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Dependency Management for the Eclipse Ecosystem

Eclipse p2, metadata and resolution

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ABSTRACT
One of the strength of Eclipse, the well-known open platform for software development, is its extensibility made possible by the built-in pluggability mechanisms. However those pluggability mechanisms only reveal their full potential when extensions created by others are made easy to distribute and obtain. The purpose of Eclipse p2 project is to build a platform addressing the challenges of distribution and obtention of Eclipse and its extensions, which posses the same dependency management issues than for component based systems. This paper focuses on the dependency management aspect of p2. It describes the metadata used to express dependencies, the overall functioning of our resolver and a description of our propositional constraints based encoding. To conclude we describe the challenges to address in future releases.

Categories and Subject Descriptors
D.2.7 [Distribution, Maintenance, and Enhancement]: Extensibility; D.2.13 [Reusable Software]: Reusable libraries; F.4.1 [Mathematical Logic]: Logic and constraint programming

General Terms
Algorithms, Design, Experimentation

Keywords
OSGi, dependency management, boolean encoding

1. INTRODUCTION
Eclipse is a very popular open platform mainly written in Java and designed from the ground up as an integration platform for software development tools but also for rich client applications [13]. As the Eclipse ecosystem becomes more and more important, the Eclipse platform itself and the vertical platforms built on Eclipse all rely on the concept of extensibility, and as such the necessity of a mechanism to acquire those extensions is primordial. To that end, almost since its inception, Eclipse featured an extension acquisition mechanism named Update Manager. However over time, as inter plug-in dependencies became more complex and expressed at a finer grain, and more versions of each component was made available, limitations were being discovered in Update Manager which were hindering the adoption and retention of Eclipse. The term “plug-in hell” was coined. It is at that time that we started to work on Eclipse p2 with the goal of building a “right-grained” provisioning platform attempting to address the challenges that Update Manager had been faced with.

One of the first challenge was heterogeneity in the set of things being deployed since over time it had become clear that most OSGi- and Eclipse-based applications needed to have a manageable way to interact with their environment (e.g JRE, Windows registry keys, etc.).

Second was the need to address in one platform the diversity of provisioning scenarios and offer a solution that would work against controlled repositories -similar to the case of linux packages managed by a specific Linux distribution-or uncontrolled repositories, would allow for fully automated solutions or user-driven ones, or would sport the delivery of extensions as well as complete products.

Finally, and the most important challenge, was to solve the “plug-in hell” that was partially rooted in the non modular way of acquiring components since Update Manager forced extensions to be installed by a special abstraction one level above the actual extension itself. The term “right-grained” provisioning is a response to this problem and indicates that p2 is not an obstruction to the granularity of what a user would want to make available or obtain.

In order to achieve this goal of “right-grained” provisioning, the efficiency, reliability and scalability of the dependency resolver was key. Having learnt from our experience of authoring the OSGi runtime resolver for Equinox, it was obvious that we would need to base our dependency analysis mechanism on proven solver techniques. Coincidentally, later that year, the work of OPIUM[16] and EDOS[12] backed up our intuition on the usability and maturity of a SAT-based approach to address the problem. The dependency problem for Eclipse is closer to the problem addressed by the follow-up to EDOS project, the Mancoosi Project[1, 15], that is the problem of updating complex open source en-

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environments. Nevertheless, dependency constraints[3] studied in both cases are significantly different. In this paper we are presenting the p2 metadata and the motivation for some of these constructs, detail the implementation of our resolver and conclude by the challenges we are interested in addressing in future releases.

2. **P2 METADATA**

Core to the majority of installers that deal with composable systems (e.g. RPM, Debian, etc.) lies a concept of metadata. One of the goals of this metadata, and the point of focus of this paper, is to capture the dependencies that exist between the components of the system and thus to find missing dependencies or to validate dependencies of a system before it is being modified. As described previously, p2 is intended to deal with more than just the typical Eclipse constructs of OSGi bundles. As such, despite the presence of dependency information in the OSGi bundles composing most of Eclipse applications, p2 abstracts dependencies from the elements being delivered in an entity called an Installable Unit (also referred to as IU). We now introduce the three kinds of installable units that p2 defines.

### 2.1 Anatomy of an installable unit

An installable unit, the simplest construct, has the following attributes:

<table>
<thead>
<tr>
<th>Greed</th>
<th>Optional</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>true</td>
<td>false</td>
<td>this is a “strong” requirement.</td>
</tr>
<tr>
<td>true</td>
<td>true</td>
<td>this is a “weak” requirement.</td>
</tr>
<tr>
<td>false</td>
<td>true</td>
<td>this is a “weakest” requirement, where the match will not be brought in.</td>
</tr>
<tr>
<td>false</td>
<td>false</td>
<td>this indicates a case where the requirement has to be satisfied but the IU with this requirement wants this to be brought in by another one. Such a need will be presented in 2.3.</td>
</tr>
</tbody>
</table>

Table 1: Greed and optional interaction.

