Computation versus Programming

- Last time, we talked about computation

\[
\begin{align*}
\text{(image=? (image+ □ ○) □)} \\
\rightarrow \text{(image=? □ □)} \\
\rightarrow \text{true}
\end{align*}
\]
Computation versus Programming

• Last time, we talked about computation

\[
\begin{align*}
\text{(image=? (image+ \text{□} \text{●}) \text{□})} \\
\rightarrow \text{(image=? \text{●} \text{□})} \\
\rightarrow \text{true}
\end{align*}
\]

• Programming?

Write an anonymizer...

\[
\begin{align*}
\text{(define (anonymize i)} \\
\text{(offset-image+ i 0 0)} \\
\text{(filled-circle (image-width i) (image-height i) \text{'blue})})
\end{align*}
\]
Computation versus Programming

- Last time, we talked about computation

\[
\begin{align*}
(image=? (image+ \text{ ?} \text{ ?}) \text{ ?}) \\
\rightarrow (image=? \text{ ?} \text{ ?}) \\
\rightarrow \text{ true}
\end{align*}
\]

- Programming?

Write an anonymizer...

\[
\begin{align*}
\text{(define (anonymize i)} \\
\text{ (offset-image+ i 0 0)} \\
\text{ (filled-circle (image-width i) (image-height i) \text{ 'blue})})
\end{align*}
\]

We somehow wrote the function in one big, creative chunk
## Design Recipe I

### Data
- Understand the input data: `num`, `bool`, `sym`, or `image`

### Contract, Purpose, and Header
- Describe (but don’t write) the function

### Examples
- Show what will happen when the function is done

### Body
- The most creative step: implement the function body

### Test
- Run the examples
# Design Recipe I

## Data
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## Test
- Run the examples
Data

Choose a representation suitable for the function input

- Fahrenheit degrees $\rightarrow$ num
- Grocery items $\rightarrow$ sym
- Faces $\rightarrow$ image
- Wages $\rightarrow$ num
- ...


Data

Choose a representation suitable for the function input

- Fahrenheit degrees ➝ num
- Grocery items ➝ sym
- Faces ➝ image
- Wages ➝ num
- ...

Handin artifact: none for now
Design Recipe I

Data

• Understand the input data: `num`, `bool`, `sym`, or `image`

Contract, Purpose, and Header

• Describe (but don’t write) the function

Examples

• Show what will happen when the function is done

Body

• The most creative step: implement the function body

Test

• Run the examples
Contract, Purpose, and Header

*Contract*

Describes input(s) and output data

- \( f2c : \text{num} \rightarrow \text{num} \)
- \( \text{is-milk?} : \text{sym} \rightarrow \text{bool} \)
- \( \text{wearing-glasses?} : \text{image image image} \rightarrow \text{bool} \)
- \( \text{netpay} : \text{num} \rightarrow \text{num} \)
Contract, Purpose, and Header

Contract

Describes input(s) and output data

- \( f2c : \text{num} \rightarrow \text{num} \)
- \( \text{is-milk?} : \text{sym} \rightarrow \text{bool} \)
- \( \text{wearing-glasses?} : \text{image image image} \rightarrow \text{bool} \)
- \( \text{netpay} : \text{num} \rightarrow \text{num} \)

Handin artifact: a comment

; \( f2c : \text{num} \rightarrow \text{num} \)
; \( \text{is-milk?} : \text{sym} \rightarrow \text{bool} \)
Contract, Purpose, and Header

Purpose

Describes, in English, what the function will do

- Converts F-degrees $f$ to C-degrees
- Checks whether $s$ is a symbol for milk
- Checks whether $p_2$ is $p_1$ wearing glasses $g$
- Computes net pay (less taxes) for $n$ hours worked
Contract, Purpose, and Header

*Purpose*

Describes, in English, what the function will do

- Converts F-degrees $f$ to C-degrees
- Checks whether $s$ is a symbol for milk
- Checks whether $p2$ is $p1$ wearing glasses $g$
- Computes net pay (less taxes) for $n$ hours worked

*Handin artifact:* a comment after the contract

```plaintext
; f2c : num -> num
; Converts F-degrees f to C-degrees
```
Contract, Purpose, and Header

**Header**

Starts the function using variables that are mentioned in purpose

- `(define (f2c f) ....)`
- `(define (is-milk? s) ....)`
- `(define (wearing-glasses? p1 p2 g) ....)`
- `(define (netpay n) ....)`
Contract, Purpose, and Header

*Header*

Starts the function using variables that are mentioned in purpose

- (define (f2c f) ....)
- (define (is-milk? s) ....)
- (define (wearing-glasses? p1 p2 g) ....)
- (define (netpay n) ....)

