Adding a Module System to Java

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Joint work with Peter Sewell and Matthew Parkinson

1. What is a module system?
2. Why Java needs a module system
3. Current solutions
4. The Java Module System (JAM)
5. improved JAM (iJAM)
6. Formalizations & proofs
7. Conclusion

What is a module system?

Definition

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module	A piece of software that *should* implement a specific function in a largely independent manner.

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dynamic reuse	sharing module's types and data.
separate compilation	ability to compile a module in isolation.

Quick look at the ML module system

- Abstraction (abstract types, module types)

```
module Foo = struct            (* implementation *)
  type t = int
  let v = 5
end

let x = 42 + Foo.v   (* OK *)

module type View = sig         (* interface *)
  type t
  val v : t
end

module Bar : View = Foo        (* abstraction *)
let y = 42 + Bar.v   (* COMPILE ERROR *)
```

Quick look at the ML module system

- Composition

  Can be structured. Functors = functions over modules.
- Static reuse

  On the scale of each file (module).
- Dynamic reuse

  Not supported.
- Separate compilation

  Each file (module) compiled separately.

Why Java needs a module system

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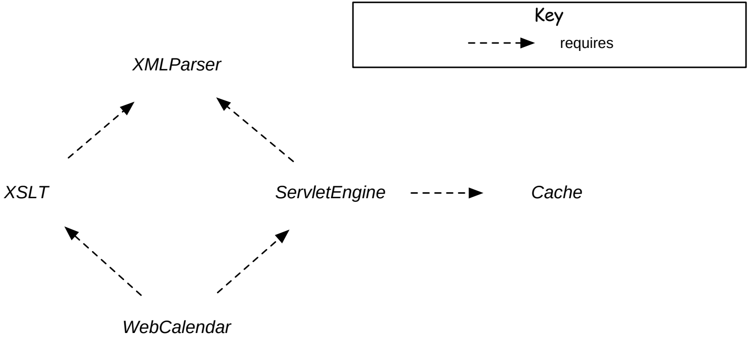
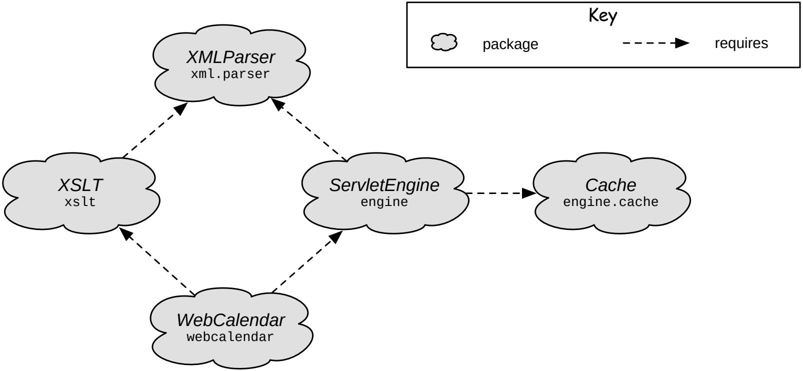
package	Part of class namespace. Serves as barrier for default access restriction, and so enables package-wide abstraction for class members.
JAR file	A group of classes/interfaces. Provides only high-level static reuse, nothing else.

An example



Servlet is a small program that runs on a web-server.

An example



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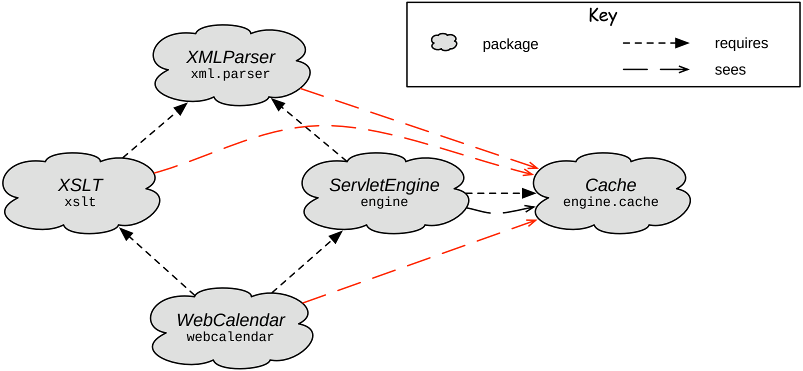

