Type-checking on Heterogeneous Sequences in Common Lisp

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Overview

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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)))
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)))`

- **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: 
  \[(1.0 \ 2.0 \ 3.0)\]
Limited capability for specifying heterogeneous sequences. You can’t specify the following.

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

- 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

- $number^+$
  - $(\text{RTE} (:+ number))$
  - Example: $(1.0 \ 2.0 \ 3.0)$
Introducing the RTE type

Rational type expression vs. RTE type specifier

- $\text{number}^+$
  - $(\text{RTE} (:+ \text{number}))$
  - Example: $(1.0 \ 2.0 \ 3.0)$

- $(\text{keyword} \cdot \text{integer})^*$
  - $(\text{RTE} (:* (\text{cat keyword integer})))$
  - 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.

\[(symbol \cdot (number^+ \cup string^+))^+\]
\[(:+ symbol (:or (:+ number) (:+ string)))\]
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)))))
 (:? (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))))
 (:? (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

\[
((\text{integer} \cdot \text{number}) \cup (\text{number} \cdot \text{integer}))
\]

\[
(:\text{or} (:\text{cat} \text{integer} \text{number}) \\
(:\text{cat} \text{number} \text{integer}))
\]
Overlapping types must be decomposed into disjoint types

\[((\text{integer} \cdot \text{number}) \cup ((\text{number} \cap \text{integer}) \cdot \text{integer}))\]

\((\text{or} (\text{cat} \text{ integer} \text{ number})
\quad (\text{cat} (\text{and} \text{ number} (\text{not} \text{ integer}))
\quad \text{integer}))\)

Diagram:

- \(P_0\) connected to \(P_1\) and \(P_2\)
- \(P_1\) connected to \(P_3\) and \(P_0\)
- \(P_2\) connected to \(P_0\) and \(P_3\)

Nodes:
- \(P_0\): integer
- \(P_1\): number
- \(P_2\): number \(\cap\) integer
- \(P_3\): integer
Overlapping types considered harmful

<table>
<thead>
<tr>
<th>Disjoint Set</th>
<th>Decomposed Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>{ 1 }</td>
<td>( A \cap \overline{B} \cap \overline{C} \cap \overline{D} \cap \overline{F} \cap \overline{H} )</td>
</tr>
<tr>
<td>{ 2 }</td>
<td>( B \cap \overline{C} \cap \overline{D} )</td>
</tr>
<tr>
<td>{ 3 }</td>
<td>( B \cap C \cap \overline{D} )</td>
</tr>
<tr>
<td>{ 4 }</td>
<td>( C \cap \overline{B} \cap \overline{D} )</td>
</tr>
<tr>
<td>{ 5 }</td>
<td>( B \cap C \cap D )</td>
</tr>
<tr>
<td>{ 6 }</td>
<td>( B \cap D \cap \overline{C} )</td>
</tr>
<tr>
<td>{ 7 }</td>
<td>( C \cap D \cap \overline{B} )</td>
</tr>
<tr>
<td>{ 8 }</td>
<td>( D \cap \overline{B} \cap \overline{C} \cap \overline{H} )</td>
</tr>
<tr>
<td>{ 9 }</td>
<td>( \mathcal{E} )</td>
</tr>
<tr>
<td>{ 10 }</td>
<td>( \mathcal{F} )</td>
</tr>
<tr>
<td>{ 11 }</td>
<td>( \mathcal{G} )</td>
</tr>
<tr>
<td>{ 12 }</td>
<td>( \mathcal{H} \cap \overline{D} )</td>
</tr>
<tr>
<td>{ 13 }</td>
<td>( D \cap \mathcal{H} \cap \overline{E} )</td>
</tr>
</tbody>
</table>
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 \textsc{subtypep}

\begin{verbatim}
(subtypep '(and integer (or (eql 1) (satisfies F)))
   '(and integer (or (eql 0) (satisfies G))))
\Rightarrow NIL, T (should be NIL, NIL)
\end{verbatim}

\begin{verbatim}
(subtypep 'compiled-function nil)
\Rightarrow NIL, NIL (should be NIL, T)
\end{verbatim}

\begin{verbatim}
(subtypep '(eql :x) 'keyword)
\Rightarrow NIL, NIL (should be T, T)
\end{verbatim}
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 $O(n)$ 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
Questions?