This paper introduces CONFIGEN, a tool that helps modularizing software. CONFIGEN allows the developer to select a set of elementary components for his software through an interactive interface. Configuration files for use by C/assembly code and Makefiles are then automatically generated, and we successfully used it as a helper tool for complex system software refactoring. CONFIGEN is based on propositional logic, and its implementation faces hard theoretical problems.

1 Introduction

A good way to build secure systems is the top-down approach, where each step refines the software towards the final implementation. The result is well-integrated, but quite monolithic. Consequently, further extensions often lead to an overuse of preprocessor conditionals and some code duplication. It is then important to refactor and modularize the code, with the goal of increasing maintainability and code reuse.

We are trying to apply this process to the implementation of the OASIS [9] kernel, an execution support for hard real-time safety critical applications. Modularizing this software has specific requirements. First, the configuration has to be chosen at compile-time (in particular, qualification for use in safety-critical environments requires that no dead code remains in the system). Second, modularity should not impact the degree of performance, in terms of execution time and memory footprint (for instance, modularity should not imply new indirections, like C++ virtual method tables). Thus, the tool should allow the static selection of a subset of the code in order to implement a specific behavior.

CONFIGEN is the tool we built to that end. It is composed of two main parts. The first one is an interactive tool that helps selecting correct software options with respect to the dependencies between the modules, and is based on propositional logic. The second part builds the source code following the set of selected options.

The paper is divided as follow. Section 2 explains the concepts and goals of CONFIGEN. Section 3 provides a set of good practice rules with concrete examples on how to use CONFIGEN, as well as our experience using it with the OASIS kernel [9]. Section 4 presents our current prototype, and the theoretical problems of its core component, the logic solver. Section 5 presents related works, and section 6 concludes.

2 The CONFIGEN approach

2.1 Configuration options

CONFIGEN operates on configuration options, rather than on modules. A module is a part of the code which, when associated with its dependencies, is “self-containing”, and often has a defined meaning that depends on the language (e.g. Java classes, ML modules, C functions and files). Configuration options
represent arbitrary pieces of code, which encompass the notion of modules, and are thus more general: it can span from several lines of code inside a function to a large set of modules.

Formally, a configuration option is a couple \((v, s_v)\) of a boolean variable \(v\) and a code selector \(s_v\). \(v\) is true when the functionality is present, and false otherwise. The code selector \(s_v\) is a function that, given a value of \(v\) and a code \(c\) (a sequence of characters), returns a subsequence of \(c\). A concrete implementation of this function is the use of the C preprocessor to eliminate conditional code (see section 2.3.2). Another one is selection in a Makefile of a subset of the files to compile or link (section 2.3.3).

\textsc{Configure} operates on closed systems, i.e. all the code and configuration options are assumed to be known when the system is built. This is a requirement of the “static configuration” approach.

Once the values for all configuration options \(v\) have been chosen, the configured code can be obtained by applying all the \(s_v\) to the original code.

### 2.2 Relations between configuration options

#### 2.2.1 Basic operators

Two operators are defined to describe all dependency relations between configuration options in the system:

- The dependency operator, \(a \Rightarrow b\), means that the configuration option \(a\) can only be present if \(b\) is present. It is equal to the standard boolean logic implication operator (also written \(\Rightarrow\)).
- The interface/implementations operator, written \(a : i_1 \mid i_2 \mid \ldots \mid i_n\), means two things:
  1. if the interface \(a\) is false, then all of the implementations \(i_1 \ldots i_n\) are false;
  2. if \(a\) is true, exactly one of \(i_1, i_2, \ldots, i_n\) is true.

The interface/implementation operator can be expressed by the following logical formula:

\[
\left( \neg a \land \bigwedge_{1 \leq k \leq n} \neg i_k \right) \lor \left( a \land \bigvee_{1 \leq k \leq n} \left[ i_k \land \left( \bigwedge_{l \neq k} \neg i_l \right) \right] \right)
\]

In fact, only this last operator is formally needed, because it is functionally complete\(^1\). But the use of the dependency operator makes things simpler for both the user and the logic simplifier.