Check: function name and variable count match contract
Contract, Purpose, and Header

*Header*

Starts the function using variables that are mentioned in purpose

- (define (f2c f) ....)
- (define (is-milk? s) ....)
- (define (wearing-glasses? p1 p2 g) ....)
- (define (netpay n) ....)

*Check:* function name and variable count match contract

*Handin artifact:* as above, but absorbed into implementation

```scheme
; f2c : num -> num
; Converts F-degrees f to C-degrees
(define (f2c f) ....)
```
Design Recipe I

Data

• Understand the input data: `num`, `bool`, `sym`, or `image`

Contract, Purpose, and Header

• Describe (but don’t write) the function

Examples

• Show what will happen when the function is done

Body

• The most creative step: implement the function body

Test

• Run the examples
Examples

Show example function calls an result

\[
(f2c 32) \ "should be" \ 0
\]
\[
(f2c 212) \ "should be" \ 100
\]
\[
(is\text{-}milk? \ 'milk) \ "should be" \ true
\]
\[
(is\text{-}milk? \ 'apple) \ "should be" \ false
\]
Examples

Show example function calls an result

\[
(f2c \ 32) \ "should \ be" \ 0 \\
(f2c \ 212) \ "should \ be" \ 100
\]

\[
(is-milk? \ 'milk) \ "should \ be" \ true \\
(is-milk? \ 'apple) \ "should \ be" \ false
\]

Check: function name, argument count and types match contract
Examples

Show example function calls an result

\[
(f2c \ 32) \ "should \ be" \ 0 \\
(f2c \ 212) \ "should \ be" \ 100
\]

\[
(is\text{-}milk? \ 'milk) \ "should \ be" \ true \\
(is\text{-}milk? \ 'apple) \ "should \ be" \ false
\]

Check: function name, argument count and types match contract

Handin artifact: as above, after header/body

; f2c : num -> num
; Converts F-degrees f to C-degrees
(define (f2c f) ....)
(f2c 32) "should be" 0
(f2c 212) "should be" 100
Design Recipe I

Data

• Understand the input data: num, bool, sym, or image

Contract, Purpose, and Header

• Describe (but don’t write) the function

Examples

• Show what will happen when the function is done

Body

• The most creative step: implement the function body

Test

• Run the examples
Fill in the body under the header

```
(define (f2c f)
  (* (- f 32) 5/9))

(define (is-milk? s)
  (symbol=? s 'milk))
```
(define (f2c f)  
  (* (- f 32) 5/9))

(define (is-milk? s)  
  (symbol=? s 'milk))

Handin artifact: complete at this point

; f2c : num -> num  
; Converts F-degrees f to C-degrees
(define (f2c f)  
  (* (- f 32) 5/9))
(f2c 32) "should be" 0  
(f2c 212) "should be" 100
Design Recipe I

Data

• Understand the input data: num, bool, sym, or image

Contract, Purpose, and Header

• Describe (but don’t write) the function

Examples

• Show what will happen when the function is done

Body

• The most creative step: implement the function body

Test

• Run the examples
Design Recipe - Each Step Has a Purpose

Data

• Shape of input data will drive the implementation

Contract, Purpose, and Header

• Provides a first-level understanding of the function

Examples

• Gives a deeper understanding and exposes specification issues

Body

• The implementation is the whole point

Test

• Evidence that it works
Compound Data

A posn is

\[(\text{make-posn} \ \text{num} \ \text{num})\]

- \[(\text{make-posn} \ 1 \ 2)\] is a value
- \[(\text{posn-x} \ (\text{make-posn} \ 1 \ 2))\] $\rightarrow$ 1
- \[(\text{posn-y} \ (\text{make-posn} \ 1 \ 2))\] $\rightarrow$ 2
Compound Data

A `posn` is

`\text{(make-posn \ num \ num)}`

- \text{(make-posn 1 2)} is a value
- \text{(posn-x (make-posn 1 2))} \rightarrow 1
- \text{(posn-y (make-posn 1 2))} \rightarrow 2

How about program design?
Design Recipe I

Data

- Understand the input data: `num, bool, sym, or image`

Contract, Purpose, and Header

- Describe (but don’t write) the function

Examples

- Show what will happen when the function is done

Body

- The most creative step: implement the function body

Test

- Run the examples
If the input is compound data, start the body by selecting the parts

; max-part : posn -> num
; Return the X part of p is it’s bigger
; than the Y part, otherwise the Y part
(define (max-part p)
  ...)

