Metaprogramming and Reflection

Common Lisp

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Syntax

```
(function-name arg1 arg2 ... argn)
```

Syntax

```
(function-name arg1 arg2 ... argn)
```

```
> (+ 1 2)
3
```

Creating Lists

```
> (cons 3 nil)
(3)
```

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Impossible as 3 is not a function

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Impossible as 3 is not a function

```
> (cons 2 '(3))
(2 3)
```

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Impossible as 3 is not a function

```
> (cons 2 '(3))
(2 3)
> (cons 1 '(2 3))
(1 2 3)
```

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Impossible as 3 is not a function

```
> (cons 2 '(3))
(2 3)
> (cons 1 '(2 3))
(1 2 3)
> (list 1 2 3)
(1 2 3)
```

Creating Lists

```
> (cons 3 nil)
(3)
> (cons 2 (3))
```

Impossible as 3 is not a function

```
> (cons 2 '(3))
(2 3)
> (cons 1 '(2 3))
(1 2 3)
> (list 1 2 3)
(1 2 3)
> '(1 2 3)
(1 2 3)
```

Studying Lists

```
> (car '(1 2 3))
1
```

Studying Lists

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

Studying Lists

```
> (car '(1 2 3))
1
> (cdr '(1 2 3))
(2 3)
> (first '(1 2 3))
1
```

Studying Lists

```
> (car '(1 2 3))
1
> (cdr '(1 2 3))
(2 3)
> (first '(1 2 3))
1
> (last '(1 2 3) 2)
(2 3)
```

Studying Lists

```
> (car '(1 2 3))
1
> (cdr '(1 2 3))
(2 3)
> (first '(1 2 3))
1
> (last '(1 2 3) 2)
(2 3)
> (last '(1 2 3))
(3)
```

Creating Functions

```
> (defun mult2 (x)
    "Multiplies x by 2"
    (* x 2))
mult2
```

Creating Functions

```
> (defun mult2 (x)
    "Multiplies x by 2"
    (* x 2))
mult2
```

defun is itself a function, it creates functions

Creating Functions

```
> (defun mult2 (x)
    "Multiplies x by 2"
    (* x 2))
mult2
```

defun is itself a function, it creates functions

```
> (mult2 3)
6
```

Studying Functions

```
> #'mult2
#<FUNCTION mult2>
```

Studying Functions

```
> #'mult2
#<FUNCTION mult2>
> (describe #'mult2)
(defun mult2 (x)
  "Multiplies x by 2"
  (* x 2))
```

Calling Functions

```
> (mult2 3)
6
```

Calling Functions

```
> (mult2 3)
6
> (funcall #'mult2 3)
6
```

Calling Functions

```
> (mult2 3)
6
> (funcall #'mult2 3)
6
> (defvar fmult2 #'mult2)
fmult2
```

Calling Functions

```
> (mult2 3)
6
> (funcall #'mult2 3)
6
> (defvar fmult2 #'mult2)
fmult2
> (funcall fmult2 3)
6
```

Summary

In Lisp it is possible to:

- define new functions,
- retrieve a function by name,
- reference a function from a variable,
- call a function from a variable.

Summary

In Lisp it is possible to:

- define new functions,
- retrieve a function by name,
- reference a function from a variable,
- call a function from a variable.

This is very similar to pointer manipulation in C

Function Pointer Manipulation in C

```
int mult2 (int c) {
 return c * 2;
}
```

Function Pointer Manipulation in C

```
int mult2 (int c) {
 return c * 2;
}
```

```
int main(void) {
   int (*fmult2) (int) = mult2;
   (*fmult2)(3);
}
```

Generating new Functions

```
> (get-source 'mult2)
(nil nil
     (defun mult2 (x)
       "Multiplies x by 2"
       (* x 2)))
```

Generating new Functions

```
> (get-source 'mult2)
(nil nil
     (defun mult2 (x)
       "Multiplies x by 2"
       (* x 2)))
```

requires ibcl

Generating new Functions

```
> (defvar smult2
    (third (get-source 'mult2)))
smult2
```