In our system the complete relationship between the configuration options can be written as a conjunction of formulas which either use the interface/implementation operator on several literals, or the dependency operator on two literals. For convenience, we also allow the use of the \(\land\) operator on the right side of a \(\Rightarrow\) operator. Other operators may be added in the future, but as of now, we do not believe that \(\neg\) or \(\lor\) are useful operators. We believe that restricting the number of operators is simpler for the developer and encourages good software practices, as described in section \(^3\).

#### 2.2.2 Textual and graphical representation

One of the main interests of using only these two operators is that they allow nice textual and graphical interfaces. In \textsc{Configure}, the user specifies its dependencies in a special “\texttt{deps}” file, whose core\(^2\) BNF is simple:

\(^1\)Proof: \(\neg x \equiv (x : x|x), 0 \equiv (\neg x : x|x), x \land y \equiv (0 : (\neg x \neg y))\)

\(^2\)The complete BNF allows some extensions, as seen sections 2.3.3 and 3.2
Each id represents a configuration option (i.e. a boolean variable), and lines can either express a dependency relation or an interface/implementation relation. The whole program relation is the conjunction of the relations in each line. Figure 1(a) presents an example of this textual representation.

The relations between configuration options using our operator also admits a nice graphical representation. This representation is a graph where nodes represent configuration options, and arrows dependency relations. An interface is a box that encloses its implementations.

Figure 1(b) gives an example on how the scheduler part of our kernel can be modularized. The microkernel can run on three different embedded platform, with ARM, PowerPC, or S12XE processors. ARM and PowerPC both have a LL/SC (load-linked/store conditional) instruction, S12XE and PowerPC provide hardware spinlocks. Note that spinlocks can also be implemented using LL/SC. At last, the scheduler depends on two subsystems, to handle the current clock and a list of contexts, for which two versions exist: one that uses spinlocks, and one that uses LL/SC instruction.

Colors represent valuation of boolean variables, as described in the following section. The interactive solver is described in details in section 4.2.

2.3 Tools and integration with the development environment

2.3.1 The configuration selector

A configuration is the assignment of a truth value to all configuration options. The most important requirement for a configuration is to be correct, i.e. that all the relations between configuration options are satisfied. It is fairly easy to write a program that checks that a given configuration is correct.

But such manual writing of a configuration would be tedious for the user, all the more because our method encourages using many configuration options (see section 3.4). Moreover, most options can be automatically constrained.

This explains why the configuration selector is necessary. Figure 1(b) is a part of a screenshot of our tool. Its interface is simple: clicking on a node switches the valuation of the corresponding options between “enforce true” (dark green), “enforce false” (dark red), and “unenforced”. Unenforced options can be in different states: “implied true” (light green), meaning that all correct configurations require the option to be true; “implied false” (light red), meaning that all correct configurations require the option to be false; and “normal” (gray), meaning that there exists correct configuration options where the option is true and others where the option is false. The tool warns the user when the enforced values are impossible to satisfy, and allows saving the configuration when every option has been assigned a value.

In the example, the user has explicitly expressed that he wants the sched and arm configuration options to be true (in dark green). Had the S12XE platform been selected instead of the ARM one, the configuration would be complete, i.e. every configuration option would have been inferred to be either true or false.

We found the use of this tool very intuitive, and that creating a new configuration was fast.

2.3.2 Generation of a config.h file

One of the main use of our tool is the generation of a config.h file for use by the C preprocessor. This is the concrete implementation of the abstract code selector presented section 2.1.
scheid \rightarrow \text{clock} \& \text{ctxlist}
\text{clock}: \text{clock}_{\text{llsc}} \mid \text{clock}_{\text{spinlock}}
\text{clock}_{\text{spinlock}} \rightarrow \text{spinlock}
\text{clock}_{\text{llsc}} \rightarrow \text{llsc}
\text{ctxlist} : \text{ctxlist}_{\text{llsc}} \mid \text{ctxlist}_{\text{spinlock}}
\text{ctxlist}_{\text{llsc}} \rightarrow \text{llsc}
\text{ctxlist}_{\text{spinlock}} \rightarrow \text{spinlock}
\text{spinlock} : \text{spinlock}_{\text{ppc}} \mid \text{spinlock}_{\text{s12xe}} \mid \text{spinlock}_{\text{llsc}}
\text{spinlock}_{\text{llsc}} \rightarrow \text{llsc}
\text{llsc} : \text{llsc}_{\text{arm}} \mid \text{llsc}_{\text{ppc}}
\text{llsc}_{\text{arm}} \rightarrow \text{arm}
\text{llsc}_{\text{ppc}} \rightarrow \text{powerpc}
\text{spinlock}_{\text{s12xe}} \rightarrow \text{s12xe}
\text{spinlock}_{\text{ppc}} \rightarrow \text{powerpc}
\text{platform} : \text{powerpc} \mid \text{s12xe} \mid \text{arm}

(a) Example of textual representation.

