CPM: A Declarative Package Manager with Semantic Versioning

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Contemporary software systems are complex!

Software packages as building blocks

- several modules with well-defined APIs
- evolve over time (efficiency improvements, new functionality)
  ⇝ versioning with version numbers (1.4.3)

Package dependencies

Package A depends on: package B version $\geq 1.2.5 \land < 2.0.0$
package C version $\geq 2.3.7 \land < 4.0.0$

Semantic versioning: `<major>`.`<minor>`.`<patch>`

Version numbers describe semantic properties:

- alternative implementation ⇝ increase `<patch>`
- extend API ⇝ increase `<minor>`
- change API ⇝ increase `<major>`
Semantic Versioning (www.semver.org)

Advantages
- describe necessary dependencies
- choose appropriate packages (.package manager)
- upgrade to newer versions without code breaks

Requirements
Packages with identical <major> must be semantically compatible

Semantic compatibility
- important to support automatic upgrading
- not checked in contemporary package managers

Our proposal:
check it automatically with property-based test tools
Property-based Testing

**Properties**
- tests parameterized over some arguments
- no side effects $\Rightarrow$ repeatable tests
- generate input values:
  - random (QuickCheck, PrologCheck, PropEr)
  - systematic enumeration (SmallCheck, GAST)
  - systematic (non-deterministic) guessing (EasyCheck, CurryCheck)

Here: Curry (Haskell syntax, logic features) + CurryCheck [LOPSTR’16]

**List concatenation is associative**

\[
\begin{align*}
[] + ys &= ys \\
(x : xs) + ys &= x : (xs + ys)
\end{align*}
\]

concIsAssociative xs ys zs = (xs ++ ys) ++ zs $\bowtie$ xs ++ (ys ++ zs)
Non-deterministic list insertion

\[
\text{ins} :: a \rightarrow [a] \rightarrow [a] \\
\text{ins} \ x \ ys = x : ys \\
\text{ins} \ x \ (y:ys) = y : \text{ins} \ x \ ys
\]

> \text{ins} 0 [1,2] \rightsquigarrow [0,1,2] \sim [1,0,2] \sim [1,2,0]

Property: insertion increments list length

\[
\text{insLength} \ x \ xs = \text{length} \ (\text{ins} \ x \ xs) <\sim> \text{length} \ xs + 1
\]

Set-based interpretation relevant:

\[ e_1 <\sim> e_2 \iff e_1 \text{ and } e_2 \text{ have identical sets of results } \]
Idea:

\( f \) defined in module \( M \) of some package in versions \( v_1 \) and \( v_2 \):

1. create renamed modules \( M_{v_1} \) and \( M_{v_2} \)
2. create new “comparison” module:
   
   \[
   \text{import qualified } M_{v_1} \\
   \text{import qualified } M_{v_2} \\
   \text{check}_M f x = M_{v_1}.f x \sim M_{v_2}.f x
   \]
3. run CurryCheck on this module

Problems:

- \( f \) defined on (package) local data types
  \( \Rightarrow \) generate bijective type mapping, use it in \( \text{check}_M f \)
- \( f \) might not terminate: use termination analysis
  \( \Rightarrow \) no check or specific check for productive operations
Lazy languages supports infinite data structures:

\[
\begin{align*}
\text{ints} :: \text{Int} & \rightarrow [	ext{Int}] \\
\text{ints} \ n &= n : \text{ints} \ (n+1) \\
\text{ints} \ 0 & \leadsto 0 : 1 : 2 : \ldots
\end{align*}
\]

\[
\begin{align*}
\text{ints2} :: \text{Int} & \rightarrow [	ext{Int}] \\
\text{ints2} \ n &= n : \text{ints2} \ (n+2) \\
\text{ints2} \ 0 & \leadsto 0 : 2 : 4 : \ldots
\end{align*}
\]

-- Equivalence testing:
\[
\text{checkInts} \ x = \text{ints} \ x \ <~> \ 	ext{ints2} \ x \ 
\leadsto \text{no counter example}...
\]

Non-terminating but productive operations

\[
f \ productive \iff \text{no infinite reduction without producing root-constructors}
\]

\[
\text{ints, ints2: productive}
\]

\[
\text{loop} \ n = \text{loop} \ (n+1) \ 
\text{-- not productive}
\]
Limit the size of values

```
data Nat = Z | S Nat -- Peano numbers

limList :: Nat → [Int] → [Int]
limList Z _ = []
limList (S n) [] = []
limList (S n) (x:xs) = x : limList n xs
```

Checking with size limits

```
limCheckInts n x = limList n (ints x) <~> limList n (ints2 x)
```

⇝ CurryCheck finds counter-example: \( n=(S (S Z)) \) \( x=1 \)

Proposition [ICLP’17]:

Limited equivalence checking is sound and complete (for total operations) for equivalence checking.
CPM: Curry Package Manager

- tool to distribute and install Curry software packages
- central package index (currently: > 50 packages, > 400 modules)
- package: Curry modules + **package specification**:
  - metadata in JSON format
  - standard fields: version number, author, name, synopsis,...
  - **dependency constraints**:
    
    "B" : ">= 2.0.0, < 3.0.0 || > 4.1.0"
    
    \( \rightsquigarrow \) depends on package \( B \) with major version \( 2 \) or in a version greater than \( 4.1.0 \)

Some CPM commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>cpm update</td>
<td>download newest version of package index</td>
</tr>
<tr>
<td>cpm search</td>
<td>search in package index</td>
</tr>
<tr>
<td>cpm install</td>
<td>installs a package (resolve all dependency constraints) with local copies of all required packages</td>
</tr>
<tr>
<td>cpm upgrade</td>
<td>re-install with newer package versions</td>
</tr>
<tr>
<td>cpm test</td>
<td>run CurryCheck on all source modules</td>
</tr>
</tbody>
</table>
cpm diff 1.2.4 check current package version against 1.2.4

Implementation of semantic versioning checking
- rename modules with version numbers
- generate comparison module
- analyze each operation defined in two package versions:
  - terminating: use standard equivalence check
  - non-terminating but productive: use equivalence checks with limits
    - generate limit operations for each data type
  - otherwise: no check, warning
- program analysis implemented with CASS [PEPM’14]

Curry prelude: 126 operations
Analysis result: 112 terminating, 11 productive, 3 non-terminating
User annotations to override analysis results:

### Annotate terminating operations

```haskell
{-# TERMINATE #-}
mccarthy n = if n<=100 then mccarthy (mccarthy (n+11))
else n-10
```

### Annotate productive operations

```haskell
{-# PRODUCTIVE #-}
primes = sieve (ints 2)
where sieve (p:xs) =
  p : sieve (filter (\x -> mod x p > 0) xs)
```

### Annotate unchecked operations

```haskell
{-# NOCOMPARE #-}
f ... = ...code with bug fixes...
```
Conclusions

CPM: Curry Package Manager

- first package manager with semantic versioning checker
  (Elm package manager: purely syntactic API comparison)
- termination important for automatic tool $\Rightarrow$ program analysis
- productivity: check also non-terminating operations (data generators)
- supports *specification-based software development*
  - package *n.0.0* contains specification [PADL’12]
  - newer package versions: better implementations
- approach applicable to all kinds of declarative languages
  functional (QuickCheck), logic (PrologCheck), functional-logic (CurryCheck), ...

Future work:

- better termination analysis
- avoid *testing*:
  - check structural equivalence of source code
  - use theorem provers to proof equivalence