

Redex: Practical Semantics Engineering

Version 5.2

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PLT Redex consists of a domain-specific language for specifying reduction semantics, plus a suite of tools for working with the semantics.

This is a reference manual for Redex. See <http://redex.racket-lang.org/> for a gentler overview. (See also the `examples` subdirectory in the `redex` collection.)

To load Redex use:

```
(require redex)
```

which provides all of the names documented in this library.

Alternatively, use the `redex/reduction-semantics` and `redex/pict` modules, which provide only non-GUI functionality (i.e., everything except `redex/gui`), making them suitable for programs which should not depend on `racket/gui/base`.

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1 Patterns

(require `redex/reduction-semantic`)

This section covers Redex's *pattern* language, used in many of Redex's forms.

Note that pattern matching is caching (including caching the results of side-conditions). This means that once a pattern has matched a given term, Redex assumes that it will always match that term.

This is the grammar for the Redex pattern language. Non-terminal references are wrapped with angle brackets; otherwise identifiers in the grammar are terminals.

```
pattern = any
          | number
          | natural
          | integer
          | real
          | string
          | variable
          | (variable-except <id> ...)
          | (variable-prefix <id>)
          | variable-not-otherwise-mentioned
          | hole
          | symbol
          | (name <id> <pattern>)
          | (in-hole <pattern> <pattern>)
          | (hide-hole <pattern>)
          | (side-condition <pattern> guard)
          | (cross <id>)
          | (<pattern-sequence> ...)
          | <racket-constant>
```

```
pattern-sequence = <pattern>
                  | ... ; literal ellipsis
                  | ..._id
```

- The `any` pattern matches any sexpression. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `number` pattern matches any number. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `natural` pattern matches any exact non-negative integer. This pattern may also

be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.

- The `integer` pattern matches any exact integer. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `real` pattern matches any real number. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `string` pattern matches any string. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `variable` pattern matches any symbol. This pattern may also be suffixed with an underscore and another identifier, in which case they bind the full name (as if it were an implicit name pattern) and match the portion before the underscore.
- The `variable-except` pattern matches any symbol except those listed in its argument. This is useful for ensuring that keywords in the language are not accidentally captured by variables.
- The `variable-prefix` pattern matches any symbol that begins with the given prefix.
- The `variable-not-otherwise-mentioned` pattern matches any symbol except those that are used as literals elsewhere in the language.
- The `hole` pattern matches anything when inside the first argument to an `in-hole` pattern. Otherwise, it matches only a hole.
- The `symbol` pattern stands for a literal symbol that must match exactly, unless it is the name of a non-terminal in a relevant language or contains an underscore.

If it is a non-terminal, it matches any of the right-hand sides of that non-terminal. If the non-terminal appears twice in a single pattern, then the match is constrained to expressions that are the same, unless the pattern is part of a grammar, in which case there is no constraint.

If the symbol is a non-terminal followed by an underscore, for example `e_1`, it is implicitly the same as a name pattern that matches only the non-terminal, (name `e_1` `e`) for the example. Accordingly, repeated uses of the same name are constrained to match the same expression.

If the symbol is a non-terminal followed by `!_`, for example `e!_1`, it is also treated as a pattern, but repeated uses of the same pattern are constrained to be different. For example, this pattern:

```
(e!_1 e!_1 e!_1)
```

matches lists of three es, but where all three of them are distinct.

Unlike a `_` pattern, the `_!_` patterns do not bind names.

If `_` names and `_!` are mixed, they are treated as separate. That is, this pattern `(e_1 e_!_1)` matches just the same things as `(e e)`, but the second doesn't bind any variables.

If the symbol otherwise has an underscore, it is an error.

- The pattern `(name symbol pattern)` matches `pattern` and binds using it to the name `symbol`.
- The (in-hole `pattern pattern`) pattern matches the first `pattern`. This match must include exactly one match against the second `pattern`. If there are zero matches or more than one match, an exception is raised.

When matching the first argument of in-hole, the `hole` pattern matches any sexpression. Then, the sexpression that matched the `hole` pattern is used to match against the second pattern.

- The (hide-hole `pattern`) pattern matches what the embedded `pattern` matches but if the pattern matcher is looking for a decomposition, it ignores any holes found in that `pattern`.
- The (side-condition `pattern guard`) pattern matches what the embedded `pattern` matches, and then the guard expression is evaluated. If it returns `#f`, the pattern fails to match, and if it returns anything else, the pattern matches. Any occurrences of `name` in the pattern (including those implicitly there via `_` patterns) are bound using `term-let` in the guard.
- The (`cross symbol`) pattern is used for the compatible closure functions. If the language contains a non-terminal with the same name as `symbol`, the pattern `(cross symbol)` matches the context that corresponds to the compatible closure of that non-terminal.
- The (`pattern-sequence ...`) pattern matches a sexpression list, where each pattern-sequence element matches an element of the list. In addition, if a list pattern contains an ellipsis, the ellipsis is not treated as a literal, instead it matches any number of duplications of the pattern that came before the ellipses (including 0). Furthermore, each `(name symbol pattern)` in the duplicated pattern binds a list of matches to `symbol`, instead of a single match. (A nested duplicated pattern creates a list of list matches, etc.) Ellipses may be placed anywhere inside the row of patterns, except in the first position or immediately after another ellipses.

Multiple ellipses are allowed. For example, this pattern:

```
((name x a) ... (name y a) ...)
```

matches this sexpression:

```
(term (a a))
```

three different ways. One where the first `a` in the pattern matches nothing, and the second matches both of the occurrences of `a`, one where each named pattern matches a single `a` and one where the first matches both and the second matches nothing.

If the ellipsis is named (ie, has an underscore and a name following it, like a variable may), the pattern matcher records the length of the list and ensures that any other occurrences of the same named ellipsis must have the same length.

As an example, this pattern:

```
((name x a) ..._1 (name y a) ..._1)
```

only matches this sexpression:

```
(term (a a))
```

one way, with each named pattern matching a single `a`. Unlike the above, the two patterns with mismatched lengths is ruled out, due to the underscores following the ellipses.

Also, like underscore patterns above, if an underscore pattern begins with `...!_`, then the lengths must be different.

Thus, with the pattern:

```
((name x a) ...!_1 (name y a) ...!_1)
```

and the expression

```
(term (a a))
```

two matches occur, one where `x` is bound to `'()` and `y` is bound to `'(a a)` and one where `x` is bound to `'(a a)` and `y` is bound to `'()`.

```
(redex-match lang pattern any)
(redex-match lang pattern)
```

If `redex-match` receives three arguments, it matches the pattern (in the language) against its third argument. If it matches, this returns a list of match structures describing the matches (see `match?` and `match-bindings`). If it fails, it returns `#f`.

If `redex-match` receives only two arguments, it builds a procedure for efficiently testing if expressions match the pattern, using the language `lang`. The procedure accepts a single expression and if the expression matches, it returns a list of match structures describing the matches. If the match fails, the procedure returns `#f`.

```
(match? val) → boolean?
val : any/c
```

Determines if a value is a match structure.

```
(match-bindings m) → (listof bind?)  
m : match?
```

This returns a list of `bind` structs that binds the pattern variables in this match.

```
(struct bind (name exp)  
             #:extra-constructor-name make-bind)  
  name : symbol?  
  exp  : any/c
```

Instances of this struct are returned by `redex-match`. Each `bind` associates a name with an *s-expression* from the language, or a list of such *s-expressions*, if the `(name ...)` clause is followed by an ellipsis. Nested ellipses produce nested lists.

```
(caching-enabled?) → boolean?  
(caching-enabled? on?) → void?  
on? : boolean?
```

When this parameter is `#t` (the default), Redex caches the results of pattern matching and metafunction evaluation. There is a separate cache for each pattern and metafunction; when one fills (see `set-cache-size!`), Redex evicts all of the entries in that cache.

Caching should be disabled when matching a pattern that depends on values other than the in-scope pattern variables or evaluating a metafunction that reads or writes mutable external state.

```
(set-cache-size! size) → void?  
size : positive-integer?
```

Changes the size of the per-pattern and per-metafunction caches. The default size is `350`.

2 Terms

Object language expressions in Redex are written using `term`. It is similar to Racket's `quote` (in many cases it is identical) in that it constructs lists as the visible representation of terms.

The grammar of *terms* is (note that an ellipsis stands for repetition unless otherwise indicated):

```
term = identifier
      | (term-sequence ...)
      | ,racket-expression
      | (in-hole term term)
      | hole
      | #t
      | #f
      | string

term-sequence = term
               | ,@racket-expression
               | ... ; literal ellipsis
```

- A term written `identifier` is equivalent to the corresponding symbol, unless the identifier is bound by `term-let`, `define-term`, or a pattern variable or the identifier is `hole` (as below).
- A term written `(term-sequence ...)` constructs a list of the terms constructed by the sequence elements.
- A term written `,racket-expression` evaluates the `racket-expression` and substitutes its value into the term at that point.
- A term written `,@racket-expression` evaluates the `racket-expression`, which must produce a list. It then splices the contents of the list into the expression at that point in the sequence.
- A term written `(in-hole tttterm ttterm)` is the dual to the pattern `in-hole` – it accepts a context and an expression and uses `plug` to combine them.
- A term written `hole` produces a hole.
- A term written as a literal boolean or a string produces the boolean or the string.

■ `(term term)`

This form is used for construction of a term.

It behaves similarly to `quasiquote`, except for a few special forms that are recognized (listed below) and that names bound by `term-let` are implicitly substituted with the values that those names were bound to, expanding ellipses as in-place sublists (in the same manner as syntax-case patterns).

For example,

```
(term-let ([body '(+ x 1)]
          [(expr ...) '(+ - (values * /))]
          [((id ...) ...) '((a) (b) (c d))])
  (term (let-values ([[id ...] expr] ...) body)))
```

evaluates to

```
'(let-values ([[a] +]
              [(b) -]
              [(c d) (values * /)])
  (+ x 1))
```

It is an error for a term variable to appear in an expression with an ellipsis-depth different from the depth with which it was bound by `term-let`. It is also an error for two `term-let`-bound identifiers bound to lists of different lengths to appear together inside an ellipsis.

`hole`

Recognized specially within `term`. A `hole` form is an error elsewhere.

`in-hole`

Recognized specially within `reduction-relation`. An `in-hole` form is an error elsewhere.

```
(term-let ([tl-pat expr] ...) body)

  tl-pat = identifier
         | (tl-pat-ele ...)

tl-pat-ele = tl-pat
            | tl-pat ... ; a literal ellipsis
```

Matches each given id pattern to the value yielded by evaluating the corresponding `expr` and binds each variable in the id pattern to the appropriate value (described below). These bindings are then accessible to the `term` syntactic form.

Note that each ellipsis should be the literal symbol consisting of three dots (and the ... elsewhere indicates repetition as usual). If `tl-pat` is an identifier, it matches any value and

binds it to the identifier, for use inside `term`. If it is a list, it matches only if the value being matched is a list value and only if every subpattern recursively matches the corresponding list element. There may be a single ellipsis in any list pattern; if one is present, the pattern before the ellipses may match multiple adjacent elements in the list value (possibly none).