(b) Graphical representation of (a).

Figure 1: An example of textual and graphical representation. Each node represents a configuration option. Rectangular nodes represent interfaces, and the nodes they encompass are their implementations. Arrows represent dependencies. Colors represent a partial resolution of the logic problem: dark green nodes have been enforced to be true, light green ones are deduced true, and light red ones are deduced false.
The config.h file is generated once all the configuration options are assigned a value. For every configuration option set to “true”, a line `#define CONFIG_<config option name>` is inserted in this file.

Every file in the project contains a `#include <config.h>`, and code can be made optional using `#ifdef CONFIG_<config option name>` or `#ifndef CONFIG_<config option name>`.

Another advantage of using CONFIGEN is the assurance that configuration options are defined consistently. In particular, this avoids the problem where a conditional is defined only if another conditional is activated. For instance, the use of spinlock is useful only on multiprocessor, which can lead to code like this:

```c
#ifdef CONFIG_SMP
#define CONFIG_SPINLOCK
#endif
#if defined(CONFIG_SMP) && !defined(CONFIG_SPINLOCK)
// conditional code
#endif
```

Thus the user always has to remind to test the CONFIG_SMP conditional before testing CONFIG_SPINLOCK, which is tedious and error-prone. The use of a single, consistent config.h avoids all needs for nested preprocessor conditionals.

With all these problems solved, the use of conditionals in C code becomes much more readable and maintainable, and allows for reusable code without sacrificing performance.

### 2.3.3 Generation of Makefiles

Experience shows that selecting code parts using only preprocessor conditionals leads to unreadable code. Often, a better way is to perform a selection of the files to be compiled in the build scripts, such as Makefiles.

One way to achieve that would be to use conditionals in the Makefile, but this makes it harder to read and more error-prone. A better way is to generate the list of objects and other targets to be built. To do that, we have extended CONFIGEN to handle properties, which are information attached to the configuration options. Properties are expressed in the dependency file, as in the following example:

```
ctxlist.objs = ctxlist_common.o
cxtlist_spinlock.objs = ctxlist_spinlock.control.o ctxlist_spinlock.exec.o
microkernel.targets = microkernel
```

These configuration options are used to generate a file config.mk:

```
all_objs = ctxlist_common.o ctxlist_spinlock.control.o ctxlist_spinlock.exec.o
all_targets = microkernel
```

This file is included in the main Makefile for the application:

```make
all: $(all_targets)
microkernel: $(all_objs)

# Special rules eventually needed to build object files
%.control.o: %.c
...
```

CONFIGEN can be easily extended to handle new properties, or other build tools than Makefile.
Usage patterns and good practice

Proper use of our tools requires to comply with a set of good practices, that help writing more modular and understandable code by using the right amount of configuration options. Indeed if creating redundant options should be avoided, it is also a bad idea to group independent concepts into a single configuration option. The following presents common use cases and the best way to describe them using CONFIGEN.

3.1 Using configuration options for modular construction

Decomposition into interface and implementations is a common practice (see the ML module system, or C++/Java abstract and concrete classes). An interface helps understanding the specification of a module (and how to use it) without needing to understand its implementation.

In C, defining a function is almost the only way of creating abstraction, and a function is not enough to define a module. However, it is possible to write modular software in C by grouping together several function definitions in one or several files, and grouping all the functions declarations in one header file that defines the interface.

CONFIGEN then helps to make these modules optional, to manage different implementations of the same module, to state dependencies between modules, and to automate their build. Moreover, module dependencies are an important information on how the software is built and how its modules interact, and CONFIGEN graphical output is very useful as a documentation. This helps in making the source code self-documenting, an important principle for understandable code (especially in open source software).

