

The **Glyph** User-Interface Library for Scala

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Abstract

Here we introduce the **Glyph** user-interface library for Scala. Its graphical features are geometrically compositional: rendered using a small subset of the facilities of Google’s **Skia**¹, as delivered (in the JVM) by the **Skija** library.² Our motivation for developing the library was our frustration, over many years, with complex UI frameworks that impose a uniform style, and that make it hard to develop novel modes of interaction.³

What has guided this work is the idea that a rich set of interactive interface components can be composed using a small collection of combining forms, and a suitable collection of elementary visual and reactive components.

Instead of (just) providing a uniformly-styled “high level” toolkit, we have provided enough elements and combining forms for an innovative UI designer to experiment with, and a collection of implementations of conventional components (for example buttons, checkboxes, text input components, notebooks) to serve as models.

Code, along with several example programs to demonstrate principles, can be found in the public repository at

<https://github.com/sufrin/Glyph>.

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¹**Skia** is a highly portable 2-D graphics library used in the implementation of several browsers, including Chrome.

²The present prototype runs on Linux, Windows, OS/X (both x86 and Apple Mx processors)

³There is nothing wrong with uniform styling: but the cost of straying outside the styling envelope needs to diminish. An interface designer who doesn’t mind learning a new language (Dart) and staying within its envelope might be rewarded by investigating Google’s **Flutter**.

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1 User Interfaces with Glyph

1.1 Introduction

A complete **Glyph** user interface (GUI) is specified as a tree of **Glyph** components, that may be *passive*, *active*, or *reactive*. Composite nodes of the tree consist of collections of components that share the same bounding box – being juxtaposed geometrically or temporally within it.

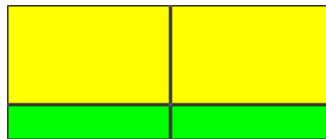
For example, suppose **a**'s bounding box is 5 units wide and 3 units high; and that of **b** is the same width and 1 unit height – perhaps as painted⁴ respectively yellow and green) by:

```
def a = FilledRect(5*units, 3*units, fg=yellow)
def b = FilledRect(5*units, 1*units, fg=green)
```

then

```
Row( Col(a, b), Col(a, b))
```

has a bounding box that is the horizontal catenation of 2 copies of the bounding box of **Col(a, b)**; the latter has a bounding box that is the vertical catenation of the bounding boxes of **a**, **b**. The outcome will be drawn as:⁵



The height of a row is the maximum height of its components; its width is the sum of its components' widths; and a row is normally drawn with its components aligned along its top edge.

So exchanging **Col** and **Row** in the above leads to:



⁴A glyph's colour and visual texture is specified by its foreground and background: both determined by properties of the **Brushes** used to paint it.

⁵We have added thin frames around *a* and *b* to show their extents within the bounding box.

The glyph trees for the two images are:



We will later show other ways of composing glyphs.

1.2 Reactive Glyphs and Focus

Reactive glyphs are the means by which user actions, such as mouse gestures and keystrokes, are coupled to the semantic actions of the application they control. As usual these actions can result in changes to the appearance of the interface.

Unless it is just a passive image in a window, one or more of the nodes in the glyph tree of a GUI will be a [ReactiveGlyph](#) – designed to respond to specific user actions such as gesturing at a window with mouse or trackpad, or typing a keystroke.

Interaction with the GUI in a window is mediated by its associated [Interaction](#) component, whose primary role is to determine which reactive glyph a user's action or a system-reported event is to be directed at, and to direct it there. To this end with each window is associated a [keyboardFocus](#), and a [mouseFocus](#) variable – both of type [Option\[ReactiveGlyph\]](#). These are managed by the [EventHandler](#) module of its associated [Interaction](#), which implements the *Focus Protocol* described in detail in Appendix C.

Mouse Focus

Normally, a mouse event (mouse motion, mouse button press or release) is directed at the reactive glyph that has the mouse focus – this is almost always the reactive glyph within whose bounding box the mouse cursor is shown. When the mouse cursor strays outside the currently mouse-focussed glyph a [GlyphLeave](#) event is directed at the glyph, and we say that the mouse focus is *uncommitted*. The mouse focus stays uncommitted until the cursor moves into a(nother) reactive glyph. The focus is now committed to this glyph, which is informed of it by being sent a [GlyphEnter](#) event.

Keyboard Focus

A reactive glyph, such as one that is going to respond to typing, will normally “grab” the keyboard focus when it receives a `GlyphEnter` event, and *may* give it up when it receives a `GlyphLeave` event.⁶ Any reactive component can acquire or be given the keyboard focus at any time; and can give it up or give it away at any time.⁷

Normally a keyboard event is directed at the reactive glyph that has the keyboard focus; when there is no such glyph, then it is first directed at the glyph that previously held the keyboard focus; and if there is no such glyph then the “orphan” event is (usually) ignored.⁸

⁶We write *may* because some glyphs do not require the mouse to be inside them in order to respond to the keyboard.

⁷Perhaps surprisingly, keyboard-focus-gained and keyboard-focus-lost events have not, so far been needed.

⁸We write *usually* because there is additional provision for catching and acting upon unfocussed keyboard events that can in principle be used to give some sort of feedback.

2 Glyphs

2.1 The Glyph Interface

The unit of graphical composition is the `Glyph`. All implemented `Glyphs`:

1. Define how they are to be “painted” on a `Surface`⁹
Painting instructions always use a *local co-ordinate space* with origin at $(0, 0)$.
2. Define the `Brushes` to be used when they are painted: usually by specifying foreground and background brushes.
3. Define the diagonal of the rectangular bounding box they will occupy on the surface.
4. Define the location of the top left corner of the abovementioned bounding box relative to the origin of the bounding box of their parent in the glyph-tree. This is usually determined when the parent glyph is laid out; and happens for the first time during the composition of the parent.
5. Define a method that yields a *structurally identical* copy of the glyph: perhaps one that uses different brushes.

A purely passive graphical glyph may be elementary (simple), or composite. Simple glyphs are constructed by *Glyph factories*, many of which require no more than a specification of the diagonal of the bounding box of the graphic: its foreground and background brushes can be specified explicitly or by default. The actual location of a glyph when painted on its surface is usually defined by its location relative to its parent in the glyph tree.

Although a glyph type is usually *defined* by a Scala class, our API convention is that instances used in application GUIs are almost invariably *constructed* by one of the methods of the Scala companion object of its class. For example

```
FilledRect(w: Scalar, h: Scalar,    fg: Brush=..., bg: Brush=...)
Rect(w: Scalar, h: Scalar,          fg: Brush=..., bg: Brush=...)
FilledOval(w: Scalar, h: Scalar,   fg: Brush=..., bg: Brush=...)
Label(text: String, font: Font = ..., fg: Brush=..., bg: Brush=...)
Polygon(w: Scalar, h: Scalar,
        fg: Brush=..., bg: Brush=...)(points: ...)
```

⁹A Surface implements the primitive methods that are used to paint shapes.

2.2 Glyph Composition

Composite glyphs are specialised instances of the `Composite` extension of `Glyph`, and are also usually constructed by *Glyph factories*. These include:

<code>Row</code>	<code>Col</code>
<code>Concentric</code>	<code>OneOf</code>

The `Row` and `Col` compositions are (almost) explainable by their names. Each has variants that explain the exact way in which components are aligned. Here are three differently-aligned rows of a pair of rectangles:¹⁰



`Row(align=Top)(b, r) Row(align=Mid)(b, r) Row(align=Bottom)(b, r)`

Here are three differently-aligned columns of a pair of rectangles.¹¹



`Col(align=Left)(b, r) Col(align=Center)(b, r) Col(align=Right)(b, r)`

The row and column compositions described above yield glyphs that are “naturally” sized. Thus, for example, a row’s width is the sum of its components’ widths, and its height is the maximum of its components’ heights. There are also fixed-size row (and column) compositions, whose row width and column height can be declared in advance, and that allow “expandable” spaces as components. Here we see a couple of examples:¹²



These were constructed by:

```
importFixedSize.Space.tab
FixedSize.Row(350f, bg=grey)(tab, redR, blueR, redR)
FixedSize.Row(350f, bg=grey)(redR, tab, blueR, tab, redR)
```

¹⁰`Row` and `Row(align=Top)` mean the same. We will later meet `Row(align=Baseline)(...)`.

¹¹`Col`, and `Col(align=Left)` mean the same.

¹²`tab` is an expandable space.

with

```
def redR: Glyph = FilledRect(50f, 25f, fg=red)
def blueR: Glyph = FilledRect(100f, 25, fg=blue)
```

Finally, below we show three of the possible `Concentric` compositions of a point and a pair of rectangles; respectively:

```
Concentric(rowAlign=Mid, colAlign=Center)(p,b,r)
Concentric(rowAlign=Mid, colAlign=Right)(p,b,r)
Concentric(rowAlign=Top, colAlign=Center)(p,b,r)
```



The vertical and horizontal aspects of their alignments are, in general, specified independently; but there are shorthands for common cases. Here we could have written:

```
Concentric.Center(p,b,r)
Concentric.Top(p,b,r)
Concentric.Right(p,b,r)
```

Grid and Table organization

It can also be helpful to organize glyph sequences in tabular form. Several methods for doing this are provided by `NaturalSize.Grid` – all invoked by first specifying various aspects of the table.

`Grid(fg: Brush=nothing, bg: Brush=nothing, padx: Scalar=0, pady: Scalar=0).method(...)`

The main *methods* of such a `Grid` are:

```
Grid(width: Int=0, height: Int=0)(glyphs: Glyph*): Composite
Table(width: Int=0, height: Int=0)(glyphs: Glyph*): Composite
Rows(width: Int=0)           (glyphs: Glyph*): Composite
Cols(height: Int=0)          (glyphs: Glyph*): Composite
grid(width: Int=0, height: Int=0)(glyphs: Seq[Glyph]): Composite
table(width: Int=0, height: Int=0)(glyphs: Seq[Glyph]): Composite
rows(width: Int=0)           (glyphs: Seq[Glyph]): Composite
cols(height: Int=0)          (glyphs: Seq[Glyph]): Composite
```

Methods with `width`, `height`, and `glyphs` formal parameters interpret their `glyphs` actual parameter as follows:¹³

1. if there's a `width` parameter then `glyphs` is interpreted as a catenation of rows of the given `width`
2. if there's a `height` parameter then `glyphs` is interpreted as a catenation of columns of the given `height`
3. if there are both `width` and `height` parameters, then:
 - (a) if one argument is omitted, `glyphs` is interpreted as if the method had only the other formal parameter (as above)
 - (b) if both arguments are omitted then `width` is taken to be `ceiling(sqrt(glyphs.length))`.

The `grid/Grid` methods present a grid of *identically-dimensioned* cells, each large enough for any of the glyphs.

The `table/Table` methods present a grid in which all cells in each column have the same horizontal dimension, and all cells in each row have the same vertical dimension.

¹³In this section `width` means “number of columns”; and `height` means “number of rows.”

The `rows/Rows` methods present a grid of row data with columns of uniform horizontal dimension, whilst analogously `cols/Cols` presents a grid of column data with rows of uniform vertical dimension.

Figures 1, 2 and 3 illustrate several ways of using the `Grid` methods `grid`, and `table`.

Individual glyphs in a grid can be made to fit their cell by various methods, including shifting in various directions within the cell, scaling to the size of the cell, and (the default) simply enlarging it to fit. Figure 3 illustrates annotations that can be made to individual glyphs that define how they are made to fit the cells they will inhabit. The data used here is the same as earlier, save that (except in the first grid) the 4th cell is a label of the form `s"cellfit($how)"` where `how` is one of the `CellFit.Method` constants:

```
case object ShiftNorth      extends Method  // ... to the top edge
case object ShiftNorthWest extends Method  // ... to the top left corner
case object ShiftWest       extends Method  // ... to the left edge ...
case object ShiftSouthWest extends Method  // ... to the bottom left ...
case object ShiftSouth     extends Method  // ... to the bottom edge ...
case object ShiftSouthEast extends Method  // ... to the bottom right ...
case object ShiftEast       extends Method  // ... to the right edge ...
case object ShiftNorthEast extends Method  // ... to the top right ...
case object Stretch         extends Method  // scaled up to fit the cell
case object Enlarge         extends Method  // centred in the cell
```

In each case the grid is composed by:

```
Grid(fg = red(width=0), padx=10, pady=10) · grid(width=3)(data)
```

1.scaled(0.8)
1000.scaled(0.8)
1000000.scaled(0.8)
1.scaled(1.0)
1000.scaled(1.0)
1000000.scaled(1.0)
1.scaled(1.5)
1000.scaled(1.5)
1000000.scaled(1.5)

1.scaled(0.8)
1000.scaled(0.8)
1000000.scaled(0.8)
1.scaled(1.0)
1000.scaled(1.0)
1000000.scaled(1.0)
1.scaled(1.5)
1000.scaled(1.5)
1000000.scaled(1.5)

Figure 1: Tables made with `.grid(width = 1)(data)` and `.rows(width = 1)(data)`

<code>.grid(width=3)(data) -- row data as uniform size cells</code>		
1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	1000.scaled(1.0)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)
<code>.grid(height=3)(data) -- col data as uniform size cells</code>		
1.scaled(0.8)	1.scaled(1.0)	1.scaled(1.5)
1000.scaled(0.8)	1000.scaled(1.0)	1000.scaled(1.5)
1000000.scaled(0.8)	1000000.scaled(1.0)	1000000.scaled(1.5)
<code>.rows(width=3)(data) -- row data in uniform width columns</code>		
1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	1000.scaled(1.0)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)
<code>.cols(height=3)(data) -- col data in uniform height rows</code>		
1.scaled(0.8)	1.scaled(1.0)	1.scaled(1.5)
1000.scaled(0.8)	1000.scaled(1.0)	1000.scaled(1.5)
1000000.scaled(0.8)	1000000.scaled(1.0)	1000000.scaled(1.5)
<code>.table(width=3)(data) -- row data as minimal width/height cols/rows</code>		
1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	1000.scaled(1.0)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)
<code>.table(height=3)(data) -- col data as minimal width/height cols/rows</code>		
1.scaled(0.8)	1.scaled(1.0)	1.scaled(1.5)
1000.scaled(0.8)	1000.scaled(1.0)	1000.scaled(1.5)
1000000.scaled(0.8)	1000000.scaled(1.0)	1000000.scaled(1.5)

Figure 2: Table presentations of a grid

<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>1000.scaled(1.0)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(Stretch)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(ShiftNorth)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(ShiftSouthWest)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(ShiftSouth)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(ShiftSouthEast)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>fitToCell(ShiftEast)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>

Figure 3: Individual cell placement with fitToCell

OneOf: Temporal Alternations of Glyphs

The `OneOf` composition is used primarily in the implementation of dynamically “paged” interfaces¹⁴ or in the presentation of alternate captions on reactive glyphs.¹⁵ It constructs a glyph whose appearance is chosen dynamically from a palette of component glyphs. Its bounding box is the union of the bounding boxes of its component glyphs; and it shows only one of them at a time, namely the one selected most recently by its `select` method, or by one of its `next()` or `prev()` methods.

