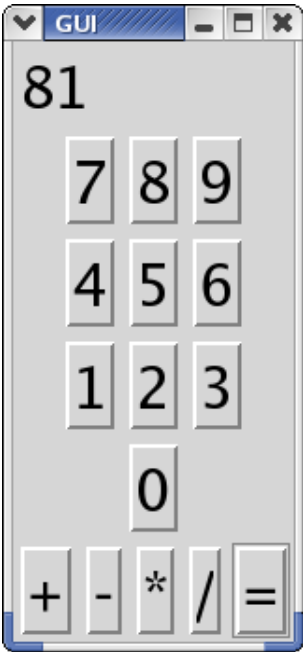


Last Time



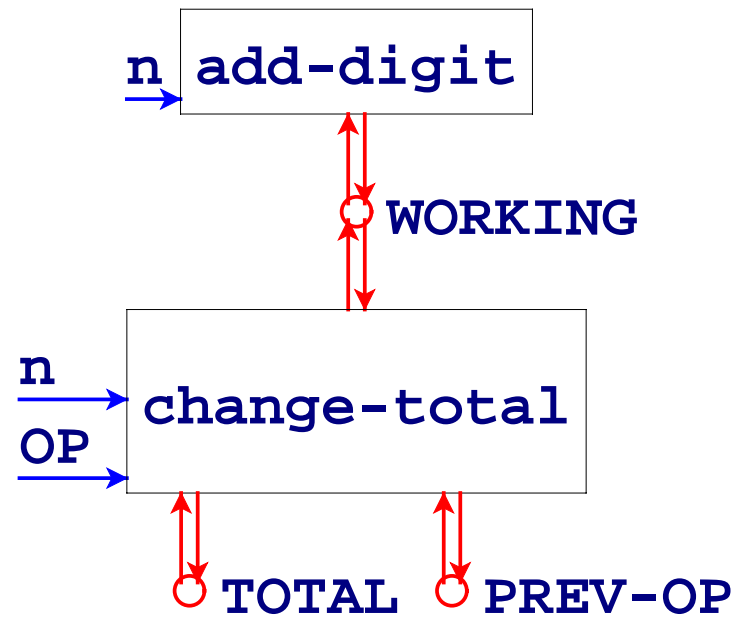
```
(define TOTAL 0)
(define WORKING 0)
(define PREV-OP +)
...
(define (add-digit n) ...)
...
(define (change-total n OP) ...)
...
```

The `add-digit` and `change-total` functions "remember" using `TOTAL`, `WORKING`, and `PREV-OP`

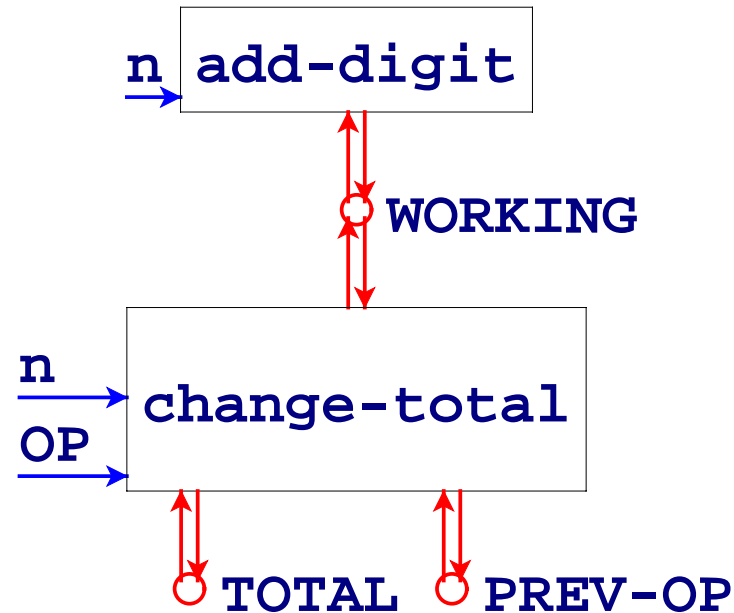
Designing Functions with State

- New design tool: organizational charts
- **Contract, Purpose, and Header** becomes **Contract, Purpose, Effect, and Header**
- Examples include starting state and effect
- Template includes potential assignments

