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- ▶ Examples: Secure shell (`ssh`, `slogin`, `sshd`), PGP (Pretty Good Privacy, a free cryptographic package), Kerberos network authentication, SSL (Secure Sockets Layer, used with `https` protocol).

"If privacy is outlawed, only outlaws will have privacy." Zimmerman (author of PGP)

Public key cryptography

Each participant has a *public key* and a *secret key*. In RSA public-key cryptosystem, each key consists of a pair of large integers.

Alice has key (P_A, S_A) .

Bob has key (P_B, S_B) .

Let \mathcal{D} be the set of permissible messages. Then we require the following conditions.

$$P_A, S_A, P_B, S_B : \mathcal{D} \rightarrow \mathcal{D}$$

$$M = S_A(P_A(M))$$

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$$M = S_B(P_B(M))$$

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Sending an encrypted message

1. Bob obtains Alice's public key P_A .
2. Bob computes the ciphertext $C = P_A(M)$ corresponding to the message M and sends C to Alice.
3. When Alice receives the ciphertext C , she applies her secret key S_A to retrieve the original message: $M = S_A(C)$.

Digital signature

1. Alice computes her **digital signature** $\sigma = S_A(M')$ for the message M' using her secret key.
2. Alice sends the message/signature pair (M', σ) to Bob.
3. When Bob receives (M', σ) , he can verify that it originated from Alice by using Alice's public key to verify that $M' = P_A(\sigma)$.

A digital signature is verifiable by anyone who has access to the signers public key. The signed message is not encrypted.

Encrypted and signed message

1. Alice computes her **digital signature** $\sigma = S_A(M')$ for the message M' using her secret key.
2. Alice appends her digital signature to the message and then encrypts the resulting pair with Bob's public key to send $P_B(M' \sigma)$.
3. Bob decrypts the message using his secret key.
4. Bob verifies Alice's signature using her public key.

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 - ▶ If factoring large integers is hard, then whether breaking RSA is hard is an unproven statement. However decades of research has not found an easy way to break the RSA system.
- ▶ A perfect tool for electronic contracts, electronic checks, e-cash, etc. However cryptography is not a panacea for every security issue.
- ▶ How do you get your public key in the beginning. Get a **certificate** from a trusted authority.
- ▶ Public-key cryptosystem involve multiple-precision arithmetic which is considerably slower. Most practical systems use a hybrid approach.

Encryption in Java

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- ▶ We can get a list of all available security providers with some simple code. See example: [security/providers/ListProviders.java](#)
- ▶ See code snippet below:

```
import java.security.Provider;
import java.security.Provider.Service;
import java.security.Security;
import java.util.Set;

public class ListProviders {
    public static void main (String[] args) {
        Provider[] list = Security.getProviders();
        for (Provider e: list) {
            System.out.println(e);
            Set<Service> serviceList = e.getServices();
            for (Service s: serviceList)
                System.out.println("\t" + s);
            System.out.println();
        }
    }
}
```

Encryption in Java

- ▶ Sample code that generates a key and uses it to encrypt information and then stores both the key and the encrypted information on the disk. See examples:

[EncryptTest.java](#) [DecryptTest.java](#)

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- ▶ Uses the Advanced Encryption Standard (**AES**)
- ▶ Code snippet:

```
// security/Encryption/EncryptTest.java
FileOutputStream dataFile = new FileOutputStream("data.encrypted");
ObjectOutputStream oos = new ObjectOutputStream(
    new FileOutputStream("key");
```

```
KeyGenerator kg = KeyGenerator.getInstance("AES");
Key key = kg.generateKey();
oos.writeObject(key);
```

```
Cipher cipher = Cipher.getInstance("AES");
byte[] data = "Hello World!".getBytes();
cipher.init(Cipher.ENCRYPT_MODE, key);
byte[] result = cipher.doFinal(data);
dataFile.write(data);
```

- ▶ **Beware!** The key is not protected. It must at least not be readable by anyone else.

Decryption in Java

- ▶ Sample code that reads in a key and uses it to decrypt information from an encrypted file.

```
// security/Encryption/DecryptTest.java
File dataFile = new File("data.encrypted");
FileInputStream data = new FileInputStream(dataFile);
ObjectInputStream ois = new ObjectInputStream( new FileInputStream("key"));

Key key = (Key) ois.readObject();
Cipher cipher = Cipher.getInstance("AES");
byte [] result = new byte[(int)dataFile.length()];
int n = data.read(result);
cipher.init(Cipher.DECRYPT_MODE, key);
byte[] original = cipher.doFinal(result);
```

- ▶ See example [securehash/SHA2Test.java](#) on how to use MD5 sums and Secure hash functions in Java. Please note that MD5 sums have a known flaw so research them fully before relying on them.

