Teach Scheme!
A Checkpoint

Matthias Felleisen (PLT)
Northeastern University

Teach Scheme, NOT A Checkpoint

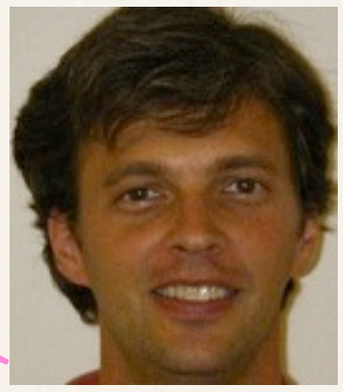
Matthias Felleisen (PLT)
Northeastern University

Thank You!

If functional programming is that good, why is it so difficult to learn?

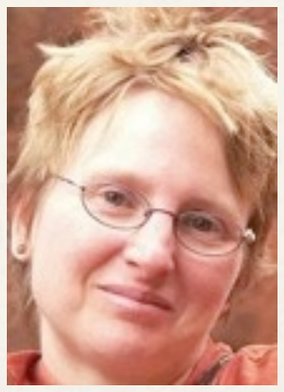
TeachScheme!

Shriram Krishnamurthi



Matthew Flatt

Robby Findler



Kathi Fisler

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If functional programming is that good, why is it so difficult to learn?

TeachScheme!

Shriram Krishnamurthi

Matthew Flatt

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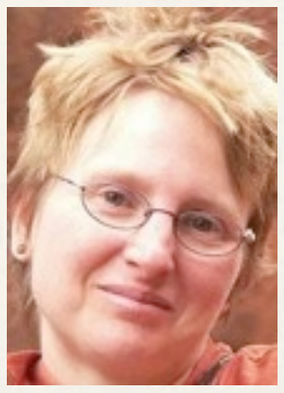
Dan Friedman



Kathi Fisler

Thank You, LFP/ICFP

Thank You, LFP/ICFP

A functional programming language is typed, lazy, *and* pure.

Thank You, LFP/ICFP

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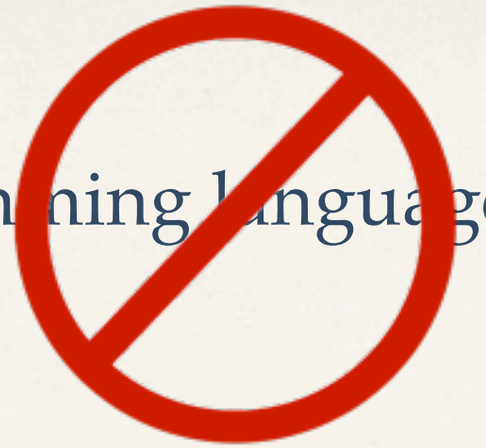

A functional programming language is typed, lazy, *and* pure.

Functional programming is one or many of:

typed

lazy

pure

Thank You, LFP/ICFP

A functional programming language is typed, lazy, *and* pure.

Functional programming is one or many of:

typed

lazy

pure

untyped

strict

impure

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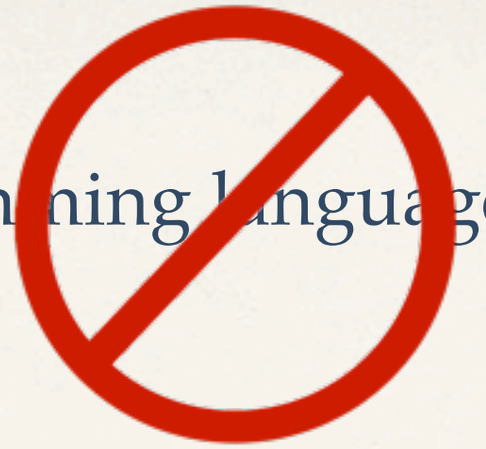

A functional programming language is typed, lazy, *and* pure.

Functional programming is one or many of:

typed

untyped

lazy

strict

impure

pure

sequential

parallel

concurrent

past

POPL '02: *Errors Matter*

ICFP '09:
Functional I/O

past

POPL '02: *Errors Matter*

ICFP '09: *Functional I/O*

From FP to Design and Beyond

Failures, What is Missing

From FP to Design and Beyond

Functional Programming is Good (TM).

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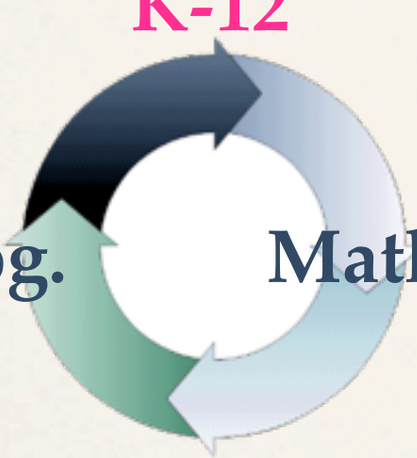
K-12

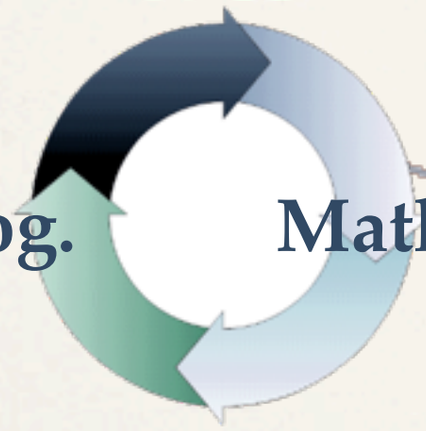


Func. Prog. Math. Instr.

Functional Programming is Good (TM).

Design for the Working SE (in College)

K-12



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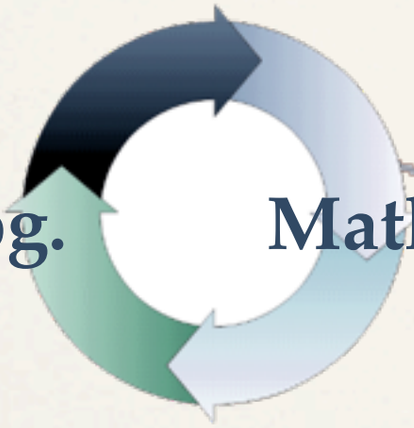

Func. Prog. **Math. Instr.**

systematic procedure

=

how to design

example 1

```
;; B -> R
(define (eval-> b)
  (cond
    [(eq? 't b) 't]
    [(eq? 'f b) 'f]
    [else (if (symbol=? (eval-> (first b)) 'f)
              (eval-> (third b))
              't)]))

(check-equal? (eval-> ex1) 't)
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example 2

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```

example 2

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(define (eval-> b)
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example 4

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;; B -> R
(define (eval-> b)
  (cond
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```

example 5

```
;; B -> R
(define (eval-> b)
  (cond
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    [else (if (symbol=? (eval-> (first b)) 'f)
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```

problem A

Design a program that does something like the program I did in class. Actually do ten or twenty or thirty of them,

problem B

Design a program that does something like the program I did in class. Actually do ten or twenty or thirty of them,

problem C

Design a program that does something like the program I did in class. Actually do ten or twenty or thirty of them,

problem D

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problem E

Design a program that does something like the program I did in class. Actually do ten or twenty or thirty of them,

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    [else (if (symbol=? (eval-> (first b)) 'f)
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(check-equal? (eval-> ex1) 't)
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example 2

```
;; B -> R
(define (eval-> b)
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    [else (if (symbol=? (eval-> (first b)) 'f)
              (eval-> (third b))
              't)]))

(check-equal? (eval-> ex1) 't)
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```

example 3

```
;; B -> R
(define (eval-> b)
  (cond
    [(eq?
    [(eq?
    [else

(check
(check
```

example 4

```
(first b)) 'f)
```

example 5

```
;; B -> R
(define (eval-> b)
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Teaching by example doesn't really work.

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Teaching features and tools doesn't work either.

But functional programming works, right?

But functional programming works, right?

```
;; These structs are used to represent
;; shapes in the Cartesian plain:

(struct rectangle (xmin xmax ymin ymax))
(struct circle (x y r))
(struct union (top bot))

;; Design the function shape-in?, which
;; determines whether some Cartesian
;; point is within some given shape.
```

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (cond
    [(rectangle? sh) (rectangle-in? sh x y)]
    [(circle? sh) (circle-in? x y sh)]
    [(union? sh)
     (or (shape-in? (union-top sh) x y)
         (shape-in? (union-bot sh) x y))]))
```

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (cond
    [(rectangle? sh) (rectangle-in? sh x y)]
    [(circle? sh) (circle-in? x y sh)]
    [(union? sh)
     (or (shape-in? (union-top sh) x y)
         (shape-in? (union-bot sh) x y))]))
```

Why is this good?

