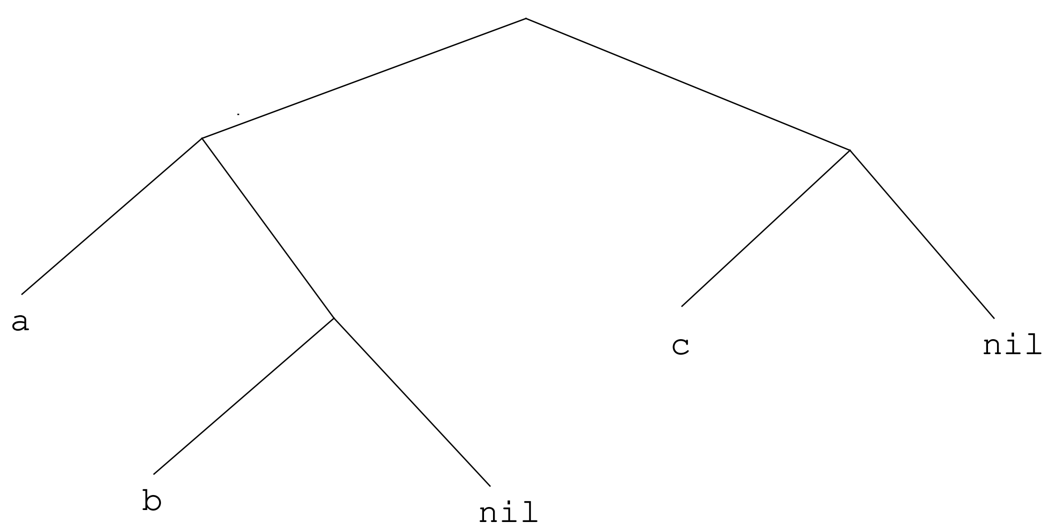
More about list representation in LISP

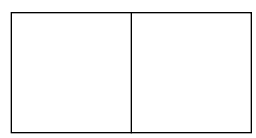
- a list can be represented by
  - the *first* or *car* of the list, and
  - the *rest* or *cdr* of the list
- the first and rest of a list can each be a list
- This suggests using a binary tree to represent a list
  - each internal node represents a list rooted at that node and has two children
    - the first of the list rooted at that node
    - the rest of the list rooted at that node
  - each leaf of the tree is an atom

`((a b) c)`

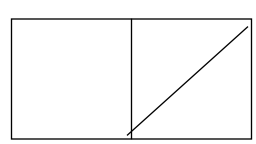


list representation in LISP

- lists are sometimes represented with “box notation”
- box notation is a variant of usual binary tree notation
- internal nodes are represented by a box with two sub-boxes

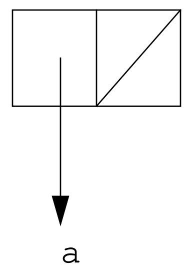


- the box represents a cons cell in memory
- the left sub-box represents a pointer to the first of the cons, the right sub-box represents a pointer to the rest of the cons
- if either is NIL, a slash is put in the sub-box

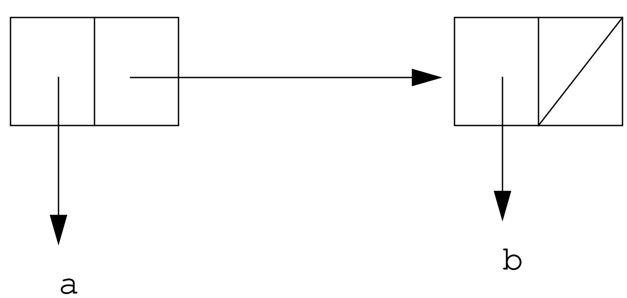


list representation in LISP

`(a)`

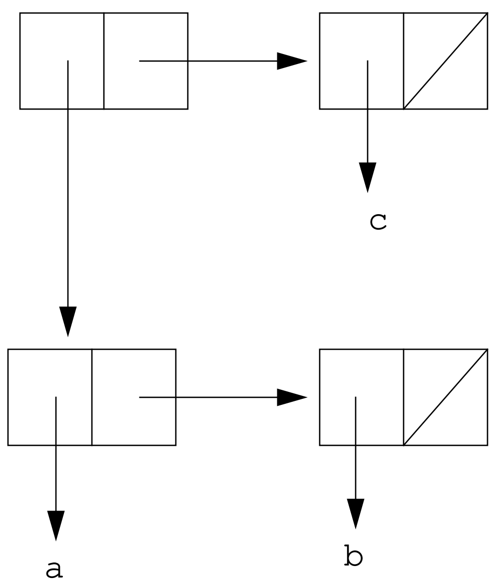


`(a b)`

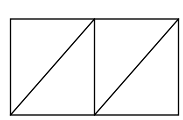


list representation in LISP

`((a b) c)`



`(())`



list representation

- What is this list?

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creating and destroying lists

- When a list-creating function like `list, cons`, or `append` is called,...
- or when list structure is read in by the LISP system...
- cons cells are allocated from free storage

- When a cons cell is no longer being used, it is returned to free storage in a garbage collection process

- In pure functional LISP, no side effects exist to change the pointers in cons cells once they are allocated

- However, Common LISP provides many functions to change cons cell pointers: list surgery

list manipulation in LISP

- ✔ implementing `append`

```
(setf abc '(a b c) xyz '(x y z))
```

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list manipulation in LISP

✔ `append` involves copying cons cells to avoid unwanted side effects

```
(setf abcxyz (append abc xyz))

abcxyz
(A B C X Y Z)

abc
(A B C)

xyz
(X Y Z)
```

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list surgery in LISP

- ✔ `nconc` works like `append` except it performs list surgery instead of copying cons cells
- ✔ `nconc` produces side effects!

```
(setf abcxyz (nconc abc xyz))

abcxyz
(A B C X Y Z)

xyz
(X Y Z)

abc
(A B C X Y Z)
```

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list surgery in LISP

- ✔ many side-effect free list manipulation functions have a counterpart which performs list surgery
- ✔ the list-surgery version will be more efficient because it does not allocate new cons cells, but instead just changes pointers in existing cons cells
- ✔ however the list-surgery version will have side effects that may be hard to predict
  - ✗ Example: `delete` works like `remove`, but performs list surgery. However the side effects of `delete` may not be what you would expect...

```
(setf tosses '(heads tails tails heads tails))
(HEADS TAILS TAILS HEADS TAILS)

(remove 'heads tosses)
(TAILS TAILS TAILS)

tosses
(HEADS TAILS TAILS HEADS TAILS)

(delete 'heads tosses)
(TAILS TAILS TAILS)

tosses
(HEADS TAILS TAILS TAILS)
```

list surgery functions

- ✔ usually the name of a function that does list surgery is the same as the corresponding side-effect-free version, preceded by “N”
  - ✗ `nreverse - reverse`
  - ✗ `nunion - union`
  - ✗ `nintersection - intersection`
  - ✗ etc.
- ✔ exceptions to this are
  - ✗ `nconc - append`
  - ✗ `delete - remove`

do-it-yourself list surgery

- setf can be used with list accessor functions to perform list surgery
- list surgery can produce circular lists

```
(setf fact3 '(circle))
(CIRCLE)

(setf (rest fact3) fact3)
```

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- there are problems with printing out circular lists, and reclaiming cons cells in circular lists during garbage collection