MD5 Sums, Secure Hash and Password Input

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- ▶ Another issue is handling password input without showing input. See the example [PasswordTest.java](#) in the folder [security/passwordinput](#) for more details.

Secure Sockets Layer

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 - ▶ Uses symmetric key cryptography for data encryption between client and server.

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 - ▶ Uses asymmetric key cryptography (public/private key) to encrypt the shared encryption key that is used during the SSL session.
 - ▶ Uses symmetric key cryptography for data encryption between client and server.
- ▶ **RMI with SSL**. Java has two classes that provide the ability to secure the communication channel using SSL/TLS (Secure Socket Layer/Transport Layer Security) protocols:
`javax.rmi.ssl.SslRMIClientSocketFactory`
`javax.rmi.ssl.SslRMIServerSocketFactory`

Overview of RMI with SSL

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- ▶ *The server sends its certificate and the client verifies it.* The certificate sent by the server comes from the server's **keystore** as a database for the contents. The client either verifies the server's signature by either trusting the server or trusting one of the signers in the certificate chain provided by the server.

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- ▶ *The client stores certificates in its truststore.* The default truststore is **cacerts**, which can be found in the following location:
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- ▶ *Next the client sends a **ChangeCipherSpec** message indicating that it is ready to communicate.* This message is followed by a **Finished** message.
- ▶ *The server responds by sending its **ChangeCipherSpec** message and a **Finished** message.*

Example SSL Handshake

```
*** ClientHello, TLSv1
RandomCookie: GMT: 1141769969 bytes = { 93, 99, 48, 178, 50, 21, 255,
207, 135, 20, 150, 233, 207, 151, 26, 126, 200, 93, 146, 59, 53, 232,
2, 209, 238, 34, 219, 178 }
Session ID: {}
Cipher Suites: [SSL_RSA_WITH_RC4_128_MD5, SSL_RSA_WITH_RC4_128_SHA,
TLS_RSA_WITH_AES_128_CBC_SHA, TLS_DHE_RSA_WITH_AES_128_CBC_SHA,
TLS_DHE_DSS_WITH_AES_128_CBC_SHA, SSL_RSA_WITH_3DES_EDE_CBC_SHA,
SSL_DHE_RSA_WITH_3DES_EDE_CBC_SHA, SSL_DHE_DSS_WITH_3DES_EDE_CBC_SHA,
SSL_RSA_WITH_DES_CBC_SHA, SSL_DHE_RSA_WITH_DES_CBC_SHA,
SSL_DHE_DSS_WITH_DES_CBC_SHA, SSL_RSA_EXPORT_WITH_RC4_40_MD5,
SSL_RSA_EXPORT_WITH_DES40_CBC_SHA, SSL_DHE_RSA_EXPORT_WITH_DES40_CBC_SHA,
SSL_DHE_DSS_EXPORT_WITH_DES40_CBC_SHA]
Compression Methods: { 0 }
***

*** ServerHello, TLSv1
RandomCookie: GMT: 1141769970 bytes = { 214, 236, 161, 51, 175, 144,
66, 122, 86, 62, 242, 54, 229, 209, 121, 18, 164, 196, 77, 233, 16, 174,
20, 9, 92, 153, 236, 197 }
Session ID: {68, 14, 7, 242, 21, 148, 20, 218, 17, 110, 197, 208, 17,
91, 178, 156, 22, 52, 57, 41, 20, 215, 6, 80, 62, 112, 182, 111, 31,
35, 51, 164}
Cipher Suite: SSL_RSA_WITH_RC4_128_MD5
Compression Method: 0
***
```

Example SSL Handshake (continued)

From Client

*** ClientKeyExchange, RSA PreMasterSecret, TLSv1

Random Secret: { 3, 1, 155, 121, 164, 80, 202, 181, 110, 118, 28, 78,
85, 173, 230, 166, 234, 188, 171, 204, 130, 167, 6, 155, 155, 178, 70,
20, 88, 244, 141, 220, 177, 167, 4, 147, 24, 129, 165, 171, 70, 23, 132,
74, 144, 20, 156, 227 }

From Client

main, WRITE: TLSv1 Change Cipher Spec, length = 1

[Raw write]: length = 6

0000: 14 03 01 00 01 01

.....

