Programming Languages

Macros

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What is a macro

- A *macro definition* describes how to transform some new syntax into different syntax in the source language
- A macro is one way to implement syntactic sugar
  - "Replace any syntax of the form **`e1 andalso e2`** with **`if e1 then e2 else false`**"
- A *macro system* is a language (or part of a larger language) for defining macros
- *Macro expansion* is the process of rewriting the syntax for each *macro use*
  - Before a program is run (or even compiled)

Using Racket Macros

- If you define a macro **`m`** in Racket, then **`m`** becomes a new special form:
  - Use **`(m …)`** gets expanded according to definition

- Example definitions (actual definitions coming later):
  - Expand **`(my-if e1 then e2 else e3)`**
    to **`(if e1 e2 e3)`**
  - Expand **`(comment-out e1 e2)`**
    to **`e2`**
  - Expand **`(my-delay e)`**
    to **`(mcons #f (lambda () e))`**

Example uses

It is like we added keywords to our language

- Other keywords only keywords in uses of that macro
- Syntax error if keywords misused
- Rewriting ("expansion") happens before execution

```
(my-if x then y else z)   ; (if x y z)
(my-if x else y then z)   ; syntax error

(comment-out (car null) #f)

(my-delay (begin (print "hi") (foo 15)))
```

Overuse

Macros often deserve a bad reputation because they are often overused or used when functions would be better

When in doubt, resist defining a macro?

But they can be used well

Now…

- How any macro system must deal with tokens, parentheses, and scope
- How to define macros in Racket
- How macro definitions must deal with expression evaluation carefully
  - Order expressions evaluate and how many times
- The key issue of variable bindings in macros and the notion of *hygiene*
  - Racket is superior to most languages here

Tokenization

First question for a macro system: How does it tokenize?

- Macro systems generally work at the level of *tokens* not sequences of characters
  - So must know how programming language tokenizes text

- Example: "macro expand **`head`** to **`car`**"
  - Would not rewrite **`(+ headt foo)`** to **`(+ cart foo)`**
  - Would not rewrite **`head-door`** to **`car-door`**
    - But would in C where **`head-door`** is subtraction

Parenthesization

Second question for a macro system: How does associativity work?

C/C++ basic example:

```
#define ADD(x,y) x+y
```

Probably *not* what you wanted:

`ADD(1,2/3)*4` means `1 + 2 / 3 * 4` not `(1 + 2 / 3) * 4`

So C macro writers use lots of parentheses, which is fine:

```
#define ADD(x,y) ((x)+(y))
```

Racket won't have this problem:

- Macro use: `(macro-name …)`
- After expansion: `( something else in same parens )`

Local bindings

Third question for a macro system: Can variables shadow macros?

Suppose macros also apply to variable bindings. Then:

```
(let  ([head 0][car 1]) head) ; 0
(let* ([head 0][car 1]) head) ; 0
```

Would become:

```
(let  ([car 0][car 1]) car) ; error
(let* ([car 0][car 1]) car) ; 1
```

This is why C/C++ convention is all-caps macros and non-all-caps for everything else

Racket does *not* work this way – it gets scope “right”!

Quote

Racket statements can be thought of as lists of tokens

We can use the built in quote operation to turn a racket program into a list of tokens

→ Quote prevents evaluation of the quoted expression

We can use an apostrophe as syntactic sugar.

```
(define x (quote (list a b c))
; or
(define x '(list a b c))
```

Quasiquote

Similar to quote but letting part of expression to be evaluated

Quasiquote and quote are the same unless we have an unquote expression

Can use the back tick for quasiquote and , for unquote

```
(define x (quasiquote
            (list (unquote a)
                  (unquote b)
                  (unquote c))
; or
(define x `(list ,a ,b ,c))
```

Example Racket macro definitions

Two simple macros

```
(define-syntax my-if                    ; macro name
  (syntax-rules (then else)             ; other keywords
    [(my-if e1 then e2 else e3)  ; macro use
     (if e1 e2 e3)]))                   ; form of expansion
```

```
(define-syntax comment-out              ; macro name
  (syntax-rules ()                      ; other keywords
    [(comment-out ignore instead)  ; macro use
     instead]))                         ; form of expansion
```

