Built-in Common Lisp Functions for Creating Lists: CONS, APPEND, and LIST

- If $l \Rightarrow$ a proper list of length n
  then (CONS x l) $\Rightarrow$ a proper list of length n+1 obtained by **inserting the value of x at the *beginning* of the list of length n.**

  Examples:

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  Examples: (CONS 'A '(B C D)) ⇒
  (CONS (+ 2 3) '(A B C)) ⇒
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  (CONS 'A nil) ⇒

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  Examples: (CONS 'A '(B C D)) ⇒ (A B C D)
  (CONS (+ 2 3) '(A B C)) ⇒ (5 A B C)
  (CONS '(+ 2 3) '(A B C)) ⇒
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  Otherwise there will be an evaluation error.
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- If the 2nd argument value passed to CONS is ***<u>not</u>*** a proper list (i.e., if it is an atom other than NIL or a dotted list), then CONS returns a ***<u>dotted</u>*** list. But in this course you are ***<u>not</u>*** expected to call CONS this way!

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The name "CONS" is a shortened form of "construct":
  - CONS is the most basic way to construct a new proper list; but the CDR of that new list will be an existing list.

- If l_1 ⇒ a proper list of length n_1
  and l_2 ⇒ a proper list of length n_2
  then (**APPEND** l_1 l_2) ⇒ a proper list of length $n_1 + n_2$
  obtained by **concatenating the lists given by l_1 and l_2.**

  EXAMPLES:

- If l_1 ⇒ a proper list of length n_1
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  EXAMPLES: (APPEND '(A B C) '(D E)) =>
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More generally:

- If $l_1, \ldots, l_k \Rightarrow k$ proper lists of lengths $n_1, \ldots, n_k$, then (APPEND $l_1 \ldots l_k$) $\Rightarrow$ a proper list of length $n_1 + \ldots + n_k$ obtained by **concatenating those k lists.**

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- If $l_1 \Rightarrow$ a proper list of length n_1
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When APPEND is called with $k \geq 2$ arguments:

- If any of the first k-1 argument values is ***not*** a proper list, then there will be an evaluation error.

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- If any of the first k-1 argument values is ***not*** a proper list, then there will be an evaluation error.

  EXAMPLE: Evaluation of (APPEND (+ 3 4) '(C D E)) produces an error, because 7 is not a list.

- If the first k-1 argument values are proper lists but the k^{th} argument value is not, then APPEND returns a *dotted* list (unless the first k-1 argument values are all NIL). But in this course you are ***not*** expected to call APPEND this way!

(LIST e_1 … e_k) $\Rightarrow$ a proper list of length k whose i^{th} element ($1 \leq i \leq k$) is the value of e_i.

EXAMPLES:

(LIST e_1 … e_k) ⇒ a proper list of length k whose i^{th} element ($1 \le i \le k$) is the value of e_i.

EXAMPLES:

```
(LIST 'P '(A B) (+ 3 4) '(F)) ⇒
(LIST (CAR '(A B)) 6 (CDR '(X Y))) ⇒
(LIST '(U V W)) ⇒
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Don't confuse the functions CONS, APPEND, and LIST!

```
(CONS                    ) ⇒
(APPEND                    ) ⇒
(LIST                    ) ⇒
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Don't confuse the functions CONS, APPEND, and LIST.
```
(CONS '(1 2 3) '(4 5)) ⇒
(APPEND '(1 2 3) '(4 5)) ⇒
(LIST '(1 2 3) '(4 5)) ⇒
```

(LIST e_1 … e_k) ⇒ a proper list of length k whose i^{th} element ($1 \leq i \leq k$) is the value of e_i.

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EXAMPLES:  (LIST 'P '(A B) (+ 3 4) '(F)) ⇒ (P (A B) 7 (F))
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      (CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
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      (LIST '(1 2 3) '(4 5)) ⇒
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(CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
(APPEND '(1 2 3) '(4 5)) ⇒ (1 2 3 4 5)
(LIST '(1 2 3) '(4 5)) ⇒
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EXAMPLES:  (LIST 'P '(A B) (+ 3 4) '(F)) ⇒ (P (A B) 7 (F))
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(CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
(APPEND '(1 2 3) '(4 5)) ⇒ (1 2 3 4 5)
(LIST '(1 2 3) '(4 5)) ⇒ ((1 2 3) (4 5))
```

```
(LIST e1 … ek) ⇒ a proper list of length k whose
                 ith element (1 ≤ i ≤ k) is the
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```

$(\texttt{LIST}\ e_1\ \ldots\ e_k) \Rightarrow$ a proper list of length k whose i^{th} element $(1 \le i \le k)$ is the value of e_i.