A **singleton flag** This flag, when set to true, will prevent a system to contain another version of the installable unit with the same identifier.

An **update descriptor** The identifier and a version range identifying predecessors to this IU. Making this relationship explicit allows to deal with IUs being renamed or avoid undesirable update paths.

An example of an Installable unit representing the SWT bundle is given in Figure 1. The few things to notice are the usage of namespace to avoid clashes between the Java packages and the IU identifier; the usage of singleton because no two versions of this bundle can be installed in the same eclipse instance; the “typing” of the IU as being a bundle (see namespace org.eclipse.equinox.p2.type valued to bundle); and the identification of the IU by providing a capability in the org.eclipse.equinox.p2.iu namespace.

Now, let’s come back on requirements and detail the semantics of greed and optional. By default, a requirement is “strong” (optional is false, greed is true). This means that the IU can only be installed if the requirement is met. If a “strong” requirement is guarded by a filter that does not pass, the requirement is ignored. When the optional flag is set to true, then a requirement becomes “weak” and it does not have to be satisfied for the IU to be installed. However any IU potentially satisfying this requirement will be considered, and a best effort will be made to satisfy the requirement.

When it comes to greed, this is a rather atypical concept that we have added to control the addition of IUs as part of the potential IUs to install in order to satisfy the user request. When the greed is true (default case, and the case for strong requirements), the IU satisfying the dependencies are added to the pool of potential candidates. However when the greed is set to false, such a requirement relies on other dependencies from its own IU or others to bring in what is necessary for its satisfaction. This is used in Figure 1 to capture the fact that even though we have an optional dependency on org.mozilla.xpcom we don’t want to try to satisfy it eagerly. As such, this optional and non greedy requirement is weaker than a typical optional dependency.

Table 1 reviews the four combinations of greed and optional.

---

1 A version range is expressed by two version number separated by a comma, and surrounded by an angle bracket, meaning value included, or a parenthesis, meaning value excluded.

2 Strong is weaker in our context than the notion of strong dependency introduced in [3]
2.2 Installable unit patch

2.2.1 The need for patches

So far, the concept of IU is pretty much on par with what most package managers are offering. However what is interesting is the different usage we have observed of this metadata and the implication it has on the rest of the system. Indeed, most people building on top of Eclipse are delivering “products” or “subsystems” and as such they want to guarantee that their customer is getting what has been tested. Failing to do this could result in a non stable product, maintenance nightmare and unsatisfied customers. However in an ecosystem where products can be mixed and where repositories can not be used as control points, guaranteeing a functional system is harder. Consequently, to palliate to these possible problems, product producers are using installable units as a grouping mechanism (also referred to as group) serving three goals:

1. Facilitate the reusability of a set of functionality by aggregating under one group a set of installable units.

2. Capture a particular configuration of the system, and thus group under one IU an extensible element and a default implementation.

3. Lock down the dependencies on installable units being used, which limits the variability of what can be installable and thus guarantees reproducibility of an installation independently of the content of the repository.

These three goals are visible in the abridged version of the Platform group shown in Figure 2. It shows the grouping of a set of unrelated functions together to facilitate reuse; how the default setup of the help system is being delivered using the org.eclipse.help.jetty IU\(^3\); and finally the ranges expressed all show the desire to precisely control a particular version of each IU being delivered.

The counter part of the lock down which is used extensively throughout Eclipse, is that it makes the delivery of service (e.g. the replacement of a particular IU by another one) complex for the following reasons:

1. Products are often made of groups, themselves recursively composed of other groups (in the Figure 2, the Platform group includes the RCP group), which can

\(^3\) Controlled repository is the approach taken by a majority of linux distributions.

\(^4\) The Eclipse help system allows different web-servers to be used.

2. Not all groups deployed on the user’s machine are in the control of the same organization. For example, someone can be running a composition of IBM and Artois University products (both including the Eclipse Platform group), but the Platform group is controlled by the Eclipse open source community. Therefore when the Platform team needs to deliver a fix to a user, it simply can not require all the referring groups to be updated.

3. Not all the dependencies onto a particular IU are known ahead of time.

2.2.2 Anatomy of an Installation Unit Patch

To palliate to these problems, p2 provides the concept of installable unit patch (referred to as patch). The simplest way to think of a patch is as a mechanism that can reach into any IU and change any requirement. A patch is a regular installable unit to which three concepts have been added:

Requirement change It represents the changes made to installable units. It is a set of requirement pairs where each pair represents a rewriting rule. In the rewriting rule, the left part captures the original requirement that needs to be replaced and the right part captures the resulting requirement. No constraints are applied to the capturing requirement or the new value, the replacement could widen the range, or narrow it, or completely change the requirement (e.g. remove a filter, change optionality, etc.). In order to provide flexibility, the capturing requirement applies on an original requirement if the ranges expressed on the two requirements intersect.