How did we get here?

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (match sh
    [(rectangle a b c d) (rectangle-in? sh x y)]
    [(circle xc yc r) (circle-in? x y sh)]
    [(union t b)
     (or (shape-in? t x y)
         (shape-in? b x y))]))
```

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
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;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (match sh
    [(rectangle a b c d) (rectangle-in? sh x y)]
    [(circle xc yc r) (circle-in? x y sh)]
    [(union t b)
     (or (shape-in? t x y)
         (shape-in? b x y))]))
```

Some might consider this a better solution.

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (match sh
    [(rectangle a b c d) (rectangle-in? sh x y)]
    [(circle xc yc r) (circle-in? x y sh)]
    [(union t b)
     (let ([in-t? (shape-in? t x y)]
           [in-b? (shape-in? b x y)])
       (or in-t? in-b?))]))
```

Why is this *bad*?

How can we prevent this?

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (match sh
    [(rectangle a b c d) (rectangle-in? sh x y)]
    [(circle xc yc r) (circle-in? x y sh)]
    [(union t b)
     (let ([in-t? (shape-in? t x y)])
       (or in-t?
           (set! in-t? (shape-in? b x y))
           in-t?))]))
```

Why is this *BAD*? How can we fail this solution?

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (shape-in? sh x y)
  (match sh
    [(rectangle a b c d) (rectangle-in? sh x y)]
    [(circle xc yc r) (circle-in? x y sh)]
    [(union t b)
     (let ([in-t? (shape-in? t x y)])
       (call/cc
         (lambda (exit)
           (or in-t?
               (exit true)
               (set! in-t? (shape-in? b x y))
               in-t?))))]))
```

Why is this *AWFUL*?

Why is it a 0/100?

```
;; [Listof Posn] -> Image
;; add red circles to background-scene for all positions in lop
(define (draw* lop) ...)
```

```
;; [Listof Posn] -> Image
;; add red circles to background-scene for all positions in lop
(define (draw* lop) ...)
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```
(define (draw* lop)
  (cond
    [(empty? lop) background-scene]
    [else (draw-one (draw* (rest lop)) (first lop))]))
```

```
;; [Listof Posn] -> Image
;; add red circles to background-scene for all positions in lop
(define (draw* lop) ...)
```

```
(define (draw* lop)
  (cond
    [(empty? lop) background-scene]
    [else (draw-one (draw* (rest lop)) (first lop))]))
```

```
(define (draw* lop)
  (foldl draw-one background-scene lop))
```

Why is this good?

How did we get here??

```
;; [Listof Number] -> [Listof Number]
;; Given a list of relative distances (lord)
;; produce a list of absolute distances
```

```
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;; Given a list of relative distances (lord)
;; produce a list of absolute distances
```

```
(define (absolute lord)
  (cond
    [(empty? lord) '()]
    [else (cons (first lord)
                (map (curry + (first lord))
                     (absolute (rest lord))))]))
```

```
;; [Listof Number] -> [Listof Number]
;; Given a list of relative distances (lord)
;; produce a list of absolute distances
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(define (absolute lord)
  (cond
    [(empty? lord) '()]
    [else (cons (first lord)
                (map (curry + (first lord))
                     (absolute (rest lord))))]))
```

```
(define (absolute.v2 lord0)
  ;; accumulator: so-far is distance
  ;;   between lord0 and lord
  (define (absolute lord so-far)
    (cond
      [(empty? lord) '()]
      [else (let* ([f (first lord)][d (+ f so-far)])
              (cons d (absolute (rest lord) d)))]))
  ;; -- IN --
  (absolute lord 0))
```

Why is this better?

How did we get here?

How do we get from the problem to the solution?

Can we get our students to repeat these thought processes on their own eventually?

Process

- represent information as data
- formulate signature & purpose
- illustrate with examples
- organize a program template
- code (define the function)
- turn examples into unit tests

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Principles

- recur structurally
- abstract from examples
- abstractions from types
- recur but generate
- ... with accumulators
- ... with mutable state

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Structural Template

- Does the data definition distinguish distinct subsets?
- Conditions over parameters that distinguish those?
- Do any of the lines involve compound data?
- Are there self-references in the data definitions?

Process

- information as data
- signature & purpose
- illustrate with examples
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Structural Coding

- Tackle the base cases first (with example).
- Otherwise remind yourself what the template expressions compute.
- Combine these values. Define auxiliaries if needed.

Process

- information as data
- signature & purpose
- ... examples
- organize template
- define the function
- examples as tests

```
;; EXERCISE:

;; Use structs to represent
;; shapes in the Cartesian plain:
;; * rectangles, * circles,
;; * combinations of two shapes.

;; Design the function shape-in?,
;; which determines whether some
;; coordinates are within a given
;; shape.
```

Process

- information as data
- signature & purpose
- ... examples
- organize template
- define the function
- examples as tests

```
(struct rectangle (xn xx yn yx))
(struct circle (x y r))
(struct union (top bot))
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (in? sh x y)
  (cond
    [(rectangle? sh)
     (rectangle-in? sh x y)]
    [(circle? sh)
     (circle-in? x y sh)]
    [(union? sh)
     (or (in? (union-top sh) x y)
         (in? (union-bot sh) x y))]))
```

Process

- information as data
- signature & purpose
- … examples
- organize template
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Process

- information as data
- signature & purpose
- … examples
- organize template
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;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
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;; is the point (x,y) within sh?
;; (3,4) is in (circle 0 0 5)
;; (3,4) not in (rectangle 0 1 0 1)
;; (3,4) in (union (circle 0 0 5) ...
(define (in? sh x y)
  (cond
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     (rectangle-in? sh x y)]
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     (circle-in? x y sh)]
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```

Process

- information as data
- signature & purpose
- illustrate with examples
- organize a template
- define the function
- examples as tests

Template

- Does the data definition distinguish distinct subsets?
- Conditions over parameters that distinguish those?
- Do any of the lines involve compound data?
- Are there self-references in the data definitions?

Template

- ... data ... distinct subsets
- ... conditions ... parameters?
- .. compound data?
- ... self-references ... in data definition?

```
;; A Shape is one of:
;; -- (rectangle Int Int Int Int)
;; -- (circle Int Int Int)
;; -- (union Shape Shape)

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Template

- ... data ... distinct subsets
- ... conditions ... parameters?
- .. compound data?
- ... self-references ... in data definition?

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Template

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;; (3,4) in (union (circle 0 0 5) ...
(define (in? sh x y)
  (cond
    [(rectangle? sh) (rectangle-x sh)
     ... (rectangle-y sh) ...]
    [(circle? sh) (circle-x sh) ...
     (circle-y sh) ... (circle-r sh)]
    [(union? sh)
     (or (in? (union-top sh) x y)
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```

Template

- ... data ... distinct subsets
- ... conditions ... parameters?
- .. compound data?
- ... self-references ... in data definition?

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Template

- information as data
- signature & purpose
- … examples
- organize template
- define the function
- examples as tests

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Template

- information as data
- signature & purpose
- … examples
- organize template
- define the function
- examples as tests

```
;; A Shape is one of:
;; ...

;; Shape Int Int -> Boolean
;; is the point (x,y) within sh?
(define (in? sh x y)
  (cond
    [(rectangle? sh)
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    [(circle? sh)
     (circle-in? x y sh)]
    [(union? sh)
     (or (in? (union-top sh) x y)
         (in? (union-bot sh) x y))]))

(check-expect
  (in? (circle 0 0 5) 3 4) true)
(check-expect
  (in? (union ... ...) 3 4) true)
```

Process

- information as data
- signature & purpose
- illustrate with examples
- organize a template
- define the function
- examples as tests

How it all helps ...

where are you stuck?

Process

- information as data
- signature & purpose
- illustrate with examples
- organize a template
- define the function
- examples as tests

How it all helps ...

where are you stuck?

Process

- information as data
- signature & purpose
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- define the function
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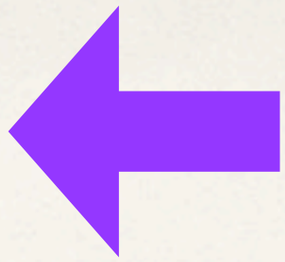
How it all helps ...

where are you stuck?

