Model-View-Controller Architecture

CS 5010 Program Design Paradigms
"Bootcamp"
Lesson 11.3

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In general, our simulations have 3 parts

- A Model (something being simulated)
- A View (a way to display some of the information in model)
- A Controller (a way to provide inputs to the model, often based on the view)

Helpful to separate these

- Each part may be complicated (separation of concerns)
- Model shouldn't care about how it is displayed
- May have several viewers and controllers
- Model and viewer may be running at different rates
- Clarify interface between controller and model.

Example: multiple viewers

- Imagine: some temperature is being monitored/modelled/controlled
- Multiple viewers:
  - display in Celsius
  - display in Fahrenheit
  - display on a slider
- May want to change/add viewers dynamically

Larger Example: Nuclear Reactor

- The reactor has many valves, sensors, etc.
- Unlike our screensavers, balls, etc. there's no single object to display.
- Best we can do is to have a viewer for each sensor and a controller for each valve.
- People add new sensors and new valves all the time.
- How can we model this?

Smaller example: Flight simulator

- Model: at each instant, calculates new state of the airplane (airspeed, altitude, attitude, etc., based on current airspeed, etc., and position of control surfaces
- View #1: digital airspeed indicator
- View #2: analog (dial) airspeed indicator
- Controller #1: pilot controls (arrow keys)
- Controller #2: copilot controls (mouse)

Our current architecture has these all mixed together

- Every Widget<%> or SWidget<%> is responsible for all 3 aspects:
  - on-tick (Model)
  - add-to-scene (View)
  - on-mouse, on-key (Controller).
- What can we do about this?

