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(54) **NESTED STRONG LOADER APPARATUS AND METHOD**

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(57) **ABSTRACT**

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An apparatus and method provides one or more controlled, dynamically loaded, modular, cryptographic fillers. Fillers may be loaded by a single loader, multiple independent loaders, or nested loaders. Loaders may be adapted to load other loaders, within cryptographic controls extant and applicable thereto. Integration into a base executable having one or more slots, minimizes, controls, and links the interface between the fillers and base executables. The filler may itself operate recursively to load another filler in nested operations, whether or not the fillers are in nested relation to one another. An ability of any filler to be loaded may be controlled by the base executable verifying the integrity, authorization, or both for any filler. The base executable may rely on an integrated loader to control loading and linking of fillers and submodules. A policy may limit each module's function, access, and potential for modification or substitution. Dynamically loaded modules (loaders, other fillers, and submodules thereof), typically represent a relatively small portion of the overall coding required by the base executable, and may provide strong controls limiting integration by providing access that is nested, layered, or both between modules, excluding direct access to or by them from the base executable or supported applications.

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(51) **Int. Cl.**<sup>7</sup> ..... **H04L 9/00**

(52) **U.S. Cl.** ..... **705/54; 705/1; 705/7; 705/8; 705/9; 705/54; 705/57; 705/67; 705/74; 705/75; 713/159; 713/164; 713/180; 713/184; 713/200**

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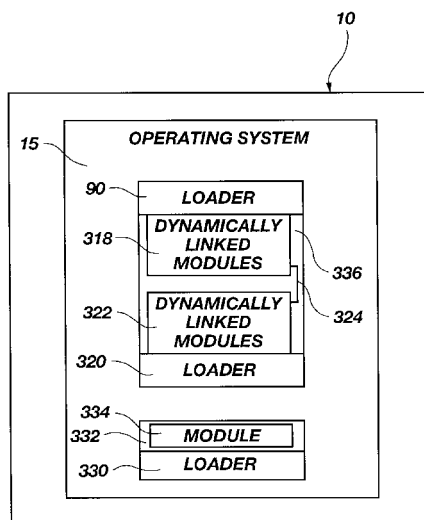
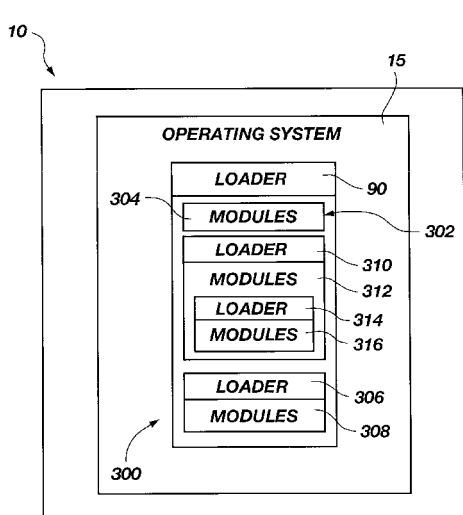
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**23 Claims, 7 Drawing Sheets**



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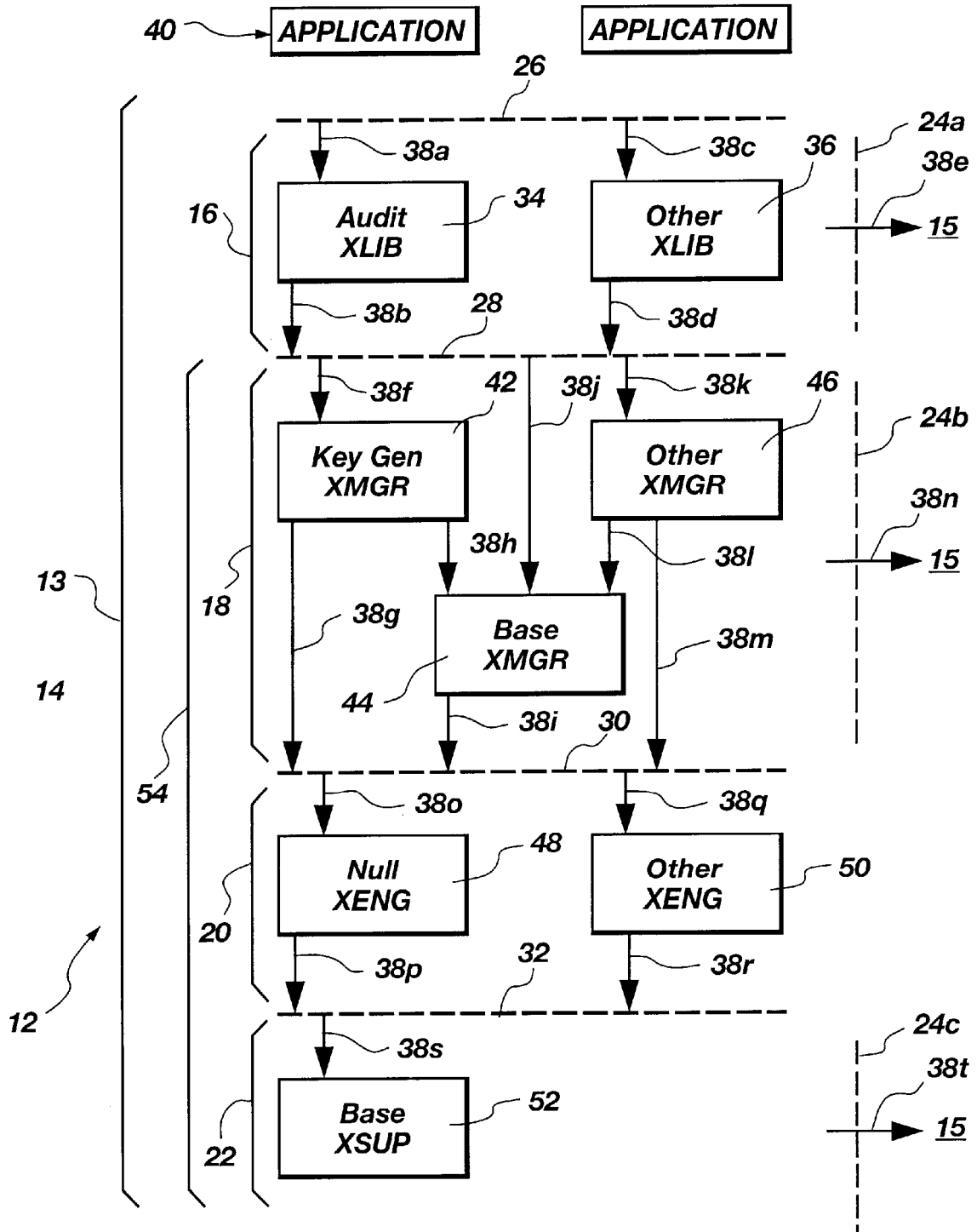