Thus the definitions¹⁶

```
def bananas = Label("Bananas", fg=white, bg=blue)
val oneof: OneOf =
  OneOf(bg = Wide · red)( bananas · rotated(0)
                           , bananas · rotated(1)
                           , bananas · rotated(2)
                           , bananas · rotated(3)
                         )
```

gives rise to the glyph that is initially drawn as:



and after the execution of `oneof.next()` is drawn as:



Subsequent invocations of `oneof.next()` will select successive components for drawing, and an invocation of `oneof.select(n)` will select its n th (modulo 4) component for drawing.¹⁷

Had `oneof` been specified without a background brush, then the background would have been one of the backgrounds of its maximal (by area) components.

¹⁴Such as those provided in the `Book()` API.

¹⁵Such as those used in the `Checkbox` and `TextToggle` APIs

¹⁶See “Glyphs are mutable” (A.1) for an explanation of why the label is defined as a function not just as a value.

¹⁷Only the currently selected component of a `OneOf` is considered in the search for a reactive glyph to handle a user gesture or keystroke. See Appendix C for details.



2.3 Brushes

A brush applies “paint” to a surface. The most important of its characteristics are its width (aka `strokeWidth`), and the colour of the paint it will apply. But it also has “shape”, in the sense that corners painted with it may be rounded, squared, mitered, *etc*; as well as having many other definable characteristics, including a human-readable name.

For example, here are definitions of the `blue` and `red` brushes used while preparing this paper.¹⁸

```
val blue = Brush("blue")(color=0xFF0000ff, width=1.0f, cap=ROUND)
val red = Brush("red") (color=0xFFFF0000, width=1.0f, cap=ROUND)
```

and `val Wide·blue` was defined as:

```
Brush("Wide·blue")(color = 0xFF0000ff,
                  width = 15.0f,
                  cap = SQUARE)
```

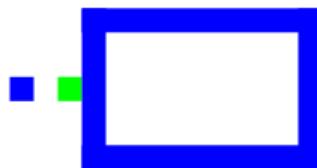
The following two images show some brush properties in action. Notice the rounded corners of the first rectangle, and that the points have all the characteristics of the brushes they were drawn with.

```
Row(align=Mid)(Point(Wide.blue(cap=ROUND)),
                Skip(Wide.blue.strokeWidth),
                Rect(150f, 100f, Wide.blue(cap=ROUND)))
```



Glyph
eg1d

```
Row(align=Mid)(Point(Wide.blue),
                Skip(Wide.blue.strokeWidth),
                Point(Wide.green), Rect(150f, 100f, Wide.blue))
```



Glyph
eg1e

¹⁸Colour is specified here by a 32-bit/4-byte integer – usually written as a hexadecimal constant. The first byte specifies its *alpha* – which is analogous to opacity or covering power; the second, third, and fourth bytes specify its red, green, and blue components.

In fact the library incorporates an embedded domain-specific language of brushes: some expressions denote new brushes or variants of existing brushes; and others denote commands that affect existing brushes.¹⁹ For example, the `Wide·blue` brush could have been defined as a variant of `blue`:

```
blue(width=15.0f, name="Wide·Blue", cap=SQUARE)
```

Brushes are cheap to build, and it is straightforward to define them *ad-hoc* while building a glyph.²⁰

For example:

```
Row(align=Mid)(  
    Point(Wide·blue(width=2*Wide·blue·strokeWidth, cap=BUTT)),  
    Skip(2*Wide·blue·strokeWidth),  
    Rect(150f, 100f, Brush(""))(color=red·color,  
                                width=Wide·blue·strokeWidth, cap=SQUARE)))
```

denotes the glyph

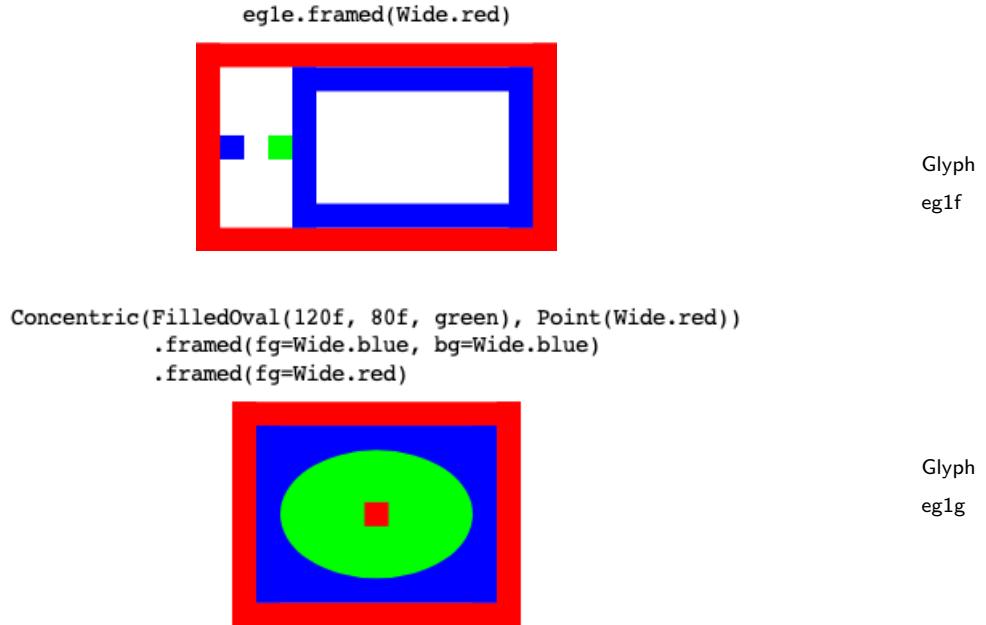


¹⁹See appendix A.2 for an explanation and examples of the latter.

²⁰Implementation details of the brush language may be of interest to the Scala programmer who likes the idea of “notationally sugared” APIs.

3 Glyph Transformers

Glyph transformers are used to derive glyphs from simpler glyphs. Almost all transformers are provided as intrinsic methods of all glyphs. For example:



It's important to understand that, as a matter of policy, transforming a glyph, g is an “algebraic” operation that denotes a tree in which g is embedded: it no more makes a “new” copy of g than (for example) the successor $\text{succ } n$ of a number n makes a “new” copy of n .²¹

Intrinsic glyph transformers include:

```
def scaled(scale: Scale): Glyph  
def enlarged(delta: Scalar, ...): Glyph  
def enlargedTo(w: Scalar, h: Scalar, ...): Glyph  
def enlargedBy(w: Scalar, h: Scalar, ...): Glyph  
def rotated(quadrants: Int, ...): Glyph  
def turned(degrees: Scalar, circular: Boolean, ...): Glyph  
def skewed(skewX: Scalar, skewY: Scalar, ...): Glyph  
def mirrored(leftRight: Boolean, topBottom: Boolean, ...): Glyph
```

²¹In light of the first prototype library implementing glyphs mutably there is an argument against this policy because it could lead to inadvertent sharing, with effects such as those described in Appendix A.1. A future prototype is envisaged in which glyphs are no longer mutable, and the policy will be irrelevant.

```

def framed(fg: Brush = Glyphs.Framed.defaultFG ,
            bg: Brush = Glyphs.Framed.defaultBG): Glyph
def edged(fg: Brush = Glyphs.Framed.defaultFG ,
            bg: Brush = Glyphs.Framed.defaultBG): Glyph
def shaded(enlarge: Scalar = 0.25f ,
            delta: Scalar = 8f ,
            down: Boolean=false , ...): Glyph
def beside(g: Glyph, align: VAlignment=Mid): Glyph
def above(g: Glyph, align: Alignment=Center): Glyph

```

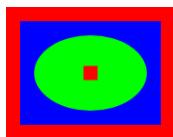
In the above signatures, the abbreviation `...` stands for the declaration that ‘fg’ and ‘bg’ parameters be inherited from the glyph being transformed, unless otherwise specified. For example, the full signature of `mirrored` is:

```

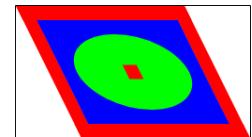
def mirrored(leftRight: Boolean, topBottom: Boolean,
              fg: Brush = thisGlyph.fg,
              bg: Brush = thisGlyph.bg): Glyph

```

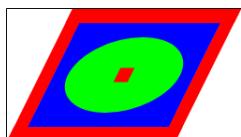
Figure 3 shows a few more examples of their use:



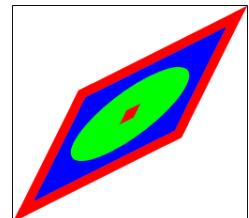
g



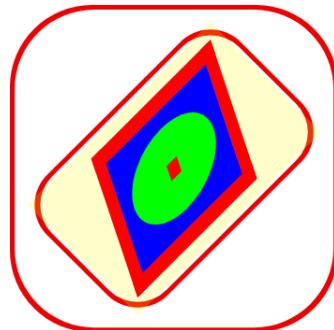
g·skewed(0·5,0)·framed()



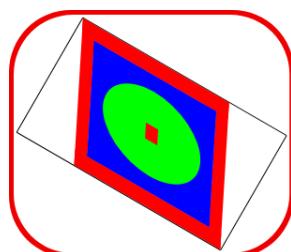
g·skewed(-0·5, 0)·framed()



g·skewed(-0·5, -0·5)·framed()



```
g·skewed(0·5f, 0f)·enlarged(27, bg=yellow(alpha=0·2f))  
·framed(redFrame)  
·turned(45f)  
·mirrored(leftRight=true, topBottom = false)  
·framed(fg=redFrame)
```



g·skewed(0·5f, 0·0f)·framed()·turned(30f)·framed(fg=redFrame)

Figure 4: Intrinsic glyph transformers in use

4 Polygonal Glyphs

4.1 Specification

Polygons (open or closed) are specified by giving the coordinates of the relevant vertices in addition to the diagonal of the bounding box they will be drawn in.²² They have several forms of constructor: all are features of `Polygon` or `FilledPolygon`. A *rough* guide to deciding on what part of the bounding box of a filled polygon gets filled is that a point is inside the polygon (therefore filled) if a line from it to some arbitrarily chosen far away point crosses one of the lines between adjacent vertices an odd number of times; it is outside if the number is even.²³

Compare the two red `FilledPolygon`s with vertices respectively given by

```
FilledPolygon(200, 200, fg = red)((0, 0), (200, 200),  
                                (200, 0), (0, 200))
```

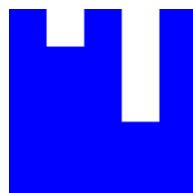
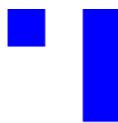
```
FilledPolygon(200, 200, fg = red)((200, 200), (0, 0),  
                                (200, 0), (0, 200))
```



Now compare the two blue `FilledPolygon`s with vertices given by

```
FilledPolygon(100, 100, fg = blue)(  
    (0,0), (20, 0), (20, 20), (40, 20), (40, 0),  
    (60,0), (60, 60), (80, 60), (80, 0), (100,0))
```

```
FilledPolygon(100, 100, fg = blue)(  
    ((100,0), (100, 100), (0, 100), (0,0),  
     (20, 0), (20, 20), (40, 20), (40, 0),  
     (60,0), (60, 60), (80, 60), (80, 0), (100,0)))
```



²²A closed polygon is one whose last vertex is the same as its first.

²³The “far away point” should be chosen so that the line is not parallel to one of the edges. This is rarely difficult.

4.2 Paint Effects

Interesting effects are possible when paints are equipped with path-effects, or are blurred.

Path Effects

In the following sequence of examples we compute the vertices of a 7-pointed regular star (a “stargon”), then construct a “wobbly” paintbrush (`blueish`) that is used to render the star both as a filled polygon and as an open polygon.

First we define generators for filled and non-filled stargon glyphs of specific colours:

```
def filledStargon(n: Int, fg: Brush): Glyph =
  FilledPolygon·$(256, 256, fg, nothing)(regularStarPath(n))

def nonFilledStargon(n: Int, fg: Brush): Glyph =
  Polygon·$(256, 256, fg, nothing)(regularStarPath(n))
```

Both use a generator for the vertices of the paths used by the `Polygon` constructors to make star glyphs: R is the length of edges of the star, with centroid at (C, C) .²⁴

```
def regularStarPath(n: Int): Seq[(Scalar, Scalar)] = {
  val C: Scalar = 128.0f
  val R: Scalar = 115f
  val star = new ArrayBuffer[(Scalar, Scalar)]
  val theta = PI - PI/n
  star += (((C + R, C)))
  for {i ← 0 until n} {
    val a = theta * i
    star += (((C + R * Math·cos(a))·toFloat, (C + R * Math·sin(a))·toFloat))
  }
  star += ((C + R, C))
  star·toSeq
}
```

Rendered straightforwardly with `fg=blue` the filled and open stargons are:

²⁴Exercise: this algorithm can be understood by thinking of the points on the path as the successive places a tortoise will stop when at each stage it moves by R in the direction *heading*, then turns through θeta – stopping when it has made $n + 1$ moves. Find out what happens if n is even, explain why, and suggest an alternative termination condition that yields stargons of *some* order for $n \geq 2$.