The design process and principles are *also* pedagogic *diagnostic* tools that help students help themselves.

Principles

- recur structurally
- abstract from examples
- abstractions from types
- recur with generate
- ... with accumulators
- ... with mutable state



how does it work here?

Principles

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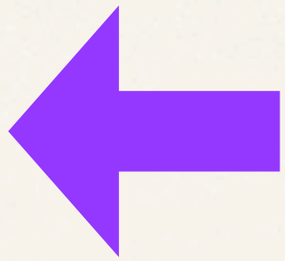

how does it work here?

How the *Process* applies to abstract: the template

```
;; [Listof Number] -> [Listof Boolean]
(define (good lon)
  (cond
    [(empty? lon) '()]
    [else (cons (negative? (first lon)) (good (rest lon)))]))
```

```
;; [Listof PersonnelRecord] -> [Listof Salary]
(define (salary* lon)
  (cond
    [(empty? lon) '()]
    [else (cons (pr-dat (first lon)) (salary* (rest lon)))]))
```

How the *Process* applies to abstract: the template

```
;; [Listof Number] -> [Listof Boolean]
(define (good lon)
  (cond
    [(empty? lon) '()]
    [else (cons (negative? (first lon)) (good (rest lon)))]))
```

```
;; [Listof PersonnelRecord] -> [Listof Salary]
(define (salary* lon)
  (cond
    [(empty? lon) '()]
    [else (cons (pr-dat (first lon)) (salary* (rest lon)))]))
```

How the *Process* applies to abstract: the coding & testing

```
;; [Listof X] [X -> Y] -> [Listof Y]
(define (map lon f)
  (cond
    [(empty? lon) '()]
    [else (cons (f (first lon)) (map (rest lon) f))]))

;; tests
(define (good lon) (map lon negative?))
(define (salary* lon) (map lon pr-salary))
```

Principles

- recur structurally
- abstract from examples
- abstractions from types
- recur with generate
- ... with accumulators
- ... with mutable state

the design process
works everywhere

but there is a problem:
if you accept ***design principle,*** the old ideas
on freshman course don't work

Principles

- recur structurally
- abstract from examples
- abstractions from types
- generative recursion
- ... with accumulators
- ... with mutable state

It replaces Turing power (and Felleisen power) with design.

Principles

- recur structurally
- abstract from examples
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It replaces Turing power (and Felleisen power) with design.

Turing and Felleisen power is *large enough*.

Principles

- recur structurally
- abstract from examples
- abstractions from types
- generative recursion
- ... with accumulators
- ... with mutable state

It replaces Turing power (and Felleisen power) with design.

Turing and Felleisen power is *large enough*.

... but students can't design accumulator-style yet

Principles

- recur structurally
- abstract from examples
- abstractions from types
- generative recursion
- ... with accumulators
- ... with mutable state

even with higher-order functions, it is impossible to ***design*** QUICKSORT

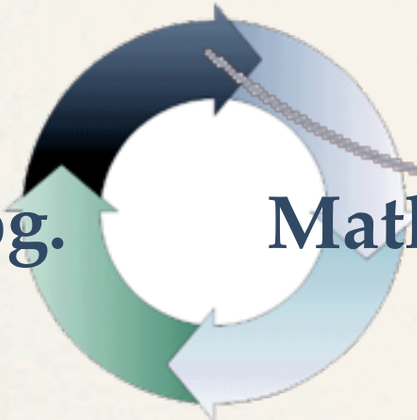
Principles

- recur structurally
- abstract from examples
- abstractions from types
- generative recursion
- ... with accumulators
- ... with mutable state

even with higher-order functions, it is impossible to ***design*** a terminating GRAPH TRAVERSAL

Upstream, Downstream

Design for the Working SE



Func. Prog. **Math. Instr.**

K-12

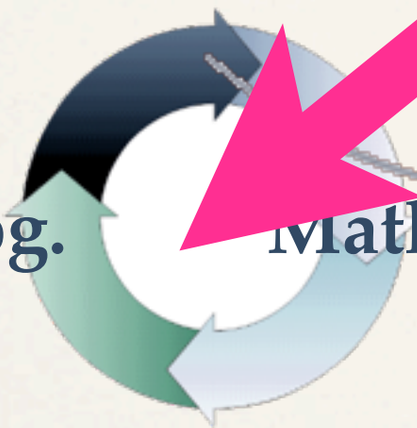
systematic procedure

=

how to design

Design for the Working SE

how about upstream?



Func. Prog. **Math. Instr.**

K-12

systematic procedure

=

how to design

Kids want to have **fun**,
but they are willing to learn
more than teachers grant

```
;; ClockTicks -> Image
(define (flying-soccer-ball t)
  (place-image 
               X0 (y t)
               BACKGROUND))

;; run program run:
(animate flying-soccer-ball)
```

Kids want to have **fun**,
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```
;; ClockTicks -> Image
(define (flying-soccer-ball t)
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;; run program run:
(animate flying-soccer-ball)
```

Kids want to have **fun**,
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more than teachers grant

