OpenSSL FIPS Object Module
Version 1.2
By the
Open Source Software Institute
http://www.oss-institute.org/

OpenSSL FIPS 140-2 User Guide
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1. Introduction

This document is a guide to the use of the OpenSSL FIPS Object Module, a software component intended for use with the OpenSSL product. It is a companion document to the OpenSSL FIPS 140-2 Security Policy document submitted to NIST as part of the FIPS 140-2 validation process. It is intended as a technical reference for developers using, and system administrators installing, the OpenSSL FIPS software, for use in risk assessment reviews by security auditors, and as a summary and overview for program managers. It is intended as a guide for annotation and more detailed explanation of the Security Policy, and not as a replacement. In the event of a perceived conflict or inconsistency between this document and the Security Policy the latter document is authoritative as only it has been reviewed and approved by the Cryptographic Module Validation Program (CMVP), a joint U.S. - Canadian program for the validation of cryptographic products (http://csrc.nist.gov/cryptval/).

Familiarity with the OpenSSL distribution and library API (Application Programming Interface) is assumed. This document is not a tutorial on the use of OpenSSL and it only covers issues specific to the FIPS 140-2 validation. For more information on the use of OpenSSL in general see the many other sources of information such as http://openssl.org/docs/ and Network Security with OpenSSL (Reference 4).

The Security Policy document (Reference 1) is available online at the NIST Cryptographic Module Validation website, http://csrc.nist.gov/groups/STM/cmvp/documents/140-1/140sp/140sp1051.pdf.

For more information on OSSI see http://www.oss-institute.org/. For more information on the OpenSSL project see http://openssl.org/. For more information on NIST and the cryptographic module validation program, see http://csrc.nist.gov/cryptval/.

For information and announcements regarding current and future OpenSSL related validations see http://openssl.org/docs/fips/fipsnotes.html.
2. Background

For the purposes of FIPS 140-2 validation the OpenSSL FIPS Object Module v1.2 is defined as a specific discrete unit of binary object code (the “FIPS Object Module”) generated from a specific set and revision level of source files embedded within a source distribution. These platform portable source files are compiled to create this object code in an isolated and separated form that is used to provide a cryptographic API (Application Programming Interface) to external applications. The term FIPS Object Module elsewhere in this document refers to this OpenSSL FIPS Object Module object code.

The FIPS Object Module provides an API for invocation of FIPS approved cryptographic functions from calling applications, and is designed for use in conjunction with standard OpenSSL 0.9.8 distributions beginning with 0.9.8j. Note: OpenSSL 1.0.0 is not supported for use with the OpenSSL FIPS Object Module. These standard OpenSSL 0.9.8 source distributions support the original non-FIPS API as well as a FIPS mode in which the FIPS approved algorithms are implemented by the FIPS Object Module and non-FIPS approved algorithms other than DH are disabled by default. These non-validated algorithms include, but are not limited to, Blowfish, CAST, IDEA, RC-family, and non-SHA message digest and other algorithms.

The FIPS Object Module was designed and implemented to meet FIPS 140-2 requirements. As such, there are no special steps required to ensure FIPS 140-2 compliant operation of the FIPS Object Module, other than building, loading, and initializing the FIPS approved and HMAC-SHA-1 digest verified source code. This process of generating the application executable object from source code for all supported platforms¹ is documented in detail in sections 4 and 5.

The FIPS Object Module provides confidentiality, integrity and message digest services. The FIPS Object Module supports the following algorithms: Triple DES, AES, RSA (for digital signatures), DH, DSA, SHA-1, SHA-224, SHA-256, SHA-384, SHA-512, and HMAC-SHA-1, HMAC-SHA-224, HMAC-SHA_256, HMAC-SHA-384, HMAC-SHA-512. The FIPS Object Module supports an ANSI X9.31 compliant pseudo-random number generator.

2.1 Terminology

During the course of the OpenSSL validation it became clear that a mapping between the terminology used by the OpenSSL developers and cryptographers and that of the CMVP and FIPS 140-2 specialists. In this section some of these distinctions are discussed.

Approved Mode

¹By definition, for all platforms to which the validation can be extended. Per the requirements of the Security Policy, any change to the documented build process renders the result non-FIPS approved
The FIPS 140-2 Approved Mode of Operation is the operation of the FIPS Object Module when all requirements of the Security Policy have been met and the software has successfully performed the power-up and self test operation (invocation of the FIPS_mode_set() function call). In this document this Approved Mode is referred to simply as FIPS mode.

Crypto Officer

System administrator. The FIPS 140-2 Crypto Officer\(^3\) is the person having the responsibility and access privileges to install, configure, and initialize the cryptographic software.

HMAC-SHA-1 digest

A HMAC-SHA-1 digest of a file using a specific HMAC key (the ASCII string “etaonrishdlcupfm”). Such digests are referred to in this document as “digests” or “fingerprints”. The digests are used for integrity checking to verify that the software in question has not been modified or corrupted from the form originally used as the basis of the FIPS 140-2 validation.

Note that the PGP or GPG signatures traditionally used to check the integrity of open source software distributions are not a component of any of the FIPS 140-2 integrity checks.

Module

The concept of the cryptographic module is an important one for FIPS 140-2, with subtle nuances. In the context of FIPS 140-2 “cryptographic module” is often referred to simply as “module”. That term is capitalized in this document as a reminder that it has a somewhat different meaning than assumed by software developers outside of a FIPS 1340-2 context.

Conceptually the Module is the binary object code and data in the FIPS Object Module for a running process. This binary object as it resides in memory is verified by the FIPS integrity test.

Note that traditionally the executable (or shared library) file on disk corresponding to this Module as a running process is also considered by the CMVP to be a Module\(^4\); an integrity check of the entire executable file on disk prior to memory mapping is considered acceptable as long as that executable file does not contain any extraneous\(^5\) software. In this traditional case the specific executable file is submitted for testing and thus the precise content (as a bit string) is known in advance.

\(^3\)The term “Officer” does not imply a requirement for a military or government official, although some military or government organizations may choose to restrict the performance of this system administration role to certain official capacities.

\(^4\)Presumably because the transformations of the disk resident file contents performed by the runtime loader are considered to be well understood and sufficiently minimal.

\(^5\)The definition of what constitutes “extraneous” is not formally specified and subject to interpretation.
In the case of the FIPS Object Module only source code is submitted for validation testing, so the bit string value of the binary object code in memory cannot be known in advance. A chain of checks beginning with the source code and continuing with each step in the transformation of that source code into a running process is established to provide the equivalent check to that used by more traditional object based validations.

The chain of checks works backwards from the software as resident in memory for a process to the executable program file from which the process was created (the existing precedent), then to the FIPS Object Module used to link the program file, and finally to the original source files used to create the FIPS Object Module. Each of those stages can be thought of as antecedents of the Module, and the integrity of each needs to be verified to assure the integrity of the Module.

2.2 The FIPS Module and Integrity Test

The FIPS Object Module is generated in binary file form, with an embedded pre-calculated HMAC-SHA-1 digest covering the module as it is loaded into application address space. The Module integrity check consists of recalculating that digest from the memory areas and comparing it to the embedded value which necessarily resides in an area not included in the calculated digest. This “in-core hashing” integrity test is designed to be both executable format independent and fail-safe.

For this scenario the Module is the text and data segments as mapped into memory for the running application.

The term Module is also used, less accurately, to designate the antecedent of that memory mapped code and data, the FIPS Object Module file residing on disk.

The FIPS Object Module is generated from source code, so the integrity of that source must also be verified. The single runtime digest check typical of pre-built binary files is replaced by a chain of digest checks in order to validate that the running code was in fact generated from the original source code. As before the term Module properly designates the text and data segments mapped into memory, but is also more loosely used to reference several levels of antecedents. These levels are discussed below.

2.3 The FIPS Integrity Test

The FIPS 140-2 standard requires an integrity test of the Module to verify its integrity at initialization. In addition to the requirement that the integrity test validate that the FIPS Object

---

6Specifically, the text and read-only data segments which constitute the initialized components of the module.
7If the digest value resided in the data area included in the calculation of that digest, the calculated value of the digest would itself be an input into that calculation.
Module code and data have not changed, two additional implicit requirements for the integrity test were identified during the validation process.

2.3.1 Requirement for Exclusive Integrity Test

An integrity test that is merely guaranteed to fail if any of the cryptographic module software changes is not sufficient. It is also necessary that the integrity test not fail if the cryptographic module software is not directly corrupted, even though the application referencing the cryptographic module may be damaged with unpredictable consequences for the correct functioning of that application. Another way of looking at this is that as application failures are out of scope of the integrity test there needs to be some level of assurance that changes to application software not affect the cryptographic module integrity test

This requirement is met with an in-core integrity test that carefully excludes any extraneous object code from the digest calculation and verification.

2.3.2 Requirement for Fixed Object Code Order

The relative order of all object code components within the module must be fixed and invariant. The usual linking process does not care about the relative order of individual object modules, e.g. both

```
gcc -o runfile alpha.o beta.o gamma.o
```

and

```
gcc -o runfile beta.o alpha.o gamma.o
```

produce functionally identical executable files. Likewise, the order of object modules in a static link library is irrelevant:

```
ar r libxxx.a alpha.o beta.o gamma.o
```

and

```
ar r libxxx.a beta.o alpha.o gamma.o
```

produce interchangeable link libraries, and a given application may not incorporate all of the object modules contained with the link library when resolving references. For the FIPS Object Module it was required that any such omission or rearrangement of the Module object modules during the application creation process not occur. This requirement is satisfied by simply compiling all the source code into a single monolithic object module:

```
ld -r -o fipscanister.o fips_start.o ... fips_end.o
```

---

8This assurance was given by showing during testing that corruption of code or data outside of the memory area containing the FIPS Object Module did not result in an integrity test failure.
with all the object modules between the \texttt{fips\_start.o} and \texttt{fips\_end.o} modules that define the low and high boundaries of a monolithic object module. All subsequent reference to this monolithic object module will preserve the relative order, and presence, of the original object code components.

2.4 \textbf{The File Integrity Chain}

Most validated products consisting of a pre-built binary executable implement the module integrity check as a digest check over portions of that executable file or the corresponding memory mapped image. For the FIPS Object Module the module integrity check instead takes the form of a chain of digest checks beginning with the source files used for the CMVP validation testing. Note that while this chain of checks is more complex, it provides much more visibility for independent verification. In the case of validated pre-built binary executables neither the FIPS 140-2 CMVP test lab nor the end user has an independent means of directly verifying that the vendor supplied software is actually derived from the validated code. With the FIPS Object Module the prospective user can independently verify that the runtime executable does indeed directly derive from the same source that was the basis of the validation.

2.4.1 \textbf{Source File (Build Time) Integrity}

“Build time” is when the FIPS Object Module is created from the OpenSSL FIPS source distribution, in accordance with the \textit{Security Policy}.

The first file integrity check occurs at build time when the HMAC-SHA-1 digest of the distribution file is calculated and compared to the stored value published in the \textit{Security Policy (Appendix B)}.

Because the source files reside in this specific distribution and cannot be modified these source files are referred to as \textit{sequestered} files.

Note that a means to calculate the HMAC-SHA-1 digest is required in order to perform this integrity check. A “bootstrap” standalone HMAC-SHA-1 utility, \texttt{fips\_standalone\_sha1}, is included in the distribution. This utility is generated first before the sequestered files are compiled in order to perform the integrity check. Appendix \texttt{C} gives an example of an equivalent utility.

2.4.2 \textbf{Object Module (Link Time) Integrity}

“Link time” is when the application is linked with the previously built and installed FIPS Object Module to generate an executable program.

The build process described in the \textit{Security Policy} results in the creation of an object module, \texttt{fipscanister.o}, and a matching digest file, \texttt{fipscanister.o.sha1}. This FIPS Object
Module contains the object code corresponding to the sequestered source files (object code for FIPS specific functions such as FIPS_mode_set() and for the algorithm implementations).

The link time integrity check occurs when the FIPS Object Module is used to create an application executable object (binary executable or shared library). The digest stored in the installed file fipscanister.o.sha1 must match the digest calculated for the fipscanister.o file.

### 2.4.3 Application Executable Object (Run Time) Integrity

Application “run time” occurs when the previously built and installed application program is invoked. Unlike the previous step this invocation is usually performed repeatedly.

The runtime integrity check occurs when the application attempts to enable FIPS mode via the FIPS_mode_set() function call. The digest embedded within the object code from fipscanister.o must match the digest calculated for the memory mapped text and data areas.

### 2.5 Relationship to the OpenSSL API

The FIPS Object Module is designed for use with the OpenSSL API. Applications linked with the FIPS Object Module and with the separate OpenSSL libraries can use both the FIPS validated cryptographic functions of the FIPS Object Module and the high level functions of OpenSSL.

First, some important definitions to avoid confusion. The **FIPS Object Module** is the special monolithic object module built from the special source distribution identified in the Security Policy. It is not the same as the OpenSSL product or any specific official OpenSSL distribution release.

A version of the OpenSSL product that is suitable for reference by an application along with the FIPS Object Module is a **FIPS compatible OpenSSL**.

When the FIPS Object Module and a FIPS compatible OpenSSL are separately built and installed on a system, the combination is referred to as a **FIPS capable OpenSSL**.

<table>
<thead>
<tr>
<th>Summary of definitions</th>
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<tr>
<td>The <strong>FIPS Object Module</strong> is the FIPS 140-2 validated module described in the Security Policy</td>
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<tr>
<td>A <strong>FIPS compatible OpenSSL</strong> is a version of the OpenSSL product that is designed for compatibility with the FIPS Object Module API</td>
</tr>
<tr>
<td>A <strong>FIPS capable OpenSSL</strong> is the combination of the separately installed <strong>FIPS Object Module</strong> along with a <strong>FIPS compatible OpenSSL</strong>.</td>
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*Table 2.5*
The OpenSSL libraries, when built from a standard OpenSSL distribution with the “fips” configuration option for use with the FIPS Object Module, will contain the usual non-FIPS algorithms and non-cryptographic supporting functions, and the non-FIPS algorithm disabling restrictions.

Note the object modules comprising the FIPS Object Module could easily be incorporated directly in the OpenSSL `libcrypto.a` library, but for the fact that such a combination (linking to a static library) is specifically forbidden by FIPS 140-2 and the CMVP.