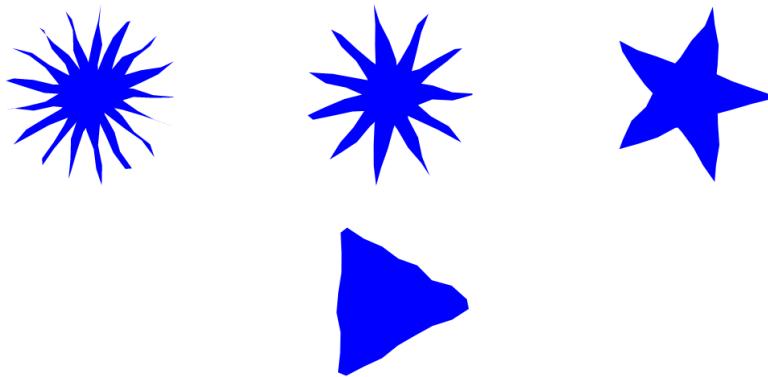
The `blueish : Brush` is the same color as blue, but wider: it has "wobbly" edges specified by a path effect described by `sliced`.

```
val blueish =
    blue(width = blue.strokeWidth*2) · sliced(25.0f, 4.0f, 1)
```

Rendered in blueish, the stargons are:

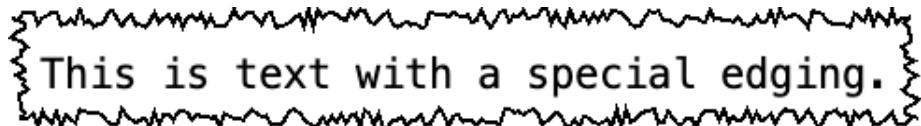


All this works for stars of arbitrary odd arity: here are stars with $n = 17, 11, 5, 3$:



Using brushes with path effects to draw frames can give aesthetically interesting results. For example:

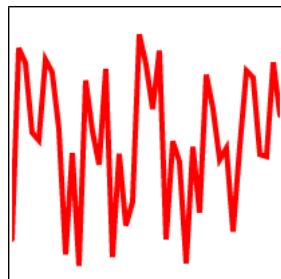
```
Label("...") · enlarged(20)
    · edged(fg = black(width = 2f) · sliced(2.5f, 5f))
    · enlarged(10))
```



The three parameters of `sliced` are, in turn, the length of each “segment” into which the path drawn by the paint will be sliced, the limit of the random displacement of the endpoints of the segment from the path, and (if it appears) a seed for the generation of the displacements.

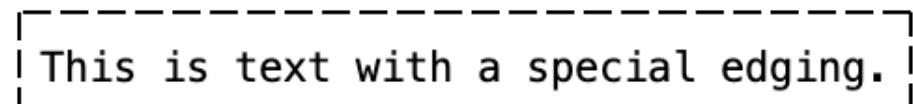
It’s easier to see the effect of the displacement limit when the path is a straight line. Here’s

```
Polygon(200, 200,  
        fg = red(width = 4f, cap = ROUND) · sliced(5f, 100f, 15)  
    )((0, 100), (200, 100)) · enlarged(4) · framed()
```



Another path effect leads to dashed/dotted lines.

```
Label("· · ·") · enlarged(20)  
      · edged(fg = black(width = 2f) · dashed(15f, 5f))  
      · enlarged(10))
```



Many other effects are available from **Skia** via **Skija**.

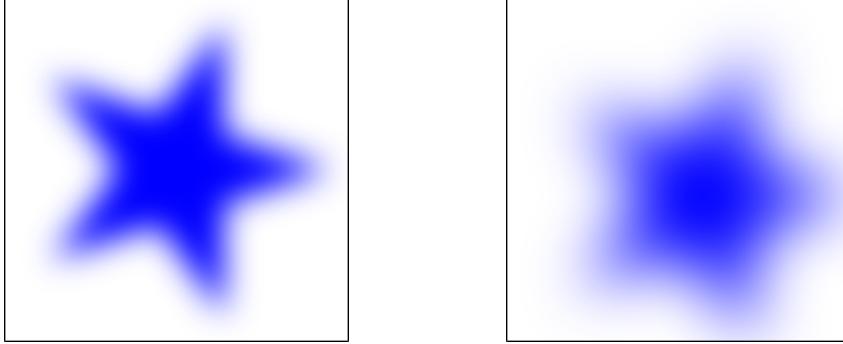
Blurred Paint Effects

The intrinsic `Brush`-transformer `blurred` yields a brush that blurs all the filled glyphs that it paints. When `brush: Brush`

```
brush · blurred( blur: Scalar, dx: Scalar=0f, dy: Scalar=0f): Brush
```

yields a blurred brush of the same colour as `brush`. When used on *filled* glyphs, it blurs their outline, and can shift the blurred outline relative to their origin (by (dx, dy)).

Below we show the effects of painting a filled star with `blue.blurred(24f)` and with `blue.blurred(48f, 20f, 20f)`. Both are `framed()`: notice that the latter is displaced by $(20, 20)$ within the natural bounding box indicated by the frame.



Blurred Frame Effects

Figure 26 shows the use of a blurred brush, as well as uses of the extrinsic `glyph` transformer

```
BlurredFrame( blur: Scalar, spread: Scalar, dx: Scalar=0f, dy: Scalar=0f, ...)
```

The styled blurred button-framing specification

```
Decoration · Blurred( blur: Scalar, spread: Scalar, dx: Scalar=0f, dy: Scalar=0f, ...)
```

is illustrated in Figure 20.

A Mutability of Glyphs and Brushes

A.1 Glyphs are mutable

In the present prototype implementation it is *essential to understand that a glyph is mutable*: in particular that its `location` and `parent` features are changed as it is incorporated in its glyph tree by its parent glyph.

This happens exactly once per glyph, and in order to use a glyph more than once it necessary to copy it. Fortunately this is straightforward: each form of glyph has a copy method that yields a fresh²⁵ structurally identical (“deep”) copy. The copy method has `fg`, `bg` arguments that specify the foreground and background brushes of the copy; and these are defaulted to those of the glyph being copied.

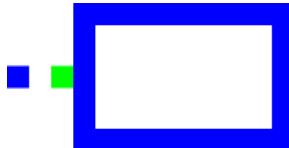
As a convenience, the `Glyph` may be “applied” with the same result:

```
def copy (fg: Brush=this·fg , bg: Brush=this·bg): Glyph
def apply(fg: Brush=this·fg , bg: Brush=this·bg): Glyph =
    this·copy(fg , bg)
```

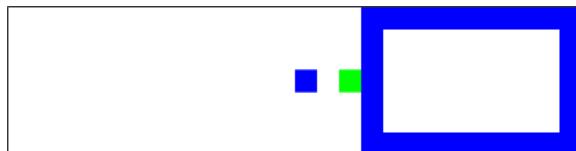
When a glyph is used twice without copying, the results are rarely what was intended. For example, here we show the outcome of using a glyph value a second time in a tree without copying. When `egc` is defined by

```
val egc: Glyph =
    Row·centered(Point(Wide·blue),
                  Skip(Wide·blue·strokeWidth),
                  Point(Wide·green),
                  Rect(150f, 100f, Wide·blue))
```

it denotes a glyph drawn as



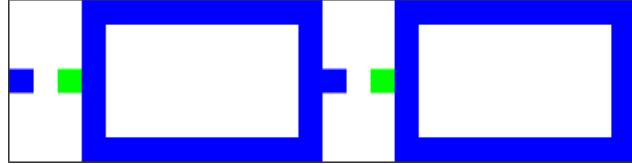
and the expression `Row(bg=white)(egc, egc)` denotes a glyph drawn as



²⁵i.e. without having set `location`, `parent`.

What is happening is that `egc`'s location relative to its parent in the glyph tree is set twice by the `Row` compositor; and the second setting is the one used during drawing.²⁶

When the glyph is copied before both uses all is well: `Row(egc(), egc())` is drawn as²⁷



A.2 Brushes are mutable

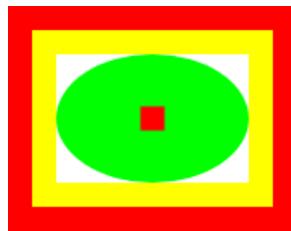
In the present prototype implementation the attributes of brushes can be changed dynamically, and the effects of these changes *apply retrospectively to every glyph that was ever drawn with them*. Although this feature is not intended to be used frequently, it can occasionally be useful: for example using a brush on part of a GUI that indicates state by changing its colour.

Brushes have “chained” methods that can be used to change their attributes; these have the same names as the attributes, for example:

```
def strokeWidth(i: Float): Brush = { ...; this }
def color(i: Int): Brush = { ...; this }
def cap(cap: PaintStrokeCap): Brush = { ...; this }
```

For example, here's what `eg1g` looks like in a context where the colour of the wide blue `Brush` has been changed retrospectively to yellow by the command:

```
Wide · blue · color(0xFFFFF00)
```



²⁶That this can occur *without warning at compile time* is a defect in the design of the library to which there are a multiplicity of potential solutions: we are considering them at the time of writing. But for the moment we advise copying as a matter of course: it's not computationally very expensive.

²⁷In fact if it's not going to be used again only one copy is needed.

The mutation methods return the glyph from which they are invoked, so to change colour, width, and cap in the same command one could write:

```
Wide · blue · color(0xFFFFF00) · strokeWidth(50) · cap(ROUND)
```

or, recalling that **Scala** methods can also be used as infix operators, one could have written:

```
Wide · blue color 0xFFFFF00 strokeWidth 50 cap ROUND
```

It is probably unwise to change a stroke width dynamically in such a way as to increase the size of a bounding box beyond its original size, for that would invalidate an important assumption made during glyph composition, namely that the sizes of component glyphs' bounding boxes do not increase after composition. This assumption is invalid for glyphs such as those built by `.framed(...)` whose bounding boxes are partly determined by the width of brushes used in them. Decreasing a stroke width dynamically does not violate this assumption.

B Text

Here we discuss the low-level API for generating simple text glyphs. The `Styled` package provides more versatile methods for composing glyphs that consist of paragraphed text.

A `Text` is a glyph-builder, *ie.* a *factory* for text glyphs. The function `text`, defined below, constructs a glyph-builder from the given string at the specified size in (the italic Courier) `typeFace`.

```
val typeFace: Typeface =
  FontMgr.getDefault()
    .matchFamilyStyle("Courier", FontStyle.ITALIC)

def text(s: String, size: Float): Text =
  Text(s, new Font(face, size))
```

The `Texts` `text1`, `text2` are glyph builders that will eventually yield glyphs. The function `em` defines an *em-width* space.

```
val text1 = text("A\u24ptText", 24.0f)
val text2 = text("A\u12ptText", 12.0f)
def em    = Skip(font(12f).measureTextWidth("m"))
```

`Texts` provide the following methods that build glyphs:

```
.asGlyph: Glyph
.atBaseline: Glyph
```

Both yield glyphs with the same bounding box: but the second yields a glyph that is expected to be drawn only within top-aligned `Row`'s.

```
Framed(grey)(text1.asGlyph(blue))
```

A blue rectangular box containing the text "A 24pt Text" in a blue font.

```
Framed(grey)(Row(text1.atBaseline(blue)))
```

A blue rectangular box containing the text "A 24pt Text" in a blue font, positioned lower than the first one.

Drawing a sequence of `atBaseline`-generated glyphs in a *top-aligned* row positions them so that their baselines coincide, and this is the intended effect.

```
Framed(grey)(Row(text1.atBaseline, em, text2.atBaseline))
```

A 24pt Text A 12pt Text

Deprecated uses of `asGlyph` and `atBaseline` glyphs

Using `asGlyph`-generated glyphs of different sizes in rows is a cheap and nasty way to simulate superscripts and subscripts and is not recommended for normal use.

```
Framed(grey)(Row(text1.asGlyph(), em, text2.asGlyph()))
```

A 24pt Text A 12pt Text

```
Framed(grey)(Row.Bottom(text1.asGlyph, em, text2.asGlyph))
```

A 24pt Text A 12pt Text

When an `atBaseline`-generated glyph does not have a `Row` as parent, it is drawn so that its baseline coincides with the top of its bounding rectangle: the result is **never** useful.

```
text1 · atBaseline(fg=blue) · framed(grey)
```

A 24pt Text

Moreover, when `atBaseline`-generated glyphs of different heights are used in a bottom- or centre-aligned row the results are **never** useful.

```
Row · centered(text1 · atBaseline(fg=black),  
                text2 · atBaseline(fg=blue)) · framed(grey)}
```

A 24pt Text A 12pt Text

C The Focus Protocol

The windows of an application’s GUI each have two foci: each is either undefined or associated with a reactive glyph.

- The window’s **keyboardFocus** is the reactive glyph that is expected to handle keyboard events within that window. Reactive glyphs usually co-operate to manage it.
- The window’s **mouseFocus** is the reactive glyph that is expected to handle mouse events, such as those arising from movements, button presses and releases, and from mouse wheel events. Such events may also originate on a trackpad, touchscreen, *etc.*

The (mouse) focus protocol is designed to ensure that events arising from the manipulation of the mouse (or other pointing device) get directed to an appropriate reactive glyph. The essence of the protocol is described below. The specification of “try to locate a reactive glyph...” is at [C.4](#).