3.2 Optional behavior in small pieces of code

There are some configuration options that affect small pieces of code, typically something too small to write a specific module. For instance, our scheduler has an optional optimization that requires a small calculation in order to avoid sending an inter-processor interrupt. The C code looks like:

```c
#define CONFIG_OPTIMIZE_SEND_IPI
if( do_calculation()) return;
#endif
send_IPI();
```

The approach we advocate using CONFIGEN is to define optimize_send_ipi as an interface with two implementations (optimize_send_ipi_yes and optimize_send_ipi_no), and make sched depend on it. The symbol CONFIG_OPTIMIZE_SEND_IPI will then be either defined or “un-defined”, depending on the chosen implementation. For convenience, the “yes/no” implementations are automatically declared in the deps file when a symbol name ends with a question mark. The final deps file is then:

```
sched -> optimize_send_ipi?
  # (auto) optimize_send_ipi? : optimize_send_ipi_yes | optimize_send_ipi_no
```

This kind of optional behavior is not restricted to yes/no choices, and this scheme accommodates to any number of options.

3.3 Optional use of a module

Sometimes the use of a module can be optional. For instance, when porting OASIS to a new platform, we do not implement memory protection in the early stages of development, in order to quickly get to
functional kernel. The recipe in the previous section can be used in this case; basically, it consists of surrounding all uses of a module by `#ifdef CONFIG_USE`.

This raises a few problems though. First, it leads to many uses of preprocessor conditionals in the code, which makes it less readable. Second, if the module is used in different places, all of them places are impacted by the conditional use of the module.

It is better to create, for this module $M$, a new implementation $M_{\text{empty}}$, in which all the functions do nothing (or are replaced by macros that do nothing). This leads to less configuration options, less code, and code easier to read.

### 3.4 Dividing configuration options

Options should be split into the smallest possible pieces. One could think that too much splitting of options would lead to a proliferation of configuration options, and would make options dependencies difficult to understand.

On the contrary, having many options and modules makes their meaning more precise. Each configuration option names a concept of the application, and giving names to precise concepts helps greatly in their understanding. Moreover, it makes the system more modular.

As an example, the OASIS micro-kernel defines a `date` configuration option that accepts three different values: `date16`, `date32`, and `date64`, which sets the size of a `date_t` integer type. The original code was written with the assumption that 16 and 32 bits `date_t` may lead to a date overflow, whereas a 64 bit field may not; therefore all the overflow-handling code was enclosed by `#if defined(DATE16) || defined(DATE32)` directives, which does not seem appropriate at first glance.

We reworked this using CONFIGEN, and here is the result:

```plaintext

date -> date_size & date_overflows?
  # (auto) date_overflows? : date_overflows_yes | date_overflows_no
date_size: date16 | date32 | date64
  date16 -> date_overflows_yes; date32 -> date_overflows_yes
  date64 -> date_overflows_no
```

Even if we added new configuration options, the resulting code is easier to understand, as the “overflow” concept is named and assumptions are explicit. It is also more modular, as we could easily change the code to allow 32 bit dates that do not overflow.

### 3.5 Testing code

When writing a unit test for a module $M$, some code has to be activated to test $M$ (e.g. calls to $M$ and checking of $M$ results), and some code has to be activated to satisfy $M$ dependencies (for instance, unit testing of our scheduler requires a special version of the context switching functions, that only log context-switch operations).

So far we found CONFIGEN to be of great help to automate the activation of these requirements. However there is still some work to do to improve this automation.

---

3Note that this much easier to achieve if the interface only expose functions, and not global variables; this is one of the reasons why it is preferable to hide global variables with static and use accessor/mutator functions.
4 The CONFIGEN prototype

4.1 The CONFIGEN script

Aside from the logic solver, CONFIGEN is an extremely simple tool, composed of less than 400 lines of Ruby code. Yet this tool does parse the `deps` file, implements the graph user interface, interacts with the solver, and outputs the `config.h` and `config.mk` files.

The parser, that builds the dependency graph from the `deps` file, was really easy to write because our syntax defines a regular language, and thus can be parsed easily using simple regular expressions.