Various non-FIPS algorithms such as Blowfish, IDEA, CAST, MD2, etc. will be included in the OpenSSL libraries (depending on the `./config` options specified in addition to `fips`). For applications that do not care about FIPS 140-2 the resulting libraries are drop-in compatible with the libraries generated without the `fips` option (a deliberate design decision to encourage wider availability and use of FIPS 140-2 validated algorithms). The converse is not true; a non-FIPS compatible OpenSSL library cannot be substituted for the FIPS compatible library for an application using FIPS mode because the FIPS specific function calls, in particular `FIPS_mode_set()`, will not be present.

Applications that do wish to use FIPS mode must call the `FIPS_mode_set()` function, and after the runtime FIPS mode initialization the non-FIPS algorithms are disabled by default.

In this sense the combination of the FIPS Object Module and the usual OpenSSL libraries constitutes a “FIPS capable API”, capable of being used for either FIPS mode operation or for conventional non-FIPS purposes as before.

### 2.6 FIPS Mode of Operation

The FIPS Object Module together with a compatible version of the OpenSSL product can be used in the generation of both FIPS mode and conventional applications. The enabling of runtime FIPS mode is explicitly performed by a function call.

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*Actually, to encourage use of `fipscanister.o` even in non-FIPS mode application, a copy is incorporated into `libcrypto.a`, but special care is taken to preclude its usage in FIPS enabled applications. The `fipsld` utility provided in the FIPS compatible OpenSSL distributions prevents that usage as follows. In static link context that is achieved by referencing the official `fipscanister.o` first on the command line, and in dynamic link context by temporarily removing it from `libcrypto.a`. This removal is necessary because dynamic linking is commonly accompanied by `-whole-archive`, which would force both copies of `fipscanister.o` into the shared library. Note the integrity check is designed as a failsafe precaution in the event of link errors -- even if two copies are included into the application in error, the integrity check will prevent the use of one copy for the integrity test and the other for the actual implementation of cryptography. In other words, if both the official `fipscanister.o` and the unvalidated version that is embedded in `libcrypto.a` both end up in an executable binary, and if `FIPS_mode_set()` returns success, the unvalidated copy will not be used for cryptography.*
2.6.1 Initialization

Only one initialization call, `FIPS_mode_set()`, is required to operate the FIPS Object Module in a FIPS 140-2 Approved mode, referred to herein as "FIPS mode". When the FIPS Object Module is in FIPS mode all security functions and cryptographic algorithms are performed in Approved mode. Use of the `FIPS_mode_set()` function call is described in §5.

A power-up self-test is performed automatically by the `FIPS_mode_set()` call, or optionally at any time by the `FIPS_selftest()` call (see Appendix D). If any power-up self-test fails the internal global error flag `FIPS_selftest_fail` is set and subsequently tested to prevent invocation of any cryptographic function calls.

The internal global flag `FIPS_mode` is set to FALSE indicating non-FIPS mode by default. The `FIPS_mode_set()` function verifies the integrity of the runtime executable using a HMAC-SHA-1 digest computed at build time. If the digests match the power-up self-test is then performed. If the power-up self-test is successful `FIPS_mode_set()` sets the `FIPS_mode` flag to TRUE and the FIPS Object Module is in FIPS mode.

2.6.2 Algorithms Available in FIPS Mode

Only the algorithms listed in table 4.5a of the Security Policy are allowed in FIPS mode. Note that Diffie-Hellman and RSA are allowed in FIPS mode for key agreement and key establishment even though they are "Non-Approved" for that purpose. RSA for sign and verify is "Approved" and hence also allowed, along with all the other Approved algorithms listed in that table.

By design, the OpenSSL API attempts to disable non-FIPS algorithms, when in FIPS mode, at the EVP level and via most low level function calls. Failure to check the return code from low level functions could result in unexpected behavior. Note also that sufficiently creative or unusual use of the API may still allow the use of non-FIPS algorithms. The non-FIPS algorithm disabling is intended as a aid to the developer in preventing the accidental use of non-FIPS algorithms in FIPS mode, and not as an absolute guarantee. It is the responsibility of the application developer to ensure that no non-FIPS algorithms are used when in FIPS mode.

OpenSSL provides a mechanism, the "ENGINE" component, for interfacing with external cryptographic devices such as accelerator cards. This mechanism is not disabled in FIPS mode. In general, if a FIPS validated cryptographic device is used with OpenSSL in FIPS mode so that all cryptographic operations are performed either by the device or the FIPS Object Module, then the result is still FIPS compliant. In general, the OpenSSL FIPS 140-2 validation still holds true in the case that other separately FIPS 140-2 validated hardware or software modules are utilized in conjunction with the OpenSSL FIPS validated cryptographic module.
However, if any cryptographic operations are performed by a non-FIPS validated device the result is not FIPS compliant. It is the responsibility of the application developer to ensure that any use of devices via the OpenSSL ENGINE support are for FIPS validated devices only (when in FIPS mode).
3. Compatible Platforms

The FIPS Object Module was built from source and tested on specific hardware/software environments (See the Security Policy). The FIPS Object Module maintains vendor affirmed FIPS 140-2 compliance on other operating systems provided that the conditions described in Section 4 of the Security Policy apply.

The FIPS Object Module is designed to run on a wide range of hardware and software platforms. Any such computing platform that meets the conditions in the Security Policy can be used to host a FIPS 140-2 validated FIPS Object Module provided that module is generated in accordance with the Security Policy. At the time the OpenSSL FIPS Object Module v 1.2 was developed all Unix®-like environments supported by the full OpenSSL distribution were also supported by the FIPS validated source files included in the FIPS Object Module. However, successful compilation of the FIPS Object Module for all such platforms was not verified. If any platform specific compilation errors occur that can only be corrected by modification of the FIPS distribution files (see Appendix B of the Security Policy) then the FIPS Object Module will not be validated for that platform. Note also that future releases of OpenSSL may support additional platforms requiring new or changed source from that of the current FIPS source distribution, in which case use of OpenSSL with the FIPS Object Module will not be validated for those new platforms.

By default, the FIPS Object Module software utilizes assembly language optimizations for some supported platforms. Currently assembler language code residing within the cryptographic module boundary is used only for the x86/Intel® ELF machine architecture. The FIPS Object Module build process will automatically select and include these assembly routines by default when performed on a x86 platform. This assembly language code was included in the validation testing and hence a FIPS Object Module built using the x86/Intel® assembly language routines is a FIPS 140-2 validated FIPS Object Module.

3.1 Build Environment Requirements

The platform portability of the FIPS Object Module source code is contingent on several basic assumptions about the build environment:

1. The environment is either a) “Unix®-like” with a make command and a ld command with a “-r” (or “-i”) option, or Microsoft Windows.

Creation of the monolithic FIPS Object Module fipscanister.o requires a linker capable of merging several object modules into one. This requirement is known to be a problem with VMS and some older versions of LD.EXE under Windows®.

10UNIX is a registered trademark of The Open Group
11Intel is a registered trademark of the Intel Corporation
2. The compiler is required to place variables declared with the `const` qualifier in a read-only segment. This behavior is true of almost all modern compilers. If the compiler fails to do so the condition will be detected at run-time and the in-core hashing integrity check will fail.

3. The platform supports execution of compiled code on the build system (i.e. build host and target are binary compatible); or the patch openssl-fips1.2.crossbuild.diff.gz as noted in the Security Policy is applied and build option “U2” is used for cross-compilation support where the in core hash is calculated on the build host.

### 3.2 Known Supported Platforms

The generation of a monolithic object module and the in-core hashing integrity test have been verified to work with both static and shared builds on the following platforms (note the ./config “shared” option is forbidden by the terms of the validation when building a FIPS validated module, but the fipscanister.o object module can be used in a shared library\(^\text{12}\)). Note a successful build of the FIPS module may be possible on other platforms; only the following were explicitly tested as of the date this document was written:

- Linux\(^\text{13}\) on x86, x86_64, IA64
- SPARC\(^\text{14}\) Solaris\(^\text{14}\), both 32 and 64 bit ABIs
- x86 Solaris\(^\text{15}\) on 32 and 64 bit ABIs
- IRIX\(^\text{15}\) 6.5, n32, and 64-bit ABIs
- Tru64\(^\text{16}\)
- HP-UX\(^\text{17}\), 32 and 64 bit PA-RISC\(^\text{17}\), 32 and 64 bit IA64
- Mac OS X\(^\text{18}\) on PowerPC\(^\text{19}\)
- Windows\(^\text{20}\) with Cygwin\(^\text{21}\) and Mingw

---

\(^{12}\)A convenient way of generating a shared library containing fipscanister.o is discussed in Appendix B
\(^{13}\)Linux is the registered trademark of Linus Torvalds in the U.S. and other countries.
\(^{14}\)SPARC and Solaris are trademarks or registered trademarks of Sun Microsystems, Inc. in the United States and other countries.
\(^{15}\)IRIX is a trademark of Silicon Graphics, Inc.
\(^{16}\)Tru64 is a registered trademark of Compaq Computer Corporation.
\(^{17}\)HP-UX is a registered trademark of Hewlett-Packard Company.
\(^{18}\)Mac OS X is a registered trademark of Apple Computer, Inc.
\(^{19}\)PowerPC is a trademark of International Business Machines Corporation in the United States, other countries, or both.
\(^{20}\)Windows is a registered trademark of Microsoft Corporation in the United States and other countries.
\(^{21}\)Cygwin is a registered trademark of Red Hat, Inc.
OpenBSD®, FreeBSD® on x86
uClinux® on ARM

Among the platforms known to not be supported are VMS® and Windows CE.

3.2.1 Code Paths and Command Sets

For the purposes of the validation testing a “platform” is a unique combination of source code and the specific build-time options used to turn that source code into binary code. The build-time inclusion of assembler optimizations effectively changes the source code, and source code selections vary based on the target architecture word size of 32 or 64 bits.

Due to budget and schedule constraints only the assembler optimizations for x86 and x86_64 were tested, so only those optimizations are available for building the FIPS Object Module. Four separate sets of source code were identified to cover plain C (no assembler) for both 32 and 64 bits, and optimizations for x86 and x86_64.

Even though the same source code is used for both Linux/Unix and Windows operating systems, the most natural build instructions are sufficiently unique to each of the two O/S families that the decision was made to test each code path for both O/S families.

The resulting eight test cases can be represented in the following tables:

<table>
<thead>
<tr>
<th>Code Path</th>
<th>Command Set</th>
<th>Representative Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Linux/Unix</td>
<td>Windows</td>
</tr>
<tr>
<td>pure C 32 bit</td>
<td>U1</td>
<td>W1</td>
</tr>
<tr>
<td>pure C 64 bit</td>
<td>U2</td>
<td>W2</td>
</tr>
<tr>
<td>x86 assembler</td>
<td>U3</td>
<td>W3</td>
</tr>
<tr>
<td>x86_64 assembler</td>
<td>U4</td>
<td>W4</td>
</tr>
</tbody>
</table>

Table 3.2.1a - Code Paths and Command Sets

where the command sets are

<table>
<thead>
<tr>
<th>Command Set Name</th>
<th>Build Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td>u1 Linux/Unix, pure C</td>
<td>./config fipscanisterbuild no-asm</td>
</tr>
</tbody>
</table>
### Command Set Name

<table>
<thead>
<tr>
<th>Command Set Name</th>
<th>Build Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>make</td>
</tr>
<tr>
<td></td>
<td>make install</td>
</tr>
<tr>
<td>u2 Linux/Unix with x86/x86_64 optimizations</td>
<td>./config fipscanisterbuild</td>
</tr>
<tr>
<td></td>
<td>make</td>
</tr>
<tr>
<td></td>
<td>make install</td>
</tr>
<tr>
<td>w1 Windows, pure C</td>
<td>ms\do_fips no-asm</td>
</tr>
<tr>
<td>w2 Windows with x86/x86_64 optimizations</td>
<td>ms\do_fips</td>
</tr>
<tr>
<td>u1 Linux/Unix, pure C, cross-compiled</td>
<td>./config fipscanisterbuild</td>
</tr>
<tr>
<td></td>
<td>make</td>
</tr>
<tr>
<td></td>
<td>make install</td>
</tr>
</tbody>
</table>

#### 3.2.1b - Command Sets

The actual representative systems tested for the validation were:

### Generic System

<table>
<thead>
<tr>
<th>Generic System</th>
<th>Actual System</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>Linux.2.6.18_i686_gcc-4.1.2 (OpenSuSE 10.2)</td>
</tr>
<tr>
<td>U2</td>
<td>Linux.2.6.20_x86-64_gcc-4.1.2 (F7)</td>
</tr>
<tr>
<td>U3</td>
<td>Linux.2.6.18_i686_gcc-4.1.2 (OpenSuSE 10.2)</td>
</tr>
<tr>
<td>U4</td>
<td>Linux.2.6.20_x86-64_gcc-4.1.2 (F7)</td>
</tr>
<tr>
<td>W1</td>
<td>WinXP.SP2_i386_MSVC.8.0 no-asm</td>
</tr>
<tr>
<td>W2</td>
<td>WinXP.SP2_x64-64_MSVC.8.0 no-asm</td>
</tr>
<tr>
<td>W3</td>
<td>WinXP.SP2_i386_MSVC.8.0 NASM, SSE2</td>
</tr>
<tr>
<td>W4</td>
<td>WinXP.SP2_x86-64_MSVC.8.0</td>
</tr>
<tr>
<td>C1</td>
<td>Linux.2.4.32-uc0_armv41 gcc-3.4.4 (uCLinux)</td>
</tr>
</tbody>
</table>

#### Table 3.2.1c - Representative Systems

#### 3.2.2 Assembler Optimizations

The only option for processor architectures other than x86 and x86_64 is to use the pure C language implementation and not any of the hand-coded performance optimized assembler as each assembler implementation requires separate FIPS testing. For example, an Itanium or PowerPC system can only build and use the pure C language module.
For x86 or x86_64 processors either the plain C or hand-coded assembler build can be performed, though there would be no advantage (from a FIPS perspective) in building the plain C version.

### 3.2.3 32 versus 64 Bit Architectures

Many 64 bit platforms provide backward compatible support for 32 bit code via hardware or software emulation. Software built on a 32 bit version of a specific operating system will generally run as-is on the equivalent 64 bit version of that operating system. Software built on a 64 bit operating system can be either 32 bit or 64 bit code depending on vendor build environment defaults and explicit build time options. Any such 64 bit code will not run on a 32 bit equivalent operating system, so care must be taken when compiling code for distribution to both 32 and 64 bit systems.

By default the FIPS Object Module build process will generate 64 bit code on 64 bit systems.

Since the command sets included in the validation testing do not permit the explicit specification of the compile time options that would otherwise be used to specify the generation of 32 or 64 bit code, it may be necessary for some platforms to build a 32 bit FIPS Object Module on a 32 bit system, and conversely for 64 bit.