(max-part (make-posn 10 11)) "should be" 11
(max-part (make-posn 7 5)) "should be" 7
If the input is compound data, start the body by selecting the parts

\[
; \text{max-part : posn \rightarrow num}
; \text{Return the X part of p is it's bigger}
; \text{than the Y part, otherwise the Y part}
\]

\[
\text{(define (max-part p)}
\text{... (posn-x p) ... (posn-y p) ...)}
\]

\[
(\text{max-part (make-posn 10 11)) "should be" 11}
(\text{max-part (make-posn 7 5)) "should be" 7}
\]
If the input is compound data, start the body by selecting the parts

; max-part : posn -> num
; Return the X part of p is it’s bigger
; than the Y part, otherwise the Y part
(define (max-part p)
  (cond
   [(> (posn-x p) (posn-y p)) (posn-x p)]
   [else (posn-y p)])
(max-part (make-posn 10 11)) "should be" 11
(max-part (make-posn 7 5)) "should be" 7
If the input is compound data, start the body by selecting the parts

```scheme
(define (max-part p)
  (cond
   [(> (posn-x p) (posn-y p)) (posn-x p)]
   [else (posn-y p)])

(max-part (make-posn 10 11)) "should be" 11
(max-part (make-posn 7 5)) "should be" 7
```

Since this guideline applies before the usual body work, let’s split it into an explicit step
Design Recipe II

Data

- Understand the input data

Contract, Purpose, and Header

- Describe (but don’t write) the function

Examples

- Show what will happen when the function is done

Template

- Set up the body based on the input data (and only the input)

Body

- The most creative step: implement the function body

Test

- Run the examples
If the input is compound data, start the body by selecting the parts

; max-part : posn -> num
; ...
(define (max-part p)
  ... (posn-x p) ... (posn-y p) ... )
If the input is compound data, start the body by selecting the parts

\[
; \text{max-part} : \text{posn} \rightarrow \text{num} \\
; \ldots\ \\
(\text{define} \ (\text{max-part} \ p) \\
\quad \ldots \ (\text{posn-x} \ p) \ldots \ (\text{posn-y} \ p) \ldots)
\]

**Check**: number of parts in template = number of parts data definition named in contract
If the input is compound data, start the body by selecting the parts

\[
\text{; max-part : posn -> num } \\
\text{; ... } \\
(\text{define (max-part p)} \\
\text{... (posn-x p) ... (posn-y p) ...)}
\]

Check: number of parts in template = number of parts data definition named in contract

A posn is

\[
(\text{make-posn num num num})
\]
If the input is compound data, start the body by selecting the parts

Handin artifact: a comment (required starting with HW 3)

; max-part : posn -> num
; Return the X part of p is it’s bigger
; than the Y part, otherwise the Y part
; (define (max-part p)
; ... (posn-x p) ... (posn-y p) ...)
(define (max-part p)
  ... (posn-x p) ... (posn-y p) ...)
(max-part (make-posn 10 11)) "should be" 11
(max-part (make-posn 7 5)) "should be" 7
Data Definitions and define-struct

Here’s what we’d like:

A snake is

(make-snake sym num sym)
Data Definitions and define-struct

Here’s what we’d like:

A snake is

(make-snake sym num sym)

We can tell DrScheme about snake:

(define-struct snake (name weight food))
Data Definitions and define-struct

Here’s what we’d like:

A snake is

\[(\text{make-snake } \text{sym } \text{num } \text{sym})\]

We can tell DrScheme about snake:

\[(\text{define-struct snake (name weight food)})\]

Creates the following:

- make-snake
- snake-name
- snake-weight
- snake-food
Data

Deciding to define *snake* is in the first step of the design recipe
Data

Deciding to define `snake` is in the first step of the design recipe

**Handin artifact:** a comment and/or `define-struct`

```scheme
; A snake is
; (make-snake sym num sym)

(define-struct snake (name weight food))
```
Data

Deciding to define \texttt{snake} is in the first step of the design recipe

\textbf{Handin artifact}: a comment and/or \texttt{define-struct}

\begin{verbatim}
; A snake is
; (make-snake sym num sym)

(define-struct snake (name weight food))
\end{verbatim}

Now that we’ve defined \texttt{snake}, we can use it in contracts
Expanding the Zoo

We have snakes, and armadillos are similar. Let’s add ants.

An ant has

• a weight
• a location in the zoo
Expanding the Zoo

We have snakes, and armadillos are similar. Let’s add ants.

