As we have seen, Scheme uses `cons` to build lists. As you may recall, `cons` takes two arguments. Up to this point, the first element has been a value and the second has been a list. When you call `cons`, Scheme actually builds a structure in memory with two parts, one of which refers to the first argument to `cons` and the other of which refers to the second. This structure is called a `cons cell` or a `pair`.

**Box-and-pointer diagrams**

Let us now consider a graphical way to represent the result of a `cons` procedure. The basic idea is to use a rectangle, divided in half, to represent the result of the `cons`. From the first half of the rectangle, we draw an arrow to the first element of a list, its car; from the second half of the rectangle, we draw an arrow to the rest of the list, its cdr. When the cdr is empty, we draw a diagonal line through the right half of the rectangle to indicate that the list stops at that point.

For instance, the value of the expression `(cons 'a null)` would be represented in this notation as follows:

![Box-and-pointer diagram](image)

Since the value of the expression `(cons 'a null)` is the list `(a)`, this diagram represents `(a)` as well.

Now consider the value of the expression

`(cons 'b (cons 'a null))`

in other words, the list `(b a)`. Here, we draw another rectangle, where the head points to `b` and the tail points to the representation of `(a)` that we already have seen. The result is:
Similarly, the list (d c b a) is the value of the expression 
(cons 'd (cons 'c (cons 'b (cons 'a null)))) and would be drawn as follows:

A similar approach may be used for lists that have other lists as elements. For example, consider the list 
((a) b (c d) e). This list contains four components, so at the top level we will need four rectangles, 
just as in the previous example for the list (d c b a). Here, however, the first component designates 
the list (a), which itself involves the box-and-pointer diagram already discussed. Similarly, the list (c d) has two boxes for its two components (as in the diagram for (b a) above). The resulting diagram is:

Throughout these diagrams, the empty list is represented by a null pointer, a diagonal line. Thus, the list 
containing the empty list, ((())) -- that is, the value of the expression (cons null null) -- is 
represented by a rectangle with lines through both halves:
Pairs that are not lists

While we consistently have discussed cons in the context of lists, Scheme allows cons to be applied even when the second argument is not a list. For example, (cons 'a 'b) is a legal expression; its value is represented by the following box-and-pointer diagram:

```
  a
/|
/ |
b
```

You may have noticed that some of your “lists” ended with a dot before the last character. In fact, whenever Scheme is asked to print out a sequence of linked pairs that don’t end with null, it uses dot notation, as in (a . b). Here, the dot indicates that cons has been applied, but the second argument is not a list. Similarly, the value of (cons 1 'a) is the pair (1 . a), and the value of (cons "Henry" "Walker") is ("Henry" . "Walker"). Using a box-and-pointer representation, this last result would be drawn as follows:

```
  "Henry"
/|
/ |
"Walker"
```

The car and cdr procedures can be used to recover the halves of one of these improper lists:

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

Note that the cdr of such a structure is not a list.

When Scheme tries to print out a pair structure, it uses what we might call an optimistic assumption. If the next thing is null or a pair, it assumes that it’s a list, and therefore uses a space before the next object. When it hits the end and finds no null, it inserts the dot there, but not earlier.

A Pair Predicate

The pair? predicate returns #t when it is given any structure that is printed as a dotted pair, or indeed any structure that cons can possibly return as its value. ( Basically, pair? determines whether the object it is given is one of those two-box rectangles.)
Recursion with pairs

Just as lists can be nested within lists, so pairs can be nested within pairs, as deeply as you like. For instance, here is a pair structure that contains the first eight natural numbers:

```
(cons (cons (cons 0 1) (cons 2 3)) (cons (cons 4 5) (cons 6 7)))
```

To build this structure in Scheme, we can use repeated calls to `cons`, thus:

```
(cons (cons (cons 0 1)
           (cons 2 3))
      (cons (cons 4 5)
           (cons 6 7)))
```

or we can use the dotted-pair notation inside a literal constant beginning with a quote:

```
'((((0 . 1) . (2 . 3)) . ((4 . 5) . (6 . 7)))
```

If we have a pair structure that is constructed by repeated invocations of `cons`, starting from constituents of some simple type such as numbers or strings, we can use pair recursion, which adapts the shape of the computation to the shape of the particular pair structure on which we operate. In pair recursion, the base cases are the values that are not pairs, and must therefore be operated on directly. For the non-base cases -- those that are pairs -- we invoke the procedure recursively twice (once for the car, once for the cdr) and combine the values of the recursive calls to get the final result of the operation.

For instance, here is how we’d find the sum of the numbers in a pair structure like the one diagrammed above:
(define sum-of-pair-structure
  (lambda (ps)
    (if (pair? ps)
        (+ (sum-of-pair-structure (car ps))
            (sum-of-pair-structure (cdr ps)))
        ps)))

> (sum-of-pair-structure (cons (cons (cons 0 1)
            (cons 2 3))
            (cons (cons 4 5)
            (cons 6 7))))
28

When this procedure is applied to a base case -- that is, just a number rather than a collection of numbers fitted into a pair structure -- it returns the number unchanged:

> (sum-of-pair-structure 19)
19

There is no such thing as an ‘‘empty pair’’ analogous to an empty list. Every pair has exactly two components, and it is always valid to take the car and the cdr of a pair. So the base case for a pair recursion is just any value that is not itself a pair.