Applicability scope It identifies the installable units to which the patch should be applied. It has enough flexibility to patch all the IUs of the system where a requirement change is applicable, or target just a few IUs. The IUs to patch are identified by requirements.

Lifecycle It indicates when the installable unit patch can be applied. This can be seen as a precondition that has to be satisfied for the patch to be applied. It represents the “when” to apply the patch whereas the applicability scope represents the “what” to patch. It takes the form of a non greedy requirement.

---

Figure 1: An IU representing the SWT bundle
The example in Figure 3 shows a patch replacing the IUs org.eclipse.ant.core and org.eclipse.ant.ui. This patch will only try to replace the references to these two IUs from the Platform group (see applicability scope) and will only be applied if the my.product IU is installed.

We have shown how installable unit patches avoid a large ripple-on change across metadata by “rewriting” requirements and also how updates to an IU could be delivered without knowing all the dependencies on it. Given the alteration possibilities, another possible use of patches is to add or remove dependencies in an installable unit you would want to reuse but had unsatisfactory dependencies.

2.3 Installable unit fragment

The third and last concept of p2 metadata is the installable unit fragment. This concept inspired from the OSGi fragment concept [2] aims at providing a mechanism to augment an installable unit by adding to it properties or configuration information. The need for this stems from the desire to make installable units as reusable as possible and thus to extract out of an installable unit the configuration information that would otherwise bind it to a particular environment. The canonical example of this is how p2 chose to handle the delivery of OSGi start levels. Some of the OSGi bundles delivered by p2 need to be configured with an information indicating when they can be started. Because the IU for OSGi bundles can be reused in different applications with different configuration needs, they can not carry the start level information so that information is separated out into an installable unit fragment. This fragment is then attached to the IU(s) it is augmenting (referred to as host) at resolution time and treated as part of the host during the installation. Fragments also offer the ability to attach to several IUs and thus deliver default configuration information to all of them, thus reducing the configuration burden.

An installable unit fragment augments the concept of installable unit by adding the concept of host requirement. This identifies the host or hosts to which the fragment applies and is expressed by a set of requirements. These requirements have to be satisfied for the fragment to be installable.

What is interesting in the expression of host requirement is the importance of the concept of greed, especially when dealing with a fragment delivering default configuration information. Indeed, in those cases, even though you have a fragment that can apply to multiple IUs does not mean that you want to install all the IUs to which it applies. To illustrate this, the host requirement is set to be non greedy. This is the case described in the fourth line of Table 1. It is used in Eclipse by the IU fragment responsible for the delivery of the default start level to every OSGi bundles installed in the system (see Figure 4). To perform its job, the host requirement of this fragment requires “IUs that are bundles” (namespace=org.eclipse.equinox.p2.iu, name=org.eclipse.platform.feature.group, range=(3.4.0, 3.5.0.v2009))

Figure 2: An IU representing the Platform subsystem of Eclipse
slice) that could potentially be part of the final solution of the resolution process by consulting all repositories also passed in. This transitive closure is done with only taking into account enough context\footnote{The context can be seen as a map of key/value pair} to evaluate the various filters but without worrying if any IU being added could be colliding with any others. For each IU, it looks at each requirement, queries the repositories for matches, and add the results of the query to a set of IU to process. In the case of fragment IUs, the host requirement is also treated and for patches the replacement value contained in the requirement changes are as well. If the requirement greed is set to false, or if the requirement enablement filter is not evaluating true, the process is short-circuited and the next requirement is considered. The slicing phase reduces the dependency problem to the only IUs applicable to a root the corresponding variable in the SAT encoding is set to true to capture the intent of the solution being searched. The generation of the propositional constraints completed, the optimization function is being generated.

**PBO-solving** The result of the projection is passed to the pseudo boolean solver SAT4J\cite{10} which is responsible for finding an assignment.

**Solution extraction** From the assignment returned by the solver, a solution is extracted and the final attachment of IU fragment to their host(s) is concretized. In case of failure the solver is invoked to produce an explanation (see section 4.4).

### 3.2 Updating

In p2, the detection and installation of all applicable updates is not a completely automated process and no simple function in the p2 API is provided to perform this operation. Instead, the only mechanism provided is a function which given a root IU and a set of repositories returns a set of candidates IUs that are updates of the given IU\footnote{Each candidate has its update descriptor match the IU it is an update of.}. This allows for selectively searching for updates or looking for an update of everything that is installed. Once all the candidates have been gathered, a subset of the matches are picked and a change request is created and passed to the resolver for validation. Because p2 is a platform, the picking responsibility is left to code outside of the scope of the core of p2. For example, the graphical interface available in the Eclipse
SDK performs filtering and the user is only presented with the most recent version of each IU to select from. The user input obtained, a corresponding profile change request is created and passed to the resolver for validation.