C.1 MouseMove events

- (a) If **mouseFocus** is defined, then
 - i If the mouse location is within the focussed glyph, direct the event to that glyph.
 - ii If mouse location is not within the focussed glyph, then direct a **GlyphLeave** event to that glyph, and set **mouseFocus** to **None**.
- (b) If **mouseFocus** is not defined, then try to locate a reactive glyph that contains the mouse location.
 - i If there is such a reactive glyph, direct a **GlyphEnter** event to it, and set **mouseFocus** to it.
 - ii If there is no such reactive glyph, ignore the event.

C.2 MouseButton events

- (a) If **mouseFocus** is defined, then

- i If the mouse location is within the focussed glyph, direct the event to that glyph.
 - ii If mouse location is not within the focussed glyph, then just set `mouseFocus` to `None`.
- (b) If `mouseFocus` is not defined, then try to locate a reactive glyph that contains the mouse location.
- i If there is such a reactive glyph, direct a `GlyphEnter` event to it, and set `mouseFocus` to it.
 - ii If there is no such reactive glyph, ignore the event.

C.3 MouseScroll events

- (a) If `mouseFocus` is defined, then direct the event to the focussed glyph.
- (b) If `mouseFocus` is not defined, then ignore the event.²⁸

In effect the protocol defined above means that a reactive glyph becomes “aware” that it has the focus when the mouse moves into it; and becomes “aware” that it no longer has the focus when the mouse moves out of it. Although it would be straightforward to change the protocol so that fewer events are ignored, we believe that in many cases the response of a glyph to an event ignored in the protocol would be to ... ignore it.

C.4 Locating Reactive Glyphs

Recall that the glyphs comprising a GUI all have their own (0,0)-origin coordinate system, and that each glyph is located relative to its parent in the glyph tree as its parent is being laid out. This approach makes it straightforward to implement geometric transforms on glyphs, such as the rotations, scalings, and skewings described briefly earlier – a transformed glyph is displayed by applying the transform before displaying the untransformed glyph.

The search for a reactive glyph that contains a location is conducted by first searching the glyph tree for the glyph that most closely contains that location, then finding its nearest reactive parent in the tree (usually, but not always, the same glyph).

²⁸We are currently considering adding a third locus, namely `scrollFocus`.

The search for the glyph that most closely contains a location is conducted top-down in the glyph tree. Composite glyphs that don't themselves contain the location are not searched, but those that do contain the location are searched for more specific components. For the moment we consider that this algorithm is adequately efficient, but if necessary glyph trees could be indexed straightforwardly.

On the other hand, experience has shown that the algorithm is not efficient enough to use during mouse motion to decide whether the mouse location is still within the focussed glyph. This is because mouse motion events are generated at high frequency as the mouse traverses a window. So instead of using the algorithm, we annotate each reactive glyph with the inverse of the (constant) transform that was (last) used to display it, then use this inverse to map the (absolute) mouse location back to the coordinate system of the reactive glyph itself.

C.5 Locating Glyphs in the presence of Overlays

Menus and dialogues are managed by the module `overlaydialogue.Dialogue` which provides a collection (possibly empty) of *overlays* per window: each of these is specified as a glyph tree with a few additional properties.

The overlays are organised as a stack of GUI “layers” drawn topmost-last: each appearing on top of its predecessor in the stack, and all appearing on top of the main GUI tree. There is also a collection of named “decorations” that , each defined by a glyph tree. These are drawn in no particular order after the main GUI and the overlay stack.

The algorithm to locate a glyph that contains the mouse is designed to find a currently-visible glyph containing the mouse in:

- i the topmost layer of the stack, or in
- ii a decoration, or in
- iii a currently-visible glyph in the application’s main GUI tree.

When the topmost layer of the stack is “modal” (*ie* represents a menu or a modal dialogue), then only (i) and (ii) above are considered.

The net effect is that glyphs in the main interface that are *completely hidden* by the topmost layer of the stack will not be selected during a mouse-focus

transfer. Normally, as far as a button is concerned, if you can't see it *all* then you can't press it.²⁹

²⁹In the exceptional situation of *loose hiding* being enabled for the topmost overlay then if you can see some of a button then you can press it.

D Anatomy of a Simple Reactive Glyph

Here we give an account of the structure of the reactive glyph class `Coloured-Button`. The appearance of such buttons is specified by a single glyph. The foreground (or the background) colour of the glyph changes when the mouse hovers over it, and when a button is pressed (but not yet released) within it. If its `background` flag is true, then it's the background colour of the button that is changed.

It inherits the features of a `GenericButton` that deal with the details of mouse-motion and button-clicks. We shall discuss these later: the main thing to understand now is that the state of an active, non-disabled button is captured by:

```
var hovered: Boolean  
var pressed: Boolean
```

The former is true if and only if the (mouse) pointer is within the button.³⁰ The latter is true if and only if the button has been pressed, but not yet released, within the bounding box of the button. When a button is released within the button, its `react` method is invoked.³¹

A button can be programmatically disabled or made inactive:

```
var disabled: Boolean  
var inactive: Boolean
```

The first part of the definition is straightforward: the constructor takes the glyph used to specify the button's appearance when neither hovered nor pressed. The brushes `down` and `hover` specify the foreground colour of the glyph when pressed and hovered, and when just hovered. If the colour of the background is to be changed on state changes, then `background` is set.

```
class ColourButton(  
    appearance: Glyph,  
    down: Brush,  
    hover: Brush,  
    val background: Boolean,  
    val react: Reaction) extends GenericButton {  
  
    override def toString: String =  
        s"ColourButton($up, $down, $hover, $background)"
```

³⁰More precisely, the bounding box of the glyph that represents the button on the screen.

³¹with a parameter, sometimes ignored, that captures the current state of the keyboard modifiers, the exact button pressed, etc.

Because we cannot rely on the `fg` (`bg`) brush of the appearance not being shared anywhere else in the GUI tree, we want to avoid changing that brush. So we construct a *copy* (`glyph`) of the appearance glyph, with `fg` (`bg`) set to `currentBrush` – a copy of the appearance’s relevant brush. We intend to use `glyph` when drawing the button; its foreground (or background) will be painted using the copied brush, and the appropriate features of that brush will be copied (from one of `up`, `down`, `hover`) according to the current state of the button.

```
val up: Brush =
  if (background) appearance.bg else appearance.fg

val currentBrush: Brush = up.copy()

val glyph: Glyph =
  if (background)
    appearance(bg=currentBrush)
  else
    appearance(fg=currentBrush)

def setCurrentBrush(b: Brush): Unit = {
  currentFG.color(b.color).width(b.strokeWidth)
}
```

The `draw` method shows the current state of the button by painting it with the appropriate brush using the appropriate opacity (alpha). It captures the current geometric transform that will be used to render its glyph.³²

```
def draw(surface: Surface): Unit = {
  val (brush, alpha) =
    if (disabled) (up, alphaDisabled) else
      if (inactive) (up, alphaUp) else
        (pressed, hovered) match {
          case (true, true) => (down, alphaDown)
          case (false, true) => (hover, alphaHover)
          case (_, _) => (up, alphaUp)
        }
  surface.withAlpha(diagonal, alpha) {
    setCurrentBrush(brush)
    glyph.draw(surface)
    surface.declareCurrentTransform(this)
  }
}
```

³²The latter is used to speed up the tracking of mouse movements. If the button is inactive or disabled, it won’t be used, but capturing it does no harm.

The following definitions can be overridden if necessary, but have proven satisfactory in practice.

```
def alphaDisabled: Int = 0x70; def alphaUp: Int = 0xFF
def alphaDown: Int = 0xFF; def alphaHover: Int = 0xF0
```

The actual glyph that will be shown must be properly installed in the GUI tree by making the button glyph its parent.

```
locally { glyph.parent = this }
```

The rest of the button glyph description is completely standard: it implements the remaining glyph features by forwarding to its “embedded” `glyph`.

```
override def diagonal: Vec = glyph.diagonal

override def glyphContaining(p: Vec): Option[Hit] =
  glyph.glyphContaining(p)

override def contains(p: Vec): Boolean =
  glyph.contains(p)

val fg: Brush = glyph.fg
val bg: Brush = glyph.bg

def copy(fg: Brush=this.fg, bg: Brush=this.bg): Glyph =
  new ColourButton(appearance(fg.copy(), bg.copy()), down, hover, react)

}
```

As usual we define a companion object to deliver methods that support the convenient construction of useful `ColourButtons`. The first one we show here provides a text-labelled button using the various defaults provided by `Brushes`. The defaults can be overridden at construction time.

```
object ColourButton {
  val up: Brush = Brushes.buttonForeground()
  val down: Brush = Brushes.buttonDown()
  val hover: Brush = Brushes.buttonHover()
  val bg: Brush = Brushes.buttonBackground
  def apply(text: String,
            up: Brush=up, down: Brush=down, hover: Brush=hover,
            bg: Brush=bg, background: Boolean = true)
            (react: Reaction): ReactiveGlyph =
  { val glyph: Glyph = Brushes.buttonText(text).asGlyph(up, bg)
    new ColourButton(glyph, down, hover, background, react)
  }

  def apply(glyph: Glyph, down: Brush, hover: Brush, background: Boolean)
```

```
(react: Reaction): ReactiveGlyph =  
new ColourButton(glyph, down, hover, background, react)  
}
```

E Examples

The best way of getting to grips with **Glyph** is to study the source of one or two of the medium-sized examples included with it: particularly [DemonstrationNotebook](#), and [CalculatorExample](#). The following few examples are considerably smaller, and not particularly useful save as a getting-started guide. The use of implicit style parameters in examples 3 and 4 means that the reader should be somewhat familiar with the notion of implicits in Scala 2.

E.1 A Passive GUI

This is an entirely passive application. Its “interface” is an (unstyled) text label. The abstract class [Application](#) provides the link between the interface and the outside world, needing only a definition of [GUI](#) to set up and populate its single main window.

```
package org.sufrin.glyph
package tests
import Glyphs.Label

object Example1 extends Application {
    val GUI: Glyph = Label("A simple label")
    override def title: String = "Example1"
}
```

On my computer, the text of the label seems a bit close to the inner edge of the window: so our first modification to the program will be to add an uncoloured 20 [ux](#)³³ border around the label. The colours and font of unstyled labels are given default values in the definition of [Label](#).

```
val GUI: Glyph = Label("A simple label") · enlarged(20)
```

The effect is discernible but not drastic.



³³Distance measurements are expressed in (possibly fractional) “logical units” ([ux](#)) – these sometimes correspond to the physical pixels on a screen, but on some high-resolution screens a [ux](#) may correspond to more than one pixel. **Glyph** manages the correspondence.

E.2 An Explicitly-styled GUI

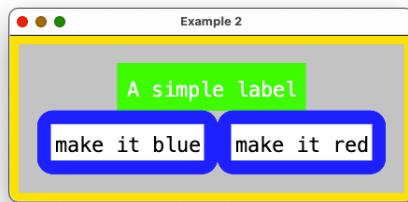
This application's interface is defined as `GUI` in the trait `Example2Interface` that is mixed-in with `Application` to form the main program.

```
package org.sufrin.glyph
package tests

import Glyphs._
import NaturalSize.{Col, Row}
import ReactiveGlyphs.TextButton

trait Example2Interface { ... }

object Example2 extends Application with Example2Interface {
  override def title: String = "Example2"
}
```



The interface is a centered column, on which there is a label above two side-by-side captioned buttons, each with a rounded blue frame around it. It is presented on a grey background with a yellow rim around it

```
trait Example2Interface {
  val blueish: Brush = blue(cap=ROUND, width=8)
  val labelColor: Brush = green()

  val GUI: Glyph = Col(bg=lightGrey).centered(
    Label("A simple label", fg=white) enlarged(20, bg=labelColor),
    Row(TextButton("make it blue") { _ ⇒ labelColor color blue · color },
        .framed(fg=blueish, bg=blueish),
        ' TextButton("make it red") { _ ⇒ labelColor color red · color },
        .framed(fg=blueish, bg=blueish))
  ) · enlarged(40f) · enlarged(20f, bg=yellow)
}
```

A `TextButton`'s default response to the mouse cursor entering it is to turn its caption green; when the cursor is pressed in this state the caption turns red, and if the cursor is released when the caption is red, then the button's reaction method is invoked. Here, each button's reaction changes the colour `labelColor` that was used to paint the background around the label.

E.3 A GUI with Implicitly Styled Glyphs

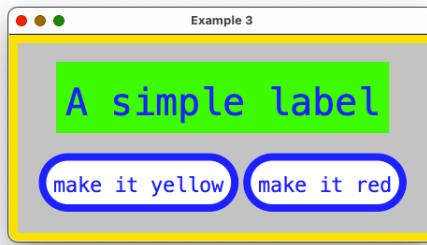
This application was derived from example 2, and has an almost identical source code structure, save that the button and label definitions are imported from the `styled` package.

```
package org.sufrin.glyph
package tests
import Glyphs._
import NaturalSize._

trait Example3Interface { ... }

object Example3 extends Application with Example3Interface {
  override def title: String = "Example 3"
}
```

Its interface looks almost the same as the previous example, save that the button framing is a little more elegant, and the simple label is in a larger font, and placed on a coloured background



The `Example3Interface` is different: it uses *implicitly-styled* glyphs and leaves much of the heavy lifting concerning font sizes, and button frames to be defined implicitly by the *enclosing context*. Here that context is provided by importing the `LocalStyle` object:

```

trait Example3Interface {
  object LocalStyle extends Styles.Basic { ... }
  import LocalStyle._
  import Spaces._
  import styled.TextButton
  import styled.TextLayout.TextLabel

  val labelColor: Brush = green()

  val GUI: Glyph = Col(bg=lightGrey) · centered(
    TextLabel("A simple label") · enlarged(20, bg=labelColor), ex,
    Row(TextButton("make it yellow") { _ ⇒ labelColor color yellow · color },
        TextButton("make it red") { _ ⇒ labelColor color red · color })
  ) · enlarged(40f) · enlarged(20f, bg=yellow)
}

```

The `LocalStyle` object is an extension of `Styles.Basic` that specifies a variety of styles by default. Here we adapt two of the defaults for use in styling our labels and our buttons. They are declared as `implicit`, and the compiler matches them to the implicit parameters of `TextLabel` and `TextButton`: their names are unimportant: the implicit matching is done on their types.