This form is a lower-level form in Redex, and not really designed to be used directly. For let-like forms that use Redex's full pattern matching facilities, see `redex-let`, `redex-let*`, `term-match`, `term-match/single`.

```
(redex-let language ([pattern expression] ...) body ...+)
```

Like `term-let` but the left-hand sides are Redex patterns, interpreted according to the specified language. It is a syntax error for two left-hand sides to bind the same pattern variable.

This form raises an exception recognized by `exn:fail:redex?` if any right-hand side does not match its left-hand side in exactly one way.

In some contexts, it may be more efficient to use `term-match/single` (lifted out of the context).

```
(redex-let* language ([pattern expression] ...) body ...+)
```

The `let*` analog of `redex-let`.

```
(define-term identifier term)
```

Defines `identifier` for use in term templates.

```
(term-match language [pattern expression] ...)
```

This produces a procedure that accepts term (or quoted) expressions and checks them against each pattern. The function returns a list of the values of the expression where the pattern matches. If one of the patterns matches multiple times, the expression is evaluated multiple times, once with the bindings in the pattern for each match.

When evaluating a `term-match` expression, the patterns are compiled in an effort to speed up matching. Using the procedural result multiple times to avoid compiling the patterns multiple times.

```
(term-match/single language [pattern expression] ...)
```

This produces a procedure that accepts term (or quoted) expressions and checks them against each pattern. The function returns the expression behind the first successful match. If that pattern produces multiple matches, an error is signaled. If no patterns match, an error is signaled.

Raises an exception recognized by `exn:fail:redex?` if no clauses match or if one of the clauses matches multiple ways.

When evaluating a `term-match/single` expression, the patterns are compiled in an effort to speed up matching. Using the procedural result multiple times to avoid compiling the patterns multiple times.

```
(plug context expression) → any
  context : any/c
  expression : any/c
```

The first argument to this function is an s-expression to plug into. The second argument is the s-expression to replace in the first argument. It returns the replaced term. This is also used when a term sub-expression contains `in-hole`.

```
(variable-not-in t var) → symbol?
  t : any/c
  var : symbol?
```

This helper function accepts an s-expression and a variable. It returns a variable not in the s-expression with a prefix the same as the second argument.

```
(variables-not-in t vars) → (listof symbol?)
  t : any/c
  vars : (listof symbol?)
```

This function, like `variable-not-in`, makes variables that do not occur in its first argument, but it returns a list of such variables, one for each variable in its second argument.

Does not expect the input symbols to be distinct, but does produce variables that are always distinct.

```
(exn:fail:redex? v) → boolean?
  v : any/c
```

Returns `#t` if its argument is a Redex exception record, and `#f` otherwise.

3 Languages

```
(define-language lang-name
  non-terminal-def ...)

non-terminal-def = (non-terminal-name ...+ ::= pattern ...+)
                  | (non-terminal-name pattern ...+)
                  | ((non-terminal-name ...+) pattern ...+)
```

This form defines the grammar of a language. It allows the definition of recursive patterns, much like a BNF, but for regular-tree grammars. It goes beyond their expressive power, however, because repeated `name` patterns and side-conditions can restrict matches in a context-sensitive way.

A `non-terminal-def` comprises one or more non-terminal names (considered aliases) followed by one or more productions.

For example, the following defines `lc-lang` as the grammar of the lambda calculus:

```
(define-language lc-lang
  (e (e e ...)
     x
     v)
  (c (v ... c e ...)
     hole)
  (v (lambda (x ...) e))
  (x variable-not-otherwise-mentioned))
```

with non-terminals `e` for the expression language, `x` for variables, `c` for the evaluation contexts and `v` for values.

`::=`

A non-terminal's names and productions may be separated by the keyword `::=`. Use of the `::=` keyword outside a language definition is a syntax error.

```
(define-extended-language extended-lang base-lang
  non-terminal-def ...)

non-terminal-def = (non-terminal-name ...+ ::= pattern ...+)
                  | (non-terminal-name pattern ...+)
                  | ((non-terminal-name ...+) pattern ...+)
```

This form extends a language with some new, replaced, or extended non-terminals. For example, this language:

```
(define-extended-language lc-num-lang
  lc-lang
  (v .... ; extend the previous 'v' non-terminal
   +
   number)
  (x (variable-except lambda +)))
```

extends `lc-lang` with two new alternatives for the `v` non-terminal, carries forward the `e` and `c` non-terminals, and replaces the `x` non-terminal with a new one (which happens to be equivalent to the one that would have been inherited).

The four-period ellipses indicates that the new language's non-terminal has all of the alternatives from the original language's non-terminal, as well as any new ones. If a non-terminal occurs in both the base language and the extension, the extension's non-terminal replaces the originals. If a non-terminal only occurs in either the base language, then it is carried forward into the extension. And, of course, `extend-language` lets you add new non-terminals to the language.

If a language is has a group of multiple non-terminals defined together, extending any one of those non-terminals extends all of them.

```
(language-nts lang) → (listof symbol?)
  lang : compiled-lang?
```

Returns the list of non-terminals (as symbols) that are defined by this language.

```
(compiled-lang? l) → boolean?
  l : any/c
```

Returns `#t` if its argument was produced by `language`, `#f` otherwise.

4 Reduction Relations

```
(reduction-relation language domain base-arrow
  reduction-case ...
  shortcuts)

  domain =
    | #:domain pattern

  base-arrow =
    | #:arrow base-arrow-name

  reduction-case = (arrow-name pattern term extras ...)

    extras = rule-name
      | (fresh fresh-clause ...)
      | (side-condition racket-expression)
      | (where pattern term)
      | (judgment-holds (judgment-form-id pat/term ...))
      | (side-condition/hidden racket-expression)
      | (where/hidden pattern term)

    shortcuts =
      | with shortcut ...

    shortcut = [(old-arrow-name pattern term)
      (new-arrow-name identifier identifier)]

    rule-name = identifier
      | string
      | (computed-name racket-expression)

    fresh-clause = var
      | ((var1 ...) (var2 ...))

    pat/term = pattern
      | term
```

Defines a reduction relation casewise, one case for each of the *reduction-case* clauses.

The optional *domain* clause provides a contract for the relation, in the form of a pattern that defines the relation's domain and codomain.

The *arrow-name* in each *reduction-case* clause is either *base-arrow-name* (default *-->*) or an arrow name defined by *shortcuts* (described below). In either case, the pattern

refers to *language* and binds variables in the corresponding term. Following the pattern and term can be the name of the reduction rule and declarations of fresh variables and side-conditions.

For example, the expression

```
(reduction-relation
  lc-lang
  (--> (in-hole c_1 ((lambda (variable_i ...) e_body) v_i ...))
    (in-hole c_1 ,(foldl lc-subst
      (term e_body)
      (term (v_i ...))
      (term (variable_i ...))))))
  beta-v))
```

defines a reduction relation for the `lc-lang` grammar.

A rule's name (used in typesetting, the `stepper`, `traces`, and `apply-reduction-relation/tag-with-names`) can be given as a literal (an identifier or a string) or as an expression that computes a name using the values of the bound pattern variables (much like the rule's right-hand side). Some operations require literal names, so a rule definition may provide both a literal name and a computed name. In particular, only rules that include a literal name may be replaced using `extend-reduction-relation`, used as breakpoints in the `stepper`, and selected using `render-reduction-relation-rules`. The output of `apply-reduction-relation/tag-with-names`, `traces`, and the `stepper` prefers the computed name, if it exists. Typesetting a rule with a computed name shows the expression that computes the name only when the rule has no literal name or when it would not typeset in pink due to `with-unquote-rewriters` in the context; otherwise, the literal name (or nothing) is shown.

Fresh variable clauses generate variables that do not occur in the term being reduced. If the *fresh-clause* is a variable, that variable is used both as a binding in the term and as the prefix for the freshly generated variable. (The variable does not have to be a non-terminal in the language of the reduction relation.)

The second form of *fresh-clauses* generates a sequence of variables. In that case, the ellipses are literal ellipses; that is, you must actually write ellipses in your rule. The variable *var1* is like the variable in first case of a *fresh-clause*; namely it is used to determine the prefix of the generated variables and it is bound in the right-hand side of the reduction rule, but unlike the single-variable fresh clause, it is bound to a sequence of variables. The variable *var2* is used to determine the number of variables generated and *var2* must be bound by the left-hand side of the rule.

The expressions within *side-condition* clauses and *side-condition/hidden* clauses are collected with `and` and used as guards on the case being matched. The argument to each side-condition should be a Racket expression, and the pattern variables in the *pattern* are bound in that expression. A *side-condition/hidden* clause is the same as

a *side-condition* clause, except that the condition is not rendered when typesetting via *redex/pict*.

Each *where clause* acts as a side condition requiring a successful pattern match, and it can bind pattern variables in the side-conditions (and *where* clauses) that follow and in the metafunction result. The bindings are the same as bindings in a *term-let* expression. A *where/hidden* clause is the same as a *where* clause, but the clause is not rendered when typesetting via *redex/pict*.

Each *judgment-holds* clause acts like a *where* clause, where the left-hand side pattern incorporates each of the patterns used in the judgment form's output positions.

Each *shortcut* clause defines arrow names in terms of *base-arrow-name* and earlier *shortcut* definitions. The left- and right-hand sides of a *shortcut* definition are identifiers, not patterns and terms. These identifiers need not correspond to non-terminals in *language*.

For example, this expression

```
(reduction-relation
  lc-num-lang
  (==> ((lambda (variable_i ...) e_body) v_i ...)
        ,(foldl lc-subst
                (term e_body)
                (term (v_i ...))
                (term (variable_i ...))))
  (==> (+ number_1 ...)
        ,(apply + (term (number_1 ...))))

  with
  [(-> (in-hole c_1 a) (in-hole c_1 b))
   (==> a b)])
```

defines reductions for the lambda calculus with numbers, where the *==>* shortcut is defined by reducing in the context *c*.

A fresh clause in *reduction-case* defined by shortcut refers to the entire term, not just the portion matched by the left-hand side of shortcut's use.

```
(extend-reduction-relation reduction-relation language more ...)
```

This form extends the reduction relation in its first argument with the rules specified in *more*. They should have the same shape as the rules (including the *with* clause) in an ordinary *reduction-relation*.

If the original reduction-relation has a rule with the same name as one of the rules specified in the extension, the old rule is removed.

