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Foreword

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Introduction

Background

An essential element of secure coding in the C programming language is a set of well-documented and enforceable coding rules. The rules specified in this Technical Specification apply to analyzers, including static analysis tools and C language compiler vendors that wish to diagnose insecure code beyond the requirements of the language standard. All rules are meant to be enforceable by static analysis.

The application of static analysis to security has been done in an ad hoc manner by different vendors, resulting in nonuniform coverage of significant security issues. This specification enumerates secure coding rules and requires analysis engines to diagnose violations of these rules as a matter of conformance to this specification. These rules may be extended in an implementation-dependent manner, which provides a minimum coverage guarantee to customers of any and all conforming static analysis implementations.

The largest underserved market in security is ordinary, non-security-critical code. The security-critical nature of code depends on its purpose rather than its environment. The UNIX finger daemon (`fingerd`) is an example of ordinary code, even though it may be deployed in a hostile environment. A user runs the client program, `finger`, which sends a user name to `fingerd` over the network, which then sends a reply indicating whether the user is logged in and a few other pieces of information. The function of `fingerd` has nothing to do with security. However, in 1988, Robert Morris compromised `fingerd` by triggering a buffer overflow, allowing him to execute arbitrary code on the target machine. The Morris worm could have been prevented from using `fingerd` as an attack vector by preventing buffer overflows, regardless of whether `fingerd` contained other types of bugs.

By contrast, the function of `/bin/login` is purely related to security. A bug of any kind in `/bin/login` has the potential to allow access where it was not intended. This is security-critical code.

Similarly, in safety-critical code, such as software that runs an X-ray machine, any bug at all could have serious consequences. In practice, then, security-critical and safety-critical code have the same requirements.

There are already standards that address safety-critical code and therefore security-critical code. The problem is that because they must focus on preventing essentially all bugs, they are required to be so strict that most people outside the safety-critical community do not want to use them. This leaves ordinary code like `fingerd` unprotected.

This Technical Specification has two major subdivisions:

— preliminary elements (Clauses 1–4) and

— secure coding rules (Clause 5).

Each secure coding rule in Clause 5 has a separate numbered subsection and a unique section identifier enclosed in brackets (for example, [ptrcomp]). The unique section identifiers are mainly for use by other documents in identifying the rules should the section numbers change because of the addition or elimination of a rule. These identifiers may be used in diagnostics issued by conforming analyzers, but analyzers are not required to do so.

Annexes provide additional information. Annex C (informative) Related Guidelines and References identifies related guidelines and references per rule. A bibliography lists documents referred to during the preparation of this Technical Specification.

The rules documented in this Technical Specification do not rely on source code annotations or assumptions of programmer intent. However, a conforming implementation may take advantage of annotations to inform the analyzer. The rules, as specified, are reasonably simple, although complications can exist in identifying exceptions. An analyzer that conforms to this Technical Specification should be able to analyze code without excessive false positives, even if the code was developed without the expectation that it would be analyzed. Many analyzers provide methods that eliminate the need to research each diagnostic on every invocation of the analyzer. The implementation of such a mechanism is encouraged but not required. This Technical Specification assumes that an analyzer's visibility extends beyond the boundaries of the current function or translation unit being analyzed (see Annex A (informative) Intra- to Interprocedural Transformations).

Completeness and soundness

The rules specified in this Technical Specification are designed to provide a check against a set of programming flaws that are known from practical experience to have led to vulnerabilities. Although rule checking can be performed manually, with increasing program complexity, it rapidly becomes infeasible. For this reason, the use of static analysis tools is recommended.

It should be recognized that, in general, determining conformance to coding rules is computationally undecidable. The precision of static analysis has practical limitations. For example, the *halting theorem* of Computer Science states that there are programs whose exact control flow *cannot* be determined statically. Consequently, any property dependent on control flow—such as halting—may be indeterminate for some programs. A consequence of this undecidability is that it may be impossible for *any* tool to determine statically whether a given rule is satisfied in specific circumstances. The widespread presence of such code may also lead to unexpected results from an analysis tool. Annex D (informative) Decidability of Rules provides information on the decidability of rules in this Technical Specification.

However checking is performed, the analysis may generate

— false negatives: Failure to report a real flaw in the code is usually regarded as the most serious analysis error, as it may leave the user with a false sense of security. Most tools err on the side of caution and consequently generate false positives. However, there may be cases where it is deemed better to report some high-risk flaws and miss others than to overwhelm the user with false positives.

— false positives: The tool reports a flaw when one does not exist. False positives may occur because the code is sufficiently complex that the tool cannot perform a complete analysis. The use of features such as function pointers and libraries may make false positives more likely.

To the greatest extent feasible, an analyzer should be both complete and sound with respect to enforceable rules. An analyzer is considered sound with respect to a specific rule if it cannot give a false-negative result, meaning it finds all violations of a rule within the entire program. An analyzer is considered complete if it cannot issue false-positive results, or false alarms. The possibilities for a given rule are outlined in Table 1.

Table 1 — Completeness and soundness

	False positives		
		Y	N
False negatives	N	Sound with false positives	Complete and sound
	Y	Unsound with false positives	Complete and unsound

The degree to which conforming analyzers minimize false-positive diagnostics is a quality of implementation issue. In other words, quantitative thresholds for false positives and false negatives are outside the scope of this Technical Specification.