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Don't confuse the functions CONS, APPEND, and LIST.

```
(CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
(APPEND '(1 2 3) '(4 5)) ⇒ (1 2 3 4 5)
(LIST '(1 2 3) '(4 5)) ⇒ ((1 2 3) (4 5))
```

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•

(LIST e_1 … e_k) ⇒ a proper list of length k whose i^{th} element ($1 \le i \le k$) is the value of e_i.

EXAMPLES:

```
(LIST 'P '(A B) (+ 3 4) '(F)) ⇒ (P (A B) 7 (F))
(LIST (CAR '(A B)) 6 (CDR '(X Y))) ⇒ (A 6 (Y))
(LIST '(U V W)) ⇒ ((U V W))
```

Don't confuse the functions CONS, APPEND, and LIST.

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- (LIST *e*) = (CONS)
-
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(LIST e_1 … e_k) ⇒ a proper list of length k whose i^{th} element ($1 \le i \le k$) is the value of e_i.

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EXAMPLES:  (LIST 'P '(A B) (+ 3 4) '(F)) ⇒ (P (A B) 7 (F))
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Don't confuse the functions CONS, APPEND, and LIST.

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(CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
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- (LIST *e*) = (CONS *e* NIL)
- (CONS *e* *l*) = (APPEND (LIST *e*) *l*)
- Evaluation of (CONS *e* *l*), (APPEND l_1 … l_k), and (LIST e_1 … e_k) does ***not*** change the values of the *e*'s and the *l*'s.
  -

(LIST e_1 … e_k) ⇒ a proper list of length k whose i^{th} element ($1 \le i \le k$) is the value of e_i.

EXAMPLES:

```
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```

Don't confuse the functions CONS, APPEND, and LIST.

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(CONS '(1 2 3) '(4 5)) ⇒ ((1 2 3) 4 5)
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(LIST '(1 2 3) '(4 5)) ⇒ ((1 2 3) (4 5))
```

- (LIST e) = (CONS e NIL)
- (CONS e l) = (APPEND (LIST e) l)
- Evaluation of (CONS e l), (APPEND l_1 … l_k), and (LIST e_1 … e_k) does ***not*** change the values of the e's and the l's.
  - If this were not the case, we would not be able to use these functions in functional programming!

More Built-in Functions That Extract Parts of Lists: SECOND, ..., TENTH, and C … R Functions

SECOND, THIRD, etc.

Recall: If l ⇒ a nonempty list, then
(FIRST l) = (CAR l) evaluates to the
1st element of the list given by l.

Also, (FIRST NIL) = (CAR NIL) ⇒ NIL.

Similarly:

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SECOND, THIRD, etc.

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<u>1st</u> element of the list given by l.

Also, (FIRST NIL) = (CAR NIL) ⇒ NIL.

Similarly:

- If l ⇒ a list of length ≥ 2, then
(SECOND l) = (CAR (CDR l)) evaluates to
the **<u>2nd</u>** element of the list given by l.
-
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SECOND, THIRD, etc.

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  (SECOND l) $\Rightarrow$ NIL if $l \Rightarrow$ a proper list of length ≤ 1.

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  (SECOND l) ⇒ NIL if l ⇒ a proper list of length ≤ 1.
- If l ⇒ a list of length ≥ 3, then **(THIRD l)** = (CAR (CDR (CDR l))) evaluates to the **<u>3rd</u>** element of the list given by l.
-

SECOND, THIRD, etc.

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- If $l \Rightarrow$ a list of length ≥ 3, then **(THIRD l)** = (CAR (CDR (CDR l))) evaluates to the <u>**3rd**</u> element of the list given by l.

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-

SECOND, THIRD, etc.

Recall: If l ⇒ a nonempty list, then (FIRST l) = (CAR l) evaluates to the **1st** element of the list given by l.

Also, (FIRST NIL) = (CAR NIL) ⇒ NIL.

Similarly:

- If l ⇒ a list of length ≥ 2, then **(SECOND l)** = (CAR (CDR l)) evaluates to the **2nd** element of the list given by l.

  (SECOND l) ⇒ NIL if l ⇒ a proper list of length ≤ 1.

- If l ⇒ a list of length ≥ 3, then **(THIRD l)** = (CAR (CDR (CDR l))) evaluates to the **3rd** element of the list given by l.

  (THIRD l) ⇒ NIL if l ⇒ a proper list of length ≤ 2.

- **(FOURTH l)**, ..., **(TENTH l)** are defined analogously.