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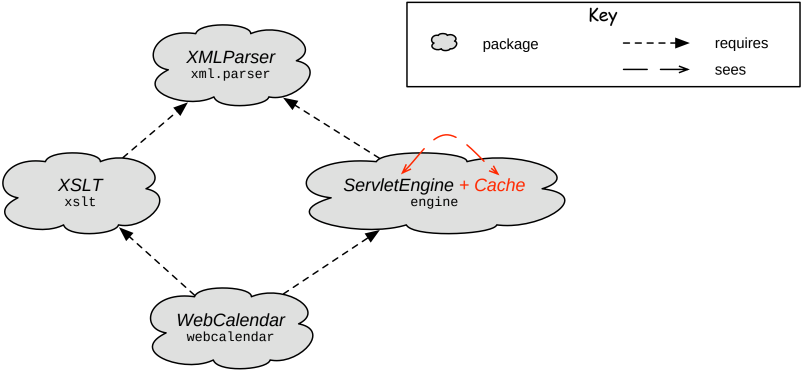

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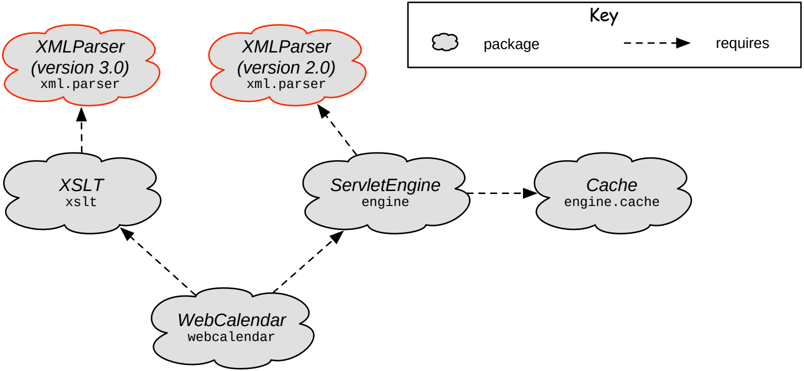
No high-level abstraction DLL/JAR Hell



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  Allow software units of different versions to co-exist.
- No separate compilation
  Allow software units to be compiled in isolation.

Current solutions

Custom classloaders

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Hard to understand/use/debug. Each company makes their own.

Design patterns

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Not very type-safe. Ad hoc.

Frameworks

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Not in language (not enforced). Not enough is enforced, e.g. no high-level abstraction or dynamic reuse.

The Java Module System (JAM)

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- be available to everyone automatically (put into the language);
- be compatible with all Java sources (but only on JVM 7+).

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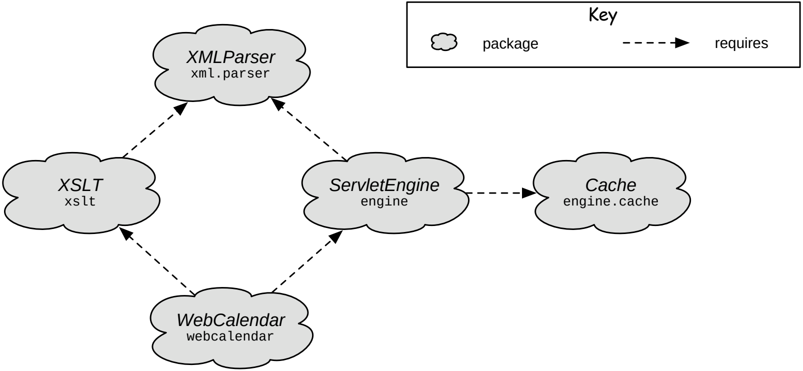
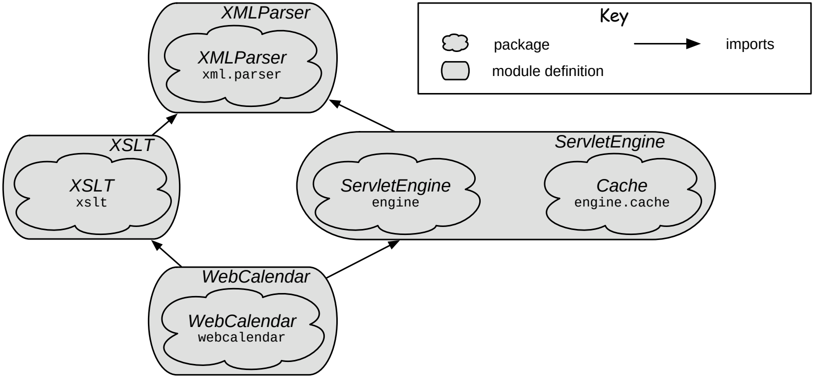
The example

