COMP4075: Lecture 12 & 13

The Threepenny GUI Toolkit

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- A program written with Threepenny is a small web server that:
  - displays the UI as a web page
  - allows the HTML ***Document Object Model*** (DOM) to be manipulated
  - handles JavaScript events in Haskell
- Works by sending JavaScript code to the client.

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- Frequent communication between browser and server: Threepenny is best used running on localhost or over the local network.
- Written by Heinrich Apfelmus.

Rich API

- Full set of widgets (buttons, menus, etc.)
- Drag and Drop
- HTML elements
- Support for CSS
- Canvas for general drawing
- Functional Reactive Programming (FRP)

Conceptual Model

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- Build and manipulate a Document Object Model (DOM): a tree-structured element hierarchy representing the document displayed by the browser.
- Set up event handlers to act on events from the elements.
- Knowing a bit of HTML helps.

The UI Monad

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The *UI* Monad

Most work take place in the the ***User Interface*** monad UI:

- Wrapper around IO; keeps track of e.g. window context.
- Instance of MonadIO, meaning that any IO operation can be lifted into UI:

$$liftIO :: IO\ a \rightarrow UI\ a$$

The Browser *Window*

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- It has an attribute $title$ that may be written:

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- Retrieving the current window context:

$$askWindow :: UI\ Window$$

- Window passed to GUI code when server started:

$$startGUI :: Config \to (Window \to UI\ ()) \to IO\ ()$$

Elements

DOM made up of elements:

$$mkElement :: String \rightarrow UI\ Element$$

An element ***created*** when action run. Argument is an HTML elemen name: `"div"`, `"h1"`, `"p"`, etc.

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Standard elements predefined:

$$\begin{aligned} div &:: UI\ Element \\ h1 &:: UI\ Element \\ br &:: UI\ Element \\ button &:: UI\ Element \end{aligned}$$

Attributes (1)

Elements and other entities like windows have attributes that can be read and written:

$$\textbf{type}\ Attr\ x\ a = ReadWriteAttr\ x\ a\ a$$
$$\textbf{type}\ WriteAttr\ x\ i = ReadWriteAttr\ x\ i\ ()$$
$$\textbf{type}\ ReadAttr\ x\ o = ReadWriteAttr\ x\ ()\ o$$
$$set :: ReadWriteAttr\ x\ i\ o \to i \to UI\ x \to UI\ x$$
$$get :: ReadWriteAttr\ x\ i\ o \to x \to UI\ o$$

$ReadWriteAttr$, $WriteAttr$ etc. are records of functions for attribute reading and/or writing.

set and get work for any type of entity.

Attributes (2)

Sample attributes:

$$title :: WriteAttr\ Window\ String$$

$$color :: WriteAttr\ Element\ String$$

$$children :: WriteAttr\ Element\ [Element]$$

$$value :: Attr\ Element\ String$$

$$(\#+) :: UI\ Element \to [UI\ Element] \to UI\ Element$$

$$(\#.) :: UI\ Element \to String \to UI\ Element$$

$(\#+)$ appends children to a DOM element.
$(\#.)$ sets the CSS class.

Attributes (3)

Example usage ($(\#)$ is reverse function application):

$$
\begin{array}{l}
\mathit{mkElement}\ \texttt{"div"} \\
\quad \#\ \mathit{set}\ \mathit{style} \quad [(\texttt{"color"}, \texttt{"\#CCAABB"})] \\
\quad \#\ \mathit{set}\ \mathit{draggable}\ \mathit{True} \\
\quad \#\ \mathit{set}\ \mathit{children}\ \mathit{otherElements}
\end{array}
$$

Events (1)

- The type $Event\ a$ represents streams of time-stamped events carrying values of type a.

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- Semantically: $Event\ a \approx [(Time, a)]$
- $Event$ is an instance of $Functor$.
- $Event$ is ***not*** an instance of $Applicative$. The type for $<\!\!*\!\!>$ would be

$$Event\ (a \to b) \to Event\ a \to Event\ b$$

However, this makes no sense as event streams in general are not synchronised.