C … R Functions

Each C … R function is equivalent to the **composition of a certain sequence of CARs and/or CDRs**:

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Each C … R function is equivalent to the **composition of a certain sequence of CARs and/or CDRs**:

- (C**AD**R *l*) = (C**A**R (C**D**R *l*)) = (SECOND *l*)
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- (C**AA**R *l*) = (C**A**R (C**A**R *l*)) = (FIRST (FIRST *l*))
- (C**DA**R *l*) = (C**D**R (C**A**R *l*)) = (REST (FIRST *l*))
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C … R Functions

Each C … R function is equivalent to the **composition of a certain sequence of CARs and/or CDRs**:

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- (C**ADDD**R *l*) = (C**A**R (C**D**R (C**D**R (C**D**R *l*)))) = (FOURTH *l*)
- (C**AA**R *l*) = (C**A**R (C**A**R *l*)) = (FIRST (FIRST *l*))
- (C**DA**R *l*) = (C**D**R (C**A**R *l*)) = (REST (FIRST *l*))
- (C**DADD**R *l*) = (C**D**R (C**A**R (C**D**R (C**D**R *l*))))
= (C**D**R (C**ADD**R *l*)) = (REST (THIRD *l*))
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-

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Each C … R function is equivalent to the **composition of a certain sequence of CARs and/or CDRs**:

- (CADR *l*) = (CAR (CDR *l*)) = (SECOND *l*)
- (CADDR *l*) = (CAR (CDR (CDR *l*))) = (THIRD *l*)
- (CADDDR *l*) = (CAR (CDR (CDR (CDR *l*)))) = (FOURTH *l*)
- (CAAR *l*) = (CAR (CAR *l*)) = (FIRST (FIRST *l*))
- (CDAR *l*) = (CDR (CAR *l*)) = (REST (FIRST *l*))
- (CDADDR *l*) = (CDR (CAR (CDR (CDR *l*))))
= (CDR (CADDR *l*)) = (REST (THIRD *l*))
- (CADADR *l*) = (CAR (CDR (CAR (CDR *l*))))
= (CADR (CADR *l*)) = (SECOND (SECOND *l*))
-
-

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Each C … R function is equivalent to the **composition of a certain sequence of CARs and/or CDRs**:

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- (CADDDR *l*) = (CAR (CDR (CDR (CDR *l*)))) = (FOURTH *l*)
- (CAAR *l*) = (CAR (CAR *l*)) = (FIRST (FIRST *l*))
- (CDAR *l*) = (CDR (CAR *l*)) = (REST (FIRST *l*))
- (CDADDR *l*) = (CDR (CAR (CDR (CDR *l*))))
  = (CDR (CADDR *l*)) = (REST (THIRD *l*))
- (CADADR *l*) = (CAR (CDR (CAR (CDR *l*))))
  = (CADR (CADR *l*)) = (SECOND (SECOND *l*))

and similarly for all other sequences of **2 – 4** **A**s and/or **D**s.

- Although authors sometimes write C … R function names that contain ***more than 4*** **A**s and/or **D**s, functions with such names are ***not*** built-in functions of most implementations of Common Lisp!
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- (C**DADD**R *l*) = (C**D**R (C**A**R (C**D**R (C**D**R *l*))))
= (C**D**R (C**ADD**R *l*)) = (REST (THIRD *l*))
- (C**ADAD**R *l*) = (C**A**R (C**D**R (C**A**R (C**D**R *l*))))
= (C**AD**R (C**AD**R *l*)) = (SECOND (SECOND *l*))

and similarly for all other sequences of **2 – 4** **A**s and/or **D**s.

- Although authors sometimes write C … R function names that contain ***more than 4*** **A**s and/or **D**s, functions with such names are ***not*** built-in functions of most implementations of Common Lisp!
- C … R function names are pronounceable: This is one reason the nondescriptive names CAR and CDR are still used.

From p. 48 of Touretzky:

CAR/CDR Pronunciation Guide

Function	Pronunciation	Alternate Name
CAR	*kar*	FIRST
CDR	*cou-der*	REST
CAAR	*ka-ar*	
CADR	*kae-der*	SECOND
CDAR	*cou-dar*	
CDDR	*cou-dih-der*	
CAAAR	*ka-a-ar*	
CAADR	*ka-ae-der*	
CADAR	*ka-dar*	
CADDR	*ka-dih-der*	THIRD
CDAAR	*cou-da-ar*	
CDADR	*cou-dae-der*	
CDDAR	*cou-dih-dar*	
CDDDR	*cou-did-dih-der*	
CADDDR	*ka-dih-dih-der*	FOURTH

