Getting Started:

Arithmetic, Algebra, and Computing

Arithmetic is Computing

- Fixed, pre-defined rules for ***primitive operators***:

$$2 + 3 = 5$$

$$4 \times 2 = 8$$

$$\cos(0) = 1$$

Arithmetic is Computing

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- Rules for combining other rules:
  - Evaluate sub-expressions first

$$4 \times (2 + 3) \quad \rightarrow \quad 4 \times 5 \quad \rightarrow \quad 20$$

Arithmetic is Computing

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$$2 + 3 \quad \rightarrow \quad 5$$

$$4 \times 2 \quad \rightarrow \quad 8$$

$$\cos(0) \quad \rightarrow \quad 1$$

- Rules for combining other rules:
  - Evaluate sub-expressions first

$$4 \times (2 + 3) \quad \rightarrow \quad 4 \times 5 \quad \rightarrow \quad 20$$

  - Precedence determines subexpressions:

$$4 + 2 \times 3 \quad \rightarrow \quad 4 + 6 \quad \rightarrow \quad 10$$

Algebra as Computing

- Definition:

$$f(x) = \cos(x) + 2$$

- Expression:

$$f(0) \rightarrow \cos(0) + 2 \rightarrow 1 + 2 \rightarrow 3$$

Algebra as Computing

- ○ Definition:

$$f(x) = \cos(x) + 2$$

- ○ Expression:

$$f(0) \rightarrow \cos(0) + 2 \rightarrow 1 + 2 \rightarrow 3$$

- First step uses the ***substitution*** rule for functions

Scheme Notation

- Put all operators at the front
- Start every operation with an open parenthesis
- Put a close parenthesis after the last argument
- Never add extra parentheses

Old	**New**
$1 + 2$	`(+ 1 2)`
$4 + 2 \times 3$	`(+ 4 (* 2 3))`
$\cos(0) + 1$	`(+ (cos 0) 1)`

Scheme Notation

- Use the keyword **`define`** instead of =
- Put **`define`** at the front, and group with parentheses
- Move open parenthesis from after function name to before

Old	New
f(x) = cos(x) + 2	`(define (f x) (+ (cos x) 2))`

Scheme Notation

- Use the keyword **`define`** instead of =
- Put **`define`** at the front, and group with parentheses
- Move open parenthesis from after function name to before

Old	New
f(x) = cos(x) + 2	`(define (f x) (+ (cos x) 2))`

- Move open parenthesis in function calls

Old	New
f(0)	`(f 0)`
f(2+3)	`(f (+ 2 3))`

Evaluation is the Same as Before

```
(define (f x) (+ (cos x) 2))

(f 0)
```

Evaluation is the Same as Before

```
(define (f x) (+ (cos x) 2))

(f 0)
 →  (+ (cos 0) 2)
```

Evaluation is the Same as Before

```
(define (f x) (+ (cos x) 2))

(f 0)
 →  (+ (cos 0) 2)
 →  (+ 1 2)
```

Evaluation is the Same as Before

```
(define (f x) (+ (cos x) 2))

(f 0)
 →  (+ (cos 0) 2)
 →  (+ 1 2)
 →  3
```

Beyond Numbers: Booleans

Numbers are not the only kind of values:

Old	New
$1 < 2 \rightarrow$ true	`(< 1 2)` → `true`
$1 > 2 \rightarrow$ true	`(> 1 2)` → `false`
$1 > 2 \rightarrow$ true	`(> 1 2)` → `false`
$2 \geq 2 \rightarrow$ true	`(>= 1 2)` → `true`

Beyond Numbers: Booleans

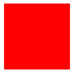
Old	New
true and false	`(and true false)`
true or false	`(or true false)`
$1 < 2$ and $2 > 3$	`(and (< 1 2) (> 2 3))`
$1 \leq 0$ and $1 = 1$	`(or (<= 1 0) (= 1 1))`
$1 \neq 0$	`(not (= 1 0))`

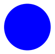
Beyond Numbers: Symbols

```
(symbol=? ’apple ’apple)  →  true

(symbol=? ’apple ’banana)  →  false
```

