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Exceptions are raised with a raise statement.

```
raise <expr>
```

<expr> must evaluate to a subclass of BaseException or an instance of one.

```
try:
    <try suite>
except <exception class> as <name>:
    <except suite>
```

The <try suite> is executed first.

If, during the course of executing the <try suite>, an exception is raised that is not handled otherwise, and

If the class of the exception inherits from <exception class>, then

The <except suite> is executed, with <name> bound to the exception.

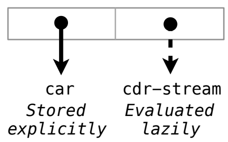
```
>>> try:
        x = 1/0
    except ZeroDivisionError as e:
        print('handling a', type(e))
        x = 0

handling a <class 'ZeroDivisionError'>
>>> x
0
```

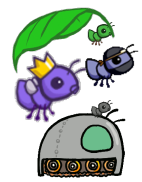
```
(car (cons 1 2)) -> 1
(cdr (cons 1 2)) -> 2
(car (cons 1 (/ 1 0))) -> ERROR
(cdr (cons 1 (/ 1 0))) -> ERROR

(car        (cons-stream 1 2)) -> 1
(cdr-stream (cons-stream 1 2)) -> 2
(car        (cons-stream 1 (/ 1 0))) -> 1
(cdr-stream (cons-stream 1 (/ 1 0))) -> ERROR
```

A stream is a Scheme pair, but the cdr is evaluated lazily




```
(define (range-stream a b)
  (if (>= a b)
      nil
      (cons-stream a (range-stream (+ a 1) b))))
(define lots (range-stream 1 10000000000000000000))
scm> (car lots)
1
scm> (car (cdr-stream lots))
2
scm> (car (cdr-stream (cdr-stream lots)))
3
```



```
(define ones (cons-stream 1 ones))
(define (add-streams s t)
  (cons-stream (+ (car s) (car t))
               (add-streams (cdr-stream s)
                            (cdr-stream t))))
(define ints (cons-stream 1 (add-streams ones ints)))
```

```
1    1    1  ...
+    +
1    2    3  ...
```

```
(define (map-stream f s)
  (if (null? s)
      nil
      (cons-stream (f (car s))
            (map-stream f
                 (cdr-stream s)))))

(define (filter-stream f s)
  (if (null? s)
      nil
      (if (f (car s))
          (cons-stream (car s)
                (filter-stream f (cdr-stream s)))
          (filter-stream f (cdr-stream s)))))
```

The built-in Scheme list data structure can represent combinations

```
scm> (list 'quotient 10 2)
(quotient 10 2)
scm> (eval (list 'quotient 10 2))
5
```

A macro is an operation performed on source code before evaluation

```
(define-macro (twice expr)
  (list 'begin expr expr))

> (twice (print 2))
2
2
(begin (print 2) (print 2))
```

Evaluation procedure of a macro call expression:

- Evaluate the operator sub-expression, which evaluates to a macro
- Call the macro procedure on the operand expressions
- Evaluate the expression returned from the macro procedure

```
scm> (map (lambda (x) (* x x)) '(2 3))
(4 9)
scm> (for x '(2 3) (* x x))
(4 9)
```

```
(define-macro (for sym vals expr)
  (list 'map (list 'lambda
                   (list sym)
                   expr) vals))
```

OR

```
(define-macro (for sym vals expr)
  `(map (lambda (,sym) ,expr) ,vals))
```

A procedure call that has not yet returned is *active.* Some procedure calls are *tail calls.* A Scheme interpreter should support an unbounded number of active tail calls.

A tail call is a call expression in a *tail context*, which are:

- The last body expression in a **lambda** expression
- Expressions 2 & 3 (consequent & alternative) in a tail context **if**
- All non-predicate sub-expressions in a tail context **cond**
- The last sub-expression in a tail context **and**, **or**, **begin**, or **let**

```
(define (factorial n k)
  (if (= n 0) k
    (factorial (- n 1)
               (* k n))))

(define (length s)
  (if (null? s) 0
    (+ 1 (length (cdr s)))))
```

Not a tail call

```
(define (length-tail s)
  (define (length-iter s n)
    (if (null? s) n
      (length-iter (cdr s) (+ 1 n)) ) )
  (length-iter s 0) )
```