The obvious drawback of this approach is that the user may have to go through several iterations of selection to find a suitable alignment of IUs to update to. However, even if p2 could provide some logic to return the most pertinent and up-to-date set of IUs using techniques like MAX-SAT [4], the results would only be relevant in case of a completely automated update mechanism, since giving the opportunity to the user to pick something from the set of updates available could invalidate the solution initially returned and thus potentially lead to similar problems.

4. CONSTRAINTS ENCODING

In the following, we describe the encoding of p2 installation problem into propositional constraints, i.e. clauses or cardinality constraints. We also provide some examples of problems generated with that encoding.

prov(IU) denotes the set of capabilities provided by the installable unit IU and req(IU) denotes the set of capabilities required by the installable unit IU. alt(cap) = {IU|cap ∈ prov(IU)} denotes the set of IUs providing a given capability. Finally, optReq(IU) denotes the optional requirements of a given IU, and versions(IU) denote the ordered set of IUs sharing the same identifier as IU but having different version attribute (IU ∈ versions(IU)), from the latest to the oldest.

4.1 Basic encoding

Each requirement of the form “IU is requires capability cap” is represented by a simple binary (Horn) clause

\[ IU_i \rightarrow cap_j \]

So, for each IU, the requirements are expressed by a conjunction of binary clauses

\[ \bigwedge_{cap_j \in req(IU_i)} IU_i \rightarrow cap_j \]

The alternatives for a given capability is given by the clause

\[ cap_i \rightarrow IU_{j1} \lor IU_{j2} \lor \ldots \lor IU_{jn} \]

where IUjn ∈ alt(capip).

Since we are only interested in the IUs to install, the above two constraints can be aggregated into a conjunction of constraints:

\[ f(IU_i) = \bigwedge_{cap_j \in req(IU_i)} (IU_i \rightarrow \bigvee_{IU \in alt(cap)} IU) \]

Note that there is the specific case of alt(capip) = ∅ which means that IU cannot be installed due to missing requirements. In that case, the unit clause ¬IU is generated.

Some installation units cannot be installed together (e.g. because of the singleton attribute set to true). This can be modeled either with a conjunction of binary negative clauses

\[ \bigwedge_{versions(IU) = \{IU_1, \ldots, IU_n\}, 1 \leq i < j \leq n} (\neg IU_i \lor \neg IU_j) \]

or equivalently with a single cardinality constraint:

\[ \sum_{IU \in versions(IU)} IU \leq 1 \]

We use the second option because our solver manages those constraints natively and because it makes the explanation support easier to implement (see 4.4 for details).

Finally, the user wants to install the installable units identified by the roots. This is modeled with unit clauses:

\[ \bigwedge_{IU_i \in rootIU} IU_i \]

Summing up, the constraints (1), (2) and (3) altogether form an instance of a classical NP-complete SAT problem. That encoding is basically the encoding presented in Edos[12] and Opium [16] and used more recently in OpenSuse 11.10.

4.2 Encoding of optionality

One of the specificity of p2 is the semantic of “weak” dependencies expressed using the greed and optional attributes. We do not have to worry here about greedy dependencies since there are simply ignored during the slicing stage. An IU IU may have optional dependencies to IU IU means that IU is not mandatory to use IU, so IU can be installed successfully if IU is not available. However, it is expected that p2 should favor the installation of optional packages if possible, i.e. that all optional packages that could be installed are indeed installed. In Figure 1, one can see that SWT has two optional dependencies on SWT accessibility2 and Mozilla XPCOM. The encoding of optional packages is done by creating two specific propositional variables: Optcap denotes the fact the capability cap is optional, and NoopIU is a variable to be satisfied in case none of the optional capabilities of IU can be installed. The first set of constraints expresses how to satisfy the required capabilities:

\[ \bigwedge_{cap_j \in optReq(IU_i)} (Optcap \rightarrow \bigvee_{IU \in alt(cap)} IU) \]

The second set of constraints expresses that if NoopIU is true then all the abstract capability variables must be false, i.e. that NoopIU can only be set to true when none of the optional dependencies could be installed.

\[ \bigwedge_{cap_j \in optReq(IU_i)} (NoopIU \rightarrow \neg Optcap) \]

Note that such set of constraints could also have been expressed equivalently by a single pseudo boolean constraint:

\[ \sum_{cap \in optReq(IU_i)} Optcap + n \times NoopIU \leq n \]

where \( n = |optReq(IU_i)| \).

We used the first option in our encoding since it looked easier to understand. The second option could be used in order to reduce the number of constraints used in the solver. Contrariwise to the encoding of the singleton attribute, there is no need to use a single constraint here because optionality

\[ http://en.opensuse.org/Package_Management/Sat_Solver/Basics \]
encoding constraints cannot prevent an IU to be installed, thus cannot be part of an explanation.