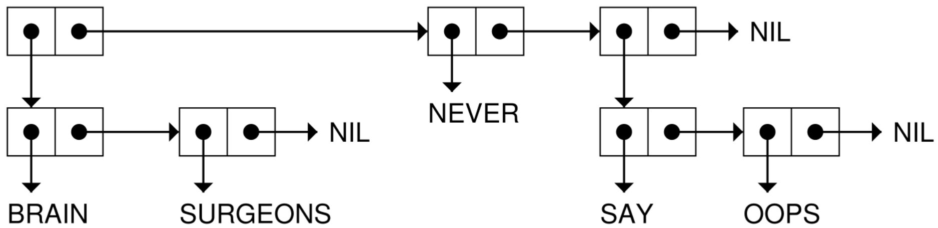
and so on

CONS Cells and the Implementation of CAR, CDR, and CONS

We have already seen "*box* and *arrow*" drawings of Lisp data objects represented by lists. Below is one example:

From p. 34 of Touretzky.

((BRAIN SURGEONS) NEVER (SAY OOPS)) represents:



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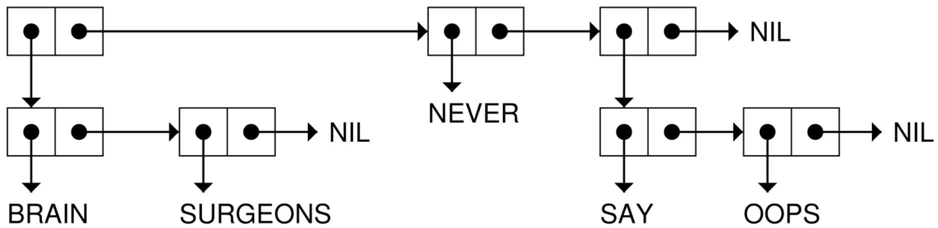
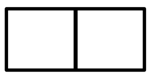


- Each of the  boxes in such a drawing represents a Lisp data object called a ***cons cell***.
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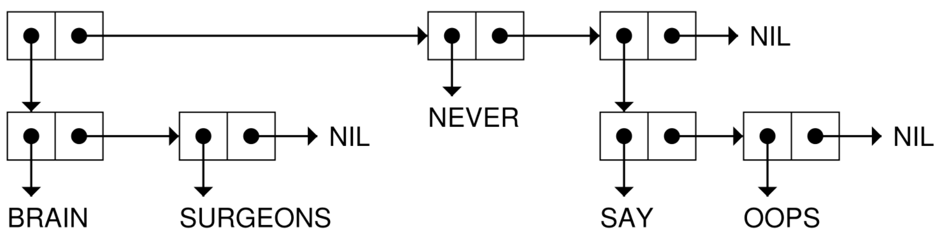
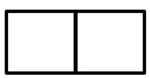


- Each of the  boxes in such a drawing represents a Lisp data object called a ***cons cell***.
- A cons cell has 2 fields that contain pointers. (Pointers are represented by the arrows in box and arrow drawings.)
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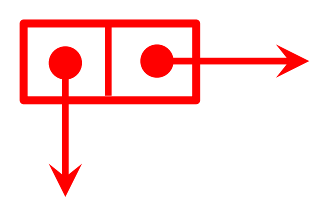

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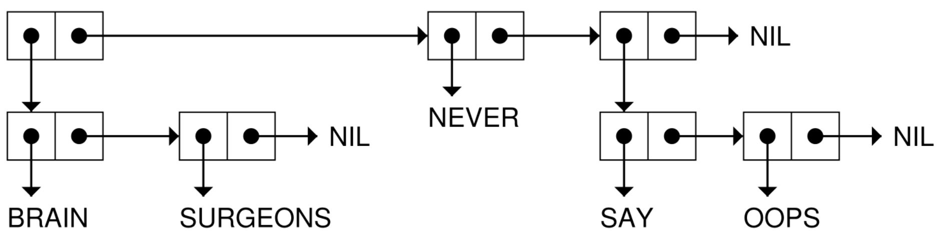
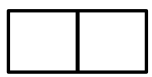


- Each of the  boxes in such a drawing represents a Lisp data object called a ***cons cell***.
- A cons cell has 2 fields that contain pointers. (Pointers are represented by the arrows in box and arrow drawings.)
  - The pointer in one field is called the ***car*** pointer; this is shown on the ***left*** side of a cons cell box.
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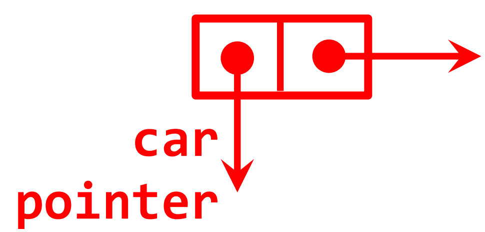