Fig. 1

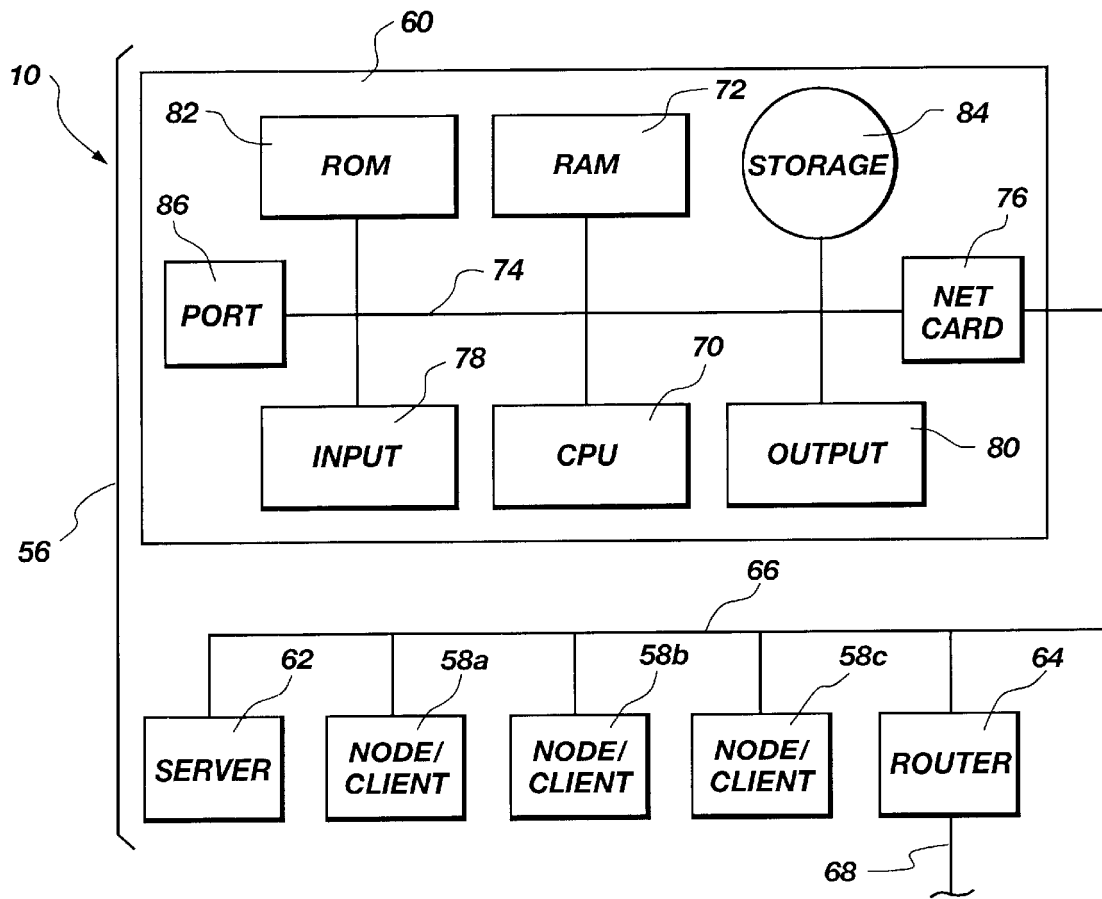


Fig. 2

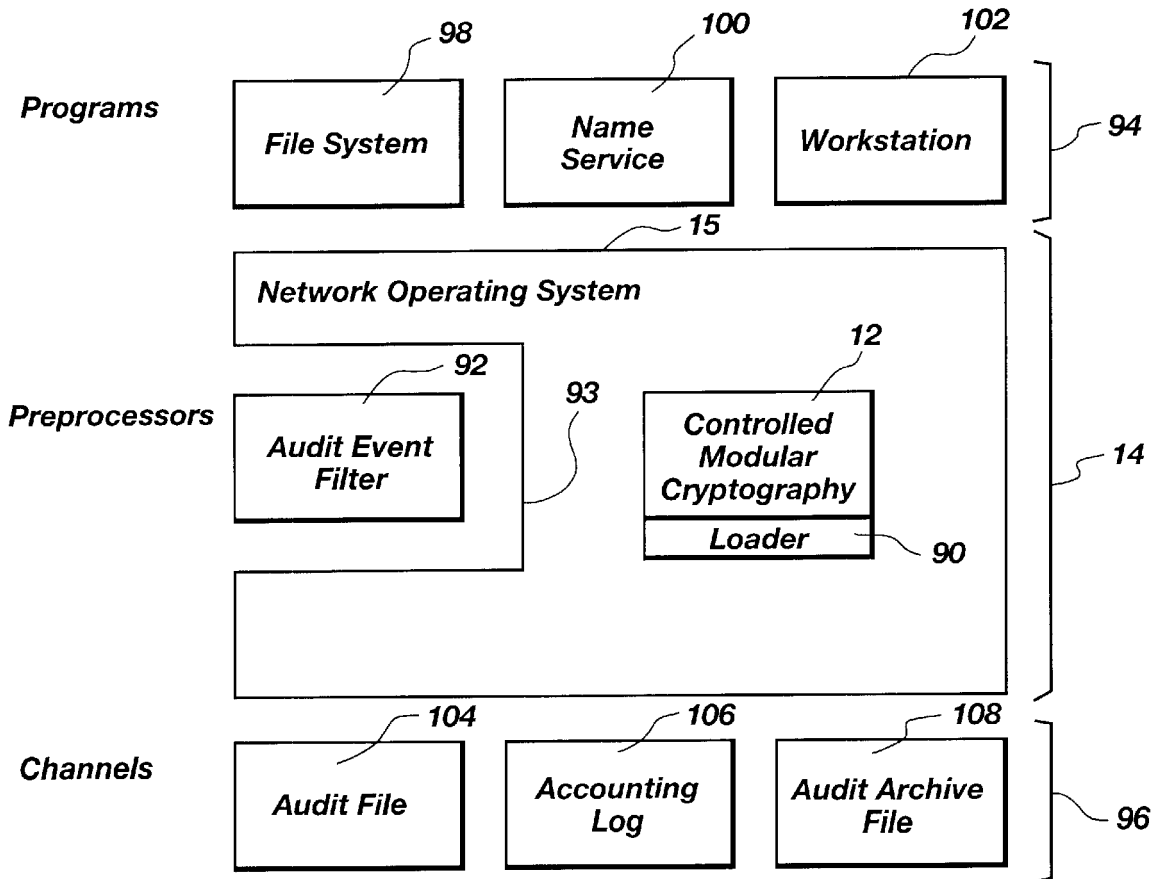


Fig. 3

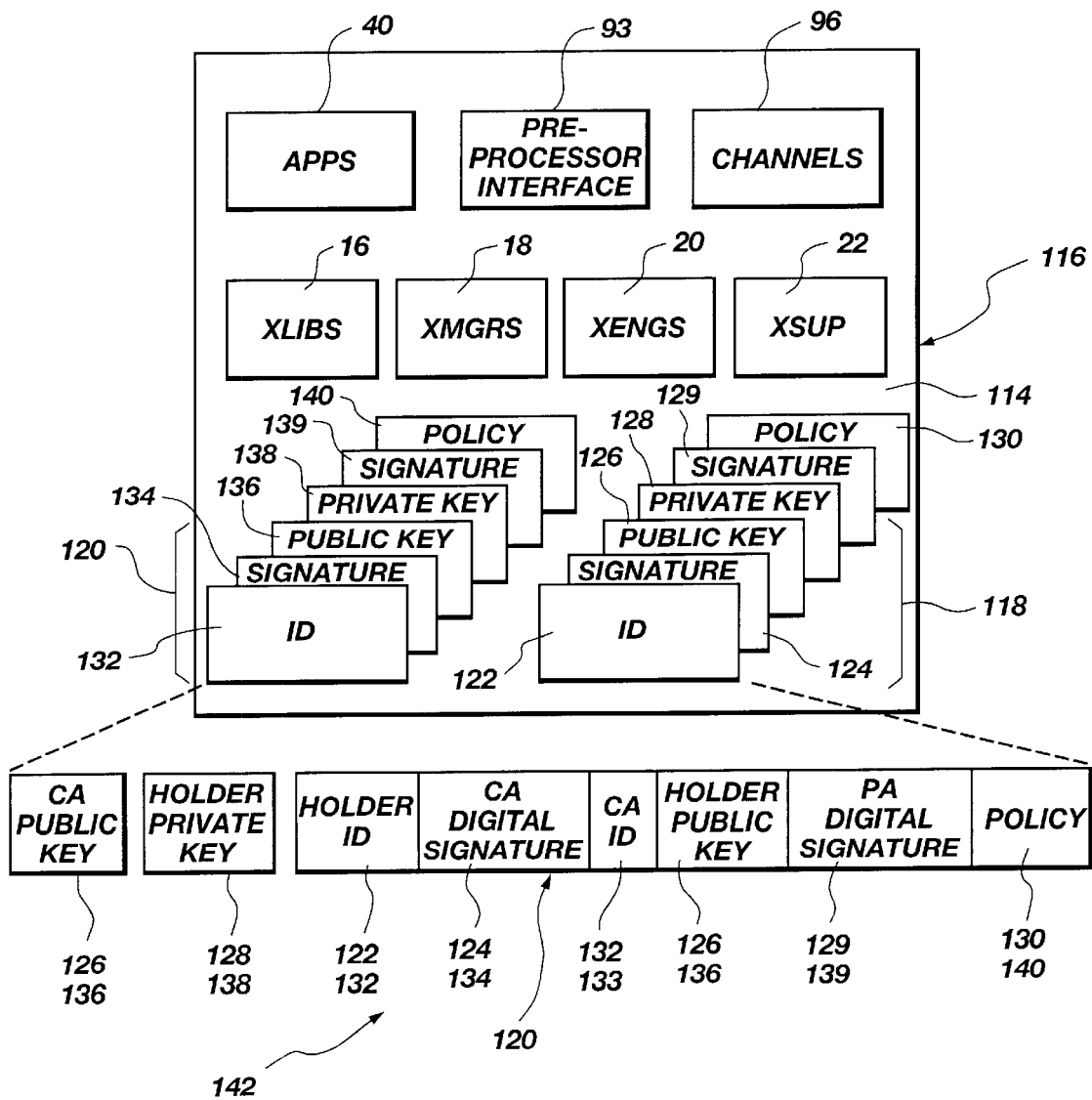


Fig. 4

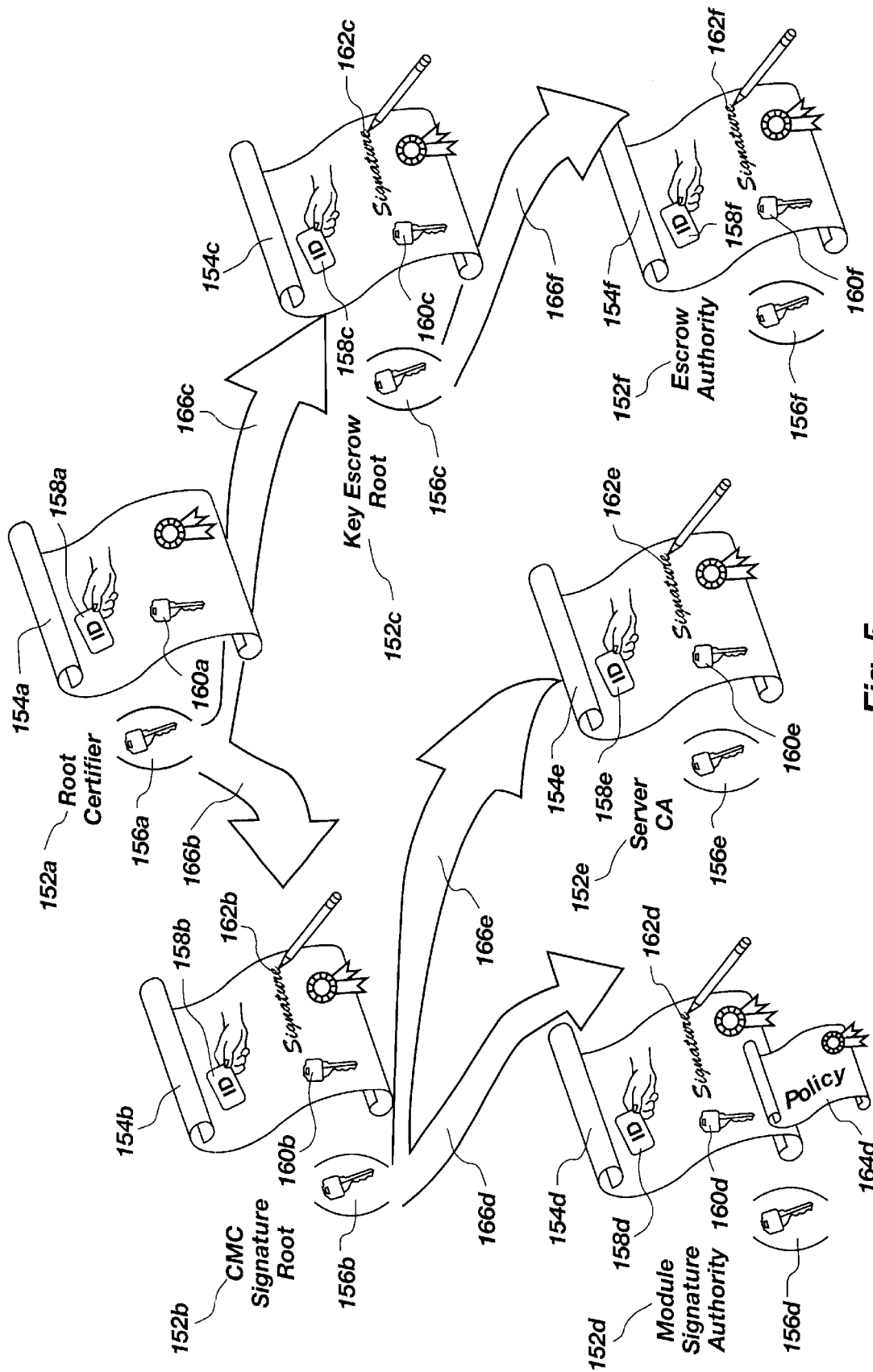
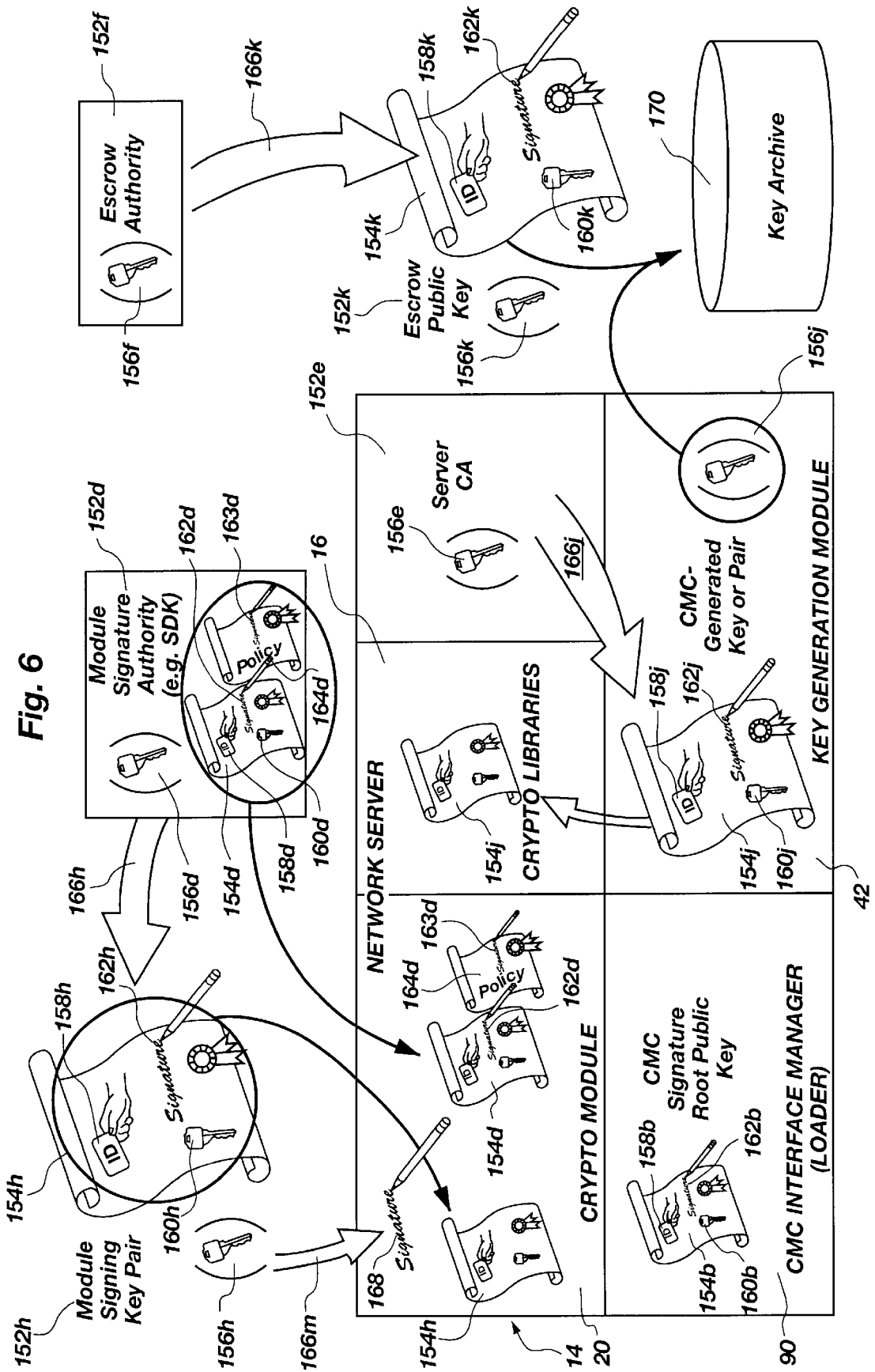