Generating new Functions

```
> (defvar smult2
    (third (get-source 'mult2)))
smult2
> smult2
(defun mult2 (x)
  "Multiplies x by 2"
  (* x 2))
```

Generating new Functions

```
> (first smult2)
defun
```

Generating new Functions

```
> (first smult2)
defun
> (second smult2)
mult2
```

Generating new Functions

```
> (first smult2)
defun
> (second smult2)
mult2
> (third smult2)
(x)
```

Generating new Functions

```
> (first smult2)
defun
> (second smult2)
mult2
> (third smult2)
(x)
> (fourth smult2)
"Multiplies x by 2"
```

Generating new Functions

```
> (first smult2)
defun
> (second smult2)
mult2
> (third smult2)
(x)
> (fourth smult2)
"Multiplies x by 2"
> (fifth smult2)
(* x 2)
```

Generating new Functions

```
> (defvar smult10
      (copy-list smult2))
smult10
```

Generating new Functions

```
> (defvar smult10
      (copy-list smult2))
smult10
> (nsubstitute 10 2 (fifth smult10))
nil
```

Generating new Functions

```
> (defvar smult10
      (copy-list smult2))
smult10
> (nsubstitute 10 2 (fifth smult10))
nil
> smult10
(defun mult2 (x)
  "Multiplies x by 2"
  (* x 10))
```

Generating new Functions

```
> smult10
(defun mult2 (x)
   "Multiplies x by 2"
  (* x 10))
```

Generating new Functions

```
> smult10
(defun mult2 (x)
   "Multiplies x by 2"
   (* x 10))
> (nsubstitute 'mult10 'mult2
                smult10)
(defun mult10 (x)
   "Multiplies x by 2"
   (* x 10))
```

Generating new Functions

```
> smult10
(defun mult10 (x)
  "Multiplies x by 2"
  (* x 10))
```

Generating new Functions

```
> smult10
(defun mult10 (x)
  "Multiplies x by 2"
  (* x 10))
> (setf (fourth smult10)
        (cl-ppcre:regex-replace "2"
          (fourth smult10) "10"))
"Multiplies x by 10"
```

Generating new Functions

```
> smult10
(defun mult10 (x)
  "Multiplies x by 10"
  (* x 10))
```

Generating new Functions

```
> smult10
(defun mult10 (x)
  "Multiplies x by 10"
  (* x 10))
> (eval smult10)
mult10
```

Generating new Functions

```
> smult10
(defun mult10 (x)
  "Multiplies x by 10"
  (* x 10))
> (eval smult10)
mult10
> (mult10 3)
30
```

Summary

- A function definition in Lisp is a list.
- This list can be studied like any list.
- New functions can be created from a list.

Beyond Functions

How would you implement while that executes its body *as long as* its condition stays true?

```
> (while condition body)
```

The While Construct

```
> (setq i 10)
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
```

The While Construct

```
> (setq i 10)
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
i is now: 9
i is now: 8
i is now: 7
...
i is now: 2
i is now: 1
i is now: 0
```

The While Construct: Using Loop

```
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
> (loop
    (if (not (/= i 0))
      (return)
      (progn
        (decf i)
        (format t "i = ~s~%" i))))
```

The While Construct: Function

```
> (defun while (test &rest body)
    (loop
      (if (not test)
          (return)
          (progn body))))
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
```

The While Construct: Function

```
> (defun while (test &rest body)
    (loop
      (if (not test)
          (return)
          (progn body))))
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
```

doesn't work because parameters are evaluated immediately

```
> (while t nil)
```

Function Evaluation in C

```
int f(int c){printf("f\n");return c;}
int g(int c){printf("g\n");return c;}
int h(int c){printf("h\n");return c;}

int main(void) {
  f(g(h(1)));
}
```

Function Evaluation in C

```
int f(int c){printf("f\n");return c;}
int g(int c){printf("g\n");return c;}
int h(int c){printf("h\n");return c;}

int main(void) {
  f(g(h(1)));
}
```

```
h
g
f
```

