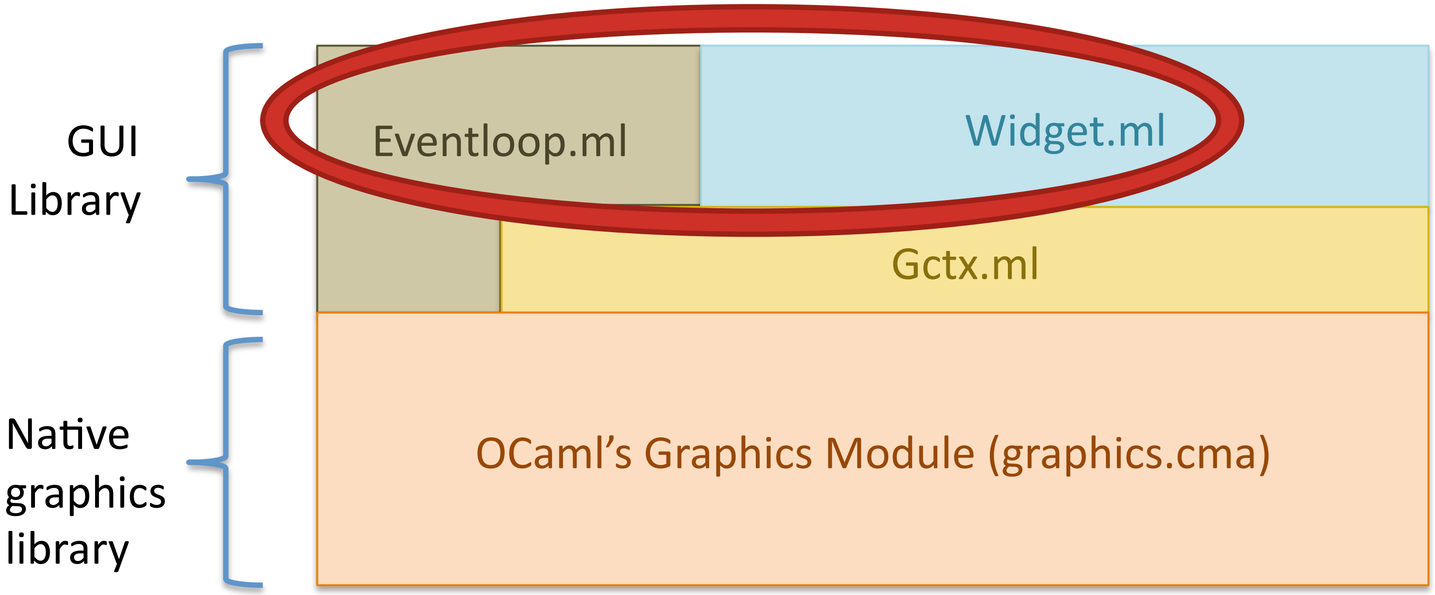
Programming Languages and Techniques (CIS120)

Lecture 18

Feb. 24, 2012

GUI Design III: Events & Listeners

GUI Library Architecture



Design Challenge #2: User Interactions

- Problem: When a user moves the mouse, clicks the button, or presses a key, the GUI should react.

swdemo.ml

```
let w = …   (* top-level widget *)

let run () :unit =
    (* open the window *)
    Graphics.open_graph "";
    let g = Gctx.create () in
    (* draw the widget *)
    w.repaint g;
    (* infinite loop so we can see the window. *)
    let rec loop () : unit = loop () in
    loop ()
```

Solution: The Event Loop

eventloop.ml

```
let run (w:Widget.t) : unit =
  Graphics.open_graph "";
  Graphics.auto_synchronize false;
  let g = Gctx.create() in

  let rec loop () =
    Graphics.clear_graph ();
    w.Widget.repaint g;
    Graphics.synchronize ();
    let e = Gctx.wait_for_event g in      (* wait for user input *)
      w.Widget.handle g e; loop ()         (* react to it *)
  in
    loop ()
```

Note: when accessing record components from another module that hasn't been opened, the module name is part of the component name. e.g "w.repaint" vs "w.Widget.repaint"

- The run function takes in the "root widget", creates the graphics window, initializes the graphics context, and then enters an infinite loop.
- The loop clears the window, repaints it, waits for a user event, and then asks the root widget to handle that event.