Finally, we express that \( IU_i \) has optional dependencies using a disjunction ending with the \( Noop_{IU_i} \) variable. That way, even if none of the optional requirements can be installed, the constraint can still be satisfied by setting \( Noop_{IU_i} \) to true.

\[
IU_i \rightarrow \bigvee_{\text{cap} \in \text{optReq}(IU_i)} \text{Abs}_{\text{cap}} \lor \text{Noop}_{IU_i}
\]

Example 1. Let’s see how to encode the optional dependencies of SWT on accessibility and xpcom shown in Figure 1:

\[
\begin{align*}
\text{Abs}_{\text{accessibility}} & \rightarrow IU_1^0 \\
\neg \text{Abs}_{\text{accessibility}} & \lor \neg \text{Noop}_{IU_{SWT}} \\
\text{Abs}_{\text{xpcom}} & \rightarrow IU_2^0 \\
\neg \text{Abs}_{\text{xpcom}} & \lor \neg \text{Noop}_{IU_{SWT}} \\
IU_{SWT} & \rightarrow \text{Abs}_{\text{accessibility}} \lor \text{Abs}_{\text{xpcom}} \lor \text{Noop}_{IU_{SWT}}
\end{align*}
\]

An alternative encoding would be:

\[
\begin{align*}
\text{Abs}_{\text{accessibility}} & \rightarrow IU_1^0 \\
\text{Abs}_{\text{xpcom}} & \rightarrow IU_2^0 \\
\neg \text{Abs}_{\text{accessibility}} & \lor \neg \text{Abs}_{\text{xpcom}} \\
IU_{SWT} & \rightarrow \text{Abs}_{\text{accessibility}} \lor \text{Abs}_{\text{xpcom}} \lor \text{Noop}_{IU_{SWT}}
\end{align*}
\]

That encoding of optionality was the original one that shipped with Eclipse 3.4. The encoding has evolved since then. This will be discussed in section 4.5.

4.3 Encoding of patches

Applying a patch from the encoding point of view only applies to requirements changes (see section 2.2), it means to enable or disable some dependencies according to the application or not of a given patch. We denote by \( patchedReqs(IU, p) \) the set of pairs \( < \text{old}, \text{new} > \) of the installable unit \( IU \) denoting the rewriting rules of patch \( p \) in the requirements of \( IU \).

We associate to each patch a new propositional variable. We introduce that variable in dependency constraints (1) and (4) the following way:

- Negatively when the patch introduces a new dependency.
- Positively when the patch removes an existing dependency.

It can be summarize that way:

\[
\bigwedge_{<\text{old}, \text{new}> \in \text{patchedReqs}(IU, p)} (p \rightarrow \text{encode}(\text{new})) \land (\text{encode}(\text{old}) \lor p)
\]

where \( \text{encode}(x) \) denote the encoding of a regular or an optional dependency. The patch encoding changes only the encoding of the requirements affected by a patch.

Example 2. The patch shown in Figure 3 would lead to the following encoding of the dependencies for the IU Platform:

\[
\begin{align*}
IU_{\text{Platform}} & \rightarrow IU_{\text{ant-core}}^{3.1.0} \lor \text{patch} \\
\text{patch} \land IU_{\text{Platform}} & \rightarrow IU_{\text{ant-core}}^{3.4.3} \\
IU_{\text{Platform}} & \rightarrow IU_{\text{ant-ui}}^{1.0.0} \lor \text{patch} \\
\text{patch} \land IU_{\text{Platform}} & \rightarrow IU_{\text{ant-ui}}^{3.1.0} \\
IU_{\text{Platform}} & \rightarrow IU_{\text{help}}^{4.0} \\
IU_{\text{Platform}} & \rightarrow IU_{\text{jetty}}^{4.0} \\
IU_{\text{Platform}} & \rightarrow IU_{\text{rcp}}^{3.1}
\end{align*}
\]

If the patch is enabled (i.e. the propositional variable patch is set to true) then the initial constraints (a) are disabled while the new dependencies (b) are enabled. If the patch is not enabled (i.e. the propositional variable patch is set to false), then the new dependencies (b) are disabled and the original optional dependencies (a) apply. Note that the requirements untouched by the patch (c) do not see their encoding changed.

4.4 When things go wrong: explanation

Explanation is key to help the user understands why a change request cannot be fulfilled. In the above encoding, one can note that there are only two reasons that could prevent a request to succeed:

- At least one of the required IUs is missing.
- The request requires two IUs sharing the same identifier but with different versions that cannot be installed together due to the singleton attribute on at least one of those IUs (see for instance Figure 5).

As a consequence, it is not hard to check why a request cannot be completed. However users expect the explanation to be returned in terms of IUs they know about, the root IUs and the IUs that they are trying to install, and would be confused if provided with just the low level dependency errors. In practice, it means that knowing why a problem occurred is not sufficient. It is important to be able to detail the whole dependencies from the root to the actual cause of the problem. For instance, in Figure 5, the user cannot install the Eclipse Platform IU version 3.5.0.20090528 because the Eclipse SDK version 3.5.0.20090430 is already installed and both of them rely on different versions of Eclipse RCP that is a singleton.