*** Finished

From Server

RMI TCP Connection(2)-132.178.248.51, WRITE: TLSv1 Change Cipher Spec, length =

[Raw write]: length = 6

0000: 14 03 01 00 01 01

.....

*** Finished

Generated using the `-Djavax.net.debug=all` option to the java VM.

Creating the setup

- ▶ Generate a keystore that has a key pair (public and private key) along with a self-signed certificate.

```
keytool -genkey -alias SecureServer -keyalg RSA -keystore  
Server_Keystore
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keytool -list -v -keystore Server_Keystore
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- ▶ To see what the certificate looks like.

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cat Server.cer
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- ▶ Next we import the server certificate into a truststore that can be used by the client.
`keytool -import -alias SecureServer -file Server.cer -keystore Client_Truststore`

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`cat Server.cer`
- ▶ Next we import the server certificate into a truststore that can be used by the client.
`keytool -import -alias SecureServer -file Server.cer -keystore Client_Truststore`
- ▶ To verify the contents of the truststore that we created, we issue the following command.
`keytool -list -v -keystore Client_Truststore`

In our example, we are working with a self-signed certificate instead of certificates signed by Certification Authority (CA). If there is a need to get the certificate signed by a CA then a Certificate Signing Request(CSR) needs to be generated. The generated CSR, then, should to be submitted along with other pertinent information to a Certification Authority such as VeriSign or USPS, who will then digitally sign the certificate.

Using SSL Sockets

- ▶ See example in the folder [security/sslsockets](#).

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- ▶ On the server side.

```
import javax.net.ssl.*;
System.setProperty("javax.net.ssl.keyStore", "Server_KeyStore");
System.setProperty("javax.net.ssl.keyStorePassword", "password");
SSLServerSocketFactory sslSrvFact =
    (SSLServerSocketFactory) SSLServerSocketFactory.getDefault();
SSLServerSocket ss = (SSLServerSocket) sslSrvFact.createServerSocket(port);
SSLSocket sock = (SSLSocket) ss.accept();
```

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SSLServerSocket ss = (SSLServerSocket) sslSrvFact.createServerSocket(port);
SSLSocket sock = (SSLSocket) ss.accept();
```

- ▶ On the client side.

```
import javax.net.ssl.*;
System.setProperty("javax.net.ssl.trustStore", "Client_Truststore");
System.setProperty("javax.net.ssl.trustStorePassword", "password");
SSLSocketFactory sslFact = (SSLSocketFactory)SSLSocketFactory.getDefault();
SSLSocket server = (SSLSocket)sslFact.createSocket(host, port);
```

Using RMI with SSL Sockets

- ▶ See examples in the folder [security/rmisslex1](#)

Using RMI with SSL Sockets

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```
System.setProperty("javax.net.ssl.keyStore", "./resources/Server_Keystore");
System.setProperty("javax.net.ssl.keyStorePassword", "password");
System.setProperty("java.security.policy", "./resources/mysecurity.policy");
RMIClientSocketFactory rmiClientSocketFactory =
    new SslRMIClientSocketFactory();
RMIServerSocketFactory rmiServerSockeyFactory =
    new SslRMIServerSocketFactory();
DateServer server = (DateServer) UnicastRemoteObject.exportObject(this, 0,
    rmiClientSocketFactory, rmiServerSockeyFactory);
Registry registry = LocateRegistry.createRegistry(port);
registry.rebind(name, server);
```


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Registry registry = LocateRegistry.createRegistry(port);
registry.rebind(name, server);
```

- ▶ On the client side.

```
System.setProperty("javax.net.ssl.trustStore", "Client_Truststore");
System.setProperty("java.security.policy", "mysecurity.policy");
Registry reg = LocateRegistry.getRegistry(host, port);
DateServer server = (DateServer) reg.lookup("DateServerImpl");
```

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System.setProperty("javax.net.ssl.trustStore", "Client_Truststore");
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Registry reg = LocateRegistry.getRegistry(host, port);
DateServer server = (DateServer) reg.lookup("DateServerImpl");
```

- ▶ Also see example in folder [security/rmisslex2](#)

References

- ▶ *JSSE (Java Secure Sockets Extension)* documentation.