- `localLabels` is almost identical to the basic `labelStyle`, except that its font is made (with the same `face`) at a different size.
- `localButtons` is almost identical to the basic `buttonStyle`, except that buttons are specified as being framed with round blue frames on a white background.

```

object LocalStyle extends Styles.Basic {
  import Styles.Decoration.Framed

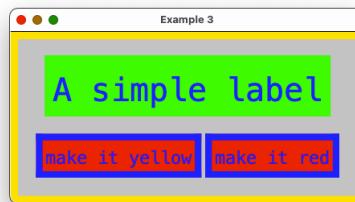
  implicit val localLabels: Styles.GlyphStyle =
    labelStyle · copy(font=GlyphTypes.Font(face, 40))
}

implicit val localButtons: Styles.ButtonStyle =
  buttonStyle · copy(frame =
    Framed(fg = blue(width = 8, cap=ROUND),
            bg = white,
            radiusFactor = 0.5f))

```

Less rounded button frames can be delivered by adopting a higher curvature (lower radius factor), and the frames are square when no radius factor (or a factor of 0) is specified.

```
implicit val localButtons: Styles·ButtonStyle =
  buttonStyle·copy(
    frame = Framed(fg = blue(width = 8, cap=SQUARE), bg = red)
  )
```

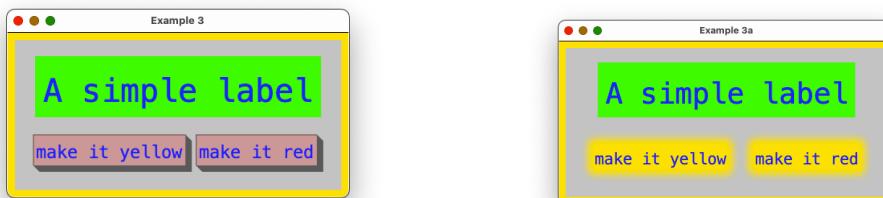


There are other kinds of button-framing, including [Shaded](#), and [Blurred](#)

```
import Styles·Decoration·{Shaded, Blurred}

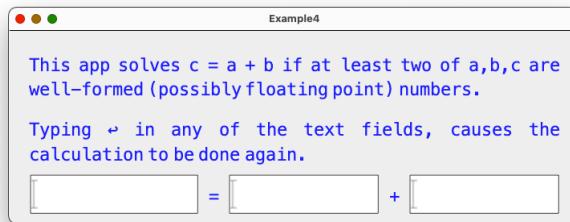
implicit val localButtons: Styles·ButtonStyle =
  buttonStyle·copy(frame = Shaded(fg = blue(width = 8), bg = red))

implicit val localButtons: Styles·ButtonStyle =
  buttonStyle·copy(frame = Blurred(blur=10f, spread=10f, fg = yellow))
```



The important thing to understand is that all styles deliver buttons with the same functionality: this means that the visual style of an interface can straightforwardly be decided upon separately from its functionality.

E.4 A Primitive Calculator



The application also uses styled components; but this time keeps to the basic style.

```
package org.sufrin.glyph
package tests

import NaturalSize.{Col, Row}
import styled.TextLayout._

object Style extends Styles.Basic
import Style._

trait Interface {
  ...
  val GUI: Glyph = Col.centered(
    help.enlarged(25),
    Row.centered(c.framed(),TextLabel("a=b"),
      a.framed(),TextLabel("a+b"),b.framed()),
    )enlarged(25)
}
```

Its `Interface` trait defines its help text, three identically-behaving text (input) fields `a`, `b`, `c`, and a couple of helpful methods.

```
trait Interface {
  val help = TextParagraphs(50, Justify)("...")

  def field(): TextField =
    TextField(size = 8, onEnter = { _ ⇒ calculemus() })

  val a, b, c = field()

  def calculemus() = ...

  val GUI: Glyph = ...
}
```

The most important of these methods is `calculemus()`. It is the core of the application: when invoked – by ENTER being typed in any of the text fields – it tries to convert each of the text fields into numbers, then calculates the third if at least two are defined.

```
def calculemus() =
  (c.text.toDoubleOption, a.text.toDoubleOption, b.text.toDoubleOption)
  match {
    case (None, Some(av), Some(bv)) => c.text = format(av+bv)
    case (Some(cv), Some(av), None) => b.text = format(cv-av)
    case (Some(cv), None, Some(bv)) => a.text = format(cv-bv)
    case (Some(cv), Some(av), Some(bv)) =>
      if (cv == av+bv) {} else c.format = text(av+bv)
    case _ =>
  }

def format(d: Double): String = f"$d%·5g"
```

A slightly different definition of the behaviour of the text fields, allows a simple error report to be given if what's in a field doesn't look like a number when enter is pressed.

```
import windowdialogues.Dialogue·OK

def field(): TextField = TextField(size = 8, onEnter = {
  case s: String if s.toDoubleOption.isDefined => calculemus()
  case s: String =>
    OK(TextLabel(s"$s·doesn't·look·like·a·number·"))
      .InFront(help)
      .start()
})
```

F Pages from DemonstrationNotebook

Figures 5 to 27 show some of the pages of the DemonstrationNotebook example. They are intended to illustrate some of the available tools in use, and their source code shows how the tools can be used.

The (top-level) notebook is structured as a sequence of pages with titles. Pages may themselves have nested notebooks, as exemplified by the "Etc*" page below.

The [Layout](#) feature of a notebook supports methods, such as `rightButtons`, `leftButtons`, ... whose invocation yields a GUI with buttons juxtaposed to a `OneOf` that has a glyph for each defined page.

```
trait DemonstrationPages
  ...

  val noteBook = new NoteBook
  val Page = noteBook·DefinePage

  Page("Help", "Help\u00a5for\u00a5the\u00a5Demonstration\u00a5Notebook") { ... }
  Page("New", "Make\u00a5a\u00a5new\u00a5or\u00a5cloned\u00a5GUI\u00a5") { ... }
  Page("Menus*", "Window\u00a5menus\u00a5and\u00a5dialogues") { ... }
  Page("Transforms*", "") { ... }
  Page("Overlays*", "Features\u00a5implemented\u00a5as\u00a5\u00a5") { ... }
  Page("Framing*", "") { ... }
  Page("Styles*", "") { ... }
  Page("Events*", "") { ... }
  Page("Fonts*", "...") { ... } (HelpStyle·labelStyle)
  Page("Etc*", "") {
    val nested = new NoteBook {}
    val Page = nested·DefinePage
    Page("Animation", "") { ... }
    Page("Grid", "buts\u00a5=\u00a58\u00a5\u00a5\u00a5") { ... }
    Page("Blurred", "") { ... }
    Page("Split", "") { ... }
    Page("Scroll", "Scrolling\u00a5and\u00a5Scaling\u00a5with\u00a5ViewPort") { ... }
    Page("OneOf", "OneOf\u00a5backgrounds") { ... }
    Page("Sliders", "") { ... }
    Page("CheckBox", "Toggles\u00a5and\u00a5Checkboxes") { ... }
    Page("Fonts", "") { ... }
    nested·Layout·rightButtons()
  }
  ...
}
```

Each of the lazy values defined below is bound to one particular notebook layout; and the top-level application logic chooses one of them as the GUI for the application. Figure 15 illustrates the “skewed buttons” presentation style.

```
...
lazy val asRNotebook = noteBook.Layout.rightButtons()
lazy val asLNotebook = noteBook.Layout.leftButtons()
lazy val asVNotebook = noteBook.Layout.rotatedButtons(3)
lazy val asSNotebook = noteBook.Layout.skewedButtons(0.2f, 0f)
lazy val asTNotebook = noteBook.Layout.topButtons()

} // end DemonstrationPages
```

The application as a whole is an instance of the Glyph `Application` trait – that provides definitions of `GUI`, `Title`, *etc*. Importantly the standard `onClose` method invokes a method that pops up a dialogue that asks for confirmation when the application window is closed.

```
object DemonstrationNotebook extends DemonstrationPages with Application {
  lazy val GUI =
    if (extraArgs contains "-notebook") asRNotebook else
    if (extraArgs contains "-rnotebook") asRNotebook else
    if (extraArgs contains "-lnotebook") asLNotebook else
    if (extraArgs contains "-snotebook") asSNotebook else
    if (extraArgs contains "-vnotebook") asVNotebook else
    if (extraArgs contains "-tnotebook") asTNotebook else
    if (extraArgs contains "-menu") asMenu else asRNotebook

  def title =
    s"""\n      SmallTest\u2014scale=$scaleFactor\u2014${extraArgs.mkString(" ", ")}\n    """

  override
  val defaultIconPath: Option[String] = Some("./flag.png")

  override
  def onClose(window: Window): Unit = confirmCloseOn(GUI)(window)
}
```

Help for the Demonstration Notebook

This application demonstrates aspects of the Glyphs library by offering the choice of several demonstration GUIs. These are usually shown on the pages of a tabbed notebook, with tabs placed to the right. Several of the pages have pages nested within them: their names have * by them.

Command-line arguments affect the notebook style (normally -notebook) and scale (normally 1.00).

```
-notebook => tabs to the right (the default)
-rnotebook => tabs to the right
-lnotebook => tabs to the left
-vnotebook => rotated tabs along the top
-tnotebook => tabs along the top
-snotebook => rotated and skewed tabs along the top

-menu => individual popup windows selected from a menu bar

-scale=d.dd the viewing scale is d.dd (1.00 by default)
```

The "New" page enables instantiation of a new GUI with a choice of tab style, viewing scale and starting screen.

The "Rescaling enabled" button enables rescaling of the GUI in response to the user changing the width of the application window interactively.

The application evolved naturally during development because we saw that unit-testing was not going to be effective. It is not, and not intended to be, a comprehensive test; but if it works at all then a very substantial proportion of the toolkit must be functioning adequately.



- Help
- New
- Menus*
- Transforms*
- Overlays*
- Framing*
- Styles*
- Events*
- Etc*

Figure 5: the Help page

Help
New
Menus*
Transforms*
Overlays*
Framing*
Styles*
Events*
Etc*

Make a new or cloned GUI

The button below starts a completely new instance of the GUI. The checkboxes determine what tab layout and scale the new instance will have; as well as what screen (if there are many) it will be shown on at first.

There is no artificial limit to the number of instances that can be running at once within a single JVM, (though space constraints within the JVM will impose a natural limit).

New instance

-notebook ✓	-scale=0.6 ✗	-screen=p✓
-lnotebook ✗	-scale=0.7 ✓	-screen=0 ✗
-snotebook ✗	-scale=0.75 ✗	-screen=1 ✗
-vnotebook ✗	-scale=0.8 ✗	-screen=2 ✗
-tnotebook ✗	-scale=0.9 ✗	
-menu ✗	-scale=1.0 ✗	
	-scale=1.2 ✗	

Unlike a new instance, a cloned instance always shares some state with the current GUI -- for example the notebook page currently being viewed, and the state of checkboxes on a page. Changes made in a GUI, are reflected in its clones only when they next receive an event (such as entry of the mouse).

Because this is intended to be used only during development, the clone button needs to be enabled (using its adjacent checkbox) before it responds to presses. Tab layout, scale, and screen are specified as for new instances.

Clone this instance

Figure 6: the New page

Window menus and dialogues

This page tests popup dialogues from which multiple choices can be made. Each of the buttons below pops up a CHOOSE popup with the specified number of choices on it.

Pressing its close button pops the dialogue down without making a choice (and yields null to the popup's continuation).

[One](#) [Two](#) [Three](#)

[Dialogues](#)
[Menus](#)
[Locators](#)

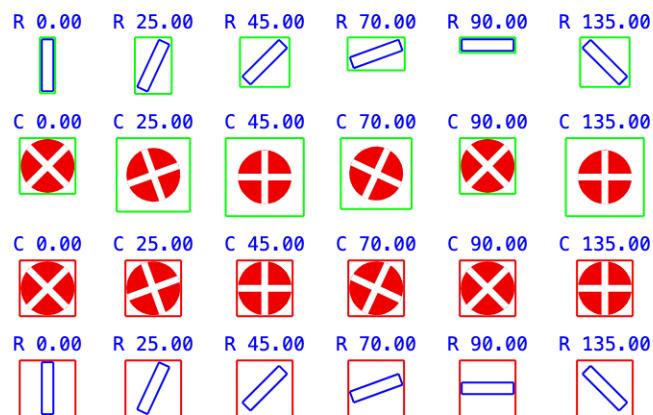
[Help](#)
[New](#)
[Menus*](#)
[Transforms*](#)
[Overlays*](#)
[Framing*](#)
[Styles*](#)
[Events*](#)
[Etc*](#)

Figure 7: the Dialogues subpage of Menus*

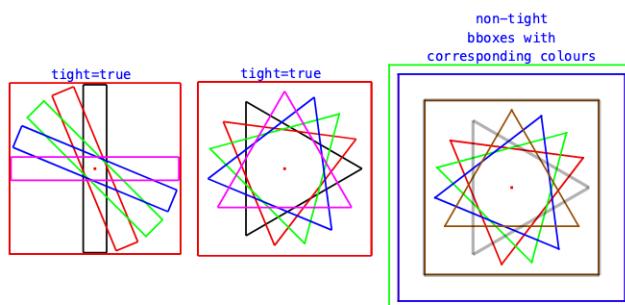
Turn transforms

The `.turned` transform with `tight=true` always yields a square bbox whose side is the larger of the two of the present glyph. For near-rotationally-symmetric glyphs this bbox fits more closely than the one yielded by `tight=false`.