Events (2)

Most events originate from UI elements; e.g.:

- $valueChange :: Element \rightarrow Event\ String$
- $click :: Element \rightarrow Event\ ()$
- $mousemove :: Element \rightarrow Event\ (Int, Int)$ (coordinates relative to the element)
- $hover :: Element \rightarrow Event\ ()$
- $focus :: Element \rightarrow Event\ ()$
- $keypress :: Element \rightarrow Event\ Char$

Events (3)

One or more handlers can be registered for events:

$$register :: Event\ a \rightarrow Handler\ a \rightarrow IO\ (IO\ ())$$

The resulting action is intended for deregistering a handler; future functionality.

Events (4)

Usually, registration is done using convenience functions designed for use directly with elements and in the UI monad:

$$on :: (element \to Event\ a)$$
$$\to element \to (a \to UI\ void) \to UI\ ()$$

For example:

$$\mathbf{do}$$
$$\ldots$$
$$on\ click\ element\ \$\ \lambda\_ \to \ldots$$
$$\ldots$$

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Behaviors (1)

- The type $Behavior\ a$ represents continuously time-varying values of type a.
- Semantically: $Behavior\ a \approx Time \rightarrow a$
- $Behavior$ is an instance of $Functor$ ***and*** $Applicative$.
- Recall that events are not an applicative. However, the following provides similar functionality:

$$
\begin{aligned}
(\langle @ \rangle) :: Behavior\ (a \rightarrow b) \\
\rightarrow Event\ a \rightarrow Event\ b
\end{aligned}
$$

Behaviors (2)

- Attributes can be set to time-varying values:

$$
\begin{aligned}
sink :: {} & \mathit{ReadWriteAttr}\ x\ i\ o \\
& \rightarrow \mathit{Behavior}\ i \rightarrow \mathit{UI}\ x \rightarrow \mathit{UI}\ x
\end{aligned}
$$

Behaviors (2)

- Attributes can be set to time-varying values:

$$sink :: ReadWriteAttr\ x\ i\ o \to Behavior\ i \to UI\ x \to UI\ x$$

- There is also:

$$onChanges :: Behavior\ a \to (a \to UI\ void) \to UI\ ()$$

But conceptually questionable as a behavior in general is ***always*** changing.

FRP (1)

Threepenny offers support for Functional Reactive Programming (FRP): transforming and composing behaviours and events as “whole values”.

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For example:

- $\mathit{filterJust} :: \mathit{Event}\ (\mathit{Maybe}\ a) \to \mathit{Event}\ a$
- $\mathit{unionWith} :: (a \to a \to a)$
  $\to \mathit{Event}\ a \to \mathit{Event}\ a \to \mathit{Event}\ a$
- $\mathit{unions} :: [\mathit{Event}\ a] \to \mathit{Event}\ [a]$
- $\mathit{split} :: \mathit{Event}\ (\mathit{Either}\ a\ b) \to (\mathit{Event}\ a, \mathit{Event}\ b)$

FRP (2)

- $accumE :: MonadIO\ m \Rightarrow a \rightarrow Event\ (a \rightarrow a) \rightarrow m\ (Event\ a)$
- $accumB :: MonadIO\ m \Rightarrow a \rightarrow Event\ (a \rightarrow a) \rightarrow m\ (Behavior\ a)$
- $stepper :: MonadIO\ m \Rightarrow a \rightarrow Event\ a \rightarrow m\ (Behavior\ a)$
- $(\lessdot@\gtrdot) :: Behavior\ (a \rightarrow b) \rightarrow Event\ a \rightarrow Event\ b$

FRP (2)

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- $stepper :: MonadIO\ m \Rightarrow a \rightarrow Event\ a \rightarrow m\ (Behavior\ a)$
- $(\lt @ \gt) :: Behavior\ (a \rightarrow b) \rightarrow Event\ a \rightarrow Event\ b$

Note: Stateful events and behaviors are returned as monadic computations.

Hello World (1)

A simple “Hello World” example:

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- Display a button

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- Display a button
- Change its text when clicked

Hello World (1)

A simple “Hello World” example:

- Display a button
- Change its text when clicked

First import the module. Large API, so partly qualified import recommended:

```haskell
module Main where

import qualified Graphics.UI.Threepenny as UI
import           Graphics.UI.Threepenny.Core
```

Hello World (2)

The $startGUI$ function starts a server:

$$startGUI :: Config \rightarrow (Window \rightarrow UI\ ()) \rightarrow IO\ ()$$

- $Config$-records carry configuartion parameters.
- $Window$ represents a browser window.
- The function $Window \rightarrow UI\ ()$ is called whenever a browser connects to the server and builds the initial HTML page.