Original Example with Packages



The example

Module definitions



The example

The source for the module definitions written in module files.

```
superpackage XMLParser {
  member xml.parser;
  export xml.parser.Parser;
}
```

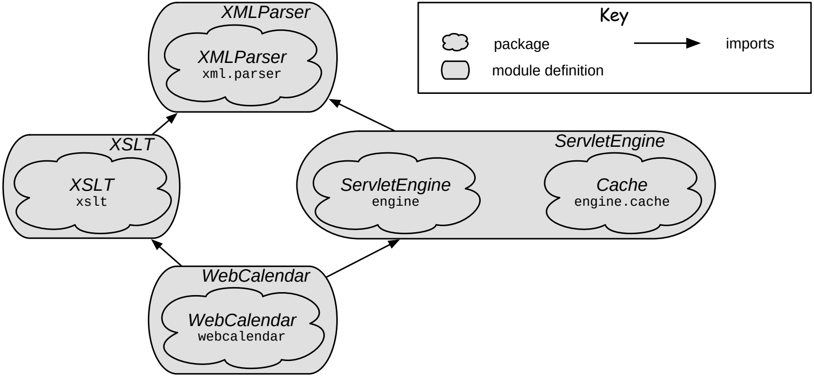
```
superpackage XSLT {
  member xslt;
  import XMLParser;
  export xslt.XSLTProcessor;
}
```

```
superpackage ServletEngine {
  member engine; member engine.cache;
  import XMLParser;
  export engine.ServletEngine;
}
```

```
superpackage WebCalendar {
  member webcalendar;
  import ServletEngine; import XSLT;
}
```