Organizational Chart, Effects, Templates

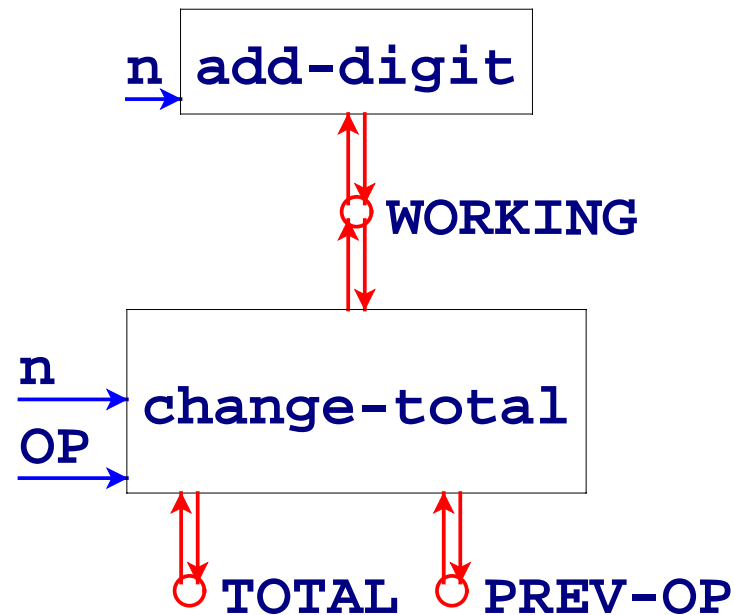


Organizational Chart, Effects, Templates



```
; add-digit : num -> true  
; Adds a digit to the number being entered  
; Effect: extends number, updates GUI  
(define (add-digit n)  
  ... n  
  ... WORKING ... (set! WORKING ...) ...)
```

Organizational Chart, Effects, Templates



```
; change-total : num (num num -> num) -> true
; Combines number and total
; Effect: sets total, resets number, sets op, updates GUI
(define (change-total n OP)
  ... n ... OP
  ... WORKING ... (set! WORKING ...)
  ... PREV-OP ... (set! PREV-OP ...)
  ... TOTAL ... (set! TOTAL ...) ...)
```

Examples

```
(begin
  (set! WORKING 0)
  (add-digit 5) "should be" true
  WORKING "should be" 5)

(begin
  (set! WORKING 10)
  (add-digit 5) "should be" true
  WORKING "should be" 105)
```

Examples

```
(begin
  (set! TOTAL 3)
  (set! WORKING 5)
  (set! PREV-OP *)
  (change-total 5 +) "should be" true
  TOTAL "should be" 15
  WORKING "should be" 0
  PREV-OP "should be" +)
```

Simpler Example

Suppose we want a GUI to manage a fish



[Run](#)

Simpler Example

Suppose we want a GUI to manage a fish



[Run](#)

New rule: keep the ***view*** and ***control*** separate from the ***model***

- The view and control are in the GUI
- The model is a fish with a weight

Simpler Example

Suppose we want a GUI to manage a fish



[Run](#)

New rule: keep the ***view*** and ***control*** separate from the ***model***

- The view and control are in the GUI
- The model is a fish with a weight

Design the model first

Fish Model

- The only operation in the model is **feed**

; feed : num -> num

; Grows the fish by n, returns new size

; Effect: adjusts the fish's weight

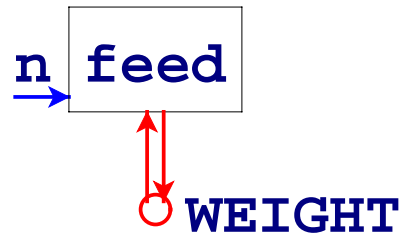
Fish Model

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; feed : num -> num

; Grows the fish by n, returns new size

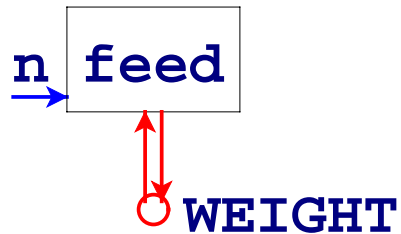
; Effect: adjusts the fish's weight



Fish Model

- The only operation in the model is **feed**

```
; feed : num -> num  
; Grows the fish by n, returns new size  
; Effect: adjusts the fish's weight
```

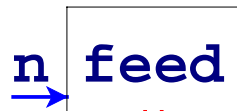


```
(define (feed n)  
  ... n ... WEIGHT  
  ... (set! WEIGHT ...) ...)
```