An ant has

- a weight
- a location in the zoo

; An ant is
; (make-ant num posn)
(define-struct ant (weight loc))
Expanding the Zoo

We have snakes, and armadillos are similar. Let’s add ants.

An ant has

• a weight
• a location in the zoo

; An ant is
;  (make-ant num posn)
(define-struct ant (weight loc))

(make-ant 0.001 (make-posn 4 5))

(make-ant 0.007 (make-posn 3 17))
• Define \texttt{ant-at-home?}, which takes an ant and reports whether it is at the origin
Programming with Ants

Contract, Purpose, and Header

; ant-at-home? : ant -> bool
; ant-at-home? : ant → bool
; Check whether ant a is home
Contract, Purpose, and Header

; ant-at-home? : ant -> bool
; Check whether ant a is home
(define (ant-at-home? a)
  ...
)
Examples

; ant-at-home? : ant -> bool
; Check whether ant a is home
(define (ant-at-home? a)
  ...)

(ant-at-home? (make-ant 0.001 (make-posn 0 0))) ' = true
(ant-at-home? (make-ant 0.001 (make-posn 1 1))) ' = false
Programming with Ants

Template

; ant-at-home? : ant -> bool
; Check whether ant a is home
(define (ant-at-home? a)
  ...
  (ant-weight a)
  ...
  (ant-loc a) ...
)

(ant-at-home? (make-ant 0.001 (make-posn 0 0))) ' = true
(ant-at-home? (make-ant 0.001 (make-posn 1 1))) ' = false
Programming with Ants

Template

; ant-at-home? : ant -> bool
; Check whether ant a is home
(define (ant-at-home? a)
  ... (ant-weight a)
  ... (posn-at-home? (ant-loc a)) ...)

New template rule: data-defn reference ⇒ template reference

Add templates for referenced data, if needed, and implement body for referenced data

(ant-at-home? (make-ant 0.001 (make-posn 0 0))) ’= true
(ant-at-home? (make-ant 0.001 (make-posn 1 1))) ’= false
programming with ants

template

; ant-at-home? : ant -> bool
; Check whether ant a is home
(define (ant-at-home? a)
  ...
  (ant-weight a)
  ...
  (posn-at-home? (ant-loc a)) ...
)

(define (posn-at-home? p)
  ...
  (posn-x p) ...
  (posn-y p) ...
)

(ant-at-home? (make-ant 0.001 (make-posn 0 0))) ' = true
(ant-at-home? (make-ant 0.001 (make-posn 1 1))) ' = false
; ant-at-home? : ant -> bool
; Check whether ant a is home
; (define (ant-at-home? a)
;   ... (ant-weight a)
;   ... (posn-at-home? (ant-loc a)) ...)
; (define (posn-at-home? p)
;   ... (posn-x p) ... (posn-y p) ...)
(define (ant-at-home? a)
  (posn-at-home? (ant-loc a)))
(define (posn-at-home? p)
  (and (= (posn-x p) 0) (= (posn-y p) 0)))

(ant-at-home? (make-ant 0.001 (make-posn 0 0))) ' = true
(ant-at-home? (make-ant 0.001 (make-posn 1 1))) ' = false
Shapes of Data and Templates

The shape of the template matches the shape of the data

; An ant is
; (make-ant num posn)

; A posn is
; (make-posn num num)

(define (ant-at-home? a)
  ...
  (ant-weight a)
  ...
  (posn-at-home? (ant-loc a)) ...
)

(define (posn-at-home? p)
  ...
  (posn-x p) ...
  (posn-y p) ...
)
Animals

All animals need to eat...

- Define `feed-animal`, which takes an animal (snake, dillo, or ant) and feeds it (5 lbs, 2 lbs, or 0.001 lbs, respectively)
Animals

All animals need to eat...

- Define `feed-animal`, which takes an animal (snake, dillo, or ant) and feeds it (5 lbs, 2 lbs, or 0.001 lbs, respectively)

What is an animal?
Animal Data Definition

; An animal is either
;   - snake
;   - dillo
;   - ant
Animal Data Definition

; An animal is either
;  - snake
;  - dillo
;  - ant

The "either" above makes this a new kind of data definition:

data with **varieties**
Animal Data Definition

; An animal is either
;  - snake
;  - dillo
;  - ant

The "either" above makes this a new kind of data definition:

data with *varieties*

Examples:

(make-snake 'slinky 10 'rats)

(make-dillo 2 true)

(make-ant 0.002 (make-posn 3 4))
Feeding Animals

; feed-animal : animal -> animal
; To feed the animal a
(define (feed-animal a)
  ...)