It is also possible on most 64-bit platforms to install a 32-bit build environment which would be supported. Details as to how to configure such an environment are out of the scope of this document.

### 3.3 Creation of Shared Libraries

The FIPS Object Module is not directly usable as a shared library, but it can be linked into an application that is a shared library. A “FIPS compatible” OpenSSL distribution will automatically incorporate an available FIPS Object Module into the `libcrypto` shared library when built using the `fips` option (see §4.2.3)
4. Generating the FIPS Object Module

This section describes the creation of a FIPS Object Module for subsequent use by an application.

4.1 Delivery of Source Code

The OpenSSL FIPS Object Module software is available only in source format. The specific distribution was taken from the FIPS development branch which was a mid-release version of OpenSSL after 0.9.8e and before 0.9.8f. This specific distribution can be found at http://www.openssl.org/source/openssl-fips-1.2.tar.gz.

The OpenSSL FIPS Object Module software was delivered to the FIPS 140-2 testing laboratory in source form as this complete OpenSSL distribution, and was built by the testing laboratory using the standard build procedure as described in the Security Policy document and reproduced below and in Appendix B.

Note this downloaded file is untrusted for any purpose until verified as described in §4.1.2, and untrusted for the purposes of building a FIPS Object Module until verified as described in §4.1.3.

Note that while the specific FIPS Object Module Distribution could be used to build the conventional OpenSSL libraries in addition to the FIPS Object Module, it should not be used for that purpose. Use of a newer version of OpenSSL (0.9.8.j+) linking against the FIPS module is effectively mandatory due to several compilation issues with gcc versions 4.2 which were present at the parent 0.9.8e/f baseline and not addressed until later.

4.1.1 Creation of a FIPS Object Module from Other Source Code

Some OpenSSL distributions other than the specific distribution used for the validation can be used to build a fipsanister.o object using undocumented build-time options. The reader is reminded that any such object code cannot be used or represented as FIPS 140-2 validated. The Security Policy document is very clear on that point.

4.1.2 Verifying Integrity of Distribution

The integrity and authenticity of the complete OpenSSL distribution should be validated manually with the PGP signatures published by the OpenSSL Team with the distributions (ftp://ftp.openssl.org/source/) to guard against a corrupted source distribution. Note this check is separate and distinct from the specific FIPS 140-2 source file integrity check (§4.1.3).

Note this PGP/GPG signature check is not related to any of the FIPS integrity checks!
The PGP signatures are contained in the file

openssl-fips-1.2.tar.gz.asc

This digital signature of the distribution file can be verified against the OpenSSL PGP public key by using the PGP or GPG applications (GPG can be obtained free of charge from [http://www.gnupg.org/](http://www.gnupg.org/))\(^\text{27}\). This validation consists of confirming that the distribution was signed by a known trusted key as identified in Appendix A, “OpenSSL Distribution Signing Keys”.

First, find out which key was used to sign the distribution. Any of several different valid keys may have been used for this purpose. The “hexadecimal key id”, an identifier used for locating keys on the keystore servers, is displayed when attempting to verify the distribution. If the signing key is not already in your keyring the hexadecimal key id of the unknown key will still be displayed:

```
$ gpg  openssl-0.9.8z.tar.gz.asc
gpg: Signature made Tue Sep 30 09:00:37 2009 using RSA key ID 49A563D9
gpg: Can't check signature: public key not found
```

**Example 4.1.2a - Find Id of Signing Key**

In this example the key id is 0x49A563D9. Next see if this key id belongs to one of the OpenSSL core team members authorized to sign distributions. The authorized keys are listed in Appendix A.

Note that some older versions of gpg will not display the key id of an unknown public key; either upgrade to a newer version or load all of the authorized keys.

If the hexadecimal key id matches one of the known valid OpenSSL core team keys then download and import the key.

PGP keys can be downloaded interactively from a keyserver web interface or directly by the pgp or gpg commands.

The hexadecimal key id of the team member key (for example, the search string "0x49A563D9") can be used to download the OpenSSL PGP key from a public keyserver ([http://www.keyserver.net/](http://www.keyserver.net/), [http://pgp.mit.edu](http://pgp.mit.edu), or others). Keys can be downloaded interactively to an intermediate file or directly by the pgp or gpg program.

\(^{27}\) Note that although PGP and GPG are functionally interoperable, some versions of PGP are currently FIPS 140 validated and no versions of GPG are. For the purposes of FIPS 140-2 validation a validated version of PGP must be used. The examples given here are applicable to both GPG and PGP.
Once downloaded to an intermediate file, *markcox.key* in this example, the key can be imported with the command:

These examples assume the *pgp* or *gpg* software is installed. The key may also be imported directly into your keyring:

```
$ gpg --import markcox.key
  gpg: key 49A563D9: public key "Mark Cox <mjc@redhat.com>" imported
  gpg: Total number processed: 1
  gpg:               imported: 1  (RSA: 1)
$
```

**Example 4.1.2b - Importing a Key from a Downloaded file**

Note that at this point we have not yet established that the key is authentic or that the distribution was signed with that key; a key that *might* be authentic has been obtained in a form where it can be utilized for further validation.

To verify that the distribution file was signed by the imported key use the *pgp* or *gpg* command with the signature file as the argument, with the distribution file also present in the same directory:

```
$ gpg --keyserver pgp.mit.edu --recv-key 49a563d9
  gpg: key 49A563D9: public key "Mark Cox <mjc@redhat.com>" imported
  gpg: Total number processed: 1
  gpg:               imported: 1  (RSA: 1)

$ gpg /work/build/openssl/openssl-0.9.8z.tar.gz.asc
  gpg: Signature made Tue Sep 30 09:00:37 2009 using RSA key ID 49A563D9
  gpg: Good signature from "Mark Cox <mjc@redhat.com>"
  gpg:          aka "Mark Cox <mark@awe.com>"
  gpg:          aka "Mark Cox <mark@c2.net>"
  gpg:          aka "Mark Cox <mcox@c2.net>"
  gpg:          aka "Mark Cox <mark@ukweb.com>"
  gpg:          aka "Mark Cox <mjc@apache.org>"
  gpg: WARNING: This key is not certified with a trusted signature!
  gpg:          There is no indication that the signature belongs to the owner.
  Primary key fingerprint: 7B 79 19 FA 71 6B 87 25 0E 77 21 E5 52 D9 83 BF
$
```

**Example 4.1.2c - PGP Key Import**

In this example the validity of the file signature with respect to the key is verified, i.e. the target file *openssl-fips-1.2.tar.gz* was signed by the key with id 49A563D9. The warning message in
this example is noting the fact that the key is not already part of the "web of trust", a relational ranking system based on manually assigned confidence levels. Instead of relying on the web of trust which will differ from one user to another the key should be matched directly to a list of known valid keys.

For this final step establish that the signing key, now known to have signed the distribution, is in fact authentic. Confirm that the key fingerprint of the key which signed the distribution, \texttt{7B 79 19 FA 71 6B 87 25 0E 77 E5 52 D9 83 BF} in this example, is one of the valid OpenSSL core team keys listed in Appendix \texttt{A}, “OpenSSL Distribution Signing Keys”.

At this point the signature of the distribution has been verified as belonging to the signing key, and the authenticity of the signing key has been verified against a reference (this document) downloaded from the NIST web site.

### 4.1.3 Verifying Integrity of the Full Distribution for the FIPS Object Module

A separate source file integrity check is required to meet the requirements of FIPS 140-2.

The HMAC-SHA-1 digest of the distribution file is published in Appendix B of the \textit{Security Policy}. The \textit{Security Policy} can be found at NIST, \url{http://csrc.nist.gov/groups/STM/cmvp/documents/140-1/140sp/140sp1051.pdf}.

This digest should be calculated and compared against the published value, as in:

```
$ env OPENSSL_FIPS=1 openssl sha1 -hmac etonrishdlcupfm openssl-fips-1.2.tar.gz
```

where the \texttt{openssl} command is from a recent version of OpenSSL that supports the \texttt{-hmac} option\textsuperscript{28}. If you don't have the \texttt{openssl} command yet it will be generated by the build process.

### 4.2 Building and Installing the FIPS Object Module with OpenSSL (Unix/Linux)

Due to significant differences in the two basic operating system families, Unix\textsuperscript{®}/Linux\textsuperscript{®} and Microsoft\textsuperscript{®} Windows\textsuperscript{®} platforms are discussed separately. Instructions for Windows\textsuperscript{®} are given in §4.3.

#### 4.2.1 Building the FIPS Object Module from Source

Next build the FIPS Object Module from source. The FIPS 140-2 validation specific code is incorporated into the generated FIPS Object Module when the \texttt{fips} configuration option is

\textsuperscript{28}The \texttt{OPENSSL_FIPS=1} environment variable will enable FIPS mode for an \texttt{openssl} command built from a FIPS capable OpenSSL distribution.
specified. Per the conditions of the FIPS 140-2 validation only two configuration commands may be used:

```bash
./config fipscanisterbuild
```
or

```bash
./config fipscanisterbuild no-asm
```
where the specific option used depends on the platform (see §3.2.1).

The specification of any other options on the command line, such as

```bash
./config fipscanisterbuild shared
```
is not permitted. Note that in the case of the “shared” option position independent code is generated by default so the generated FIPS Object Module can be included in a shared library\(^{29}\).

Note that as a condition of the FIPS 140-2 validation no other user specified configuration options may be specified. This restriction means that an optional install prefix cannot be specified – however, there is no restriction on subsequent manual relocation of the generated files to the desired final location.

Then:

```bash
make
```
to generate the FIPS Object Module file `fipscanister.o`, the digest for the FIPS Object Module file, `fipscanister.o.sha1`, and the source file used to generate the embedded digest, `fips_premain.c`. The `fipscanister.o`, `fipscanister.o.sha1`, and `fips_premain.c` files are intermediate files (i.e., used in the generation of an application but not referenced by that application at runtime). The object code in the `fipscanister.o` file is incorporated into the runtime executable application at the time the binary executable is generated.

This should also be obvious, but modifications to any of the intermediate files generated by the “`./config fipscanisterbuild`” or “`make`” commands are not permitted. If the original distribution is modified, or if anything than those three specified commands are used, or if any intermediate files are modified, the result is not FIPS validated.

### 4.2.2 Installing and Protecting the FIPS Object Module

\(^{29}\)If not for the FIPS validation prohibition, on most but not all platforms the “shared” option could safely be chosen regardless of the intended use. See Appendix H for one known exception.
The system administrator should install the generated `fipscanister.o`, `fipscanister.o.sha1`, and `fips_premain.c` files in a location protected by the host operating system security features. These protections should allow write access only to authorized system administrators (FIPS 140-2 Crypto Officers) and read access only to authorized users.

For Unix® based or Linux® systems this protection usually takes the form of root ownership and permissions of 0755 or less for those files and all parent directories. When all system users are not authorized users the world (public) read and execute permissions should be removed from these files.

The usual

```
make install
```

will install the `fipscanister.o`, `fipscanister.o.sha1`, `fips_premain.c`, and `fips_premain.c.sha1` files in the target location (typically `/usr/local/ssl/fips-1.0/lib/` for Unix® based or Linux® systems.) with the appropriate permissions to satisfy the security requirement. These four files constitute the validated FIPS Object Module, the (many) other files also installed by this command are not validated. Note that it is also permissible to install these files in other locations by other means, provided that they are protected as noted above:

```
    cp fipscanister.o fipscanister.o.sha1 <target-directory>
    cp fips_premain.c fips_premain.c.sha1 <target-directory>
```

Note that `fipscanister.o` can either be statically linked into an application binary executable, or statically linked into a shared library.

### 4.2.3 Building a FIPS Capable OpenSSL

At this point a full OpenSSL library has been installed. However, the special distribution required to generate the validated FIPS Object Module does not correspond exactly to any official OpenSSL releases. Once the validated FIPS Object Module has been generated the other OpenSSL components can be replaced with components from a different OpenSSL distributions. Any 0.9.8 releases from j onwards (i.e. 0.9.8j or above) can be used for this purpose. OpenSSL 1.0 is not compatible. The commands

```
./config fips <...other options...>
make <...options...>
make install
```
will install the new OpenSSL without overwriting the validated FIPS Object Module files. The
\--with-fipslibdir option can be used to explicitly reference the location of the FIPS Object
Module (fipscanister.o).

The combination of the validated FIPS Object Module plus an OpenSSL distribution built in this
way is referred to as a FIPS capable OpenSSL, as it can be used either as a drop-in replacement for
a non-FIPS OpenSSL or for use in generating FIPS mode applications.

Note that a standard OpenSSL distribution built for use with the FIPS Object Module must have the
\.\config fips option specified. Other configuration options may be specified in addition to
fips, but omission of the fips option will cause errors when using the OpenSSL libraries with
the FIPS Object Module.

4.3 Building and Installing the FIPS Object Module with OpenSSL
(Windows)

The build procedure for Windows is similar to that for the regular OpenSSL product, using MSVC
and NASM for compilation. Note MASM is not supported.

The second stage uses VC++ to link OpenSSL 0.9.8j or later against the installed FIPS module, to
obtain the complete FIPS capable OpenSSL. Both static and shared libraries are supported.

4.3.1 Building the FIPS Object Module from Source

Build the FIPS Object Module from source:

\texttt{ms\do\_fips [no-asm]}

where the no-asm option may or may not be present depending on the platform (see §3.2.1).

Note that as a condition of the FIPS 140-2 validation no other user specified configuration options
may be specified.

4.3.2 Installing and Protecting the FIPS Object Module

The system administrator should install the generated fipscanister.obj, 
fipscanister.obj.sha1, and fips_premain.c files in a location protected by the host
operating system security features. These protections should allow write access only to authorized
system administrators (FIPS 140-2 Crypto Officers) and read access only to authorized users.
For Microsoft® Windows® based systems this protection can be provided by ACLs limiting write access to the administrator group. When all system users are not authorized users the Everyone (public) read and execute permissions should be removed from these files.

4.3.3 Building a FIPS Capable OpenSSL

The final stage is VC++ compilation of a standard OpenSSL distribution to be referenced in conjunction with the previously built and installed FIPS Object Module.

Download an OpenSSL 0.9.8 distribution, 0.9.8j or later. Follow the standard Windows® build procedure except that instead of the command:

perl Configure VC-WIN32

do:

perl Configure VC-WIN32 fips --with-fipslibdir=c:\fips\path

where "c:\fips\path" is wherever the FIPS module from the first stage was installed. Static and shared library builds are supported.