Let \( S \) be the set of the constraints encoding presented in the previous sections. From a logical point of view, it is possible to compute one minimal subset \( S' \) of the constraints that cannot be satisfied altogether: \( S' \subseteq S, S' \models \bot, \forall S'' \subseteq S\, S'' \models \bot \). Such set of constraints is often called a MUS (minimal unsatisfiable subformula). \( S' \) is an explanation of the impossibility to fulfill the request. If the subset contains a negated literal (specific case of Equation (1), \( \neg IU_x \in S' \)) then the global explanation is a missing requirement, i.e. the request cannot be completed because \( IU_x \) cannot be found in the user’s repositories. If the subset contains a cardinality constraints (\( \sum IU_v \leq 1 \in S' \)), then the global explanation is a singleton attribute violation, i.e. the request cannot be completed because it requires several versions of \( IU_v \). Note that if we decided to use a clausal encoding instead of the cardinality constraints encoding, we would have lost the one to one mapping between the original dependencies and the constraints of our encoding.

There are several ways in practice to compute \( S' \) from \( S \). The ones based on local search algorithms[14] detect constraints that are likely to be part of \( S' \) among the most falsified ones during the search and compute \( S' \) in a second step using a complete SAT solver. A more recent and widely used approach is based on the analysis of the last conflict found by a conflict driven SAT solver[17]. Such approach requires some changes in the SAT solver to keep track of all resolutions steps and does not ensure that the computed subset \( S'' \subseteq S \) is minimal. A third approach is to rely on a new encoding of the problem into an optimization problem
using selector variables \([11]\): it is possible to use an optimization function on selector variables to compute a set \(S'\) of minimal size. Finally, a generic approach to explanation in constraints solvers was proposed in \([9]\) and implemented in Ilog solver: QuickXplain. The main advantage of such approach is to be independent of the underlying solver, and to work with any kind of constraints.

Our approach inherits some ideas from all those approaches. We decided to implement the QuickXplain algorithm in our framework because it is non intrusive (does not require any change to the solver) and works perfectly with mixed constraints (clauses and cardinality constraints in our case). We use selector variables in our encoding to allow the QuickXplain algorithm to enable/disable the constraints when computing \(S'\). Finally, the constraints given to the QuickXplain algorithm are ordered in decreasing order of their activity in the spirit of the local search approaches.

More precisely, we translate \(S\) into \(S'\) by adding a new selector variable \(sel_i\) to each constraint in \(S\): \(S' = \{ sel_i \lor s_i \mid s_i \in S \}\). Let \(SEL\) denotes the set of all added selector variables. Instead of looking for an assignment satisfying \(S\), we are looking for an assignment satisfying \(S'\) under the assumption that all variables in \(SEL\) are set to false, \(S'' = S' \land \neg \exists_{sel \in SEL} sel\).\(^{11}\) If such assignment exists, it is an assignment satisfying \(S\), so we are done. If it is not the case, then we use a tailored version of the QuickXplain algorithm that makes use of the selector variables to enable/disable constraints in order to compute \(S'\).

### 4.5 From decision to optimisation

When all the constraints can be satisfied, there are usually many possible solutions, that are not of equal quality for the end user. Here are a few remarks regarding the quality of the expected solution:

1. An IU should not be installed if there is no dependency to it.
2. If several versions of the same bundle exist, the latest one should preferably be used.
3. When optional requirements exist, the optional requirements should be satisfied as much as possible.
4. User installed patches should be applied independently of the consequences of its application (i.e. the version of the IUs forced, the number of installable optional dependencies, etc.).

We are now looking for the “best” solution, not just any solution, i.e. we moved from providing a certificate for the answer to a decision problem (NP-complete from a complexity theory point of view) to return the solution of an optimization problem (NP-hard). Furthermore, we need to solve a multi-criteria optimization problem since it is likely that several IUs do have optional requirements and that several IUs are available in multiple versions.

To solve our problem, we build a linear optimization function to minimize in which the propositional variables are either given a penalty (positive integer) or a reward (negative integer) to prevent or favor their appearance in the computed assignment.

\(^{11}\)Assumption based satisfiability testing is available in all Minisat\([7]\) inspired solvers (including SAT4J).

- Each version of an IU gets a penalty as a power of 2 proportional to its age, the older it is the more penalized it is:
  \[
  \sum_{IU_v \in \text{versions}(IU_v)} 2^i \times IU_v^i 
  \]
  That way, each installation of an IU raises at least a penalty equals to one, thus expressing that only required IUs should be installed.

