLACE WITH REAL GRAPHICS XXX. Different possibilities for packing child components within a box. The upper left shows horizontal and vertical layout. The upper right shows some possible alignements. The lower left shows that a child could possibly be anchored in one of 9 positions. As well, it could "expand" to fill the space either horizontally (as shown) or vertically, or both. The lower right shows both a fixed amount of space between the children and an expanding spring between the child components.

both (the lower left graphic in Figure 0.7). Additionally, it is desirable to be able to place a fixed amount of space between child components or a spring between components. A spring forces all subsequent to children to the far right or bottom of the container (the lower right graphic in Figure 0.7).

When a top-level window is resized, these space allocations must be made. To help, the different toolkits allows the components to have a size specifed. Some combination of a minimum size, a preferred size, a default size, a specific size, or a maximum size are allowed. Specifying fixed sizes for components is generally frowned upon, as they don't scale well when a user resizes a window and they don't work well when different languages are used on the controls when an application is localized.

Frames

A box container may have a border drawn around it to visually separate its contents from others. This border may also have a title. In GTK+ these are called frames, but this word is reserved in Tcl/Tk and Java.

Expanding boxes

In order to save screen space, a means to hide a boxes contents can be used. This hiding/showing is initiated by a mouse click on a disclosure button or trigger icon.

Paned boxes

If automatic space allocation between two child components is not desired, but rather a means for the user to allocate the space is, then a *paned container* may be used. These offer one or more horizontal or verticales sash that can be clicked and dragged to apportion space between the child omponents.

Grid layout

By nesting box containers, a great deal of flexibility in layout can be achieved. However, there is still a need for the alignment of child components in a tabular manner. The most flexible alignments allow for different sizes for each column and each row, and additionally, the ability for the child components to span multiple columns or rows. Within each cell (or cells) the placement of a child component mirrors that of the lower left graphic of Figure 0.7. Some specification where to anchor the component when there are nine possible positions plus expanding options must made.

Tabbed Notebooks

A notebook is a common container to hold one or more pages (or children). The different pages are shown by the user through the clicking of a corresponding tab. The metaphor being a tabbed notebook. Modern web browsers take advantage of this container to allow several web pages to be open at once.

Example

The KDE pring dialog of Figure 0.1 shows most of the containers previously described.

The top-level window has the generic title "Print – KPDF." This window appears to have four child components: a frame labeled `Printer`, a notebook with open tab `Copies`, a grid layout for specifying the print system, and a box for holding five buttons at the bottom.

The lower left `Options` button has `<<` to indicate that clicking this will close an exanding box, in this case a box that contains the lower three components above. So in fact, there are two visible child components of the top-level window.

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The framed box holds a grid layout with five columns and 6 rows. The sizes allocated to each column are visible in the first row. It is quickly seen that each column has a different size. The last row has a text entry area that spans the second and third columns. The first column has only labels. These are anchored to the left side of the allowed space. The Apple human interface guide (**?**) suggests using colons for text that provides context for controls, and the KDE designers do to.

The displayed page of the notebook shows two child components, both framed boxes. A pleasant amount of space between the frames and their child components has been chosen. The `Page Selection` frame has components including radio buttons, a text area, a horizontal separator, and a combo box.

The print system information is displayed in a grid layout that has been right aligned within its parent container – the expanded group, but its children are center-balanced with the label "Print system currently used" is right aligned and "Server..." is left aligned within their cells.

The button box shows five buttons as child components. At first glance the sizing appears to show that each button is drawn to fully show its label with some fixed space placed between the buttons. If the dialog is expanded, it is seen that there is a spring between the 3rd and 4th buttons, so that the first 3 are aligned with the left side of the window and the last two the right side.