This command is followed by the usual

ms\do_nasm

and

nmake -f ms\ntdll.mak

to build the shared libraries only, or

nmake -f ms\nt.mak

to build the OpenSSL static libraries. The standard OpenSSL build with the fips option will use a base address for libeay32.dll of 0xFB00000 by default. This value was chosen because it is unlikely to conflict with other dynamically loaded libraries. In the event of a clash with another dynamically loaded library which will trigger runtime relocation of libeay32.dll the integrity check will fail with the error

FIPS_R_FINGERPRINT DOES NOT MATCH_NONPIC_RELATED
A base address conflict can be resolved by shuffling the other DLLs or re-compiling OpenSSL with an alternative base address specified with the --with-baseaddr= option.

Note that the developer can identify which DLLs are relocated with the Process Explorer utility from [http://www.microsoft.com/technet/sysinternals/ProcessesAndThreads/ProcessExplorer.mspx](http://www.microsoft.com/technet/sysinternals/ProcessesAndThreads/ProcessExplorer.mspx).

The resulting FIPS capable OpenSSL can be used for shared or static linking. The shared library built (when ms\ntdll.mak is used as the Makefile) links fipscanister.o into libeay32.dll using fipslink.pl in accordance with the requirements of the Security Policy.
5. Creating Applications Which Reference the FIPS Object Module

Only minor modifications are needed to adapt most applications that currently use OpenSSL for cryptography to use the FIPS capable OpenSSL with the FIPS Object Module. This checklist summarizes the modifications which are covered in more detail in the following discussion:

![Figure 4 - Application Checklist](image)

Appendix C contains a simple but complete sample application utilizing the FIPS Object Module with OpenSSL as described in this section.

5.1 Exclusive Use of the FIPS Object Module for Cryptography

In order for the referencing application to claim FIPS 140-2 validation all cryptographic functions utilized by the application must be provided exclusively by the FIPS Object Module. The OpenSSL API used in conjunction with the FIPS Object Module in FIPS mode is designed to automatically disable all non-FIPS cryptographic algorithms.

5.2 FIPS Mode Initialization

Somewhere very early in the execution of the application FIPS mode must be enabled. This should be done by invocation of the `FIPS_mode_set()` function call, either directly or indirectly as in these following examples.

Note that it is permitted to not enable FIPS mode, in which case OpenSSL should function as it always has. The application will not, of course, be operating in validated mode.

Option 1: Direct call to `FIPS_mode_set()`
Option 2: Indirect call via OPENSSL_config()

The OPENSSL_config() call can be used to enable FIPS mode via the standard openssl.conf configuration file:

```c
#include OPENSSL_FIPS
if(options.no_fips <= 0)
{
    if(FIPS_mode_set(1))
    {
        ERR_load_crypto_strings();
        ERR_print_errors_fp(stderr);
        exit(1);
    }
    else
        fprintf(stderr,"*** IN FIPS MODE ***\n");
}
#endif
```

Example 5.2a – Direct Invocation of FIPS_mode_set()

The call to OPENSSL_config("XXXX_conf") will check the system default OpenSSL configuration file for a section XXXX_conf. If section XXXX_conf is not found then the section defaults to openssl_conf. The resulting section is checked for a alg_section specification naming a section that can contain an optional “fips_mode = yes” statement.
Example 5.2c – Sample openssl.conf File

Note that OPENSSL_config() has no return code. If a configuration error occurs it will write to STDERR and forcibly exit the application. Applications that want finer control can call the underlying functions such as CONF_modules_load_file() directly.

5.3 Generate Application Executable Object

Note that applications interfacing with the FIPS Object Module are outside of the cryptographic boundary.

When statically linking\[30\] the application with the FIPS Object Module two steps are necessary:

1. The HMAC-SHA-1 digest of the FIPS Object Module file must be calculated and verified against the installed digest to ensure the integrity of the FIPS Object Module.

2. A HMAC-SHA1 digest of the FIPS Object Module code and read-only data must be generated and embedded in the application executable object for use by the FIPS_mode_set() function at runtime initialization.

5.3.1 Linking under Unix/Linux

The OpenSSL distribution contains a utility, fipsld, which both performs the check of the FIPS Object Module and generates the new HMAC-SHA-1 digest for the application executable. The fipsld utility has been designed to act as a front end for the actual compilation and linking

\[30\]Note that where fipscanister.o has been incorporated in a shared library then subsequent dynamic linking of an application to that shared library is done the usual way and these steps are irrelevant.
operations in order to ease the task of modifying an existing software project to incorporate the FIPS Object Module. It can be used to create either binary executables or shared libraries.

The fipsld command requires that the CC and/or FIPSLD_CC environment variables be set, with the latter taking precedence. These variables allow a typical Makefile to be used without modification by specifying a command of the form

```
make CC=fipsld FIPSLD_CC=gcc
```

where fipsld is invoked by make in lieu of the original compiler and linker (gcc in this example), and in turn invokes that compiler where appropriate. Note that CC=fipsld can be passed to autoconf configure scripts as well.

This type of command line macro overloading will work for many smaller software projects. The makefile can also be modified to achieve the same macro substitutions. Depending on the form of the Makefile this substitution may be as simple as defining FIPSLD_CC to reference the actual C compiler and redefining the CC macro to reference fipsld:

```
FIPSLD_CC = $(CC)
CC = fipsld
.
.
<application>: $(OBJS)
  $(CC) $(CFLAGS) -o $@ $(OBJS) $(LIBCRYPTO) ...
```

Setting CC=fipsld is appropriate when the link rules rely on $(CC) instead of ld to produce the executable images, but in some cases it may be desirable or necessary to not redefine the $(CC) macro variable. A typical makefile rule referencing fipsld directly for the link step would look something like\(^1\):

```
OPENSSLDIR = /usr/local/ssl/fips-1.0
FIPSMODULE = $(OPENSSLDIR)/lib/fipscanister.o
.
.
<application>: $(OBJS) $(FIPSMODULE)
  env FIPSLD_CC=$(CC) fipsld $(CFLAGS) -o $@ $(OBJS) \
  $(LIBS) $(LIBCRYPTO)
```

\(^1\)The use of env is actually redundant in a Makefile context, but is specified here to give a command line also valid for non-Bourne shells.
Even though the `fipsld` command name implies use as a replacement for the `ld` command, it also invokes the C compiler between the two link stages, hence `fipsld` can also replace `$(CC)` in rules producing .o object files, replacing both compilation and linking steps for the entire Makefile, i.e.:

```
<application>.o: <application>.c
   $(CC) $(CFLAGS) -c <application>.c ...

<application>: $(OBJS)
   ld -o $@ $(OBJS) $(LIBCRYPTO) ...
```

becomes

```
<application>: <application>.c
   env FIPSLD_CC=$(CC) fipsld $(CFLAGS) -c <application>.c \ 
      $(LIBCRYPTO) ...
```

Larger software projects are likely to prefer to modify only the Makefile rule(s) linking the application itself, leaving other Makefile rules intact. For these more complicated Makefiles the individual rules can be modified to substitute `fipsld` for just the relevant compilation linking steps.

The `fipsld` command is designed to locate `fipscanister.o` automatically. It will verify that the HMAC-SHA-1 digest in file `fipscanister.o.sha1` matches the digest generated from `fipscanister.o`, and will then create the file `<application>` containing the object code from `fipscanister.o`, and embedded within that the digest calculated from the object code and data in `fipscanister.o`.

At runtime the `FIPS_mode_set()` function compares the embedded HMAC-SHA-1 digest with a digest generated from the text and data areas. This digest is the final link in the chain of validation from the original source to the application executable object file.

### 5.3.2 Linking under Windows

For a shared library application just linking with the DLL is sufficient. Linking an application with the static libraries involves a bit more work, and can be complicated by the fact that GUI based tools are often used for such linking.

For the Windows® environment a perl script `fipslink.pl` is provided which performs a function similar to `fipsld` for Unix®/Linux®. Several environment variables need to be set:

```
FIPS_LINK is the linker name, normally “link”
```
FIPS_CC is the C compiler name, normally “cl”

FIPS_CC_ARGS is a string of C compiler arguments for compiling fips_premain.c

PREMAIN_DSO_EXE should be set to the path to fips_premain_dso.exe if a DLL is being linked (can be omitted otherwise)

PREMAIN_SHA1_EXE is the full path to fips_standalone_sha1.exe

FIPS_TARGET is the path of the target executable or DLL file

FIPSLIB_D is the path to the directory containing the installed FIPS module

When these variables are specified fipslink.pl can be called in the same way as the standard linker. It will automatically check the hashes, link the target, generate the target in-core hash, and link a second time to embed the hash in the target file.

The static library Makefile ms\nt.mak in the OpenSSL distribution gives an example of the usage of fipslink.pl.

5.4 Application Implementation Recommendations

This section describes additional steps not strictly required for FIPS 140-2 validation but recommended as good practice.

Provide an Indication of FIPS Mode

Security and risk assessment auditors will want to verify that an application utilizing cryptography is using FIPS 140-2 validated software in a FIPS compliant mode. Many such applications will superficially appear to function the same whether built with a non-FIPS OpenSSL, when built with the FIPS Object Module and running in non-FIPS mode, and when built with the FIPS Object Module and running in FIPS mode.

As an aid to such reviews the application designer should provide a readily visible indication that the application has initialized the FIPS Object Module to FIPS mode, after a successful return from the FIPS_mode_set() API call. The indication can take the form of a tty or stdout message, a syslog entry, or an addition to a protocol greeting banner. For example a SSH server could print a protocol banner of the form:

SSH-2.0-OpenSSH_3.7.1p2 FIPS
to provide an easily referenced indication that the server was properly initialized to FIPS mode.

**Graceful Avoidance of Non-FIPS Algorithms**

Many applications allow end user and/or system administrator configurable specification of cryptographic algorithms. The OpenSSL API used with the FIPS Object Module in FIPS mode is designed to return error conditions when an attempt is made to use a non-FIPS algorithm via the OpenSSL API. These errors may result in unexpected failure of the application, including fatal assert errors for algorithm functions calls lacking a testable return code. However, there is no guarantee that the OpenSSL API will always return an error condition in every possible permutation or sequence of API calls that might invoke code relating to non-FIPS algorithms. In any case, it is the responsibility of the application programmer to avoid the use of non-FIPS algorithms. Unexpected run-time errors can be avoided if the cipher suites or other algorithm selection options are defaulted to FIPS approved algorithms, and if warning or error messages are generated for any end user selection of non-FIPS algorithms.

### 5.5 Documentation and Record-keeping Recommendations

The supplier or developer of a product based on the FIPS Object Module cannot claim that the product itself is FIPS 140-2 validated under certificate #1051. Instead a statement similar to the following is recommended:

> Product XXXX uses an embedded FIPS 140-2-validated cryptographic module (Certificate #1051) running on a YYYY platform per FIPS 140-2 Implementation Guidance section G.5 guidelines.

where XXXX is the product name (“Cryptomagical Enfabulator v3.1®“) and YYYY is the host operating system (“Solaris 10”).

While not strictly required by the Security Policy or FIPS 140-2, a written record documenting compliance with the Security Policy would be a prudent precaution for any party generating and using or distributing an application that will be subject to FIPS 140-2 compliance requirements. This record should document the following:

For the FIPS Object Module generation:

1. Where the openssl-fips-1.2.tar.gz distribution file was obtained from, and how the HMAC SHA-1 digest of that file was verified per Appendix B of the Security Policy.
2. The host platform on which the fipscanister.o, fipscanister.o.sha1, fips_premain.c, and fips_premain.c.sha1 files were generated. This platform
identification at a minimum should note the processor architecture (“x86”, “PA-RISC”,...), the operating system (“Solaris 10”, “Windows XP”,...), and the compiler (“gcc 3.4.3”,...).

3. An assertion that the fipscanister.o module was generated with the three commands
   
   ```
   ./config fipscanisterbuild [no-asm]
   make
   make install
   ```
   and specifically that no other build-time options were specified.

4. A record of the HMAC SHA-1 digest of the fipscanister.o (the contents of the fipscanister.o.sha1 file). That digest identifies this specific FIPS Object Module; if you immediately build another module it will have a different digest and is a different FIPS Object Module.

5. An assertion that the contents of the distribution file were not manually modified in any way at any time during the build process.

For the application in which the FIPS Object Module is embedded:

1. A record of the HMAC SHA-1 digest of the fipscanister.o that was embedded in the application.
2. An assertion that the application does not utilize any cryptographic implementations other than those provided by the FIPS Object Module or contained in the FIPS capable OpenSSL 0.9.8j+ libraries (where non-FIPS algorithms are disabled in FIPS mode).
3. A description of how the application clearly indicates when FIPS mode is enabled (assuming that FIPS mode is a runtime selectable option). Note that the application must call FIPS_mode_set(), whether that call is triggered by runtime options or not.

### 5.6 When is a Separate FIPS 140-2 Validation Required?

When a decision is made on whether a particular IT solution is FIPS 140-2 compliant multiple factors need to be taken into account, including the FIPS Pub 140-2 standard, FIPS 140-2 Derived Test Requirements, CMVP FAQ and Implementation Guidance. The ultimate authority in this process belongs to the CMVP. The CMVP provides its current interpretations and guidelines as to the interpretation of the FIPS 140-2 standard and the conformance testing/validation process on its public web site [http://csrc.nist.gov/cryptval/](http://csrc.nist.gov/cryptval/).

In particular, the only official document known to us which discusses use of embedded cryptographic modules is the CMVP FAQ available at [http://csrc.nist.gov/cryptval/140-1/CMVPFAQ.pdf](http://csrc.nist.gov/cryptval/140-1/CMVPFAQ.pdf). This FAQ (Frequently Asked Questions document) discusses incorporation of another vendor’s cryptographic modules in a subsection of Section 2.2.1 entitled "Can I incorporate another vendor’s validated cryptographic module". In particular, the following is specified:
"Yes. A cryptographic module that has already been issued a FIPS 140-1 or FIPS 140-2 validation certificate may be incorporated or embedded into another product. The new product may reference the FIPS 140-1 or FIPS 140-2 validated cryptographic module so long as the new product does not alter the original validated cryptographic module. A product which uses an embedded validated cryptographic module cannot claim itself to be validated; only that it utilizes an embedded validated cryptographic module. There is no assurance that a product is correctly utilizing an embedded validated cryptographic module - this is outside the scope of the FIPS 140-1 or FIPS 140-2 validation."

Note that the CMVP FAQ does specify that a FIPS 140-1/2 validated module may be incorporated into another product. It then specifies that making a decision on whether a product is correctly utilizing an embedded module is outside of the scope of the FIPS 140-1 or FIPS 140-2 validation.