Events and Event Handling

- An *event* is a signal
  - e.g. a mouse click or release, mouse motion, or keypress
- Events carry data
  - e.g. state of the mouse button, the coordinates of the mouse, the key pressed
- An event can be *handled* by some widget
  - The top-level loop waits for an event and then gives it to the root widget.
  - The widgets forward the event down the tree until some widget handles the event (or no suitable widget is found, in which case the event is just dropped)
  - e.g. a button handles a mouse click event
- Typically, the widget that handles an event *updates some state* of the GUI
  - e.g. to record whether the light is on and change the label of the button
- User sees the reaction to the event when the GUI repaint itself
  - e.g. button has new label, canvas is a new color

Reactive Widgets

Graphics library

```
type status = {
  mouse_x : int;      (* X coordinate of the mouse *)
  mouse_y : int;      (* Y coordinate of the mouse *)
  button : bool;      (* true if a mouse button is pressed *)
  keypressed : bool;  (* true if a key has been pressed *)
  key : char;         (* the character for the key pressed *)
}
```

widget.mli

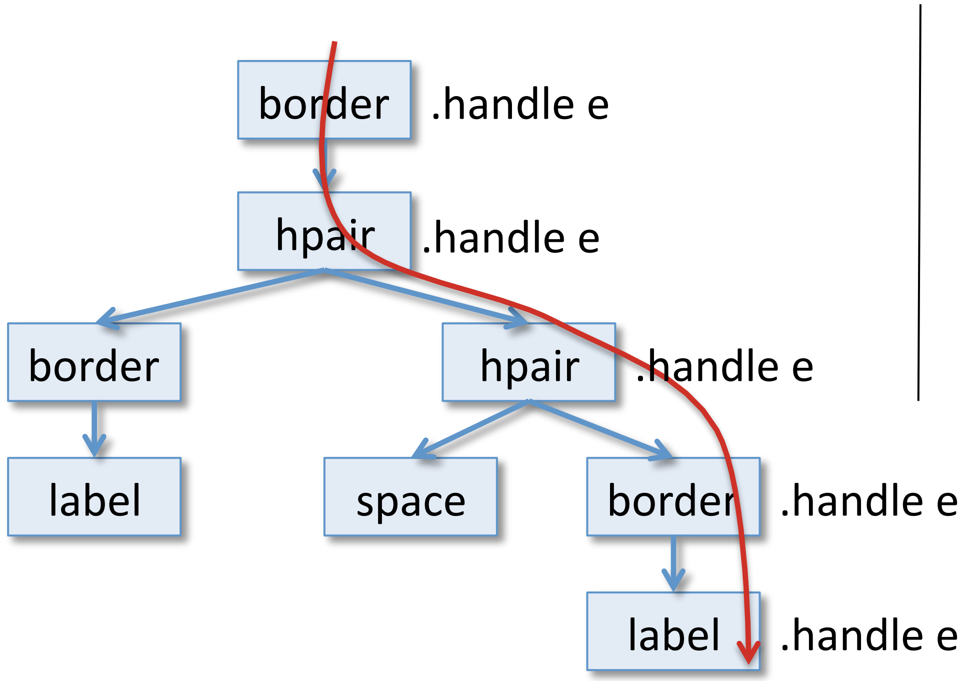
```
type event = Graphics.status

type t = {
  repaint : Gctx.t -> unit;
  size    : Gctx.t -> Gctx.dimension;
  handle  : Gctx.t -> event -> unit     (* NEW! *)
}
```

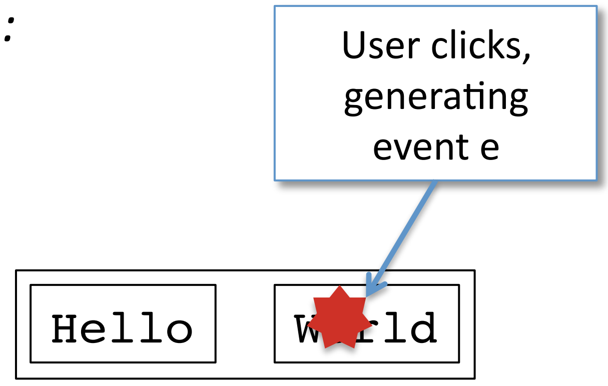
The graphics context translates the location of the event to widget-local coordinates

Event-handling: Containers

Container widgets propagate events to their children:



Widget tree



On the screen

Event Handling: Routing

- When a container widget handles an event, it passes the event to the appropriate child
- The Gctx.t must be translated so the child can interpret the event in its own local coordinates.

widget.ml

```
let border (w:t):t =
  { repaint = …;
    size = …;
    handle = (fun (g:Gctx.t) (e:Gctx.event) ->
       w.handle (Gctx.translate g (2,2)) e);
  }
```

Routing events through hpair widgets

- The event handler of an hpair must check to see whether the event should be handled by the left or right widget.
  - Check the event's coordinates against the *size* of the left widget
  - If the event is within the left widget, let it handle the event
  - Otherwise check the event's coordinates against the right child's
  - If the right child gets the event, don't forget to translate its coordinates

```
handle =
(fun (g:Gctx.t) (e:Gctx.event) ->
   if event_within g e (w1.size g)
   then w1.handle g e
   else
   let g = (Gctx.translate g (fst (w1.size g), 0)) in
     if event_within g e (w2.size g)
     then w2.handle g e
     else ());
```

Stateful Widgets

What state do the event handlers modify?

How can widgets expose extra this state to the application?

A stateful `label` Widget

```
let label (s: string) : t =
  let r = ref s in
     { repaint =
        (fun (g: Gctx.t) -> Gctx.draw_string g (0,0) !r);
      handle = (fun _ _ -> ());
      size = (fun (g: Gctx.t) -> Gctx.text_size g !r)
    }
```

- The label “object” can make its string mutable. The three “methods” can encapsulate that string.
- But what if the application wants to change this string in response to an event?

A stateful `label` Widget

widget.ml

```
type label_controller = { set_label: string -> unit }

let label (s: string) : t * label_controller =
  let r = ref s in
    ({ repaint =
        (fun (g: Gctx.t) -> Gctx.draw_string g (0,0) !r);
      handle = (fun _ _ -> ());
      size = (fun (g: Gctx.t) -> Gctx.text_size g !r)
    },
    { set_label = fun (s: string) -> r := s })
```

- A *controller* object gives access to the state.
  - e.g. the `label_controller` object provides a way to set the label
- Each kind of stateful widget gets its own kind of controller
  - As we'll see, Java's subtyping helps manage this complexity