Hello World (3)

Start a server listening on port 8023;
static content served from `../wwwroot`:

$$
\begin{aligned}
&main :: IO\ ()\\
&main = \mathbf{do}\\
&\quad startGUI\\
&\qquad defaultConfig\\
&\qquad\quad \{jsPort \quad = Just\ 8023,\\
&\qquad\quad\ \ jsStatic = Just\ \texttt{"../wwwroot"}\}\\
&\qquad setup
\end{aligned}
$$

Hello World (4)

Start by setting the window title:

$$setup :: Window \to UI\ ()$$
$$setup\ window = \mathbf{do}$$
$$\quad return\ window\ \#\ set\ UI.title\ \texttt{"Hello World!"}$$

Reversed function application: $(\#) :: a \to (a \to b) \to b$

set has type:

$$set :: ReadWriteAttr\ x\ i\ o \to i \to UI\ x \to UI\ x$$

The window reference is a pure value, passed in, hence the need to lift it into a UI computation using $return$.

Hello World (5)

Then create a button element:

$$button \leftarrow UI.button \mathbin{\#} set\ UI.text\ \texttt{"Click me!"}$$

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$$button \leftarrow UI.button \# set\ UI.text$$ `"Click me!"`

Note that $UI.button$ has type:

$$UI.button :: UI\ Element$$

A new button is is ***created*** whenever that action is run.

Hello World (5)

Then create a button element:

$$button \leftarrow UI.button \# set\ UI.text\ \texttt{"Click me!"}$$

Note that $UI.button$ has type:

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A new button is is ***created*** whenever that action is run.

DOM elements can be accessed much like in JavaScript: searched, updated, moved, inspected.

Hello World (6)

To display the button, it must be attached to the DOM:

$$getBody\ window\ \#{+}\ [element\ button]$$

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The combinator $(\#{+})$ appends DOM elements as children to a given element:

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Hello World (6)

To display the button, it must be attached to the DOM:

$$getBody\ window \#\!+ [element\ button]$$

The combinator $(\#\!+)$ appends DOM elements as children to a given element:

$$(\#\!+) :: UI\ Element \rightarrow [UI\ Element] \rightarrow UI\ Element$$

$getBody$ gets the body DOM element:

$$getBody :: Window \rightarrow UI\ Element$$

Here, $element$ is just $return$.

Hello World (7)

Finally, register an event handler for the click event to change the text of the button:

$$on\ UI.click\ button\ \$\ const\ \$\ \mathbf{do}$$
$$\quad element\ button$$
$$\qquad \#\ set\ UI.text\ \texttt{"I have been clicked!"}$$

Types:

$$on :: (element \rightarrow Event\ a) \rightarrow element$$
$$\qquad \rightarrow (a \rightarrow UI\ void) \rightarrow UI\ ()$$
$$UI.click :: Element \rightarrow Event\ ()$$

Buttons (1)

$$mkButton :: String \rightarrow UI\ (Element, Element)$$
$$mkButton\ title = \mathbf{do}$$
$$\quad button \leftarrow UI.button\ \#.\ \texttt{"button"}\ \#+\ [string\ title]$$
$$\quad view \leftarrow UI.p\ \#+\ [element\ button]$$
$$\quad return\ (button, view)$$
$$mkButtons :: UI\ [Element]$$
$$mkButtons = \mathbf{do}$$
$$\quad list \leftarrow UI.ul\ \#.\ \texttt{"buttons-list"}$$
$$\quad \ldots$$

Buttons (2)