Beyond Numbers: Images

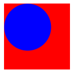
`(filled-rect 35 35 ’red)` → 

`(filled-circle 25 25 ’blue)` → 

Beyond Numbers: Images

`(filled-rect 35 35 ’red)` →

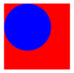
`(filled-circle 25 25 ’blue)` →

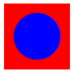
`(image+` `)` → 

Beyond Numbers: Images

(filled-rect 35 35 ’red) → 🟥

(filled-circle 25 25 ’blue) → ●

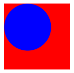
(image+ 🟥 ●) → 

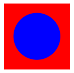
(offset-image+ 🟥 5 5 ●) → 

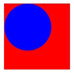
Beyond Numbers: Images

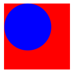
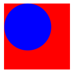
(filled-rect 35 35 'red) → 🟥

(filled-circle 25 25 'blue) → ●

(image+ 🟥 ●) → 

(offset-image+ 🟥 5 5 ●) → 

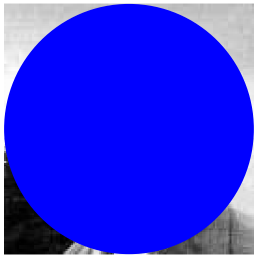
(image=? (image+ 🟥 ●) )

→ (image=?  )

→ true

Programming with Images

```
(define (anonymize i)
  (offset-image+
   i
   0 0
   (filled-circle (image-width i)
                  (image-height i)
                  'blue)))
```

(anonymize) → ... → 

Conditionals

Conditionals in Algebra

General format of conditionals in algebra:

$$\begin{cases} \textit{answer} & \textit{question} \\ \textit{...} & \\ \textit{answer} & \textit{question} \end{cases}$$

Example:

$$\text{abs}(x) = \begin{cases} x & \text{if } x > 0 \\ -x & \text{otherwise} \end{cases}$$

abs(10) = 10

abs(-7) = 7

Conditionals

General syntax of **cond** in Scheme:

```
(cond
  [question answer]
  ...
  [question answer])
```

- Any number of **cond** lines
- Each line has one *question* expression and one *answer* expression

Conditionals

General syntax of **cond** in Scheme:

```
(cond
  [question answer]
  ...
  [question answer])
```

- Any number of **cond** lines

- Each line has one *question* expression and one *answer* expression

```
(define (abs x)
  (cond
    [(> x 0) x]
    [else (- x)]))
(abs 10) "should be" 10
(abs -7) "should be" 7
```

Completing max-image

- Use **cond** to complete `max-image`

```
(define (max-image a b)
  (cond
    [(bigger-image? a b) a]
    [else b]))
```

Evaluation Rules for cond

First question is literally `true` or `else`

```
(cond
  [true answer]
  ...
  [question answer])
```

→ *answer*

- Keep only the first answer

Evaluation Rules for cond

First question is literally `true` or `else`

```
(cond
  [true answer]
                           →  answer
  ...
  [question answer])
```

- Keep only the first answer

Example:

```
(+ 1 (cond              → (+ 1 1) → 2
       [true 1]
       [false 0]))
```

Evaluation Rules for cond

First question is literally `true` or `else`

```
(cond
  [true answer]
  ...                    →  answer
  [question answer])
```

- Keep only the first answer

Example:

```
(- 1 (cond                    → (- 1 0) → 1
       [true 0]
       [(< 10 12) 10]
       [(>= 10 12) 12]))
```

Evaluation Rules for cond

First question is literally `true` or `else`

```
(cond
  [true answer]              →  answer
  ...
  [question answer])
```

- Keep only the first answer

Example:

```
(* 1 (cond              →  (* 1 0)  →  0
       [true 0]))
```

Evaluation Rules for cond

First question is literally `false`

```
(cond
  [false answer]
  [question answer]
  ...
  [question answer])
```

→

```
(cond
  [question answer]
  ...
  [question answer])
```

- Throw away the first line

Evaluation Rules for cond

First question is literally `false`

```
(cond                                (cond
  [false answer]                       [question answer]
  [question answer]          →         ...
  ...                                  [question answer])
  [question answer])
```

- Throw away the first line

Example:

```
(+ 1 (cond               → (+ 1 (cond
       [false 1]                      [true 17]))
       [true 17]))

                             → (+ 1 17) → 18
```

Evaluation Rules for cond

First question isn’t a value, yet

```
(cond                              (cond
  [question answer]          →       [nextques answer]
  ...                                ...
  [question answer])                 [question answer])
```

where *question* → *nextques*

- Evaluate first question as sub-expression

Evaluation Rules for cond

First question isn’t a value, yet

```
(cond                            (cond
  [question answer]                [nextques answer]
  ...                      →       ...
  [question answer])               [question answer])
```

where *question* → *nextques*

- Evaluate first question as sub-expression

Example:

```
(+ 1 (cond               → (+ 1 (cond
       [(< 1 2) 5]                 [true 5]
       [else 8]))                  [else 8]))

                           → (+ 1 5) → 6
```