Hereunder R denotes a rectangle, C denotes a circular glyph, and T denotes a triangle. Tight bounding boxes are shown in red, non-tight in green.



R/T turned d, for d in 0, -22.5, -45, -67.5, -90



- Help
- New
- Menus*
- Transforms*
- Overlays*
- Framing*
- Styles*
- Events*
- Etc*

Figure 8: the Turn subpage of Transforms*

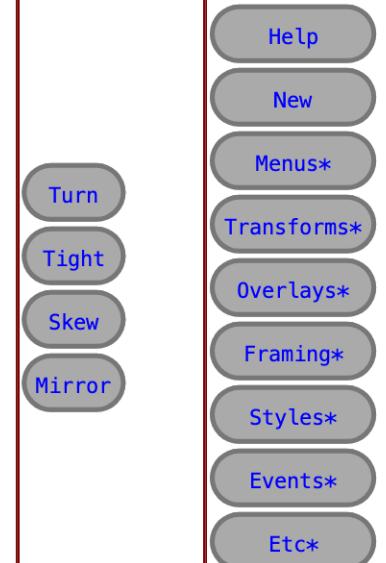
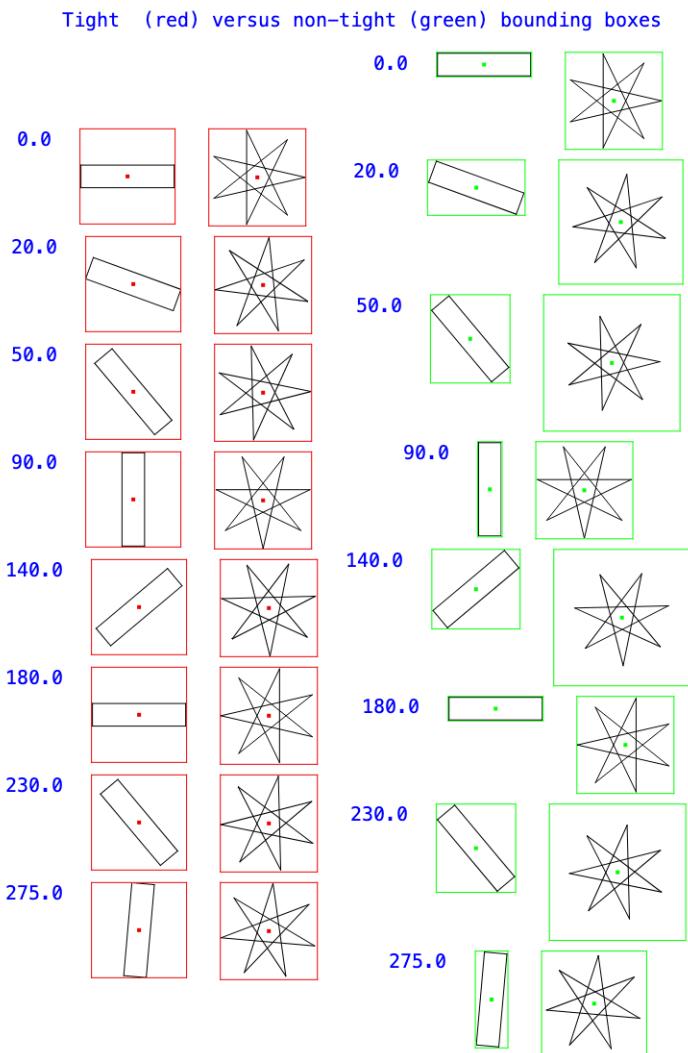
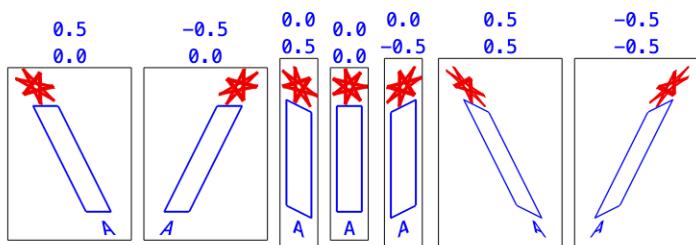


Figure 9: the Tight subpage of Transforms*

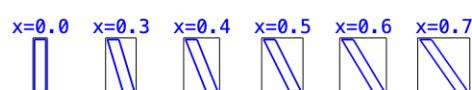
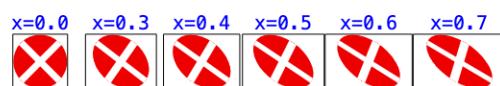
He
 N
 Mer
 Trans
 Over
 Fram
 Sty
 Eve
 Et

Skew transforms

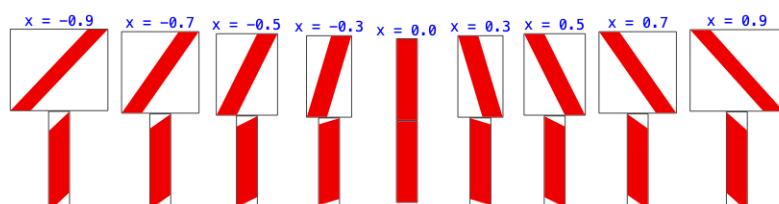
`g.skewed(dx, dy)` skews `g` rightwards as `y` increases, and downwards as `x` increases



`.skewed(x, 0)`



`R.skewed(x, 0).above(R.skewed(0, x))`



Turn
 Tight
 Skew
 Mirror

Figure 10: the Skew subpage of Transforms*

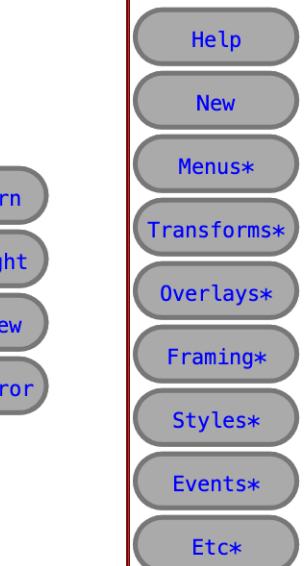
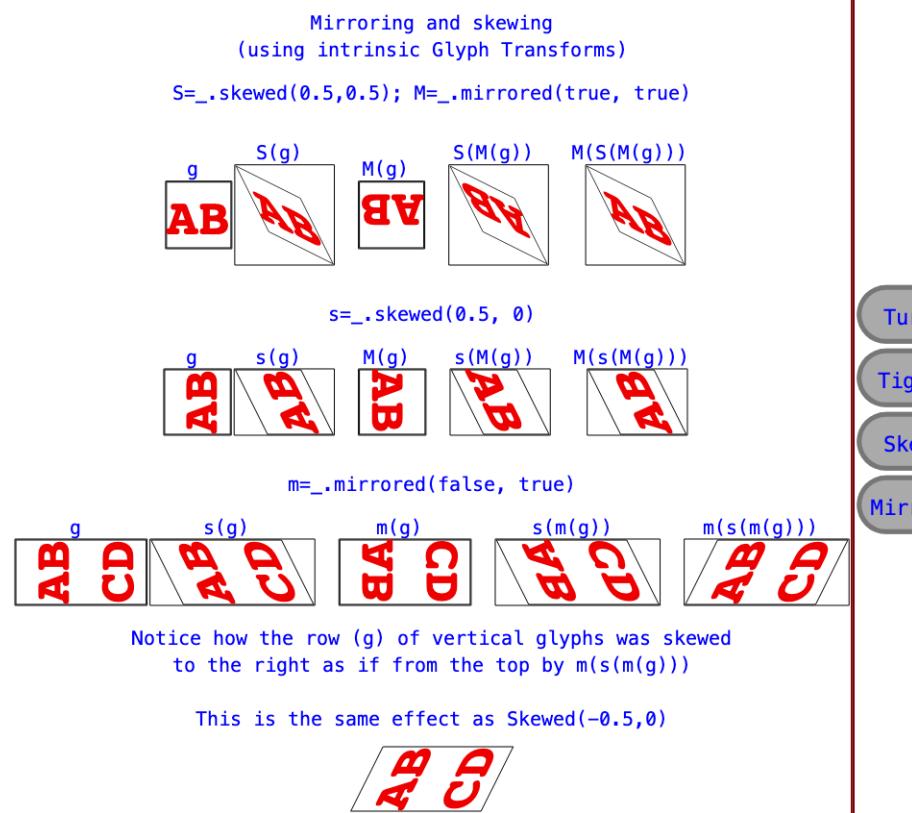


Figure 11: the Mirror subpage of Transformations*

- [Help](#)
- [New](#)
- [Menus*](#)
- [Transforms*](#)
- [Overlays*](#)
- [Framing*](#)
- [Decoration*](#)
- [Events*](#)
- [Fonts*](#)
- [Etc*](#)

Features implemented as overlay layers and annotations

This page tests annotation-style overlays, using the low-level annotation API.

The checkbox below enables/disables overlaying of a 10x10 grid on the whole of the current window, no matter what page/subpage is showing. The grid can be useful when exploring the dimensions of glyphs.

A checkbox always appears on the grid: pressing this disables the grid, which can only be re-enabled by the checkbox below.

Grid:

The button below pops up an annotation overlay that points to the East wall of the window. The overlay stays up until its button is pressed, no matter what page/subpage of the app is showing.

[Point to the East wall of the window](#)

Figure 12: the Annotation subpage of Overlays*

When enabled, clicking on this grey strip enables the current GUI's appearance to be saved as a timestamped image. It can be enabled/disabled with the checkbox on the Help page, or with the button that appears on the Etc*/CheckBox page.

Features implemented as overlay layers and annotations

On this page we are testing modal dialogues implemented on overlays within the current window. You can exit the dialogue without making a choice by clicking on the topmost grey bar or typing ESC. You can shift the location of the dialogue by using the direction keys.

Each dialogue explains where it was intended to pop up (relative to the blue rectangle). The location of a dialogue that might be partly off screen are adjusted to make it (as far as possible) visible.

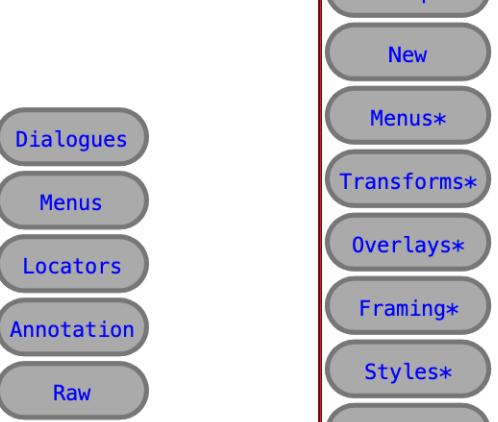
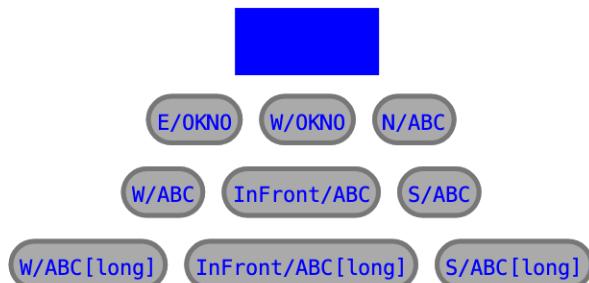


Figure 13: the Dialogues subpage of Overlays* (vertical tabs notebook)

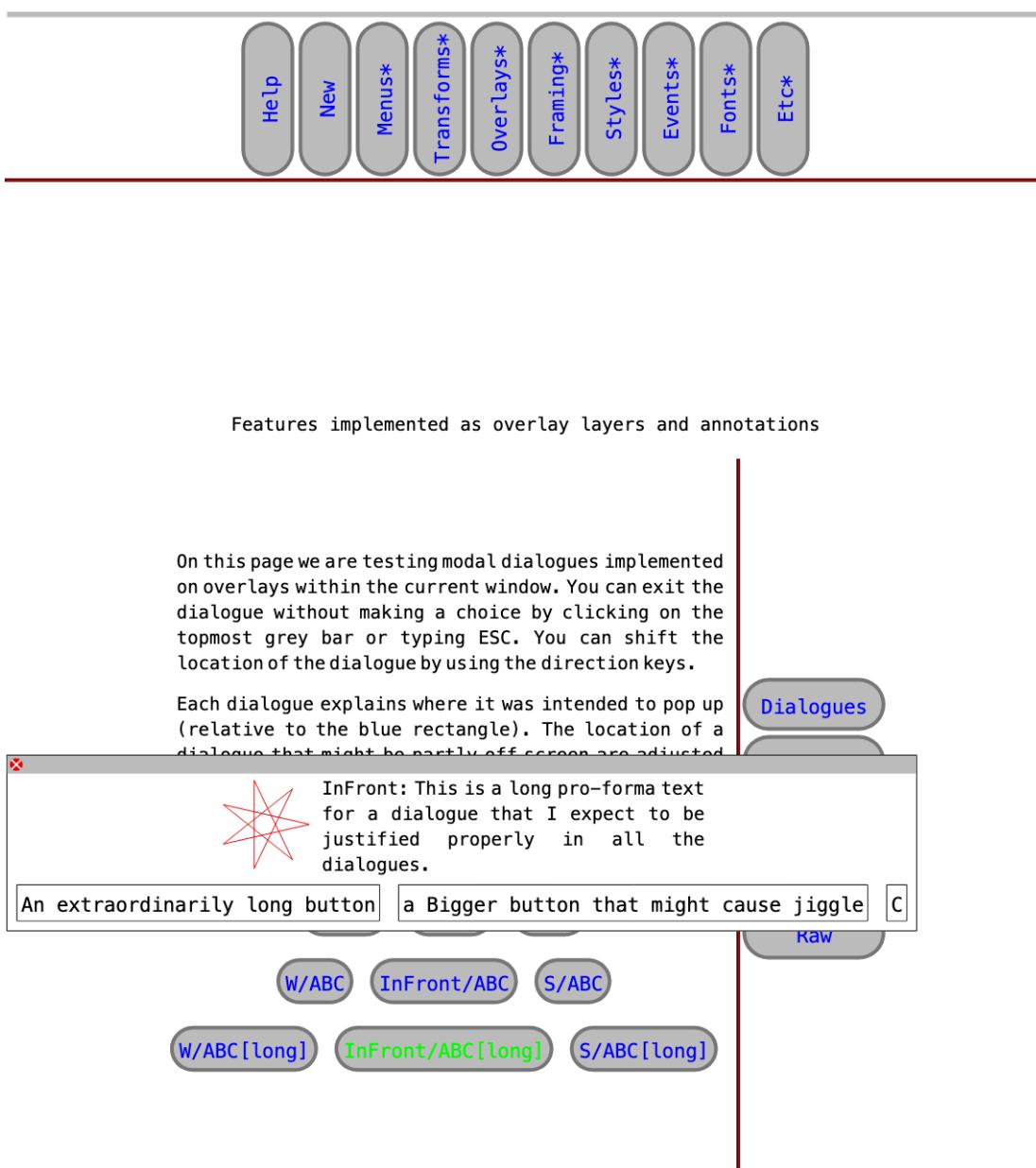


Figure 14: a Popped-up dialogue (vertical tabs notebook)