```
(big-bang GameState0
  (to-draw ;; GameState -> Image
           render-state-as-image)
  (on-tick ;; GameState -> GameState
           handle-clock-tick)
  (on-key  ;; GameState KeyEvent -> GameState
           handle-key-event)
  ...)
```

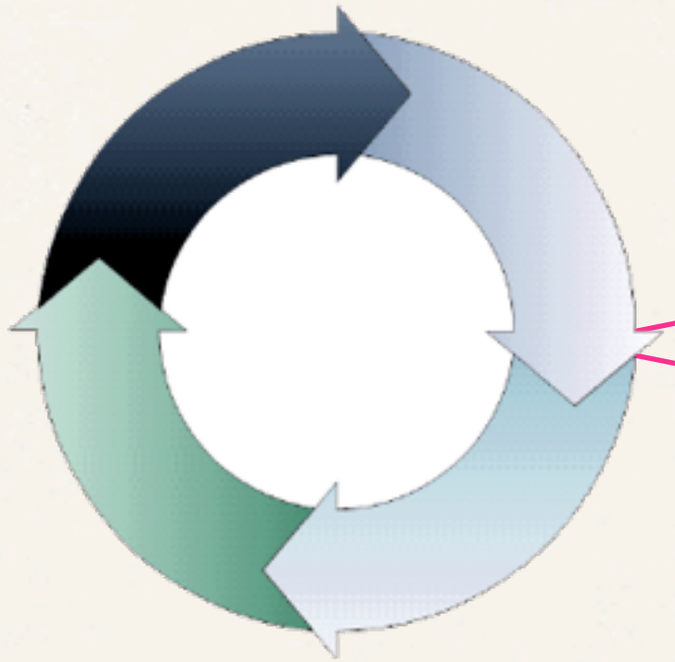
- images as a datatype
- functional animations
- functional interactive games

Kids want to have **fun**,
but they are willing to learn more than teachers grant

Felleisen, Findler, Flatt, Krishnamurthi
A Functional I/O System
ICFP 2009, Edinburgh

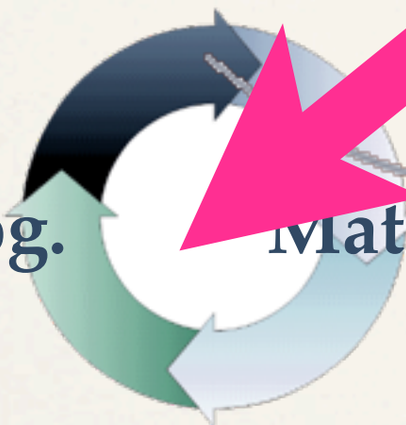
Kids want to have **fun**,
but they are willing to learn more than teachers grant

Functional Programming & Design



- algebra, *n*-ary functions
- geometry & trigonometry
- even pre-calculus

helping kids,
helps freshman



Func. Prog. Math. Instr.

K-12

Design for the Working SE

systematic procedure
=
how to design

Design for the Working SE

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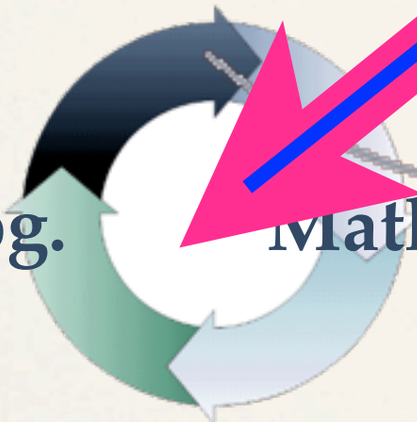


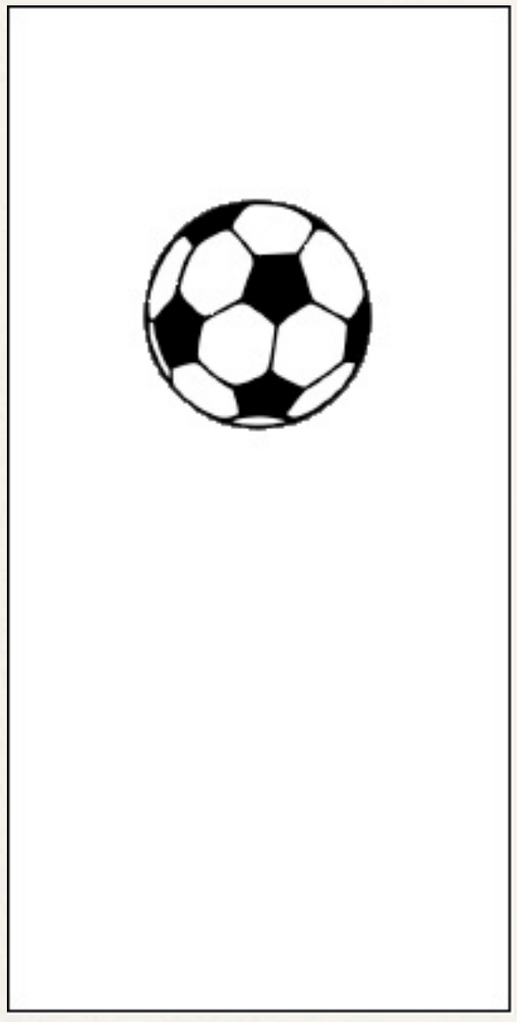
Func. Prog. **Math. Instr.**

K-12

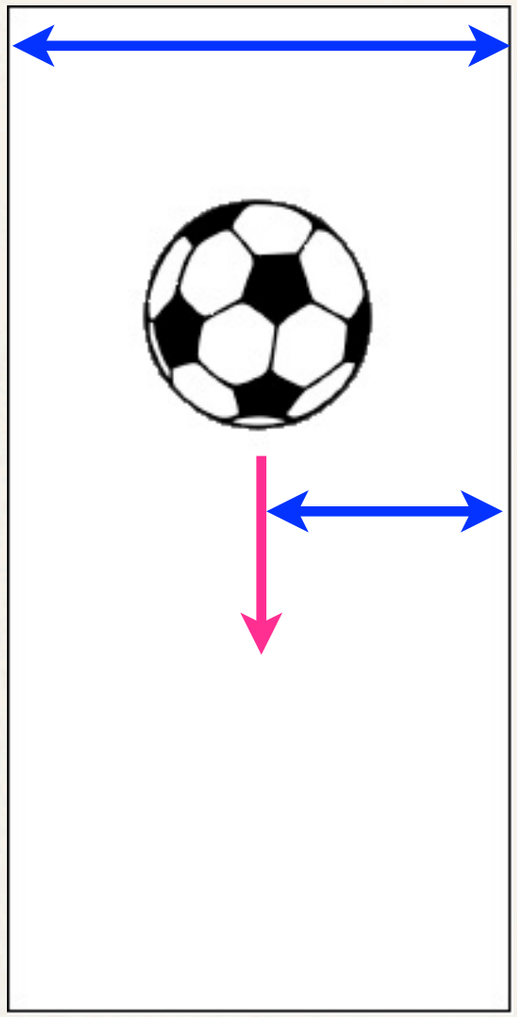
systematic procedure
=
how to design

How to Design ... Worlds

How to Design ... Worlds

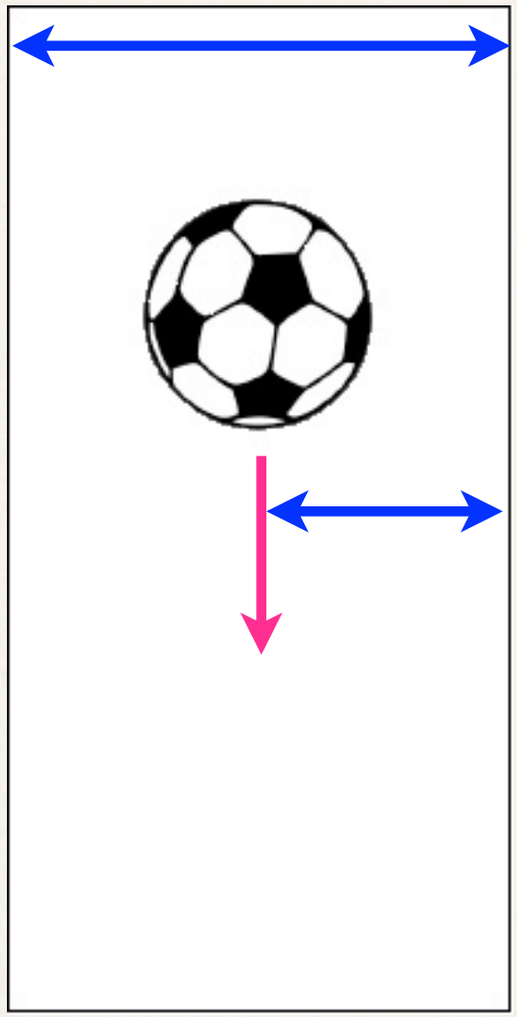


How to Design ... Worlds



1. Identify those properties that change and those that remain the same.

How to Design ... Worlds



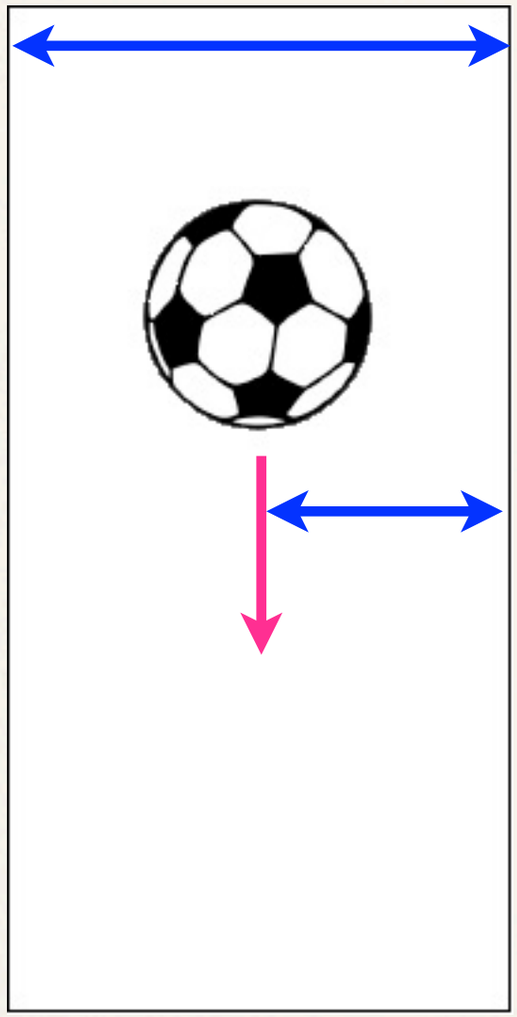
1. Identify those properties that change and those that remain the same.

2. Formulate data definitions (GameState) for properties that change and constant definitions for those that don't.

This creates a function wish list:

```
;; tickh: GameState-> GameState
;; keyh: GameState KeyEvent -> GameState
;; mouseh: GameState ... -> GameState
...
```

How to Design ... Worlds



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;; tickh: GameState-> GameState
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```

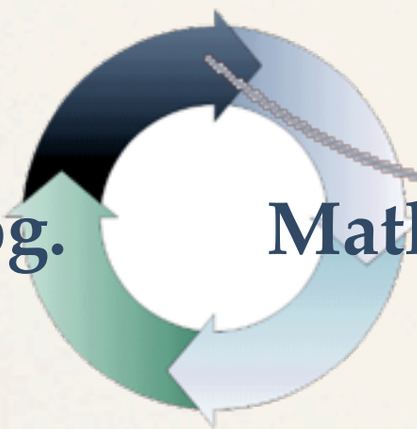
3. Associate game actions (movement of ball) to world actions (clock tick, key handler, mouse event, etc).

Worlds provide a place to start, and a wish list to work off.

- Program design driven by wish lists.
- Functions organized around data (OO).
- Mostly structural designs.

Design for the Working SE

Func. Prog. **Math. Instr.**



K-12

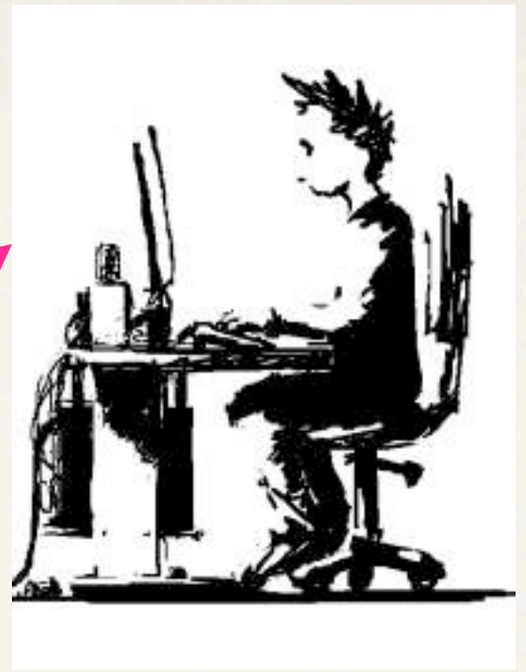
systematic procedure

=

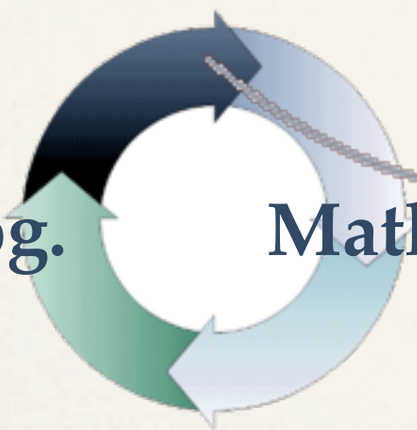
how to design,

but don't forget some fun

how about downstream?



Design for the Working SE



Func. Prog. **Math. Instr.**

K-12

systematic procedure

=

how to design,

but don't forget some fun

HtDP

structure

animation

abstraction

games

generative

client & server

accumulator

Downstream: Challenges & Opportunities

HtDP

structure

animation

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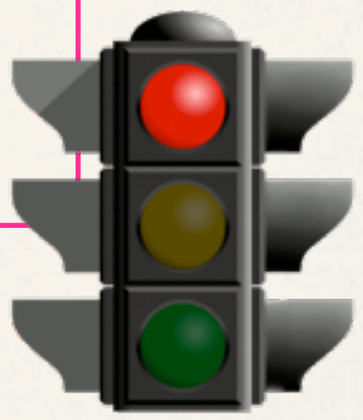
accumulator

Downstream: Challenges & Opportunities

what if a student must us JAVA or PYTHON on the first co-op?



HtDP

structure

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Downstream: Challenges & Opportunities

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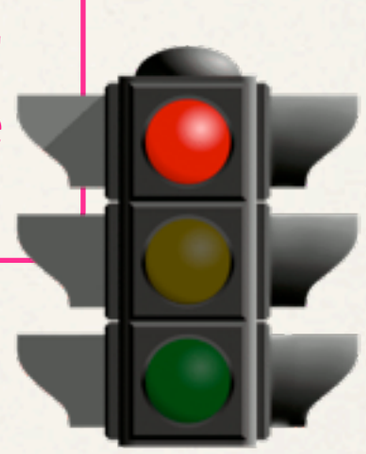
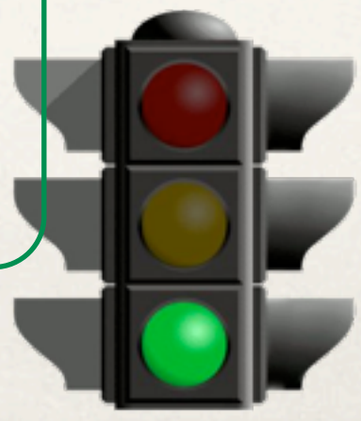


what can we teach students that we couldn't have taught them before?



HtDP

structure

abstraction

generative

accumulator

Downstream: how to connect to industrial practice (OOP)

HtDC

structure ~ class organization

structure & state

abstraction ~ inheritance & overriding

abstraction ~ traversals

abstraction ~ generics

---

design ~ OO patterns

---

iteration vs OO methods

APIs & iteration

HtDP

structure
abstraction
generative
accumulator

Downstream: how to connect to industrial practice (OOP)

HtDC

structure ~ class organization

structure & state

abstraction ~ inheritance & overriding

abstraction ~ traversals

abstraction ~ generics

design ~ OO patterns

iteration vs OO methods

APIs & iteration

Problem isolated, but not solved

HtDP

structure

animation

abstraction

games

generative

client & server

accumulator

Downstream @ Northeastern
introduce freshmen
to theorem proving
about interesting programs

Logic and Program Design

unit tests ~ conjectures: QuickCheck

conjectures ~ explicit proofs & theorems

games ~ automatic theorem proving

structure ~ automatic theorem proving

---

theorems: games ~ virtual machines

ACL2 isn't Racket: lack of safety

ACL2 isn't Racket: lack of modules

ACL2 isn't Racket: lack of HO functions

HtDP

structure

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Logic and Program Design

unit tests ~ conjectures: QuickCheck

conjectures ~ explicit proofs & theorems

games ~ automatic theorem proving

structure ~ automatic theorem proving

reward!

---

theorems: games ~ virtual machines

ACL2 isn't Racket: lack of safety

ACL2 isn't Racket: lack of modules

ACL2 isn't Racket: lack of HO functions

Summary

How to Design Classes

Logic and Program Design

How to Design Programs

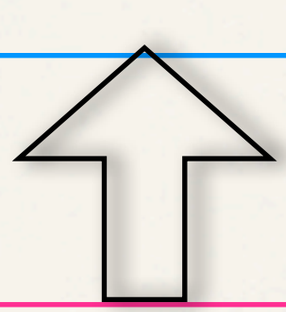
Freshman Year

Summary

large scale
semester-long
unit and system tests
team rotation

Software Development

Middler Year



How to Design Classes

Logic and Program Design

How to Design Programs

Freshman Year

Failures & Challenges

Untitled 2 - DrRacket

```
;; ClockTicks -> Image
(define (flying-soccer-ball t)

  (place-image  X0 (y t) BACKGROUND))

;; run program run:
(animate flying-soccer-ball)
```

```
Welcome to DrRacket, version 5.0.1.6--2010-09-23(3d16dd6/g) [3m].
Language: Beginning Student.
101
>
```

Beginning Student 24:0 245.43 MB

Teaching languages matter.

The IDE matters.

Untitled 2 - DrRacket

```
;; ClockTicks -> Image
(define (flying-soccer-ball t)

  (place-image  X0 (y t) BACKGROUND))

;; run program run:
(animate flying-soccer-ball)
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Welcome to DrRacket, version 5.0.1.6--2010-09-23(3d16dd6/g) [3m].
Language: Beginning Student.
101
>
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Teaching languages matter.

The IDE matters.

Beginning Student 24:0 245.43 MB

We failed to bring across how much they matter:

Crestani & Sperber, ICFP '10

Untitled 2 - DrRacket

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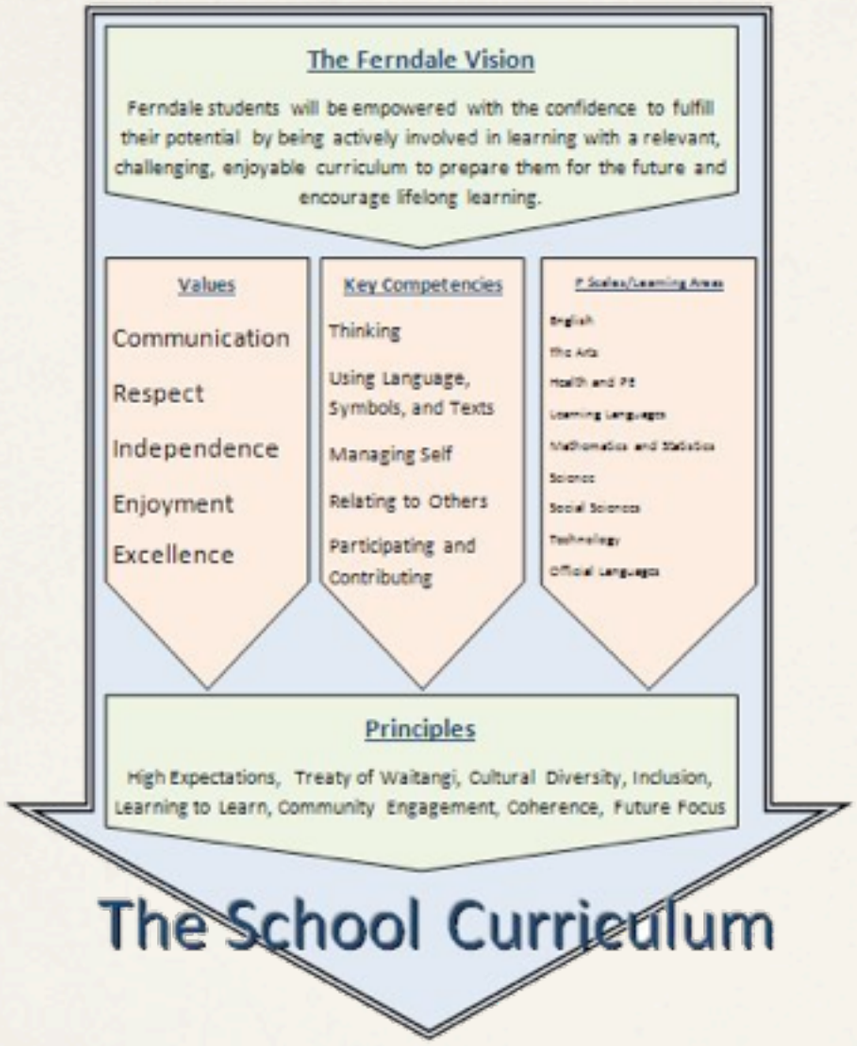
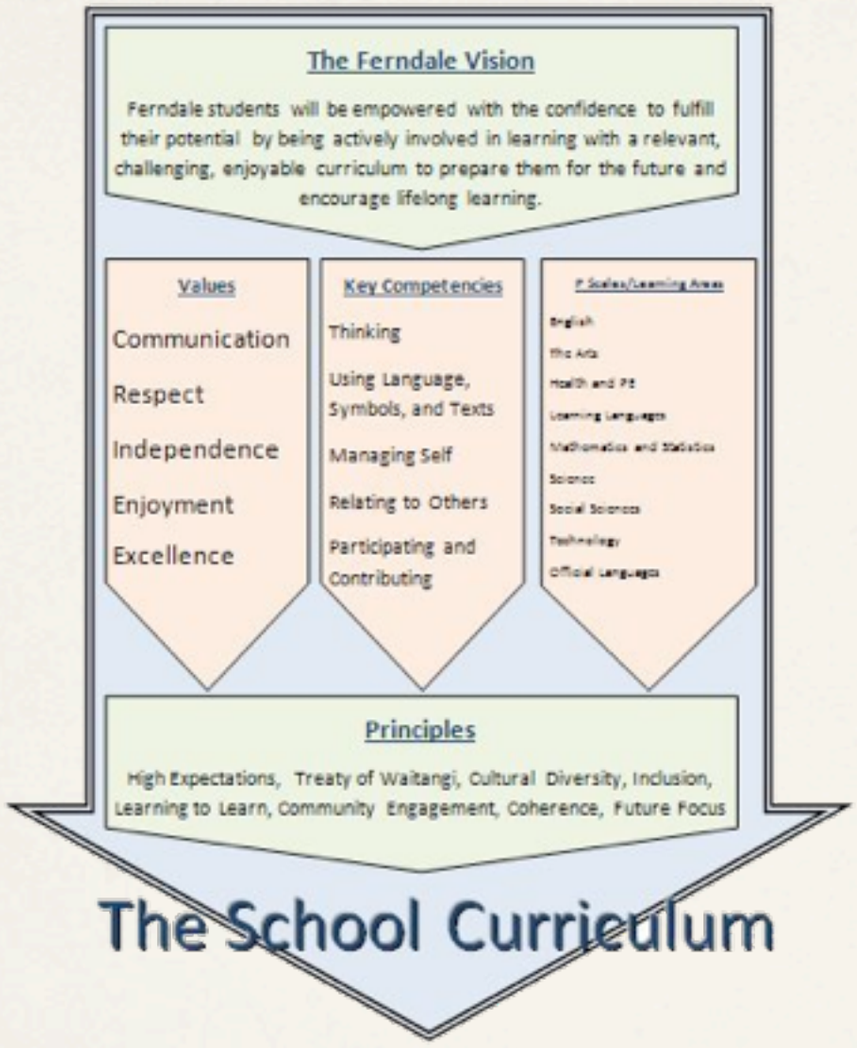
We failed to evaluate them scientifically and systematically:
Marceau, Fisler, & Krishnamurthi, SFP '10



Changing the curriculum is difficult.

A new effort has one shot only.



Choose your name wisely.
To this day people think
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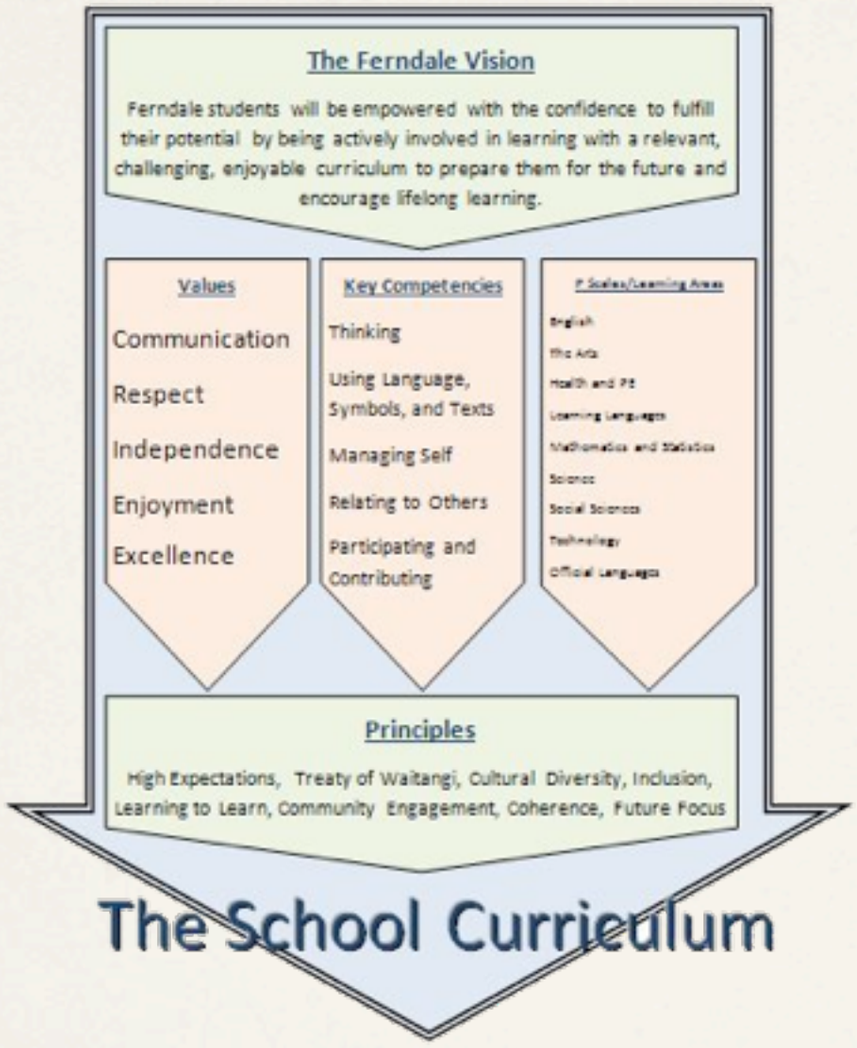