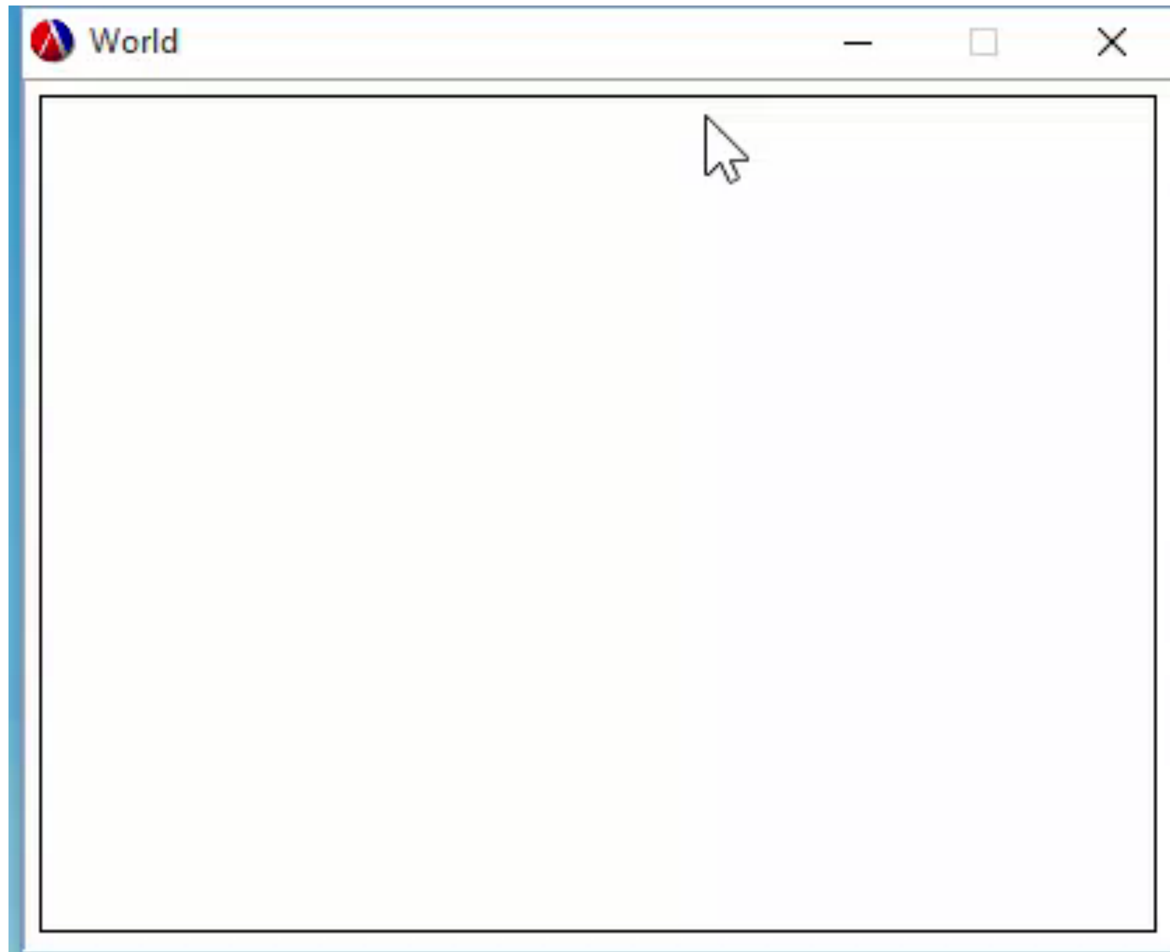
Instead: MVC architecture

- Divide a simulation into:
  - Model: the part that actually simulates the system in question
  - View: the part that displays the state of the system
  - Controller: the part that takes user input and transmits it to the model

Working Example

- Imagine we have a particle (a point mass), bouncing in a one-dimensional space of some fixed size.
- It's a point mass, so we can't see it, but we have sensors that measure its position and velocity.
- We also have controllers that control its position and velocity (separately).
- "p" adds a position controller, "v" adds a velocity controller.

Demonstration



Views and Controllers are often tightly linked

- In many examples, Views and Controllers are tightly linked
  - mouse or keyboard input is interpreted relative to screen position & the viewer that's running at that screen position.
- So we'll treat them together and call them controllers.
- Note: with other input devices, controllers and viewers may be entirely separate:
  - E.g. a flight simulator with a joystick