Fig. 5





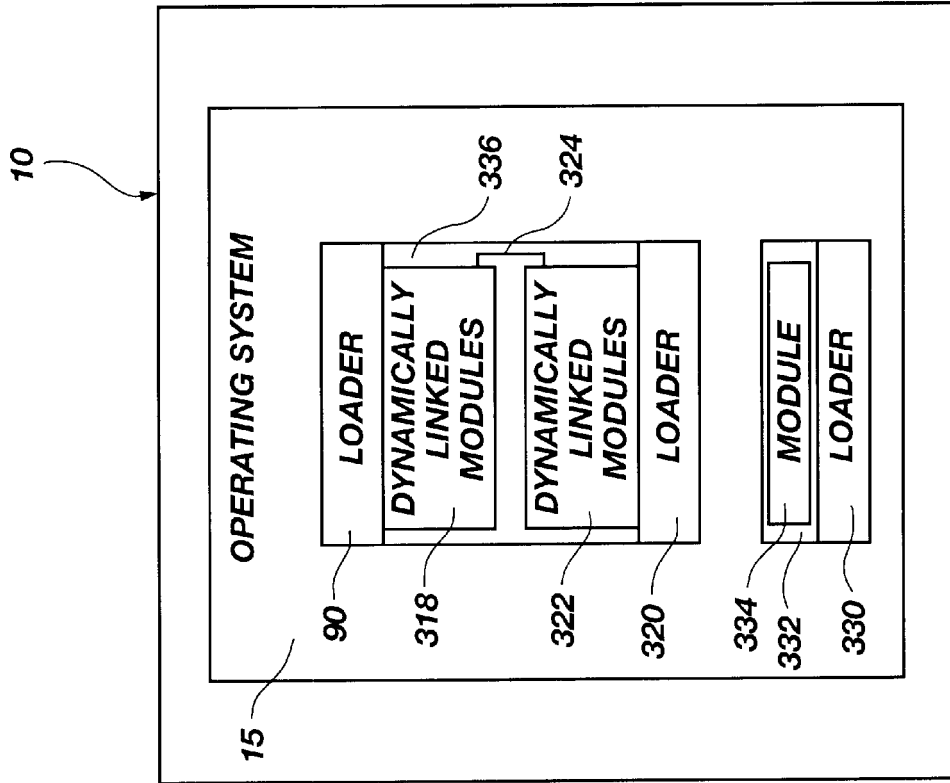


Fig. 8

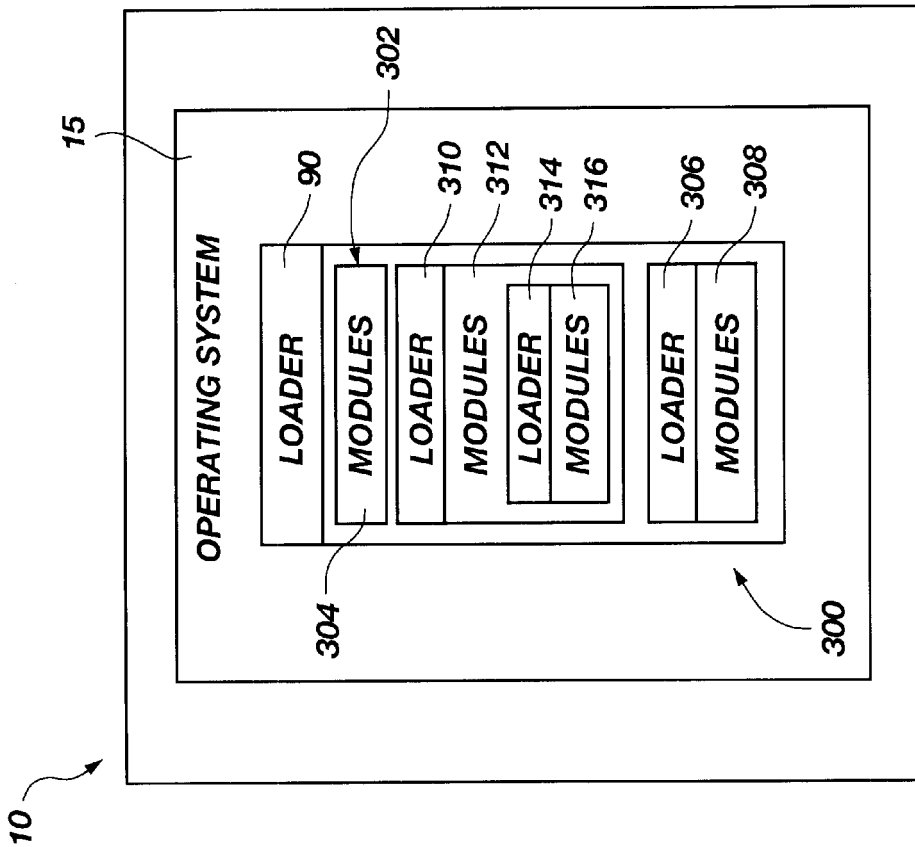


Fig. 7

## NESTED STRONG LOADER APPARATUS AND METHOD

### RELATED APPLICATIONS

This application is a Continuation-In-Part of and claims priority to copending U.S. Provisional Patent Application Ser. No. 60/079,133, filed on Mar. 23, 1998.

### BACKGROUND

#### 1. The Field of the Invention

The present invention relates to cryptographic systems and methodology. More particularly, the present invention relates to novel apparatus systems and the capability of hosting a plurality of individual modularized methods for allowing encrypting applications within a single use application operating on a computer and to separately control the access, use, and authorization of each of the individual encrypting applications.

#### 2. The Background Art

Encryption is a technology dating from ancient times. In modern times, encryption of military communications has been common. However, since the famous "ENIGMA" machine of World War II, cryptography has been used in numerous functions. One of those functions is special purpose software or applications that may be hosted on computers. Hiding underlying algorithms, limiting access, inhibiting reverse engineering, limiting unauthorized use, controlling licensure, and the like may be legitimate uses of cryptography.

#### Cryptographic Processes

Modern cryptography protects data transmitted over high-speed electronic lines or stored in computer systems. There are two principal objectives: secrecy, to prevent the unauthorized disclosure of data, and integrity (or authenticity), to prevent the unauthorized modification of data. The process of disguising plaintext data in such a way as to hide its substance is encryption, and the encrypted result is cyphertext. The process of turning cyphertext back into plaintext is decryption.

A cryptographic algorithm, also called a cipher, is the computational function used to perform encryption and/or decryption. Both encryption and decryption are controlled by a cryptographic key or keys. In modern cryptography, all of the security of cryptographic algorithms is based in the key or keys and depends not at all on keeping any details of the algorithms secret.

There are two general types of key-based cryptographic algorithms: symmetric and public-key. Symmetric algorithms (also called secret-key algorithms) are algorithms where the encryption key can be calculated from the decryption key and vice versa (and in fact these keys are usually the same). These require that a sender and receiver agree on these keys before they can protect their communications using encryption. The security of these algorithms rests in the key, and divulging the key allows anyone to encrypt and decrypt data or messages with it.

In public-key algorithms (also called asymmetric algorithms), the keys used for encryption and decryption different from each other in such a way that at least one key is computationally infeasible to determine from the other. To ensure secrecy of data or communications, only the decryption key need be kept private, and the encryption key can thus be made public without danger of encrypted data being decipherable by anyone other than the holder of the private decryption key. Conversely, to ensure integrity of data or communications, only the encryption key need be kept

private, and a holder of a publicly-exposed decryption key can be assured that any cyphertext that decrypts into meaningful plaintext using this key could only have been encrypted by the holder of the corresponding private key, thus precluding any tampering or corruption of the cyphertext after its encryption.

Most public-key cryptographic algorithms can be used to provide only one of secrecy or integrity but not the other; some algorithms can provide either one but not both. Only the RSA (Rivest, Shamir, and Adleman) public-key algorithm (U.S. Pat. No. 4,405,829), whose security is based on the difficulty of factoring large numbers, has been able to be used to provide both secrecy and integrity.

A private key and a public key may be thought of as functionally reciprocal. Thus, whatever a possessor of one key of a key pair can do, a possessor of the other key of the key pair can undo. The result is that pairwise, secret, protected communication may be available without an exchange of keys. Thus, in general, a receiver, in possession of its own private key may be enabled to use its own copy of a sender's public key, to decrypt data encrypted with a sender's private key corresponding to the sender's public key.

An asymmetric algorithm assumes that public keys are well publicized in an integrity-secure manner. A sender (user of a public key associated with a receiver) can then know that the public key is valid, effective, and untampered with. One way to ensure integrity of data packets is to run data through a cryptographic algorithm. A cryptographic hash algorithm may encrypt and compress selected data. Such hash algorithms are commercially available. For example, the message digest 5 (MD 5), and the message digest 4 (MD 4) are commercially available software packages or applications for such functions.

A certificate may be thought of as a data structure containing information or data representing information, associated with assurance of integrity and/or privacy of encrypted data. A certificate binds an identity of a holder to a public key of that holder, and may be signed by a certifying authority. A signature is sometimes spoken of as binding an identity of a holder to a public key in a certificate. As a practical matter, a certificate may be very valuable in determining some level of confidence in keys associated with encryption. That is, just how "good" is an encryption in terms of privacy and integrity? That confidence level may be established by means of a certificate hierarchy. By certificate hierarchy is meant a certification process or series of processes for providing certificates from a trusted authority to another creator of keys.

A certificate, being a data structure, may contain, for example, data regarding the identity of the entity being certified as the holder of the key associated with the certificate, the key held (typically it is a public key), the identity (typically self-authenticating) of the certifying authority issuing the certificate to the holder, and a digital signature, protecting the integrity of the contents of the certificate. A digital signature may typically be based on the private key of the certifying authority issuing the certificate to the holder. Thus, any entity to whom the certificate is asserted may verify the signature corresponding to the private key of the certifying authority.

In general, a signature of a certifying authority is a digital signature. The digital signature associated with a certificate enables a holder of the certificate, and one to whom the certificate is asserted as authority of the holder, to use the signature of the certifying authority to verify that nothing in the certificate has been modified. This verification is accom-

plished using the certificate authority's public key. This is a means to verify the integrity and authenticity of the certificate and of the public key in the certificate.

#### Cryptographic Policies

Government authorities throughout the world have interests in controlling the use of cryptographic algorithms and keys. Many nations have specific policies directed to creation, use, import, and export of cryptographic devices and software. Numerous policies may exist within a single government. Moreover, these policies are undergoing constant change periodically.

Cryptographic policies may limit markets. For example, a cryptographic algorithm may not be included in software shipped to a country having laws restricting its importation. On the other hand, such a cryptographic device may be desired, highly marketable, and demanded by the market in another country. Thus, generalized software development, standardization of software, and the like may become difficult for software vendors. Moreover, users have difficulties attendant with supporting limited installed bases of specialized software. That is, a sufficient installed base is required to assure adequate software.

In short, cryptographic use policies sometimes constrain the set of cryptographic algorithms that may be used in a software system. In addition to restrictions on allowable algorithms, cryptographic use policies may also place constraints on the use and strength of keys associated with those algorithms. Software shipped or used in any country must be in compliance with the policies extant.

Another common aspect of certain cryptographic use policies is a requirement that a copy of cryptographic keys be stored or "escrowed" with an appropriate authority. However, the mechanisms necessary to satisfy different policies can vary greatly.

Cryptography, especially public key cryptography, provides certain benefits to software designers. U.S. Pat. Nos. 4,200,700, 4,218,582, and 4,405,829 are directed to such technology and are incorporated herein by reference. These benefits are available in situations where data may be shared. Many modern software packages (applications, operating systems, executables) are used in businesses or in other networks where multiple "clients" may share a network, data, applications, and the like. Most modern software packages employ cryptography in some form.

One application for cryptography in network management or network operating systems includes authentication. Also, integrity of data packets transferred, encryption of files, encoding associated with licenses for software or servers, and license distribution or serving are some of the applications for cryptography.

Users may be identified and their rights to access may be authenticated by means of passwords on a network. Cryptography is typically used to transfer some authentication, integrity, verification, or the like in a secure manner across a network that may be open to channel tapping. Public key cryptography is typically used in such a circumstance. Another application of cryptography for authentication involves a single sign-on. For example, a user may need to enter a single password at the beginning of a session. This may remain true regardless of the number of servers that may eventually be called into service by the individual user (client) during this single session. Historically, scripts have been used to provide a single sign-on, but public key mechanisms are now being provided for this function.

Users have previously demonstrated that networks may be subject to attack by spoofing of network control packets. This procedure may be demonstrated in playback and in

man-in-the-middle scenarios. By such spoofing, users may obtain unauthorized privileges on a network server. Adding packet signatures, keyed on a per-session basis may provide improved packet integrity.

File encryption is becoming more available. Such encryption has particular use in the special circumstance of audit files. For example, a need exists to protect an audit trail from inspection or modification, or both, by a system administrator, even though the audit trail remains under the system administrator's physical control.

Certain licensing schemes may use various encryption modes to protect software against piracy by end users and others throughout a distribution chain. Data structures, cryptography methodologies, checks, and other protection mechanisms may be proprietary to a software developer. Nevertheless, license server mechanisms are being developed to support control of the use of application software in conformity with licenses. Licenses may be provided by an application software provider. The license server may use public key cryptography to create and verify signed data structures. Secret key cryptography may be used to support authentication and file encryption.

Certain applications may provide file confidentiality using proprietary, exportable, secret key algorithms. Users in large numbers make use of such algorithms. Nevertheless, considerable interest in breaking such proprietary algorithms has been successful with certain software. Proprietary encryption methodologies have been consistently broken, given enough time and attention by interested hackers.

Certain applications use public key cryptography for digital signatures. Market leaders in software have provided relatively weak secret key algorithms adopted by others. Thus, files written in different applications from different vendors, even encrypted files, may be opened by an application from any of the vendors using the market leader's secret key algorithm. Within a single product line, a vendor of software applications may use multiple algorithms. Several, if not a plethora of, algorithms exist, including both secret key algorithms and public key algorithms. Stream and block ciphers, as well as hash functions are available and well documented in the computer programming art. Also, certain algorithms are the subject of patent applications which may cloud their broadly based use.

What is needed is a standardized cryptography methodology for distribution across entire product lines. Moreover, encryption technologies are needed for permitting a licensee of a principal software manufacturer to become a third party vendor or value-added distributor capable of producing its own proprietary software, software additions, or pre-planned software modules. Currently, software-with-a-hole may provide an operating system with a cryptographic module that fits in the "hole" in an operating system. However, software manufacturers using this technology typically require that a third-party vendor send its product to the principal software manufacturer for integration. The manufacturer may then provide all interfacing and wrapping of the third-party's filler (such as an encryption engine) to fit within the "hole" in the software of the manufacturer.

Also, export restrictions exist for encryption technology. Limiting the strength of exported cryptography is established by statute. To be exportable, such products must meet certain criteria (primarily limitations on key size) that effectively prevent the exportation of strong cryptographic mechanisms usable for data confidentiality. Moreover creating "cryptography with a hole" is undesirable for several reasons, including export and import restrictions. Cryptography with a hole is the presence of components specifically

designed or modified to allow introduction of arbitrary cryptographic mechanisms by end users. A great escalation of the difficulty of such introduction, without creating numerous, individually customized software packages, is a major need today, although not necessarily well-recognized.

Certain foreign countries have more stringent regulation of the importation of encryption technology by non-government entities. A government may require that any imported encryption technology be subject to certain governmental policies as well as key escrow by some governmental agency. Key escrow systems may be easily provided in software, but integrity and assurance remain difficult. Using only software, reliable key escrow may be impossible, in the absence of very high assurance. For example, Class B3 or A1 may be required of a "trusted computing base" in order to protect keys against disclosure or modification. Likewise, protection of algorithms against disclosure or modification, and escrow against bypass, are also often required. Under any circumstances, software offers few protections when compared with hardware solutions.

