Exploring software systems
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For a typical COBOL program, the data division consists of 50% of the lines of code. Automatic type inference can help to understand the large collections of variable declarations contained therein, showing how variables are related based on their actual usage. The most problematic aspect of type inference is pollution, the phenomenon that types become too large, and contain variables that intuitively should not belong to the same type.

The aim of the chapter is to provide empirical evidence for the hypothesis that the use of subtyping is an effective way for dealing with pollution. The main results include a tool set to carry out type inference experiments, a suite of metrics characterizing type inference outcomes, and the conclusion that only one instance of pollution was found in the case study conducted. The work presented in this chapter was published earlier as [DM01].

5.1 Introduction

In this chapter, we will be concerned with the variables occurring in a COBOL program. The two main parts of a COBOL program are the data division, containing declarations for all variables used, and the procedure division, which contains the statements performing the program's functionality. Since it is in the procedure division that the actual computations are made, one would expect this division to be larger than the data division. Surprisingly, we found that in a typical COBOL system this is not the case: the data division often comprises more than 50% of the lines of code.\footnote{For three different systems, each approximately 100,000 LOC, we found averages of 53%, 43%, and 58%, respectively.} We even encountered several programs in which 90% of the lines of code were part of the data division.
An Empirical Study into COBOL Type Inferencing

Chapter 5

(As we have seen in the previous chapter, one reason for this is that COBOL does not distinguish between type and variable declarations.)

These figures have two implications. First of all, they suggest that only a subset of all declared variables are actually used in a COBOL program. If 90% of the lines are variable declarations, it is unlikely that the remaining 10% will use all these variables. Indeed, in the systems we studied, we have observed that less than 50% of the variables declared are used in the procedure division.\(^2\)

These figures also indicate that maintenance programmers need help when trying to understand the data division part. Just reading the data division will involve browsing through a lot of irrelevant information. Thus, the minimal help is to see which variables are in fact used, and which ones are not. In addition to that, the maintenance programmer will want to understand the relationships that hold between variables. In COBOL, some of these relations can be derived from the data division, such as whether a variable is part of a larger record, whether it is a redefine (alias) of another variable, or whether it is a predicate on another variable (level 88).

But not all relevant relations between variables are available in the data division. When do two different variables hold values that represent the same business entity? Can a given variable ever receive a value from some other given variable? What values are permitted for this variable? Is the value of this variable ever written to file? Is the value of this variable passed as output to some other program? What values are actually used for a given variable? What are the operations permitted on a given variable?

In strongly typed languages, questions like these can be answered by inspecting the types that are used in a program. First, a type helps to understand what set of values is permitted for a variable. Second, types help to see when variables represent the same kind of entities. Third, they help to hide the actual representation used (array versus record, length of array, ...), allowing a more abstract view of the variable. Last but not least, types for input and output parameters of procedures immediately provide a “signature” of the intended use of the procedure.

Unfortunately, the variable declarations in a COBOL data division suffer from a number of problems that make them unsuitable to fulfill the roles of types as discussed above. In COBOL, it is not possible to separate type definitions from variable declarations. This has three unpleasant consequences. First, when two variables need the same record structure, this structure is repeated. Second, whenever a data division contains a repeated record structure, the lack of type definitions makes it difficult to determine whether that repetition is accidental (the two variables are not related), or whether it is intentional (the two variables should represent the same sort of entity). Third, the absence of explicit types leads to a lack of abstraction, since there is no way to hide the actual representation of a variable into some type name.

In short, the problem we face with COBOL programs is that types are needed to understand the myriads of different variables, but that the COBOL language does not support the notion of types.

\(^2\) For the Mortgage system under study in this chapter, on average 58% of the variables declared in a program were never used, the percentages ranging from 2.6% for the smallest up to 95% for the largest program.
In Chapter 4, we have proposed a solution to this problem. Instead of deriving type information from the data division, we perform a static analysis on the programs to infer types from the usage of variables in the procedure division. The basic idea of type inference is simple: if the value of a variable is assigned or compared to another variable, we want to infer that these two variables should have the same type. However, just inferring a type equivalence for every assignment will not do. As an example, a temporary string value could receive values from names, streets, cities, etc., which should all have different types. Via transitivity of equivalence, however, all variables assigned to that string variable would receive the same type. This phenomenon, that a type equivalence class becomes too large, and contains variables that intuitively should not belong to the same type, is called pollution. In order to avoid pollution, we have proposed to introduce subtyping for assignments rather than type equivalence (Chapter 4).

Moreover, we will discuss how relational algebra can be used for implementing COBOL type inferencing. Relational algebra has recently been proposed as a valuable tool for various reverse engineering and program understanding activities, such as architecture recovery [Hol98, FKO98]. It is based on Tarski’s relational operators [Tar41], such as union, subtraction, relational composition, etc. The use of relational algebra helps us to completely separate COBOL-specific source code analysis from calculating with types. Moreover, it enables us to specify type relationships at an appropriate level of abstraction.