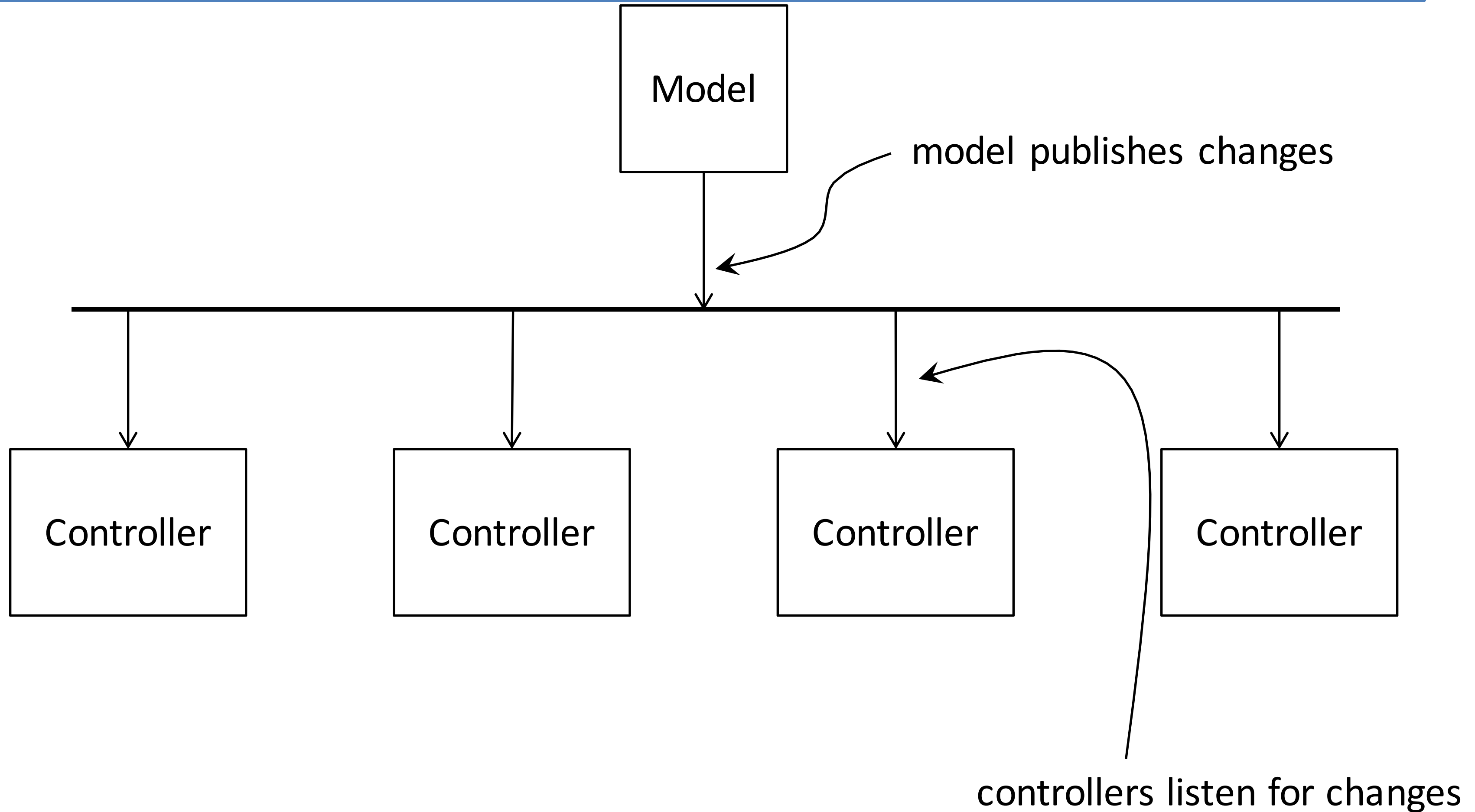
Model and Controllers are weakly linked

- Each controller is linked to a single model
- A model may be linked to many controllers
- Set of controllers may change dynamically.