To avoid the tedious development of a complex HMI, we use a graphviz\(^4\) feature that can output images and HTML image maps such that clicking on a node would send different HTTP requests. So all CONFIGEN has to do is to output the graph to the dot file format with the correct options, implement a small web server to handle the different “node clicked” requests, communicate with the logic solver, and ask graphviz to do all the redisplay work with the result of the solver. This way, a standard web browser stands for the graphical interface. Printing the `config.h` and `config.mk` files was just trivial scripting.

4.2 The logic solver

Every time the user clicks on a node, he sets the corresponding configuration symbol (i.e. logical literal) to a truth value, sequentially TRUE (1), then FALSE (0), then back to the “unset” state. The idea is, after each click, to infer which configuration symbols have to be TRUE or FALSE subsequently to the user action.

4.2.1 Formal definition of the problem

Let us define the following notations:

- \(X = (x_1, \ldots, x_n)\) is the set of literals defined in the `deps` file, and \(f(x_1, \ldots, x_n)\) the boolean expression corresponding to the dependency graph.
- \(\mathcal{A}\) is a boolean clause defining the partial truth assignment, as defined by the clicks of the user. We note \(U_1 \subset X\) (resp. \(U_0 \subset X\)) the set of literals forced to 1 (resp. to 0) by the user. For the rest of this section, we assume without loss of generality that the literals are ordered as follows:
  \[
  x_1, \ldots, x_m, x_{m+1}, \ldots, x_{p}, x_{p+1}, \ldots, x_n
  \quad \text{with } m \leq p < n
  \]
  Therefore we have: \(\mathcal{A} \equiv \left( \bigwedge_{i \in \{1, \ldots, m\}} \neg x_i \right) \land \left( \bigwedge_{j \in \{m+1, \ldots, p\}} x_j \right)\)
- Let \(f_{\mathcal{A}} = f \land \mathcal{A}\). I.e. \(f_{\mathcal{A}}\) is the function obtained after setting in the expression of \(f\) all the literals in \(U_1\) and \(U_0\).

Then our problem is to find the biggest subsets \(S_0\) and \(S_1\) of \(\{x_{p+1}, \ldots, x_n\}\) such that \(S_0 \cap S_1 = \emptyset\) and:

- \(\forall x \in S_0\), \(\{ f_{\mathcal{A}} \Rightarrow \neg x \}\) is a tautology
- \(\forall x \in S_1\), \(\{ f_{\mathcal{A}} \Rightarrow x \}\) is a tautology

**Theorem 1.** The problem of finding whether a given literal is in \(S_1\) (resp. \(S_0\)) is co-NP-complete.

\(^4\)An open-source graph visualization software: [http://www.graphviz.org](http://www.graphviz.org)
Before proving this theorem, let us show the following result:

Lemma 1. The satisfiability problem \( (P) \) of a boolean expression \( f(x_1, \ldots, x_n) \) described by the \texttt{deps} file (whose operators are described in section 2.2.1) is NP-complete.

Proof of Lemma [7] Let us prove first that \( (P) \) is a NP-hard problem. For that purpose, we can easily reduce any 3-SAT instance, a well-known NP-complete problem, to a formula such as \( f \). Indeed, each clause \( (y_1 \lor y_2 \lor y_3) \) of a 3-CNF expression can be written using the interface/implementations operator as: \( \neg(0 : (y_1 | y_2 | y_3)) \) (see the footnote on p. [33] for the expression of the “\( \neg \)” operator and the “0” Boolean constant with our operators). As this transformation can clearly be processed in polynomial time, \( (P) \) is then NP-hard.

But \( (P) \) is also in NP. Indeed, an algorithm that non-deterministically chooses the Boolean value of each literal \( (x_1, \ldots, x_n) \) can easily decide in polynomial time if the formula \( f(x_1, \ldots, x_n) \) is true for the chosen valuation.

Since \( (P) \) is both NP and NP-hard, it is NP-complete. \( \square \)

Proof of Theorem [7] We will prove this theorem for literals in \( S_1 \); the case of literals belonging to \( S_0 \) is almost identical.

Provided a partial truth assignment \( \mathcal{A} \equiv (\bigwedge_{i \in \{1, \ldots, m\}} \neg x_i) \land (\bigwedge_{j \in \{m+1, \ldots, p\}} x_j) \) and an unvalued literal \( x_k \) (with \( k \in \{m + 1, \ldots, n\} \)), let us note \( (P') \) the problem of deciding if \( f(x_1, \ldots, x_n) \land \mathcal{A} \land \neg x_k \) is satisfiable. Note that \( (f_{\mathcal{A}} \Rightarrow x_k) \) is a tautology iff \( f_{\mathcal{A}} \land \neg x_k \) is not satisfiable. Therefore, proving that the complement problem \( (P') \) is NP-complete will prove the theorem.