All experiments are done on MORTGAGE, a real-life COBOL/CICS system from the banking environment. This system consists of 100,000 lines of code; with all copybooks (include files) expanded (unfolded), it consists of 250,000 lines of code. It conforms to the COBOL-85 standard, which is the most widely used COBOL version. Compared to a COBOL code base of 3 million lines we have available, MORTGAGE contains fairly representative COBOL code (it is neither the worst nor the best code).

5.2 Type Inference

In this section, we summarize the essentials of COBOL type inferencing: a more complete presentation is given in Chapter 4. We start by describing the primitive types that we distinguish. Then, we describe how type relations can be derived from the statements in a single COBOL program, and how this approach can be extended to system-level analysis leading to inter-program dependencies. Finally, we show how the analysis can be extended to include types for literals, discuss the notion of pollution, and conclude with an example.
5.2.1 Primitive Types

We distinguish three primitive types: (1) elementary types such as numeric values or strings; (2) arrays; and (3) records. Initially every declared variable gets a unique primitive type. Since variable names qualified with their complete record name must be unique in a COBOL program, these names can be used as labels within a type to ensure uniqueness. Furthermore, we qualify variable names with program or copybook names to obtain uniqueness at the system level. We use $T_A$ to denote the primitive type of variable $A$.

5.2.2 Type Equivalence

By looking at the expressions occurring in statements, an equivalence relation between primitive types can be inferred. We distinguish three cases:

1. Relational expressions: from a relational expression such as $v = u$ or $v \leq u$ an equivalence between $T_v$ and $T_u$ is inferred.

2. Arithmetic expressions: from an arithmetic expression such as $v + u$ or $v \times u$ an equivalence between $T_v$ and $T_u$ is inferred.

3. Array accesses: from two different accesses to the same array, such as $a[v]$ and $a[u]$ an equivalence between $T_v$ and $T_u$ is inferred.

When we speak of a type we will generally mean an equivalence class of primitive types. For presentation purposes, we may also give names to types based on the names of the variables part of the type. For example, the type of a variable with the name L100-DESCRIPTION will be called DESCRIPTION-type.

5.2.3 Subtyping

By looking at the assignment statements, we infer a subtype relation between primitive types. Note that the notion of assignment statements corresponds to COBOL statements such as MOVE, COMPUTE, MULTIPLY, etc. From an assignment of the form $v := u$ we infer that $T_u$ is a subtype of $T_v$, i.e., $v$ can hold at least all the values $u$ can hold.

5.2.4 Union Types

From a COBOL redefine clause, we infer a union type relation between primitive types. When a given entry $v$ in the data division redefines another entry $u$, we infer that $T_v$ and $T_u$ are part of the same union type.

5.2.5 System-Level Analysis

In addition to inferring type relations within individual programs, we derive type relations at the system-wide level. We infer that the types of the actual parameters of
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A program call (listed in the COBOL USING clause) are subtypes of the formal parameters (listed in the COBOL LINKAGE section), and that variables read from or written to the same file or table have equivalent types. Furthermore, we want to ensure that if a variable is declared in a copybook, its type is the same in all the different programs that copybook is included in. In order to do this, we derive relations that denote the origins of primitive types and the import relation between programs and copybooks. These relations are then used to link types via copybooks.

5.2.6 Literals

A natural extension of our type inference algorithm involves the analysis of literals that occur in a COBOL program. Whenever a literal value \( I \) is assigned to a variable \( v \), we conclude that the value \( I \) must be a permitted value for the type of \( v \). Likewise, when \( v \) and \( I \) are compared, \( I \) is considered a permitted value for the type of \( v \). Literal analysis indicates permitted values for a type. Moreover, if additional analysis indicates that variables in this type are only assigned values from this set of literals, we can infer that the type in question is an enumeration type.

5.2.7 Pollution

The intuition behind type equivalence is that if the programmer would have used a typed language, he or she would have chosen to give a single type to two different COBOL variables whose types are inferred to be equivalent. We speak of type pollution if an equivalence is inferred which is in conflict with this intuition.

Typical situations in which pollution occurs include the use of a single variable for different purposes in different program slices; the use of a global variable acting as a formal parameter, to which a range of different variables can be assigned; and the use of a PRINT-LINE string variable for collecting output from various variables.

5.2.8 Example

Figure 5.1 contains a COBOL fragment illustrating various aspects of type inferencing. The first half contains the declarations of variables, containing their physical types, i.e., how many bytes they occupy. The second half contains the actual statements from which type relations between variables are inferred.

Going from bottom to top, we first see (line 41) that variable A00-FILLED is compared to N100, from which we infer that they belong to the same type. From line 39, we then infer an additional type equivalence, adding A00-MAX to this equivalence class. We thus obtain one type, for three different variables. If we also take a look at the data division, we see that this equivalence is in accordance with their declared picture layouts (in lines 13, 14, and 20), which are all numeric data elements. However, we cannot infer such equivalences from just the pictures, as entirely unrelated data structures may share the same physical layout (for example, N200 in line 21).