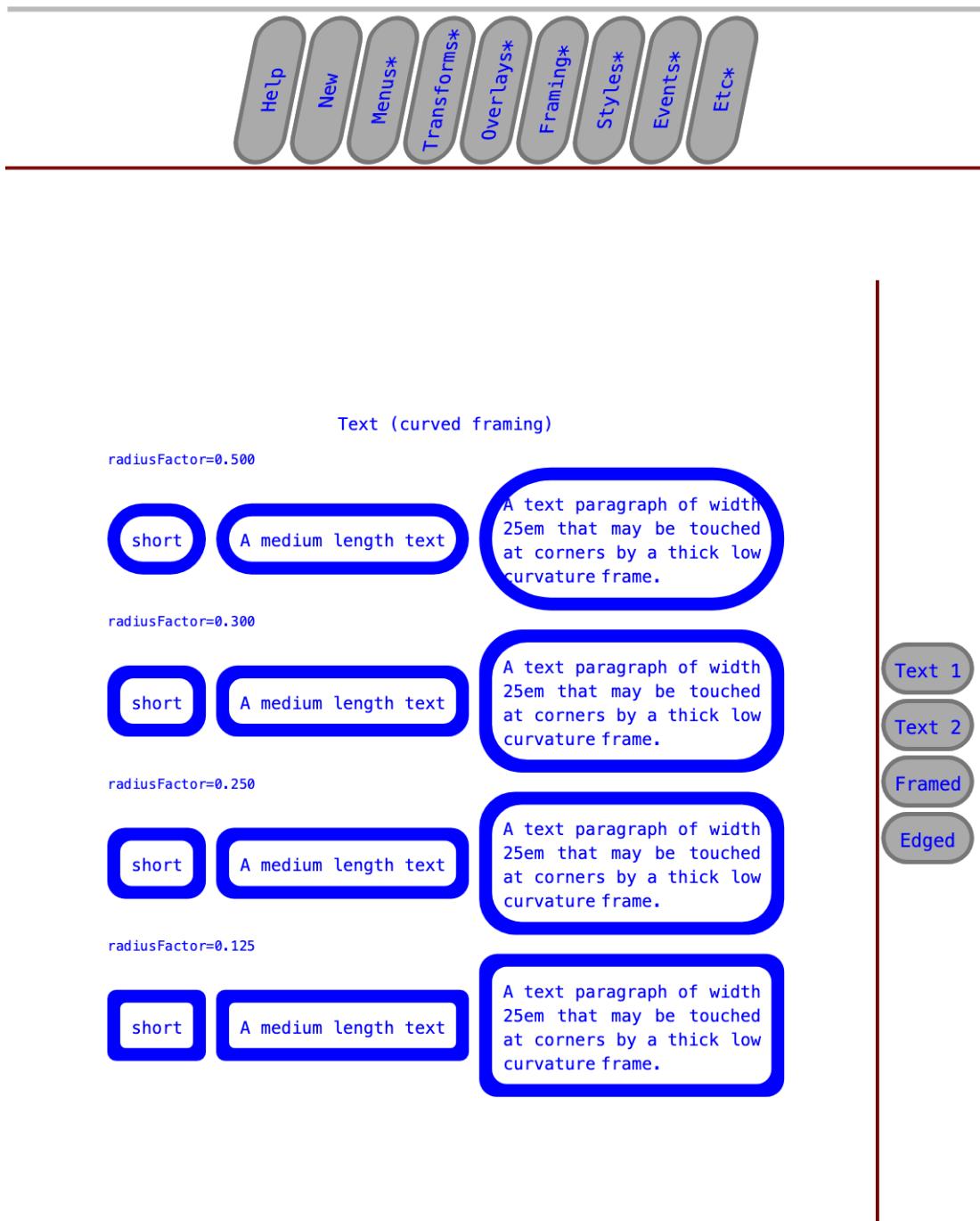


Figure 15: the Text1 subpage of **Framing*** (skewed tabs notebook)

Help
 New
 Menus*
 Transforms*
 Overlays*
 Framing*
 Styles*
 Events*
 Etc*

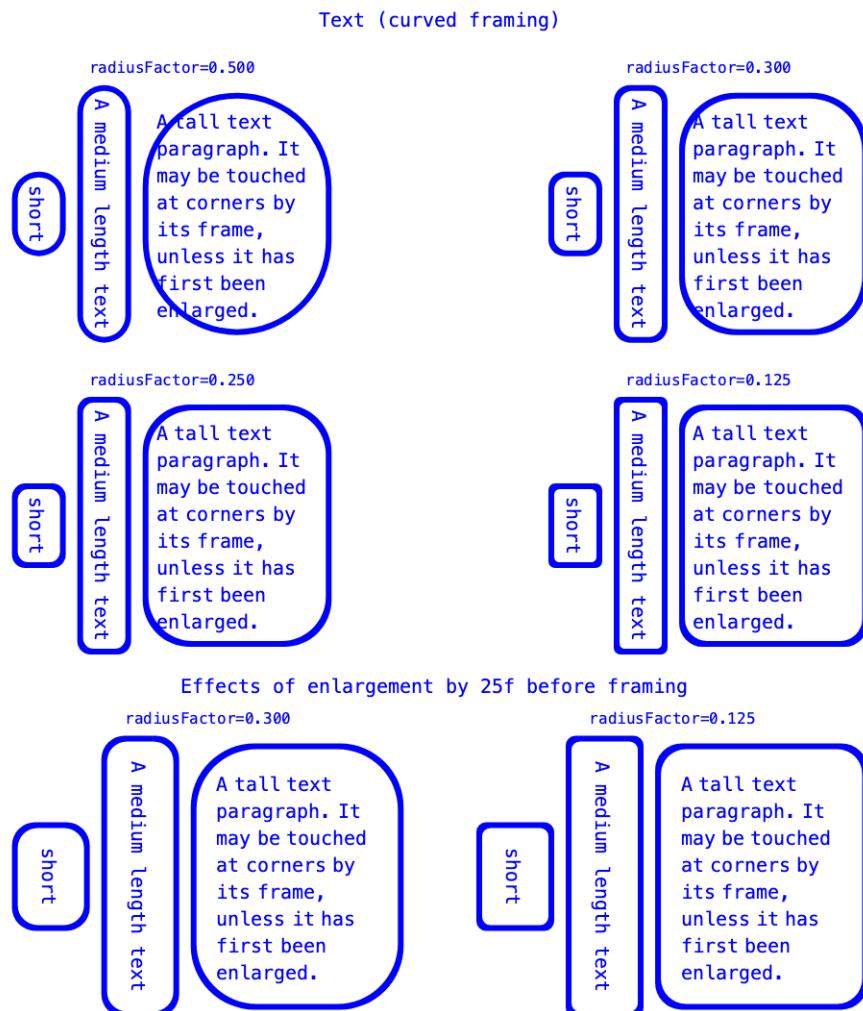


Figure 16: the Text2 subpage of Framing*

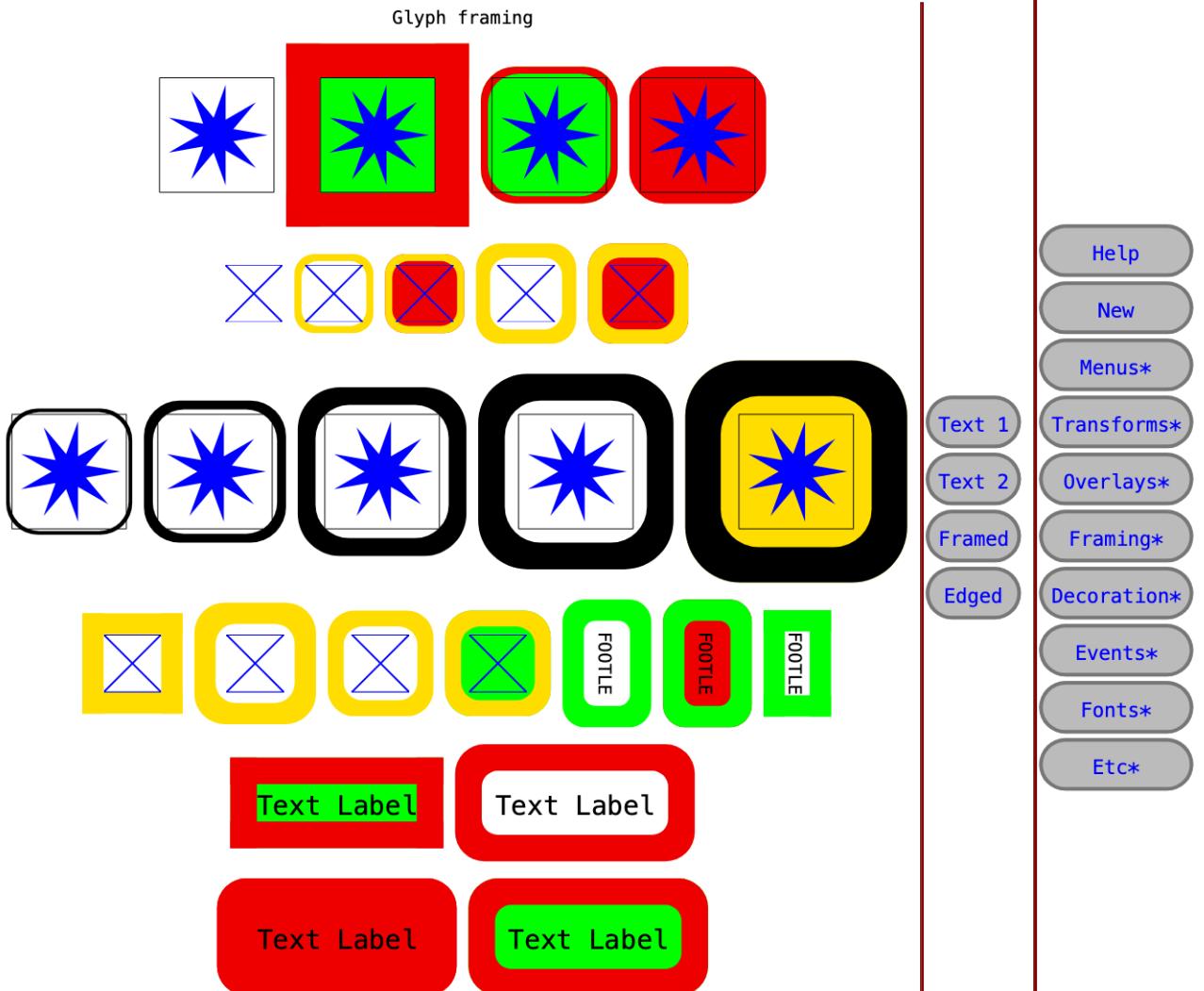


Figure 17: the Framed subpage of Framing*

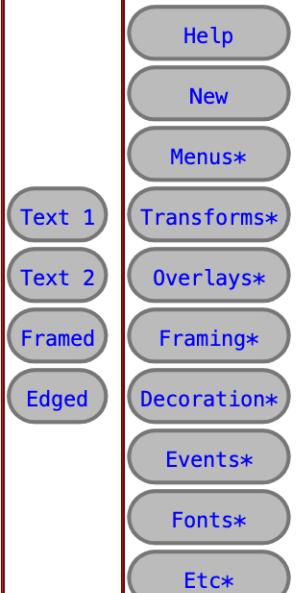
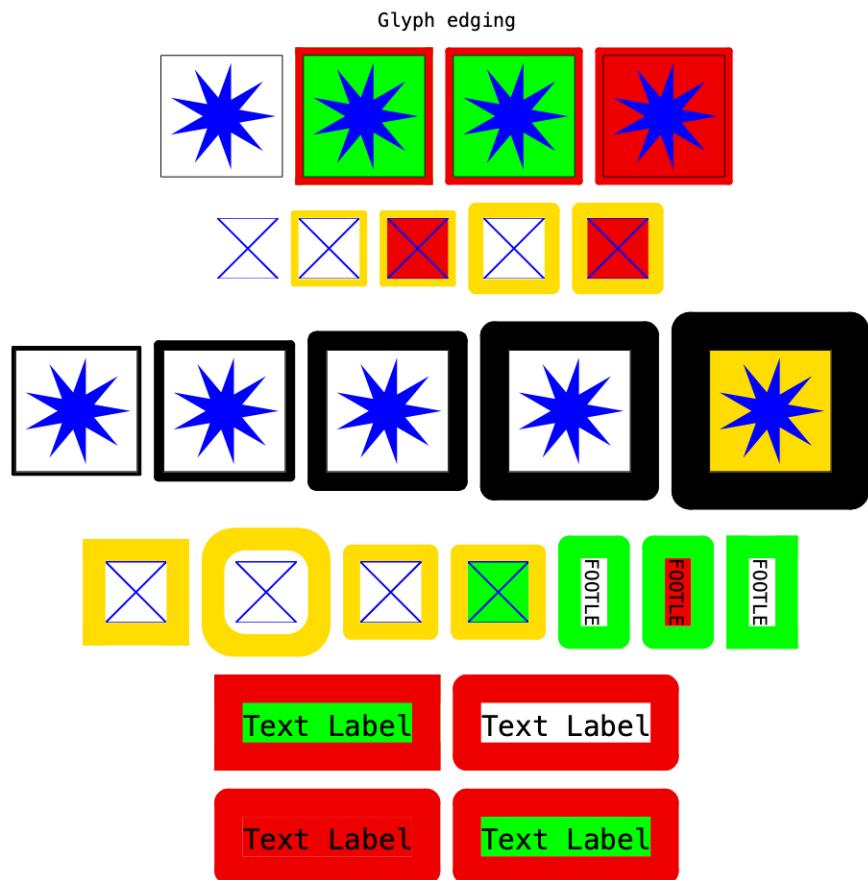