A subsection of Section 2.1 of the CMVP FAQ entitled "A vendor is selling me a crypto solution - what should I ask?" states:

"Verify with the vendor that the application or product that is being offered is either a validated cryptographic module itself (e.g. VPN, SmartCard, etc) or the application or product uses an embedded validated cryptographic module (toolkit, etc). Ask the vendor to supply a signed letter stating their application, product or module is a validated module or incorporates a validated module, the module provides all the cryptographic services in the solution, and reference the modules validation certificate number."

It is specified that the module provides "all the cryptographic services in the solution". It is not specified that the module provides "all the security-relevant services in the solution". A typical IT product may provide a variety of services, both cryptographic and non-cryptographic. A network protocol such as SSH or TLS provides both cryptographic services such as encryption and network services such as transmission of data packets, packet fragmentation, etc.

The FIPS 140-2 standard is focused on the cryptography. There are many generic security relevant functionalities such as anti-virus protection, firewalls, IPS/IDS and others which are not currently covered by the FIPS 140-2 standard. An anti-virus solution which uses a cryptographic module for its operations can satisfy requirements of the FIPS 140-2 by delegating its cryptographic functions to an embedded FIPS 140-2 validated module. Including the entire anti-virus solution in the FIPS 140-2 validation would hardly improve the overall security since FIPS 140-2 does not currently have requirements in the field of anti-virus protection. In a similar fashion, the FIPS 140-2 standard does not currently have requirements related to network vulnerabilities or denial of service attacks.

Validated modules typically provide algorithm implementations only, no network functionality such as IPSec, SSH, TLS etc. This does not, for example, prevent Microsoft Windows from providing IPSec/IKE and TLS/SSL functionality. Therefore, for example, an OpenSSH based product properly using the OpenSSL FIPS Object Module would not differ from Microsoft using its Microsoft Kernel Mode Crypto Provider in Microsoft IPSec/IKE client which is shipped with every
copy of Windows. If an application product delegates all cryptographic services to a validated module the entire product will be FIPS compliant.

A typical network protocol, such as IPSec/IKE, TLS, SSH, S-MIME or 802.11 protocol family may provide a complex variety of services. Some aspects of such services may have a cryptographic nature and utilize Approved or “allowed for use” cryptographic algorithms, such as encryption, decryption, signatures, hashes, message digests and others. Other services provided by a network protocol may be of non-cryptographic nature, such as packet routing, packet assembly/disassembly, defragmentation, radio and link layer communications, firewalling, network address translation, address resolution, quality of service, re-transmission and others. While the ultimate verdict for a particular solution belongs to the CMVP, it is generically logical to assume that non-cryptographic services of a particular network protocol or a set of protocols may be implemented outside of a validated cryptographic module. This is also logical having in mind that in many cases non-cryptographic services of a particular protocol may be delegated to other devices in the IT solution. For instance, in some wireless LAN access systems an implementation of the 802.11 protocol set is provided jointly by a wireless access switch and a wireless access point, where the wireless access point may provide non-cryptographic services of the 802.11 protocol set such as radio transmissions, frequency and signal strength control, initial wireless client association and others. Another widely used example is a web server offloading cryptographic functionality of the HTTPS/TLS protocol to a FIPS 140-2 validated cryptographic accelerator card (many such cards are available on the market).

In addition to consulting the written CMVP guidance, it is then also important to consider industry-wide interpretation patterns and precedents in this field. After performing a review of the FIPS 140-2 validated products list [http://csrc.nist.gov/cryptval/140-1/140val-all.htm](http://csrc.nist.gov/cryptval/140-1/140val-all.htm) one may conclude that implementing non-cryptographic services of a particular network protocol outside of a validated cryptographic module can in many cases be considered as an industry trend. There are multiple examples which illustrate such a trend. For illustration purposes only we can take a look at the example of the Microsoft Kernel Module


Note that there are many other modules which follow a similar trend, this module is just one example out of many. The analysis here is generic, applies to a large number of validated modules, and is not intended to make any specific statements as to the validation of this particular module.

As specified by the vendor, the Kernel Module is used by the vendor implementation of the IPSec/IKE protocol


In particular it is stated that
"Both IPSEC and EFS in Windows 2000, XP, and Server 2003 use the FIPS-140-1 or FIPS 140-2 (as appropriate) evaluated Kernel Mode Cryptographic Module to encrypt the traffic packet data and file contents respectively if configured appropriately with the selections of FIPS compliant algorithms."

A review of the Kernel Module Security Policy then shows that the module's services are specified as services performing cryptographic algorithms supported by IPSec/IKE(such as encryption/decryption and key agreement) and not as providing a full IPSec/IKE protocol implementation. This could again serve as an illustration of the fact that non-cryptographic services of a particular protocol are in many cases implemented outside of a cryptographic module. A similar analysis could be performed for other protocols specified in


such as S/MIME (used in Outlook), TLS (used in Explorer), Remote Desktop Protocol and Encrypting File System. Other examples can be discussed by analyzing the list of historically validated products http://csrc.nist.gov/cryptval/140-1/140val-all.htm. In general the vendor of a product based on the OpenSSL FIPS Object Module should be able to find an existing validated module, and similar products claiming validation by virtue of that module, for one of several large well-known IT companies.

In conclusion, both the historical perspective and the current CMVP guidance point to a possibility of non-cryptographic services in an IT solution being implemented outside of a validated cryptographic module. We are not aware of any CMVP regulations explicitly denying use of embedded validated cryptographic modules to satisfy the requirements of FIPS 140-2 statement, provided that the set of conditions specified in the CMVP FAQ and other relevant documentation is satisfied. With this in mind, the ultimate decision for a particular product/protocol belongs to the CMVP and the analysis presented here can serve for discussion purposes only.

The main job of a FIPS 140-2 testing lab is to consistently apply the FIPS 140-2 standard, the Derived Test Requirements and the Implementation Guidance to all modules which the testing lab checks. Testing labs can have suggestions for further improvements which could be communicated to the CMVP and potentially incorporated in the future versions of the standard or in the implementation guidance.

Since the CMVP does not have a formal program for validation of IT solutions with embedded FIPS 140-2 modules, the question is how is the actual compliance/non-compliance determined. In practice the compliance is determined by the federal agency/buyer selecting the solution. During the process the customer may contact the CMVP, testing labs or security experts for an opinion. In many cases, though, the buyers make such decisions independently. Here it should be noted that FIPS 140-2 is only a baseline and each federal agency may establish its own requirements exceeding the requirements of FIPS 140-2. In the particular example of network protocols federal agencies generally do accept networking products (IPSec/TLS/SSH etc.) with embedded FIPS 140-2 validated cryptographic software modules or hardware cards as FIPS 140-2 compliant.
For those vendors desiring a “sanity check” of the compliance status of their OpenSSL FIPS Object Module based product, OSSI can perform a review and provide an opinion letter stating whether, based on information provided by the vendor, that product appears to OSSI to satisfy the requirements of the OpenSSL FIPS Object Module Security Policy. This opinion letter can include a review by one or more CMVP test labs and/or a OpenSSL team member as appropriate. This opinion letter clearly states that only the CMVP can provide an authoritative ruling on FIPS 140-2 compliance.

6. Future Plans

The current validated FIPS Object Module has a number of limitations, among them:

1. Not all FIPS compliant cryptographic algorithms are validated (ECC, for example). An algorithm test involves coding a test driver (dsa/fips_dsatest.c, hmac/fips_hmactest.c, etc. in the ./fips/ subdirectory) to process input test vectors in a format described in a standards document. Most of these were relatively straightforward, if tedious, to code, though a few required considerable trial-and-error experimentation to interpret.

2. Not compatible with OpenSSL 1.0 where a number of data structures are not binary compatible with OpenSSL 0.9.8 on which the FIPS module is based.

These first OpenSSL FIPS validations were pioneer efforts that confronted many uncertainties in the validation process with limited resources. Now that the initial validations have been awarded and the requirements for a source code validation are better understood these limitations can be addressed in future validations.

Any such future validation will have one fixed cost, the CMVP testing laboratory fee, plus whatever costs are associated with the specific software development items. For that reason the more financial co-sponsors are involved in a given validation, the lower the cost to each sponsor.

Any interested parties willing to consider co-sponsoring a future OpenSSL FIPS 140-2 or 140-3 validation effort should contact

Steve Marquess
OpenSSL Software Foundation
1829 Mount Ephraim Road
Adamstown, MD 21710
USA
877-673-6775 office
marquess@opensslfoundation.com
http://opensslfoundation.com/

or

John Weathersby
Executive Director
Open Source Software Institute
8 Woodstone Plaza
Adamstown, MD 21790
USA
601-427-0152 office
601-818-7161 cell
601-427-0156 fax
jmw@oss-institute.org
for information on current plans and the opportunities for participation. Note plans for new validations will be announced at http://www.openssl.org/docs/fips/fipsnotes.html.
7. REFERENCES


The algorithm certificates:

- **RSA**: http://csrc.nist.gov/groups/STM/cavp/documents/aes/aesval.html#323
- **DSA**: http://csrc.nist.gov/groups/STM/cavp/documents/dss/dsaval.htm#264
- **3DES**: http://csrc.nist.gov/groups/STM/cavp/documents/des/tripledesval.html#627
- **AES**: http://csrc.nist.gov/groups/STM/cavp/documents/aes/aesval.html#695
- **HMAC**: http://csrc.nist.gov/groups/STM/cavp/documents/mac/hmacval.html#373
- **SHA-1,2**: http://csrc.nist.gov/groups/STM/cavp/documents/shs/shaval.htm#723
Appendix A  OpenSSL Distribution Signing Keys

In order to be considered FIPS 140-2 validated the FIPS Object Module must be derived from an OpenSSL distribution signed by one of these authorized keys, as shown by the value in the Fingerprint row.

The procedure for verifying that a source distribution was signed by one of these keys is described in detail in §4.1.2.

Note the fingerprint formats are slightly different for the two different types of keys (RSA and DSA).

<table>
<thead>
<tr>
<th>OpenSSL Core Team PGP Keys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Id</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>49A563D9</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>26BB437D</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>F295C759</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>9C58A66D</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>2118CF83</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>E06D2CB1</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
<tr>
<td>5A6A9B85</td>
</tr>
<tr>
<td>Fingerprint</td>
</tr>
</tbody>
</table>
Appendix B  CMVP Test Procedure

Instructions for building OpenSSL and performing the FIPS 140-2 and related algorithm tests on Linux®/Unix® Microsoft Windows® based platforms are given here. These instructions are primarily of interest to the CMVP testing laboratory performing the validation testing, or anyone wishing to verify that the executable library generates the same output for the algorithm tests performed by the testing laboratory.

Note there is no requirement for end users or application developers to run these tests, this discussion is included for reference purposes to illustrate the algorithm testing performed by the CMVP test lab. Note this step requires a large directory tree of input test data files produced by the testing lab using a NIST provided tool (CAVS); several sets of input and response values can be found http://www.openssl.org/docs/fips/.

B.1 Building the Software - Linux/Unix

1. Copy the OpenSSL distribution (openssl-fips-1.2.tar.gz) to a directory on the test system. Approximately 80Mb free space is needed.

2. Perform the standard build. Use of a script file or comparable means of capturing the output is highly recommended.

   gunzip -c openssl-fips-1.2.tar.gz | tar xf -
   cd openssl
   ./config fipscanisterbuild [no-asm]
   make

   ...where the no-asm option may or not be present depending on the platform.

3. Optionally run

   make test

   to perform the standard integrity test. A large amount of output is generated. If an error occurs processing will be aborted.

B.2 Algorithm Tests - Linux/Unix

4. Add the subtree of test data to the distribution work area:
cd fips
unzip <zipfile of test vectors>.zip -d testvectors

5. Run the FIPS 140-2 algorithm tests:

    perl mkfipsscr.pl --dir=testvectors --rspdir=resp
    sh fipstests.sh

This step runs the algorithm tests specific to the FIPS mode. Again a large amount of output will be generated. If an error occurs processing will be aborted.

6. The many (approximately 198) generated *.rsp files will be found in the ./testvectors/ directory tree under ./fips:

    find testvectors/ -name '*.rsp'

7. The generated responses can be tested against another set of known good testvector responses at pathname FIPS_TVOK=<pathname> with:

    make fips_test_diff FIPS_TVOK=<pathname>

This comparison automatically suppresses the whitespace and comment line differences and ignores the seven testvector files that are always different.

8. The tree of *.rsp files can be extracted for comparison with another tree:

    find testvectors -name '*.rsp' | cpio -oc > rspl.cpio

     .

     .

    cd /tmp
    mkdir rspl rsp2
    cd rspl; cpio -ic < rspl.cpio
    cd ../rsp2; cpio -ic < rsp2.cpio
    diff -r . ../rsp1

---

Due to the nature of the cryptographic operations involved the following responses files will always be different:

<table>
<thead>
<tr>
<th>KeyPair.rsp</th>
<th>DSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQGen.rsp</td>
<td>DSA</td>
</tr>
<tr>
<td>SigGen.rsp</td>
<td>DSA</td>
</tr>
<tr>
<td>SigGen15.rsp</td>
<td>RSA</td>
</tr>
<tr>
<td>SigGenPSS.rsp</td>
<td>RSA</td>
</tr>
<tr>
<td>SigGenRSA.rsp</td>
<td>RSA</td>
</tr>
<tr>
<td>SigGenPSS.rsp</td>
<td>RSA</td>
</tr>
</tbody>
</table>

These files are listed in the file ./fips/fips-nodiff.txt that is referenced by the fips_test_diff makefile target.
If the only other differences are the commented date-time labels then the trees match:

```bash
diff -r ./testvectors/aes/resp/CBCGFSbox128.rsp \
     ../rsp1/testvectors/aes/resp/CBCGFSbox128.rsp
  6c6
 < # Thu Mar  4 11:05:36 2004
---
> # Fri Feb 20 12:21:24 2004
```  

```bash
diff -r ./testvectors/aes/resp/CBCGFSbox192.rsp \
     ../rsp1/testvectors/aes/resp/CBCGFSbox192.rsp
  6c6
 < # Thu Mar  4 11:05:36 2004
---
> # Fri Feb 20 12:21:24 2004
```

### B.3 Building the Software - Windows

1. Copy the OpenSSL distribution (openssl-fips-1.2.tar.gz) to a directory on the test system. Approximately 80Mb free space is needed.