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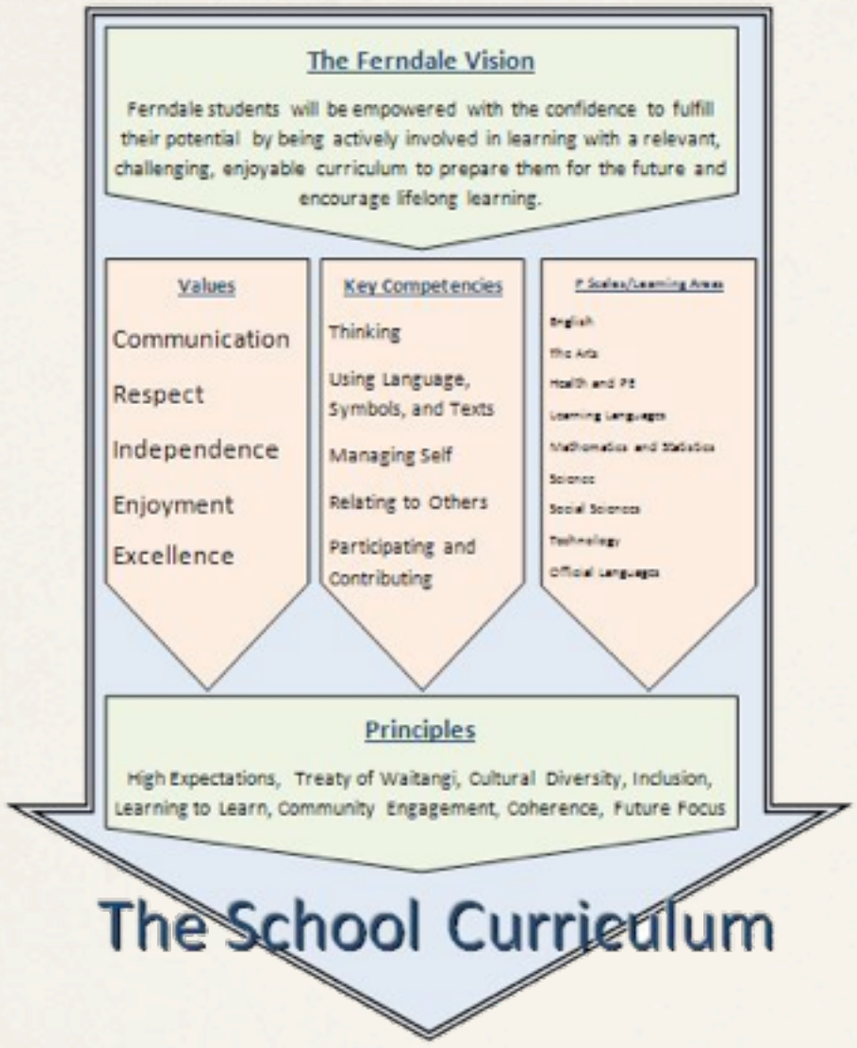

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Get consumers involved.
Appreciate *all* contributions from teachers.

All computer science curricula start from a course on the *currently fashionable* programming language.

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Every first course must be about *a programming language.* Yours must be about Scheme. What's this **DESIGN** stuff?

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Every first course must be about *a programming language.* Yours must be about Scheme. What's this **DESIGN** stuff?

Our curriculum requires **whole-sale adoption**. It is nearly impossible to integrate bits and pieces.

It is *not* about
imperative vs **functional**
programming.

It is about
inductive vs **indexed**
programming.

Where are the for loops?

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imperative vs **functional**
programming.

It is about
inductive vs **indexed**
programming.

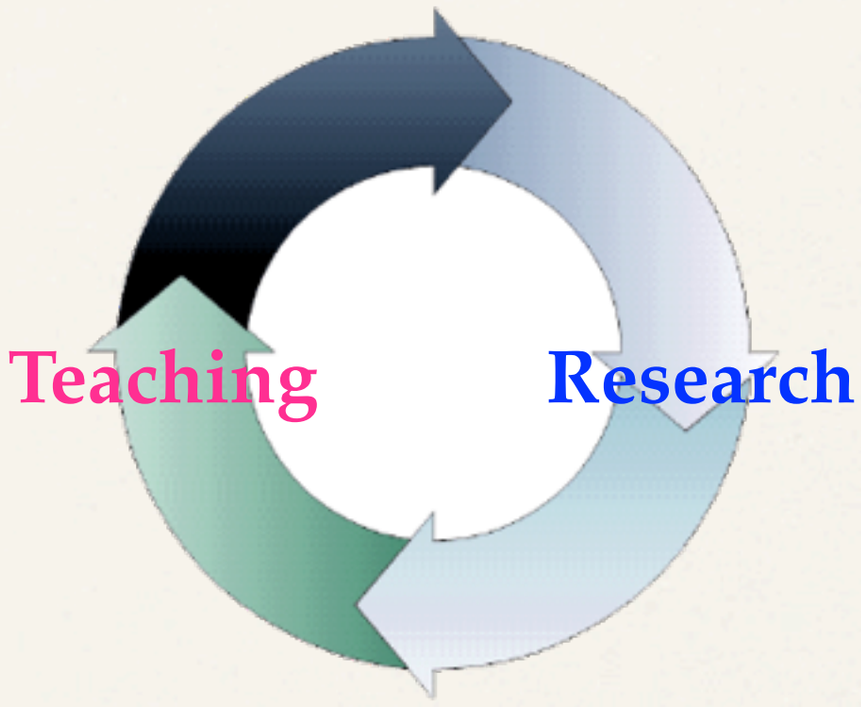
Where are the for loops?

Challenge: we need a design recipe for dealing with indexed data structures *well*.

Our community is you.
Getting involved is
good for the kids
and good for you.

Get our community involved.

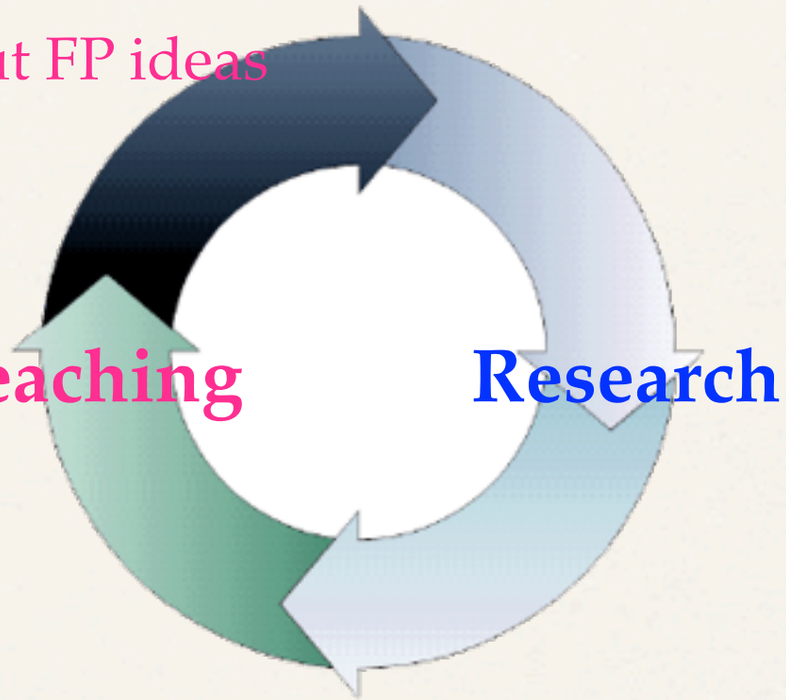
The Virtuous Cycle of Teaching & Research



The Virtuous Cycle of Teaching & Research

It's not about Racket, its about FP ideas

It's about changing Comp Sci



And we can help others, too

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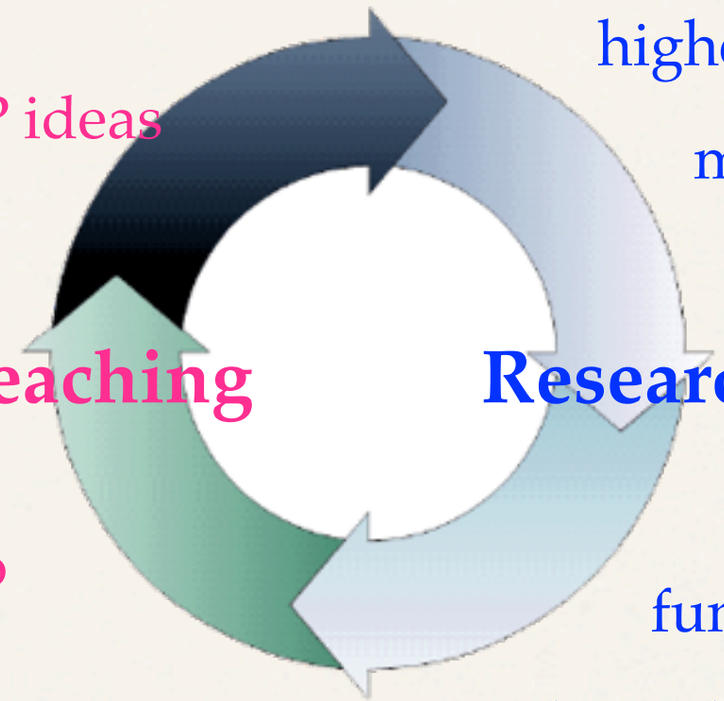

the language is the OS (ICFP '00)

higher-order contracts (ICFP '02)

modularized macros (ICFP '02)

slideshow (ICFP '05)

JVM continuations (ICFP '07)

scribbling manuals (ICFP '09)

functional (gui) i/o (ICFP '09

logical occurrence typing (ICFP '10)

fortified macros (ICFP '10)

Conclusions

- Design is a topic.