In addition to adding the rules specified to the existing relation, this form also reinterprets the rules in the original reduction, using the new language.

```
(union-reduction-relations r ...) → reduction-relation?  
r : reduction-relation?
```

Combines all of the argument reduction relations into a single reduction relation that steps when any of the arguments would have stepped.

```
(reduction-relation->rule-names r) → (listof symbol?)  
r : reduction-relation?
```

Returns the names of the reduction relation's named clauses.

```
(compatible-closure reduction-relation lang non-terminal)
```

This accepts a reduction, a language, the name of a non-terminal in the language and returns the compatible closure of the reduction for the specified non-terminal.

```
(context-closure reduction-relation lang pattern)
```

This accepts a reduction, a language, a pattern representing a context (ie, that can be used as the first argument to `in-hole`; often just a non-terminal) in the language and returns the closure of the reduction in that context.

```
(reduction-relation? v) → boolean?  
v : any/c
```

Returns `#t` if its argument is a reduction-relation, and `#f` otherwise.

```
(apply-reduction-relation r t) → (listof any/c)  
r : reduction-relation?  
t : any/c
```

This accepts reduction relation, a term, and returns a list of terms that the term reduces to.

```
(apply-reduction-relation/tag-with-names r  
                                           t)  
→ (listof (list/c (union false/c string?) any/c))  
r : reduction-relation?  
t : any/c
```

Like `apply-reduction-relation`, but the result indicates the names of the reductions that were used.

```

(apply-reduction-relation* r
                           t
                           [#:cache-all? cache-all?])
→ (listof any/c)
  r : reduction-relation?
  t : any/c
  cache-all? : boolean? = (current-cache-all?)

```

Accepts a reduction relation and a term. Starting from `t`, it follows every reduction path and returns all of the terms that do not reduce further. If there are infinite reduction sequences that do not repeat, this function will not terminate (it does terminate if the only infinite reduction paths are cyclic).

If the `cache-all?` argument is `#t`, then `apply-reduction-relation*` keeps a cache of all visited terms when traversing the graph and does not revisit any of them. This cache can, in some cases, use a lot of memory, so it is off by default and the cycle checking happens by keeping track only of the current path it is traversing through the reduction graph.

```

(current-cache-all?) → boolean?
(current-cache-all? cache-all?) → void?
  cache-all? : boolean?

```

Controls the behavior of `apply-reduction-relation*` and `test-->>`'s cycle checking. See `apply-reduction-relation*` for more details.

Examples:

```

> (define-language empty-lang)
> (define R
  (reduction-relation
   empty-lang
   (--> 0 1)
   (--> 0 2)
   (--> 2 3)
   (--> 3 3)))
> (apply-reduction-relation R 0)
'(2 1)
> (apply-reduction-relation* R 0)
'(1)

```

```
-->
```

Recognized specially within `reduction-relation`. A `-->` form is an error elsewhere.

```
fresh
```

Recognized specially within reduction-relation. A fresh form is an error elsewhere.

| with

Recognized specially within reduction-relation. A with form is an error elsewhere.

5 Other Relations

```
(define-metafun language
  metafunction-contract
  [(name pattern ...) term extras ...]
  ...)

metafunction-contract =
  | id : pattern ... -> range

  range = pattern
  | pattern or range
  | pattern ∨ range
  | pattern ∪ range

  extras = (side-condition racket-expression)
  | (side-condition/hidden racket-expression)
  | (where pat term)
  | (where/hidden pat term)
  | (judgment-holds
     (judgment-form-id pat/term ...))
```

The `define-metafun` form builds a function on sexpressions according to the pattern and right-hand-side expressions. The first argument indicates the language used to resolve non-terminals in the pattern expressions. Each of the rhs-expressions is implicitly wrapped in `term`.

The `side-condition`, `hidden-side-condition`, `where`, and `where/hidden` clauses behave as in the `reduction-relation` form.

Raises an exception recognized by `exn:fail:redex?` if no clauses match, if one of the clauses matches multiple ways (and that leads to different results for the different matches), or if the contract is violated.

Note that metafunctions are assumed to always return the same results for the same inputs, and their results are cached, unless `caching-enabled?` is set to `#f`. Accordingly, if a metafunction is called with the same inputs twice, then its body is only evaluated a single time.

As an example, these metafunctions finds the free variables in an expression in the `lc-lang` above:

```
(define-metafun lc-lang
  free-vars : e -> (x ...)
  [(free-vars (e_1 e_2 ...))
   (U (free-vars e_1) (free-vars e_2) ...)]
```

```

[(free-vars x) (x)]
[(free-vars (lambda (x ...) e))
 (- (free-vars e) (x ...))]

```

The first argument to `define-metafunction` is the grammar (defined above). Following that are three cases, one for each variation of expressions (`e` in `lc-lang`). The free variables of an application are the free variables of each of the subterms; the free variables of a variable is just the variable itself, and the free variables of a lambda expression are the free variables of the body, minus the bound parameters.

Here are the helper metafunctions used above.

```

(define-metafunction lc-lang
  U : (x ...) ... -> (x ...)
  [(U (x_1 ...) (x_2 ...) (x_3 ...) ...)
   (U (x_1 ... x_2 ...) (x_3 ...) ...)]
  [(U (x_1 ...))
   (x_1 ...)]
  [(U) ()])

(define-metafunction lc-lang
  - : (x ...) (x ...) -> (x ...)
  [(- (x ...) ()) (x ...)]
  [(- (x_1 ... x_2 x_3 ...) (x_2 x_4 ...))
   (- (x_1 ... x_3 ...) (x_2 x_4 ...))
   (side-condition (not (memq (term x_2) (term (x_3 ...))))))]
  [(- (x_1 ...) (x_2 x_3 ...))
   (- (x_1 ...) (x_3 ...))]

```

Note the side-condition in the second case of `-`. It ensures that there is a unique match for that case. Without it, `(term (- (x x) x))` would lead to an ambiguous match.

```

(define-metafunction/extension f language
  metafunction-contract
  [(g pattern ...) term extras ...]
  ...)

```

Defines a metafunction `g` as an extension of an existing metafunction `f`. The metafunction `g` behaves as if `f`'s clauses were appended to its definition (with occurrences of `f` changed to `g` in the inherited clauses).

For example, `define-metafunction/extension` may be used to extend the `free-vars` function above to the forms introduced by the language `lc-num-lang`.

```

(define-metafunction/extension free-vars lc-num-lang

```

```
free-vars-num : e -> (x ...)
[(free-vars-num number)
 ()]
[(free-vars-num (+ e_1 e_2))
 (U (free-vars-num e_1)
    (free-vars-num e_2)))]
```

```
| (in-domain? (metafunction-name term ...))
```

Returns `#t` if the inputs specified to *metafunction-name* are legitimate inputs according to *metafunction-name*'s contract, and `#f` otherwise.

```
| (define-judgment-form language
  option ...
  rule ...)
```

```

    option = mode-spec
           | contract-spec

    mode-spec = #:mode (form-id pos-use ...)

    contract-spec = #:contract (form-id pattern ...)

    pos-use = I
            | 0

    rule = [conclusion
           premise
           ...]
          | [premise
           ...
           dashes
           conclusion]

    conclusion = (form-id pat/term ...)

    premise = (judgment-form-id pat/term ...) maybe-ellipsis
            | (where pattern term)
            | (where/hidden pattern term)

    pat/term = pattern
            | term

    maybe-ellipsis =
            | ...

    dashes = ---
            | ----
            | -----
            | etc.

```

Defines *form-id* as a relation on terms via a set of inference rules. Each rule must be such that its premises can be evaluated left-to-right without “guessing” values for any of their pattern variables. Redex checks this property using the mandatory *mode-spec* declaration, which partitions positions into inputs *I* and outputs *O*. Output positions in conclusions and input positions in premises must be *terms* with no uses of `unquote`; input positions in conclusions and output positions in premises must be *patterns*. When the optional *contract-spec* declaration is present, Redex dynamically checks that the terms flowing through these positions match the provided patterns, raising an exception recognized by `exn:fail:redex` if not.

For example, the following defines addition on natural numbers:

```

> (define-language nats
  (n z (s n)))
> (define-judgment-form nats
  #:mode (sum I I 0)
  #:contract (sum n n n)
  [(sum z n n)]
  [(sum (s n_1) n_2 (s n_3))
   (sum n_1 n_2 n_3)])

```

The judgment-holds form checks whether a relation holds for any assignment of pattern variables in output positions.

Examples:

```

> (judgment-holds (sum (s (s z)) (s z) (s (s (s z)))))
#t
> (judgment-holds (sum (s (s z)) (s z) (s (s (s n)))))
#t
> (judgment-holds (sum (s (s z)) (s z) (s (s (s (s n)))))
#f

```

Alternatively, this form constructs a list of terms based on the satisfying pattern variable assignments.

Examples:

```

> (judgment-holds (sum (s (s z)) (s z) (s (s (s n)))) n)
'(z)
> (judgment-holds (sum (s (s z)) (s z) (s (s (s (s n))))) n)
'()
> (judgment-holds (sum (s (s z)) (s z) (s (s (s n)))) (s n))
'((s z))

```

Declaring different modes for the same inference rules enables different forms of computation. For example, the following mode allows judgment-holds to compute all pairs with a given sum.

```

> (define-judgment-form nats
  #:mode (sumr 0 0 I)
  #:contract (sumr n n n)
  [(sumr z n n)]
  [(sumr (s n_1) n_2 (s n_3))
   (sumr n_1 n_2 n_3)])
> (judgment-holds (sumr n_1 n_2 (s (s z))) (n_1 n_2))
'((z (s (s z))) ((s (s z)) z) ((s z) (s z)))

```


A rule's `where` and `where/hidden` premises behave as in reduction-relation and define-metafunction.

Examples:

```
> (define-judgment-form nats
  #:mode (le I I)
  #:contract (le n n)
  [(le z n)]
  [(le (s n1) (s n2))
   (le n1 n2)]
> (define-metafunction nats
  pred : n -> n or #f
  [(pred z) #f]
  [(pred (s n)) n])
> (define-judgment-form nats
  #:mode (gt I I)
  #:contract (gt n n)
  [(gt n1 n2)
   (where n3 (pred n1))
   (le n2 n3)]
> (judgment-holds (gt (s (s z)) (s z)))
#t
> (judgment-holds (gt (s z) (s z)))
#f
```

A literal ellipsis may follow a judgment premise when a template in one of the judgment's input positions contains a pattern variable bound at ellipsis-depth one.

Examples:

```
> (define-judgment-form nats
  #:mode (even I)
  #:contract (even n)
  [(even z)]
  [(even (s (s n)))
   (even n)])
> (define-judgment-form nats
  #:mode (all-even I)
  #:contract (all-even (n ...))
  [(all-even (n ...))
   (even n) ...])
> (judgment-holds (all-even (z (s (s z)) z)))
#t
> (judgment-holds (all-even (z (s (s z)) (s z))))
#f
```

Redex evaluates premises depth-first, even when it doing so leads to non-termination. For example, consider the following definitions:

```
> (define-language vertices
  (v a b c))
> (define-judgment-form vertices
  #:mode (edge I 0)
  #:contract (edge v v)
  [(edge a b)]
  [(edge b c)])
> (define-judgment-form vertices
  #:mode (path I I)
  #:contract (path v v)
  [(path v v)]
  [(path v_1 v_2)
   (path v_2 v_1)]
  [(path v_1 v_3)
   (edge v_1 v_2)
   (path v_2 v_3)])
```

Due to the second `path` rule, the follow query fails to terminate:

```
> (judgment-holds (path a c))
```

The "examples" directory demonstrates three use cases:

- "typing-rules.rkt" — defines a type system in a way that supports mechanized typesetting. When a typing judgment form can be given a mode, it can also be encoded as a metafunction using `where` clauses as premises, but Redex cannot typeset that encoding as inference rules.
- "sos.rkt" — defines an SOS-style semantics in a way that supports mechanized typesetting.
- "multi-val.rkt" — defines a judgment form that serves as a multi-valued metafunction.

```
(judgment-holds judgment)
(judgment-holds judgment term)

judgment = (judgment-form-id pat/term ...)
```

In its first form, checks whether `judgment` holds for any assignment of the pattern variables in `judgment-id`'s output positions. In its second form, produces a list of terms by instantiating the supplied term template with each satisfying assignment of pattern variables. See `define-judgment-form` for examples.