An assignment example is given in line 31, where NAME is assigned to NAME-PART. Here we infer that the type of NAME is a subtype of NAME-PART. In line 26, another vari-
Figure 5.1: Excerpt from a real-life Cobol program.
able, INITIALS, is assigned to NAME-PART as well, giving rise to a second subtype relationship, now between INITIALS and NAME-PART. In this way, INITIALS and NAME share a common supertype (NAME-PART), but there is no direct relationship inferred between them. If we look at the declared physical layout we see that all three are strings of a different length (in lines 3, 4, and 12). NAME-PART is the largest, capable of accepting values from both INITIALS and NAME.

In fact, NAME-PART is a global variable acting as a formal parameter for the procedure R300-COMPOSE-NAME (COBOL does not support the declaration of parameters for procedures). What we infer is that the type of the actual parameter is a subtype of the formal parameter. Just deriving equivalences from assignments would lead to pollution: it would give all the actual parameters, in this case the two different concepts “initials” and “first name”, the same type.

5.2.9 Practical Value

COBOL type inferencing provides a theory for grouping variables based on their usage. This is of great practical value for the understanding and (semi-automated) transformation of COBOL legacy systems. Example application areas are discussed in Chapter 4, and include the introduction of symbolic names for literal values (per type), extraction of system interfaces based on parameter types, migration to strongly typed languages such as Pascal, identification of candidate classes in legacy systems, and type-related modifications such as the Euro and year 2000 problem.

Another major application is to use type inferencing to support the migration of COBOL to the new COBOL standard, which is an object-oriented extension of COBOL-85 [ISO00]. This new version of COBOL does support types, and offers the possibility of using type definitions. Type inferencing supports the detection of these types in existing COBOL programs, thus allowing old systems to benefit from the new language features.

5.3 Implementation using Relational Algebra

This section describes how we use relational algebra to implement type inference for COBOL systems. We start by giving an overview of the tool architecture. Then, we describe the facts that are derived from COBOL sources. We continue with a discussion of how these facts are combined and abstracted to infer more involved type relations. Finally, we describe the extension of this approach to the system level.

5.3.1 Tool Architecture

The set of tools we use for applying type inference to COBOL systems is shown in Figure 5.2. It separates source code analysis, inferencing and presentation, making it easier to adapt the toolset to different source languages or other ways of presenting the types found.
In the first phase, a collection (database) of facts is derived from the COBOL sources. For that purpose, we use a parser generated from the COBOL grammar discussed in [BSV97a]. The parser produces abstract syntax trees (ASTs) in a textual representation called the AsFix format. These ASTs are then processed using a Java package which implements the visitor design pattern [GHJV94]. The fact extractor itself is a refinement of this visitor which emits type facts at every node of interest (for example, assignments, relational expressions, etc.).

In the second phase, the derived facts are combined and abstracted to infer a number of conclusions regarding type relations. Both facts and conclusions are stored in a simple ASCII format, as also used in, for example, Rigi [MOTU93]. One of the tools we use for inferring type relations is grok [Hol98], a calculator for relational algebra [Tar41]. Relational algebra provides operators for relational composition, for computing the transitive closure of a relation, for computing the difference between two relations, and so on. We use it, for example, to turn the derived type facts into the required equivalence relation. In addition to relational algebra, we use Unix tools like sort, uniq, awk, etc. to manipulate the relation files.

In the final phase, we pass information about the type relations to the end-user. In this chapter, we conduct an analysis of the effects of pollution, for which we collect and present a range of statistical data. Other options include the generation of data structures in a language supporting explicit type definitions, and visualization of type information via graphs.

### 5.3.2 Derived Facts

The different kinds of facts derived from the COBOL sources are listed in Figure 5.3. The contain and union relations are derived from the data division, the remaining ones from the procedure division.

Observe that the relations in this figure indicate the degree of language independence of type inferencing: it can be applied to any language from which these facts can be derived. Other languages like Fortran, C, or IBM 370 assembly, can be analyzed by

![Figure 5.2: Overview of the type inference tool set.](#)
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<table>
<thead>
<tr>
<th>relation</th>
<th>dom</th>
<th>rng</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>assign</td>
<td>$T_v$</td>
<td>$T_u$</td>
<td>an expression of type $T_v$ is assigned to a variable of type $T_u$</td>
</tr>
<tr>
<td>expression</td>
<td>$T_v$</td>
<td>$T_u$</td>
<td>variables of types $T_v$ and $T_u$ are used in the same expression</td>
</tr>
<tr>
<td>arrayIndex</td>
<td>$T_a$</td>
<td>$T_i$</td>
<td>variable of type $T_i$ is used as index in array of type $T_a$</td>
</tr>
<tr>
<td>contain</td>
<td>$T_v$</td>
<td>$T_f$</td>
<td>structured type $T_v$ contains $T_f$</td>
</tr>
<tr>
<td>union</td>
<td>$T_v$</td>
<td>$T_u$</td>
<td>types $T_v$ and $T_u$ are part of the same union type</td>
</tr>
<tr>
<td>literalAssign</td>
<td>$T_v$</td>
<td>$l$</td>
<td>literal $l$ is assigned to a variable of type $T_v$</td>
</tr>
<tr>
<td>literalExp</td>
<td>$T_v$</td>
<td>$l$</td>
<td>literal $l$ is compared to a variable of type $T_v$</td>
</tr>
<tr>
<td>arrayLitIdx</td>
<td>$T_a$</td>
<td>$l$</td>
<td>literal $l$ is used as index in array of type $T_a$</td>
</tr>
</tbody>
</table>