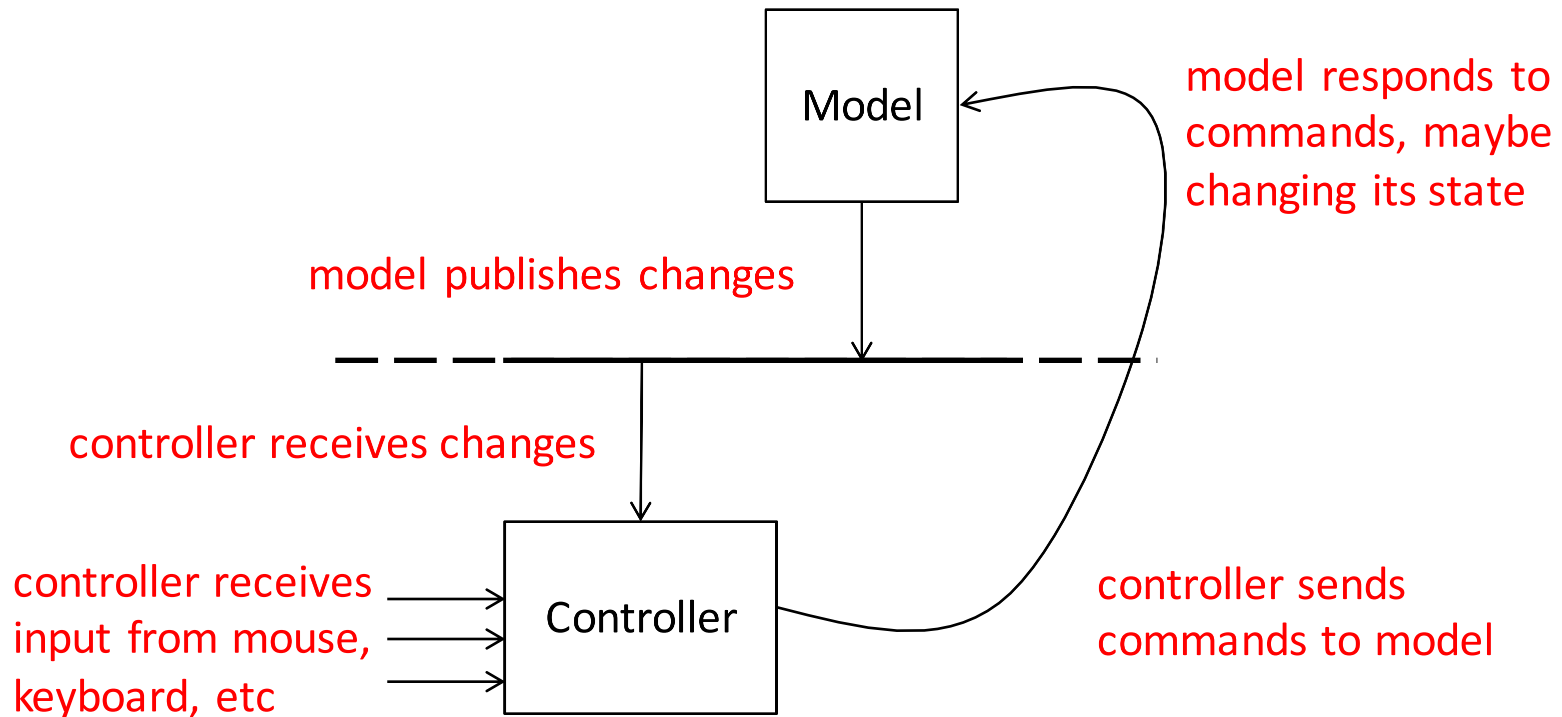
Solution: Use publish-subscribe

- Model publishes changes in its state to the subscribed controllers.
- Each controller responds to its mouse and keyboard inputs by sending commands to the model.
- Model changes its state in response to commands it receives