Customers, whether third-party vendors, distributors, or end users, need information security. International commercial markets need products that may be marketed internationally without a host of special revisions that must be tracked, updated, and maintained with forward and backward compatibility as to upgrades and the like. Meanwhile, such solutions as key escrow do not receive ready customer acceptance in U.S. markets, particularly where a government is an escrow agent. Furthermore, individual customers or vendors may wish to operate individualized cryptography systems or other authenticable applications in conjunction with a single operating system or host application. Currently, no provision exists for allowing such customization in a controlled, authenticable environment.

Therefore, what is needed is a cryptography apparatus and method that may be mass produced in a variety of products across an entire product line. A technology, or product that can be sold in identical form both domestically and abroad is highly desirable. An encryption method and apparatus are needed that may provide improved methods for security and integrity of data provided by cryptographic algorithms and keys themselves, without requiring "trust" between sender and receiver.

Also needed is a key escrow mechanism for corporate environments. For example, file encryption by an employee will usually be required to be subject to an escrow key in the possession of the employer. Also, in conjunction with signature authorities, delegation of such authority may be useful in a corporate environment. Nevertheless, each corporate user may be viewed as a secondary (vendor) level desiring to have its own encryption and escrow control of all copies of all keys.

What is needed is a method for producing cryptographic applications that may be customized individually, from individual modules. That is, what is needed is modules that may be used to limit the capabilities of cryptographic applications without proliferating individual customized software products that may become very difficult to maintain, upgrade, support, and the like. What is needed is an apparatus and method that can separate a cryptography application or a cryptography filler for an operating system "slot" into modules. Modules need to be configured to minimize the extent of interfaces and the amount of code that must be interfaced. Modules should minimize the number of exclusions from a system that must be patched or replaced in order to enable the software system to satisfy relevant cryptography usage policies.

What is needed also are an apparatus and method effective to enable a manufacturer of a cryptographic engine to produce a single implementation of a modular package embodying particular cryptographic algorithms. The manufacturer should remain able to include that implementation in all versions of a software product. This should be true regardless of different key usage policies mandated by various regulatory authorities. It should be true regardless of a requirement for disabling of certain of the included algorithms.

Also needed is an alternative to prior art systems that require both a "policy" and an algorithm implementation to be supplied (even lastly shipped) from the manufacturer of a cryptography engine as the wrapping and certifying entity. Instead, what is needed is an apparatus having an architecture and implementation by which a manufacturer of a cryptographic engine need not be the same entity as a supplier/generator of a policy (e.g. government) to which the cryptographic engine's algorithms are constrained to conform.

Beneficial, and therefore desirable or needed, is an apparatus and method having distinct executable modules and policy data structures sufficiently separable to reduce the cost of customizing an entire software system. Thus, a system is needed that is adaptable to inexpensive customization without implementing an embedded policy.

Also needed is an apparatus and method for separating a policy from an algorithm to enable flexibility in the management and delivery of cryptographic capabilities in conformance with the local regulations. For example, some method is needed by which a manufacturer can produce a cryptographic engine, but exclude a policy certificate permitting use of the algorithms implemented by that engine. That is, a method is needed by which a manufacturer or one or more other policy certificate authorities may separately offer key and policy authorization, certification, and verification conforming to local regulations.

Further need exists for an apparatus and method whereby a plurality of dynamically linked cryptographic modules might be hosted within a single base application. Accordingly, the dynamically inked cryptographic modules might be separately accessed, authorized, and used, and might operate independently of each other. Such a need exists whereby the individual dynamically linked cryptographic modules, singly, or as a whole might be absent from the base application without significantly limiting the operation of the base application.

#### BRIEF SUMMARY AND OBJECTS OF THE INVENTION

In view of the foregoing, it is a primary object of the present invention to provide an apparatus and method by which a plurality of individual and distinct modular cryptography modules might be hosted by a single base application operating on a computer

It is another object of the invention to provide such an apparatus and method by which the plurality of individual and distinct modular cryptography modules might be separately loaded into individual slots within the host program.

It is another object of the invention to provide an apparatus and method for dynamic loading of the plurality of individual and distinct modular cryptography modules into the base executable in a manner to prevent substitution, modification, extension, or misuse of algorithms implementable by the modules and whereby each of the independent slots may have independent mechanisms for authorization of the modular cryptography modules.

It is another object of the invention to provide such an apparatus and method whereby the modules act as fillers for the slots and whereby modules filling separate slots might act independently and transparently from each other.

It is another object of the invention to provide such an apparatus and method whereby the presence or absence of a particular module within any of the slots does not prevent the proper operation of the base program.

It is another object of the invention to provide such an apparatus and method whereby the plurality of slots might be serviced by a single loader or individual loaders, and whereby the slots might be recursively constrained with inner slots located inside of outer slots and each slot being provided with an independent loader capable of authorization and linking.

Consistent with the foregoing objects, and in accordance with the invention as embodied and broadly described herein, an apparatus and method are disclosed in certain embodiments of the present invention as including a controlled modular cryptography system.

A principle feature provided by an apparatus and method in accordance with the invention includes limitation of software integration. For example, a software integration limiter may provide a cryptographic operating system with a "slot." That is, an operating system may be thought of as a block of executable instructions storable in a memory device, and loadable on a processor. An additional feature under the invention is that a plurality of such slots might exist within a given base application, such as network operating systems for example. The individual slots may be filled by different applications or components of applications, such as distinct types of cryptography systems or cryptography systems having different functions, or cryptography systems by different customers or vendors.

Furthermore, the various slots may have differing mechanisms for authenticating and linking the different applications loadable therein. For instance, each slot may use a separate public or private key for authentication purposes.

The individual slots may be serviced by a single loader, or each may have its own loader. Furthermore, the individual slots may be recursively loadable, with certain of the slots operating within others of the slots.

The software integration limiter in accordance with the invention may provide an architecture and coding to limit the integration of modular application allowed to fill these slots. Thus, the operating system or other base application cannot operate at all, or may be configured to not operate with cryptographic capability, absent an authorized, added software "filler" filling each of the slots.

Another feature available in an apparatus and method in accordance with the invention may be a vendor-constrained, remotely sealed, software integration limiter. For example, prior art systems may require that a manufacturer receive, license for import, and wrap the code of value-added resellers and vendors, incorporating the codes into a cryptographically enabled software product.

By contrast, an apparatus and method in accordance with the invention may provide for a universal "base executable" comprising a software system for operating on a computer. A software development kit may be provided with certain authorizations to an agent, vendor, distributor, or partner. The authorizations may be provided as certificates permitting the agent to create software modules and wrap them without their contents being known, even to the original manufacturer of the "base executable" or the software development kit. Such a system may then include a con-

strained policy obtained by the agent, vendor, etc., in cooperation with a government, to meet the import laws of the country of sale of the entire package, the software "base executable," modules from vendors, and an authorizing policy.

Such a system may allow an agent (development partner, third party value-added seller, module vendor, distributor) to provide sealed encryption algorithms. The algorithms may remain known only to the agent, (partner, distributor, etc.) although accessed for linking using keys authorized by the manufacturer of the base executable.

The software development kit may provide for an authorization mechanism, such as a certificate of authority immediately identified with the software development kit and the agent. Any "base executable" may then verify any module from any vendor to determine that the vendor has produced a module in accordance with policy constraints imposed on the software development kit and verified by the "base executable" produced by the manufacturer.

Thus, a universal "base executable" may be exportable by a manufacturer and importable by a distributor or reseller. A distributor may be responsible to obtain the proper licensure for cryptographic equipment and functionality. The "base executable" can verify that all modules operating within a slot to which the particular authorization module is assigned come from a software development kit assigned to a vendor operating within prescribed bounds of policy authorization and other permitted functionality.

In short, the "base executable" knows how to recognize a valid signature provided from a module created on a proper software development kit. A software development kit may produce or generate proper digital signatures. The agent's, distributor's, or partner's module product may then carry the proper signature. Therefore, the "base executable" may recognize and run only those modules having valid signatures corresponding to software development kit "toolboxes" of known, authorized agents or distributors, and in accordance with authorized policies. The base executables may be different for each slot and each base executable may recognize only certain digital signatures.

Another feature of an apparatus and method in accordance with the invention may be a null engine. A null engine may be provided by a manufacturer with any "base executable" (principal software product, operating system), having no enabled cryptographic capability.

Nevertheless, the null engine may support all interfaces required by a "slot" in the base executable, and all functionalities except cryptographic capabilities required by a "filler." Thus, for example, an operable software system may be delivered having no cryptographic capability, simply by providing a filler including a null engine to fill the "slot" within the software product (operating system, base executable) provided by the manufacturer. Thus, where only certain of the slots are available for use by a particular customer, the slots that are not available may be filled by null engines.

Another feature of the apparatus and method in accordance with the invention may be flexible key escrow capability. This feature may be thought of as a modular key escrow method. Escrow capability may escalate from a self escrow. For example, an individual company, individual user, or the like, may hold and control all keys. At an opposite extreme, an escrow of a key may reside with some other independently authorized escrow agent. A key escrow may reside with a governmental agency itself as required in some countries.

Another feature of an apparatus and method in accordance with the invention may include cryptographic wrapping of keys. That is, wrapping may be thought of as tamper proofing (authentication) and encrypting (secrecy protection) a key. Prior art system's keys may be simply bit strings of sufficient length and complexity to reduce the probability of their being deciphered.

Here, a holder's identification and a certification authority's identification may be applied to a key itself. The digital signature of the certifying authority may enable verification of such certification. The keys may be centrally managed, such as by a management module in the "base executable" from a manufacturer. Such a module can therefore restrict creation, distribution, and use of keys, especially within a network or internetwork.

Another feature of an apparatus and method in accordance with the invention may include quality-graded certificates. The certificates may be generated by distributors (value-added resellers, module vendors, agents, partners). However, the certificates may provide a "pedigree" indicating an integrity level of the cryptography provided by a certificated software product. Thus, a purchaser of software who will become a user or owner (holder) may know the cryptographic strength (algorithm, key length) or quality (integrity; value limit of assurance) of the systems used or created, with a verification that cannot be forged.

Another feature of an apparatus and method in accordance with the invention may be provision of cryptographic engines that are not independently usable. For example, id) cryptographic engines may be comprised of, or included with, wrapped, non-linkable modules that can only be used in a filler to fill a "slot" in a base executable (principal software application) from a specified manufacturer.

Thus, unlike the prior art where a cryptographic engine obtained by a vendor or third party may be used with any software, cryptographic engines made in accordance with the invention may not be enabled absent verification of their integrity, applicability, policy, or the like by a base executable (principal software product). A separate slot or software instruction limiter operating within a loader within a slot may verify any and all modules attempting to link with the base executable through the slot and vice versa. Different types of modular applications and cryptography systems may be enabled through different slots.

Another feature of an apparatus and method in accordance with the invention may be constraining the linking of modules to a specific class of module, or within a specific class of module, through the use of cryptography. Thus, for example, a hierarchy of linking may be created within individual software modules, so that all modules may link only to peers (associated modules in one filler) and may not necessarily be able to link directly with selected modules of the total group of peer modules with the same filler. For example, an application or library module may not bypass a limiting manager module to interface with a cryptographic engine module.

Another feature of an apparatus and method in accordance with the invention may include a restriction of the use of cryptography, by use of cryptographic methods. Thus, for example, a manufacturer may produce a library of cryptographic functions that is much stronger than what would ordinarily be exportable under the laws of the United States, or importable under the laws of receiving countries.

For example, if only a 40-bit engine may be exported under normal circumstances, a library may be created in which a digital encryption standard using 64 bits exists

within the library. Nevertheless, the more powerful standard may not be implemented, absent the proper keys which are themselves encrypted and maintained under the control of the manufacturers and the policies provided.

Thus, the above objects may be met by one or more embodiments of an apparatus and method in accordance with the invention. Likewise, one or more embodiments of an apparatus and method in accordance with the invention may provide the desirable features as described.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and features of the present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments of the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

FIG. 1 is a schematic block diagram of modules arranged in one embodiment of an architecture for an apparatus and method in accordance with the invention,

FIG. 2 is a schematic block diagram of an apparatus in a network for hosting and implementing the embodiment of FIG. 1;

FIG. 3 is a schematic block diagram of an example of executables operable in a processor for implementing the embodiment of the invention illustrated in FIG. 1;

FIG. 4 is a schematic block diagram illustrating examples of data structures in a memory device corresponding to the apparatus of FIGS. 1-3;

FIG. 5 is a schematic block diagram illustrating certificate hierarchies for implementing one embodiment of an apparatus and method in accordance with the invention; and

FIG. 6 is a schematic block diagram of certain operational processes for one embodiment of a controlled modular cryptography system implemented in accordance with the invention.

FIG. 7 is a schematic block diagram illustrating a recursive arrangement of slots in accordance with the invention.

FIG. 8 is a schematic block diagram illustrating alternative arrangements for including a plurality of slots in a base application.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It will be readily understood that the components of the present invention, as generally described and illustrated in the Figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the system and method of the present invention, as represented in FIGS. 1 through 6, is not intended to limit the scope of the invention, as claimed, but it is merely representative of certain presently preferred embodiments of the invention.

The presently preferred embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. Reference numerals having trailing letters may be used to represent specific individual items (e.g. instantiations) of a generic item associated with the reference numeral. Thus, a number 156a, for example, may be the same generic item as number 156f, but may result from a different version,

instantiation, or the like. Any or all such items may be referred to by the reference numeral 156.