Figure 5.3: Derived Facts.

adding a parser and fact extractor for those languages. Furthermore, since the facts for different languages can easily be combined, this approach allows for the transparent analysis of multi-language systems where, for example, some parts are written in 

COBOL and other parts are written in assembly.

5.3.3 Inferred Relations

The resolution process infers relations between types from the facts that were derived from the COBOL system. Our resolution process is based on relational algebra and is implemented using grok [Hol98].

The three key relations inferred are typeEquiv, subtypeOf, and literalType, summarized in Figure 5.4. Besides the relations in Figure 5.4, some auxiliary relations are inferred. These include: arrayIndexEquiv for equivalence of types through array access (if variables $i$ and $j$ are used as indexes for the same array $A$, their types should be equivalent), subtypeEquiv for type equivalence through subtyping (if $T_A \leq T_B$ and $T_B \leq T_A$, we get $T_A = T_B$), and transSubtypeOf for the transitive closure of subtypeOf.

The resolution algorithm is outlined in pseudo code in Figure 5.5. The operators used are those of relational algebra and can be mapped directly to grok operators. Note that function abstraction and unbounded iteration are not available in grok. For

<table>
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<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>typeEquiv</td>
<td>$T_1$</td>
<td>$T_2$</td>
<td>type $T_1$ is equivalent to type $T_2$</td>
</tr>
<tr>
<td>subtypeOf</td>
<td>$T_1$</td>
<td>$T_2$</td>
<td>type $T_1$ is subtype of type $T_2$</td>
</tr>
<tr>
<td>literalType</td>
<td>$T$</td>
<td>$l$</td>
<td>type $T$ contains literal $l$</td>
</tr>
</tbody>
</table>

Figure 5.4: Inferred Relations.
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arrayIndexEquiv := arrayIndex^{-1} \circ arrayIndex
typeEquiv := arrayIndexEquiv \cup expression
subtypeOf := assign
repeat
  subtypeEqiv := equiv(subtypeOf + \cap (subtypeOf+)^{-1})
typeEquiv := equiv(typeEquiv \cup subtypeEquiv)
subtypeOf := subtypeOf \setminus typeEquiv
subtypeOf := subtypeOf \cup subtypeOf \circ typeEquiv
  \cup typeEquiv \circ subtypeOf
until fixpoint of (typeEquiv, subtypeOf)
literalType := typeEquiv \circ (literalExp \cup literalAssign
  \cup (arrayIndex^{-1} \circ arrayLiteralIndex))

fun equiv(R) := (R \cup R^{-1})^*

Figure 5.5: Outline of the resolution algorithm.

this reason, in the actual implementation the functions were written out explicitly and
bounded iteration is used. The number of iterations was determined heuristically; for
the case study conducted, 5 iterations were sufficient. We were informed that addition
of unbounded iteration is considered for future releases of GROK.

5.3.4 System-Level Types

In order to do system-level type inference, the primitive types have to be unique for
the whole system. As described in Section 5.2.5, this can be done by qualifying them
with program names. Primitive types derived from copybooks that are included in
the data division should be qualified using the copybook’s name — this ensures that
variables of those types will have the same type in all the programs that this copybook
is included in.

However, this approach does not allow us to deal with system-level type inference
without loading all COBOL sources in memory at once. We would need to analyze
self-contained clusters of programs and copybooks, in order to qualify types with the

<table>
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<th>relation</th>
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<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>decl</td>
<td>m</td>
<td>T_v</td>
<td>module m declares T_v</td>
</tr>
<tr>
<td>copy</td>
<td>m_1</td>
<td>m_2</td>
<td>module m_1 imports m_2</td>
</tr>
<tr>
<td>actualParam</td>
<td>P.n</td>
<td>T_v</td>
<td>n'th actual parm. of P has type T_v</td>
</tr>
<tr>
<td>formalParam</td>
<td>P.n</td>
<td>T_v</td>
<td>n'th formal parm. of P has type T_v</td>
</tr>
</tbody>
</table>

Figure 5.6: Derived System-Level Relations.
correct names. Such clusters are likely to become as large as the complete system.  

To facilitate complete separation of the analysis of copybooks and programs, we derive all information as before, and add extra facts from COBOL sources concerning the use of copybooks and declaration of types. The extra relations are described in Figure 5.6.