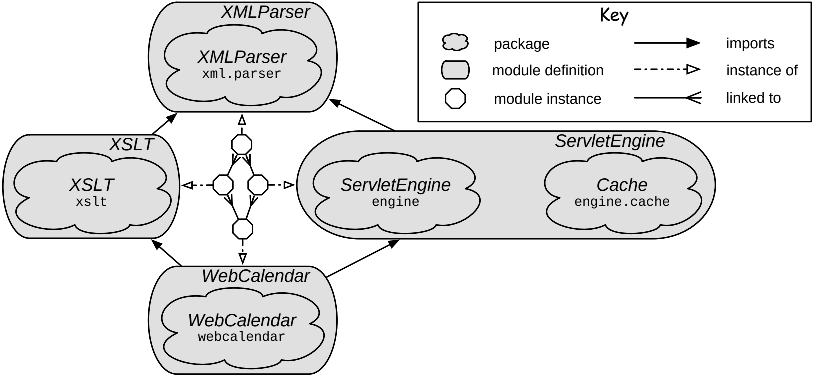
The example

Module definitions



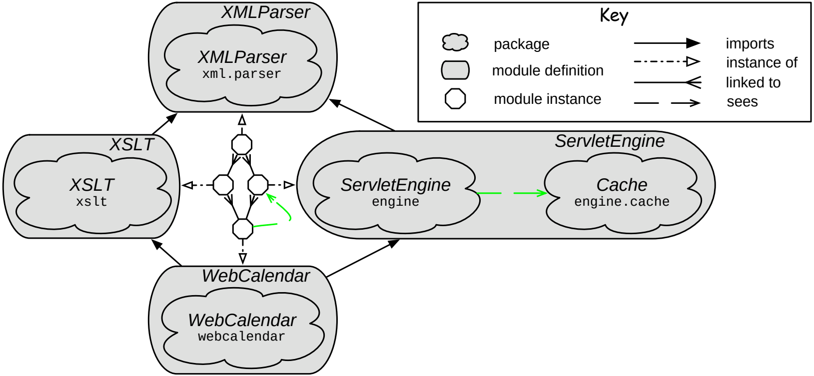
The example

Module definitions and their instances



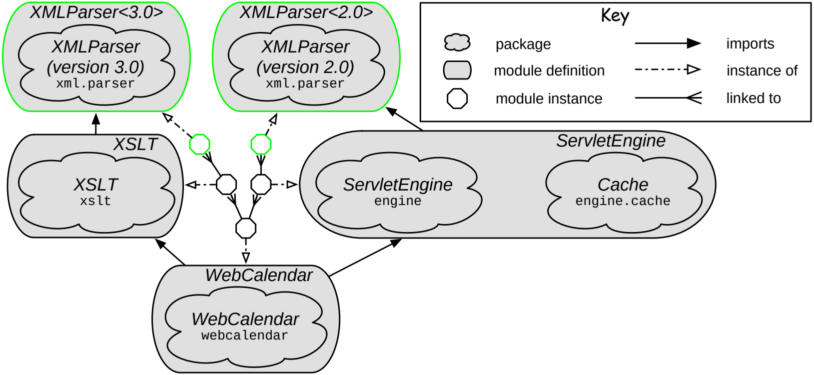
The example

High-level abstraction



The example

High-level abstraction No DLL/JAR hell

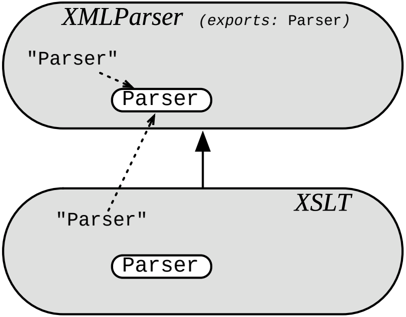


Summary of JAM's concepts

Module file	A file *naming* the packages. Also mentions what is imported/exported.
Module definition	(a.k.a. superpackage) A file *containing* the packages. Compiled from a module file and classes.
Module instance	A runtime instance of a module definition that is linked up to other module instances.
Repository	A runtime entity where an administrator can (un-)install or initialize module definitions.

We discovered two major deficiencies with JAM

1. unintuitive class resolution



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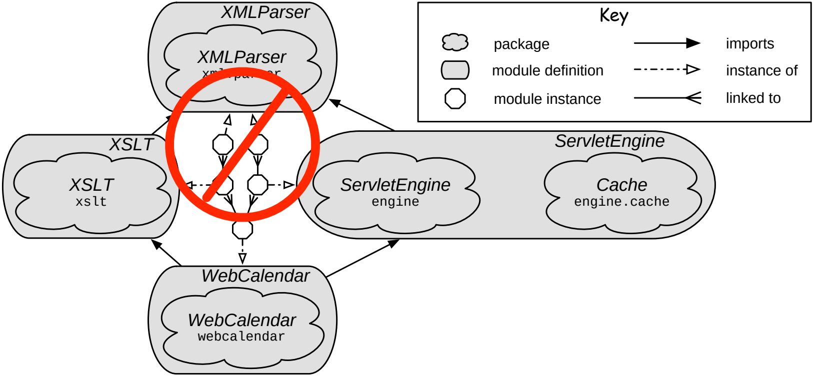
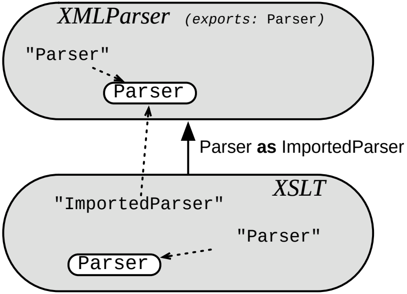
2. only a single instance of each module permitted



improved JAM
(iJAM)

Our proposals to fix JAM's problems

1. adapt class resolution & allow class renaming



superpackage XSLT {
.. **import** XMLParser **with** Parser **as** ImportedParser; ..
}

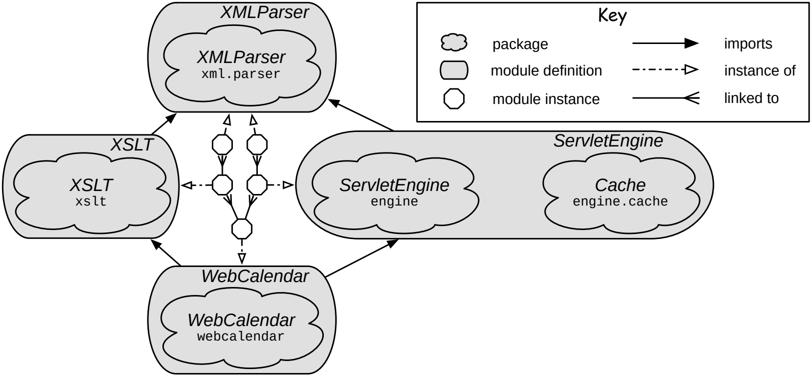
Our proposals to fix JAM's problems

2. allow the user to specify sharing policies

IMPORT OPTION	SHORT DESCRIPTION
import *m*	Uses JAM's default sharing policy. Can be overriden by **replicating** — see below.
import shared *m*	Explicitly requests a shared instance of *m*.
import own *m*	Requests a separate instance of *m*.
import *m* **as** *amn*	Requests an instance (shared under name *amn*).

ANNOTATION	SHORT DESCRIPTION
(no annotation)	Instantiation depends on the importer's policy.
replicating	Default import results in a new instance.
singleton	Always shares a single instance.