Referring to FIGS. 1-3, a method and apparatus for providing controlled modular cryptography is illustrated in software modules, supporting hardware, and as executables distributed through a processor. Reference is next made to FIGS. 4-6, which illustrate in more detail, schematic block diagrams of certain preferred embodiments of an apparatus and method for implementing controlled modular cryptography in accordance with the invention.

Those of ordinary skill in the art will, of course, appreciate that various modifications to the detailed schematic diagram of FIGS. 1-6 may easily be made without departing from the essential characteristics of the invention as described. Thus, the following description of the detailed schematic diagrams of FIGS. 1-6 is intended only as an example, and it simply illustrates certain presently preferred embodiments of an apparatus and method consistent with the invention as claimed herein.

Referring now to FIGS. 1-6, a controlled modular cryptography (CMC) process 12 or method 12 may be implemented using a plurality of modules 13. The CMC process 12, alternately referred to herein as CMC 12, may be embedded within another executable 14 such as a network operating system 14. The network operating system 14 may include an operating system proper 15, what would conventionally be known in a generic operating system as the operating system 15.

The operating system 14 may also have provision for insertion of a pre-processor 92 in a conventional hole 93.

By contrast, the CMC 12 is not accessible by third parties at a pre-processor slot 93. Third parties may create pre-processors 92 having direct access to the operating system 15. Prior art cryptographic engines are often mere pre-processors interposed between applications 40 and the operating system 15. Likewise, the unauthorized installation by a third party of a cryptographic engine in a pre-processor slot 93 may be rendered virtually impossible by the CMC 12 and operating system 15. Instead, the CMC 12 may be loaded into the base executable 14 such as the operating system 14 in a manner that embeds the CMC 12 into the operating system 14 and prevents interfacing by any third party to the cryptographic capability of the CMC 12. (See FIG. 3.)

Referring now to FIGS. 1-6, and more particularly to FIG. 1, the controlled modular cryptography 12 may include library modules 16 for interfacing with applications 40. Each library module 16 (X library 16, or simply library 16) may be application-specific.

The loader 90 (see FIG. 3) provides layering (hierarchical linking) or nesting (recursive loading or linking) of interfaces. The layering may effectively prevent applications 40 and an operating system proper 15, for example, from interfacing directly with controlling modules 13 (e.g. manager modules 18) or with engines 20 (e.g. cryptographic engine 50). The loader 90 may do this directly by dynamic loading of modules 13, enforcing restrictions on access to interfaces between levels 16, 18, 20, 22, 15 illustrated in FIG. 1.

Manager modules 18 as well as the original loader 90 loading a filler 12 (CMC 12) may assure that a layering hierarchy is enforced between modules to limit interfaces. Manager modules 18 may interface with library modules 16. The manager modules 18 may also interface with the cryptographic engines 20, or engine modules 20. Support modules 22 may interface with engine modules 20 also.

Library modules 16, manager modules 18, and support modules 22 may interface which the operating system 15 in

one preferred embodiment of an apparatus and method in accordance with the invention. The engines 20 may be enabled to interface only with other modules 13, and not with the operating system 15.

The subdivision of modules 13 in a layering architecture (e.g. layer 18 is manager modules 18 including modules 42, 44, 46) great flexibility may be obtained. Since modules 13 are dynamically bound by the loader 90, and managed by a manager module 18, the modules 13 may be modified or exchanged as needed and as authorized. Management modules 18 not yet envisioned may be added in the future, without revising the base executable 14, or even the filler 12, outside the module 13 in question.

For example, a management module 18 may support cryptographic-token PIN (personal identification number) management, not available in an initially purchased product 14. Another example may be added support for policy management enhancements, such as providing separate APIs (application programming interfaces) for encrypting and decrypting ubiquitous financial data used by banks.

New functionality, not typically used or required in current practice by banks, may include a separate key type or size specifically for financial data. Such keys 156, 160 may be relatively stronger than general keys 156, 160, while use, holders, data types, and the like may be restricted by policies 164 crafted for special financial purposes. Thus financial keys 156, 160 may be managed differently from other general types of keys 156, 160.

Referring now to FIG. 2, a network 56 may comprise a plurality of nodes 58 (e.g. clients 58). Although the clients 58a, 58b, 58c are illustrated, the computers of the clients 58, server 62, and router 64 may also be thought of as being hosted, programmed to run on, any computer 58, 60, 62, 64 on a network 56. Likewise, the CMC 12 may be programmed into any of those computers 58, 60, 62, 64. By node is meant a computer on a network 56 in its broadest sense.

Likewise, the host 60 or server 60 may actually be programmed to function as one of several servers 62 or routers 64. As a practical matter, the server 62 may be replaced by the server 60. A node 58 may include some or all of the structural contents illustrated for the server 60. For example, if every node 58 comprises a computer, every node 58 may have any or all of the components 70-86.

A network 56 may include a backbone 66 for interconnecting all the nodes 58 or clients 58. The router 64 may also connect to one or more other networks 68. The network 68 may be a local area network (LAN), wide area network (WAN) or any size of internetwork.

The server 60 may include a CPU 70 or processor 70 for hosting the operating system 14 and CMC 12. As a practical matter, a random access memory 72, or RAM 72, may temporarily store, in part or in total, any or all codes and data associated with executables within the CMC 12. For example, during operation of the CMC 12, individual modules 13 might be stored, or a portion thereof might be stored in the RAM 72.

The CPU 70 and RAM 72 may be connected by a bus 74. Also on the bus may be operably connected a network card 76 or network interface circuit 76 (net card 76), one or more input devices 78, and output devices 80, or the like. Additional memory devices such as a read-only memory 82 (ROM 82) and a storage device 84 (such as a hard disk 84), may be operably connected to the bus 74 to communicate data with the processor 70.

Additional ports 86 may be provided as appropriate. As a practical matter, the input device 78 and output device 80

may merely represent ports for accessing one or more available input or output devices **78, 80**. Similarly, with the distributed nature of hardware and software in a modern computing environment, other devices may be accessed, through the net card **76**, elsewhere on the network **56**.

Referring to FIG. 1 once more, the interfacing between modules **13** may be restricted. Such a restriction may provide additional assurance that the CMC **12** may not be misused, modified, or replaced improperly. Therefore, certain of the modules **13** may have operating system interfaces **24**. For example, the interfaces **24a, 24b, 24c** represent the interfaces between the libraries **16**, managers **18**, base **22**, respectively, shared with the operating system **15**.

In the illustrated embodiment of FIG. 1, the engines **20** share no interface with the operating system **15**. Instead, the engines **20** may interface through the base support **22**. Library interface **26** represents the interface between library **16** and applications **40**. The library interface **26** may be considered to be an interface between the CMC **12** and applications **40**.

The libraries **16** may be structured to interface directly with applications **40**. The foundation **54** or the CMC foundation **54** may be thought of as the core of the CMC **12**. The managers **18** provide cryptographic facility as well as controlling access to and between modules **13**, especially in the core **12**. The interface between the CMC enforcement by the foundation **54** and applications outside the base executable **14** is moved away from the manager interface **28** by the library interface **26** and interposed libraries **16**. Thus, applications **40** are not permitted to interface directly with the (controlling) management modules **18**. This further avoids creation of cryptography with a hole.

The manager interface **28** represents the interface between the manager modules **18** and the library modules **16**. The engine interface **30** represents the interface between engines **20** and the manager modules **18**. The support interface **32** represents the interface between the engines **20** and the support modules **22**.

In general, communications **38** may be calls from upper layers **40, 16, 18, 20** shown to lower layers **16, 18, 20, 22**, respectively, in FIG. 1. Each layer **16, 18, 20, 22** may properly execute without requiring anything from a layer **18, 20, 22, 15**, respectively, below.

For example, in one embodiment of an apparatus and method in accordance with the invention, one library **16** may be an audit library **34**. For example, the audit library **34** may have functional responsibility for encrypting security audit data for storage. The underlying data may correspond to events of significance to audit executables. The network **56** itself may be managed by an individual acting as a system manager, yet the audit data encrypted by the audit library **34** may be inaccessible to the system manager.

Other libraries **36** may be provided. Each of the libraries **36** may be application-specific. In one presently preferred embodiment, each of the applications **40** interfacing at the library interface **26** may have an associated, unique, library module **36** provided.

The key generation manager **42** may create symmetric keys or asymmetric key pairs provided to cryptographic engines **20**. The key generation manager **42** may also perform the escrow function of the escrow archive **170** (see FIG. 6). A base manager **44** may provide enforcement of policies **164**.

Access to modules **13**, such as the engines **20**, and access to cryptographic algorithms within engine modules **20**, and the like, may be enforced by the manager modules **18**. In one

embodiment of an apparatus and method in accordance with the invention, the base manager **44** may provide an enforcement function with respect to all functions and all modules **13**. Other managers **46** may also be provided. For example, manager modules **46** may alter methods of policy enforcement for the escrow of keys **156**.

In one embodiment, the CMC **12** may be provided with a null engine **48**. A null engine **48** may be operated to interface at the engine interface **30** and the support interface **32** while providing no enablement of cryptographic capability. Thus a base executable **14** may be fully functional otherwise, including all necessary interfaces to the filler **12** (CMC **12**), while having no enabled cryptographic capability. The interfaces **26, 24** to the filler **12** may be as secure as if the dynamically loaded modules were manufactured as integrated portions of the base executable **14**.

Thus, an apparatus **10** may be provided as a base executable **14**, having fully imbedded support for a cryptographic engine **20**. However, the presence of a null engine **48** accommodates all the proper interfaces **30, 32** while actually providing no cryptographic capability.

Thus, a CMC **12** (filler **12**) may be provided with a base executable **14**, including a null engine **48**, exhibiting minimal differences with respect to the operating system **15** as compared to another cryptographically-enabled product. Meanwhile, other engines **50** may be provided by a manufacturer or a third party vendor authorized to create cryptographic engines **20** according to some policy and authorization.

A base support module **52** may provide some minimal set of operating system instructions for the engines **20**. That is, in general, the engines **20** need some access to the operating system. Nevertheless, for providing the assurance that engines **20** may not be created, modified, extended, circumvented, inserted, or the like, in an unauthorized fashion, the support module **52** may intervene. Thus, the base module **52** may provide access to some limited number of functions from the operating system **15** for the engine **20**.

Referring now to FIG. 3, an operating system **14** may be implemented in one embodiment of an apparatus and method in accordance with the invention to include a loader **90**. The loader **90** may be associated with the operating system proper **15**. The functional responsibility of the loader **90** may be to dynamically load and properly link all modules **13** into the CMC **12** (filler **12**), for example, installing (e.g. embedding) them into the operating system **14**.

More specifically, the loader **90** may be tasked with the functional responsibility to provide all proper linking between modules **13**. Linking may be enabled on a layer-to-layer (or interface **28, 30, 32**) basis rather than on a module-by-module basis. For example, a binding may exist between any two modules **13** in a layer (e.g. layer **18**, or layer of manager modules **18**). Binding may also exist between any module (e.g. modules **42, 44, 46**) in that layer (e.g. layer of managers **18**) and another module (e.g. modules **48, 50**) in a layer (e.g. layer **20**, or layer of engines **20**) sharing an interface (e.g. interface **30**) with that layer (e.g. layer **18**).

Specific modules **13** need not be individually limited and controlled by the loader **90**.

In one embodiment, individual modules **13** may be bound (linked). Thus, for example, only those functional features authorized for a key generation manager **42**, or a cryptographic engine **50**, might be enabled by being properly bound.

In one example, a cryptographic engine **50** may be manufactured to contain numerous algorithms. However,



according to some policy 164 (see e.g. FIGS. 5, 6) incorporated into a certificate 154, a manager 46 and the loader 90 may limit linking (binding) to an enablement of algorithms and engines 20. A manager module 46 may also control key usage, including length and function. Function may be distinguished between, for example, encryption versus authentication. Use may be controlled based upon, for example, a manufacturer's (of the module 13) signature 162 and key type.

The operating system 15 may support a selection of pre-processors 92 such as the audit event filter 92. Pre-processors may be adaptable to fit in a hole 93 readily available for the purpose. In one currently preferred embodiment of an apparatus and method in accordance with the invention, a CMC 12 is not adaptable to be implemented as a preprocessor 92. Instead, the CMC 12 may be limited to interfacing only with the operating system proper 15 as illustrated in FIG. 1, and only after proper loading by a loader 90. Even within the operating system 15, the CMC 12 may be limited to interfacing with the operating system 15 through a limited number of interfaces 24.

As a practical matter, certain applications 94 or programs 94 have resident portions within the server 60 hosting the operating system 14. For example, a file system 98, a name service 100, a work station 102 and the like may have resident portions operating in the processor 70. Even if, for example, a server 62 is operating as a file server, the file system 98 may be a portion of a file server executable that needs to be resident within the processor 70 of the server 60 in order for the server 60 to communicate with the server 62 over the network 66.

Generally, certain data may need to flow into and out of the operating system 14. Accordingly, a number of channels 96 or data flow paths 96 may need to exist. As a practical matter, the channels 96 may be comprised of either paths, data itself, or as executables hosted on the processor 70 for the purpose of providing communication. Thus, an audit file 104, an accounting log 106, an archive file 108, and the like may be provided as channels 96 for communication.

Thus, the overall operating system 14 along with the applications 94 and channels 96 may be thought of as a local system 110 or the local processes 110. These local processes 110 operate within the CPU 70. The CPU 70 is a processor within the server 60 or host 60. As a practical matter, the processor 70 may be more than a single processor 70. The processor 70 may also be a single processor operating multiple threads under some multitasking operating system 15.