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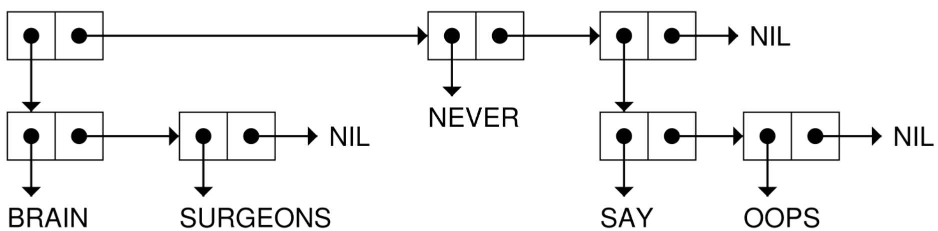
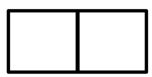


- Each of the  boxes in such a drawing represents a Lisp data object called a ***cons cell***.
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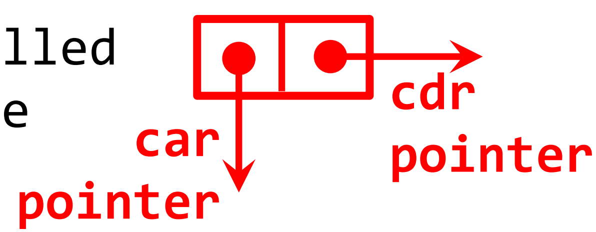
  - The pointer in one field is called the ***car*** pointer; this is shown on the ***left*** side of a cons cell box.
  - The pointer in the other field is called the ***cdr*** pointer; this is shown on the ***right*** side of a cons cell box.



Lisp implementations deal with S-expressions via pointers:

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- When passing an S-expression as argument to a function call or returning an S-expression as the result of a function call, *what do we actually pass or return*?

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  - In some implementations this may not actually be true when the S-expression in question is a number or a character, but even then it's OK for Lisp programmers to assume it's true, as that assumption won't lead to wrong predictions about the *observable behavior* of the code.

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- Every nonempty list has a "root" cons cell, which is *the unique cons cell of the list that is **not** pointed at by a car or cdr pointer of another cons cell of the list.*
  Example:

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- When passing an S-expression as argument to a function call or returning an S-expression as the result of a function call, *what do we actually pass or return*?

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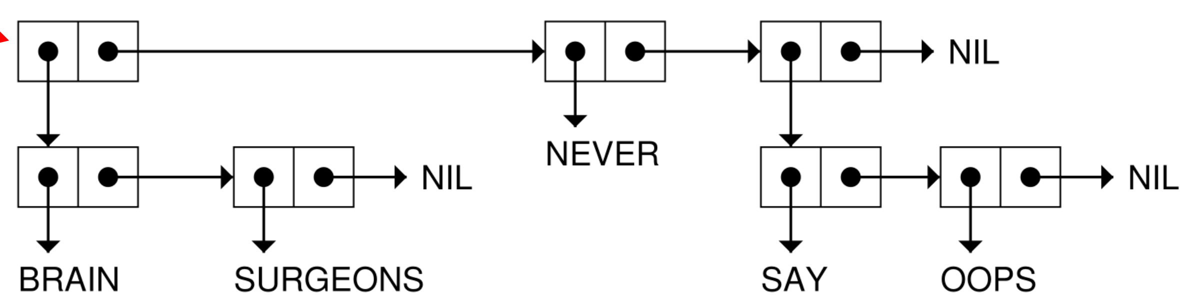
- Every nonempty list has a "root" cons cell, which is *the unique cons cell of the list that is **not** pointed at by a car or cdr pointer of another cons cell of the list.*

  Example:

  This cons cell is the "root" cons cell of the list.



-

Lisp implementations deal with S-expressions via pointers:

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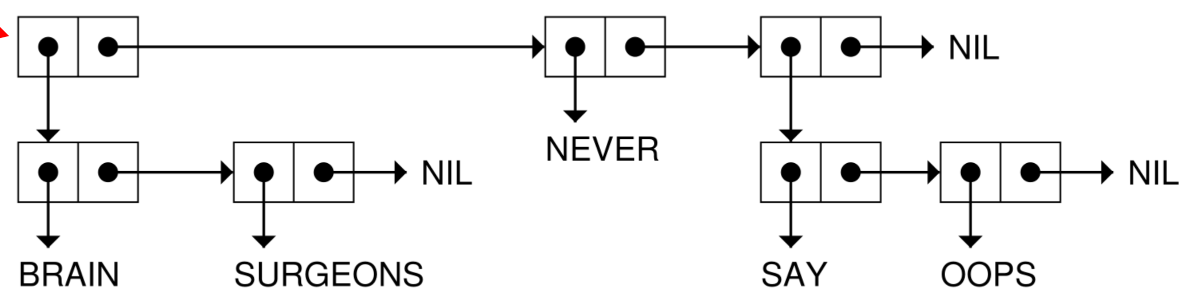