The While Construct: Function

```
> (defun while (test &rest body)
    (loop
      (if (not test)
          (return)
          (progn body))))
> (while (/= i 0)
    (decf i)
    (format t "i is now: ~s~%" i))
```

doesn't work because parameters are evaluated immediately

```
> (while t nil)
```

The While Construct: Function

```
> (while '(/= i 0)
    '(decf i)
    '(format t "i is now: ~s~%" i))
```

The While Construct: Function

```
> (while '(/= i 0)
    '(decf i)
    '(format t "i is now: ~s~%" i))
> (defun while (test &rest body)
    (loop
      (if (not (eval test))
          (return)
          (mapcar #'eval body))))
```

The While Construct: Function

```
> (while '(/= i 0)
    '(decf i)
    '(format t "i is now: ~s~%" i))
> (defun while (test &rest body)
    (loop
      (if (not (eval test))
          (return)
          (mapcar #'eval body))))
```

works, but using while is less readable than intended

Summary

- Arguments of functions are evaluated first.
- To prevent evaluation, use **quote** (or ’).
- Use **eval** to evaluate an expression.

The While Construct: Macro

```
> (loop
    (if (not (/= i 0))
      (return)
      (progn
        (decf i)
        (format t "i = ~s~%" i))))
```

The While Construct: Macro

```
> (loop
    (if (not (/= i 0))
      (return)
      (progn
        (decf i)
        (format t "i = ~s~%" i))))
> (defmacro while (test &body body)
    (list 'loop
      (list 'if (list 'not test)
        (list 'return)
        (cons 'progn body))))
```

The While Construct: Macro

```
> (loop
    (if (not (/= i 0))
      (return)
      (progn
        (decf i)
        (format t "i = ~s~%" i))))
> (defmacro while (test &body body)
    `(loop
       (if (not ,test)
         (return)
         (progn ,@body))))
```

Macros

Macros are programs that write programs

- they return lists representing Lisp code.
- they don't evaluate their arguments.
- they are evaluated at *compile time*.

Creating an OO language

```
> (makeClass Speaker (name)
    (makeMethod speak (sentence)
      (format t
        "Listen all of you: ~s~%"
        sentence)))
```

Creating an OO language

```
> (makeClass Speaker (name)
    (makeMethod speak (sentence)
      (format t
        "Listen all of you: ~s~%"
        sentence)))
> (defvar alex (new 'Speaker "Alex"))
```

Creating an OO language

```
> (makeClass Speaker (name)
    (makeMethod speak (sentence)
      (format t
        "Listen all of you: ~s~%"
        sentence)))
> (defvar alex (new 'Speaker "Alex"))
> (call alex 'speak "Hello World!")
Listen all of you: "Hello World!"
```

Creating an OO language

```
> (makeClass Speaker (name)
    (makeMethod speak (sentence)
      (format t
        "Listen all of you: ~s~%"
        sentence)))
> (defvar alex (new 'Speaker "Alex"))
> (call alex 'speak "Hello World!")
Listen all of you: "Hello World!"
> (getinstvar alex 'name)
Alex
```

Creating an OO language

```
> (makeClass Speaker ()
    (makeMethod "..."))
```

Creating an OO language

```
> (makeClass Speaker ()
    (makeMethod "..."))
```

A class is composed of:

- a name,
- some instance variables,
- and some method definitions.

Creating an OO language

```
> (makeClass Speaker ()
    (makeMethod "..."))
```

A class is composed of:

- a name,
- some instance variables,
- and some method definitions.

```
> (defstruct cls
    name
    vars
    mths)
```

Creating an OO language

```
> (makeClass Speaker ()
    (makeMethod "..."))
```

```
> (defmacro makeClass (name iVars
                       &body meths)
    `(push
       (make-cls
         :name ',name
         :vars ',iVars
         :mths
           ',(mapcar #'eval meths))
       *classes*))
```

Creating an OO language

```
> (makeMethod speak (sentence)
    (format t "..." sentence))
```

Creating an OO language

```
> (makeMethod speak (sentence)
    (format t "..." sentence))
```

A method is composed of:

- a name,
- some parameters,
- a body

Creating an OO language

```
> (makeMethod speak (sentence)
    (format t "..." sentence))
```

A method is composed of:

- a name,
- some parameters,
- a body

```
> (defstruct mth
    name
    lmbd)
```

Creating an OO language

```
> (makeMethod speak (sentence)
    (format t "..." sentence))
```

Creating an OO language

```
>  (makeMethod speak (sentence)
     (format t "..." sentence))
```

```
>  (defmacro makeMethod (name
                         argNames &body body)
     `(make-mth
         :name ',name
         :lmbd (lambda ,argNames
                       ,@body)))
```

Creating an OO language

```
> (new 'Speaker "Alex")
```

Creating an OO language

```
> (new 'Speaker "Alex")
```

An object is composed of:

- a reference to its class,
- some values for its instance variables

Creating an OO language

```
> (new 'Speaker "Alex")
```

An object is composed of:

- a reference to its class,
- some values for its instance variables

```
> (defstruct obj
    cls
    values)
```

Creating an OO language

```
> (call alex 'speak "Hello World!")
Listen all of you: "Hello World!"
```

Creating an OO language

```
> (call alex 'speak "Hello World!")
Listen all of you: "Hello World!"
```

A call is a function with:

- the receiver object,
- a method name,
- and a list of parameters.

Creating an OO language

```
> (call alex 'speak "Hello World!")
Listen all of you: "Hello World!"
```

A call is a function with:

- the receiver object,
- a method name,
- and a list of parameters.

```
(defun call (obj name &rest params)
   "...")
```

Creating an OO language

```
(defun call (obj name &rest params)
  (let* ((cls (obj-cls obj))
         (mth (getMethod cls name)))
    (apply (mth-lmbd mth)
           params)))
```

Creating an OO language

```
(defun call (obj name &rest params)
  (let* ((cls (obj-cls obj))
         (mth (getMethod cls name)))
    (apply (mth-lmbd mth)
           params)))
```

```
(defun getMethod (cls name)
  (find name (cls-mths cls)
        :key #'mth-name))
```

Creating an OO language

```
> (getinstvar alex 'name)
Alex
```

Creating an OO language

```
> (getinstvar alex 'name)
Alex
```

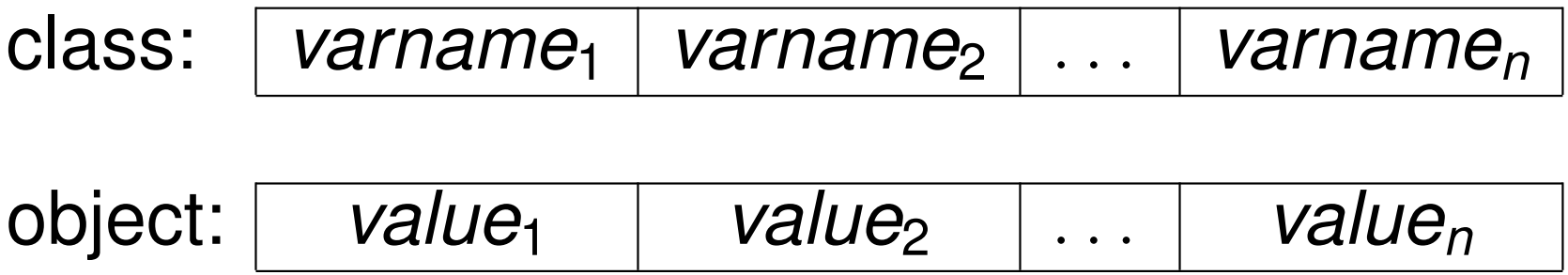
Looking for an instance variable value from its name involves:

- getting the position of the name in the list of all instance variables of the class,
- taking the value at this position in the list of all values of the object.

class:	$varname_1$	$varname_2$	...	$varname_n$

object:	$value_1$	$value_2$	...	$value_n$

Creating an OO language




```
(defun getInstVar (obj name)
  (let* ((cls (obj-cls obj))
         (vars (cls-vars cls))
         (pos (position name vars)))
    (nth pos (obj-values obj))))
```

Handling this

An object must be able to get its instance variables and call methods by using this.