Data representing executables or information may be stored in a memory device 72, 82, 84. Referring now to FIG. 4, one may think of a dynamic data structure 114 or an operating system data structure 114 storable in an operable memory 116. That is, for example, the operating memory 116 may be within the RAM 72 of the host 60. All or part of the data structure 114 may be moved in and out of the processor 70 for support of execution of executables.

The data structure 114, may be dynamic. The modules 13 for example, may be dynamically loadable, such as network loadable modules. Thus, for example, a host 60 may operate without having any fixed, storable, data structure 114. That is, no static data structure need be assembled and stored in a manner that may make it vulnerable to being copied or otherwise inappropriately accessed. The data structure 114 may only exist dynamically during operation of the processor 70, and even then need not all exist in the memory device 116 (e.g. RAM 72) simultaneously at any time. Thus,

additional assurance is provided against misuse, and abuse of data and executables in a CMC 12 associated with an operating system 14.

The data structure 114 may contain a certificate 118 and certificate 120. A certificate 118, for the purposes of FIG. 4, may be thought of as an instantiation of a certificate 154 associated with the operating system 14 and its included CMC 12. The certificate 118 may be thought of as the data certifying the holder of a certificate operating and using the data structure 116. By certificate 120 is meant data provided in a certificate issued to the holder.

A certificate 118, 120 may also be thought of as a binding of a holder ID 122, 132 to a public key 126, 136, certified by a digital signature 124, 134 of a certifying authority. An issuer (e.g. 152b) or authority and a holder (e.g. 152d) may each be a holder (e.g. 152b) to a higher authority (e.g. 152a), and issuer (e.g. 152d) to a lower holder (e.g. 152h), respectively.

When discussing authorities, holders, receivers, and the like, it is important to realize that such an authority, holder, sender, receiver, or the like may actually be a hardware device, or a software operation being executed by a hardware device. Any hardware device, operating software, or data structure in a memory device may be owned, controlled, operated, or otherwise associated with an individual or an entity. Nevertheless, insofar as the invention is concerned, names of such entities may be used to represent the hardware, software, data structures, and the like controlled or otherwise associated with such entities.

As a practical matter, a certificate 118 authenticating the rights of the CMC 12 may contain an identification record 122 identifying the holder (the specific instance of the CMC 12), a signature record 124 verifying the higher certification authority upon which the holder depends, and a public key record 126 representing the public key of the holder. The private key 128 may be very carefully controlled within the CMC foundation 54 using encryption for wrapping. The private key 128 may be associated with the holder (CMC 12) and is the private half 128 of a key pair including the public key 126. Thus, by means of the private key 128, the holder may create the signature 134 in the certificate 120 for another use of the key pair 136, 138.

Meanwhile, a certification authority 152 (see FIGS. 5-6) may provide to a holder or sign 166, the certificate 118 (one of the certificates 154). The certificate 120 may reside in to) another computer or simply be allocated to a different thread or process than that of the certificate 118.

As a practical matter, a private key 128, 138 may be protected by physical security. Therefore, a private key 128, 138 may typically be controlled and be cryptographically wrapped except when dynamically loaded into a dynamic data structure 114.

The private key 128 may be used to certify an identification record 132 identifying a new holder. A signature 134 created by use of the private key 128 may verify the authenticity and quality of the certificate 120 and public key 136. The public key 136 may be thought of as the matching key 136 to a key pair including the private key 138 created by the new holder of the certificate 120. That is, one may think of a new holder, as a process, or an individual, issuing a public key 136 certified by the signature 134 of the private key 128 as duly authorized to create software which functions within the limits of a policy 140. The certificate 118, an instance of a certificate 154 held by the CMC 12, may have a signature 124 by a higher certifying authority 152.

A policy 130, 140 may limit the authorization of the holder identified by the ID 122, 132 and certified by the

digital signature **124**, **134**. A policy **130**, **140** may incorporate the limitations governing the use of algorithms in engines **20**, for example. Thus, a policy **130**, **140** may be thought of, for example, as the rules enforced by a manager module **18** controlling access to and from a module **13**, such as an engine (e.g. cryptographic engine **50**).

Each policy **164** (e.g. **164d**, see FIG. **5**) may contain a digital signature **163** (e.g. **163d**) of the certifying authority **152** (e.g. **152b**) above the holder **152** (e.g. **152d**) of the certificate **154** (e.g. **154d**) and policy **164** (e.g. **164d**). The policy **164** (e.g. **164d**) may thus be bound to the corresponding certificate **154** (e.g. **154d**) by the digital signature **163d**.

In one embodiment, policies **164** may be generated by a separate policy authority using a policy authority digital signature **129**, **139** (see FIG. **4**). A policy authority signature **129**, **139** binding a policy **130**, **140** to a certificate **118**, **120** need not be different from a certificate authority signature **124**, **134**, but may be. This is analogous to the certification authorities **152** for certificates **154**. Thus, the policies **164** may be provided and signed **166** by a certifying signature **163** binding the policy **164** to a corresponding certificate **154**. Nevertheless, the policy **164** may be certified by a policy authority **129**, **139** other than the certificate authority **152** creating the corresponding certificate **154**.

Referring to FIGS. **4-6**, the certificate **118** may include identification records **122**. The identification records **122** may contain information recursively identifying the higher certifying authority (e.g. **152a**, **152b**), as well as the holder (CMC **12**) certified. However, the signature **124** may be verified by using the public key of the higher authority **152**. For example, the signature records **124** may comprise a signature of a signature root authority **152b** or higher authority **152a** certifying, which authority is known by the identification **133**. The private key **128** may be thought of as a key by which the holder (e.g. the CMC **12**) creates signatures **134** for certificates **120** associated with, for example the key generation module **42** of the base executable **14** (see FIG. **6**).

The identification records **132** may typically identify the holder of the certificate **154** associated with the certificate **120**. Although the signature **134** is associated with the certifying authority providing the certificate **120**, and itself holding the certificate **118**, identification records **133** may identify the certifying authority **152** (e.g. associated with the ID **122**). The signature **134** may be used by entities or processes needing to verify the authorization of the holder (entity identified by the ID **132**) of the certificate **120**.

As a practical matter, a private key **128**, **138** is typically not stored in the clear in any non-volatile storage generally available. That is, a private key **128**, **138** may typically be unwrapped or loaded only dynamically to minimize the chance of any unauthorized access. The private key **128**, **138** may optionally be stored within a cryptographic co-processor, for example an additional processor **70**. The cryptographic co-processor may be embodied as a chip, a token, a PCMCIA card, a smart card, or the like. The private key **128** may be unwrapped in the co-processor for use only within the co-processor.

The applications **40** the preprocessor **93** and the channels **96** may be stored in the data structure **114**. Nevertheless, the data structure **114** may be distributed.

The library modules **16**, the manager modules **18**, the engines **20**, and the support modules **22** may be stored in the data structure **114**. In one embodiment, the data structure **114** may all be resident in the RAM **72** in some dynamic fashion during operation of the operating system **14** functioning in the processor **70**.

The certificate **120** may be embodied as illustrated in the frames **142**. The identification record **132** may be thought of as a data segment **132** associated with a holder. The segment **133** may be provided to identify a certifying authority **152**. Each public key **136**, **126** may be represented as bits of a segment **136**, **126** in the frame **142**. The signature **134**, **124** of a certifying authority **152** may be represented as another set of bits of a segment **134**, **124** in the frame **142**. The policy **140**, **130** may be represented by another segment **140**, **130**. The certificates **118**, **120** may have corresponding (e.g. even identical) policies **130**, **140** under which to operate.

The public key **136**, **126** is identified with the holder ID **132**, **122**. A public key **136**, **126** is typically published to other functions or to other entities, just as a certification authority's **152a**, **152b**, **152c** public key **160a**, **160b**, **160c** is published. Thus, a certifying authority's public key **136**, **126** is illustrated in FIG. **4** as being separate from the frame **142**. The public key **136**, **126** may be embedded in another certificate held by a certifying authority. Similarly, a holder's private key **138**, **128** may be maintained with utmost security. Therefore, a holder's private key **138**, **128** is not available with the holder's published public key **136**, **126**, except to the holder. Thus, a holder's private key **138**, **128** may not actually be generally available or associated with the certificate **120**, or certificate **118**, respectively, in the frame **142**.

Referring now to FIGS. **4-6**, the certificate hierarchy is illustrated, as is the implementation of operational keys **156**, **160**. Reference numerals having trailing letters, may be thought of as specific examples of a generic structure or function associated with the reference numeral alone. Thus, a certifier or certification authority **152** is a general expression, whereas the root certifier **152a** and the CMC signature root **152b** are specific examples of a certification authority **152**.

In general, an authority **152** (e.g. root certifier **152a**), may issue a certificate **154** (e.g. **154b**, **154c**). A certificate **154** (e.g. **154b**, **154c**) may be associated with authorization of a certificate holder (e.g. **152b**, **152c**) by a certification authority **152** (or just authority **152**). Associated with a certificate **154** may be certain data **120**, **118**. For example, in one embodiment, a certificate **154** may actually be embodied as a frame **142** as illustrated in FIG. **4**.

In general, a certificate **154** (e.g. **154b**) may be prepared by an authority **152** (e.g. **152a**) using a private key **156** (e.g. **156a**) held securely in the possession of the authority **152** (e.g. **152a**). A certificate **154** (e.g. **154b**), itself, may contain information such as the holder identification **158** identifying the holder to whom the authority **152** has issued the certificate **154**. Note that the holder **152** (e.g. **152b**) may itself be another authority **152** (e.g. **152b**) to a lower level holder **152** (e.g. **152d**).

The certificate **154** may also include the authority's **152** signature **162**. By signature **162** is meant, a digital signature as known in the cryptographic art. Also included in the certificate **154**, or linked by the signature **162** with the corresponding certificate **154**, may be a policy **164**. A policy **164** represents the extent of the authorization provided by the certificate **154** (e.g. **154a**) to the holder (e.g. **154b**) of the certificate from the authority **152** (e.g. **152a**) in order to produce cryptographic functionality.

For example, a holder **152d** may have a certificate **154d** and private key **156d** authorizing the holder **152d** to produce modules, such as cryptographic engines **20**, manager modules **18**, library modules **16**, or symmetric or asymmetric keys **156**. The policy **164d** may embody the restrictions,

limitations, and authorizations extended to the holder **152d** of the certificate **154d**.

In one embodiment, the enforcement of policies **164** may be managed in one or more of several, relatively sophisticated ways. For example, a policy **164** might permit a private key of a relatively long length, such as 1024 bits, to be used for digital signatures **162** only. On the other hand, a private key **156** used to wrap symmetric keys may be permitted to extend only to 768 bits, and only on condition that the key **156** be escrowed.

Also, rules for "composition" of policies **164** (certificated features or functions), or perhaps more descriptively, "superposition" of policies **164**, may be embodied in manager modules **18**. For example, more than a single policy may be loaded within a filler **12**, for one of several reasons. For example, modules **13** from different vendors may be manufactured under different authorities **152**. Also by way of example, as in FIG. 4, a policy authority digital signature **129**, **139**, certifying a respective policy **130**, **140**, need not be from the same source as a certificate authority digital signature **124**, **134**, but may be.

Meanwhile, a manager module **18** may be programmed to enforce the most restrictive intersection of all features (e.g., certificated features or functions such as quality, cryptographic strength, etc.). For example, one policy **164** (a certificated feature) may require that key-wrapping keys may be 1024 bits long and must be escrowed. Another policy **164** in another module **13** in the same filler **12** may require that keys be only 512 bits long, but need not be escrowed. The cryptographic manager module **18** may require a key length limit of 512 bits, and require escrow also. Thus a superposition of policies **164** may use the most restrictive intersection of policy limitations.

An authority **152**, thus certifies **166** or provides a signing operation **166** for a certificate **154** for a holder. Referring to FIG. 5, the certification authority **152a** (the root certifier **152a**) is an authority **152**, to the CMC signature root **152b** as a holder, both with respect to the certificate **154b**.

Each certificate **154**, is signed using a private key **156** of a certifying authority **152**. For example, the certifiers **152a**, **152b**, **152e** use private keys **156a**, **156b**, **156e**, respectively, to sign the certificates **154b** and **154e** delivered to the CMC signature root **152b** and server CA **152e**, and certificate **154j** forwarded by the key generation module **42**.

The certificate **154b** also includes a public key **160b**. A public key **160**, in general, is one half of a key pair including a private key **156**. For example, the private **156a**, **156b**, **156c**, **156d**, **156e**, **156f**, **156g**, **156h** is the matched half associated with the public **160a**, **160b**, **160c**, **160d**, **160e**, **160f**, **160g**, **160h**. The key pair **156a**, **160a**, is associated with the root certifier **152a**. Similarly, the private key **156b** may be used by the CMC signature root **152b** to certify **166d**, **166e** the certificates **154d**, **154e** with the signatures **162d**, **162e**. Thus, in turn, each of the public keys **160d**, **160e**, respectively, is the public key half of the pair that includes the private key **156d**, **156e**, respectively.

A holder, such as the module signature authority **152d** or the server certification authority **152e** may verify the validity of the public key **160b** using the signature **162b** and the public key **160a**. Similarly, a processor entity may verify the validity of the certificates **154d**, **154e**, respectively, by recourse to the signature **162d**, **162e**, respectively and the publicly available public key **160b** responsible.