- Each \(Noop_i\) variable gets a penalty to favor the installation of optional IU.
  \[
  \sum 2^K \times Noop_i 
  \]
  where \(K\) is a constant such that \(2^K\) is greater than the maximum penalty for a version (i.e. \(K > \max(|\text{versions}(IU_v)|)\)).

- Each \(Abs_e\) variable gets a reward to favor the installation of optional dependencies
  \[
  \sum -2^{K+1} \times Abs_e 
  \]

- Each \(patch\) variable gets a reward of \(n \times -2^{K+3}\) if it is applicable (where \(n\) denotes the number of applicable patches), else a penalty of \(2^{K+1} + 2^{K+2}\)
  \[
  \sum_{p_i \in \text{applicablePatches}()} n \times -2^{K+3} p_i + \sum_{p_i \notin \text{applicablePatches}()} 2^{K+2} p_i 
  \]

The objective function of our optimization problem is thus to minimize \((7) + (8) + (9) + (10)\). The weights in \((7)\) are not satisfactory since they do not provide a total order on the final solution. Suppose that we have two IUs \(IU_a\) and \(IU_b\) that are available in respectively 3 and 2 versions (namely \(IU_{a_1}, IU_{a_2}, IU_{a_3}\) and \(IU_{b_1}, IU_{b_2}\)). The objective function for those IUs is thus

\[
IU_{a_1}^3 + 2 \times IU_{a_2}^2 + 4 \times IU_{a_3}^1 + IU_{b_1}^3 + 2 \times IU_{b_2}^1 
\]

The best solution for such objective function if both \(IU_a\) and \(IU_b\) must be installed is obviously to install \(IU_{a_1}\) and \(IU_{b_1}\). However, if those two IUs cannot be installed together, the solver will answer that the best option is either to install \(IU_{a_1}\) or \(IU_{b_1}\) or \(IU_{a_2}\) and \(IU_{b_2}\).

The common approach to solve this problem is to rank each IUs in a total order, \(IU_1 < IU_2 < \ldots < IU_m\), meaning that \(IU_i\) is more important than \(IU_j\) if \(IU_j < IU_i\). Then the coefficients of the optimization function should be generated in such a way that the sum of the coefficients of \(IU_j\) should be smaller than the smallest coefficient of \(IU_i\). In our example, it would mean for instance to use the following optimization function:

\[
IU_{a_1}^3 + 2 \times IU_{a_2}^2 + 4 \times IU_{a_3}^1 + 8 \times IU_{b_1}^2 + 16 \times IU_{b_2}^1 
\]

In that case, the best option is still to install \(IU_{a_1}\) and \(IU_{b_1}\), but the second best option is to install \(IU_{a_2}\) and \(IU_{b_2}\).

Unfortunately, as noted before, we are in the context of uncontrolled repositories, so there is no obvious/easy way to order the IUs in a total order, so it was decided to keep the initial solution \((7)\) instead of ranking arbitrarily the IUs.

Another drawback of our objective function appeared recently when new IUs got added to the release repository. The part \((9)\) of the optimization function has the undesirable effect to favor the installation of optional requirements
Cannot complete the install because of a conflicting dependency.
Software being installed: org.eclipse.platform.sdk 3.5.0.I20090528
Software currently installed: org.eclipse.sdk.ide 3.5.0.I20090430
Only one of the following can be installed at once:
  org.eclipse.rcp.configuration_root.gtk.linux.x86 1.0.0.I20090430
  org.eclipse.rcp.configuration_root.gtk.linux.x86 1.0.0.I20090528
Cannot satisfy dependency:
  From: org.eclipse.platform.sdk 3.5.0.I20090430-2300
  To: org.eclipse.rcp.configuration_root.gtk.linux.x86 [1.0.0.I20090430]
  From: org.eclipse.rcp.configuration.feature.group 1.0.0.I20090528
  To: org.eclipse.rcp.configuration_root.gtk.linux.x86 [1.0.0.I20090528]
  From: org.eclipse.sdk.ide 3.5.0.I20090430-2300
  To: org.eclipse.rcp.configuration.feature.group [1.0.0.I20090528]

Figure 5: Example of explanation

of an IU even if such IU is not installed. A contextualization
of the reward is necessary to fix such problem:

In the constraints our first solution to this problem has
been to contextualize (4):

\[\bigwedge_{cap_j \in \text{opt Req}(IU_i)} (Abs_{cap_j} \land IU_i \Rightarrow \bigvee_{IU_z \in \text{alt}(cap_j)} IU_z)\] (11)