Handling this

An object must be able to get its instance variables and call methods by using this.

```
> (makeClass Speaker (name)
    (makeMethod getName ()
      (getInstVar 'this 'name)))
```

Handling this

An object must be able to get its instance variables and call methods by using this.

```
> (makeClass Speaker (name)
    (makeMethod getName ()
      (getInstVar 'this 'name)))
> (call alex 'getname)
Alex
```

Handling this

An object must be able to get its instance variables and call methods by using this.

```
> (makeClass Speaker (name)
    (makeMethod getName ()
      (getInstVar 'this 'name)))
> (call alex 'getname)
Alex
```

This requires the system to keep track of the *current object*.

Handling this

An object must be able to get its instance variables and call methods by using this.

```
> (makeClass Speaker (name)
    (makeMethod getName ()
      (getInstVar 'this 'name)))
> (call alex 'getname)
Alex
```

This requires the system to keep track of the *current object*.

```
> (defparameter *cur-obj* nil)
```

Handling this

```
(defun getInstVar (obj name)
  (let* ((theObj
            (if (equal obj 'this)
                *cur-obj*
                obj))
         (cls (obj-cls theObj))
         (vars (cls-vars cls))
         (pos (position name vars)))
    (nth pos (obj-values theObj))))
```

Handling this

```
(defun getInstVar (obj name)
  (let* ((theObj
            (if (equal obj 'this)
                *cur-obj*
                obj))
         (cls (obj-cls theObj))
         (vars (cls-vars cls))
         (pos (position name vars)))
    (nth pos (obj-values theObj))))
```

When is *cur-obj* updated?

Handling this

```
(defun getInstVar (obj name)
  (let* ((theObj
            (if (equal obj 'this)
                *cur-obj*
                obj))
         (cls (obj-cls theObj))
         (vars (cls-vars cls))
         (pos (position name vars)))
    (nth pos (obj-values theObj))))
```

When is *cur-obj* updated? Before it is *used*!

Handling this

```
(defun getInstVar (obj name)
  (let* ((theObj
            (if (equal obj 'this)
                *cur-obj*
                obj))
         (cls (obj-cls theObj))
         (vars (cls-vars cls))
         (pos (position name vars)))
    (nth pos (obj-values theObj))))
```

When is *cur-obj* updated? Before it is *used*!
As this is only used when a method is executed, the method call needs to do the updating job.

Handling this

The method call needs to do the updating job:

```
(defun call (obj name &rest params)
  (let* ((cls (obj-cls obj))
         (mth (getMethod cls name))
         (*cur-obj* obj))
    (apply (mth-lmbd mth)
           params)))
```

Handling this

We also want to pass this as first argument to call:

```
(defun call (obj name &rest params)
  (let* ((theObj
          (if (equal obj 'this)
              *cur-obj*
              obj))
         (cls (obj-cls theObj))
         (mth (getMethod cls name)))
    (setf *cur-obj* theObj)
    (apply (mth-lmbd mth)
           params)))
```

Creating an OO language

Possible improvements:

- setting of instance variables
- inheritance
- constructors
- dedicated syntax

Creating Domain-Specific Languages

```
(makeClass Speaker (name)
  (makeMethod speak (s)
    (format t "I say: ~a" s))
  (makeMethod getName ()
    (call 'this 'speak "hi!")
    (getInstVar 'this 'name)))
```

Creating Domain-Specific Languages

```
(makeClass Speaker (name)
  (makeMethod speak (s)
    (format t "I say: ~a" s))
  (makeMethod getName ()
    (call 'this 'speak "hi!")
    (getInstVar 'this 'name)))
```

```
(makeMethod getName ()
    {c speak "hi!"}
    {i name})
```

Creating Domain-Specific Languages

```
;; {c speak "hi!"} {i name}
(set-macro-character #\{
 (lambda (str)
   (let ((type (read-char str))
         (l (read-delimited-list
                          #\} str)))
     (case type
      (#\c `(call 'this
                  ',(car l)
                  ,@(cdr l)))
      (#\i `(getInstVar 'this
                        ',(car l)))))))
```

Summary

- Lisp has powerful functions to manipulate lists.
- Lisp source code is made of lists.
- As a result, meta-programming is made easy.