Referring to FIGS. 5 and 6, generation of private/public key pairs **156**, **160** and subsequent certification **166** may be represented by cascading certificates **154**. For example, at

the top or root of all certification authorities **152** may be a root certifier **152a**. The root certifier **152a** may generate a private **156a**, and a public key **160a**, as a key pair **156**, **160**. The root certifier **152a** need have no signature **162**. The root certifier **152a** in such circumstance must be "trusted". Another method, other than a digital signature **162** of a higher certifying authority **152**, may typically be required for verifying the public key **160a** of the root certifier **152a**.

Only one root certifier **152a** (RC **152a**) is needed for the entire world. In one embodiment, the root certifier **152a** may be an entity willing and able to credibly assume liability for the integrity of public keys **160**, and the integrity of associated certificates **154**. For example, an insurer, or a company known and trusted by the entire business world, may serve as a root certifier **152a**. Such companies may include large, multinational insurance companies and banks. The root certifier **152a** is functionally responsible to physically protect the secret key **156a**. The root certifier **152a** is also responsible to distribute the public key **160a**.

The root certifier **152a** may authorize private/public key pairs **156b**, **160b** to be created by the CMC signature root **152b**. The integrity of the public key **160b**, and the identity **158b** of the CMC signature root may be certified by a digital signature **162b** created by the root certifier **152a** using the private key **156a**.

Any subsequent entity, receiving a certificate **154** cascading from the CMC signature root **152b** as a certifying authority **152**, may verify the certificate **154**. For example, the certificate **154b**, and its contents (public key **160b**, ID **158b**, and signature **162b**) may be verified using the signature **162b**. The signature **162b** may be created using the private key **156a**. Therefore, the signature **162b** can be verified using the public key **160a** available to the entity to whom the authority of a certificate **154b** is asserted as authentication.

The root certifier **152a** may have its public key **160a** embedded in the base executable **14**. Alternatively, any method making the public key **160a** securely available may be used. In this example, the base executable **14** or principal software product **14** may typically, be an operating system **14**. The base executable **14**, operating system **14** or base executable **14** may be thought of as including everything that arrives in the base executable associated with a newly purchased, generic, software package **14**. This may sometimes be referred to as "the base executable **14**." As a practical approach, the CMC signature root **152b** may be associated with, and the private key **156b** be in the possession of, the "manufacturer." For example the manufacturer of a base executable **14**, such as a network operating system **14** may be the holder of the private key **156b** used to certify all public keys **160d** and associated certificates **154d** of the module signature authority **152**.

As a practical matter, the highest level of public key **160** embedded in (or otherwise securely available to) a base executable **14** may be the signature root key **160b** associated with the certificate **154b**. An instantiation of the certificate **154b** may be embedded in, or otherwise securely available to, the CMC loader **90**. Thus, the loader **90** may verify against the manufacturer's public key **160b** (available to the loader) the signature **162d** in the certificate **154d** effectively presented by the module **13**. That is, one may think of the certificate **154d** as being included in the cryptographic module **13** (engine **20**) of FIG. 6 by a module vendor.

Thus, the loader **90** may verify that a vendor is authorized to produce the modules **13** under the policy **164d** bound to the certificate **154d**. However, the foregoing starts at the

wrong end of the process. The signature **168** on the module **13** is present for verification of the module by the loader **90**. The signature **168**, encrypted using the private key **156h**, may be verified by recourse to (e.g. decryption using) the public key **160h**. The key **160h** is presented in the certificate **154h**, also available with the module **13**.

In turn, the signature **162h** on the certificate **154h**, may be verified using the public key **160d**. The key **160d** corresponds to the private key **156d** used to encrypt the signature **162h**. The key **160d** is available in the certificate **154d** with the module **13**. The certificate **154d** and key **160d** are verified by the signature **162d** on the certificate **154d** with the module. The signature **162d** may be verified (e.g. such as by decryption or other means) using the public key **160b** of the CMC signature root **152b**. An instantiation of this key **160b** is available to the loader **90** with the certificate **154d**, as discussed above. By having the certificate **154d** independently of the modules **13**, the loader may thus verify each module **13** before loading into the filler **12** (CMC **12**).

As an example, the CMC signature root **152b** may be associated with the manufacturer of the base executable **14**. The base executable **14** may be thought of as the principal software product **14**, such as an operating system **14**. By contrast, the CMC **12** may be thought of as a filler **12**, a modularized segment that is required to be present within the base executable **14**, but which may be modified, customized, limited, authorized, or the like, by a manufacturer for a class of customers or by a suitably authorized, third-party vendor of modules.

In the case of a base executable **14** that serves as a network operating system **14**, such as Novell Netware™, the manufacturer, (Novell, in this example) may be the CMC signature root **152b**. Another example may be a third-party vendor of modules **13**. A third party vendor of modules **13** may produce, for example, engine modules **20** for insertion into the CMC **12**, but may be a value-added reseller of the base executable **14** adapted with such a cryptographic engine module **20** or other module **13**.

For purposes of discussion, a manufacturer may be thought of as the maker of the base executable **14**. A vendor or third party vendor may be thought of as the maker of modules **13** for inclusion in the CMC **12** (filler **12**) portion of the base executable **14**. A distributor, reseller, or third party reseller may be thought of as a seller of base executables **14** purchased from a manufacturer. The manufacturer may distribute and create modules **13**. A vendor of modules **13** may be a distributor of the base executable **14**, also.

Thus, a situation of great interest involves a manufacturer desiring to provide the base executable **14**, while certifying a vendor's module products **13**. The modules **13** may be integrated as part of the CMC **12** of the base executable **14** after the base executable **14** is shipped from the manufacturer. As discussed above, shipment of a base executable **14** in some standard configuration is desirable. In a preferred embodiment a base executable **14** shipped into a foreign country having import restrictions on cryptography, may provide a reliable method for enabling authorized cryptography exactly, while disabling all other potential uses of cryptography. Minimum modification, interfacing, and cost may be provided by an apparatus and method in accordance with the invention, with maximum assurance of authorization and control, all at a reasonable processing speed.

The CMC signature root **152b** may be responsible for manufacturing and exporting the base executable **14** to customers (users) and third party resellers, and supporting

software development kits (SDKs) to third party vendors. The manufacturer may be a maker of modules **13** also. Typically, the manufacturer may produce the null engine **48**, at least.

The module signature authority **152d** associated with the ID **158d** may be that of the holder of a software development kit for modules **13**. A policy **164d** bound to the certificate **154d** may be certified by the signature **162d** of the CMC signature root's **152b** private key **156b**.

The policy **164d** may be enforced by the manager module **42** and embodies the limits on the use and strength of keys **156d**. For example, the length (strength) of keys **156** useable under the policy **164d** and the types of modules **13** may be controlled by statute in each country of importation for the base executable **14**.

A loader **90** from the manufacturer may control linking of modules **13**. Thus, a third party, including a module vendor cannot change the limitations inherent in a key, the policy, or the like.

A policy **164**, in general, may define the maximum strength of the key. A module signature authority **152d**, holding a particular authorized software development kit may create different types of keys **156** as long as each is within the bounds of the policy **164d**. The module signature authority **152d** may also then certify a module-signing key pair **152h** authority for each module type produced and sold. Certificate **154h**, so signed using the private key **156d**, may provide a key **156h** to sign each module **13**, such as the cryptographic modules **13** exemplified by the engine **20** of FIG. 6. Meanwhile a module signature authority **152d** may certify embedded keys **160h** and associated certificates **154h** automatically by using the software development kit.

Note that a chain or cascade of certificates **154d**, **154h** may be used in a module in order to have the signatures **162** for the loader **90** to verify. The loader **90** may then verify the keys **160d**, **160h** using signatures **162d**, **162h** of the certificates **154d**, **154h** to authorize the loading of the module **20** (see FIG. 6).

Verification may be necessary in order for the loader to have the certified keys **160d**, **160h**, **160b** necessary for verifying the module signature **168**. That is, a vendor may use a software development kit containing a module signature authority **152d** to create some number of module signing key pairs **152h**.

The private keys **156h** may be used to sign **166m** with a signature **168** every module **13** created. Note that the modules **16**, **10**, **42** in the base executable **14** of FIG. 6 may all be thought of generically as modules **13** as in FIG. 1. The certificate hierarchy **154h**, **154d**, **154b** of the module **13** may all be verified by the loader **90** using the appropriate public keys **160d**, **160b**, to verify the respective signatures **162h**, **162d** from the certificates **154h**, **154d**.

The server certifying authority **152e** (CA **152e**) may be produced by the manufacturer based on a CMC signature root **152**. The server certificate authority **152e** may be embodied in the server **60** (see FIGS. 2,6) on a server-by-server basis. Thus, a server **60** may generate keys **156j** or pairs as shown in FIG. 6. Thus, the server **60** is able to certify by a key generation manager **42** keys **160** generated by that server **60**.

A private key **156** may preferably be unique to an individual server **60** so that there is no need to provide a globally exposed private key **156**. The private key **156e** of the server certificate authority **152e** of FIG. 6 may be the only private key **156** embedded in a base executable **14** or operating system **14** hosted by a server **60**. This may be very important

for providing signatures **162j** for certifying **166j** other keys **160j** and IDs **158j** signatures **162**.

As a practical matter, by embedding is meant alternate methods that may be implemented in the server **60** in another manner well adapted to dynamic loading. For example, the private key **156e** may not necessarily need to be embedded, as in the illustrated example. Rather, the key **156e** may simply be "securely available," such as by reading from a secure hardware device. Thus, a key **156e** may be securely available to the CMC **12** in the server **60** and function as well as if actually embedded. The expression embedded should be interpreted broadly enough to include this "securely available" approach. This is particularly true since dynamic loading in combination with cryptographic techniques herein for verification make such methods readily tractable.

In general, a private key **156** may be used to produce certifying signatures **162**. A key **156** may also be used to decrypt data received when it has been encrypted using a corresponding public key **160** to ensure privacy.

Both keys **156**, **160** may be necessary for both privacy and integrity, but they are used at opposite ends of a communication. That is, for example, the CMC signature root **152b** may use the public key **160** of the module signature authority to assure privacy of communication to the module signature authority **152d**. The module signature authority **152d**, may use the public key **160b** of the CMC signature root **152b**. Each **152b**, **152d** may use its own private key **156b**, **156d** to decrypt received messages. Integrity may be verified by a signature **162** authored using an appropriate private key **156b**, **156d**. Meanwhile, authenticity of communications, such as a signature **162d**, created using a private key **156b**, may be verified by an entity using the corresponding, published, public key **160b**.

As a matter of good cryptographic practice, integrity and confidentiality (privacy) may rely on separate keys. A module **13** may employ a plurality of private/public key pairs **156/160**. One pair may be used for channel confidentiality. A separate and distinct pair may be used for channel integrity.

The certificates **154** in the base executable **14**, for example in the module **13**, and loader **90** illustrate authentication of the cascade of certificates. Initially, the modules **13** of FIG. **6** are signed by the signature **168** created with the private key **156h**.

The public key **160h** may be used to verify the signature **168**. References to decryption of signatures **168** mean verification, which requires some amount of decryption.

The authenticity of the public key **160h** is assured by the signature **162h** on the certificate **154h**. The signature **162h** is verified using the public key **160d** in the certificate **154d** available.

The authenticity of the public key **160d** is assured by the signature **162d** on the certificate **154d**. The signature **162d** is verified using the public key **160b** in the certificate **154b** available.

This illustrates the practical limit to authentication. The following is not separately illustrated in the architecture, but could be implemented. The authenticity of the public key **160b** could be assured by the signature **162b** by obtaining the certificate **154b**. The signature **162b** would have to be verified using the public key **160a** in the certificate **154a** available. Note that some other mechanism must be used to verify the certificate **154a**.

A server may generate keys for cryptographic operations. For example, a separate set of keys **156j** may exist for each client **58** on the network **56**.

Asymmetric systems are more computationally expensive than symmetric systems. The key length used in asymmetric systems is typically much longer than that for symmetric systems. (e.g. asymmetric keys may be 1–2 k bits long, versus 40, 64, or 128 bits for typical symmetric keys). In cryptographic protection schemes, an asymmetric algorithm may be used to protect a symmetric key that will be distributed to a client **50** encrypted using the client's public key **160** and decrypted by the client's corresponding private key **156**. A shared secret key may be used for shared symmetric key communication in a network **56**. Thus, the server CA private key **156e** may be used to generate a signature certifying other public/private key pairs **160**, **156**. That pair **156**, **160** may be used to certify another pair or to distribute a symmetric key pair.

A certificate **154** is needed for a public key **160**, and must be signed (**162**) using the corresponding private key **156**. A private key **156**, for example, is used to certify any public key **160** created in the key generation module **42** of FIG. **6**. That is, the key generation module **42** may generate a key pair **156**, **160**; in which the server CA private key **156e** is used to sign the certificate **154j** created by the key generation module for the cryptographic libraries. The server CA private key **156** may be used to sign all certificates **154** (with included public key **160**) generated by the CMC filler **12** in the base executable **14** of to operating system **14** hosted on the server **60**.

A server key (not shown), which may be symmetric, may be generated by the key generation module **42** and used for key wrapping. All keys that should be kept secret may be wrapped for being transmitted or stored secretly outside of the CMC **12**, such as in a cryptographic library **36**.

Certain of the attributes of a key **156** (algorithm, archive, type, etc.) may be wrapped along with the key **156** before being passed outside of the CMC **12**. Thus a private half of an asymmetric key pair, or a symmetric, secret key should be wrapped preceding any export or output from the CMC **12**.

The libraries **16** may be (typically must be) application-specific, and anything transmitted to them may be considered to be outside of the control of the CMC **12** once it is transmitted to the library **16**.