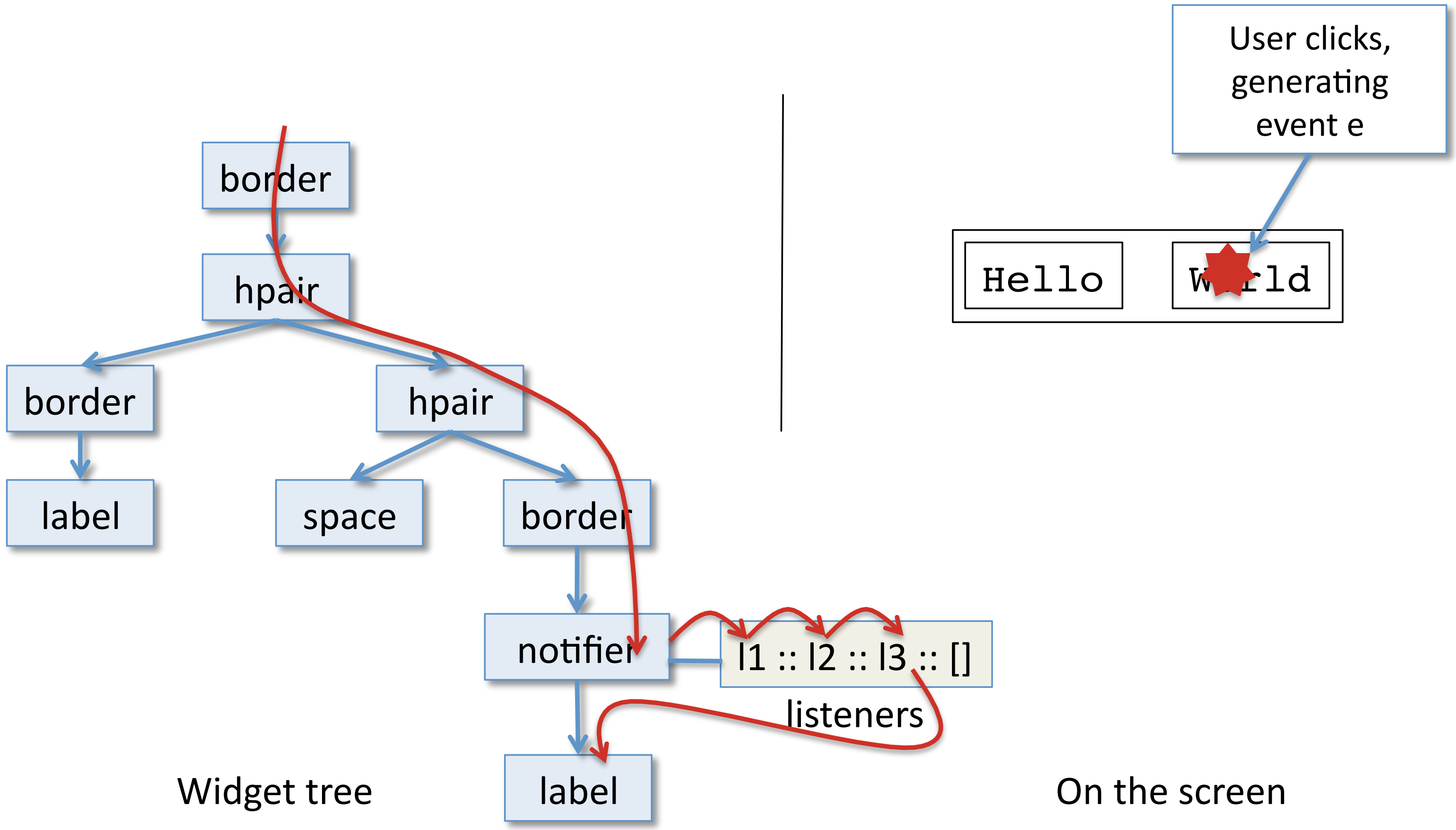
Event Listeners

How to react to events in a modular way?

Event Listeners

- Widgets may want to react to many different sorts of events
- Example: Button
  - button click: changes the state of the paint program and button label
  - mouse movement: tooltip? highlight?
  - key press: provide keyboard access to the button functionality?
- Want these reactions to be independent of each other
  - Each sort of event handled by a different *event listener* (i.e. a first-class function)
  - Reactive widgets may have *several* listeners to handle a triggered event
  - Listeners react in sequence, earlier ones may prevent the event from propagating
- A *notifier* is a container widget that adds event listeners to a node in the widget hierarchy
- Note: this way of structuring event listeners is based on Java's Swing Library design
  - We adopt the terminology from Swing.

Listeners and Notifiers Pictorially



Notifiers

- A *notifier* is a container widget that adds event listeners to a node in the widget hierarchy

- The *event listeners* “eavesdrop” on the events flowing through the node
  - The event listeners are stored in a list
  - They react in order, if one of them handles the event the later ones do not hear it
  - If none of the listeners handle the event, then the event continues to the child widget

- List of event listeners can be updated by using a notifier_controller

Listeners

widget.ml

```
type listener_result =
   | EventFinished
   | EventNotDone

type listener = Gctx.t -> Gctx.event -> listener_result

(* Performs an action upon receiving a mouse click. *)
let mouseclick_listener (action: unit -> unit) : listener =
  fun (g:Gctx.t) (e: Gctx.event) ->
    if Gctx.button_pressed g e
    then (action (); EventFinished)
    else EventNotDone
```

- A listener returns EventFinished if it handled the event (i.e. the event should not be passed on) and EventNotDone otherwise.
- A mouseclick_listener performs an action and stops the event when it “hears” a mouse click, and passes on the event to later listeners otherwise

Notifiers and Notifier Controllers

widget.ml

```
type notifier_controller = { add_listener: listener -> unit }

let notifier (w: t) : t * notifier_controller =
  let listeners = ref [] in
   ({repaint = w.repaint;
     handle = (fun (g:Gctx.t) (e: Gctx.event) ->
       let rec loop (l: listener list) : unit =
         begin match l with
         | [] -> w.handle g e
         | h::t -> begin match h g e with
                   | EventFinished -> ()
                   | EventNotDone -> loop t
                   end
         end in
         loop !listeners);
      size = w.size
    },
    { add_listener =
      fun newl -> listeners := newl::!listeners }
```

Loop through the list of listeners, allowing each one to process the event. If they all pass on the event, send it to the child.