Feeding Animals

; feed-animal : animal -> animal
; To feed the animal a
(define (feed-animal a)
 ...)

(feed-animal (make-snake 'slinky 10 'rats))
"should be" (make-snake 'slinky 15 'rats)

(feed-animal (make-dillo 2 true))
"should be" (make-dillo 4 true)

(feed-animal (make-ant 0.002 (make-posn 3 4)))
"should be" (make-ant 0.003 (make-posn 3 4))
Template for Animals

For the template step...

```
(define (feed-animal a)
  ...)
```

- Is `a` compound data?
Template for Animals

For the template step...

\[
\text{(define (feed-animal a)}
\]
\[
\text{...)}
\]

- Is \text{a} compound data?

- Technically yes, but the definition \text{animal} doesn’t have \text{make-something}, so we don’t use the compound-data template rule
Template for Varieties

Choice in the data definition

; An animal is either
;  - snake
;  - dillo
;  - ant

means \texttt{cond} in the template:

\begin{verbatim}
(define (feed-animal a)
  (cond
    [...  ...]
    [...  ...]
    [...  ...]
    [...  ...]))
\end{verbatim}

Three data choices means three \texttt{cond} cases
Questions for Varieties

(define (feed-animal a)
  (cond
    [...  ...]
    [...  ...]
    [...  ...]
    [...  ...]))

How do we write a question for each case?
Questions for Varieties

\[
\text{(define (feed-animal a)}
\text{(cond}
\text{[... [...]}\n\text{[... [...]}\n\text{[... [...]}\n\text{[... [...]}\n)\n\]

How do we write a question for each case?

It turns out that

\[
\text{(define-struct snake (name weight food))}
\]

provides \text{snake}?

\[
\text{(snake? (make-snake 'slinky 5 'rats))} \rightarrow \text{true}
\]
\[
\text{(snake? (make-dillo 2 true))} \rightarrow \text{false}
\]
\[
\text{(snake? 17)} \rightarrow \text{false}
\]
(define (feed-animal a)
  (cond
    [(snake? a) ...]
    [(dillo? a) ...]
    [(ant? a) ...]))

New template rule: varieties ⇒ cond
(define (feed-animal a)
  (cond
    [(snake? a) ...]
    [(dillo? a) ...]
    [(ant? a) ...]))

New template rule: varieties ⇒ cond

Now continue template case-by-case...
Template

(define (feed-animal a)
  (cond
    [(snake? a) ... (feed-snake a) ...]
    [(dillo? a) ... (feed-dillo a) ...]
    [(ant? a) ... (feed-ant a) ...]))

Remember: references in the data definition ⇒ template references
(define (feed-animal a)
  (cond
    [(snake? a) ... (feed-snake a) ...]
    [(dillo? a) ... (feed-dillo a) ...]
    [(ant? a) ... (feed-ant a) ...]))

Remember: references in the data definition ⇒ template references

; An animal is either
; - snake
; - dillo
; - ant
Shapes of Data and Templates

; An animal is either
; - snake
; - dillo
; - ant

; A snake is
; (make-snake sym num sym)

; A dillo is
; (make-dillo num bool)

; An ant is
; (make-ant num posn)

; A posn is
; (make-posn num num)

(define (feed-animal a)
  (cond
    [(snake? a) ... (feed-snake a) ...]
    [(dillo? a) ... (feed-dillo a) ...]
    [(ant? a) ... (feed-ant a) ...]))

(define (feed-snake s)
  ... (snake-name s) ... (snake-weight s)
  ... (snake-food s) ...)

(define (feed-dillo d)
  ... (dillo-weight d)
  ... (dillo-alive? d) ...)

(define (feed-ant a)
  ... (ant-weight d)
  ... (feed-posn (ant-loc d)) ...)

(define (feed-posn p)
  ... (posn-x p) ... (posn-y p) ...)
Design Recipe III

**Data**
- Understand the input data

**Contract, Purpose, and Header**
- Describe (but don’t write) the function

**Examples**
- Show what will happen when the function is done

**Template**
- Set up the body based on the input data (and *only* the input)

**Body**
- The most creative step: implement the function body

**Test**
- Run the examples
When the problem statement mentions \(N\) different varieties of a thing, write a data definition of the form

\[
; \ A \ \text{thing is} \\
; \quad - \ \text{variety}_1 \\
; \quad \ldots \\
; \quad - \ \text{variety}_N
\]
### Design Recipe III

#### Data
- Understand the input data

#### Contract, Purpose, and Header
- Describe (but don’t write) the function

#### Examples
- Show what will happen when the function is done

#### Template
- Set up the body based on the input data (and *only* the input)

#### Body
- The most creative step: implement the function body

#### Test
- Run the examples
Examples

When the input data has varieties, be sure to pick each variety at least once.