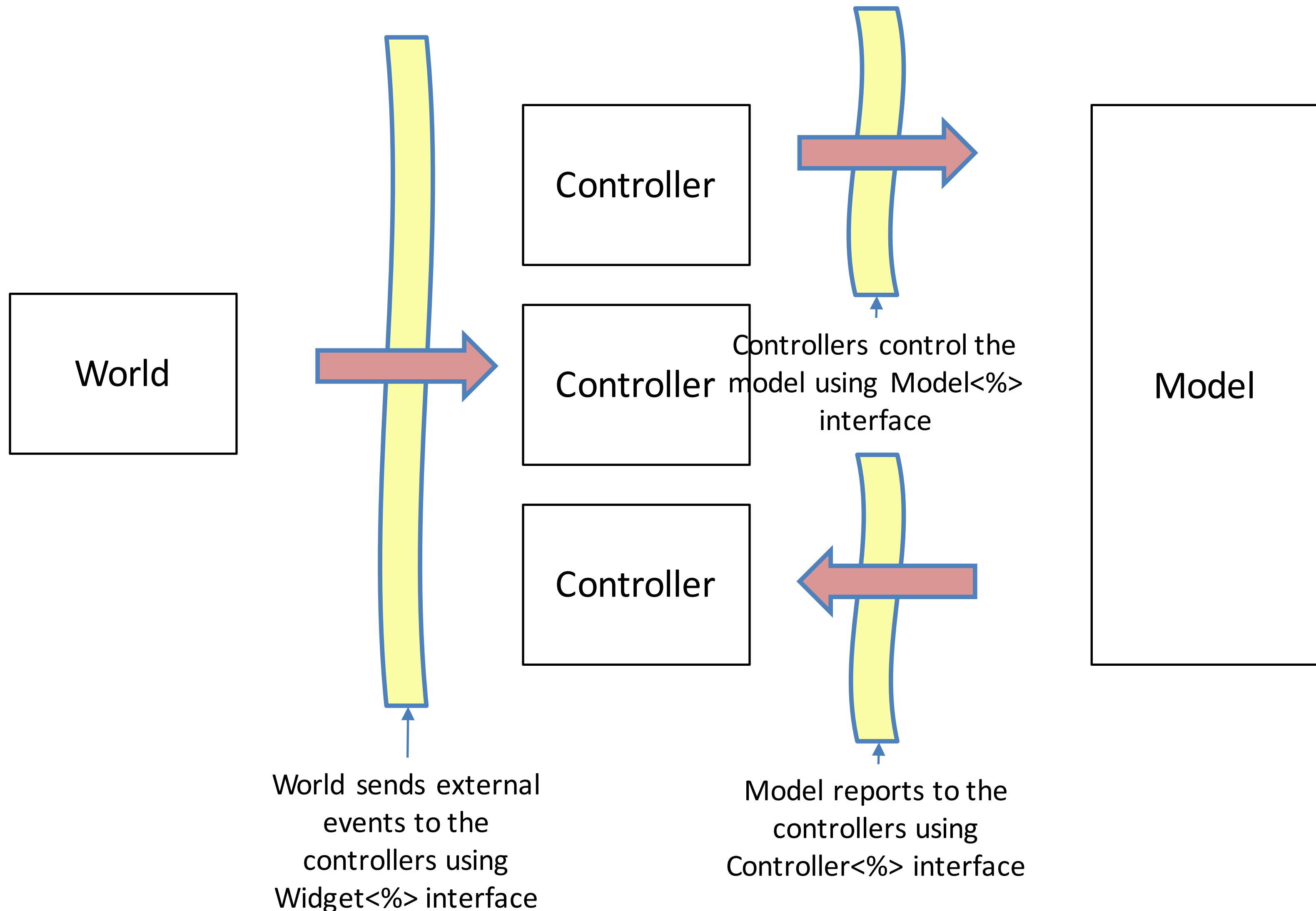
One model, many controllers



MVC Feedback loop



This is a 3-tier architecture



Interfaces.rkt

```
#lang racket
;; new version, based on WidgetWorks

(provide World<%> SWidget<%> Controller<%> Model<%>)

(define World<%>
  (interface ()

    ; SWidget<%> -> Void
    add-widget     ; we have only Stateful Widgets

    ; PosReal -> Void
    run
    ))

(define SWidget<%>
  (interface ()
    add-to-scene            ; Scene -> Scene
    after-tick              ; -> Void
    after-button-up         ; Nat Nat -> Void
    after-button-down       ; Nat Nat -> Void
    after-drag              ; Nat Nat -> Void
    after-key-event         ; KeyEvent -> Void
    ))
```

```
(define Controller<%>
  (interface (SWidget<%>)

    ;; Signal -> Void
    ;; receive a signal from the model and adjust
    ;; controller accordingly
    receive-signal

    ))

(define Model<%>
  (interface ()

    ;; -> Void
    after-tick

    ;; Controller<%> -> Void
    ;; Registers the given controller to receive signal
    register

    ;; Command -> Void
    ;; Executes the given command
    execute-command
))

;; registration protocol:
;; model sends the controller an initialization signal
as soon as it registers.
```

Data Definitions for Communicating with Model

```
(define-struct set-position-command  (pos) #:transparent)
(define-struct incr-velocity-command (dv)  #:transparent)

;; A Command is one of
;; -- (make-set-position Real)
;;    INTERP: set the position of the particle to pos
;; -- (make-incr-velocity Real)
;;    INTERP: increment the velocity of the particle by dv

(define-struct position-signal (pos) #:transparent)
(define-struct velocity-signal (v)   #:transparent)

;; A Signal is one of
;; -- (make-position-signal Real)
;; -- (make-velocity-signal Real)
;;    INTERP: report the current position or velocity of the
;;            particle
```

World.rkt (1)

```
;; A World is a
;;  (make-world model canvas-width canvas-height)

(define (make-world m w h)
  (new World%
    [model m][canvas-width w][canvas-height h]))

(define World%
  (class* object% (World<%>)

    (init-field canvas-width)  ; Nat
    (init-field canvas-height) ; Nat

    ;; the model
    (init-field model)     ; Model<%>
    (init-field [widgets empty])   ; ListOf(Swidget<%>)

    (super-new)
```

The world contains a list of SWidgets and a model. The model receives only after-tick messages; the others receive the usual Swidget<%> messages.

```
;; (Widget -> Void) -> Void
(define (for-each-widget fn)
  (for-each fn widgets))

;; (Widget Y -> Y) Y ListOfWidget -> Y
(define (foldr-widgets fn base)
  (foldr fn base widgets))
```

We use **for-each-widget** and **foldr-widgets** to distribute messages to the widgets.

```
(define empty-canvas
  (empty-scene canvas-width canvas-height))

(define/public (add-widget w)
  (set! widgets (cons w widgets)))
```

World.rkt (2)

```
(define/public (run rate)
  (big-bang this
    (on-tick
      (lambda (w) (begin (after-tick) w))
      rate)
    (on-draw
      (lambda (w) (to-scene)))
    (on-key
      (lambda (w kev)
        (begin
          (after-key-event kev)
          w)))
    (on-mouse
      (lambda (w mx my mev)
        (begin
          (after-mouse-event mx my mev)
          w)))))

(define (after-tick)
 (begin
  (send model after-tick)
  (for-each-widget
    (lambda (c) (send c after-tick)))))

(define (after-key-event kev)
  (for-each-widget
    (lambda (c) (send c after-key-event kev))))
```

Calling the **run** method invokes **big-bang** on this object. The **big-bang** handlers are all local functions in the class, not accessible from outside.