That way, the variable \(Abs_{IU_i}\) can be forced to true
by the objective function but it will not fire the in-
stallation of the dependencies if the \(IU_i\) is not to be
installed. However, that solution has an unexpected
behavior in the following test case: suppose that \(IU_a\)
has an optional dependency on capability \(b\) provided
by \(IU_b\) that has in turn an optional dependency on
the capability \(c\) provided by \(IU_c\) for which we have
\(\text{alt}(IU_c) = \emptyset\). We would generate the following constraints:

\[
\begin{align*}
Abs_c \land IU_b & \Rightarrow \bot \equiv \neg Abs_c \lor \neg IU_b \\
Abs_b \land IU_a & \Rightarrow IU_b \\
IU_a & \Rightarrow IU_b \lor \text{Noop}_{IU_a}
\end{align*}
\] (a)

Since we would like to satisfy as many \(Abs_c\) variables
as possible, the solver would force \(Abs_c\) and \(Abs_b\)
 to be set to true. As a consequence, \(IU_b\) has to be set
to false to satisfy (a). This is possible because the de-
pendency to \(IU_b\) is optional, else a strong dependency
would force \(IU_b\) to be set to true. Such unexpected
behavior is a direct consequence of changing the con-
straints because of a wrong behavior of the objective
function. The fix should not change the constraints
but the objective function itself.

In the objective function The other option is to use a
non linear optimization function in our problem, i.e.
to make the reward a function of both the abstract
variable \(Abs_{cap_j}\) and \(IU_j\) where \(cap_j \in \text{opt Req}(IU_j)\):

\[\sum_{j} -2^{K+1} \times Abs_{cap_j} \times IU_j\] (12)

The problem is that our solver does not propose yet an
easy way to work with non linear optimization func-
tions. A solution based on the introduction of new
variables \(y_k \leftrightarrow Abs_{cap_j} \times IU_j\) where \(y_k\) replaces \(Abs_{cap_j} \times IU_j\) in the objective function and with the additional
constraints \(y_k \rightarrow Abs_{cap_j} \lor IU_j, Abs_{cap_j} \rightarrow y_k, IU_j \rightarrow y_k\) should fix that issue.

That last issue was discovered late in the release cycle of
Eclipse 3.5 Galileo. Considering the fact that meeting the
scenario of the issue of the first option was less likely than
introducing a new issue by integrating a barely untested
implementation of the second option in SAT4J, the former
has been adopted for Eclipse 3.5.

5. CONCLUSION AND PERSPECTIVE

We presented Eclipse p2, a “right-grained” provisioning
platform aimed at solving the diversity of provisioning re-
quirements in a componentized world. We focused on pre-
senting the three metadata constructs which allow the as-
bsemble of complex products from components:

- Installable unit, to capture dependencies among com-
  ponent at their lowest level, but also to capture lock
downs and ease reusability by grouping;
- Installable unit patch, to tweak dependencies of instal-
lable units that can’t be changed;
- Installable unit fragment, to “augment” an installable
  unit and as such allow for installable units to be as
  reusable as possible by staying context free from their
  used one deployed.

From there we presented the overall functioning of our re-
 resolver and gave a description of our SAT-based encoding
that is resolved by the SAT4J Pseudo Boolean solver.

We can report that this approach that has been live for more
than one year has proven to be reliable, efficient and scal-
able even when faced with repositories containing more
than 10000 installable units and solution involving about 3000
 installable units. Furthermore, a direct consequence of our
work is the integration of the very same technology to man-
age dependencies in other Java related products, namely the
upcoming major release of Maven (Maven3) and the reposit-
ory manager Nexus.
That said, we are looking to further improve the metadata and the resolver to facilitate composition and to address the challenges encountered so far. For the metadata, the main changes we want to investigate are:

1. The ability for the line-up information that is usually expressed in groups to be extracted out into a new kind of installable units. Once extracted, this information would no longer be directly encoded as propositional constraints but would instead be used to drive the optimization function. We hope that such a change would facilitate the serviceability by avoiding the need to create patches, but the biggest challenge with this feature would be composability of several of these new IUs.

2. The ability to express capabilities and requirements on other domains than just version and version ranges. For example we are thinking about adding scalars to describe the amount of memory available.

3. Add negation and disjunction to improve the expressiveness of the requirements.

On the resolver, the main changes planned surround:

1. Stability of resolution to not cause updates of IUs that are not directly related to the change request being performed. The canonical example is where requirements toward an IU tolerate several possibilities and the installation of something new cause the update of the IU because a newer version is available in the repositories. We hope that the concept of line-up previously described will help here.

2. Resolution over a set of profiles, in order to perform the coordinated management of several applications meant to work together (e.g. the client needs to be in sync with the server).

3. Speed up the explanation process. Depending on the size of the set of constraints, it can take several minutes to provide the answer which is not ideal in an interactive tool. This is caused by the \( n \times \log(n) \) satisfiability tests used by the explanation algorithm used (QuickXplain) where \( n \) is the size of the input of the algorithm in number of constraints. \( n \) can be as big as the number of constraints in the encoding in the worst case. The idea is to ask more information to the SAT solver instead of using a purely external approach as currently in order to minimize \( n \) in the spirit of [6, 5].

6. REFERENCES