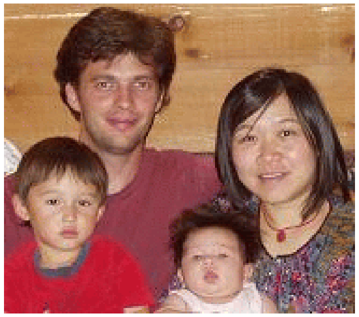
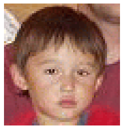
Evaluation Rules for cond

Only queston is false answers

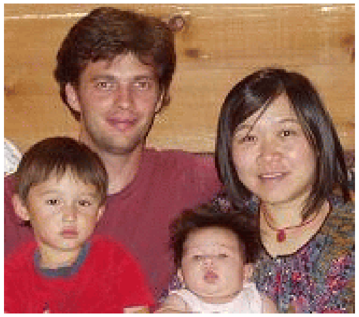
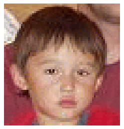
```
(cond
 [false 10])
```

→ *error: all questions false*

Finding Images

(image-inside?  ) → true

Finding Images

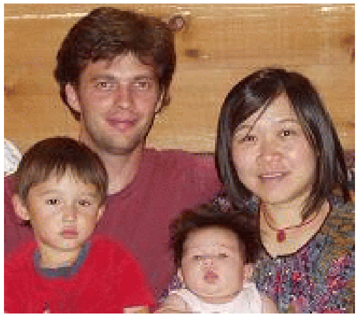
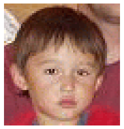
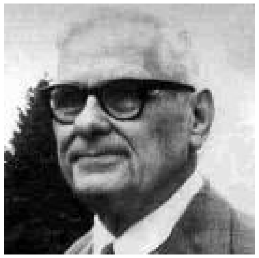
(image-inside?  ) → true

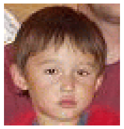
(image-inside?) → false

Image Tests in Conditionals

Now we can combine such operators with **cond**:

```
; detect-person : image image image -> image
; Returns a or b, depending on which is in i
(define (detect-person i a b)
  (cond
    [(image-inside? i a) a]
    [(image-inside? i b) b]))
```

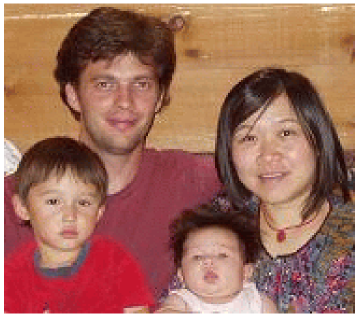
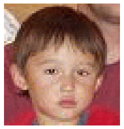
(detect-person   )

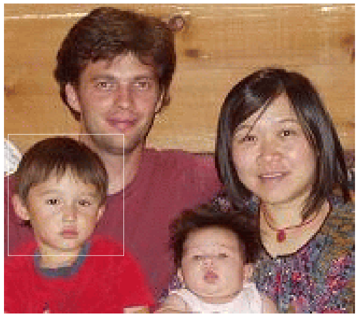
"should be" 

Compound Data

Finding and Adjusting Images

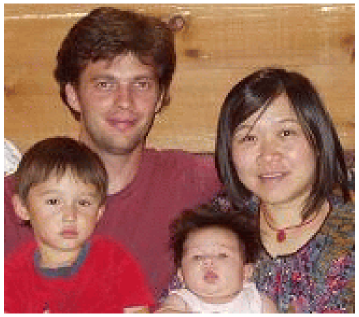
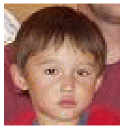
Suppose we want to write `frame-person`:

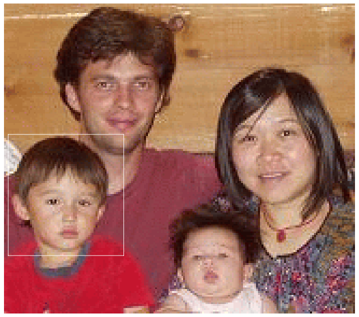
(frame-person  )

"should be" 

Finding and Adjusting Images

Suppose we want to write **`frame-person`**:

(frame-person   **)**

"should be" 