after-tick is sent to the model and to each widget

after-key-event is sent just to each widget

World.rkt (3)

```
(define (to-scene)
  (foldr-widgets
   (lambda (widget scene)
     (send widget add-to-scene scene))
   empty-canvas))

;; decode the mouse event and send
;; button-down/drag/button-up
;; events to each widget
(define (after-mouse-event mx my mev)
  (for-each-widget
    (mouse-event->message mx my mev)))

;; Nat Nat MouseEvent -> (Widget -> Void)
(define (mouse-event->message mx my mev)
  (cond
    [(mouse=? mev "button-down")
     (lambda (obj)
      (send obj after-button-down mx my))]
    [(mouse=? mev "drag")
     (lambda (obj)
       (send obj after-drag mx my))]
    [(mouse=? mev "button-up")
     (lambda (obj)
       (send obj after-button-up mx my))]
    [else (lambda (obj) 1111)]))

))
```

to-scene calls the **add-to-scene** method on each widget, and folds the results

after-mouse-event decodes the mouse event and sends the appropriate method call to each widget. This version of the code breaks up the task differently than **WidgetWorks.rkt** did. Do you understand how each version works?

Puzzle: why must the **else** line be of the form **(lambda (obj) ....)** ?

Model.rkt (1)

```
(define Model%
  (class* object% (Model<%>)

    ;; boundaries of the field
    (field [lo 0])
    (field [hi 200])

    ;; position and velocity of the object
    (init-field [x (/ (+ lo hi) 2)])
    (init-field [v 0])

    ; ListOfController<%>
    (init-field [controllers empty])

    (super-new)

    ;; Controller -> Void
    ;; register the new controller
    ;; and send it some data for initialization
    (define/public (register c)
      (begin
        (set! controllers (cons c controllers))
        (send c receive-signal
          (make-position-signal x))
        (send c receive-signal
          (make-velocity-signal v))))
```

```
;; -> Void
;; moves the object by v.
;; if the resulting x is >= 200 or <= 0
;; reports x at ever tick
;; reports velocity only when it changes
(define/public (after-tick)
  (set! x (within-limits lo (+ x v) hi))
  (publish-position)
  (if (or (= x hi) (= x lo))
    (begin
      (set! v (- v))
      (publish-velocity))
    'nonsense-value-13))

(define (within-limits lo val hi)
  (max lo (min val hi)))
```

Whenever the model changes its position or velocity, it sends the new data to the controllers.

As promised by the registration protocol, the model sends each new controller its data.

Model.rkt (2)

```
;; Command -> Void
;; decodes the command, executes it, and
;; sends updates to the controllers.
(define/public (execute-command cmd)
  (cond
    [(set-position-command? cmd)
     (begin
       (set! x
        (set-position-command-pos cmd))
       (publish-position))]
    [(incr-velocity-command? cmd)
     (begin
       (set! v
         (+ v
           (incr-velocity-command-dv cmd)))
       (publish-velocity))]))
```

Executes the given command and publishes changes to the registered controllers.

```
;; report position or velocity to each
;; registered controller:

   (define (publish-position)
     (let ((msg
              (make-position-signal x)))
       (for-each
         (lambda (c)
          (send c receive-signal msg))
         controllers)
       ))

   (define (publish-velocity)
     (let ((msg (make-velocity-signal v)))
       (for-each
         (lambda (c)
          (send c receive-signal msg))
         controllers)))
```

PositionController.rkt (excerpts)

```
;; a PositionController% is a
;;  (new PositionController% [model Model<%>])

(define PositionController%
  (class* object% (Controller<%>)

    (init-field model)  ; the model

    ; the position of the center of the
    ; controller on the canvas
    (init-field [x 150] [y 100])

    (init-field [width 120][height 50])

    (field [half-width  (/ width  2)])
    (field [half-height (/ height 2)])

    ;; the position of the particle
    (field [particle-x 0])
    (field [particle-v 0])

    ;; ... code for dragging ...

    ;; ... code for display ...
```

Receive signals from the model and update **particle-x** or **particle-v**

```
;; Signal -> Void
;; decodes signal and updates local data
(define/public (receive-signal sig)
  (cond
    [(position-signal? sig)
     (set! particle-x (position-signal-pos sig))]
    [(velocity-signal? sig)
     (set! particle-v (velocity-signal-v sig))]))
```