I

Recognized specially within `define-judgment-form`, the I keyword is an error elsewhere.

0

Recognized specially within `define-judgment-form`, the 0 keyword is an error elsewhere.

```
(define-relation language
  relation-contract
  [(name pattern ...) term ...] ...)

relation-contract =
  | form-id  $\subseteq$  pattern x ... x pattern
  | form-id  $\subseteq$  pattern  $\times$  ...  $\times$  pattern
```

Similar to `define-judgment-form` but suitable only when every position is an input. There is no associated form corresponding to `judgment-holds`; querying the result uses the same syntax as metafunction application.

The contract specification for a relation restricts the patterns that can be used as input to a relation. For each argument to the relation, there should be a single pattern, using `x` or `\times` to separate the argument contracts.

Examples:

```
> (define-language types
  (( $\tau$   $\sigma$ ) int
    num
    ( $\tau \rightarrow \tau$ )))
> (define-relation types
  subtype  $\subseteq$   $\tau \times \tau$ 
  [(subtype int num)]
  [(subtype ( $\tau_1 \rightarrow \tau_2$ ) ( $\sigma_1 \rightarrow \sigma_2$ ))
   (subtype  $\sigma_1 \tau_1$ )
   (subtype  $\tau_2 \sigma_2$ )]
  [(subtype  $\tau \tau$ )]
> (term (subtype int num))
#t
> (term (subtype (int  $\rightarrow$  int) (num  $\rightarrow$  num)))
#f
> (term (subtype (num  $\rightarrow$  int) (num  $\rightarrow$  num)))
#t
```

Note that relations are assumed to always return the same results for the same inputs, and their results are cached, unless `catching-enable?` is set to `#f`. Accordingly, if a relation is called with the same inputs twice, then its right-hand sides are evaluated only once.

```
(current-traced-metafunctions) → (or/c 'all (listof symbol?))  
(current-traced-metafunctions traced-metafunctions) → void?  
  traced-metafunctions : (or/c 'all (listof symbol?))
```

Controls which metafunctions are currently being traced. If it is `'all`, all of them are. Otherwise, the elements of the list name the metafunctions to trace.

The tracing looks just like the tracing done by the `racket/trace` library, except that the first column printed by each traced call indicate if this call to the metafunction is cached. Specifically, a `c` is printed in the first column if the result is just returned from the cache and a space is printed if the metafunction call is actually performed.

Defaults to `'()`.

6 Testing

```
(test-equal e1 e2)
```

Tests to see if *e1* is equal to *e2*.

```
(test-->> rel-expr option ... e1-expr e2-expr ...)  
  
option = #:cycles-ok  
        | #:equiv pred-expr  
        | #:pred pred-expr  
  
rel-expr : reduction-relation?  
pred-expr : (--> any/c any)  
e1-expr  : any/c  
e2-expr  : any/c
```

Tests to see if the term *e1-expr*, reduces to the terms *e2-expr* under *rel-expr*, using *pred-expr* to determine equivalence.

If `#:pred` is specified, it is applied to each reachable term until one of the terms fails to satisfy the predicate (i.e., the predicate returns `#f`). If that happens, then the test fails and a message is printed with the term that failed to satisfy the predicate.

This test uses `apply-reduction-relation*`, so it does not terminate when the resulting reduction graph is infinite, although it does terminate if there are cycles in the (finite) graph.

If `#:cycles-ok` is not supplied then any cycles detected are treated as a test failure. If a *pred-expr* is supplied, then it is used to compare the expected and actual results.

```
(test--> rel-expr option ... e1-expr e2-expr ...)  
  
option = #:equiv pred-expr  
  
rel-expr : reduction-relation?  
pred-expr : (--> any/c any/c anyc)  
e1-expr  : any/c  
e2-expr  : any/c
```

Tests to see if the term *e1-expr*, reduces to the terms *e2-expr* in a single *rel-expr* step, using *pred-expr* to determine equivalence.

Examples:

```

> (define-language L
  (i integer))
> (define R
  (reduction-relation
   L
   (--> i i)
   (--> i ,(add1 (term i)))))
> (define (mod2=? i j)
  (= (modulo i 2) (modulo j 2)))
> (test--> R #:equiv mod2=? 7 1)
FAILED :36.0
expected: 1
actual: 8
actual: 7
> (test--> R #:equiv mod2=? 7 1 0)
> (test-results)
1 test failed (out of 2 total).

(test-->> option ... rel-expr start-expr goal-expr)

option = #:steps steps-expr

rel-expr : reduction-relation?
start-expr : any/c
goal-expr : (or/c (-> any/c any/c)
              (not/c procedure?))
steps-expr : (or/c natural-number/c +inf.0)

```

Tests to see if the term *start-expr* reduces according to the reduction relation *rel-expr* to a term specified by *goal-expr* in *steps-expr* or fewer steps (default 1,000). The specification *goal-expr* may be either a predicate on terms or a term itself.

| test-->>E

An alias for test-->>E.

Examples:

```

> (define-language L
  (n natural))
> (define succ-mod8
  (reduction-relation
   L
   (--> n ,(modulo (add1 (term n)) 8))))

```

```

> (test-->>⇒ succ-mod8 6 2)
> (test-->>⇒ succ-mod8 6 even?)
> (test-->>⇒ succ-mod8 6 8)
FAILED :43.0
term 8 not reachable from 6
> (test-->>⇒ #:steps 6 succ-mod8 6 5)
FAILED :44.0
term 5 not reachable from 6 (within 6 steps)
> (test-results)
2 tests failed (out of 4 total).
(test-predicate p? e)

```

Tests to see if the value of `e` matches the predicate `p?`.

```
(test-results) → void?
```

Prints out how many tests passed and failed, and resets the counters so that next time this function is called, it prints the test results for the next round of tests.

```
(make-coverage subject)

subject = metafunction
         | relation-expr

```

Constructs a structure (recognized by `coverage?`) to contain per-case test coverage of the supplied metafunction or reduction relation. Use with `relation-coverage` and `covered-cases`.

```
(coverage? v) → boolean?
v : any/c
```

Returns `#t` for a value produced by `make-coverage` and `#f` for any other.

```
(relation-coverage) → (listof coverage?)
(relation-coverage tracked) → void?
tracked : (listof coverage?)

```

Redex populates the coverage records in `tracked` (default `null`), counting the times that tests exercise each case of the associated metafunction and relations.

```
(covered-cases c) → (listof (cons/c string? natural-number/c))
c : coverage?
```

Extracts the coverage information recorded in `c`, producing an association list mapping names (or source locations, in the case of metafunctions or unnamed reduction-relation cases) to application counts.

Examples:

```
> (define-language empty-lang)
> (define-metafunction empty-lang
  [(plus number_1 number_2)
   ,(+ (term number_1) (term number_2))])
> (define equals
  (reduction-relation
   empty-lang
   (--> (+) 0 "zero")
   (--> (+ number) number)
   (--> (+ number_1 number_2 number ...)
        (+ (plus number_1 number_2)
           number ...))
   "add"))
> (let ([equals-coverage (make-coverage equals)]
      [plus-coverage (make-coverage plus)])
  (parameterize ([relation-coverage (list equals-coverage
                                           plus-coverage)])
    (apply-reduction-relation* equals (term (+ 1 2 3)))
    (values (covered-cases equals-coverage)
            (covered-cases plus-coverage))))
'(("add" . 2) ("eval:48:0" . 1) ("zero" . 0))
'(("eval:47:0" . 2))

(generate-term term-spec size-expr kw-args ...)
(generate-term term-spec)

term-spec = language pattern
           | #:source metafunction
           | #:source relation-expr

kw-args = #:attempt-num attempts-expr
          | #:retries retries-expr

size-expr : natural-number/c
attempt-num-expr : natural-number/c
retries-expr : natural-number/c
```

In its first form, `generate-term` produces a random term according to `term-spec`, which is either a language and a pattern, the name of a metafunction, or an expression producing a reduction relation. In the first of these cases, the produced term matches the given pattern (interpreted according to the definition of the given language). In the second and third cases, the produced term matches one of the clauses of the specified metafunction or reduction relation.

In its second form, `generate-term` produces a procedure for constructing terms according to *term-spec*. This procedure expects *size-expr* (below) as its sole positional argument and allows the same optional keyword arguments as the first form. The second form may be more efficient when generating many terms.

The argument *size-expr* bounds the height of the generated term (measured as the height of its parse tree).

Examples:

```
> (define-language L
    (n number))
> (generate-term L (+ n_1 n_2) 5)
'+ 1 1)
> (define R
    (reduction-relation
      L
      (--> (one-clause n) ())
      (--> (another-clause n) ())))
> (random-seed 0)
> (generate-term #:source R 5)
'(another-clause 2)
> (define R-left-hand-sides
    (generate-term #:source R))
> (R-left-hand-sides 0)
'(one-clause 1)
> (R-left-hand-sides 1)
'(another-clause 1)
> (define-metafunction L
    [(F one-clause n) ()]
    [(F another-clause n) ()])
> (generate-term #:source F 5)
'(another-clause 2)
```

The optional keyword argument `attempt-num-expr` (default 1) provides coarse grained control over the random decisions made during generation; increasing `attempt-num-expr` tends to increase the complexity of the result. For example, the absolute values of numbers chosen for integer patterns increase with `attempt-num-expr`.

The random generation process does not actively consider the constraints imposed by side-condition or `_!_` patterns; instead, it uses a “guess and check” strategy in which it freely generates candidate terms then tests whether they happen to satisfy the constraints, repeating as necessary. The optional keyword argument `retries-expr` (default 100) bounds the number of times that `generate-term` retries the generation of any pattern. If `generate-term` is unable to produce a satisfying term after `retries-expr` attempts, it raises an exception recognized by `exn:fail:redex:generation-failure?`.

```
(redex-check language pattern property-expr kw-arg ...)

kw-arg = #:attempts attempts-expr
        | #:source metafunction
        | #:source relation-expr
        | #:retries retries-expr
        | #:print? print?-expr
        | #:attempt-size attempt-size-expr
        | #:prepare prepare-expr

property-expr : any/c
attempts-expr : natural-number/c
relation-expr : reduction-relation?
retries-expr : natural-number/c
print?-expr : any/c
attempt-size-expr : (-> natural-number/c natural-number/c)
prepare-expr : (-> any/c any/c)
```

Searches for a counterexample to *property-expr*, interpreted as a predicate universally quantified over the pattern variables bound by *pattern*. `redex-check` constructs and tests a candidate counterexample by choosing a random term *t* that matches *pattern* then evaluating *property-expr* using the `match-bindings` produced by matching *t* against *pattern*.