Next, we compose the copy and decl relations, and infer a copyOf relation that indicates which types used in a program are actually “copies” of types that were declared in a copybook (Figure 5.7). This join is done on the imported module field \( m_2 \) of the copy relation with the module field \( m \) of the decl relation.

Finally, the copyOf relation between \( T_p \) and \( T_c \) is interpreted as a substitution on the derived relations replacing all occurrences of \( T_p \) by \( T_c \). This substitution propagates type dependencies through copybooks.

At this point we have achieved the same database as we would have obtained by analyzing all sources at once, but now using a modular approach. Such a modular approach allows us to analyze large industrial-scale systems that are too big to be handled in memory at once.

**Example 5.3.1** Suppose we derive the following information from programs \( P \) and \( Q \):

- subtypeOf \( P.A \ P.B \) copy \( P \ Z \) decl \( Z \ Z.B \)
- subtypeOf \( Q.B \ Q.C \) copy \( Q \ Z \)

Program \( P \) and \( Q \) both use variable \( B \) and import copybook \( Z \) in which \( B \) is declared.

Joining the copy and decl relations yields two copyOf facts:

- copyOf \( P.B \ Z.B \)
- copyOf \( Q.B \ Z.B \)

After substituting these in subtypeOf, we get:

- subtypeOf \( P.A \ Z.B \)
- subtypeOf \( Q.B \ Z.C \)

Observe that, via transitivity of the subtypeOf relation, we can now infer that \( P.A \) is a subtype of \( Q.C \), a relation that could not have been found without the propagation through the copybook.

We have written a dedicated C program to perform the substitution since standard Unix tools like sed or perl could not handle the amount of substitutions involved.\(^3\) Time complexity of this program is \( O(n \log n + m \log m) \) (where \( n \) is the number of tuples in copyOf, and \( m \) is number of tuples in the database), and its space requirements are \( O(n) \).

\(^3\) For example, for MORTGAGE, the copyOf relation contains 121,915 tuples.

<table>
<thead>
<tr>
<th>relation</th>
<th>dom</th>
<th>rng</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>copyOf</td>
<td>( T_p )</td>
<td>( T_c )</td>
<td>( T_p ) is a copy of ( T_c )</td>
</tr>
</tbody>
</table>

Figure 5.7: Inferred System-Level Relations.
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5.4 Assessing Derived Facts

In this section we study the nature of the facts that can be directly derived from the COBOL sources, i.e., without applying the resolution step. This means that we only look at the intra-module dependencies, and only consider direct subtype relationships, not transitive ones. This will help us to understand to what extent individual programs are responsible for causing pollution. In the next section, we will look at inter-module dependencies, and relationships arising from taking the transitive closure.

The database that is derived from the MORTGAGE sources contains 34,313 unique facts. An overview of these is shown in Figure 5.8. All duplicates were removed, thus, if variable $v$ is assigned to variable $u$ in two different statements in a certain program, this results in only one subtype relation between $T_v$ and $T_u$. The majority of facts are from decl and contain. Type equivalence and subtype relationships are inferred from the remaining facts. An interesting observation is that the assign relation is almost 9 times as large as the expression relation. This means that variables in a COBOL program are much more often moved around (assigned) than tested for their value. In this section, we will particularly look at these assign-facts.

![Figure 5.8: Facts derived from MORTGAGE.](image-url)
5.4.1 Direct Subtypes per Type

A variable that receives values from many different other variables is a potential cause for pollution. Therefore, in this section we will search for those types that have many different subtypes, i.e., types of variables that are assigned values from many other variables.

In Figure 5.9 we show, for each program, the highest number of different subtypes that a single type has. The numbers at the x-axis can be seen as program IDs – they are given in order of increasing program size. As an example, the program with ID-number 20 (one of the smaller programs) has a pulse of length 2 associated with it, i.e., the type with the most different subtypes just has 2 different subtypes.

The dashed line indicates the average number of subtypes per type. It shows that most types have just 1 or 2 subtypes. To compute the average number of subtypes per type, only those types that have at least one subtype were taken into account (hence this average will always be larger than 1), ignoring types that were not used at all, or only in expressions. The overall average number of subtypes is 1.18.

Most programs do not contain types with more than 5 subtypes; one program contains a type with an exceptionally large number of 45 different subtypes. If we look at the COBOL code underlying these data, we can understand the high maximum of 45. This involves the type of a variable called P800-LINE, which is a string of length 132. It acts as the formal parameter of a section called Y800-PRINT-LINE. Whenever data is

![Figure 5.9: Max. no. of subtypes per program before resolution.](image)
to be printed, it is moved into that variable and the Y800-PRINT-LINE section is called. Type inference concludes that the types of all the variables that are printed this way, are subtypes of the type of Y800-PRINT-LINE.