- When passing a nonempty list as argument to a function call, or returning a nonempty list as the result of a function call, we pass or return ***a pointer to the "root" cons cell of that list***.

```
p. 43 of Touretzky explains the evaluation of
           (CAR '(THE BIG BOPPER))
as follows:
```

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(CAR '(THE BIG BOPPER))
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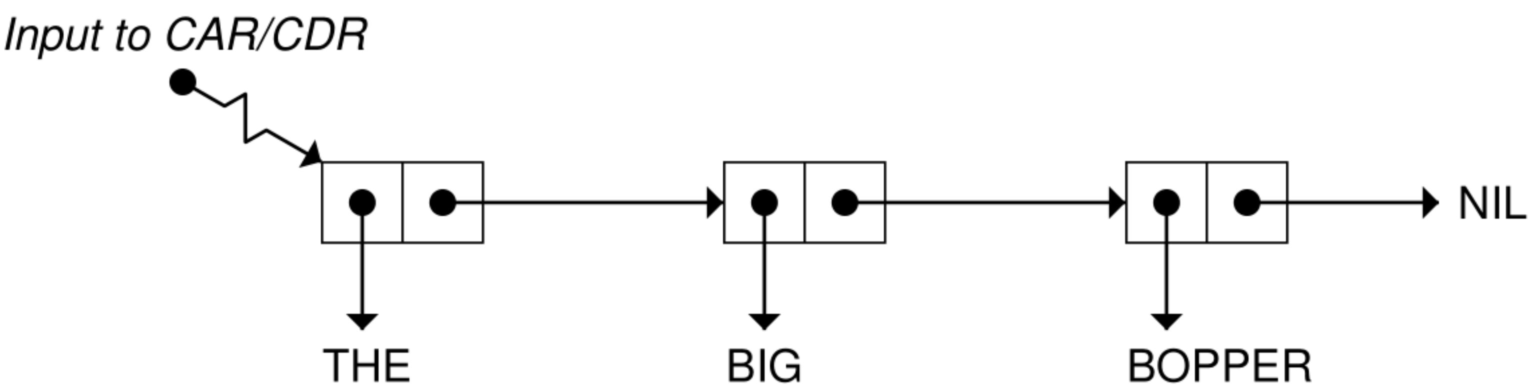
as follows:

When this list is used as input to a function such as CAR, what the function actually receives is not the list itself, but rather a pointer to the first cons cell:



CAR follows this pointer to get to the actual cons cell and extracts the pointer sitting in the CAR half. So CAR returns as its result a pointer to the symbol THE.

p. 43 of Touretzky then explains the evaluation of

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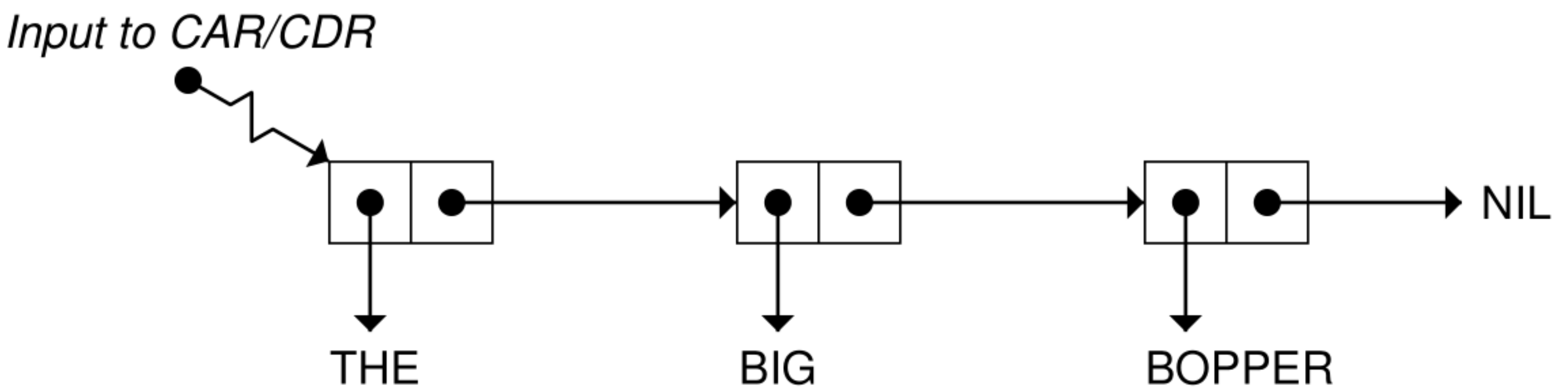

CDR follows the pointer to get to the cons cell, and extracts the pointer sitting in the CDR half, which it returns. So the result of CDR is a pointer to the list (BIG BOPPER).