`redex-check` generates at most *attempts-expr* (default `(default-check-attempts)`) random terms in its search. The size and complexity of these terms tend to increase with each failed attempt. The `#:attempt-size` keyword determines the rate at which terms grow by supplying a function that bounds term size based on the number of failed attempts (see `generate-term`'s `size-expr` argument). By default, the bound grows according to the `default-attempt-size` function.

When *print?-expr* produces any non-`#f` value (the default), `redex-check` prints the test outcome on `current-output-port`. When *print?-expr* produces `#f`, `redex-check` prints nothing, instead

- returning a `counterexample` structure when the test reveals a counterexample,
- returning `#t` when all tests pass, or
- raising a `exn:fail:redex:test` when checking the property raises an exception.

The optional `#:prepare` keyword supplies a function that transforms each generated example before `redex-check` checks *property-expr*. This keyword may be useful when

property-expr takes the form of a conditional, and a term chosen freely from the grammar is unlikely to satisfy the conditional's hypothesis. In some such cases, the `prepare` keyword can be used to increase the probability that an example satisfies the hypothesis.

When passed a metafunction or reduction relation via the optional `#:source` argument, `redex-check` distributes its attempts across the left-hand sides of that metafunction/relation by using those patterns, rather than `pattern`, as the basis of its generation. It is an error if any left-hand side generates a term that does not match `pattern`.

Examples:

```
> (define-language empty-lang)
> (random-seed 0)
> (redex-check
  empty-lang
  ((number_1 ...)
   (number_2 ...))
  (equal? (reverse (append (term (number_1 ...))
                           (term (number_2 ...))))
          (append (reverse (term (number_1 ...)))
                  (reverse (term (number_2 ...))))))
redex-check: counterexample found after 5 attempts:
((1 0) (0))
> (redex-check
  empty-lang
  ((number_1 ...)
   (number_2 ...))
  (equal? (reverse (append (term (number_1 ...))
                           (term (number_2 ...))))
          (append (reverse (term (number_2 ...)))
                  (reverse (term (number_1 ...))))))
  #:attempts 200)
redex-check: no counterexamples in 200 attempts
> (let ([R (reduction-relation
  empty-lang
  (--> ( $\Sigma$ ) 0)
  (--> ( $\Sigma$  number) number)
  (--> ( $\Sigma$  number_1 number_2 number_3 ...)
        ( $\Sigma$  ,(+ (term number_1) (term number_2))
                 number_3 ...)))]])
  (redex-check
   empty-lang
   ( $\Sigma$  number ...)
   (printf "~s\n" (term (number ...)))
   #:attempts 3
   #:source R))
```

```

()
(1)
(3 0)
redex-check: no counterexamples in 1 attempt (with each clause)
> (redex-check
  empty-lang
  number
  (begin
    (printf "checking ~s\n" (term number))
    (positive? (term number)))
  #:prepare (λ (n)
             (printf "preparing ~s; " n)
             (add1 (abs n))))
  #:attempts 3)
preparing 0; checking 1
preparing 0; checking 1
preparing 1; checking 2
redex-check: no counterexamples in 3 attempts

```

```

(struct counterexample (term)
  #:extra-constructor-name make-counterexample
  #:transparent)
term : any/c

```

Produced by `redex-check`, `check-reduction-relation`, and `check-metafunction` when testing falsifies a property.

```

(struct exn:fail:redex:test exn:fail:redex (source term)
  #:extra-constructor-name make-exn:fail:redex:test)
source : exn:fail?
term : any/c

```

Raised by `redex-check`, `check-reduction-relation`, and `check-metafunction` when testing a property raises an exception. The `exn:fail:redex:test-source` component contains the exception raised by the property, and the `exn:fail:redex:test-term` component contains the term that induced the exception.

```

(check-reduction-relation relation property kw-args ...)

kw-arg = #:attempts attempts-expr
         | #:retries retries-expr
         | #:print? print?-expr
         | #:attempt-size attempt-size-expr
         | #:prepare prepare-expr

```

```

property : (-> any/c any/c)
attempts-expr : natural-number/c
retries-expr : natural-number/c
print?-expr : any/c
attempt-size-expr : (-> natural-number/c natural-number/c)
prepare-expr : (-> any/c any/c)

```

Tests *relation* as follows: for each case of *relation*, *check-reduction-relation* generates *attempts* random terms that match that case's left-hand side and applies *property* to each random term.

This form provides a more convenient notation for

```

(redex-check L any (property (term any))
 #:attempts (* n attempts)
 #:source relation)

```

when *relation* is a relation on L with n rules.

```

(check-metafunction metafunction property kw-args ...)

kw-arg = #:attempts attempts-expr
        | #:retries retries-expr
        | #:print? print?-expr
        | #:attempt-size attempt-size-expr
        | #:prepare prepare-expr

property : (-> (listof any/c) any/c)
attempts-expr : natural-number/c
retries-expr : natural-number/c
print?-expr : any/c
attempt-size-expr : (-> natural-number/c natural-number/c)
prepare-expr : (-> (listof any/c) (listof any/c))

```

Like *check-reduction-relation* but for metafunctions. *check-metafunction* calls *property* with lists containing arguments to the metafunction. Similarly, *prepare-expr* produces and consumes argument lists.

Examples:

```

> (define-language empty-lang)
> (random-seed 0)

```

```

> (define-metafunctor empty-lang
   $\Sigma$  : number ... -> number
  [( $\Sigma$ ) 0]
  [( $\Sigma$  number) number]
  [( $\Sigma$  number_1 number_2 number_3 ...)
   ( $\Sigma$  ,(+ (term number_1) (term number_2)) number_3 ...)])
> (check-metafunctor  $\Sigma$  ( $\lambda$  (args) (printf "~s\n" args)) #:attempts 2)
()
()
(0)
(0)
(2 1)
(0 1)
check-metafunctor: no counterexamples in 2 attempts (with each
clause)
| (default-attempt-size n)  $\rightarrow$  natural-number/c
| n : natural-number/c

```

The default value of the `#:attempt-size` argument to `redex-check` and the other randomized testing forms, this procedure computes an upper bound on the size of the next test case from the number of previously attempted tests `n`. Currently, this procedure computes the base 5 logarithm, but that behavior may change in future versions.

```

| (default-check-attempts)  $\rightarrow$  natural-number/c
| (default-check-attempts attempts)  $\rightarrow$  void?
| attempts : natural-number/c

```

Determines the default value for `redex-check`'s optional `#:attempts` argument. By default, `attempts` is 1,000.

```

| (redex-pseudo-random-generator)  $\rightarrow$  pseudo-random-generator?
| (redex-pseudo-random-generator generator)  $\rightarrow$  void?
| generator : pseudo-random-generator?

```

`generate-term` and the randomized testing forms (e.g., `redex-check`) use the parameter `generator` to construct random terms. The parameter's initial value is (`current-pseudo-random-generator`).

```

| (exn:fail:redex:generation-failure? v)  $\rightarrow$  boolean?
| v : any/c

```

Recognizes the exceptions raised by `generate-term`, `redex-check`, etc. when those forms are unable to produce a term matching some pattern.

Debugging PLT Redex Programs

It is easy to write grammars and reduction rules that are subtly wrong. Typically such mistakes result in examples that get stuck when viewed in a `traces` window.

The best way to debug such programs is to find an expression that looks like it should reduce, but doesn't, then try to find out which pattern is failing to match. To do so, use the `redex-match` form.

In particular, first check if the term in question matches the your system's main non-terminal (typically the expression or program non-terminal). If it does not match, simplify the term piece by piece to determine whether the problem is in the term or the grammar.

If the term does match your system's main non-terminal, determine by inspection which reduction rules should apply. For each such rule, repeat the above term-pattern debugging procedure, this time using the rule's left-hand side pattern instead of the system's main non-terminal. In addition to simplifying the term, also consider simplifying the pattern.

If the term matches the left-hand side, but the rule does not apply, then one of the rule's `side-condition` or `where` clauses is not satisfied. Using the bindings reported by `redex-match`, check each `side-condition` expression and each `where` pattern-match to discover which clause is preventing the rule's application.

7 GUI

```
(require redex/gui)
```

This section describes the GUI tools that Redex provides for exploring reduction sequences.

```
(traces reductions
  expr
  [#:multiple? multiple?
   #:pred pred
   #:pp pp
   #:colors colors
   #:racket-colors? racket-colors?
   #:scheme-colors? scheme-colors?
   #:filter term-filter
   #:x-spacing x-spacing
   #:y-spacing y-spacing
   #:layout layout
   #:edge-labels? edge-labels?
   #:edge-label-font edge-label-font
   #:graph-pasteboard-mixin graph-pasteboard-mixin])
→ void?
reductions : reduction-relation?
expr : (or/c any/c (listof any/c))
multiple? : boolean? = #f
pred : (or/c (-> sexp any)
           (-> sexp term-node? any)) = (lambda (x) #t)
pp : (or/c (any -> string)
           (any output-port number (is-a?/c text%) -> void))
     = default-pretty-printer
     (listof
      (cons/c string?
               (and/c (listof (or/c string? (is-a?/c color%)))
                       (lambda (x) (<= 0 (length x) 6))))))
     = '()
racket-colors? : boolean? = #t
scheme-colors? : boolean? = racket-colors?
term-filter : (-> any/c (or/c #f string?)) any/c)
             = (lambda (x y) #t)
x-spacing : number? = 15
y-spacing : number? = 15
layout : (-> (listof term-node?) void) = void
edge-labels? : boolean? = #t
edge-label-font : (or/c #f (is-a?/c font%)) = #f
graph-pasteboard-mixin : (make-mixin-contract graph-pasteboard<?>)
                        = values
```


This function opens a new window and inserts each expression in *expr* (if *multiple?* is *#t* – if *multiple?* is *#f*, then *expr* is treated as a single expression). Then, it reduces the terms until at least *reduction-steps-cutoff* (see below) different terms are found, or no more reductions can occur. It inserts each new term into the gui. Clicking the reduce button reduces until *reduction-steps-cutoff* more terms are found.

The *pred* function indicates if a term has a particular property. If it returns *#f*, the term is displayed with a pink background. If it returns a string or a *color%* object, the term is displayed with a background of that color (using *the-color-database* to map the string to a color). If it returns any other value, the term is displayed normally. If the *pred* function accepts two arguments, a term-node corresponding to the term is passed to the predicate. This lets the predicate function explore the (names of the) reductions that led to this term, using *term-node-children*, *term-node-parents*, and *term-node-labels*.

The *pred* function may be called more than once per node. In particular, it is called each time an edge is added to a node. The latest value returned determines the color.

The *pp* function is used to specially print expressions. It must either accept one or four arguments. If it accepts one argument, it will be passed each term and is expected to return a string to display the term.