5.4.2 Direct Supertypes per Type

Another figure of interest consists of the number of supertypes per primitive type, i.e., types of variables that are assigned to many other variables. Figure 5.10 shows the number of supertypes per type. Again, most types that have a supertype have one or two supertypes, the average being 1.32. Most of the maxima are below 6, but a number of programs contain types with many more supertypes, for example with 17, 18, or 19 different ones.

If we look at the COBOL source code, we can explain the role of these types. The type with 19 supertypes occurs in a (fairly large) program with ID-number 104, and turns out to be the type of a CURSOR variable, used in a CICS interactive setting. We will refer to this type as CURSOR-type. The variable of this type navigates through the screen positions of a terminal. It is compared with, and copied into a number of different variables representing screen positions of certain fields, such as the position where to enter the name of a person. All these positions together, each declared with numeric picture, share one subtype: the CURSOR-type. Thus, the number 19 is not due to pollution, but rather provides meaningful information for understanding the program.

![Figure 5.10: Max. no. of supertypes per program before resolution.](image)

Figure 5.10: Max. no. of supertypes per program before resolution.
namely that all these types share the values of their common CURSOR-subtype. This CURSOR-mechanism is used by many different programs, and thus is the explanation for most of the maxima higher than 6 occurring in Figure 5.10.

One of the non-CURSOR cases occurs in the program with ID-number 90. It concerns a so-called DESCRIPTION-type which has 17 different supertypes. It is the type of an output field of a procedure for reading a value from a particular database. The particular database contains a wide variety of data, and depending on some of the input parameters, different sorts of data are returned. Each of these becomes a supertype of the DESCRIPTION-type.

### 5.4.3 Type Equivalence

In addition to looking at the subtype relations, we can look at the direct type equivalence relations we derive, i.e., we look at types that occur in the same relational or arithmetic expressions. The statistics derived needed for this is based on fewer input tuples, as we know from Figure 5.8 that there are almost 9 times fewer expression tuples than assign tuples. The resulting figure, however, is quite similar to Figure 5.10, so we omitted the figure.

If we look at the maxima, they are again 19, 18, and lower. As with the supertypes, one of the types responsible for this is the CURSOR-type. A variable of this type is compared with 18 other variables. Therefore, we conclude that the types of these 18 variables must be the same as the CURSOR-type. The resulting type represents a screen position.

Another type that is equivalent to many other types is the so-called DFHBMEOF-type. This is the type of a special CICS variable which has a constant value for a certain control character. After reading the input entered from a screen, the status characters for the strings that were read are compared with this CICS variable. The types of those status characters are thus equivalent to the type of that CICS variable in our approach.

### 5.5 Assessing Inferred Relations

In this section we examine the relations that result from applying the resolution step. This will help us to understand the merits of resolution and how it affects type pollution.

Before executing the resolution process, we prepare the derived facts for system-level analysis. The copyOf relation that is inferred from the copy and decl relations contains 121,915 tuples. The propagation of copyOf information in the derived database takes 6 seconds. The resolution was done using a grok script implementing the algorithm in Figure 5.5 which takes 7 minutes for the case study at hand (on a Sun Ultra 10 (300MHz), 576 Mb memory).

After resolution, the database contains 202,848 tuples. An overview of these is shown in Figure 5.11. For a number of relations (such as arrayIndex or literalExp), the number of tuples in the resulting database is smaller than before since the substitution
results in some tuples becoming duplicates. For others, such as subtypeOf, the number of tuples increases, via propagation of the equivalence relation.

### 5.5.1 Subtype Relation

One of the goals of the resolution process is to improve the subtypeOf relation by removing tuples for which we have more specific information, namely that they are part of the typeEquiv relation. On the other hand the subtypeOf relation is also extended with information of the typeEquiv relation. For example, if $T_A \leq T_B$ and $T_B \equiv T_C$ then also $T_A \leq T_C$. The percentage of subtypes that are added or removed as a result of both modifications is shown in Figure 5.12.

In this figure we see that for most programs, resolution reduces the number of subtypes. The average reduction in these programs is 18.4% with a maximum of 47.1%. There are however a couple of programs in which the number of subtypes grows. The average growth in these programs is 54.5% and the maximum is 393.8%. Inspection of these programs shows that the cause of these large numbers is again the CURSOR that was earlier described in Sections 5.4.2 and 5.4.3. The reason for this is that CURSOR is the subtype of a lot of types (say set $S$), and it is equivalent to a number of types (say set $E$). Since the resolution process ensures that all types in set $E$ become subtypes of all the types in set $S$, the resulting database contains a rather large number of subtypes ($|S| \times |E|$ to be precise) just because of this CURSOR.

![Figure 5.11: Information inferred from Mortgage.](image-url)
As not all variables are used in comparisons (recall that in COBOL it is very common
to just move variables), other types with many sub- or supertypes (such as DESCRIPTION
and P800-LINE) but which are never used in comparisons, play no role of importance
here.

5.5.2 Type Equivalence

The typeEquiv partitions types into equivalence classes. An overview of all classes that
occur in MORTGAGE and their sizes is presented in Figure 5.13.