A function call (CAR *L*) is evaluated as follows:

1.

2.

3.

4.

A function call (CAR *l*) is evaluated as follows:

1. Evaluate *l*: This yields a pointer to the data object that is *l*'s value.
2.

3.
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1. Evaluate *l*: This yields a pointer to the data object that is *l*'s value.
2. If *l*'s value is a ***nonempty list***, then the pointer given by step 1 points to the list's "root" cons cell.

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3.
4.

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   In this case we **return** that cons cell's ***car*** pointer.
3.
4.

A function call (CAR *l*) is evaluated as follows:

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3. If *l*'s value is **NIL**, then we **return** a pointer to .
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p. 54 of Touretzky explains the evaluation of (CONS 'HELLO '(THERE MISS DOOLITTLE)) as follows:

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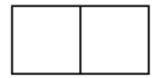
CONS creates a new cons cell: 

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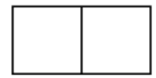
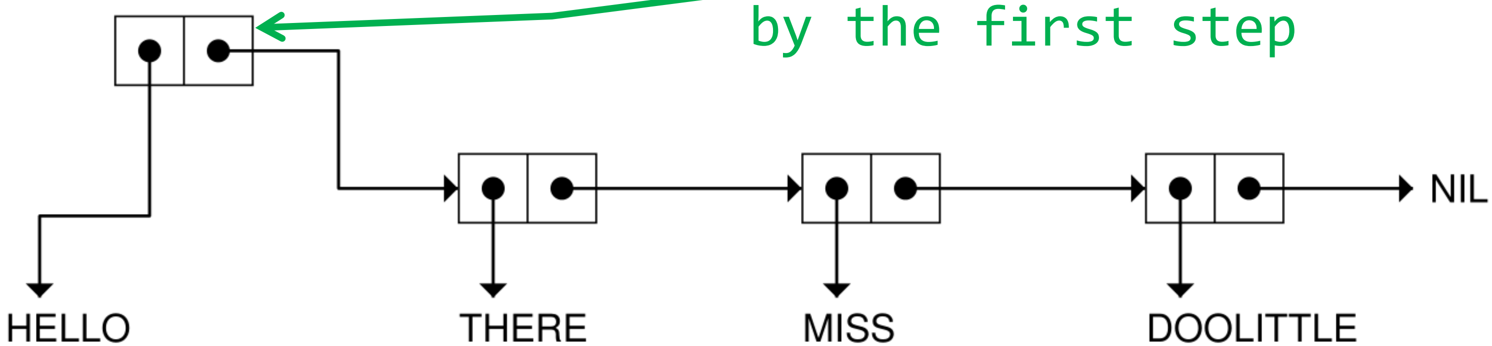
CONS creates a new cons cell: 

It fills in the CAR and CDR pointers:

The new cons cell created by the first step



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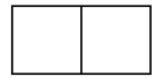
CONS creates a new cons cell: 