We can reduce in polynomial time any problem \( (P) \) to a \( (P') \) problem by extending the set of literals addressed by \( (P) \). Let \( y \not\in X \) and \( z \not\in X \) be any two literals, then the following formula is an instance of \( (P') \) with \( n + 2 \) variables:

\[
\frac{f(x_1, \ldots, x_n) \land (y \Rightarrow y) \land (z \Rightarrow z) \land \bigwedge_{x_{\mathcal{A}}} \neg z}{F(y, z, x_1, \ldots, x_n)}
\]

With the previous notations, we have in this case \( U_0 = \emptyset, U_1 = \{y\}, \mathcal{A} = y \). If this formula is satisfiable, then so is \( f \); conversely, if \( f \) is satisfiable, the above formula is also satisfiable (with \( y \) set to “true” and \( z \) set to “false”). \( (P') \) is thus a NP-hard problem. For the same reasons than for \( (P) \) (see Lemma [7]), it is also NP-complete.

Therefore, deciding if a literal belongs to \( S_1 \) is indeed a co-NP-complete problem. \( \square \)

We have proved here that in the most general case, the problem addressed is co-NP complete. However, deciding if \( f_{\mathcal{A}} \Rightarrow x_k \) is a tautology is meaningful only if \( f_{\mathcal{A}} \) is satisfiable itself, i.e. if the logical description of the system is “coherent”, and if the options chosen so far by the user are not contradictory. Therefore, another approach would be to ensure this property first with a regular SAT-solver, then to search if \( f_{\mathcal{A}} \land \neg x_k \) is satisfiable or not. This last step is probably easier than a co-NP problem. Moreover, once \( f \) has been proved to be satisfiable, it should be easier to prove that \( f_{\mathcal{A}} \) is satisfiable every time the user iteratively appends new literals to \( \mathcal{A} \) by clicking.

4.2.2 Internals of the solver

Our logic solver applies a simple and intuitive heuristic to compute subsets of \( S_0 \) and \( S_1 \). The idea is to compute and simplify the \( f_{\mathcal{A}} \) expression for each assignment \( \mathcal{A} \) provided by the user, then to convert
it to a CNF form using a straightforward algorithm\(^5\). Then, all clauses of the final expression that are literals (resp. negated literals) belong to \(S_1\) (resp. \(S_0\)).

To this purpose, the dependency graph expressed in \texttt{deps} is translated into a boolean expression that only uses \(\land, \lor, \text{ and literal } \neg\). The formal simplifier can then manipulate this boolean expression and apply the following basic logic rules:

\[
\begin{align*}
    x \land 1 &= x & x \land 0 &= 0 & x \land f(x, \ldots) &= x \land f(1, \ldots) & \neg x \land f(x, \ldots) &= \neg x \land f(0, \ldots) \\
    x \lor 1 &= 1 & x \lor 0 &= x & x \lor f(x, \ldots) &= x \lor f(0, \ldots) & \neg x \lor f(x, \ldots) &= \neg x \lor f(1, \ldots)
\end{align*}
\]

before converting the result to a CNF. The literals and negated literals clauses are then extracted and sent back to the Ruby script for display.

In most cases, our solver managed to find the whole subsets \(S_0\) and \(S_1\). In some however, it failed to see all dependencies. For instance, in the example of figure 1(b) \(\text{p.35}\) our solver was actually unable to deduce from \{\text{arm} = 1, \text{sched} = 1\} that \text{lisc} (and subsequently \text{lisc}\_\text{arm}) is always true\(^7\). The reason for this failure is that the policy described above is not sufficient to deduce from:

\[
(a \oplus b) \land (a \Rightarrow c) \land (b \Rightarrow c) = (a \lor b) \land (\neg b \lor \neg a) \land (a \lor c) \land (\neg b \lor c)
\]

that \(c\) is necessarily always true.