; An animal is either
;   - snake
;   - dillo
;   - ant

(feed-animal (make-snake 'slinky 10 'rats))
"should be" (make-snake 'slinky 15 'rats)

(feed-animal (make-dillo 2 true))
"should be" (make-dillo 4 true)

(feed-animal (make-ant 0.002 (make-posn 3 4)))
"should be" (make-ant 0.003 (make-posn 3 4))
Design Recipe III

Data

- Understand the input data

Contract, Purpose, and Header

- Describe (but don’t write) the function

Examples

- Show what will happen when the function is done

Template

- Set up the body based on the input data (and only the input)

Body

- The most creative step: implement the function body

Test

- Run the examples
Template

When the input data has varieties, start with `cond`

- **N** varieties ⇒ **N** `cond` lines
- Formulate a question to match each corresponding variety
- Continue template steps case-by-case

```
(define (feed-animal a)
  (cond
    [(snake? a)    ...]
    [(dillo? a)    ...]
    [(ant? a)      ...]]))
```
Template

When the input data has varieties, start with `cond`

- **N** varieties $\Rightarrow$ **N** `cond` lines
- Formulate a question to match each corresponding variety
- Continue template steps case-by-case

When the data definition refers to a data definition, make the template refer to a template

```
(define (ant-at-home? a)
  ...
  (ant-weight a)
  ...
  (posn-at-home? (ant-loc a)) ...
)

(define (posn-at-home? p)
  ...
  (posn-x p) ...
  (posn-y p) ...
)
Template

When the input data has varieties, start with \texttt{cond}

- \texttt{N} varieties $\Rightarrow$ \texttt{N} \texttt{cond} lines
- Formulate a question to match each corresponding variety
- Continue template steps case-by-case

When the data definition refers to a data definition, make the template refer to a template

\begin{verbatim}
(define (feed-animal a)
  (cond
    [(snake? a) ... (feed-snake a) ...]
    [(dillo? a) ... (feed-dillo a) ...]
    [(ant? a) ... (feed-ant a) ...]))
\end{verbatim}
Our zoo was so successful, let’s start an aquarium

For a fish, we only care about its weight, so for two fish:

; An aquarium is
; (make-aq num num)
(define-struct aq (first second))
Aquarium Template

; An aquarium is
; (make-aq num num)

Generic template:

; func-for-aq : aquarium -> ...
; (define (func-for-aq a)
; ... (aq-first a) ... (aq-second a) ...)


Aquarium Template

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Generic template:
; func-for-aq : aquarium -> ...
; (define (func-for-aq a)
; ... (aq-first a) ... (aq-second a) ...)

; aq-weight : aquarium -> num
(define (aq-weight a)
  (+ (aq-first a) (aq-second a)))

(aq-weight (make-aq 7 8)) "should be" 15
Aquarium Template

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Generic template:
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; aq-weight : aquarium -> num
(define (aq-weight a)
  (+ (aq-first a) (aq-second a)))

(aq-weight (make-aq 7 8)) "should be" 15

And so on, for many other simple aquarium functions...
Tragedy Strikes the Aquarium

Poor blue fish... now we have only one
Tragedy Strikes the Aquarium

Poor blue fish... now we have only one

Worse, we have to re-write all our functions...

; An aquarium is
; (make-aq num)
(define-struct aq (first))
Aquarium Template, Revised

; An aquarium is
;  (make-aq num)

; func-for-aq : aquarium -> ...
; (define (func-for-aq a)
;  ... (aq-first a) ...)
Aquarium Template, Revised

; An aquarium is
; (make-aq num)

; func-for-aq : aquarium -> ...
; (define (func-for-aq a)
; ... (aq-first a) ...)

; aq-weight : aquarium -> num
(define (aq-weight a)