Need an operator that reports *where* an image exists

Finding an Image Position

```
find-image : image image -> num num
```

Finding an Image Position

~~`find-image : image image -> num num`~~

Must return a single value

Correct contract:

```
find-image : image image -> posn
```

- A **posn** is a ***compound value***

Positions

- A **posn** is

  ```
  (make-posn X Y)
  ```

  where **X** is a **num** and **Y** is a **num**

Positions

- A **posn** is

  ```
  (make-posn X Y)
  ```

  where **X** is a **num** and **Y** is a **num**

Examples:

```
(make-posn 1 2)

(make-posn 17 0)
```

Positions

- A **posn** is

  ```
  (make-posn X Y)
  ```

  where **X** is a **num** and **Y** is a **num**

Examples:

```
(make-posn 1 2)
(make-posn 17 0)
```

A **posn** is a value, just like a number, symbol, or image

posn-x and posn-y

The **posn-x** and **posn-y** operators extract numbers from a **posn**:

```
(posn-x (make-posn 1 2))  →  1

(posn-y (make-posn 1 2))  →  2
```

posn-x and posn-y

The **posn-x** and **posn-y** operators extract numbers from a **posn**:

```
(posn-x (make-posn 1 2))  →  1
(posn-y (make-posn 1 2))  →  2
```

- General evaluation rules for any **X** and **Y**:

```
(posn-x (make-posn X Y))  →  X
(posn-y (make-posn X Y))  →  Y
```

Positions and Values

Is `(make-posn 100 200)` a value?

Positions and Values

Is `(make-posn 100 200)` a value?

Yes.

A **posn** is

```
(make-posn X Y)
```

where **X** is a **num** and **Y** is a **num**

Positions and Values

Is `(make-posn (+ 1 2) 200)` a value?

Positions and Values

Is `(make-posn (+ 1 2) 200)` a value?

No. `(+ 1 2)` is not a `num`, yet.

Positions and Values

Is `(make-posn (+ 1 2) 200)` a value?

No. `(+ 1 2)` is not a `num`, yet.

- Two more evaluation rules:

```
(make-posn X Y)  →  (make-posn Z Y)
                        when X  →  Z

(make-posn X Y)  →  (make-posn X Z)
                        when Y  →  Z
```

Positions and Values

Is `(make-posn (+ 1 2) 200)` a value?

No. `(+ 1 2)` is not a `num`, yet.

- Two more evaluation rules:

```
(make-posn X Y)  →  (make-posn Z Y)
                          when X  →  Z

(make-posn X Y)  →  (make-posn X Z)
                          when Y  →  Z
```

Example:

```
(make-posn (+ 1 2) 200)  →  (make-posn 3 200)
```

Posn Examples

```
(make-posn (+ 1 2) (+ 3 4))

(posn-x (make-posn (+ 1 2) (+ 3 4)))

; pixels-from-corner : posn -> num
(define (pixels-from-corner p)
  (+ (posn-x p) (posn-y p)))
(pixels-from-corner (make-posn 1 2))

; flip : posn -> posn
(define (flip p)
  (make-posn (posn-y p) (posn-x p)))
(flip (make-posn 1 2))
```

Copy

Programmer-Defined Compound Data

Other Kinds of Data

Suppose we want to represent snakes:

- name
- weight
- favorite food

What kind of data is appropriate?

Other Kinds of Data

Suppose we want to represent snakes:

- name
- weight
- favorite food

What kind of data is appropriate?

Not **`num`**, **`bool`**, **`sym`**, **`image`**, or **`posn`**...

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)
```

But **`make-snake`** is not built into DrScheme

Data Definitions and define-struct

Here's what we'd like:

A **`snake`** is
`(make-snake sym num sym)`

But **`make-snake`** is not built into DrScheme

We can tell DrScheme about **`snake`**:

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

Data Definitions and define-struct

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A **snake** is

```
(make-snake sym num sym)
```

But **make-snake** is not built into DrScheme

We can tell DrScheme about **snake**:

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

Creates the following:

- **make-snake**
- **snake-name**
- **snake-weight**
- **snake-food**

Data Definitions and define-struct

Here's what we'd like:

A **snake** is

```
(make-snake sym num sym)
```

But **make-snake** is not built into DrScheme

We can tell DrScheme about **snake**:

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

Creates the following:

```
(snake-name (make-snake X Y Z))  →  X
(snake-weight (make-snake X Y Z))  →  Y
(snake-food (make-snake X Y Z))  →  Z
```