2. Perform the standard build.
   
   ```bash
cd openssl
ms\do_fips [no-asm]
out32dll\fips_test_suite
```
   
   ...where the `no-asm` option may or not be present depending on the platform.

### B.4 Algorithm Tests - Windows

3. This procedure is similar to that for Linux/Unix:

   ```bash
cd fips
unzip <zip file of test vectors>.zip -d testvectors
perl mkfipsscr.pl --win32 --dir=testvectors --rspdir=resp \.\fipstests.bat
```
There is no bundled zip/unzip command for most versions of Microsoft Windows, but many third
tparty implementations are available, such as http://gnuwin32.sourceforge.net/packages/unzip.htm.

B.5  FIPS 140-2 Test - All Platforms

A test driver program has been provided to demonstrate both successful and failed power-up self-
tests and the invocation of some basic cryptographic operations. This program was developed
during the course of the FIPS 140-2 validation as a aid to the test lab evaluators. This test program,
fips_test_suite, can be found in the ./test/ subdirectory.  This program behaves the
same for Linux/Unix and Windows; for Windows invoke as \fips_test_suite instead of
./fips_test_suite as shown in this example.

1. When executed with no argument output similar to the following is produced:

$ ./fips_test_suite
   FIPS-mode test application

1. Non-Approved cryptographic operation test...
   a. Included algorithm (D-H)...successful
2. Automatic power-up self test...successful
3. AES encryption/decryption...successful
4. RSA key generation and encryption/decryption...successful
5. DES-ECB encryption/decryption...successful
6. DSA key generation and signature validation...successful
7a. SHA-1 hash...successful
7b. SHA-256 hash...successful
7c. SHA-512 hash...successful
7d. HMAC-SHA-1 hash...successful
7e. HMAC-SHA-224 hash...successful
7f. HMAC-SHA-256 hash...successful
7g. HMAC-SHA-384 hash...successful
7h. HMAC-SHA-512 hash...successful
8. Non-Approved cryptographic operation test...
   a. Included algorithm (D-H)...successful as expected
9. Zero-ization...
   Generated 128 byte RSA private key
   BN key before overwriting:
   8E0CD7345733DA2922DFDA0C8FC79F5B7F67567E8391C81FA0A3298DF1CEDC6A33646A0840F5
   5F098711075F457943FC3407197660851E21B7918A0B0728D4F33F1210FC22A52EF8BB20353F
   98BB3C8C7E2FC5C36B49AC28E0932568CFCC948E6F4923F42906BC8B14E4071E8960EF17974C8
   70C541241B4F3BB3D5F001E45C01
   BN key after overwriting:
   8045F430EAD7D1AD7F7E3582517692DC69F958844C62FDE68DF62F31A26F1F319BDE04A62DBCB
   B0965B7055BB45B613E428B29F2797884DFC1B51B593346F9B9470FB660F91B8FA487A4E69A
   B7FFC23135CF5107FD62D5E355D613462F085D5235D62A897B398F7089FD91144B3AF33492
   BD0C5B7FB93B43DD26CE26B60E9DF
   char buffer key before overwriting:
   4850f0a33aedd3af6e477f8302b10968
2. To demonstrate the effect of a corrupted Known Answer Test invoke the `fips_test_suite` command with one of the arguments `aes`, `des`, `dsa`, `rsa`, `sha1`, `rng`. The command must be invoked separately with each argument for the KAT test to fail for each separate algorithm. Output similar to the following will be produced for each algorithm (AES in this example):

```bash
$ ./fips_test_suite aes
FIPS-mode test application
3. AES encryption/decryption with corrupted KAT...
$```

### B.6 Testvector Data Files and the `mkfipsscr.pl` Utility

The FIPS 140-2 test labs use CMVP provided Windows based software known as the “CAVS tool” to generate the testvector data files used for the algorithm tests. The CAVS tool performance used to be an issue (requiring days to produce testvector data sets) however it has been improved and this is no longer an issue. The only constant is the name of the actual `.rsp` files of input data. For the initial validation there were 196 unique file name with 2 duplicate names, for a total of 198 files:

<table>
<thead>
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<td>TDES</td>
<td>TCFB8subtab.req</td>
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<td>TDES</td>
<td>TCFB64counter.req</td>
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<td>TDES</td>
<td>TCFB64Monte1.req</td>
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<td>KeyGenRSA.req</td>
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<td>SHA224ShortMsg.req</td>
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<td>SHA256ShortMsg.req</td>
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<tr>
<td>DSA</td>
<td>SigGen.req</td>
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</tbody>
</table>
In order to facilitate the processing of testvector data a series of utilities were developed, culminating in the mkfipssccr.pl program. This program searches a target directory for the known *.rsp files and generates a script referencing the actual pathnames for those files. That script can then be executed to perform the algorithm tests that generate the *.rsp result files. The mkfipssccr.pl program reports unrecognized duplicate *.rsp files and any files that were expected but not found.

Testvector data sets are generally received as *.zip files, rarely as *.tgz. A typical pathname structure (for this validation) is as follows:

```text
OpenSSL vectors (Linux 32 bit No ASM)
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/HMAC
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/HMAC/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/HMAC/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/AES
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/AES/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/AES/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/TDES
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/TDES/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/TDES/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/SHA
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/SHA/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/SHA/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/DSA
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/DSA/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/DSA/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RNG
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RNG/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RNG/req
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA/resp
OpenSSL vectors (Linux 32 bit No ASM)/OpenSSL-x86_noASM_Linux-SALT-0 1.2/RSA/req
```

Note the typical use of embedded spaces in the directory names. The data files will generally (though not necessarily) be carriage return-line feed delimited.
If multiple platforms are involved in a validation the testvector files for several platforms may be
interspersed in the same directory tree. We have also received testvector files for a single platform
in multiple different *.zip files, so the mkfipssrc.pl program must be able to filter the
relevant *.rsp files out of multiple subdirectories.

The following mkfipssrc.pl options can be used to accommodate various representations of
testvector files:

- --win32 Generate Windows style script (default is *nix)
- --onedir All executables are in current directory
- --quiet Suppress warnings
- --dir=<dirname> Only search named directory
- --rspdir=<dirname> Name of subdirs for *.rsp files (default resp)
- --tprefix=<prefix> Path to test executables
- --shwrap_prefix=<prefix> Path to shlib_wrap.sh (*nix only)
- --filter=<string> Only search pathnames containing <string>

B.7 Files for a Runtime Validation

Many vendors validate binary code generated from OpenSSL source. The minimal set of files
needed to obtain a validation of the binary shared libraries libfips.so.0.9.8 (Linux/Unix) or
liboss1fips.dll (Windows) are generated as follows:

For Linux/Unix:

```bash
./config fipsds0
make
mkdir ../<target_dir>/
cp test/fips_*test ../<target_dir>/
cp test/fips_*vs ../<target_dir>/
cp test/fips_test_suite ../<target_dir>/
cp util/shlib_wrap.sh ../<target_dir>/
cp libfips.so.0.9.8 ../<target_dir>/
cp fips/mkfipsscr.pl ../<target_dir>/
```

will place all the files needed for the test lab validation testing in the target directory
../<target_dir>/ . The test lab then runs the binaries in that target directory as follows:

```bash
cd ../<target_dir>/
unzip zipfile of test vectors.zip
perl mkfipsscr.pl --onedir --rspdir=resp
sh fipstest.sh
./shlib_wrap.sh ./fips_test_suite
```

The test vectors are sometimes in tar or tat.gz format, in which case the appropriate command
would be used such as <gunzip -c <tarball of test vectors>.tar.gz | tar xf -.
For Windows:\footnote{Note that for the original \texttt{openssl-fips-1.2.tar.gz} and some subsequent 0.9.8k+ source distributions the \texttt{do_fips.bat} file must be modified to change \texttt{“fipscanisterbuild”} to \texttt{“fipsdso”}. Such modifications are permissible in the context of a complete new validation.}: 

```
perl Configure VC-WIN32 fipsdso
nmake -f ms\do_fips
copy test\fips*_test <target_dir>
copy test\fips*_vs <target_dir>
copy test\fips_test_suite <target_dir>
copy libsslfips.dll <target_dir>
copy fipslink.pl <target_dir>
```

The test lab then executes the binaries in that target directory:

```
unzip <zipfile of test vectors>.zip
perl mkfipsscr.pl --win32 --onedir --rspdir=resp
fipstests.bat
fips_test_suite
```

There is no bundled tar or unzip command for most versions of Microsoft Windows, but many third party implementations are available, such as \url{http://gnuwin32.sourceforge.net/packages/gtar.htm} and \url{http://gnuwin32.sourceforge.net/packages/unzip.htm}.

Note that the Microsoft Visual C++ Redistributable package (\url{http://www.microsoft.com/downloads/details.aspx?displaylang=en&FamilyID=200b2fd9-ae1a-4a14-984d-389c36f85647}) may be required to execute these programs on a system that does not have a version of Microsoft Visual C++ installed.

### B.8 Retrofitting the \texttt{fipsalgtest.pl} Utility

As of the 0.9.8k OpenSSL baseline, which post-dates the OpenSSL FIPS Object Module v1.2 validation, a new more comprehensive replacement for \texttt{mkfipsscr.pl} was developed. Since this utility is external to the cryptographic module it can be used for v1.2 based validations.

Copy \texttt{fipsalgtest.pl} from a 0.9.8k or later OpenSSL distribution, and in place of the \texttt{mkfipsscr.pl} and \texttt{fipstest.sh} scripts referenced earlier in this appendix, simply run

```
perl fipsalgtest.pl --dir=testvectors --generate
```

to generate the \texttt{*.rsp} files for submission to the test lab.
Subsequently running `fipsalgtest.pl` without the `--generate` option will perform some sanity checks on the previously generated `*.rsp` files. If run on the stock OpenSSL FIPS Object Module v1.2 some DSA errors will be reported:

```bash
$ perl fipsalgtest.pl --dir=testvectors --generate
Running DSA tests
Don't know how to keyver.
WARNING: error executing verify test KeyPair ../util/shlib_wrap.sh
../test/fips_dssvs keyver <2009-04-16-Sample-all//DSA/rsp/KeyPair.tst
>2009-04-16-Sample-all//DSA/rsp/KeyPair.ver
Running RSA tests
Running SHA tests
Running HMAC tests
Running RAND (AES) tests
Running AES tests
Running Triple DES tests

ALGORITHM TEST VERIFY SUMMARY REPORT:
Tests skipped due to missing files: 0
Algorithm test program execution failures: 0
Test comparisons successful: 172
Test comparisons failed: 0
Test sanity checks successful: 5
Test sanity checks failed: 0
Sanity check program execution failures: 1

***TEST FAILURE***
```

These errors are seen because some of the sanity checks had not yet been written for v1.2. The `fips_dssvs.c` file from OpenSSL 0.9.8k and later provides those checks.

The `fipsalgtest.pl` utility provides a number of options:

- `--debug`            Enable debug output
- `--dir=<dirname>`    Optional root for `*.req` file search, default "."  
- `--filter=<regexp>`  Optional regexp prefix for `*.req` file names
- `--onedir <dirname>` Assume all components in current directory
- `--rspdir=<dirname>`  Name of subdirectories containing `*.rsp` files
- `--shwrap_prefix=<prefix>` Path prefix for the `shlib_wrap.sh` script, default "./util".
- `--tprefix=<prefix>`  Prefix for the directory containing the test binaries
- `--ignore-bogus`     Ignore duplicate or bogus files
- `--ignore-missing`   Ignore missing test files
- `--quiet`            Shhh....
- `--generate`         Generate algorithm test output
- `--win32`            Win32 environment (O/S detection is automatic)

Individual algorithm tests can be selectively specified with options of the form `--enable-xxx` or `--disable-xxx` where `xxx` is one of the algorithm specifications

```bash
dsa
rsa
```
rsa-pss0 (disabled by default)
rsa-pss62
sha
hmac
rand-aes
rand-des2 (disabled by default)
aes
aes-cfb1 (disabled by default)
des3

The --ignore-bogus and --ignore-missing options suppress the error exit if the target test vector directory contains more or fewer *.rsp files than expected (a not uncommon occurrence in validation testing).

Note that as TDES CFB1 and AES CFB1 support has been added to the 0.9.8 branch following 0.9.8k the fipsalgtest.pl defaults will change accordingly, so use of recent fipsalgtest.pl versions with the original v1.2 code will require that the options --disable-aes-cfb1 and --disable-des3-cfb1 be specified.
Appendix C  Example OpenSSL Based Application

This example shows a simple application using OpenSSL cryptography which will qualify as FIPS 140-2 validated when built and installed in accordance with the procedures in §5. In this application all cryptography is provided through the FIPS Object Module and the FIPS mode initialization is performed via the FIPS_mode_set() call. The command generates a HMAC-SHA-1 digest of an input stream or a file, using the same arbitrary key as the OpenSSL FIPS Module file integrity check:

```
$ ./hmac -v hmac.c
FIPS mode enabled
8f2c8e4f60607613471c11287423f8429b068eb2
$
$ ./hmac < hmac.c
8f2c8e4f60607613471c11287423f8429b068eb2
$
```

Note this sample command is functionally equivalent to:

```
env OPENSSL_FIPS=1 openssl -hmac etanrishdlcupfm hmac.c
```

The OPENSSL_FIPS=1 environment variable enables FIPS mode for a openssl command generated from a FIPS capable OpenSSL distribution.

Makefile

```
CC = gcc
OPENSSLDIR = /usr/local/ssl
LIBCRYPTO = $(OPENSSLDIR)/lib/libcrypto.a
INCLUDES = -I$(OPENSSLDIR)/include
CMD = hmac
OBJ = $(CMD).o

$(CMD): $(OBJ)
    FIPS_LD_CC=$(CC) $(OPENSSLDIR)/bin/fipsld -o $(CMD) $(OBJ) \
    $(LIBCRYPTO)

$(OBJ): $(CMD).c
    $(CC) -c $(CMD).c $(INCLUDES)

clean:
    rm $(OBJ)
```

Note the line

```
$(OPENSSLDIR)/fips/fipsld -o $(CMD) $(OBJ)
```
uses the fipsld command from the distribution source tree to perform the function of verifying the fipscanister.o digest and generating the new embedded digest in the application executable object.

**Source File**

```c
/*
 * Sample application using FIPS mode OpenSSL.

This application will qualify as FIPS 140-2 validated when built, installed, and utilized as described in the "OpenSSL FIPS 140-2 Security Policy" manual.