  (aq-first a))

(aq-weight (make-aq 7)) "should be" 7
Aquarium Template, Revised

; An aquarium is
; (make-aq num)

; func-for-aq : aquarium -> ...
; (define (func-for-aq a)
; ... (aq-first a) ...)

; aq-weight : aquarium -> num
(define (aq-weight a)
  (aq-first a))

(aq-weight (make-aq 7)) "should be" 7

And so on, for all of the aquarium functions...
The Aquarium Expands

Hooray, we have two new fish!
The Aquarium Expands

Hooray, we have two new fish!

Unfortunately, we have to re-re-write all our functions...

; An aquarium is
; (make-aq num num num num)
(define-struct aq (first second third))
Our data choice isn’t working

- An aquarium isn’t just 1 fish, 2 fish, or 100 fish — it’s a collection containing an arbitrary number of fish
- No data definition with just 1, 2, or 100 numbers will work

To represent an aquarium, we need a list of numbers

We don’t need anything new in the language, just a new idea
Structs as Boxes

Pictorially,

- `define-struct` lets us define a new kind of box
- The box can have as many compartments as we want, but we have to pick how many, once and for all

\[
\text{(define-struct \textit{snake} (name weight food))}
\]

\[
\Rightarrow \begin{array}{c}
\text{box}
\end{array}
\]

\[
\text{(define-struct \textit{ant} (weight loc))}
\]

\[
\Rightarrow \begin{array}{c}
\text{box}
\end{array}
\]
Boxes Stretch

The boxes stretch to fit any one thing in each slot:

'slinky 12 'rats

Even other boxes:

0.002 2 3

Still, the number of slots is fixed
Suppose that

- You have four things to pack as one
- You only have 2-slot boxes
- Every slot must contain exactly one thing

How can you create a single package?
Packing Boxes

This isn’t good enough

because it’s still two boxes...
Packing Boxes

This isn’t good enough

because it’s still two boxes...

But this works!
Packing Boxes

And here’s 8 fish:
Packing Boxes

And here’s 8 fish:

And here’s 16 fish!
Packing Boxes

And here’s 8 fish:

And here’s 16 fish!

But what if we just add 1 fish, instead of doubling the fish?

But what if we have 0 fish?
General Strategy for Packing Boxes

Here’s a general strategy:

- For 0 fish, use **empty**
- If you have a package and a new fish, put them together

To combine many fish, start with **empty** and add fish one at a time
General Strategy for Packing Boxes

Here’s a general strategy:

• For 0 fish, use empty

• If you have a package and a new fish, put them together

To combine many fish, start with empty and add fish one at a time empty
General Strategy for Packing Boxes

Here’s a general strategy:

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To combine many fish, start with **empty** and add fish one at a time
To represent the aquarium as a list of numbers, use the same idea:

- For 0 fish, use `empty`
- If you have a list and a number, put them together with `make-bigger-list`
General Strategy for a List of Numbers

To represent the aquarium as a list of numbers, use the same idea:

- For 0 fish, use `empty`
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General Strategy for a List of Numbers

To represent the aquarium as a list of numbers, use the same idea:

- For 0 fish, use `empty`
- If you have a list and a number, put them together with
  `make-bigger-list`

\[
\text{empty}
\]

\[
(\text{make-bigger-list} \ 10 \ \text{empty})
\]
General Strategy for a List of Numbers

To represent the aquarium as a list of numbers, use the same idea:

- For 0 fish, use `empty`
- If you have a list and a number, put them together with `make-bigger-list`