The controller allows new listeners to be added to the list.

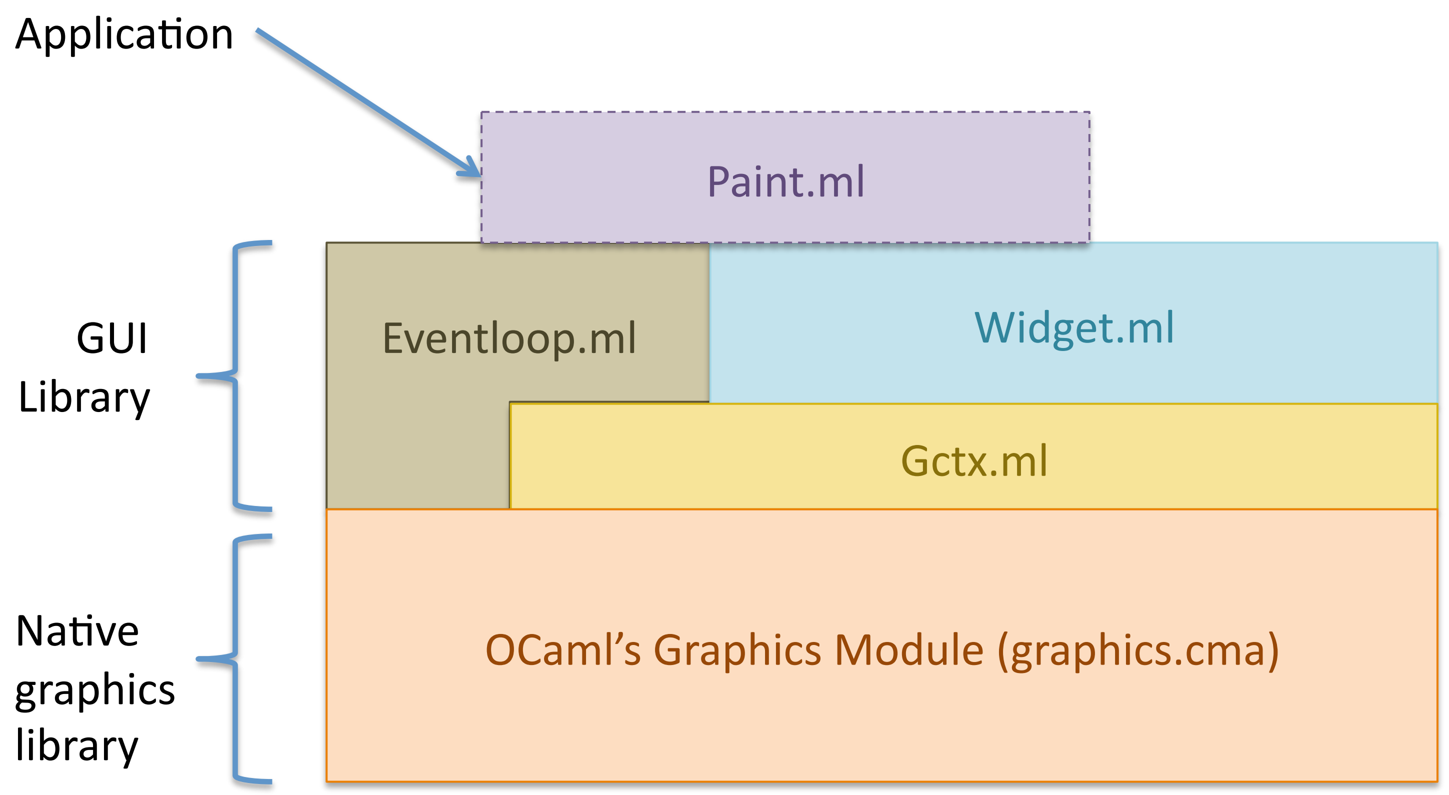
Buttons (at last!)

widget.ml

```
(* A text button *)
let button (s: string) : t * label_controller *
                         notifier_controller =
  let (w, lc)  = label s in
  let (w', nc) = notifier w in
  (w', lc, nc)
```

- A button widget is just a label wrapped in a notifier
- Add a mouseclick_listener to the button using the notifier_controller
- (For aesthetic purposes, you can but a border around the button after the fact.)

GUI Program Architecture



Demo: lightswitch.ml

Putting it all together.