Escrow is controlled by a manager **14** such as the key generation manager **42**, a cryptographic manager **18**. In any case, every key **156j** generated should be saved throughout its useful life. A key **156j** may be saved, typically, in an encrypted format in a secure environment called a key archive **170**. The archived key **156j** may first be encrypted, and the key **160** to that encryption is the escrow public key **160k**. The corresponding public key **160j** is also archived, although it may be publicly available.

The escrow authority **152f** may be an entity generating a public/private key pair **160,156** for each server **60** in order to encrypt (privacy protect) private keys **156** before archival. Thus, the escrow authority **152f** may have a private key **156f** unique to itself, which is used to sign **162k** the certificates **154k** for all of those public/private key pairs **156k**, **160k**. The escrow authority **152f** may receive its private/public key pair **156f**, **160f** from a key escrow root **152c**. The key escrow root key **156c** may certify the key **160f** held by the escrow authority **152f**. The manufacturer of the base executable **14**, (Novell, in the example above, may be (i.e. control) the key escrow root **152c**.

The certificate **154c** held by the key escrow root **152c** may itself be signed by the root certifier **152a** certifying the public key pair **160c** of the key escrow root **152c**. Thus, the key escrow path (certifications **166**, cascade) of certificates

154 and keys 156, 160 may have its source in the root certifier 152a, just as the CMC signature root 152b does.

An escrow authority 152f may hold the private key 156f to the archive holding the encrypted, escrowed keys 156. The archive 170 may actually be inside the server 60. Thus, the holder of the base executable 14 has all the encrypted keys 156.

However, a government or some such agency may require certain keys of the escrow authority 152f. A manufacturer, such as Novell, the operating system manufacturer, in the example above, could also serve this function as well as being the key escrow root 152c. This may be advantageous for the same reasons that a manufacturer would be the signature root 152b. The escrow authority 152f may give to the agent the escrow private key 156f for the specific server. This may be the private half 156k of an escrow key 156 that the keys 156 in question were encrypted in for archiving. The government may then go to the user of the server 60 to get access to the archive 170 in the server 60 of the owner of all the keys 156j.

Some governments may want to be the escrow authority 152f for all escrow keys. The government may unlock the key archive 170 whenever desired. In certain countries, the key archive 170 may be in possession of a trusted third party or the government. For example, the key generation module 42 may need to create keys 156j, encrypt them, and send them as data to a trusted third party acting for the government to control the archive 170.

From the above discussion, it will be appreciated that the present invention provides controlled modular cryptography in an executable designed to be embedded within another executable such as a network operating system, or the like. Cryptographic capability is controlled by a manager module operating according to a policy limiting the capability and access of other modules, particularly that of the cryptographic engine. Thus, a system 14 (a base executable 14) may be provided having nearly all of the capabilities of the "filler" 12 intact. A very limited interface between a filler 12 and its internal engine selection 20 provides for examination of engines 20 by regulatory authority. Moreover, the restricted interfaces 30, 32 between the engines 20 and the remaining modules 13 of the filler 12 present great difficulty to those who would modify, circumvent, or replace any portion of the filler 12 (CMC 12) in an attempt to alter its capabilities. Meanwhile, asymmetric key technology provides for enforcement of all controls, thus providing privacy and integrity for all communications, operations, exchanging of keys, and the like.

Referring to FIG. 7, an operating system 15 may include a loader 90 in an apparatus 10. The loader 90 may be one of several nested loaders 300. For example, the loader 90 controls access to a location 302 as described above. Modules 304 may be loaded dynamically by the loader 90. If no cryptographic capability is to be included in any module 304, a null engine 48 may be installed in the place of the module 304. Additionally, any of the modules 13 (see FIG. 1) may be loaded as the module 304, as permitted in any of the architectural options described above. Thus, a module 304 may actually include the entire base executable base 14 of a filler 12 in the entire hierarchical arrangement provided.

In the embodiment of FIG. 7, a nested loader 306 is preferably loaded by the loader 90. Accordingly, a third party, properly authorized, as described above, may provide a loader 306 to be loaded into the location 302 by the loader 90. The loader 306 may be authorized by proper certificates 154, keys 156, and policies 164 to be properly

loaded and linked by the loader 90. Thus, any module 304, 308, or the like may also be an entire hierarchical system 14 of modules 13.

Also, a loader 310, properly verified, loaded, and dynamically linked into the location 302, may include therein modules 312, which might in turn comprise another loader 314. Thus, not only may multiple loaders 306, 310 be loaded into the location 302 by a principal loader 90, but the loader 310, may also be adapted to load other loaders 314. Thus, the loader 314 may recursively implement the properly authorized, verified and controlled operations corresponding to those performed by the loader 90, within the domain defined and allocated to the loader 314. That is, the loader 314 may not supplant nor circumvent the loader 90. Rather, the loader 314 is loaded, linked, and controlled in accordance with the authorizations verified by the loader 90 and implemented thereby. Likewise, the loader 314 may simply be a module 304 of an entire hierarchy 14 of modules 13 (See FIG. 1). Thus, a more restrictive environment provided by an extant policy 130, 140 may be implemented in a module 316 than in higher level modules such as the module 304.

Thus, FIG. 7 illustrates nested loading of multiple modules 304, 308 which are independent from one another, and concurrently, loading of other modules 312, 316 recursively. Since the controls implemented by the filler 12 in the operating system 15 may be recursively applied, differing levels of security may be imposed between modules 302, 308, 312, and 316 within the apparatus 10. Typically, greatest security imposed will be within the recursion 90, 310, 314.

Referring to FIG. 8, an operating system 15 may have multiple loaders 90, 320 integrated with the operating system 15. In one embodiment, the loaders 90, 320 may be "visible" to one another. Alternatively, the loaders 90, 320 may be completely independent and transparent of one another.

One embodiment, dynamically linked modules 318, 322 may not be "aware" of each other's existence. In an alternative embodiment, a link 324 may be established dynamically between the modules 318, 322. Because the loaders 90, 320 operate dynamically according to the infrastructure provided as described above for FIGS. 1-6, security and control may be assured. As a practical matter, multiple loaders 90, 320, aware of one another or not, create no new risk not already accommodated. One may see that the modules 318, 322 represent a multiplicity of linked filler modules 12 of the basic embodiment 14.

Thus, relative interdependence or independence of the modules 318, 322 is a matter of design choice. Similarly, what may be done with an individual module 13, 304, 308, 312, 316, 318, 322 may be done with any number of modules as described above. Accordingly, multiple sets of hierarchies 14 of modules 13, recursive loading of loaders 306, 314 by loaders 90, 310, respectively, and loading by plurality of loaders 90, 320, may all be encompassed within selected embodiments of an apparatus 10 in accordance with the invention.

Moreover, the loader 90 may be independent of another loader 330 having a separate slot 332 associated therewith. Accordingly, the loader 330 may load a module 334 into the slot 332. As discussed above, the module 334 may actually implement multiple modules 13. Additionally, the module 334 may itself include nesting, recursion, and other processes. In the depicted embodiment of the FIG. 8, the loaders 90, 330 are typically transparent to one another. Thus, the

slot **332**, serviced by the loader **330**, and the slot **336**, serviced by the loader **90** are not available or visible to the opposing loaders **90**, **330**, respectively. Furthermore, each of the loaders **330** may have separate authorization mechanisms, for example, each may have a separate public or private key or digital signature associated therewith the public keys associated with the different loaders **90**, **330** can be the subject of different distribution channels.

Thus, multiple slots **302**, **330**, **336** serviced by one or more loaders **90**, **320**, **330**, may be controlled as described above to provide a broad spectrum of flexible, yet highly controllable, dynamically integrated executables and data.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative, and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed and desired to be secured by United States Letters Patent is:

1. An apparatus comprising a digital computer having a processor for executing applications and a plurality of executable modules comprising:

a base executable loadable into the computer to perform a base function, the base executable module being provided with at least one slot adapted to receive a filler module;

a first filler module containing a unique property recognizable by the base executable, and alterable exclusively by an authorized creator of the first filler module; and

the base executable, programmed to verify the presence of the unique property, and to dynamically load the filler module into the at least one slot only if the unique property verifies correctly.

2. The apparatus of claim **1** wherein the first filler module further comprises a loader module for verifying another unique property associated with another module and loading the other module only after the other unique property verifies correctly.

3. The apparatus of claim **1**, wherein the at least one slot comprises a plurality of slots.

4. The apparatus of claim **3**, wherein the plurality of slots is adapted to receive a plurality of fillers recursively loaded.

5. The apparatus of claim **4** wherein each filler of the plurality of fillers comprises a loader for recursively loading another filler of the plurality of fillers in a nested relation.

6. The apparatus of claim **5**, wherein each loader is programmed to verify a unique property associated with the other filler module, to be verified by the loader before loading the other filler.

7. The apparatus of claim **1** further comprising:

a loader module integral to the base executable, programmed to verify the presence of the unique property, and to dynamically load the filler module only if the unique property verifies correctly; and

the first filler module further comprising a second loader module, executable to verify another unique property associated with a second filler module, and to load the second filler module into a second slot of the plurality of slots.

8. The apparatus of claim **7**, wherein the second loader module is effective to control invocations of and by the second filler module.

9. The apparatus of claim **7**, wherein the second filler module further comprises a plurality of modules and the second loader module is effective to provide linking between the plurality of modules in a layered hierarchy containing levels, and in which a linking of a first module of the plurality of modules at a first level to a second module of the plurality of modules at a second level defines an allowability of an invocation of the second module by the first module.

10. The apparatus of claim **7**, wherein the base executable is further provided with a plurality of slots, including the second slot, for receiving executable modules, and in which the second loader module is effective to link the plurality of slots in a layered hierarchy containing slot levels, and in which a linking of the second slot at a first slot level to a third slot of the plurality of slots at a second slot level determines an allowability of an invocation of a third filler module loaded into the third slot by the second filler module loaded into the second slot.

11. An article comprising a memory device having blocks for storing executables and data, the article including a first block storing a plurality of executable modules, executable by a processor, the first block comprising:

a base module loadable to be executed by the processor to perform a base function, the base module being provided with at least one slot adapted to receive a first filler module;

the first filler module executable by a processor and containing a unique property recognizable by a loader, the unique property being alterable exclusively by an authorized creator of the first filler module;

the loader module integral to the base module and programmed to verify the presence of the unique property in the first filler module, and to dynamically load the filler module only if the unique property verifies correctly;

the base executable, provided with a second slot of the at least one slot; and

the filler module further comprising a second loader module effective to verify another unique property associated with the second filler module and to load the second filler module into the second slot only after the other unique property verifies correctly.

12. The article of claim **11**, wherein the second loader module is effective to control invocation of and by the second filler module.

13. The article of claim **11**, wherein the second filler module further comprises a plurality of modules and the second loader module is effective to link the plurality of modules in a layered hierarchy containing levels, and in which a linking of a first module of the plurality of modules at a first level to a second module of the plurality of modules at a second level defines an allowability of an invocation of the second module by the first module.

14. The article of claim **11**, wherein the first filler module further comprises a second loader module effective to link the plurality of slots in a layered hierarchy containing slot levels, and in which a linking of the second slot at a first slot level to a third slot of the plurality of slots at a second slot level defines an allowability of an invocation of a third filler in the third slot by the second filler in the second slot.

15. The article of claim **11**, wherein the first filler module further comprises an engine.

16. The article of claim **15**, wherein the engine is a cryptographic engine programmed to execute a cryptographic algorithm.

17. A method for limiting integration of software modules into a base module, executable by a processor of a computer, the method comprising:

providing a base module executable by the processor, the base module having slots for receiving filler modules, and having a first loader programmed to operate with a base executable to control loading of a first filler module into a first slot;

providing the first filler module containing a second loader effective to be executed by the processor, the first filler module containing a unique property recognizable by the first loader, and alterable exclusively by an authorized creator of the first filler module;

executing the base module by the processor;

executing the loader by the processor;

verifying by the loader the presence of the unique property in the first filler module, loading dynamically the first filler module only after the loader verifies the unique property successfully;

executing the first filler module, including the second loader, by the processor;

verifying by the second loader a second unique property in a second filler module; and

loading dynamically the second filler module only after the second loader verifies the second unique property successfully.

18. The method of claim 17, wherein the first filler module comprises an engine.

19. The method of claim 17, wherein the first unique property is a digital signature, and the second unique property is another digital signature.

20. The method of claim 17, further comprising:

controlling, by the first loader, linking of the second filler module to the first filler module to enable invocations of and by the second filler module.

21. The method of claim 20, wherein the second filler module comprises a plurality of modules, and the method further comprises:

linking by the second loader module the plurality of modules to one another in a layered hierarchy; and

controlling invocation of a first other module of the plurality of modules by a second other module of the plurality of modules, in accordance with links completed by the linking step.

22. The method of claim 17 further comprising:

loading dynamically each of multiple filler modules into a corresponding slot of the slots; and

linking dynamically by the second loader module each filler module of the multiple filler modules in a layered hierarchy, the layered hierarchy containing slot levels, and a linking of a second slot at a first slot level to a third slot of the multiple slots at a second slot level defining an allowability of an invocation of a third filler module in the third slot by the second filler module in the second slot.

23. The method of claim 17 further comprising:

loading recursively and dynamically by the second loader, other filler modules in remaining slots only after verifying a corresponding unique property by the second other filler module; and

linking dynamically by the second loader module the other filler modules in a layered hierarchy, the layered hierarchy containing levels, and a linking of a first other filler module at a first level to a second other filler module at a second level defining an allowability of an invocation of the second other filler module by the first other filler module.

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