Even if the solver shows its limitations, it remains correct in the sense that it will never deduce an erroneous literal value, e.g. that would define unwanted options, or that would result in an unsatisfiable expression.

The solver is written in C; its performances were not measured precisely, but for all the dependencies trees that we used so far to model the OASIS kernel, the calculus time appeared immediate. It has not been tested yet on larger scale projects, mainly because it is still an “ad-hoc” tool, that requires a lot of improvements before being subject to a relevant performance evaluation.

Evolutions will be discussed in section\(^6\) Although the solver approach is obviously not suitable for (even approximate) solving of SAT-problems, (especially when compared to dedicated tools such as MiniSat\(^6\)), we believe we can make it more efficient by focusing only on a meaningful restricted set of boolean expressions, e.g. only those represented by an acyclic graph.

## 5 Related works

Using boolean logic to manage and validate complex dependencies schemes has been done before in different application domains, including software architecture.

Our development approach is close to the \textit{Software Product Line} engineering technique\(^8\), as it promotes modularity and re-usability as development-driving key concepts. The features of a SPL are usually represented as an oriented graph (\textit{feature diagram}). The semantics of this graph has been formalized and studied\(^5\), although to the best of our knowledge it is not used in any practical application.

The \textit{Kconfig} Linux kernel configurator is a tool similar to ours. With the use of \textit{Kconfig} script files and a dedicated syntax, the kernel developers have a powerful and efficient way to express internal dependencies.

The user has therefore a great freedom in the choice of his kernel components (see Sincero’s work\(^11\) – an attempt to bridge the gap between the SPL and the Open Source communities, and the Linux Kernel documentation\(^7\). However no graph representation of the dependencies is provided, nor

\(^5\)The algorithm consists in recursively applying distributivity property of the \(\land\) operator.

\(^6\)By literal \(\neg\) we mean that the operator may only be applied to boolean variables, not to operators. E.g. \(\neg(a \land b)\) is prohibited, whereas \((\neg a) \lor (\neg b)\) is not.

\(^7\)Indeed, the mandatory choice of one option in \textit{clock} as well as in \textit{ctxlist} will either set \textit{lisc} directly, or will set \textit{spinlock, then spinlock\_lisc} which is the last available choice, then \textit{lisc}.

\(\text{http://www.kernel.org}\) see Documentation/kbuild/ directory
any interactive interface such as ours.

The main link between software components dependencies and propositional logic comes from the work of Mancinelli, Abate, Boender and Di Cosmo on Free Open-Source Software distributions, through the EDOS and Mancoosi projects [12]. In [10], a SAT-solver is used to address the installability problem of a set of packages; in [11], the dependency graph of a package repository is analyzed to identify “sensible” components that may widely impact the system if corrupted or removed.

6 Conclusion

This paper has presented CONFIGEN, a tool for managing software configuration options. We exposed the concepts behind CONFIGEN, showed how it can be integrated in a software development project, and described a set of good practices and examples that come from our experience using CONFIGEN for system development. We also presented the graphical interface of CONFIGEN, the associated logic solver and the theoretical problem it addresses.

CONFIGEN is still a prototype, but has already proved to be very useful. The tools are simple to use and have helped in refactoring a complex software, making it easier to understand. It also encourages good software practices. We found the graphical interface of great help when defining new modules.

There are many future possible developments. It might be interesting to extract the dependency file from the source code, using source code annotations for instance. Another interesting point would be to guide the user’s choices with “automatic” implementations, that would discard by default rarely used options (e.g. benchmarking modules). At last, the work of [11] could also be used to isolate critical features, with application to quality assurance.

Many interesting developments also remain to be done in the solver. The problem we need to solve is co-NP-complete in the general case; however we did not take into account many restrictions yet. For instance, the current proof uses implementation/interfaces operators in which some implementations belong to multiple interfaces, which does not happen in real use. Moreover, we do not use cycles in the use cases encountered so far. It is possible that with such restrictions, the problem we try to solve becomes polynomial. Even if it is not, there are strong relationships between successive iterations of the problem to solve (i.e. they differ by only one truth assignment), which could be exploited by an incremental solver. Meanwhile, it would be more appropriate to connect to a SAT-solver and get the complete solution, as suggested in [4,2]. Such solvers could also be used to get the set of all the possible configurations, e.g. for testing purposes.

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