This command calculates a HMAC-SHA-1 digest of a file or input data stream using the same arbitrary hard-coded key as the FIPS 140-2 source file build-time integrity checks and runtime executable file integrity check.
 */

#include <stdio.h>
#include <string.h>
#include <openssl/hmac.h>

static char label[] = "@(#)FIPS approved SHA1 HMAC";

static void dofile(FILE *fp)
{
    HMAC_CTX ctx;
    unsigned char hmac_value[EVP_MAX_MD_SIZE];
    int hmac_len, i;
    char key[16] = "etaonrishdlcupfm";
    char buf[256];

    /* Generate digest of input stream */
    HMAC_Init(&ctx, key, sizeof(key), EVP_sha1());
    while(fgets(buf,sizeof(buf)-1,fp)) {
        HMAC_Update(&ctx, buf, strlen(buf));
    }
    HMAC_Final(&ctx, hmac_value, &hmac_len);
    HMAC_cleanup(&ctx);

    for(i = 0; i < hmac_len; i++) printf("%02x", hmac_value[i]);
    printf("\n");
    return;
}

main(int argc, char *argv[])
{
    char *opt = NULL;
    int verbose = 0;
```
int fipsmode = 1;
FILE *fp = stdin;
int i;

/* Process command line arguments */
i = 0;
while(++i < argc) {
    opt = argv[i];
    if (!strcmp(opt,"-v")) verbose = 1;
    else if (!strcmp(opt,"-c")) fipsmode = 0;
    else if ('-' == opt[0]) {
        printf("Usage: %s <filename>\n", argv[0]);
        puts("Options:");
        puts("\t-c\tUse non-FIPS mode");
        puts("\t-v\tVerbose output");
        exit(1);
    } else break;
}

/* Enter FIPS mode by default */
if (fipsmode) {
    if(FIPS_mode_set(1)) {
        verbose && fputs("FIPS mode enabled\n", stderr);
    } else {
        ERR_load_crypto_strings();
        ERR_print_errors_fp(stderr);
        exit(1);
    }
}

if (i >= argc) {
    dofile(fp);
} else {
    while(i < argc) {
        opt = argv[i];
        if ((fp = fopen(opt,"r")) == NULL) {
            fprintf(stderr,"Unable to open file \"%s\"\n", opt);
            exit(1);
        }
        dofile(fp);
        fclose(fp);
        i++;
    }
}

exit(0);
Appendix D  FIPS API Documentation

D.1  FIPS_mode

NAME
FIPS mode - NIST FIPS 140-2 Approved mode of operation

DESCRIPTION
When built with the fips config option in accordance with some additional
procedural requirements the OpenSSL FIPS Object Module can be used to satisfy
requirements for FIPS 140-2 validated cryptography.

OVERVIEW
The OpenSSL FIPS Object Module must be built with the fips config option. The
application must call FIPS_mode_set() to enable FIPS mode. When in FIPS mode only
the FIPS approved encryption algorithms
are usable:

+RSA
+DSA
+DES in CBC, (CFB1), CFB8, CFB64, ECB, OFB modes
+DH
+AES in CBC, (CFB1), CFB8, CFB128, ECB, OFB modes with 128/192/256 bit keys
+SHA-1, SHA-2
+HMAC

Other non-FIPS approved algorithms such a Blowfish, MD5, IDEA, RC4, etc. are
disabled in FIPS mode.

If the FIPS power-up self-test fails subsequent cryptographic operations are disabled
and the application will have to exit.

To be considered FIPS 140-2 validated the OpenSSL FIPS Object Module must use the
validated version of the FIPS specific OpenSSL source code.

While most platforms and applications can use the OpenSSL FIPS Object Module to
satisfy NIST requirements for FIPS 140-2 validated cryptography there are additional
additional requirements beyond the call to FIPS_mode_set(). A more complete discussion
of the OpenSSL FIPS mode can be found in the OpenSSL FIPS 140-2 Security Policy which
can be found at http://csrc.nist.gov/cryptval/140-1/140sp/140sp1051.pdf.

Information about FIPS 140 can be found at http://csrc.nist.gov/cryptval/.

NOTES
The power-up self-test can take a significant amount of time on slower systems.

HISTORY
FIPS mode support was introduced in version m of OpenSSL.

SEE ALSO

FIPS_mode_set(7)

D.2 FIPS_mode_set(), FIPS_selftest()

NAME

FIPS_mode_set, FIPS_selftest - perform FIPS power-up self-test

SYNOPSIS

#include <openssl/fips/fips.h>

int FIPS_mode_set(int ONOFF)

int FIPS_selftest(void)

DESCRIPTION

FIPS_mode_set() enables the FIPS mode of operation for applications that have complied with all the provisions of the OpenSSL FIPS 140-2 Security Policy. Successful execution of this function call with non-zero ONOFF is the only way to enable FIPS mode. After verifying the integrity of the executable object code using the stored digest FIPS_mode_set() performs the power-up self-test.

When invoked with ONOFF of zero FIPS_mode_set() exits FIPS mode.

FIPS_selftest() can be called at any time to perform the FIPS power-up self-test.

If the power-up self-test fails subsequent cryptographic operations are disabled. The only possible recovery is a successful re-invocation of FIPS_mode_set() which is unlikely to work unless the original path was incorrect.

RETURN VALUES

A return code of 1 indicates success, 0 failure.

SEE ALSO

FIPS_mode(7)

HISTORY

FIPS support was introduced in version m of OpenSSL.

D.3 Error Codes

In order to minimize the size of the FIPS module only numeric error codes are returned. When used in conjunction with a FIPS capable OpenSSL distribution these numeric codes will
automatically be converted to the usual text format for display, but the FIPS specific standalone utilities print out numerical error codes. These can be interpreted with the `openssl errstr` command or by checking the source file at the referenced location:

```bash
$ ../util/shlib_wrap.sh ./fips_shatest
ERROR:2d06c071:lib=45,func=108,reason=113:file=fips.c:line=274:1,129d0
$ 
$ openssl errstr 2d06c071
error:2D06C071:FIPS routines:FIPS_mode_set:unsupported platform
$
```

The `FIPS_mode_set()` call or other function calls in FIPS mode can return any of the following errors:

- **FIPS_R_CANT_READ_EXE**  
  "cannot read exe"

- **FIPS_R_CANT_READ_EXE_DIGEST**  
  "cannot read exe digest"

- **FIPS_R_CONTRADICTING_EVIDENCE**  
  "contradicting evidence"

- **FIPS_R_EXE_DIGEST_DOES_NOT_MATCH**  
  "exe digest does not match"

- **FIPS_R_FINGERPRINT_DOES_NOT_MATCH**  
  "fingerprint does not match"
  
  The integrity test has failed.

- **FIPS_R_FINGERPRINT_DOES_NOT_MATCH_NONPIC_RELOCATED**  
  "fingerprint does not match nonpic relocated"
  
  This Microsoft Windows specific error indicates that there might be a DLL address conflict which needs to be addressed by re-basing the offending DLL.

- **FIPS_R_FINGERPRINT_DOES_NOT_MATCH_SEGMENT_ALIASING**  
  "fingerprint does not match segment aliasing"
  
  This error is returned when a defective compiler has merged .rodata (read-only) and .data (writable) segments. This situation effectively degrades the read-only status of constant tables and leaves them without hardware protection, thus jeopardizing the FIPS mode of operation.

- **FIPS_R_FIPS_MODE_ALREADY_SET**  
  "fips mode already set"

- **FIPS_R_INVALID_KEY_LENGTH**  
  "invalid key length"

- **FIPS_R_KEY_TOO_SHORT**  
  "key too short"

- **FIPS_R_NON_FIPS_METHOD**  
  "non fips method"

  Attempted non FIPS-compliant DSA usage.

- **FIPS_R_PAIRWISE_TEST_FAILED**  
  "pairwise test failed"

  One or more of the algorithm pairwise consistency tests has failed.

- **FIPS_R_RSA_DECRYPT_ERROR**  
  "rsa decrypt error"

- **FIPS_R_RSA_ENCRYPT_ERROR**  
  "rsa encrypt error"

- **FIPS_R_SELFTEST_FAILED**  
  "selftest failed"

  One or more of the algorithm known answer tests has failed.

- **FIPS_R_TEST_FAILURE**  
  "test failure"

- **FIPS_R_UNSUPPORTED_PLATFORM**  
  "unsupported platform"

  Indicates the validity of the digest test is unknown for the current platform.
Appendix E  Platform Specific Notes

Note: the material in this appendix will be removed from upcoming revisions of this document and relocated elsewhere. That new location will be at, or linked from, http://www.openssl.org/docs/fips/.

E.0  Nomenclature for ABIs:

Among other things an ABI is characterized by implicit (or default) integer, long integer, and pointer sizes with the letters I, L, P:

- I stands for sizeof(int)
- L stands for sizeof(long)
- P stands for size(void*), i.e. the size of a pointer

For example, HP-UX for Itanium/IA64 implements two separate ABIs, 32 bit “ILP32” and 64 bit “I32/LP64”. In the first case sizeof(int)=sizeof(long)=sizeof(void*)=4 or 32 bits, while for the latter sizeof(int)=4 or 32 bits and sizeof(long)=sizeof(void*)=8 or 64 bits.

Considerations for Linux:

Due to the diversity of hardware platforms supported by Linux no universal guidance can be given. For Linux on x86_64, 32 bit code generation could be performed by installing 32-bit Linux x86 on an alternative partition or booting it off a "live CD" (or rather "live DVD" as there is insufficient room for a compiler on a CD). For other 64 bit platforms the generation of 32 bit code is more of a challenge, most likely requiring access to old hardware on a corresponding 32-bit Linux can be booted. However, while being perfectly capable of running corresponding legacy 32-bit *user-land* code, most 64-bit non-x86_64 hardware can't run corresponding 32-bit kernels (or rather those 32-bit kernelsl not won't know how to handle such CPU). Note that there are some "pure" 64-bit Linux implementation which have no 32-bit legacy counterpart, such as Alpha and Itanium.

Considerations for HP-UX:

HP-UX PA-RISC: It is not known if there are any HP-UX systems that capable of booting either 32- or 64-bit kernels. Presumably old hardware would be needed to compile 32-bit PA-RISC binaries.

HP-UX Itanium: There is only a 64-bit kernel and no way to compile ILP32 Itanium code. Note incidentally a subtle point, there is no such thing as legacy 32-bit Itanium code. The ILP32 Itanium ABI was introduced to facilitate porting or re-compilation of non-64-bit safe applications from other 32-bit platforms, a backward compatibility of sorts that is really a source code compatibility.
This is apart from the fact that HP-UX Itanium can run legacy 32-bit PA-RISC binaries via emulation.

Considerations for Windows:

Microsoft Windows Win64 only implements “IL32/P64” where sizeof(int)=sizeof(long)=32 bits and sizeof(void*)=64 bits. For Win64 “non 64 bit safe” code is code that is compiled for Win64 but which treats pointers as if they were 32 bit values, and the Win64 kernel can be instructed to execute any particular .exe to a 4Gb address space (the size of a 32 bit pointer).

The FIPS Object Module built on Win64 can be used with either “64 bit safe” or “non-64 bit safe” application code.

Microsoft Visual Studio C++ 2005 comes with a number of different compilers (cl.exe programs). Depending on the install options and target system types several different tool chains may be present. For example, on a Win32/X86 system the following may be present:

1. Win32/x86 cl.exe generating x86 code
2. Win32/x86 cl.exe generating x86_64(x64) code
3. Win32/x86 cl.exe generating IA64 code
4. Win32/x86 cl.exe generating ARM code (for Mobile PC)

A Win64/x86_64 (aka “x64” in Windows-speak) system will have all of the above plus

5. Win64/x64 cl.exe generating x86_64(x64) code

The Platform SDK and DDK for Win64 also adds one more compiler,

6. Win64/IA64 cl.exe generating IA64 code

Only the first four will be present on a Win32/x86 system. Note that there are two different compilers generating x86_64 code. On either Win32 or Win64 at least three of these will be cross-compilers with no option to run code on the same system and hence cannot be used for building the FIPS Object Module. Note it doesn't really matter which compiler is used as long as the resulting binary code can be executed. For example, on Win64 x86_64 systems either the Win32/x86 cl.exe generating x86_64 code (which can be qualified as cross-compiler) or Win64/x64 cl.exe may be used. Likewise for Itanium, either the Win32/x86 cl.exe generating IA64 code (which can be qualified as a cross-compiler) or Win64/IA64 cl.exe may be used. The only difference in this case would be compilation time as the because Win32/x86 compiler would be slower.

To build Win32/x86 compatible code on a Win64 system start

    %SYSTEMROOT%\syswow64\cmd.exe
and make sure a cl.exe generating x86 code is in %PATH%.

Most people associate the term “backward compatibility” with backward binary compatibility, as when a 64-bit system is capable of running 32-bit binary code (for the same OS) without recompilation. For example, a x86_64 system can run x86 binary code, a sparcv9 system can run sparcv8 binary code, etc. Win64 can do this, i.e. both Win64 x86_64 and Win64 Itanium can run Windows x86 binaries. But Win64 can do something else as well; the Win64 kernel can provide a run-time environment for re-compiled non-64-bit safe applications. Thus backwards compatibility in Win64 is two-fold: binary and "source."

Note that backward "source" compatibility in Win64 (on both x86_64 and Itanium) is nothing like ILP32 in HP-UX Itanium. In HP-UX Itanium ILP32 applications have a distinct binary format, require separate sets of run-time libraries such as libc.so, and use dedicated system call interfaces. The Win64 kernel on the other hand can simply can be instructed to restrict a the address space for a particular application to 2GB. That restriction makes it possible for that application to safely cast pointers to 32-bit integer and back, a characteristic of non-64-bit safe programs. But this is done with no dedicated ILP32 ABI, no special ntdll.dll, nothing but a single bit in .exe header, which can be set in the link stage with /LARGEEADDRESSAWARE:NO (and even manipulated subsequently with editbin). This capability means that the same .dll can be used in both 64-bit safe and non-64-bit safe applications.

### E.1 Compiler placement of read-only data

The in-core hashing mechanism requires that read-only data be placed in a read-only data segment. The FIPS_set_mode() function is designed to detect situations where this requirement is not met. One example of this problem is on 32 bit\(^\text{34}\) HP-UX PA-RISC when using gcc to generate position independent code (-FPIC). At least some versions of gcc do not discriminate read-only data and put it into a writable data segment. This problem has been observed with gcc 3.2.3 and 3.4.2. This placement effectively voids the embedded digest value and the verification procedure is bound to fail.

A simple test program will demonstrate the problem. On a 32 bit HP-UX PA-RISC system using gcc the commands