- Teaching is a means to explore design. And it helps people.

- Research follows naturally.

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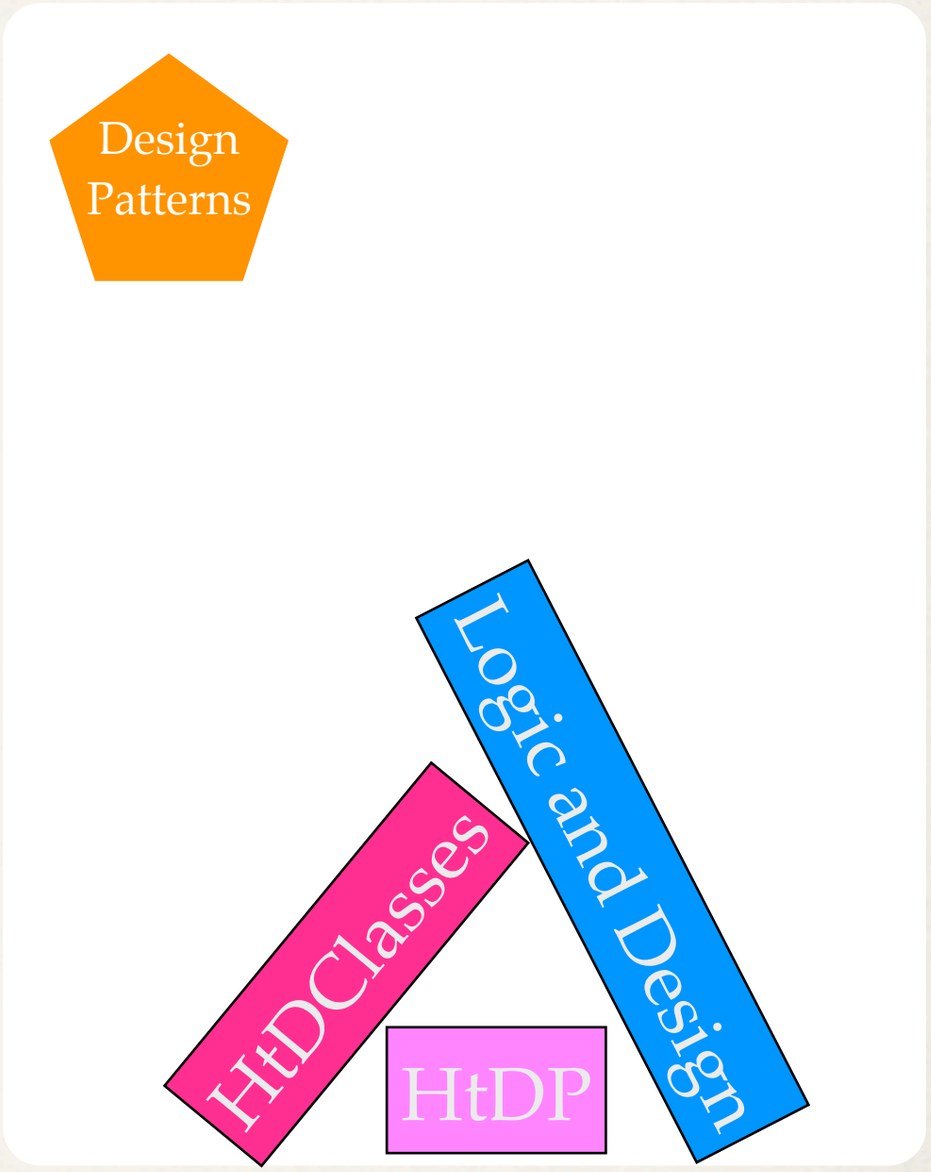

Design is a big map with lots of white space.

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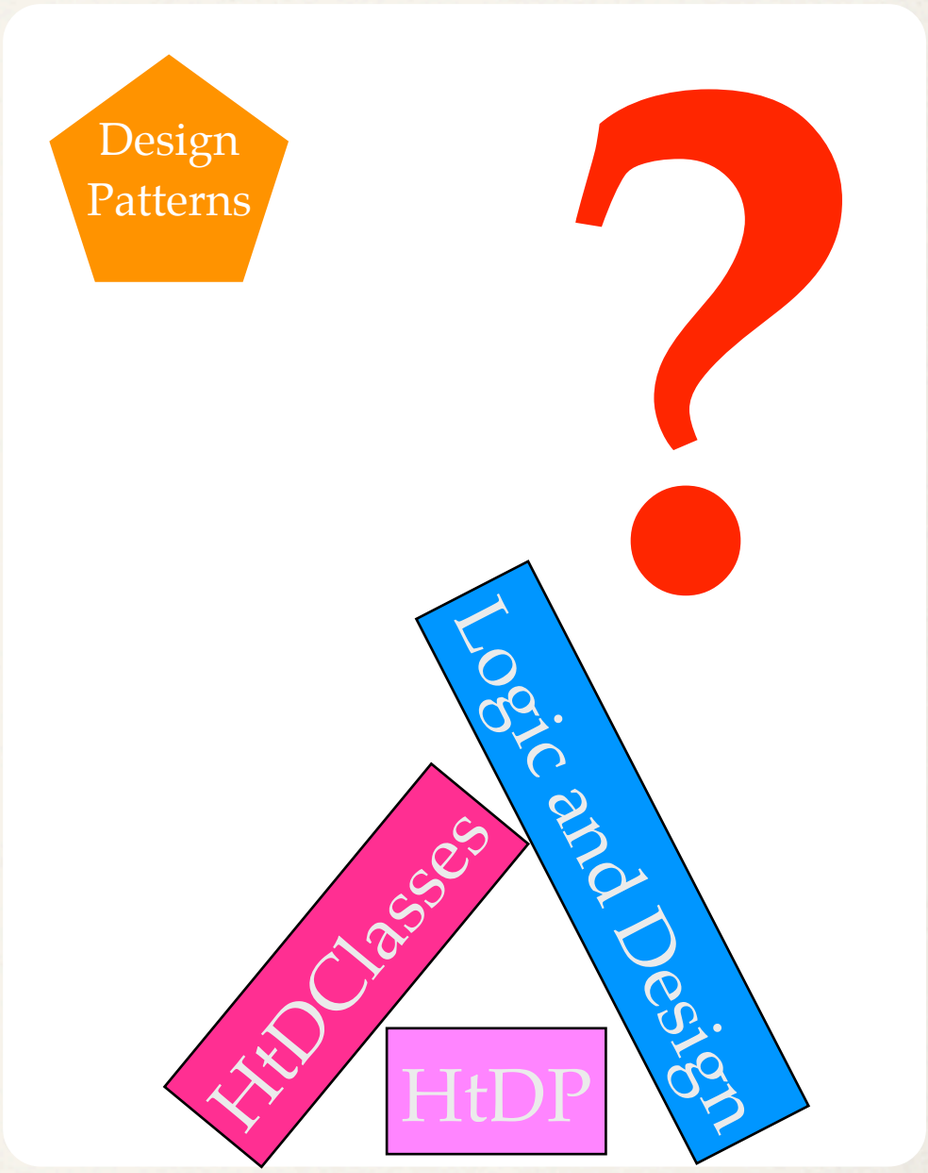

Design is a big map with lots of white space.

The End

(in order of appearance)

The End

(in order of appearance)

Matthew Flatt
Shriram Krishnamurthi
Robby Findler
Kathi Fisler
John Clements
Paul Graunke
Kathy Gray
Scott Owen
Jacob Matthews
Adam Wick
Paul Steckler
Philippe Meunier

Eli Barzilay
Jay McCarthy
Mike Sperber
Sam Tobin-Hochstadt
Carl Eastlund
Ryan Culpepper
Stevie Strickland
Casey Klein
Christos Dimoulas
Kevin Tew
Jon Rafkind
Danny Yoo
Guillaume Marceau
Vincent St. Amour
James Swaine
Stephen Chang