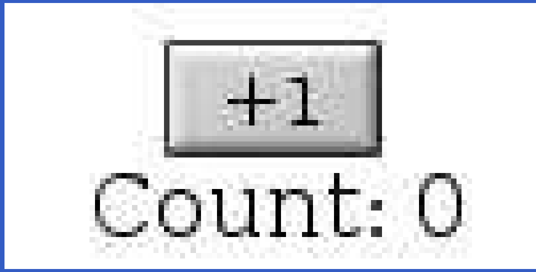
```
(button1, view1) ← mkButton button1Title
on UI.hover button1 $ \_ → do
  element button1 # set text (button1Title ++ " [hover]")
on UI.leave button1 $ \_ → do
  element button1 # set text button1Title
on UI.click button1 $ \_ → do
  element button1 # set text (button1Title ++ " [pressed]"
  liftIO $ threadDelay $ 1000 * 1000 * 1
  element list
    #+ [UI.li # set html "<b>Delayed</b> result!"]
```

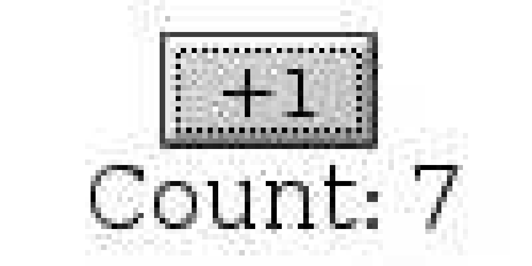
Buttons (3)

```haskell
(button2, view2) <- mkButton button2Title
on UI.hover button2 $ \_ -> do
    element button2 # set text (button2Title ++ " [hover]")
on UI.leave button2 $ \_ -> do
    element button2 # set text button2Title
on UI.click button2 $ \_ -> do
    element button2 # set text (button2Title ++ " [pressed]"
    element list
        #+ [UI.li # set html "Zap! Quick result!"]
return [list, view1, view2]
```

Counter Example 1 (1)

Simple counter, basic imperative style.





Idea:

- Keep the count in an imperative variable
- The click event handler increments the counter and updates the display accordingly.

Counter Example 1 (2)

```
setup :: Window -> UI ()
setup window = do
  return window
    # set UI.title "Counter Example 1"
  let initCount = 0
  counter <- liftIO $ newIORef initCount
  button  <- UI.button # set UI.text "+1"
  label   <- UI.label # set UI.text
                          ("Count: " ++
                           show initCount)
```

Counter Example 1 (3)

$$
\begin{array}{l}
\mathit{getBody}\ \mathit{window}\ \#+\ [\mathit{UI}.\mathit{center} \\
\qquad\qquad\qquad\qquad\qquad \#+\ [\mathit{element}\ \mathit{button}, \\
\qquad\qquad\qquad\qquad\qquad\quad\ \ \mathit{UI}.\mathit{br}, \\
\qquad\qquad\qquad\qquad\qquad\quad\ \ \mathit{element}\ \mathit{label}]] \\
\mathit{on}\ \mathit{UI}.\mathit{click}\ \mathit{button}\ \$\ \mathit{const}\ \$\ \mathbf{do} \\
\quad \mathit{count} \leftarrow \mathit{liftIO}\ \$\ \mathbf{do} \\
\qquad \mathit{modifyIORef}\ \mathit{counter}\ (+1) \\
\qquad \mathit{readIORef}\ \mathit{counter} \\
\quad \mathit{element}\ \mathit{label}\ \#\ \mathit{set}\ \mathit{UI}.\mathit{text}\ (\texttt{"Count: "} +\!\!+ \\
\qquad\qquad\qquad\qquad\qquad\qquad\quad \mathit{show}\ \mathit{count})
\end{array}
$$

Counter Example 2 (1)

Counter with reset, “object-oriented” style.

Idea:

- Make a counter object with encapsulated state and two operations: reset and increment.
- Make a display object with a method for displaying a value.

Counter Example 2 (2)

Make a counter object:

$$
\begin{aligned}
&mkCounter :: Int \rightarrow UI\ (UI\ Int, UI\ Int)\\
&mkCounter\ initCount = \mathbf{do}\\
&\quad counter \leftarrow liftIO \$ newIORef\ initCount\\
&\quad \mathbf{let}\ reset = liftIO \$ writeIORef\ counter\ initCount\\
&\qquad\qquad\qquad\qquad \gg return\ initCount\\
&\qquad\quad incr\ \ = liftIO \$ modifyIORef\ counter\ (+1)\\
&\qquad\qquad\qquad\qquad \gg readIORef\ counter\\
&\quad return\ (reset, incr)
\end{aligned}
$$