Figure 18: the Edged subpage of Framing*

```

The buttons here are all of the form
    styled.TextButton("..."){_=> }(style)
where
    style =
        buttonStyle.copy(
            frame = Framed(fg = darkGrey(width=...),
                           bg = lightGrey,
                           enlarge = 0.25f,
                           radiusFactor = ...
            ))

```

(width=2, radiusFactor=0.5)

(width=4, radiusFactor=0.5)

(width=8, radiusFactor=0.5)

(width=10, radiusFactor=0.5)

(width=2, radiusFactor=0.25)

(width=4, radiusFactor=0.25)

(width=8, radiusFactor=0.25)

(width=10, radiusFactor=0.25)

Framed
Blurred
Shaded

Help
New
Menus*
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Figure 19: the Framed subpage of Styles*

The buttons here are all of the form
styled.TextButton("..."){_=>}(style)
where
localStyle =
buttonStyle.copy(up=buttonStyle.up.copy(fg=white))
style =
localStyle.copy(
frame=
Decoration.Blurred(...)
))

Blurred(fg=blue, blur=10f, spread=5f)

Blurred(fg=blue, blur=10f, spread=10f)

Blurred(fg=blue, blur=20f, spread=10f)

style=buttonStyle.copy(frame=Decoration.Unframed)

This is an unframed button with an edge around it

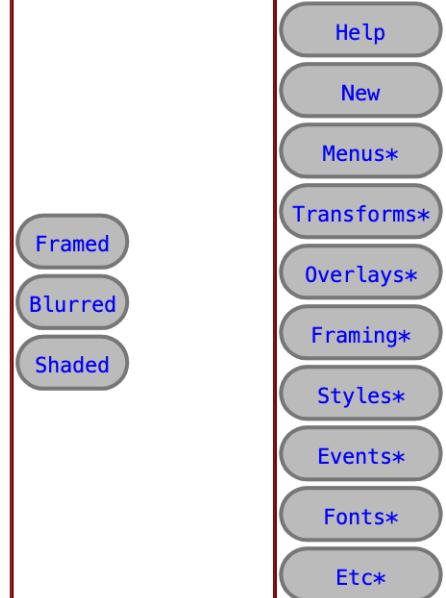


Figure 20: the Blurred subpage of Styles*

Mouse and keyboard events happening in the coloured frame below are shown in the log beneath it. The most recent event is also shown in the coloured frame.

Move events occur very frequently as the mouse traverses the frame, and successive Moves in a sequence are usually for physically close locations. Checking the box below suppresses the second and subsequent Move reports in such a sequence.

Shorten the log of Move sequences:

00031 GlyphLeave

```
00000 GlyphEnter [keyboard grabbed]
00001 Move@(166.02295,30.622742)
00002 Move@(173.02295,12.622742)
00003 GlyphLeave
00004 GlyphEnter [keyboard grabbed]
00005 Move@(192.02295,62.62274)
00006 Move@(188.02295,94.62274)
00007 GlyphLeave
00008 GlyphEnter [keyboard grabbed]
00009 Move@(650.02295,14.622742)
00010 GlyphLeave
You are now eliding adjacent move events
00011 GlyphEnter [keyboard grabbed]
00012 Move@(584.02295,45.62274)
00015 GlyphLeave
00016 GlyphEnter [keyboard grabbed]
00017 Move@(514.02295,75.62274)
00031 GlyphLeave
```

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Figure 21: the Events subpage of Events*

A grid of rotating buttons. Individual buttons are started/stopped by clicking on them; and can be started or stopped together with the Start all / Stop all toggle button. The speed of the last started/stopped button(s) can be adjusted with the Faster/Slower buttons.

Start all **Faster** **Slower**

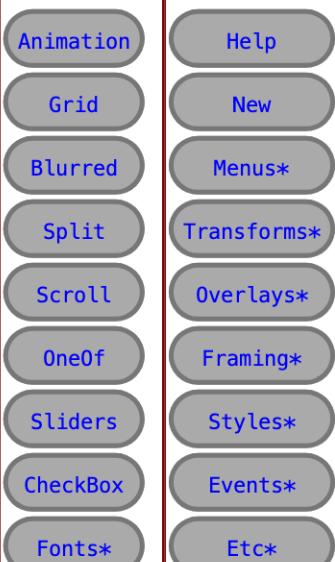
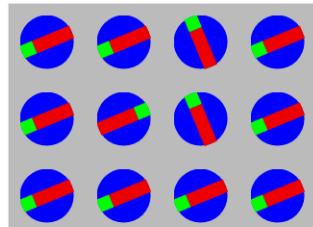


Figure 22: the Animation subpage of Etc* (mid-animation)

Rows/cols Cell sizes Glyph Placement

data = 8 blurred-frame buttons

.grid(width=5)(data) as rows

Button 1	Button 2	Button 3	Button 4	Button 5
Button 6	Button 7	Button 8		

.grid(width=4)(data) as rows

Button 1	Button 2	Button 3	Button 4
Button 5	Button 6	Button 7	Button 8

.grid(height=5)(data) as cols .grid(height=4)(data) as cols

Button 1	Button 6
Button 2	Button 7
Button 3	Button 8
Button 4	
Button 5	

Button 1	Button 5
Button 2	Button 6
Button 3	Button 7
Button 4	Button 8

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Figure 23: the Rows/cols subpage of Etc*.Grid

Rows/Cols	Cell sizes	Glyph Placement
<code>data = 9 variable sized labels. Grid(... padx=10, pady=10)</code>		
<code>.grid(width=3)(data) -- row data as uniform size cells</code>		
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>1000.scaled(1.0)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>.grid(height=3)(data) -- col data as uniform size cells</code>		
<code>1.scaled(0.8)</code>	<code>1.scaled(1.0)</code>	<code>1.scaled(1.5)</code>
<code>1000.scaled(0.8)</code>	<code>1000.scaled(1.0)</code>	<code>1000.scaled(1.5)</code>
<code>1000000.scaled(0.8)</code>	<code>1000000.scaled(1.0)</code>	<code>1000000.scaled(1.5)</code>
<code>.rows(width=3)(data) -- row data as uniform width rows</code>		
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>1000.scaled(1.0)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>.cols(height=3)(data) -- col data as uniform height rows</code>		
<code>1.scaled(0.8)</code>	<code>1.scaled(1.0)</code>	<code>1.scaled(1.5)</code>
<code>1000.scaled(0.8)</code>	<code>1000.scaled(1.0)</code>	<code>1000.scaled(1.5)</code>
<code>1000000.scaled(0.8)</code>	<code>1000000.scaled(1.0)</code>	<code>1000000.scaled(1.5)</code>
<code>.table(width=3)(data) -- row data as minimal width/height cols/rows</code>		
<code>1.scaled(0.8)</code>	<code>1000.scaled(0.8)</code>	<code>1000000.scaled(0.8)</code>
<code>1.scaled(1.0)</code>	<code>1000.scaled(1.0)</code>	<code>1000000.scaled(1.0)</code>
<code>1.scaled(1.5)</code>	<code>1000.scaled(1.5)</code>	<code>1000000.scaled(1.5)</code>
<code>.table(height=3)(data) -- col data as minimal width/height cols/rows</code>		
<code>1.scaled(0.8)</code>	<code>1.scaled(1.0)</code>	<code>1.scaled(1.5)</code>
<code>1000.scaled(0.8)</code>	<code>1000.scaled(1.0)</code>	<code>1000.scaled(1.5)</code>
<code>1000000.scaled(0.8)</code>	<code>1000000.scaled(1.0)</code>	<code>1000000.scaled(1.5)</code>

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Figure 24: the Cell Sizes subpage of Etc*.Grid

Rows/Cols
Cell sizes
Glyph Placement

`grid with data(4).fitToCell(...)` [Enlarge/ShiftNorth/ShiftWest/ShiftSouth/ShiftEast/Stretch]

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(Enlarge)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(ShiftNorth)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(ShiftWest)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(ShiftSouthEast)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(ShiftEast)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

1.scaled(0.8)	1000.scaled(0.8)	1000000.scaled(0.8)
1.scaled(1.0)	fitToCell(Stretch)	1000000.scaled(1.0)
1.scaled(1.5)	1000.scaled(1.5)	1000000.scaled(1.5)

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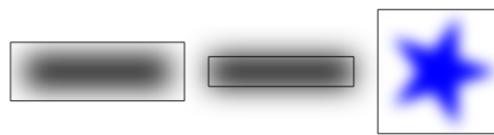
Fonts*

Figure 25: the Glyph Placement subpage of Etc*.Grid

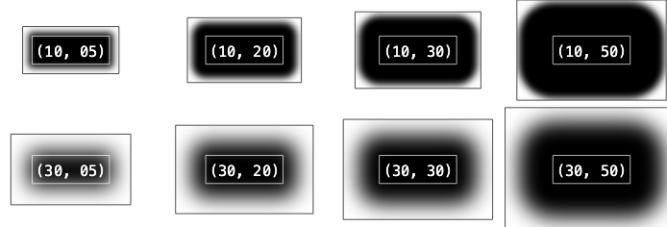
Painting filled material with a blurred brush leads to the paint coverage being enlarged by the blur of the brush

```
b30=black.blurred(30.00, 0.00, 0.00)
FilledRect(150, 30, fg=b30).enlargedBy(30f, 30f).framed()
FilledRect(150, 30, fg=b30).framed()

b15=blue.blurred(15.00, 0.00, 0.00)
filledStargon(5, fg=b15, C=64f, R=60f).framed()
```



BlurredFrame(blur, spread)(...)



BlurredFrame(blur, spread, -blur/2f, -blur)(...)

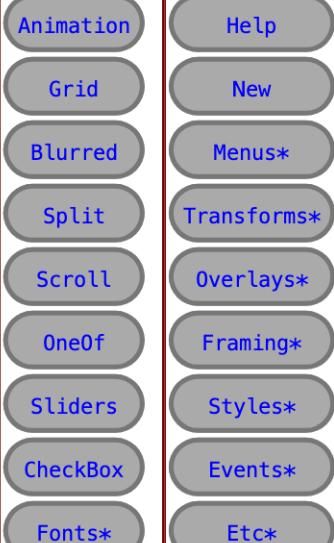
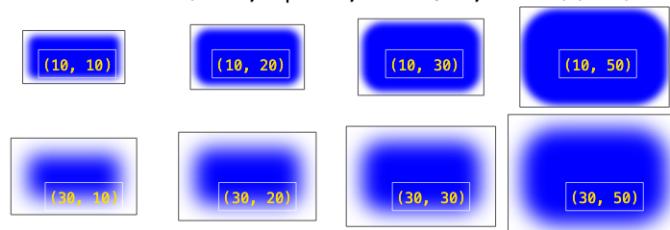


Figure 26: the Blurred subpage of Etc*

This is a test of the SplitScreen glyph. The test shows a pair of glyphs side by side, each of which contains some text and a reactive glyph. Here we have coupled the SplitScreen dynamically with a Slider.Horizontal that sets the boundary between the left and right glyphs, accompanied by three buttons that respectively move the boundary to the left, exchange left and right, and move the boundary to the right.

Notice how the reactivities respond when the cursor hovers over parts of them that are not visible, namely by giving up the focus if they happened to have it.

This is a justified text that may be quite small. You'll see it on a split screen. It'll be a bit wider than the other thing on the screen. When the text on the other screen is not the same width we'll see what happens.

The Left Button

The Right Button



Below we test the SplitScreen with a static size large enough to accomodate both glyphs. It was, incidentally, built from copies of the left and right glyphs that appear above; so also acts as a test for deep-copying of all the glyphs involved in their construction.

This is a justified piece of text that may be quite small. You'll see it on a split screen. When the text on the other screen is not the same width we'll see what happens.

The Left Button

This is a left-justified piece of text that may be quite small. You'll see it on a split screen. It'll be a bit wider than the other thing on the screen.

The Right Button



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Figure 27: the Split subpage of Etc*

Acknowledgements

This work would not have been possible were it not for the open source [Skia](#), [Skija](#), and [JWM](#) projects.

I am grateful to Sasha Walker*, for her patience in waiting for me to develop the initial working prototype of this library, and for her tolerance when listening to explanations of my implementation of the focus protocol.

Dominic Catizone* made a remark that helped me solve a problem with designing the geometry of (non-quadrant) rotations of bounding boxes.

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