Fish Model

- The only operation in the model is `feed`

```
; feed : num -> num  
; Grows the fish by n, returns new size  
; Effect: adjusts the fish's weight
```



```
(define (feed n)  
  ... n ... WEIGHT  
  ... (set! WEIGHT ...) ...)
```

```
(begin  
  (set! WEIGHT 1)  
  (feed 10) "should be" 11  
  WEIGHT "should be" 11)
```

Fish Model Implementation

```
; feed : num -> num
; Grows the fish by n, returns new size
; Effect: adjusts the fish's weight
(define (feed n)
  (begin
    (set! WEIGHT (+ WEIGHT n))
    WEIGHT))

(begin
  (set! WEIGHT 1)
  (feed 10) "should be" 11
  WEIGHT "should be" 11)
```

Implementing the View and Controller



Use the GUI teachpack to construct view and control

- Message objects implement the view
- Button callbacks implement the control



Often, the model never calls the control

Complete Fish Program

```
; The model:
(define WEIGHT 3)
; feed : num -> num
; ...
(define (feed n)
  (begin
    (set! WEIGHT (+ n WEIGHT))
    WEIGHT))
... tests here ...

; The view:
(define msg (make-message (number->string WEIGHT)))
; The control:
(define (feed-button n)
  (make-button (string-append "Feed " (number->string n))
    (lambda (evt)
      (draw-message
        msg
        (number->string (feed n))))))
(create-window
  (list (list msg) (list (feed-button 1) (feed-button 3))))
```

Multiple Fish

As we saw last time, if we want multiple fish, we can use `local`

```
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          (define (feed n)
            (begin
              (set! WEIGHT (+ WEIGHT n))
              WEIGHT))
          ...]
    (create-window ...)))
```

Evaluating make-fish

```
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          (define (feed n)
            (begin
              (set! WEIGHT (+ WEIGHT n))
              WEIGHT))
          ...]
    (create-window ...)))
(make-fish 5)
```

Evaluating make-fish

```
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          (define (feed n)
            (begin
              (set! WEIGHT (+ WEIGHT n))
              WEIGHT))
          ...]
    (create-window ...)))
(make-fish 5)
```

→

```
...
(local [(define WEIGHT 5)
        (define (feed n)
          (begin
            (set! WEIGHT (+ WEIGHT n))
            WEIGHT))
        ...]
  (create-window ...))
```

Evaluating make-fish

```
...  
(local [(define WEIGHT 5)  
        (define (feed n)  
          (begin  
            (set! WEIGHT (+ WEIGHT n))  
            WEIGHT))  
        ...]  
(create-window ...))
```

Evaluating make-fish

```
...  
(local [(define WEIGHT 5)  
        (define (feed n)  
          (begin  
            (set! WEIGHT (+ WEIGHT n))  
            WEIGHT))  
        ...])  
(create-window ...))
```

→

```
...  
(define WEIGHT65 5)  
(define (feed67 n)  
  (begin  
    (set! WEIGHT65 (+ WEIGHT65 n))  
    WEIGHT65))  
...  
(create-window ...))
```

Multiple Fish

Every time we call **make-fish** a new **WEIGHT** is created for the new fish

We can make a whole aquarium....

Multiple Fish

Every time we call **make-fish** a new **WEIGHT** is created for the new fish

We can make a whole aquarium....

- How can we get the current total weight of all fish?
- How can we auto-feed all fish?

Multiple Fish

Every time we call `make-fish` a new `WEIGHT` is created for the new fish

We can make a whole aquarium....

- How can we get the current total weight of all fish?
- How can we auto-feed all fish?

Problem: `make-fish` returns only a window

The renamed `WEIGHT` is completely hidden

Returning the Weight

Does this help?

```
; make-fish : num -> num
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          ...]
    (begin
      (create-window ...)
      WEIGHT)))
```

Returning the Weight

Does this help?

```
; make-fish : num -> num
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          ...]
    (begin
      (create-window ...)
      WEIGHT))))
```

No:

```
(make-fish 5)
→ (local [(define WEIGHT 5) ...] ... WEIGHT)
→ (define WEIGHT73 5) ... WEIGHT73
→ → (define WEIGHT73 5) ... 5
```