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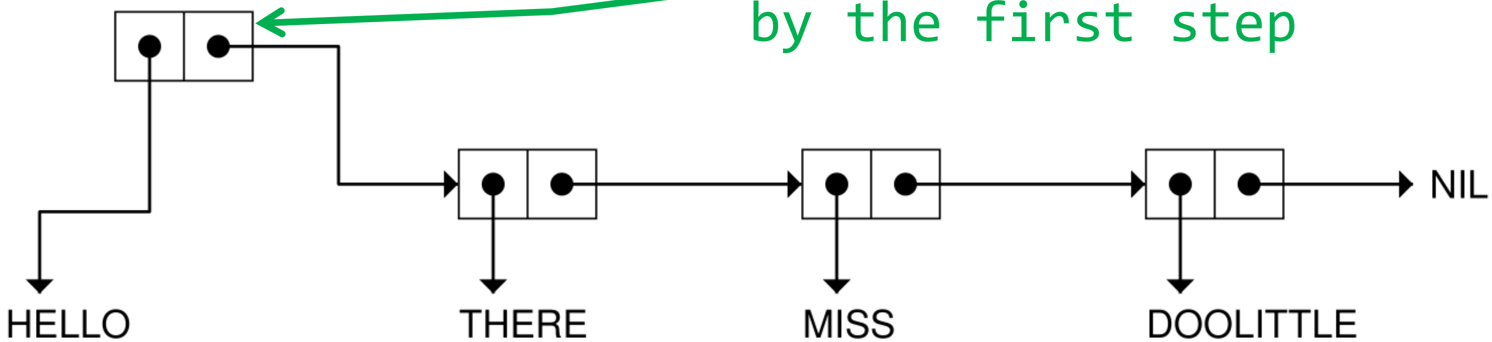
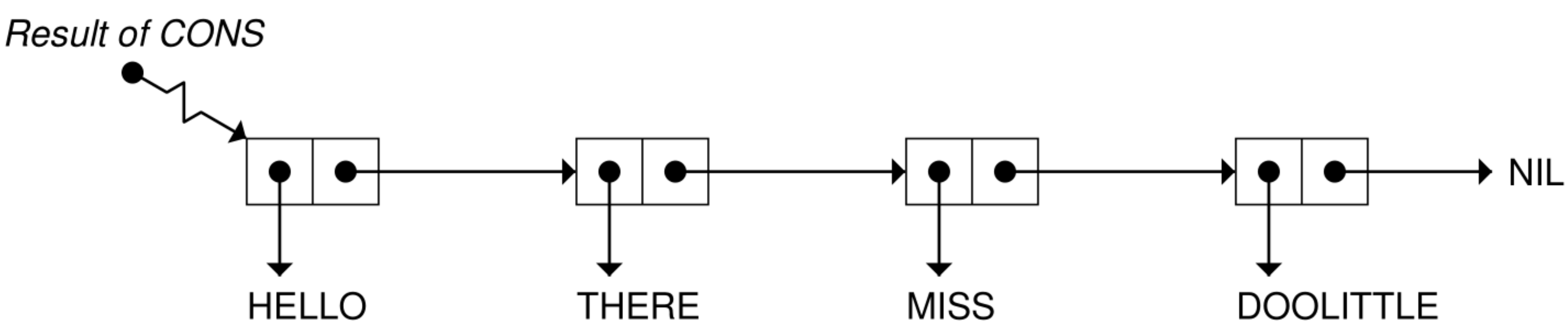


And it returns a pointer to the new cell, which is now the head of a cons cell chain one longer than CONS's second input:



A function call (CONS *x* *L*) is evaluated as follows:

1.

2.

3.

4.

5.

A function call (CONS *x* *l*) is evaluated as follows:

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A function call (CONS *x* *l*) is evaluated as follows:

1. Evaluate *x* and *l*: This yields pointers to 2 data objects, namely *x*'s value and *l*'s value.
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3. Store the pointer to *x*'s value that was found at step 1 in the ***car*** pointer field of the new cons cell.
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- See p. 59 of Touretzky for an explanation of how a function call **(LIST 'FOO 'BAR 'BAZ)** is evaluated.
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- See pp. 162 – 3 of Touretzky for an explanation of how a function call **(APPEND '(A B C) '(D E))** is evaluated.

Predicates and Conditionals

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  Answer:

  Exercise: What is the value of **(if () 1 2)** in Lisp?

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  Answer: As 0 represents *true*, the value is 1.

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  - The fact that () represents false will actually be important when we consider the predicate MEMBER!
- Recall that T and NIL are constant symbols that evaluate to themselves: So T and NIL never have to be quoted, just as numbers never have to be quoted!

Equality Predicates

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- Lisp has several predicates for testing equality, of which the following four are the most commonly used:
  -
  -
  -
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    - (equal (+ 1.0 2) 3.0) ⇒ T
    - (equal 0.5 1/2) ⇒ NIL
    - (equal (/ 1 2) 1/2) ⇒ T
    - (equal 0.5 (/ 1 2)) ⇒

Equality Predicates

- Lisp has several predicates for testing equality, of which the following four are the most commonly used:
  - equal
  - eql
  - eq
  - =

- (equal *x* *y*) ⇒ T if the argument values are equal
  (equal *x* *y*) ⇒ NIL if the argument values are not equal
  - (equal (car '(a b c)) (cadr '(1 a b c))) ⇒ T
  - (equal (cdr '(a b c)) (cdr '(1 a b c))) ⇒ NIL
  - (equal (list 'a 'b 'c) (cdr '(1 a b c))) ⇒ T
  - (equal (+ 1 2) 3) ⇒ T
  - (equal (+ 1 2) 3.0) ⇒ NIL
  - (equal (+ 1.0 2) 3.0) ⇒ T
  - (equal 0.5 1/2) ⇒ NIL
  - (equal (/ 1 2) 1/2) ⇒ T
  - (equal 0.5 (/ 1 2)) ⇒ NIL