Figure 5.13(a) contains the classes if resolution is only done on a per-program basis,
i.e., without taking system-wide propagation via copybooks and program calls into
account. On this program level, resolution does not have a big influence on these
equivalence classes. The explanation for this is that the classes at the program level
are small and tightly connected, so all relations are already found by analyzing the
code (e.g., if 3 variables are equivalent, they will all be compared to each other so the
transitive closure does not find new tuples). The maxima are still 19 and 18 and the
average class size is 3. Furthermore, approximately 90% of the classes have less than 5
equivalent elements.

Things get more interesting at the system level presented in Figure 5.13b. The max-
imum class size jumps to 201, followed by 118 but the total number of different classes

![Figure 5.12: Subtypes added by resolution.](image-url)
drops to 191, one third of the number of classes before resolution. Again, approximately 90% of the classes have less than 5 equivalent elements.

Inspection of the derived equivalence classes shows that the class with 201 elements contains all elements that are equivalent to the CURSOR-type. All CURSOR classes occurring in different programs are taken together, as the underlying CURSOR variable is declared in a copybook. When we look at the code we see that the elements in this class are typically used in a relational expression with the CURSOR-type, although in some cases they are both a sub- and supertype of it and therefore inferred to be equivalent.

The next biggest class has 118 elements and represents a type holding some CICS status information. It contains all elements equivalent to the DFHBMEOF-type described in Section 5.4.3, again coming from a copybook.

The class with 39 elements represents the index type for some array type. The elements in this class were typically found using the rule for array index equivalence. It contains the primitive types of variables that were used to access arrays in loops and those that were used for checking array bounds. Here the array variable was declared in a copybook.

The last class we will discuss here is the one with 24 elements. This class represents the so-called RELATION-ID-type and is worth mentioning since it contains a form of pollution that is not solved by subtyping. The spurious type is the so-called MORTGAGE-ID-type which is unrelated to the RELATION-ID-type according to the business logic. The reason that they end up in the same class is that both types are used as

<table>
<thead>
<tr>
<th>class size</th>
<th># of classes</th>
<th>percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>373</td>
<td>63.4%</td>
</tr>
<tr>
<td>3</td>
<td>99</td>
<td>16.8%</td>
</tr>
<tr>
<td>4</td>
<td>53</td>
<td>9.0%</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>1.7%</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>1.4%</td>
</tr>
<tr>
<td>7</td>
<td>29</td>
<td>4.9%</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>0.9%</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>0.7%</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>0.3%</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
<td>0.3%</td>
</tr>
<tr>
<td>sum</td>
<td>588</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>class size</th>
<th># of classes</th>
<th>percent of total</th>
</tr>
</thead>
<tbody>
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<td>135</td>
<td>70.7%</td>
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<td>2.1%</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>4.7%</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>3.1%</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>1.0%</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>201</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>sum</td>
<td>191</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

(a) program level (b) system level

Figure 5.13: Size and frequency of equivalence classes.
parameter of a “function” that does a sanity check on the number (11-check) and returns the corrected number when necessary. In the call both types become subtypes of the input type of that function. After the call, the output is moved back so the output type becomes a subtype of RELATION-ID and MORTGAGE-ID. Since the input and output type for this function is the same, RELATION-ID becomes a subtype MORTGAGE-ID and vice versa so they are considered to be equivalent.

We can solve such pollution by deriving an additional cast relation during fact extraction. Whenever a variable of a supertype is assigned to a variable of a subtype, we derive that the supertype is casted into the subtype. Furthermore, we can use data flow analysis to derive what are the input- and what are the output- parameters of a function. This mechanism also allows us to deal with explicit casts as, for example, can occur in C programs.

5.6 Related Work

A principal source of inspiration to us was Lackwit, a tool for understanding C programs by means of type inference [Oj97]. Lackwit performs a type analysis of variables based on their usage. The analysis results are used to find abstract data types, detect abstraction violations, identify unused variables, and to detect certain types of errors. New in our work is not only the significantly different source language, but also the use of subtyping for dealing with pollution, and the use of type inference to classify literals. Another paper discussing type inference for C is by Sniff and Reps [SR96], who use inferred types to generalize C functions to C++ function templates.

Our approach is also related to various tools for the analysis and correction of the year 2000 problem where date seeds are tracked through the statements in a program [HP96, NBOS99, KMUO98]. In year 2000 analysis, preventing pollution (called classification noise in [KMUO98]) is an important issue. We have not been able to find papers that propose the use of subtyping to do this. This chapter adds a strong empirical basis for using subtyping to reduce pollution.