Recursive call is a tail call

- Recursive decomposition: finding simpler instances of a problem.
- E.g., **count_partitions(6, 4)**
- Explore two possibilities:
  - Use at least one 4
  - Don't use any 4
- Solve two simpler problems:
  - **count_partitions(2, 4)**
  - **count_partitions(6, 3)**
- Tree recursion often involves exploring different choices.

```
def count_partitions(n, m):
    if n == 0:
        return 1
    elif n < 0:
        return 0
    elif m == 0:
        return 0
    else:
        with_m = count_partitions(n-m, m)
        without_m = count_partitions(n, m-1)
        return with_m + without_m
```

```
(define size 5) ; => size
(* 2 size) ; => 10
(if (> size 0) size (- size)) ; => 5
(cond ((> size 0) size) ((= size 0) 0) (else (- size))) ; => 5
((lambda (x y) (+ x y size)) size (+ 1 2)) ; => 13
(let ((a size) (b (+ 1 2))) (* 2 a b)) ; => 30
(map (lambda (x) (+ x size)) (quote (2 3 4))) ; => (7 8 9)
(filter odd? (quote (2 3 4))) ; => (3)
(list (cons 1 2) size 'size) ; => ((1 . 2) 5 size)
(list (equal? 1 2) (null? nil) (= 3 4) (eq? 5 5)) ; => (#f #t #f #t)
(list (or #f #t) (or) (or 1 2)) ; => (#t #f 1)
(list (and #f #t) (and) (and 1 2)) ; => (#f #t 2)
(append '(1 2) '(3 4)) ; => (1 2 3 4)
(not (> 1 2)) ; => #t
(begin (define x (+ size 1)) (* x 2)) ; => 12
`(+ size (- ,size) ,(* 3 4)) ; => (+ size (- 5) 12)
(force (delay (+ 1 2))) ; => 3
```

```
;; Return a copy of s reversed.
(define (reverse s)
  (define (iter s r)
    (if (null? s) r
      (iter (cdr s)
            (cons (car s) r))))
  (iter s nil))
```

```
;; Apply fn to each element of s.
(define (map fn s)
  (define (map-reverse s m)
    (if (null? s) m
      (map-reverse
        (cdr s)
        (cons (fn (car s)) m))))
  (reverse (map-reverse s nil)))
```

A **table** has columns and rows

Latitude	Longitude	Name
38	122	Berkeley
42	71	Cambridge
45	93	Minneapolis

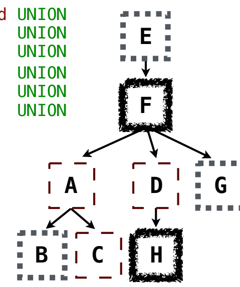
A **column** has a name and a type

A **row** has a value for each column

```
SELECT [expression] AS [name], [expression] AS [name], ... ;

SELECT [columns] FROM [table] WHERE [condition] ORDER BY [order];
```

```
CREATE TABLE parents AS
  SELECT "abraham" AS parent, "barack" AS child UNION
  SELECT "abraham"          , "clinton"         UNION
  SELECT "delano"           , "herbert"         UNION
  SELECT "fillmore"         , "abraham"         UNION
  SELECT "fillmore"         , "delano"          UNION
  SELECT "fillmore"         , "grover"          UNION
  SELECT "eisenhower"       , "fillmore";
```




```
CREATE TABLE dogs AS
  SELECT "abraham" AS name, "long" AS fur UNION
  SELECT "barack"         , "short"       UNION
  SELECT "clinton"        , "long"        UNION
  SELECT "delano"         , "long"        UNION
  SELECT "eisenhower"     , "short"       UNION
  SELECT "fillmore"       , "curly"       UNION
  SELECT "grover"         , "short"       UNION
  SELECT "herbert"        , "curly";
```

```
SELECT a.child AS first, b.child AS second
  FROM parents AS a, parents AS b
  WHERE a.parent = b.parent AND a.child < b.child;
```

First	Second
barack	clinton
abraham	delano
abraham	grover
delano	grover

The number of groups is the number of unique values of an expression

A having clause filters the set of groups that are aggregated

```
select weight/legs, count(*) from animals
       group by weight/legs
       having count(*)>1;
```

weight/legs	count(*)
5	2
2	2

weight/legs=5
weight/legs=2
weight/legs=2
weight/legs=3
weight/legs=5
weight/legs=6000

kind	legs	weight
dog	4	20
cat	4	10
ferret	4	10
parrot	2	6
penguin	2	10
t-rex	2	12000

```
CREATE TABLE ints(n UNIQUE, prime DEFAULT 1);
INSERT INTO ints VALUES (2, 1), (3, 1);
INSERT INTO ints(n) VALUES (4), (5), (6), (7), (8);
UPDATE ints SET prime=0 WHERE n > 2 AND n % 2 = 0;
DELETE FROM ints WHERE prime=0;
```

n	prime
2	1
3	1
5	1
7	1

The way in which names are looked up in Scheme and Python is called *lexical scope* (or *static scope*).