Summary

Macros

- can be used to create source code,
- don’t evaluate their arguments,
- are evaluated at compile time.

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Macros are programs that write programs.

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- can be used to create source code,
- don’t evaluate their arguments,
- are evaluated at compile time.

Macros are programs that write programs.

Macros can also be used to install a new syntax.

A Glimpse at CLOS

```
> (defclass circle ()
    (radius center))
#<standard-class circle>
```

A Glimpse at CLOS

```
> (defclass circle ()
    (radius center))
#<standard-class circle>
> (make-instance 'circle)
#<circle {B9C4249}>
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius)
     (center :accessor circle-center)))
#<standard-class circle>
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius)
     (center :accessor circle-center)))
#<standard-class circle>
> (setf c (make-instance 'circle))
#<circle {ABC02C1}>
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius)
     (center :accessor circle-center)))
#<standard-class circle>
> (setf c (make-instance 'circle))
#<circle {ABC02C1}>
> (setf (circle-radius c) 6)
6
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius)
     (center :accessor circle-center)))
#<standard-class circle>
> (setf c (make-instance 'circle))
#<circle {ABC02C1}>
> (setf (circle-radius c) 6)
6
> (circle-radius c)
6
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius
             :initarg :radius)
     (center :accessor circle-center
             :initarg :center)))
#<standard-class circle>
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius
             :initarg :radius)
     (center :accessor circle-center
             :initarg :center)))
#<standard-class circle>
> (setf c (make-instance 'circle
                         :radius 6))
#<circle {AC2CD31}>
```

A Glimpse at CLOS

```
> (defclass circle ()
    ((radius :accessor circle-radius
             :initarg :radius)
     (center :accessor circle-center
             :initarg :center)))
#<standard-class circle>
> (setf c (make-instance 'circle
                         :radius 6))
#<circle {AC2CD31}>
> (circle-radius c)
6
```

A Glimpse at CLOS

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
#<standard-method area (circle)>
```

A Glimpse at CLOS

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
#<standard-method area (circle)>
> (setf c (make-instance 'circle
                         :radius 6))
#<circle {ACBC0F1}>
```

A Glimpse at CLOS

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
#<standard-method area (circle)>
> (setf c (make-instance 'circle
                         :radius 6))
#<circle {ACBC0F1}>
> (area c)
113.09733552923255d0
```

Auxiliary methods

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
```

Auxiliary methods

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
> (defmethod area :before ((c circle))
    (format t "I'm tired..."))
```

Auxiliary methods

```
> (defmethod area ((c circle))
    (* pi (expt (circle-radius c) 2)))
> (defmethod area :before ((c circle))
    (format t "I'm tired..."))
> (area c)
I'm tired...
113.09733552923255d0
```

Auxiliary methods

```
(setf cache nil)
```

Auxiliary methods

```
(setf cache nil)
(defun from-cache (c)
  (find (circle-radius c) cache
        :key #'car))
```

Auxiliary methods

```
(setf cache nil)
(defun from-cache (c)
  (find (circle-radius c) cache
        :key #'car))
(defun to-cache (c area)
  (push (cons (circle-radius c) area)
        cache)
  area)
```

Auxiliary methods

```
(defmethod area :around ((c circle))
 (let ((value (from-cache c)))
  (if value
   (progn
     (princ "Using the cache :-)")
     (cdr value))
   (progn
     (princ "So tired...")
     (to-cache c (call-next-method))))))
```

Auxiliary methods

```
(defmethod area :around ((c circle))
 (let ((value (from-cache c)))
  (if value
   (progn
     (princ "Using the cache :-)")
     (cdr value))
   (progn
     (princ "So tired...")
     (to-cache c (call-next-method))))))
> (area c)
So tired...I'm tired...
113.09733552923255d0
```

Auxiliary methods

```
> (area c)
So tired...I'm tired...
113.09733552923255d0
```

Auxiliary methods

```
> (area c)
So tired...I'm tired...
113.09733552923255d0
> (area c)
Using the cache :-)
113.09733552923255d0
```

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