Recently, two papers appeared which rely on type theory to deal with the year 2000 problem [RFT99, EHM+99]. These papers do not address the problem of pollution, but do contain an interesting algorithm for propagating type information through the elements of aggregate data structures such as arrays or records. Our approach essentially treats each aggregate as a single scalar value. If, however, two entire records are moved, types can also be propagated through the individual fields. Such moves may even cross field boundaries if the two records differ in record layout, or if records are aliased using COBOL’s redefine statement. [RFT99, EHM+99] provide an algorithm that finds a minimal splitting of all aggregates such that types can be correctly propagated for the resulting “atoms”. In the previous chapter (Chapter 4), we proposed a weaker method using an inference rule called substructure completion, which just ensures that type equivalences between structurally equivalent aggregates are propagated to the components. As discussed later, we plan to combine this algorithm with our type inferencing approach to see if we can further improve the accuracy.

Chen et al. [CTJ+94] describe a (semi)-automatic approach for COBOL variable
classification. They distinguish a fixed set of categories, such as input/output, constant, local variable etc., and each variable is placed into one or more of these classes. They provide a set of rules to infer this classification automatically, essentially using data flow analysis. Their technique is orthogonal to ours: the types we infer can be used for both local and global variables, for variables that are used for databases access and for those that are not, etc.

Newcomb and Kotik [NK95] describe a method for migrating COBOL to object orientation. Their approach takes all level 01 records as starting point for classes. Records that are structurally equivalent, i.e., matching in record length, field offset, field length, and field picture, but possibly with different names, are called “aliases”. According to Newcomb and Kotik, “for complex records consisting of 5-10 or more fields, the likelihood of false positives is relatively small, but for smaller records the probability of false positives is fairly large.” [NK95, p. 240]. Our way of type inferencing may help to reduce this risk, as it provides a complementary way of grouping such 01 level records together based on usage.

Wegman and Zadek [WZ91] describe a method to detect whether the value of a variable occurring at a particular point in the program is constant and, if so, what that value is. Merlo et al. [MGHDM95] describe an extension of this method that allows detection of all constants that can be the value of a particular variable occurrence. This differs from our approach which finds all constants that can be assigned to any variable of a given type. Furthermore, the methods described in both papers take the flow of control into account where as our approach is flow-insensitive (control flow is completely ignored). Consequently, their results are more precise (e.g., we report constants that are used in dead code) but their approach is also more expensive.

Gravley and Lakhotia [GL96] identify enumeration types that are modeled using \#define preprocessor directives. Their approach is orthogonal to ours since they group constants which are defined “in the same context” (i.e., close to each other in the program text) whereas we group constants based on their usage in the source code.

Concerning the tool used for implementing type inference, there is second suite of relational algebra tools available from Philips, as described by [FKO98]. An alternative to the use of relational algebra, is to view type inferencing as a graph traversal problem. A graph querying formalism such as GReQL [KW99] can then be used to compute the closures of several relations. A second alternative is to use one of several program analysis frameworks. Of particular interest is BANE, the Berkely ANalysis Engine as described by [AFFS98]. BANE provides constraint specification and resolution components, which can be to experiment with program analyses in which properties of types are expressed as constraints.

5.7 Concluding Remarks

5.7.1 Contributions

In this chapter, we carried out an empirical study into the relations between variables established by COBOL type inference. We argued that such relations are necessary in a
Cobol setting: Cobol programs contain a large number of variable declarations (50% of a program's lines of code consist of variable declarations), but only half of these variables are actually used. Inferred types help to understand how variables are used and how they are related to each other.

The empirical study aimed at finding out how the problem of pollution is handled by the use of subtyping. Pollution occurs when a counter-intuitive type equivalence is found for two variables. Since it is impossible to check by hand the hundreds of type equivalences classes found by type inferencing, we devised a suite of numeric measurements directing us to potential pollution spots.

We manually inspected, and explained, the results from these measurements. Of all inferred type equivalence classes, only one contains a clear case of pollution: in Section 5.5.2 we discuss how type casts could help to address this problem.

To conduct our experiments, we developed a tool environment permitting all sorts of experiments. An important new element is the use of relational algebra to do the inference of type conclusions from derived type facts. Moreover, we devised a modular approach to infer types for variables playing a system-wide role. Thanks to this modular approach, system-level type analysis scales up to large systems.

5.7.2 Future Work

Now that we have all machinery for conducting large scale type inferencing experiments in place, and now that we understand which data to collect, we are in a position to apply type inference to more Cobol systems. We intend to do this, and collect statistical data on other case studies as well.

A question of interest is how we can further improve the accuracy of our type inferencing approach by deconstructing aggregates into "atoms" of the appropriate size, following the algorithm of [RFT99, EHM+99]. An important problem to be solved is how to combine this algorithm with subtyping, in order to minimize the danger of pollution.

At the moment, we are conducting experiments with new ways of presenting type relations. One way is to visualize type relations as graphs. We are integrating such graphs with the Cobol documentation generator covered in [DK99a]. This generator provides an abstract view of Cobol systems, highlighting essential relationships between programs, databases, screens, etc. Types play an important role in this form of documentation, as they help to characterize the interfaces of Cobol modules, or the interplay of variables occurring in the Cobol programs.

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4 This work on the presentation and visualization of type relations in the context of supporting software exploration and re-documentation is described in Chapter 7.