Type-checking on Heterogeneous Sequences

in Common Lisp

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Overview

Common Lisp Types

What is a *type* in Common Lisp?

Definition (from CL specification)

A (possibly infinite) set of objects.

Definition (type specifier)

An expression that denotes a type.

Atomic examples

`t`, `integer`, `number`, `asdf:component`

Type specifiers come in several forms.

- Compound type specifiers
    - `(eql 12)`
    - `(member :x :y :z)`
    - `(satisfies oddp)`
    - `(and (or number string) (not (satisfies MY-FUN)))`

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  - `(and (or number string) (not (satisfies MY-FUN)))`
- Specifiers for the empty type
  - `nil`
  - `(and number string)`
  - `(and (satisfies evenp) (satisfies oddp))`

Using types with sequences

Compile time

```
(lambda (x y)
   (declare (type (vector float) x y))
   (list x y))
```

Run time

```
(typep my-list '(cons t (cons t (cons string))))
```

Limitations

Limited capability for specifying heterogeneous sequences. You can't specify the following.

- An arbitrary length, non-empty, list of floats:
  `(1.0 2.0 3.0)`

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- An arbitrary length, non-empty, list of floats:
  `(1.0 2.0 3.0)`
- A plist such as:
  `(:x 0 :y 2 :z 3)`

The Rational Type Expression

Introducing the RTE type

Rational type expression *vs.* RTE type specifier

- *number*$^+$
    - `(RTE (:+ number))`
    - Example: `(1.0 2.0 3.0)`

Introducing the RTE type

Rational type expression *vs.* RTE type specifier

- $number^{+}$
  - `(RTE (:+ number))`
  - Example: `(1.0 2.0 3.0)`
- $(keyword \cdot integer)^{*}$
  - `(RTE (:* (:cat keyword integer)))`
  - Example: `(:x 0 :y 2 :z 3)`

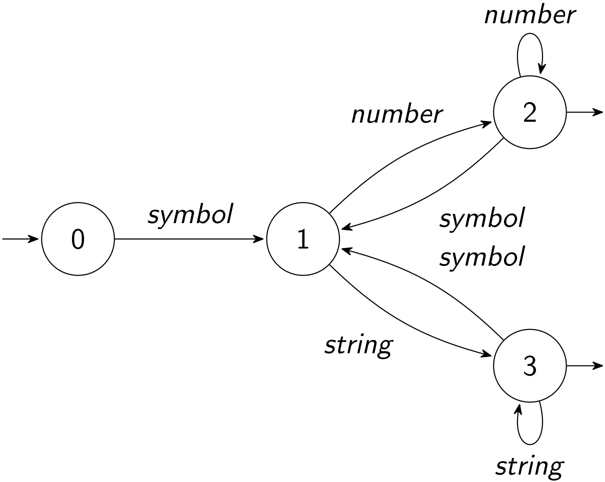
Use RTE anywhere CL expects a type specifier.

```
(typedef plist (type)
  `(and list
        (RTE (:* keyword ,type))))

(defun foo (A B)
  (declare (type (RTE (:+ number)) A)
           (type (plist float) B))
  ...)
```

An RTE can be expressed as a finite state machine.

$(\mathit{symbol} \cdot (\mathit{number}^{+} \ \cup \ \mathit{string}^{+}))^{+}$

`(:+ symbol (:or (:+ number) (:+ string)))`



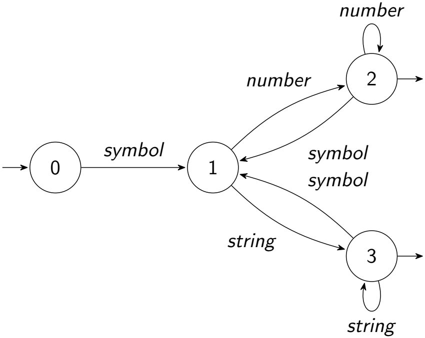
Generated Code

State machine can be expressed in CL code

```
(lambda (seq)
  (declare (optimize (speed 3) (debug 0) (safety 0)))
  (typecase seq
    (list
     ...)
    (simple-vector
     ...)
    (vector
     ...)
    (sequence
     ...)
    (t nil)))
```