Returning the Feeder

Only *functions* inside `make-fish` can see `WEIGHT`

Returning the Feeder

Only *functions* inside `make-fish` can see `WEIGHT`

So maybe `make-fish` should return a function:

```
; make-fish : num -> (num -> num)
(define (make-fish init-weight)
  (local [(define WEIGHT init-weight)
          (define (feed n) ... WEIGHT ...)
          ...]
    (begin
      (create-window ...)
      feed))))
```

```
(make-fish 5)
```

```
→ (local [(define WEIGHT 5) (define (feed n) ... WEIGHT ...) ...]
    ... feed)
```

```
→ (define WEIGHT77 5) (define (feed81 n) ... WEIGHT77 ...) ... feed81
```

Feeding an Aquarium

```
; A live-fish is
;   (num -> num)

; make-fish : num -> live-fish
...
(define aquarium (list (make-fish 5)
                       (make-fish 3)
                       (make-fish 12)))

; aq-weight : list-of-live-fish -> num
(define (aq-weight l)
  (foldr (lambda (f r) (+ (f 0) r)) 0 l))

; feed-all : n list-of-live-fish -> ...
(define (feed-all n l)
  (map (lambda (f) (f n)) l))
```

for-each

The built-in function `for-each` is like `map`, but it returns `(void)`

```
; feed-all! : n list-of-live-fish -> (void)
; Feeds n to each live-fish in l
; Effect: each live-fish becomes heavier
(define (feed-all! n l)
  (for-each (lambda (f) (f n)) l))
```

for-each

The built-in function `for-each` is like `map`, but it returns `(void)`

```
; feed-all! : n list-of-live-fish -> (void)
; Feeds n to each live-fish in l
; Effect: each live-fish becomes heavier
(define (feed-all! n l)
  (for-each (lambda (f) (f n)) l))
```

```
(begin
  (define l (list (make-fish 1) (make-fish 2)))
  (feed-all! 3 l) "should be" (void)
  l "should be" (list (make-fish 4) (make-fish 5)))
?
```


for-each

The built-in function `for-each` is like `map`, but it returns `(void)`

```
; feed-all! : n list-of-live-fish -> (void)
; Feeds n to each live-fish in l
; Effect: each live-fish becomes heavier
(define (feed-all! n l)
  (for-each (lambda (f) (f n)) l))
```

```
(begin
  (define l (list (make-fish 1) (make-fish 2)))
  (feed-all! 3 l) "should be" (void)
  l "should be" (list (make-fish 4) (make-fish 5)))
?
```

- This test doesn't completely capture the effect

for-each

The built-in function `for-each` is like `map`, but it returns `(void)`

```
; feed-all! : n list-of-live-fish -> (void)
; Feeds n to each live-fish in l
; Effect: each live-fish becomes heavier
(define (feed-all! n l)
  (for-each (lambda (f) (f n)) l))
```

```
(begin
  (define l (list (make-fish 1) (make-fish 2)))
  (feed-all! 3 l) "should be" (void)
  ((first l) 0) "should be" 4
  ((first (rest l)) 0) "should be" 5)
```

for-each

The built-in function `for-each` is like `map`, but it returns `(void)`

```
; feed-all! : n list-of-live-fish -> (void)
; Feeds n to each live-fish in l
; Effect: each live-fish becomes heavier
(define (feed-all! n l)
  (for-each (lambda (f) (f n)) l))

(begin
  (define l (list (make-fish 1) (make-fish 2)))
  (feed-all! 3 l) "should be" (void)
  ((first l) 0) "should be" 4
  ((first (rest l)) 0) "should be" 5)
```

- Testing with state is often difficult
- Avoid this difficulty by avoiding state whenever possible

A Tale of Two Fish Representations

```
; A fish is
```

```
;   num
```

```
; A live-fish is
```

```
;   (num -> num)
```

- A **fish** represents a fish of a particular weight
 - Feed the fish \Rightarrow new value
- A **live-fish** represents a fish with a particular identity
 - Feed the fish \Rightarrow same value, new state

A Tale of Two Fish Representations

```
; A fish is
```

```
; num
```

```
; A live-fish is
```

```
; (num -> num)
```

live-fish is more closely reflects reality

- On the one hand, reflecting reality makes things more intuitive
- On the other hand, reality can be messy

Key question when designing a program: what to represent

Encapsulation

Packaging fish state with its operations is called ***encapsulation***

More on encapsulation soon...

Design with State Summary

- Deciding to use state: often motivated by GUIs
 - Split into model and view/controller
- The design recipe for state
 - Charts (no handin artifact)
 - Effects (handin with purpose)
 - Template with assignments (handin optional)
 - Multi-step tests (handin as usual)
- Design for the single-instance case, then encapsulate if necessary