If the *pp* function takes four arguments, it should render its first argument into the port (its second argument) with width at most given by the number (its third argument). The final argument is the text where the port is connected – characters written to the port go to the end of the editor.

The *colors* argument, if provided, specifies a list of reduction-name/color-list pairs. The traces gui will color arrows drawn because of the given reduction name with the given color instead of using the default color.

The *cdr* of each of the elements of *colors* is a list of colors, organized in pairs. The first two colors cover the colors of the line and the border around the arrow head, the first when the mouse is over a graph node that is connected to that arrow, and the second for when the mouse is not over that arrow. Similarly, the next colors are for the text drawn on the arrow and the last two are for the color that fills the arrow head. If fewer than six colors are specified, the specified colors are used and then defaults are filled in for the remaining colors.

The *racket-colors?* argument (along with *scheme-colors?*, retained for backward compatibility), controls the coloring of each window. When *racket-colors?* is *#t* (and *scheme-colors?* is *#t* too), *traces* colors the contents according to DrRacket’s Racket-mode color scheme; otherwise, *traces* uses a black color scheme.

The *term-filter* function is called each time a new node is about to be inserted into the graph. If the filter returns false, the node is not inserted into the graph.

The *x-spacing* and *y-spacing* control the amount of space put between the snips in the

default layout.

The `layout` argument is called (with all of the terms) when new terms are inserted into the window. In general, it is called after new terms are inserted in response to the user clicking on the reduce button, and after the initial set of terms is inserted. See also [term-node-set-position!](#).

If `edge-labels?` is `#t` (the default), then edge labels are drawn; otherwise not.

The `edge-label-font` argument is used as the font on the edge labels. If `#f` is supplied, the `dc<%/>` object's default font is used.

The traces library uses an instance of the `mrlib/graph` library's `graph-pasteboard<%/>` interface to layout the graphs. Sometimes, overriding one of its methods can help give finer-grained control over the layout, so the `graph-pasteboard-mixin` is applied to the class before it is instantiated. Also note that all of the snips inserted into the editor by this library have a `get-term-node` method which returns the snip's `term-node`.

```
(traces/ps reductions
  expr
  file
  [#:multiple? multiple?
   #:pred pred
   #:pp pp
   #:colors colors
   #:filter term-filter
   #:layout layout
   #:x-spacing x-spacing
   #:y-spacing y-spacing
   #:edge-labels? edge-labels?
   #:edge-label-font edge-label-font
   #:graph-pasteboard-mixin graph-pasteboard-mixin]
  #:post-process post-process)
→ void?
reductions : reduction-relation?
expr : (or/c any/c (listof any/c))
file : (or/c path-string? path?)
multiple? : boolean? = #f
pred : (or/c (-> sexp any)
        (-> sexp term-node? any)) = (lambda (x) #t)
pp : (or/c (any -> string)
         (any output-port number (is-a?/c text%) -> void))
     = default-pretty-printer
```

```

      (listof
colors : (cons/c string?
          (and/c (listof (or/c string? (is-a?/c color%)))
                (lambda (x) (<= 0 (length x) 6))))
      = '()
term-filter : (-> any/c (or/c #f string?) any/c)
            = (lambda (x y) #t)
layout : (-> (listof term-node?) void) = void
x-spacing : number? = 15
y-spacing : number? = 15
edge-labels? : boolean? = #t
edge-label-font : (or/c #f (is-a?/c font%)) = #f
graph-pasteboard-mixin : (make-mixin-contract graph-pasteboard<?>)
                        = values
post-process : (-> (is-a?/c graph-pasteboard<?>) any/c)

```

This function behaves just like the function `traces`, but instead of opening a window to show the reduction graph, it just saves the reduction graph to the specified `file`.

All of the arguments behave like the arguments to `traces`, with the exception of the `post-process` argument. It is called just before the PostScript is created with the graph pasteboard.

```

(stepper reductions t [pp]) → void?
reductions : reduction-relation?
t : any/c
pp : (or/c (any -> string)
        (any output-port number (is-a?/c text%) -> void))
    = default-pretty-printer

```

This function opens a stepper window for exploring the behavior of the term `t` in the reduction system given by `reductions`.

The `pp` argument is the same as to the `traces` function but is here for backwards compatibility only and should not be changed for most uses, but instead adjusted with `pretty-print-parameters`. Specifically, the highlighting shown in the stepper window can be wrong if `default-pretty-printer` does not print sufficiently similarly to how `pretty-print` prints (when adjusted by `pretty-print-parameters`'s behavior, of course).

```

(stepper/seed reductions seed [pp]) → void?
reductions : reduction-relation?
seed : (cons/c any/c (listof any/c))
pp : (or/c (any -> string)
        (any output-port number (is-a?/c text%) -> void))
    = default-pretty-printer

```

Like `stepper`, this function opens a stepper window, but it seeds it with the reduction-sequence supplied in `seed`.

```
(term-node-children tn) → (listof term-node?)  
  tn : term-node?
```

Returns a list of the children (ie, terms that this term reduces to) of the given node.

Note that this function does not return all terms that this term reduces to – only those that are currently in the graph.

```
(term-node-parents tn) → (listof term-node?)  
  tn : term-node?
```

Returns a list of the parents (ie, terms that reduced to the current term) of the given node.

Note that this function does not return all terms that reduce to this one – only those that are currently in the graph.

```
(term-node-labels tn) → (listof (or/c false/c string?))  
  tn : term-node
```

Returns a list of the names of the reductions that led to the given node, in the same order as the result of `term-node-parents`. If the list contains `#f`, that means that the corresponding step does not have a label.

```
(term-node-set-color! tn color) → void?  
  tn : term-node?  
  color : (or/c string? (is-a?/c color%) false/c)
```

Changes the highlighting of the node; if its second argument is `#f`, the coloring is removed, otherwise the color is set to the specified `color%` object or the color named by the string. The `color-database<>` is used to convert the string to a `color%` object.

```
(term-node-color tn) → (or/c string? (is-a?/c color%) false/c)  
  tn : term-node?
```

Returns the current highlighting of the node. See also `term-node-set-color!`.

```
(term-node-set-red! tn red?) → void?  
  tn : term-node?  
  red? : boolean?
```

Changes the highlighting of the node; if its second argument is `#t`, the term is colored pink, if it is `#f`, the term is not colored specially.

```
(term-node-expr tn) → any
  tn : term-node?
```

Returns the expression in this node.

```
(term-node-set-position! tn x y) → void?
  tn : term-node?
  x : (and/c real? positive?)
  y : (and/c real? positive?)
```

Sets the position of *tn* in the graph to (x,y) .

```
(term-node-x tn) → real
  tn : term-node?
```

Returns the x coordinate of *tn* in the window.

```
(term-node-y tn) → real
  tn : term-node?
```

Returns the y coordinate of *tn* in the window.

```
(term-node-width tn) → real
  tn : term-node?
```

Returns the width of *tn* in the window.

```
(term-node-height tn) → real?
  tn : term-node?
```

Returns the height of *tn* in the window.

```
(term-node? v) → boolean?
  v : any/c
```

Recognizes term nodes.

```
(reduction-steps-cutoff) → number?
(reduction-steps-cutoff cutoff) → void?
  cutoff : number?
```

A parameter that controls how many steps the `traces` function takes before stopping.

```
(initial-font-size) → number?  
(initial-font-size size) → void?  
  size : number?
```

A parameter that controls the initial font size for the terms shown in the GUI window.

```
(initial-char-width) → (or/c number? (-> any/c number?))  
(initial-char-width width) → void?  
  width : (or/c number? (-> any/c number?))
```

A parameter that determines the initial width of the boxes where terms are displayed (measured in characters) for both the stepper and traces.

If its value is a number, then the number is used as the width for every term. If its value is a function, then the function is called with each term and the resulting number is used as the width.

```
(dark-pen-color) → (or/c string? (is-a?/c color<%>))  
(dark-pen-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))  
(dark-brush-color) → (or/c string? (is-a?/c color<%>))  
(dark-brush-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))  
(light-pen-color) → (or/c string? (is-a?/c color<%>))  
(light-pen-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))  
(light-brush-color) → (or/c string? (is-a?/c color<%>))  
(light-brush-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))  
(dark-text-color) → (or/c string? (is-a?/c color<%>))  
(dark-text-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))  
(light-text-color) → (or/c string? (is-a?/c color<%>))  
(light-text-color color) → void?  
  color : (or/c string? (is-a?/c color<%>))
```

These six parameters control the color of the edges in the graph.

The dark colors are used when the mouse is over one of the nodes that is connected to this edge. The light colors are used when it isn't.

The pen colors control the color of the line. The brush colors control the color used to fill the arrowhead and the text colors control the color used to draw the label on the edge.

```
(pretty-print-parameters) → (-> (-> any/c) any/c)
(pretty-print-parameters f) → void?
  f : (-> (-> any/c) any/c)
```

A parameter that is used to set other `pretty-print` parameters.

Specifically, whenever `default-pretty-printer` prints something it calls `f` with a thunk that does the actual printing. Thus, `f` can adjust `pretty-print`'s parameters to adjust how printing happens.

```
(default-pretty-printer v port width text) → void?
  v : any/c
  port : output-port?
  width : exact-nonnegative-integer?
  text : (is-a?/c text%)
```

This is the default value of `pp` used by `traces` and `stepper` and it uses `pretty-print`.

This function uses the value of `pretty-print-parameters` to adjust how it prints.

It sets the `pretty-print-columns` parameter to `width`, and it sets `pretty-print-size-hook` and `pretty-print-print-hook` to print holes and the symbol `'hole` to match the way they are input in a term expression.

8 Typesetting

```
(require redex/pict)
```

The `redex/pict` library provides functions designed to automatically typeset grammars, reduction relations, and metafunction written with `plt redex`.

Each grammar, reduction relation, and metafunction can be saved in a `.ps` file (as encapsulated postscript), or can be turned into a `pict` for viewing in the REPL or using with Slideshow (see *Slideshow: Figure and Presentation Tools*).

8.1 Picts & PostScript

This section documents two classes of operations, one for direct use of creating postscript figures for use in papers and for use in DrRacket to easily adjust the typesetting: `render-term`, `render-language`, `render-reduction-relation`, `render-relation`, `render-judgment-form`, `render-metafunctions`, and `render-lw`, and one for use in combination with other libraries that operate on pict: `term->pict`, `language->pict`, `reduction-relation->pict`, `relation->pict`, `judgment-form->pict`, `metafunction->pict`, and `lw->pict`. The primary difference between these functions is that the former list sets `dc-for-text-size` and the latter does not.

```
(render-term lang term file) → (if file void? pict?)
  lang : compiled-lang?
  term : any/c
  file : (or/c #f path-string?)
```

Renders the term `term`. If `file` is `#f`, it produces a `pict`; if `file` is a path, it saves Encapsulated PostScript in the provided filename. See `render-language` for details on the construction of the `pict`.

```
(term->pict lang term) → pict?
  lang : compiled-lang?
  term : any/c
```

Produces a `pict` like `render-term`, but without adjusting `dc-for-text-size`.