Code generating implementing state machine

```
(tagbody
 0
   (unless seq (return nil))
   (typecase (pop seq)
     (symbol (go 1))
     (t (return nil)))
 1
   (unless seq (return nil))
   (typecase (pop seq)
     (number (go 2))
     (string (go 3))
     (t (return nil)))
 2
   (unless seq (return t))
   (typecase (pop seq)
     (number (go 2))
     (symbol (go 1))
     (t (return nil)))
```



```
 3
   (unless seq (return t))
   (typecase (pop seq)
     (string (go 3))
     (symbol (go 1))
     (t (return nil)))))
```

destructuring-case

Example of `destructuring-case`

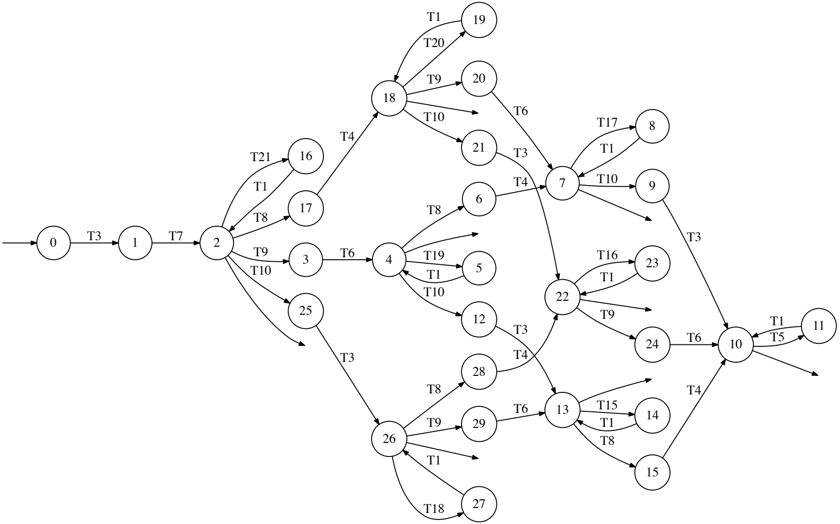
```
(destructuring-case DATA
  ;; Case-1
  ((a b &optional (c ""))
   (declare (type integer a)
            (type string b c))
   ...)

  ;; Case-2
  ((a (b c)
    &key (x t) (y "") z
      &allow-other-keys)
   (declare (type fixnum a b c)
            (type symbol x)
            (type string y)
            (type list z))
   ...))
```

```
(typecase DATA
  ;; Case-1
  ((rte (:cat integer
              string
              (:? string)))
   ...destructuring-bind...)

  ;; Case-2
  ((rte ...complicated...)
   ...destructuring-bind...





   ...))
```

Regular type expression denoting Case-2

```
(:cat
 (:cat fixnum (:and list (rte (:cat fixnum fixnum))))
  (:and (:* keyword t)
    (:cat
     (:* (not (member :x :y :z)) t)
     (:or :empty-word
       (:cat (eql :z) fixnum (:* (not (member :x :y)) t)
        (:?  (eql :y) string (:* (not (eql :x)) t)
         (:? (eql :x) symbol (:* t t))))

       (:cat (eql :z) fixnum (:* (not (member :x :y)) t)
        (:?  (eql :x) symbol (:* (not (eql :y)) t)
         (:? (eql :y) string (:* t t))))

       (:cat (eql :y) string (:* (not (member :x :z)) t)
        (:?  (eql :z) fixnum (:* (not (eql :x)) t)
         (:? (eql :x) symbol (:* t t))))

       (:cat (eql :x) symbol (:* (not (member :y :z)) t)
        (:?  (eql :z) fixnum (:* (not (eql :y)) t)
         (:? (eql :y) string (:* t t))))

       (:cat (eql :y) string (:* (not (member :x :z)) t)
        (:?  (eql :x) symbol (:* (not (eql :z)) t)
         (:? (eql :z) fixnum (:* t t))))

       (:cat (eql :x) symbol (:* (not (member :y :z)) t)
        (:?  (eql :y) string (:* (not (eql :z)) t)
         (:? (eql :z) fixnum (:* t t))))))))
```

Finite State Machine of Case-2 of destructuring-case

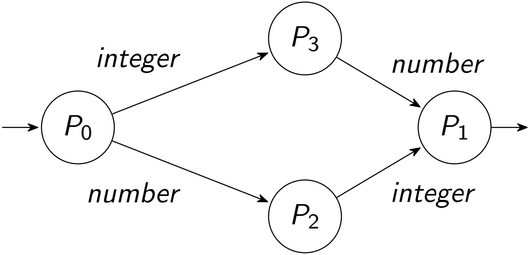


Overlapping Types

Rational type expression with *overlapping* types

$$((integer \cdot number) \cup (number \cdot integer))$$

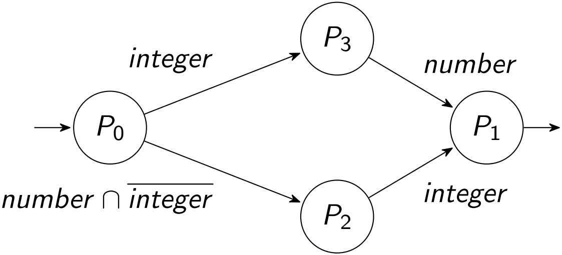
```
(:or (:cat integer number)
     (:cat number integer))
```