If the form of the use matches, do the corresponding expansion

- In these examples, list of possible use forms has length 1
- Else syntax error

Revisiting delay and force

Recall our definition of promises from earlier

- Should we use a macro instead to avoid clients' explicit thunk?

```
(define (my-delay th)
  (mcons #f th))

(define (my-force p)
  (if (mcar p)
      (mcdr p)
      (begin (set-mcar! p #t)
             (set-mcdr! p ((mcdr p)))
             (mcdr p))))
```

```
(f (my-delay (lambda () e)))
```

```
(define (f p)
  (… (my-force p) …))
```

A delay macro

- A macro can put an expression under a thunk
  - Delays evaluation without explicit thunk
  - Cannot implement this with a function
- Now client should *no*t use a thunk (that would double-thunk)
  - Racket's pre-defined **`delay`** is a similar macro

```
(define-syntax my-delay
  (syntax-rules ()
    [(my-delay e)
     (mcons #f (lambda() e))]))
```

```
(f (my-delay e))
```

What about a force macro?

We could define **`my-force`** with a macro too

- Good macro style would be to evaluate the argument exactly once (use **`x`** below, not multiple evaluations of **`e`**)
- Which shows it is bad style to use a macro at all here!
- Do not use macros when functions do what you want

```
(define-syntax my-force
  (syntax-rules ()
    [(my-force e)
     (let([x e])
        (if (mcar x)
            (mcdr x)
            (begin (set-mcar! x #t)
                   (set-mcdr! p ((mcdr p)))
                   (mcdr p)))))]))
```

Another bad macro

Any *function* that doubles its argument is fine for clients

```
(define (dbl x) (+ x x))
(define (dbl x) (* 2 x))
```

- These are equivalent to each other

So macros for doubling are bad style but instructive examples:

```
(define-syntax dbl (syntax-rules()[(dbl x)(+ x x)]))
(define-syntax dbl (syntax-rules()[(dbl x)(* 2 x)]))
```

- These are not equivalent to each other. Consider:

```
(dbl (begin (print "hi") 42))
```

More examples

Sometimes a macro *should* re-evaluate an argument it is passed

- If not, as in **`dbl`**, then use a local binding as needed:

```
(define-syntax dbl
  (syntax-rules ()
     [(dbl x)
      (let ([y x]) (+ y y))]))
```

Also good style for macros not to have surprising evaluation order

- Good rule of thumb to preserve left-to-right
- Bad example (fix with a local binding):

```
(define-syntax take
  (syntax-rules (from)
     [(take e1 from e2)
      (- e2 e1)]))
```

Local variables in macros

In C/C++, defining local variables inside macros is unwise

- When needed done with hacks like **`__strange_name34`**

Here is why with a silly example:

- Macro:

```
(define-syntax dbl
  (syntax-rules ()
     [(dbl x) (let ([y 1])
                (* 2 x y))]))
```

- Use:

```
(let ([y 7]) (dbl y))
```

- Naïve expansion:

```
(let ([y 7]) (let ([y 1])
               (* 2 y y)))
```

- But instead Racket “gets it right,” which is part of *hygiene*

The other side of hygiene

This also looks like it would do the “wrong” thing

– Macro:

```
(define-syntax dbl
  (syntax-rules ()
     [(dbl x) (* 2 x)]))
```

– Use:

```
(let ([* +]) (dbl 42))
```

– Naïve expansion:

```
(let ([* +]) (* 2 42))
```

– But again Racket’s *hygienic macros* get this right!

How hygienic macros work

A hygienic macro system:

1. Secretly renames local variables in macros with fresh names
2. Looks up variables used in macros where the macro is defined

Neither of these rules are followed by the “naïve expansion” most macro systems use

- Without hygiene, macros are much more brittle (non-modular)

On rare occasions, hygiene is not what you want

- Racket has somewhat complicated support for that

More examples

See the code for macros that:

- A for loop for executing a body a fixed number of times
  - Shows a macro that purposely re-evaluates some expressions and not others
- Allow 0, 1, or 2 local bindings with fewer parens than **`let*`**
  - Shows a macro with multiple cases
- A re-implementation of **`let*`** in terms of **`let`**
  - Shows a macro taking any number of arguments
  - Shows a recursive macro