This function is primarily designed to be used with Slideshow or with other tools that combine `picts` together.

```
(render-language lang [file #:nts nts]) → (if file void? pict?)
  lang : compiled-lang?
  file : (or/c false/c path-string?) = #f
  nts : (or/c false/c (listof (or/c string? symbol?)))
        = (render-language-nts)
```


Renders a language. If *file* is #f, it produces a pict; if *file* is a path, it saves Encapsulated PostScript in the provided filename. See [render-language-nts](#) for information on the *nts* argument.

This function parameterizes [dc-for-text-size](#) to install a relevant dc: a [bitmap-dc%](#) or a [post-script-dc%](#), depending on whether *file* is a path.

See [language->pict](#) if you are using Slideshow or are otherwise setting [dc-for-text-size](#).

```
(language->pict lang [#:nts nts]) → pict?
 lang : compiled-lang?
 nts : (or/c false/c (listof (or/c string? symbol?)))
      = (render-language-nts)
```

Produce a pict like [render-language](#), but without adjusting [dc-for-text-size](#).

This function is primarily designed to be used with Slideshow or with other tools that combine pict's together.

```
(render-reduction-relation rel
 [file
  #:style style])
→ (if file void? pict?)
 rel : reduction-relation?
 file : (or/c false/c path-string?) = #f
 style : reduction-rule-style/c = (rule-pict-style)
```

Renders a reduction relation. If *file* is #f, it produces a pict; if *file* is a path, it saves Encapsulated PostScript in the provided filename. See [rule-pict-style](#) for information on the *style* argument.

This function parameterizes [dc-for-text-size](#) to install a relevant dc: a [bitmap-dc%](#) or a [post-script-dc%](#), depending on whether *file* is a path. See also [reduction-relation->pict](#).

The following forms of arrows can be typeset:

```
-->  -+>  ==>  ->  =>  ..>  >->  ~~>  ~>  :->  :->  c->  ->>
>-  <-  >>-  <<-
```

```
(reduction-relation->pict r [#:style style]) → pict?
 r : reduction-relation?
 style : reduction-rule-style/c = (rule-pict-style)
```

Produces a pict like [render-reduction-relation](#), but without setting [dc-for-text-size](#).

This function is primarily designed to be used with Slideshow or with other tools that combine pict's together.

```
(render-metafunction metafunction-name)  
(render-metafunction metafunction-name filename)  
(render-metafunctions metafunction-name ...)  
(render-metafunctions metafunction-name ... #:file filename)
```

Like `render-reduction-relation` but for metafunctions.

Similarly, `render-metafunctions` accepts multiple metafunctions and renders them together, lining up all of the clauses together.

This function sets `dc-for-text-size`. See also `metafunction->pict` and `metafunctions->pict`.

```
(metafunction->pict metafunction-name)
```

This produces a pict, but without setting `dc-for-text-size`. It is suitable for use in Slideshow or other libraries that combine pict's.

```
(metafunctions->pict metafunction-name ...)
```

Like `metafunction->pict`, this produces a pict, but without setting `dc-for-text-size` and is suitable for use in Slideshow or other libraries that combine pict's. Like `render-metafunctions`, it accepts multiple metafunctions and renders them together.

```
(render-relation relation-name)  
(render-relation relation-name filename)
```

Like `render-metafunction` but for relations.

This function sets `dc-for-text-size`. See also `relation->pict`.

```
(render-judgment-form judgment-form-name)  
(render-judgment-form judgment-form-name filename)
```

Like `render-metafunction` but for judgment forms.

This function sets `dc-for-text-size`. See also `relation->pict`.

```
(relation->pict relation-name)
```

This produces a pict, but without setting `dc-for-text-size`. It is suitable for use in Slideshow or other libraries that combine pict's.

```
(judgment-form->pict judgment-form-name)
```

This produces a pict, but without setting `dc-for-text-size`. It is suitable for use in Slideshow or other libraries that combine pict.

8.2 Customization

```
(render-language-nts) → (or/c false/c (listof symbol?))  
(render-language-nts nts) → void?  
  nts : (or/c false/c (listof symbol?))
```

The value of this parameter controls which non-terminals `render-language` and `language->pict` render by default. If it is `#f` (the default), all non-terminals are rendered. If it is a list of symbols, only the listed symbols are rendered.

See also `language-nts`.

```
(extend-language-show-union) → boolean?  
(extend-language-show-union show?) → void?  
  show? : boolean?
```

If this is `#t`, then a language constructed with `extend-language` is shown as if the language had been constructed directly with `language`. If it is `#f`, then only the last extension to the language is shown (with four-period ellipses, just like in the concrete syntax).

Defaults to `#f`.

Note that the `#t` variant can look a little bit strange if `. . . .` are used and the original version of the language has multi-line right-hand sides.

```
(render-reduction-relation-rules)  
  → (or/c false/c (listof (or/c symbol? string? exact-nonnegative-integer?)))  
(render-reduction-relation-rules rules) → void?  
  rules : (or/c false/c (listof (or/c symbol? string? exact-nonnegative-integer?)))
```

This parameter controls which rules in a reduction relation will be rendered. The strings and symbols match the names of the rules and the integers match the position of the rule in the original definition.

```
(rule-pict-style) → reduction-rule-style/c  
(rule-pict-style style) → void?  
  style : reduction-rule-style/c
```

This parameter controls the style used by default for the reduction relation. It can be `'horizontal`, where the left and right-hand sides of the reduction rule are beside each other or `'vertical`, where the left and right-hand sides of the reduction rule are above each other. The `'compact-vertical` style moves the reduction arrow to the second line and uses less space between lines. The `'vertical-overlapping-side-conditions` variant, the side-conditions don't contribute to the width of the pict, but are just overlaid on the second line of each rule. The `'horizontal-left-align` style is like the `'horizontal` style, but the left-hand sides of the rules are aligned on the left, instead of on the right.

```
reduction-rule-style/c : flat-contract?
```

A contract equivalent to

```
(symbols 'vertical
         'compact-vertical
         'vertical-overlapping-side-conditions
         'horizontal)
```

```
(arrow-space) → natural-number/c
(arrow-space space) → void?
  space : natural-number/c
```

This parameter controls the amount of extra horizontal space around the reduction relation arrow. Defaults to 0.

```
(label-space) → natural-number/c
(label-space space) → void?
  space : natural-number/c
```

This parameter controls the amount of extra space before the label on each rule, except in the `'vertical` and `'vertical-overlapping-side-conditions` modes, where it has no effect. Defaults to 0.

```
(metafunction-pict-style)
  (or/c 'left-right
        'up-down
        'left-right/vertical-side-conditions
        'up-down/vertical-side-conditions
        'left-right/compact-side-conditions
        'up-down/compact-side-conditions
        'left-right/beside-side-conditions)
→
(metafunction-pict-style style) → void?
```

```

      (or/c 'left-right
           'up-down
           'left-right/vertical-side-conditions
style : 'up-down/vertical-side-conditions
        'left-right/compact-side-conditions
        'up-down/compact-side-conditions
        'left-right/beside-side-conditions)

```

This parameter controls the style used for typesetting metafunctions. The `'left-right` style means that the results of calling the metafunction are displayed to the right of the arguments and the `'up-down` style means that the results are displayed below the arguments.

The `'left-right/vertical-side-conditions` and `'up-down/vertical-side-conditions` variants format side conditions each on a separate line, instead of all on the same line.

The `'left-right/compact-side-conditions` and `'up-down/compact-side-conditions` variants move side conditions to separate lines to avoid making the rendered form wider than it would be otherwise.

The `'left-right/beside-side-conditions` variant is like `'left-right`, except it puts the side-conditions on the same line, instead of on a new line below the case.

```

(delimit-ellipsis-arguments?) → any/c
(delimit-ellipsis-arguments? delimit?) → void?
delimit? : any/c

```

This parameter controls the typesetting of metafunction definitions and applications. When it is non-`#f` (the default), commas precede ellipses that represent argument sequences; when it is `#f` no commas appear in those positions.

```

(linebreaks) → (or/c #f (listof boolean?))
(linebreaks breaks) → void?
breaks : (or/c #f (listof boolean?))

```

This parameter controls which cases in the metafunction are rendered on two lines and which are rendered on one.

If its value is a list, the length of the list must match the number of cases and each boolean indicates if that case has a linebreak or not.

This influences the `'left/right` styles only.

```

(metafunction-cases)
→ (or/c #f (and/c (listof (and/c integer?
                           (or/c zero? positive?)))
                 pair?))

```

```
(metafunction-cases cases) → void?
  (or/c #f (and/c (listof (and/c integer?
    cases : (or/c zero? positive?)))
    pair?))
```

This parameter controls which cases in a metafunction are rendered. If it is `#f` (the default), then all of the cases appear. If it is a list of numbers, then only the selected cases appear (counting from 0).

```
(label-style) → text-style/c
(label-style style) → void?
  style : text-style/c
(grammar-style) → text-style/c
(grammar-style style) → void?
  style : text-style/c
(paren-style) → text-style/c
(paren-style style) → void?
  style : text-style/c
(literal-style) → text-style/c
(literal-style style) → void?
  style : text-style/c
(metafunction-style) → text-style/c
(metafunction-style style) → void?
  style : text-style/c
(non-terminal-style) → text-style/c
(non-terminal-style style) → void?
  style : text-style/c
(non-terminal-subscript-style) → text-style/c
(non-terminal-subscript-style style) → void?
  style : text-style/c
(non-terminal-superscript-style) → text-style/c
(non-terminal-superscript-style style) → void?
  style : text-style/c
(default-style) → text-style/c
(default-style style) → void?
  style : text-style/c
```

These parameters determine the font used for various text in the pict. See `text` in the `texpic` collection for documentation explaining `text-style/c`. One of the more useful things it can be is one of the symbols `'roman`, `'swiss`, or `'modern`, which are a serif, sans-serif, and monospaced font, respectively. (It can also encode style information, too.)

The `label-style` is used for the reduction rule label names. The `literal-style` is used for names that aren't non-terminals that appear in patterns. The `metafunction-style` is used for the names of metafunctions. The `paren-style` is used for the parentheses (including “[”, “]”, “{”, and “}”, as well as “(” and “)”), but not for the square brackets used for

in-hole decompositions, which use the `default-style`. The `grammar-style` is used for the “:=” and “|” in grammars.

The `non-terminal-style` parameter is used for the names of non-terminals. Two parameters style the text in the (optional) "underscore" component of a non-terminal reference. The first, `non-terminal-subscript-style`, applies to the segment between the underscore and the first caret (^) to follow it; the second, `non-terminal-superscript-style`, applies to the segment following that caret. For example, in the non-terminal reference x_y^z , x has style `non-terminal-style`, y has style `non-terminal-subscript-style`, and z has style `non-terminal-superscript-style`.