Overlapping types must decomposed into *disjoint* types

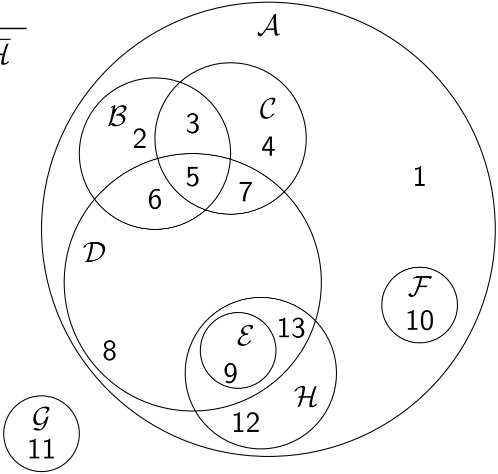
$$((integer \cdot number) \;\cup\; ((number \cap \overline{integer}) \cdot integer))$$

```
(:or (:cat integer number)
     (:cat (and number (not integer))
           integer))
```



Overlapping types considered harmful

Disjoint Set	Decomposed Expression
{ 1 }	$\mathcal{A} \cap \overline{\mathcal{B}} \cap \overline{\mathcal{C}} \cap \overline{\mathcal{D}} \cap \overline{\mathcal{F}} \cap \overline{\mathcal{H}}$
{ 2 }	$\mathcal{B} \cap \overline{\mathcal{C}} \cap \overline{\mathcal{D}}$
{ 3 }	$\mathcal{B} \cap \mathcal{C} \cap \overline{\mathcal{D}}$
{ 4 }	$\mathcal{C} \cap \overline{\mathcal{B}} \cap \overline{\mathcal{D}}$
{ 5 }	$\mathcal{B} \cap \mathcal{C} \cap \mathcal{D}$
{ 6 }	$\mathcal{B} \cap \mathcal{D} \cap \overline{\mathcal{C}}$
{ 7 }	$\mathcal{C} \cap \mathcal{D} \cap \overline{\mathcal{B}}$
{ 8 }	$\mathcal{D} \cap \overline{\mathcal{B}} \cap \overline{\mathcal{C}} \cap \overline{\mathcal{H}}$
{ 9 }	$\mathcal{E}$
{ 10 }	$\mathcal{F}$
{ 11 }	$\mathcal{G}$
{ 12 }	$\mathcal{H} \cap \overline{\mathcal{D}}$
{ 13 }	$\mathcal{D} \cap \mathcal{H} \cap \overline{\mathcal{E}}$



How to calculate type disjoint-ness and equivalence.

```
(defun type-intersection (T1 T2)
  `(and ,T1 ,T2))

(defun types-disjoint-p (T1 T2)
  (subtypep (type-intersection T1 T2) nil))

(defun types-equivalent-p (T1 T2)
  (multiple-value-bind (T1<=T2 okT1T2) (subtypep T1 T2)
    (multiple-value-bind (T2<=T1 okT2T2) (subtypep T2 T1)
      (values (and T1<=T2 T2<=T1) (and okT1T2 okT2T2)))))
```

Interesting Difficulties Encountered

Performance and correctness problems with SUBTYPEP

```
(subtypep '(and integer (or (eql 1) (satisfies F)))
          '(and integer (or (eql 0) (satisfies G))))
```

⟹ *NIL, T (should be NIL, NIL)*

```
(subtypep 'compiled-function nil)
```

⟹ *NIL, NIL (should be NIL, T)*

```
(subtypep '(eql :x) 'keyword)
```

⟹ *NIL, NIL (should be T, T)*

Recursive types forbidden

Neither the CL type system nor the RTE extension are expressive enough to specify recursive types such as:

```
(deftype singleton (type)
 `(or (cons ,type nil)
      (cons (singleton ,type))))
```

```
(deftype proper-list (type)
  `(cons ,type (or null
                   (proper-list ,type))))
```

Missing CL API for type reflection and extension

- Can't ask whether a particular type exists? *I.e.*, is there a type `foo` ?
- *E.g.*, Given two RTE type specifiers, we can calculate whether one is a subtype of the other. Unfortunately, CL provides no `SUBTYPE` hook allowing me to make this calculation.

Future Research

- Static analysis of `destructuring-case` to detect unreachable code or overlapping cases.
- Investigate performance of type decomposition (disjoint-izing).
- Apply to other dynamic languages (*e.g.*, Python, Scala/JVM, Julia/LLVM).

Summary

- Regular expression style type-based pattern matching on CL sequences.
- RTE type allows $\mathcal{O}(n)$ type checking of CL sequences.
- Non-linear complexity moved to compile time.
- Source-code available at `https://www.lrde.epita.fr/wiki/Publications/newton.16.els`

Q/A

Questions?