Receive key events from the world and send commands to the model

```
;; KeyEvent -> Void
;; interpret +,- as commands to the model
;; +/- alter position of the particle
(define/public (after-key-event kev)
  (if selected?
    (cond
      [(key=? "+" kev)
       (send model execute-command
         (make-set-position-command
           (+ particle-x 5)))]
      [(key=? "-" kev)
       (send model execute-command
         (make-set-position-command
           (- particle-x 5))
         )])
    2345))
```

VelocityController.rkt

```
(define VelocityController%
  (class* object% (Controller<%>)

    (init-field model)  ; the model

    ; the position of the center of the
    ; controller on the canvas
    (init-field [x 150] [y 100])

    (init-field [width 120][height 50])

    (field [half-width  (/ width  2)])
    (field [half-height (/ height 2)])

    ;; the position of the particle
    (field [particle-x 0])
    (field [particle-v 0])

    ;; ... code for dragging ...

    ;; ... code for display ...
```

setup, signal-reception just the same

```
;; Signal -> Void
;; decodes signal and updates local data
(define/public (receive-signal sig)
  (cond
    [(report-position? sig)
     (set! particle-x (report-position-pos sig))]
    [(report-velocity? sig)
     (set! particle-v (report-velocity-v sig))]))

;; KeyEvent -> Void
;; interpret +,- as commands to the model
;; +/- alter velocity of the particle
(define/public (after-key-event kev)
  (if selected?
    (cond
      [(key=? "+" kev)
       (send model execute-command
         (make-incr-velocity-command 1))]
      [(key=? "-" kev)
       (send model execute-command
         (make-incr-velocity-command -1))])
    3456))
```

+ and – are interpreted differently: as commands to change the *velocity* of the model.

Notice that the commands form a rudimentary programming language.

Lots of opportunity here for sharing implementation via inheritance; we just haven't done so.

ControllerFactory.rkt

```
(require "Interfaces.rkt")
(require "VelocityController.rkt")
(require "PositionController.rkt")
(require 2htdp/universe)

(provide ControllerFactory%)

(define ControllerFactory%

  (class* object% (SWidget<%>)

    ; the world in which the controllers will live
    (init-field w)   ; World<%>

    ; the model to which the controllers will be connected
    (init-field m)   ; Model<%>

    (super-new)

    ; KeyEvent -> Void
    (define/public (after-key-event kev)
      (cond
        [(key=? kev "v") (add-viewer VelocityController%)]
        [(key=? kev "p") (add-viewer PositionController%)]
        ))


    (define/public (add-viewer viewer-class)
      (send w add-widget (new viewer-class [model m])))

    (define/public (add-to-scene s) s)

    (define/public (after-tick) 122)
    (define/public (after-button-down mx my) 123)
    (define/public (after-drag mx my) 124)
    (define/public (after-button-up mx my) 125)

    ))
```

require the definitions of the different controllers

The Controller Factory is an ordinary SWidget. It takes keyboard input and adds a new controller to the world in which it lives.

"v" adds a new VelocityController; "p" adds a new PositionController.

add-viewer takes a class as an argument; this is legal in Racket but not possible in most OO languages.

The factory is invisible, and has no other behaviors– it responds to all other messages without changing its state.

top.rkt

```
#lang racket

(require "Model.rkt")
(require "World.rkt")
(require "ControllerFactory.rkt")


(define (run rate)
  (let* ((m (new Model%))
         (w (make-world m 400 300)))
    (begin
      (send w add-widget
        (new ControllerFactory% [m m][w w]))
      (send w run rate))))
```

Require only the classes that are used

Create a new model, and a world containing that model

Add a controller factory to the world

Last, run the world

Takeaways from this Lesson

- MVC is a widely-used architecture
- It is a 3-tier architecture
- It divides the system up into relatively small, easy-to-understand pieces.
- 3 interfaces:
  - world -> controllers
  - controllers -> model
  - model -> controllers
- 2 publish/subscribe relationships allow controllers to be created dynamically.
  - world publishes to controllers
  - model publishes to controllers
- Controller -> Model interface is a rudimentary programming language

Next Steps

- Study the relevant files in the Examples folder.
- If you have questions about this lesson, ask them on the Discussion Board
- Do Problem Set #11.