Our proposals to fix JAM's problems



replicating superpackage XMLParser {...}

Reviewing desired modularity properties

	ML	Java
abstraction	types, modules	access, interface
composition	inner, functors	inheritance, inner
static reuse	per file	per class (JAR)
dynamic reuse	no	per object
separate compilation	per file	no

	JAM (LJAM)	iJAM
abstraction	[Java], exports	[JAM], renaming
composition	[Java], imports	[JAM], renaming
static reuse	[Java], mod. def.s	[JAM]
dynamic reuse	[Java], forced per module	[Java], optional per module
separate compilation	no*	no*

*SMARTJAVAMOD [FTfJP'05] uses *compositional constraints* [POPL'05] to provide separate compilation for JAM-like modules.

Formalizations & proofs

What we did

- designed & formalized the core of JAM (40% JSR-277 & 80% JSR-294) on top of LJ — obtaining LJAM.
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- proved type soundness (in Isabelle/HOL) for LJ, for LJAM, and for iJAM.
- tools used:

Isabelle	A tool for writing computer-verified maths. (essential for this scale).
Ott	A tool for writing definitions of PLs [ICFP'07]: ASCII source ⟶ LaTeX/Coq/HOL/Isabelle

Why?

- The JAM JSRs are written in English only (+180 pages), including statements like:

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- Subtle bugs are found early.
- When available, one can (dis-)prove properties about the specification.

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An example 'statement reduction' ($config \longrightarrow config'$) rule:

$$\frac{L\,(x) = oid \qquad H\,(oid,\ f\,) = v}{(P,\ L,\ H,\ var = x\,.\,f\ ;\ \overline{s_l}^{\,l}) \longrightarrow (P,\ L\,[var \mapsto v],\ H,\ \overline{s_l}^{\,l})}\ \textsc{R\_FIELD\_READ}$$

Formalization overview

Name	Description	Ott LOD	No. of rules
LJ	an imperative fragment of Java	1381	85
LJAM	formalisation of core JAM	2502	164
iJAM	LJAM with fixes	2671	180

Results

We proved type-soundness for all three formalisations by proving:

Theorem (Progress)

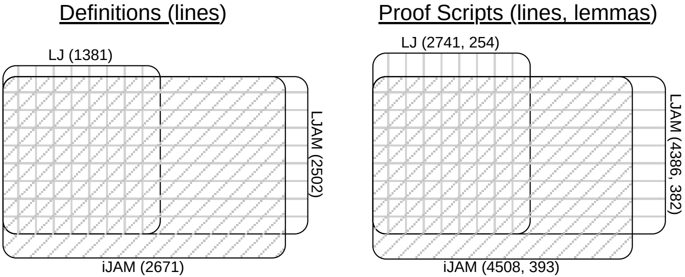
$$\Gamma \vdash (P, L, H, \overline{s}) \ \wedge \ \overline{s} \neq [] \implies \exists \mathit{config}. \ (P, L, H, \overline{s}) \longrightarrow \mathit{config}$$

and

Theorem (Type Preservation)

$$\Gamma \vdash \mathit{config} \wedge (\mathit{config} \longrightarrow \mathit{config}' \vee \mathit{config} \xrightarrow{a} \mathit{config}') \implies \exists \Gamma'. \ \Gamma \subseteq_m \Gamma' \ \wedge \ \Gamma' \vdash \mathit{config}'$$

Definition & proof script reuse



Relative area corresponds to relative number of lines.

Implementation

We wrote a proof-of-concept implementation in Java, which can closely follow the semantics of either LJAM or iJAM.

In particular, we implemented:

- module files (with JavaCC);
- repositories;
- module definitions;
- module instances;
- the module initialization mechanism;
- LJAM's and iJAM's class resolution (with classloaders): *each module is a classloader, which delegates class resolution according to the class lookup semantics.*

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- using the formalization we **found & fixed** some problems;
- this work was completed relatively quickly, on the timescale of language evolution process;
- formalizing real PLs and their updates now seems **feasible** (and **recommended**)!

Future plans

- extract implementation of LJ/LJAM/iJAM from its Isabelle definition;
- apply developed ideas to a large project.

More information

For more information, publications, documentation, definitions, and Java implementation of LJAM/iJAM, see

`http://www.cl.cam.ac.uk/~rs456/`

Papers:

- Strniša, R., Sewell, P., Parkinson, M.: The Java Module System: Core Design and Semantics Definition. In: Proc. of OOPSLA'07
- Strniša, R.: Fixing the Java Module System, in Theory and in Practice. *Submitted to FTfJP'08 (ECOOP).*