The `default-style` is used for parenthesis, the dot in dotted lists, spaces, the "where" and "fresh" in side-conditions, and other places where the other parameters aren't used.

```
(label-font-size) → (and/c (between/c 1 255) integer?)
(label-font-size size) → void?
  size : (and/c (between/c 1 255) integer?)
(metafunction-font-size) → (and/c (between/c 1 255) integer?)
(metafunction-font-size size) → void?
  size : (and/c (between/c 1 255) integer?)
(default-font-size) → (and/c (between/c 1 255) integer?)
(default-font-size size) → void?
  size : (and/c (between/c 1 255) integer?)
```

These parameters control the various font sizes. The `default-font-size` is used for all of the font sizes except labels and metafunctions.

```
(reduction-relation-rule-separation)
→ (parameter/c (and/c integer? positive? exact?))
(reduction-relation-rule-separation sep) → void?
  sep : (parameter/c (and/c integer? positive? exact?))
```

Controls the amount of space between clauses in a reduction relation. Defaults to 4.

```
(curly-quotes-for-strings) → boolean?
(curly-quotes-for-strings on?) → void?
  on? : boolean?
```

Controls if the open and close quotes for strings are turned into “ and ” or are left as merely “ and ”.

Defaults to `#t`.

```
(current-text) → (-> string? text-style/c number? pict?)
(current-text proc) → void?
  proc : (-> string? text-style/c number? pict?)
```

This parameter's function is called whenever Redex typesets some part of a grammar, reduction relation, or metafunction. It defaults to slideshow's `text` function.

```
(arrow->pict arrow) → pict?  
  arrow : symbol?
```

Returns the pict corresponding to `arrow`.

```
(set-arrow-pict! arrow proc) → void?  
  arrow : symbol?  
  proc : (-> pict?)
```

This functions sets the pict for a given reduction-relation symbol. When typesetting a reduction relation that uses the symbol, the thunk will be invoked to get a pict to render it. The thunk may be invoked multiple times when rendering a single reduction relation.

```
(white-bracket-sizing)  
  → (-> string? number? (values number? number? number? number?))  
(white-bracket-sizing proc) → void?  
  proc : (-> string? number? (values number? number? number? number?))
```

This parameter is used when typesetting metafunctions to determine how to create the `[]` characters. Rather than using those characters directly (since glyphs tend not to be available in PostScript fonts), they are created by combining two '[' characters or two ']' characters together.

The procedure accepts a string that is either "[" or "]", and returns four numbers. The first two numbers determine the offset (from the left and from the right respectively) for the second square bracket, and the second two two numbers determine the extra space added (to the left and to the right respectively).

The default value of the parameter is:

```
(λ (str size)  
  (let ([inset-amt (floor/even (max 4 (* size 1/2)))]  
        (cond  
          [(equal? str "[")  
           (values inset-amt  
                   0  
                   0  
                   (/ inset-amt 2))]  
          [else  
           (values 0  
                   inset-amt  
                   (/ inset-amt 2)  
                   0)])))
```


where `floor/even` returns the nearest even number below its argument. This means that for sizes 9, 10, and 11, `inset-amt` will be 4, and for 12, 13, 14, and 15, `inset-amt` will be 6.

```
(horizontal-bar-spacing)
→ (parameter/c exact-nonnegative-integer?)
(horizontal-bar-spacing space) → void?
  space : (parameter/c exact-nonnegative-integer?)
```

Controls the amount of space around the horizontal bar when rendering a relation (that was created by `define-relation`). Defaults to 4.

```
(relation-clauses-combine)
→ (parameter/c (-> (listof pict?) pict?))
(relation-clauses-combine combine) → void?
  combine : (parameter/c (-> (listof pict?) pict?))
```

`combine` is called with the list of pict's that are obtained by rendering a relation; it should put them together into a single pict. It defaults to `(λ (l) (apply vc-append 20 l))`

8.3 Removing the Pink Background

When reduction rules, a metafunction, or a grammar contains unquoted Racket code or side-conditions, they are rendered with a pink background as a guide to help find them and provide alternative typesettings for them. In general, a good goal for a PLT Redex program that you intend to typeset is to only include such things when they correspond to standard mathematical operations, and the Racket code is an implementation of those operations.

To replace the pink code, use:

```
(with-unquote-rewriter proc expression)
```

It installs `proc` the current unquote rewriter and evaluates `expression`. If that expression computes any pict's, the unquote rewriter specified is used to remap them.

The `proc` should be a function of one argument. It receives a `lw` struct as an argument and should return another `lw` that contains a rewritten version of the code.

```
(with-atomic-rewriter name-symbol
                     string-or-thunk-returning-pict
                     expression)
```

This extends the current set of atomic-rewriters with one new one that rewrites the value of `name-symbol` to `string-or-pict-returning-thunk` (applied, in the case of a thunk), during the evaluation of `expression`.

`name-symbol` is expected to evaluate to a symbol. The value of `string-or-thunk-returning-pict` is used whenever the symbol appears in a pattern.

```
(with-compound-rewriter name-symbol
                        proc
                        expression)
```

This extends the current set of compound-rewriters with one new one that rewrites the value of `name-symbol` via `proc`, during the evaluation of `expression`.

`name-symbol` is expected to evaluate to a symbol. The value of `proc` is called with a `(listof lw)`, and is expected to return a new `(listof (or/c lw? string? pict?))`, rewritten appropriately.

The list passed to the rewriter corresponds to the `lw` for the sequence that has `name-symbol`'s value at its head.

The result list is constrained to have at most 2 adjacent non-`lws`. That list is then transformed by adding `lw` structs for each of the non-`lws` in the list (see the description of `lw` below for an explanation of logical-space):

- If there are two adjacent `lws`, then the logical space between them is filled with whitespace.
- If there is a pair of `lws` with just a single non-`lw` between them, a `lw` will be created (containing the non-`lw`) that uses all of the available logical space between the `lws`.
- If there are two adjacent non-`lws` between two `lws`, the first non-`lw` is rendered right after the first `lw` with a logical space of zero, and the second is rendered right before the last `lw` also with a logical space of zero, and the logical space between the two `lws` is absorbed by a new `lw` that renders using no actual space in the typeset version.

```
(with-compound-rewriters ([name-symbol proc] ...)
                          expression)
```

Shorthand for nested `with-compound-rewriter` expressions.

```
(struct lw (e
            line
            line-span
            column
            column-span
            unq?
            metafunction?)
        #:constructor-name make-lw
        #:mutable)
```

```

      (or/c string?
          symbol?
          pict?
          (listof (or/c (symbols 'spring) lw?)))
e :
line : exact-positive-integer?
line-span : exact-positive-integer?
column : exact-positive-integer?
column-span : exact-positive-integer?
unq? : boolean?
metafunction? : boolean?

```

The `lw` data structure corresponds represents a pattern or a Racket expression that is to be typeset. The functions listed above construct `lw` structs, select fields out of them, and recognize them. The `lw` binding can be used with `copy-struct`.

The values of the `unq?` and `metafunction?` fields, respectively, indicate whether the `lw` represents an unquoted expression or a metafunction application. See `to-lw` for the meanings of the other fields.

```

(build-lw e line line-span column column-span) → lw?
      (or/c string?
          symbol?
          pict?
          (listof (or/c (symbols 'spring) lw?)))
e :
line : exact-positive-integer?
line-span : exact-positive-integer?
column : exact-positive-integer?
column-span : exact-positive-integer?

```

Like `make-lw` but specialized for constructing `lws` that do not represent unquoted expressions or metafunction applications.

```
(to-lw arg)
```

This form turns its argument into `lw` structs that contain all of the spacing information just as it would appear when being used to typeset.

Each sub-expression corresponds to its own `lw`, and the element indicates what kind of subexpression it is. If the element is a list, then the `lw` corresponds to a parenthesized sequence, and the list contains a `lw` for the open paren, one `lw` for each component of the sequence and then a `lw` for the close parenthesis. In the case of a dotted list, there will also be a `lw` in the third-to-last position for the dot.

For example, this expression:

```
(a)
```

becomes this lw (assuming the above expression appears as the first thing in the file):

```
(build-lw (list (build-lw "(" 0 0 0 1)
                (build-lw 'a 0 0 1 1)
                (build-lw ")" 0 0 2 1))
          0 0 0 3)
```

If there is some whitespace in the sequence, like this one:

```
(a b)
```

then there is no lw that corresponds to that whitespace; instead there is a logical gap between the lws.

```
(build-lw (list (build-lw "(" 0 0 0 1)
                (build-lw 'a 0 0 1 1)
                (build-lw 'b 0 0 3 1)
                (build-lw ")" 0 0 4 1))
          0 0 0 5)
```

In general, identifiers are represented with symbols and parenthesis are represented with strings and pict's can be inserted to render arbitrary pictures.

The line, line-span, column, and column-span correspond to the logical spacing for the redex program, not the actual spacing that will be used when they are rendered. The logical spacing is only used when determining where to place typeset portions of the program. In the absence of any rewriters, these numbers correspond to the line and column numbers in the original program.

The line and column are absolute numbers from the beginning of the file containing the expression. The column number is not necessarily the column of the open parenthesis in a sequence – it is the leftmost column that is occupied by anything in the sequence. The line-span is the number of lines, and the column span is the number of columns on the last line (not the total width).

When there are multiple lines, lines are aligned based on the logical space (ie, the line/column & line-span/column-span) fields of the lws. As an example, if this is the original pattern:

```
(all good boys
   deserve fudge)
```

then the leftmost edges of the words "good" and "deserve" will be lined up underneath each other, but the relative positions of "boys" and "fudge" will be determined by the natural size of the words as they rendered in the appropriate font.

When `'spring` appears in the list in the `e` field of a `lw` struct, then it absorbs all of the space around it. It is also used by `to-lw` when constructing the pict's for unquoted strings. For example, this expression

```
,x
```

corresponds to these structs:

```
(build-lw (list (build-lw "" 1 0 9 0)
               'spring
               (build-lw x 1 0 10 1))
         1 0 9 2)
```

and the `'spring` causes there to be no space between the empty string and the `x` in the typeset output.

```
(to-lw/stx stx) → lw?
  stx : syntax?
```

This is the runtime variant on `to-lw`; it accepts a syntax object and returns the corresponding `lw` structs. It only uses the location information in the syntax object, so metafunctions will not be rendered properly.

```
(render-lw language/nts lw) → pict?
  language/nts : (or/c (listof symbol?) compiled-lang?)
  lw : lw?
```

Produces a pict that corresponds to the `lw` object argument, using `language/nts` to determine which of the identifiers in the `lw` argument are non-terminals.

This function sets `dc-for-text-size`. See also `lw->pict`.

```
(lw->pict language/ntw lw) → pict?
  language/ntw : (or/c (listof symbol?) compiled-lang?)
  lw : lw?
```

Produces a pict that corresponds to the `lw` object argument, using `language/nts` to determine which of the identifiers in the `lw` argument are non-terminals.

This does not set the `dc-for-text-size` parameter. See also `render-lw`.

```
(just-before stuff lw) → lw?
  stuff : (or/c pict? string? symbol?)
  lw : lw?
(just-after stuff lw) → lw?
  stuff : (or/c pict? string? symbol?)
  lw : lw?
```

These two helper functions build new lws whose contents are the first argument, and whose line and column are based on the second argument, making the new loc wrapper be either just before or just after that argument. The line-span and column-span of the new lw is always zero.

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