```
  echo "const int i=0;" > a.c
  gcc -c a.c
  size a.o
  gcc -c -FPIC a.c
  size a.o
  gcc -v
```

\(^\text{34}\)Note this problem occurs for 32 bit code whether executed on a 32 or 64 bit processor. 64 bit PA-RISC code has not been observed to exhibit this problem.
generate the output
\[
\begin{align*}
8 + 0 + 0 &= 8 \\
0 + 8 + 0 &= 8
\end{align*}
\]

Reading specs from /usr/local/lib/gcc-lib/hppa2.0n-hp-hpux11.00/3.2.3/specs
Configured with: ../gcc-3.2.3/configure --enable-languages=c,c++ --with-gnu-as
Thread model: single
gcc version 3.2.3

On the same 32 bit HP-UX PA-RISC system using the HP C compiler the commands:

\[
\begin{align*}
echo \"const int i=0;\" &> a.c \\
cc -Ae -c a.c \\
cc -Ae +Z -c a.c \\
cc -V -Ae -c a.c
\end{align*}
\]

give the result

\[
\begin{align*}
4 + 0 + 0 &= 4 \\
4 + 0 + 0 &= 4
\end{align*}
\]
cpp.ansi: HP92453-01 B.11.11.32871.GP HP C Preprocessor (ANSI)
ccom: HP92453-01 B.11.X.34412-34415.GP HP C Compiler

The workaround for this bug is to advise users to use the HP C compiler for their 32-bit HP-UX PA-RISC applications until/if gcc is fixed.

### E.2 Bugs in Microsoft TLS Implementation

In FIPS mode the number of available ciphersuites is restricted to those using 3DES, AES, SHA-1 and SHA-2, resulting in negotiation of AES and 3DES in CBC mode with a TLS client. At least some versions of the Microsoft SSL/TLS implementation of CBC are unable to handle the empty fragments inserted in CBC mode by OpenSSL as a countermeasure for a minor security issue.

A discussion of this security issue can be found at [http://www.openssl.org/~bodo/tls-cbc.txt](http://www.openssl.org/~bodo/tls-cbc.txt). The general consensus of the OpenSSL developers who implemented the FIPS mode is that this vulnerability is relatively minor.

This use of empty fragments can be disabled with the function call

\[
\text{SSL_CTX_set_options(ctx,SSL_OP_DONT_INSERT_EMPTY_FRAGMENTS)}
\]

Note the rudimentary https server provided by the (FIPS compatible) openssl command can be used to test for this bug:

\[
\text{OPENSSL_FIPS=1 openssl s_server -www [-debug]}
\]
Note that TLS is disabled by default for the Microsoft Internet Explorer (go to “Tools” menu, select “Internet Options...”, select “Advanced”, scroll top the bottom and enable “Use TLS 1.0”).

### E.3 Solaris and gcc Problems

There is a known problem with some versions of gcc\(^{35}\) on x86 Solaris where a program linked with the OpenSSL libcrypto will segfault in "\_init".

Every object module consists of segment fractions which are merged by the link-editor. For example, .text fractions from all *.o files are concatenated to form the program .text segment. Every such fraction is allowed to specify alignment in the resulting image and the link-editor is expected to align it accordingly. When different fractions specify different alignments the link-editor pads the previous fragment until the alignment requirement for the currently processed fragment is met. The value used for padding varies by implementation. Solaris ld uses a value of zero, which means that for executable segments machine code is padded with zeros. That means that if the processor attempts to interpret that zero padding (opcode 0), it would execute a series of ‘add %al, (%eax)’ instructions. Depending on the value in register %eax that instruction might work or it might incur a segmentation violation. But, even if the instruction does not segfault it can cause unpredicted behavior later on. A better choice of padding value would be one which maps into an instruction which has no effect on the processor state. In x86 context 0x90 (the NOP machine instruction) would be an appropriate value.

Why is only the .init segment is affected and not .text? Because .text fragments contain either complete functions and padding zeros are preceded by flow transfer instructions, such as return or branch), or code fragments that never complete (e.g. calling "exit this process" system call). In other words padding is never executed in .text segments. The .init fragments on the other hand contain pure code and are concatenated to form a linear stream of machine code. The padding values are therefore executed as machine instructions and non-NOP padding is bound to have undesired side effects such as segmentation violation.

Andy Polyakov has prepared a patch of sorts to address this issue ([http://www.openssl.org/~appro/values.c](http://www.openssl.org/~appro/values.c)). This “patch”, a single file which is both a shell script and a C source file, modifies the Solaris gcc development environment only, not the OpenSSL code. On Solaris linking with libc requires linking with an object module which instantiates the _lib_version constant. This object module is commonly provided by Sun and is linked first prior to crtbegin.o. The patch procedure strategically places a replacement module\(^{36}\) on the gcc library search path. But in addition to _lib_version the replacement module contains an .init

---

\(^{35}\)And with the Sun C compiler also, but OpenSSL currently does not use assembler optimizations with that compiler.

\(^{36}\)The values.c patch actually installs several files with names of the form values-X?.o. Which of these files is referenced depended on the compiler options. For example, “cc -Xc ...” references values-Xc.o, “cc -Xt ...” references values-Xt.o, and gcc references values-Xc.o if -ansi is specified and values-Xa.o otherwise.
snippet, which simply checks if the value following the snippet code is zero (i.e., the troublesome padding) or not and conditionally skips over or executes it.

The alignment of this replacement module .init fragment and the OpenSSL .init fragments is chosen carefully to work with both older and newer versions of gcc. If OpenSSL .init fragments were not aligned the way they are, then padding following the last one would cause the problem with older versions of gcc. Lack of replacement module padding preceding the first OpenSSL .init fragment would cause the problem with newer versions of gcc. The patch addresses both older and newer gcc versions.

Note the end-user does not need to patch anything to run the linked application. Replacement modules are linked statically (just like the original ones) into either application or shared object code.

The gcc installation modifications can be reverted by removing the files “values-X*.o” from the directory containing libgcc.a. The location of that directory can be obtained by executing “gcc -print-libgcc-file-name”.

### E.5 HP-UX Vendor Support


HP was a sponsor of the original OpenSSL FIPS Object Module validation.

### E.6 Apple OS X Support

The build environment can be specified by the auxiliary files:

```
setenv-reset.sh
setenv-darwin-i386.sh  (for 32 bit)
setenv-darwin-x86_64.sh (for 64 bit)
```

These files can be obtained from:

[http://openssl.com/fips/1.2/platforms/osx/](http://openssl.com/fips/1.2/platforms/osx/)

Note the instructions are very similar for the two platforms (32 and 64 bit), the only essential difference being the use of the appropriate environment settings.
First we set the environment variables to define the target platform in the appropriate workarea containing the source files:

```
$ cd openssl-fips-1.2.4
$ . ../setenv-reset.sh  
    (note leading dot ".")
$ . ../setenv-darwin-1386.sh  
    (for 32 bit)
$ . ../setenv-darwin-x86_64.sh  
    (for 64 bit)
```

At this point we are ready to commence the standard FIPS canister build for the target platform.

```
$ ./config fipscanisterbuild
should see several screens of output
$ make
should see lots of output
$ cd ..
```

The architecture type can be confirmed with the `lipo` command:

```
$ lipo -info openssl-fips-1.2.4/test/fips_algvs
Non-fat file: openssl-fips-1.2.4/test/fips_algvs is
architecture: i386  
    (for 32 bit)
Non-fat file: openssl-fips-1.2.4/test/fips_algvs is
architecture: x86_64  
    (for 64 bit)
$ 
```

Note the `make` command automatically generates the `fips_algvs` utility, no separate `make build_algvs` command is necessary.

The `fips_algvs` utility can now be invoked:

```
$ openssl-fips-1.2.4/test/fips_algvs  fips_test_suite
$ 
    FIPS-mode test application

1. Non-Approved cryptographic operation test...
    a. Included algorithm (D-H)...successful
2. Automatic power-up self test...successful
3. AES encryption/decryption...successful
   
   char buffer key after overwriting:
   ccfe6b7c02eb009d3157a67a4c2fe4e5
```
successful as expected

All tests completed with 0 errors
$

E.7 Apple iOS Support

The build environment requires the auxiliary files:

setenv-reset.sh
setenv-darwin-i386.sh
setenv-ios-10.sh (for use with OS X 10)
setenv-ios-11.sh (for use with OS X 11)
ios-incore-1.2.4.tar.gz

These files can be obtained from:

http://openssl.com/fips/1.2/platforms/ios/

The ios-incore.tar.gz file contains an OS X and iOS specific "incore" utility to determine the object code digest.

The ios-project.tar.gz file contains OS X and iOS specific files that define Xcode "project" information needed to create the test suite application for the iOS platform.

Setup

On the OS X build system:

$ gunzip -c openssl-fips-1.2.4.tar.gz | tar xf -

As the integrity check requires calculation of a fingerprint and the Darwin host cannot directly execute the target images, we use the cross-compilation approach of calculating the incore image on the build host using a separate "incore" utility.

To compile the "incore" utility.

$ . setenv-reset.sh (note the leading dot ".")
$ . setenv-darwin-i386.sh (note the leading dot ".")
$ cd openssl-fips-1.2.4
$ gunzip -c ../ios-incore-1.2.4.tar.gz | tar xf -
$ ./config fipsanisterbuild
should see several screens of output
$ make
should see lots of output
$ cd iOS
    should see several lines of output
$ make

The output of the build process is a utility `incore_macho` that should be installed in a location in the PATH (this is done automatically for this build process). Note this utility is a native binary that executes on the Darwin host.

Confirm the utility works:

```bash
$ ./incore_macho
usage:
    ./incore_macho [--debug] [-exe|-dso] executable
```

Then cleanup the build which was just done in order to construct the incore utility – it is no longer needed once `incore_macho` has been built.

```bash
$ cd ..
$ make clean (remove host build except for iOS directory)
$ rm -f *.dylib (remove left over dynamic libraries)
```

This instructions from this point assume the build environment has been prepared, including the creation of the "incode_macho" utility, as documented in the previous section.

Cross-compilation

This step can be performed either via a SSH command line session or in a terminal window in a graphical session (e.g. VNC).

First we set the environment variables to define the target platform, and confirm the pathnames are correct in the first window. Note that while these commands look similar to those recently executed for the generation of the incore utility, there are some subtle differences. This time around we are cross-compiling binaries for the iOS target device:

```bash
$ cd openssl-fips-1.2.4
$ . ../setenv-reset.sh (note the leading dot ".")
$ . ../setenv-ios-NN.sh (note the leading dot ".")
$ llvm-gcc -v (confirm we have the PATH right)
Target: i686-apple-darwin10
Using built-in specs.
Target: i686-apple-darwin11
Configured with: /private/var/tmp/llvmgcc42/llvmgcc42-2336.1~1/src/configure --disable-checking --enable-werror
At this point we are ready to commence the standard FIPS canister build for the target platform.

```bash
$ ./config fipscanisterbuild
should see several screens of output
$ make
should see lots of output
$ make install
should see lots of output
```

The output will be installed into the `/usr/local/ssl/Release-iphoneos` area (the installation location can be adjusted in the `setenv-ios-NN.sh` script).

Note we can confirm that these binaries are for the iOS target device:

```bash
$ lipo -info /usr/local/ssl/Release-iphoneos/lib/fipscanister.o
Non-fat file: /usr/local/ssl/Release-iphoneos/lib/fipscanister.o is architecture: armv7
$
Appendix F  Restrictions on the Export of Cryptography

Government restrictions and regulations on the use, acquisition, and distribution of cryptographic products are a matter of concern for some potential users.

F.1  Open Source Software

In the United States the current export regulations appear to more or less leave open source software in source code format alone, except for a reporting requirement to the Bureau of Industry and Security (BIS) of the U.S. Department of Commerce; see http://bxa.doc.gov/Encryption/pubavailencsourcecodenofify.html.

When in doubt consultation with legal experts would be appropriate. An example of an E-mail message sent to comply with this reporting requirement is:

To: crypt@bis.doc.gov, enc@nsa.gov, web_site@bis.doc.gov
Subject: TSU NOTIFICATION

SUBMISSION TYPE: TSU
SUBMITTED BY: Steve Marquess
SUBMITTED FOR: Veridical Systems, Inc.
POINT OF CONTACT: Steve Marquess
PHONE and/or FAX: 301-831-8447
MANUFACTURER: N/A
PRODUCT NAME/MODEL #: OpenSSL
ECCN: 5D002

NOTIFICATION: http://cvs.openssl.org/dir

Employee(s) of Veridical Systems, Inc. are participating in the development of the freely available open source OpenSSL product by providing feedback on new releases, by requesting new features, and by correspondence either to the developer and user mailing lists or directly with the core developers. This correspondence may include suggested source code fragments or patches. All versions of any such contributions incorporated in any of the OpenSSL software will be publicly accessible at http://cvs.openssl.org/dir.

No response was received (or expected).

Other links of interest:

http://bxa.doc.gov/Encryption/ChecklistInstr.htm
F.2 “Export Jobs, Not Crypto”

For software exported in binary form the situation is far less certain. As incredible and unbelievably opposed to common sense as it seems, current U.S. export controls appear to restrict the export from the U.S. of software products that use the OpenSSL product, even if OpensSSL is used exclusively for all cryptographic functionality.

From what has been relayed from several vendors affected by these export restrictions, export approval for software utilizing OpenSSL is contingent on a number of factors including the type of linking (static build-time linking or dynamic run-time linking). Static linking is more desirable, apparently something to do with the concept of an “open cryptographic interface”. Evidently a product where the end user can easily substitute a new cryptographic library (a newer version of OpenSSL, say) is not permissible.

Needless to say the written regulations and expert commentary are varied, so advice of legal counsel is recommended. The only other safe course of action would be to pay non-U.S. citizens to develop the cryptographic software overseas and import it into the U.S., as imports are not restricted. Foreigners who benefit financially from this situation refer to the U.S. “export jobs, not crypto” policy.

Links of interest:

http://www.axsmith.com/Encryption_Law.htm
http://cryptome.org/bx-a-bernstein.htm
APPENDIX G  Security Policy Errata

The formal Security Policy (http://csrc.nist.gov/groups/STM/cmvp/documents/140-1/140sp/140sp1051.pdf) is a controlled document and so, as with the validated software proper, cannot readily be changed. This section lists known errors in that document.

Appendix A
The entry “x84-64” in the last row of the table should be “x86-64”. The sentence “Verify that the SHA-1 HMAC digest ...” in Installation Instructions should read “Verify the SHA-1 HMAC digest...”. Reported by Thomas Hruska of Shining Light Productions.

Appendix B