```
(make-bigger-list 10 empty)
(make-bigger-list 5 (make-bigger-list 10 empty))
```
General Strategy for a List of Numbers

To represent the aquarium as a list of numbers, use the same idea:

- For 0 fish, use \texttt{empty}
- If you have a list and a number, put them together with \texttt{make-bigger-list}

\begin{verbatim}
(make-bigger-list 10 empty)
(make-bigger-list 5 (make-bigger-list 10 empty))
(make-bigger-list 7 (make-bigger-list 5 (make-bigger-list 10 empty)))
\end{verbatim}
List of Numbers

; A list-of-num is either
;   - empty
;   - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))
List of Numbers

; A list-of-num is either
;   - empty
;   - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))

Generic template:
; func-for-lon : list-of-num -> ...
(define (func-for-lon l)
  ...)

List of Numbers

; A list-of-num is either
;  - empty
;  - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))

Generic template:
; func-for-lon : list-of-num -> ...
(define (func-for-lon l)
  (cond
   [(empty? l) ...]
   [(bigger-list? l) ...]))
List of Numbers

; A list-of-num is either
;   - empty
;   - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))

Generic template:
; func-for-lon : list-of-num -> ...
(define (func-for-lon l)
  (cond
    [(empty? l) ...]
    [(bigger-list? l)
     ... (bigger-list-first l)
     ... (bigger-list-rest l)
     ...]])
List of Numbers

; A list-of-num is either
;  - empty
;  - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))

Generic template:
; func-for-lon : list-of-num -> ...
(define (func-for-lon l)
  (cond
   [(empty? l) ...]
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    ... (bigger-list-first l)
    ... (bigger-list-rest l)
    ...]))
; A list-of-num is either
; - empty
; - (make-bigger-list num list-of-num)
(define-struct bigger-list (first rest))

Generic template:
; func-for-lon : list-of-num → ...
(define (func-for-lon l)
  (cond
    [(empty? l) ...]
    [(bigger-list? l)
      ... (bigger-list-first l)
      ... (func-for-lon (bigger-list-rest l))
      ...])))
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  ...)

Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  ...)

(aq-weight empty) "should be" 0
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  ...)

(aq-weight empty) "should be" 0

(aq-weight (make-bigger-list 2 empty))
"should be" 2
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  ...
)

(aq-weight empty) "should be" 0

(aq-weight (make-bigger-list 2 empty))
"should be" 2

(aq-weight (make-bigger-list 5 (make-bigger-list 2 empty)))
"should be" 7
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  (cond
    [(empty? l) ...]
    [(bigger-list? l)
     ... (bigger-list-first l)
     ... (aq-weight (bigger-list-rest l))
     ...]]))

(aq-weight empty) "should be" 0

(aq-weight (make-bigger-list 2 empty))
"should be" 2

(aq-weight (make-bigger-list 5 (make-bigger-list 2 empty)))
"should be" 7
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  (cond
   [(empty? l) 0]
   [(bigger-list? l)
    (+ (bigger-list-first l)
       (aq-weight (bigger-list-rest l)))]))

(aq-weight empty) "should be" 0

(aq-weight (make-bigger-list 2 empty)) "should be" 2

(aq-weight (make-bigger-list 5 (make-bigger-list 2 empty))) "should be" 7
Aquarium Weight

; aq-weight : list-of-num -> num
; Sums the fish weights in l
(define (aq-weight l)
  (cond
   [(empty? l) 0]
   [(bigger-list? l)
     (+ (bigger-list-first l)
       (aq-weight (bigger-list-rest l)))]))

Try examples in the stepper

(aq-weight empty) "should be" 0

(aq-weight (make-bigger-list 2 empty)) "should be" 2

(aq-weight (make-bigger-list 5 (make-bigger-list 2 empty))) "should be" 7
Pipes

- Pipes end in faucets (open or closed) and sometimes branch
Pipes

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Pipes

- Pipes end in faucets (open or closed) and sometimes branch

; A pipeline is either
;  - bool
;  - (make-straight sym pipeline)
;  - (make-branch pipeline pipeline)
(define-struct straight (kind next))
(define-struct branch (next1 next2))
Example Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)

false
Example Pipelines

; A pipeline is either
;  - bool
;  - (make-straight sym pipeline)
;  - (make-branch pipeline pipeline)

true
Example Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)

(make-straight 'copper false)
Example Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)

(make-straight 'copper
  (make-straight 'lead false))
Example Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)

(make-branch
  (make-branch (make-straight 'copper true) false)
  (make-branch false false))
Programming with Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)
Programming with Pipelines

; A pipeline is either
;   - bool
;   - (make-straight sym pipeline)
;   - (make-branch pipeline pipeline)
Programming with Pipelines

; A pipeline is either
;  - bool
;  - (make-straight sym pipeline)
;  - (make-branch pipeline pipeline)

(define (func-for-pipeline pl)
  (cond
[(boolean? pl) ...]
[(straight? pl)
  ... (straight-kind pl)
  ... (func-for-pipeline (straight-next pl)) ...]
[(branch? pl)
  ... (func-for-pipeline (branch-next1 pl))
  ... (func-for-pipeline (branch-next2 pl)) ...]])
Programming with Pipelines

; A pipeline is either
; - bool
; - (make-straight sym pipeline)
; - (make-branch pipeline pipeline)

(define (func-for-pipeline pl)
  (cond
    [(boolean? pl) ...]
    [(straight? pl)
      ... (straight-kind pl)
      ... (func-for-pipeline (straight-next pl)) ...]
    [(branch? pl)
      ... (func-for-pipeline (branch-next1 pl))
      ... (func-for-pipeline (branch-next2 pl)) ...])))
Pipeline Examples

- Implement the function `water-running?` which takes a pipeline and determines whether any faucets are open
- Implement the function `modernize` which takes a pipeline and converts all ‘lead’ straight pipes to ‘copper’
- Implement the function `off` which takes a pipeline and turns off all the faucets
- Implement the function `lead-off` which takes a pipeline and turns off all the faucets that receive water through a lead pipe
- Implement the function `twice-as-long` which takes a pipeline and inserts a ‘copper’ straight pipe before every existing piece of the pipeline