Counter Example 2 (3)

Make a display object:

$$
\begin{aligned}
&\mathit{mkDisplay} :: \mathit{Int} \to \mathit{UI}\ (\mathit{Element}, \mathit{Int} \to \mathit{UI}\ ())\\
&\mathit{mkDisplay}\ \mathit{initCount} = \mathbf{do}\\
&\quad \mathbf{let}\ \mathit{showCount}\ \mathit{count} =\\
&\qquad\qquad \texttt{"Count: "} +\!\!+\ \mathit{show}\ \mathit{count}\\
&\quad \mathit{display} \leftarrow \mathit{UI.label}\ \#\ \mathit{set}\ \mathit{UI.text}\\
&\qquad\qquad\qquad\qquad\qquad (\mathit{showCount}\ \mathit{initCount})\\
&\quad \mathbf{let}\ \mathit{dispCount}\ \mathit{count} =\\
&\qquad\qquad ()\ {<}\$\ \mathit{element}\ \mathit{display}\\
&\qquad\qquad\qquad\qquad \#\ \mathit{set}\ \mathit{UI.text}\ (\mathit{showCount}\ \mathit{count})\\
&\quad \mathit{return}\ (\mathit{display}, \mathit{dispCount})
\end{aligned}
$$

Counter Example 2 (4)

$$setup :: Window \to UI\ ()$$

$$setup\ window = \mathbf{do}$$

$$\quad return\ window$$

$$\qquad \#\ set\ UI.title\ \texttt{"Counter Example 2"}$$

$$\quad \mathbf{let}\ initCount = 0$$

$$\quad (reset, incr) \leftarrow mkCounter\ initCount$$

$$\quad (display, dispCount) \leftarrow mkDisplay\ initCount$$

$$\quad buttonRst \leftarrow UI.button\ \#\ set\ UI.text\ \texttt{"RST"}$$

$$\quad buttonInc \leftarrow UI.button\ \#\ set\ UI.text\ \texttt{"+1"}$$

Counter Example 2 (5)

$$
\begin{aligned}
&getBody\ window \\
&\quad \#\!+ [\, UI.center \#\!+ [\, element\ buttonRst, \\
&\qquad\qquad\qquad\qquad\quad element\ buttonInc, \\
&\qquad\qquad\qquad\qquad\quad UI.br, \\
&\qquad\qquad\qquad\qquad\quad element\ display]] \\
&on\ UI.click\ buttonRst \mathbin{\$} const \mathbin{\$} reset \ggg dispCount \\
&on\ UI.click\ buttonInc \mathbin{\$} const \mathbin{\$} incr \ggg dispCount
\end{aligned}
$$

Counter Example 3 (1)

Counter with reset, FRP style.

Idea:

- Accumulate the button clicks into a ***time-varying*** count; i.e., a $Behavior\ Int$.
- Make the text attribute of the display a time-varying text directly derived from the count; i.e., a $Behavior\ String$.

Counter Example 3 (2)

$$
\begin{array}{l}
setup :: Window \rightarrow UI\ () \\
setup\ window = \textbf{do} \\
\quad return\ window \\
\qquad \#\ set\ UI.title\ \texttt{"Counter Example 3"} \\
\quad \textbf{let}\ initCount = 0 \\
\quad buttonRst \leftarrow UI.button\ \#\ set\ UI.text\ \texttt{"RST"} \\
\quad buttonInc \leftarrow UI.button\ \#\ set\ UI.text\ \texttt{"+1"} \\
\quad \textbf{let}\ reset \quad = (const\ 0)\ \ <\$\ UI.click\ buttonRst \\
\quad \textbf{let}\ incr \quad = (+1) \qquad\ \ <\$\ UI.click\ buttonInc
\end{array}
$$

Note: $Event$ and $Behavior$ are instances of $Functor$.