Lexical scope: The parent of a frame is the environment in which a procedure was *defined.* (lambda ...)

Dynamic scope: The parent of a frame is the environment in which a procedure was *called.* (mu ...)

```
> (define f (mu (x) (+ x y)))
> (define g (lambda (x y) (f (+ x x))))
> (g 3 7)
13
```

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Scheme programs consist of expressions, which can be:
- Primitive expressions: 2, 3.3, true, +, quotient, ...
- Combinations: (quotient 10 2), (not true), ...

Numbers are self-evaluating; *symbols* are bound to values.
Call expressions have an operator and 0 or more operands.

A combination that is not a call expression is a *special form*:
- **If** expression: (if <predicate> <consequent> <alternative>)
- Binding names: (define <name> <expression>)
- New procedures: (define (<name> <formal parameters>) <body>)

```
> (define pi 3.14)
> (* pi 2)
6.28
```

```
> (define (abs x)
    (if (< x 0)
        (- x)
        x))
> (abs -3)
3
```

Lambda expressions evaluate to anonymous procedures.

(lambda (<formal-parameters>) <body>)   λ

Two equivalent expressions:

```
(define (plus4 x) (+ x 4))
(define plus4 (lambda (x) (+ x 4)))
```

An operator can be a combination too:

```
((lambda (x y z) (+ x y (square z))) 1 2 3)
```

In the late 1950s, computer scientists used confusing names.
- **cons**: Two-argument procedure that **creates a pair**
- **car**: Procedure that returns the **first element** of a pair
- **cdr**: Procedure that returns the **second element** of a pair
- **nil**: The empty list

They also used a non-obvious notation for linked lists.
- A (linked) Scheme list is a pair in which the second element is nil or a Scheme list.
- Scheme lists are written as space-separated combinations.
- A dotted list has an arbitrary value for the second element of the last pair. Dotted lists may not be well-formed lists.

```
> (define x (cons 1 2))
> x
(1 . 2)
> (car x)
1
> (cdr x)
2
> (cons 1 (cons 2 (cons 3 (cons 4 nil))))
(1 2 3 4)
```

Not a well-formed list!

Symbols normally refer to values; how do we refer to symbols?

```
> (define a 1)
> (define b 2)
> (list a b)
(1 2)
```

No sign of "a" and "b" in the resulting value

Quotation is used to refer to symbols directly in Lisp.

```
> (list 'a 'b)
(a b)
> (list 'a b)
(a 2)
```

Symbols are now values

Quotation can also be applied to combinations to form lists.

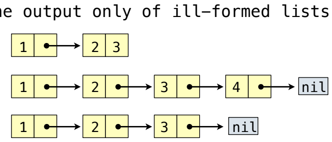
```
> (car '(a b c))
a
> (cdr '(a b c))
(b c)
```

Dots can be used in a quoted list to specify the second element of the final pair.

```
> (cdr (cdr '(1 2 . 3)))
3
```

However, dots appear in the output only of ill-formed lists.

```
> '(1 2 . 3)
(1 2 . 3)
> '(1 2 . (3 4))
(1 2 3 4)
> '(1 2 3 . nil)
(1 2 3)
> (cdr '((1 2) . (3 4 . (5))))
(3 4 5)
```




```python
class Pair:
    """A Pair has first and second attributes.

    For a Pair to be a well-formed list,
    second is either a well-formed list or nil.
    """
    def __init__(self, first, second):
        self.first = first
        self.second = second
```

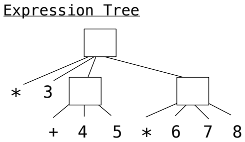
```
>>> s = Pair(1, Pair(2, Pair(3, nil)))
>>> print(s)
(1 2 3)
>>> print(Pair(1, 2))
(1 . 2)
>>> print(Pair(1, Pair(2, 3)))
(1 2 . 3)
>>> print(Pair(1, Pair(2, 3)).second)
(2 . 3)
```