Security focus

The purpose of this Technical Specification is to specify analyzable secure coding rules that can be automatically enforced to detect security flaws in C-conforming applications. To be considered a security flaw, a software bug must be triggerable by the actions of a malicious user or attacker. An attacker may trigger a bug by providing malicious data or by providing inputs that execute a particular control path that in turn executes the security flaw. Implementers are encouraged to distinguish violations that operate on untrusted data from those that do not.

Taint analysis

Taint and tainted sources

Certain operations and functions have a domain that is a subset of the type domain of their operands or parameters. When the actual values are outside of the defined domain, the result might be either undefined or at least unexpected. If the value of an operand or argument may be outside the domain of an operation or function that consumes that value, and the value is derived from any external input to the program (such as a command-line argument, data returned from a system call, or data in shared memory), that value is *tainted*, and its origin is known as a *tainted source*. A tainted value is not necessarily known to be out of the domain; rather, it is not known to be in the domain. Only values, and not the operands or arguments, can be tainted; in some cases, the same operand or argument can hold tainted or untainted values along different paths. In this regard, *taint* is an attribute of a value originating from a tainted source.

Restricted sinks

Operands and arguments whose domain is a subset of the domain described by their types are called *restricted sinks*. Any pointer arithmetic operation involving an integer operand is a restricted sink for that operand. Certain parameters of certain library functions are restricted sinks because these functions perform address arithmetic with these parameters, or control the allocation of a resource, or pass these parameters on to another restricted sink. All string input parameters to library functions are restricted sinks because it is possible to pass in a character sequence that is not null terminated. The exceptions are `strncpy` and `strncpy_s`, which explicitly allow the source character sequence not to be null-terminated. For purposes of this Technical Specification, we regard `char *` as a reference to a null-terminated array of characters.

Propagation

Taint is propagated through operations from operands to results unless the operation itself imposes constraints on the value of its result that subsume the constraints imposed by restricted sinks. In addition to operations that propagate the same sort of taint, there are operations that propagate taint of one sort of an operand to taint of a different sort for their results, the most notable example of which is `strlen` propagating the taint of its argument with respect to string length to the taint of its return value with respect to range.

Although the exit condition of a loop is not normally itself considered to be a restricted sink, a loop whose exit condition depends on a tainted value propagates taint to any numeric or pointer variables that are increased or decreased by amounts proportional to the number of iterations of the loop.

Sanitization

To remove the taint from a value, it must be *sanitized* to ensure that it is in the defined domain of any restricted sink into which it flows. Sanitization is performed by *replacement* or *termination*. In replacement, out-of-domain values are replaced by in-domain values, and processing continues using an in-domain value in place of the original. In termination, the program logic terminates the path of execution when an out-of-domain value is detected, often simply by branching around whatever code would have used the value.

In general, sanitization cannot be recognized exactly using static analysis. Analyzers that perform taint analysis usually provide some extralinguistic mechanism to identify sanitizing functions that sanitize an argument (passed by address) in place, return a sanitized version of an argument, or return a status code indicating whether the argument is in the required domain. Because such extralinguistic mechanisms are outside the scope of this specification, this Technical Specification uses a set of rudimentary definitions of sanitization that is likely to recognize real sanitization but might cause nonsanitizing or ineffectively sanitizing code to be misconstrued as sanitizing. The following definition of sanitization presupposes that the analysis is in some way maintaining a set of constraints on each value encountered as the simulated execution progresses: *a given path through the code sanitizes a value with respect to a* *given restricted sink if it restricts the range of that value to a subset of the defined domain of the restricted sink type*. For example, sanitization of signed integers with respect to an array index operation must restrict the range of that integer value to numbers between zero and the size of the array minus one.

This description is suitable for numeric values, but sanitization of strings with respect to content is more difficult to recognize in a general way.

Tainted source macros

The function-like macros `GET_TAINTED_STRING` and `GET_TAINTED_INTEGER` defined in this section are used in the examples in this Technical Specification to represent one possible method to obtain a tainted string and tainted integer.

```
#define GET_TAINTED_STRING(buf, buf_size)     \
  do {                                         \
    const char *taint = getenv("TAINT");       \
    if (taint == 0) {                          \
      exit(1);                                 \
    }                                          \
                                               \
    size_t taint_size = strlen(taint) + 1;     \
    if (taint_size > buf_size) {               \
      exit(1);                                 \
    }                                          \
                                               \
    strncpy(buf, taint, taint_size);           \
  } while (0)

#define GET_TAINTED_INTEGER(type, val)              \
  do {                                               \
    const char *taint = getenv("TAINT");             \
    if (taint == 0) {                                \
      exit(1);                                       \
    }                                                \
                                                     \
    errno = 0;                                       \
    long tmp = strtol(taint, 0, 10);                 \
    if ((tmp == LONG_MIN || tmp == LONG_MAX) &&      \
        errno == ERANGE)                             \
      ; /* retain LONG_MIN or LONG_MAX */            \
    if ((type)-1 < 0) {                              \
      if (tmp < INT_MIN)                             \
        tmp = INT_MIN;                               \
      else if (tmp > INT_MAX)                        \
        tmp = INT_MAX;                               \
    }                                                \
    val = tmp;                                       \
  } while (0)
```