Counter Example 3 (3)

$$
\begin{aligned}
count &\leftarrow accumB\ 0\ \$\ unionWith\ const\ reset\ incr \\
display &\leftarrow UI.label \\
&\qquad \#\ sink\ UI.text \\
&\qquad\qquad (fmap\ showCount\ count)
\end{aligned}
$$

Type signatures:

$$
\begin{aligned}
&accumB :: MonadIO\ m \Rightarrow \\
&\qquad a \rightarrow Event\ (a \rightarrow a) \rightarrow m\ (Behavior\ a) \\
&unionWith :: (a \rightarrow a \rightarrow a) \\
&\qquad \rightarrow Event\ a \rightarrow Event\ a \rightarrow Event\ a \\
&sink :: ReadWriteAttr\ x\ i\ o \\
&\qquad \rightarrow Behavior\ i \rightarrow UI\ x \rightarrow UI\ x
\end{aligned}
$$

Counter Example 3 (4)

$$
\begin{aligned}
&\mathit{getBody}\ \mathit{window} \\
&\quad \#\!+ [\,\mathit{UI}.\mathit{center}\ \#\!+ [\,\mathit{element}\ \mathit{buttonRst}, \\
&\qquad\qquad\qquad\qquad\qquad \mathit{element}\ \mathit{buttonInc}, \\
&\qquad\qquad\qquad\qquad\qquad \mathit{UI}.\mathit{br}, \\
&\qquad\qquad\qquad\qquad\qquad \mathit{element}\ \mathit{display}\,]\,]
\end{aligned}
$$

Counter Example 3 (4)

$$\begin{aligned}&getBody\ window\\&\quad \#+ [UI.center \#+ [element\ buttonRst,\\&\qquad\qquad\qquad\qquad element\ buttonInc,\\&\qquad\qquad\qquad\qquad UI.br,\\&\qquad\qquad\qquad\qquad element\ display]]\end{aligned}$$

- No callbacks.

Counter Example 3 (4)

$$
\begin{aligned}
&getBody\ window \\
&\quad \#{+}\ [UI.center\ \#{+}\ [element\ buttonRst, \\
&\qquad\qquad\qquad\qquad\qquad element\ buttonInc, \\
&\qquad\qquad\qquad\qquad\qquad UI.br, \\
&\qquad\qquad\qquad\qquad\qquad element\ display]]
\end{aligned}
$$

- No callbacks.
- Thus no “callback soup” or “callback hell”!

Counter Example 3 (4)

$$
\begin{aligned}
&getBody\ window\\
&\quad \#+ [UI.center \#+ [element\ buttonRst,\\
&\qquad\qquad\qquad\qquad\qquad element\ buttonInc,\\
&\qquad\qquad\qquad\qquad\qquad UI.br,\\
&\qquad\qquad\qquad\qquad\qquad element\ display]]
\end{aligned}
$$

- No callbacks.
- Thus no “callback soup” or “callback hell”!
- Fairly declarative description of system: ***Whole-value Programming***.

Counter Example 3 (4)

$$\begin{aligned}&getBody\ window\\&\quad \#+ [UI.center \#+ [element\ buttonRst,\\&\qquad\qquad\qquad\qquad element\ buttonInc,\\&\qquad\qquad\qquad\qquad UI.br,\\&\qquad\qquad\qquad\qquad element\ display]]\end{aligned}$$

- No callbacks.
- Thus no “callback soup” or “callback hell”!
- Fairly declarative description of system: ***Whole-value Programming***.
- This style of programming has had significant impact on programming practice well beyond FP.

Currency Converter (1)

```
return window # set title "Currency Converter"
dollar ← UI.input
euro ← UI.input
getBody window #+ [
  column [
    grid [[string "Dollar:", element dollar]
         ,[string "Euro:", element euro]]
  , string "Amounts update while typing."
  ]]
```

Currency Converter (2)

```
euroIn ← stepper "0" $ UI.valueChange euro
dollarIn ← stepper "0" $ UI.valueChange dollar
let
  rate = 0.7 :: Double
  withString f =
      maybe "-" (printf "%.2f") ∘ fmap f ∘ readMay
  dollarOut = withString (/rate) <$> euroIn
  euroOut = withString (*rate) <$> dollarIn
element euro # sink value euroOut
element dollar # sink value dollarOut
```

Reading

- Overview, including references to tutorials and examples:
  `http://wiki.haskell.org/Threepenny-gui`
- API reference:
  `http://hackage.haskell.org/package/threepenny-gui`