The Calculator language has primitive expressions and call expressions

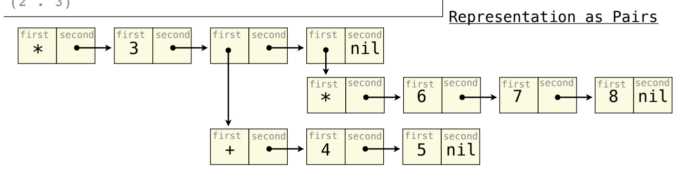
Calculator Expression

```
(* 3
   (+ 4 5)
   (* 6 7 8))
```

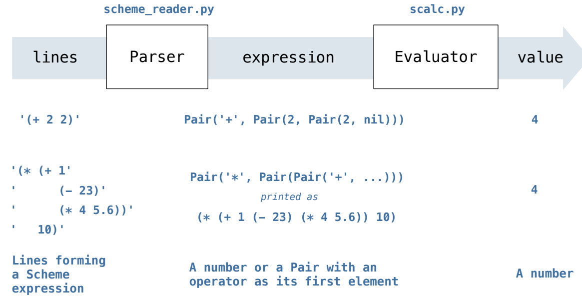
Expression Tree



Representation as Pairs



A basic interpreter has two parts: a *parser* and an *evaluator*.



A Scheme list is written as elements in parentheses:

($\langle$element$_0\rangle$ $\langle$element$_1\rangle$ ... $\langle$element$_n\rangle$)   A Scheme list

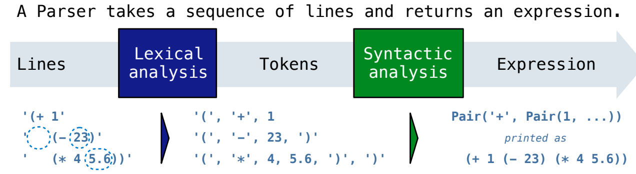
Each <element> can be a combination or atom (primitive).

(+ (* 3 (+ (* 2 4) (+ 3 5))) (+ (- 10 7) 6))

The task of *parsing* a language involves coercing a string representation of an expression to the expression itself.

Parsers must validate that expressions are well-formed.

A Parser takes a sequence of lines and returns an expression.



- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

- Tree-recursive process
- Balances parentheses
- Returns tree structure
- Processes multiple lines

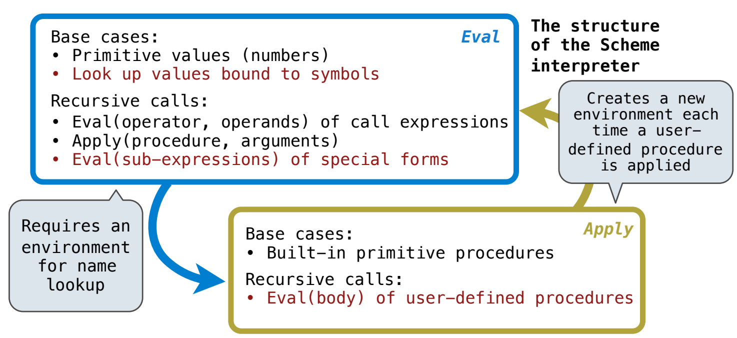
Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.

Each call to scheme_read consumes the input tokens for exactly one expression.

Base case: symbols and numbers

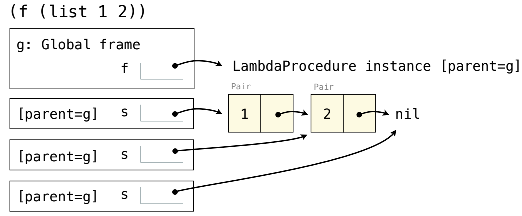
Recursive call: scheme_read sub-expressions and combine them

The structure of the Scheme interpreter



To apply a user-defined procedure, create a new frame in which formal parameters are bound to argument values, whose parent is the **env** of the procedure, then evaluate the body of the procedure in the environment that starts with this new frame.

```
(define (f s) (if (null? s) '(3) (cons (car s) (f (cdr s)))))
(f (list 1 2))
```



How to Design Functions:

1) Identify the information that must be represented and how it is represented. Illustrate with examples.

2) State what kind of data the desired function consumes and produces. Formulate a concise answer to the question *what* the function computes.

3) Work through examples that illustrate the function's purpose.

4) Outline the function as a template.

5) Fill in the gaps in the function template. Exploit the purpose statement and the examples.

6) Convert examples into tests and ensure that the function passes them.