Implementation and Simulation of Secure Sockets Layer (SSL) in Windows Presentation Foundation

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Outline

- Introduction
- Previous Work
- Background of SSL/TLS and Attacks on It
- Implementation
- Limitations and Future Work

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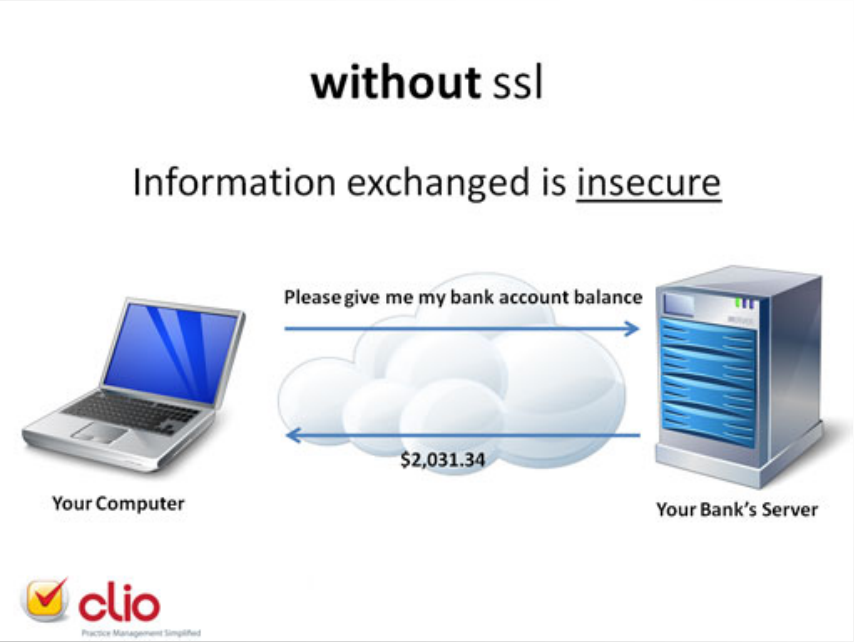
Introduction

- Insecure communication between a web server and browser
- Intercepting/sniffing messages transmitted through an insecure channel



[www.goclio.com]

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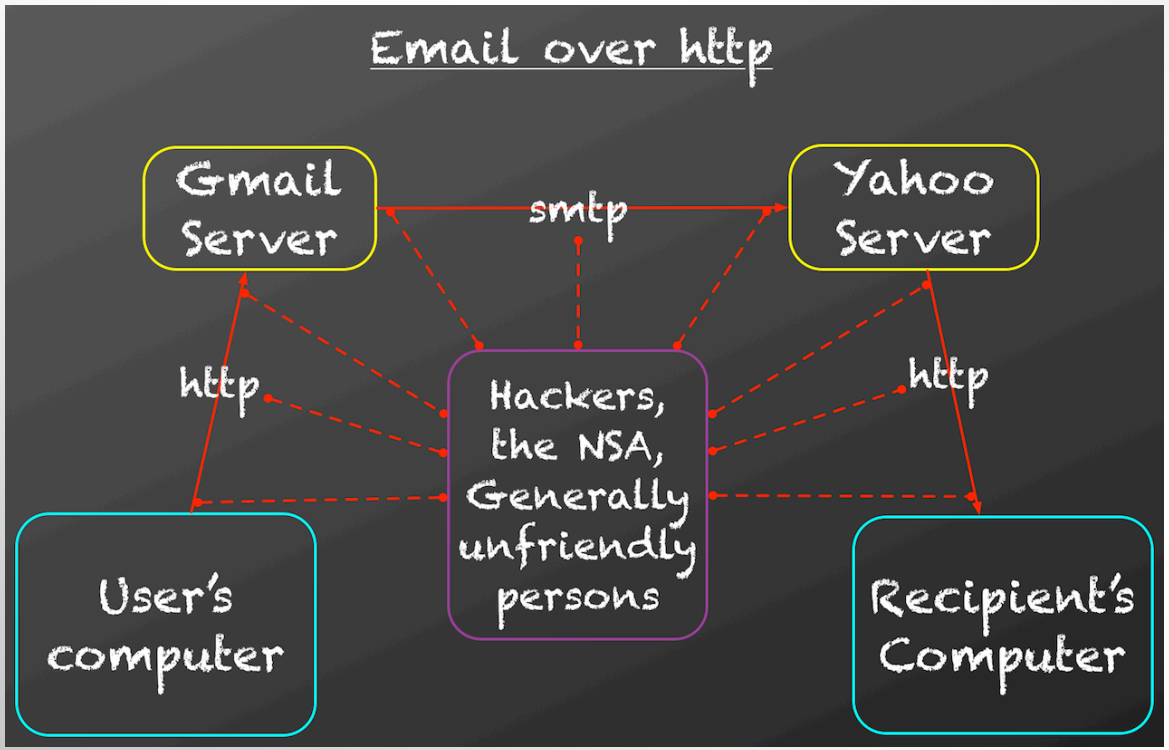
Illustration

- Insecure E-mail communication over HTTP between the e-mail server and the user



[www.kryptocake.com]

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Previous Work

- Several Open-source programs available for teaching Cryptography
  - CrypTool

    Open source e-learning software to experiment with various cryptographic algorithms and programs in the area of cryptography and cryptanalysis

CrypTool 1	CrypTool 2	JCrypTool	CrypTool Online
First version of CrypTool that has simple GUI which demonstrates different cryptographic algorithms	Successor of CrypTool 1 that supports visual programming and has plugin based architecture	Modern, easy-to-use application that allows users to develop their own cryptographic plugins	Online version of CrypTool that allows users to experiment with different algorithms

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Previous Work (cont…)

CrypTool 1	CrypTool 2	JCrypTool	CrypTool Online
Written in C++, runs on Windows	Written in C# using WPF, runs on Windows	Written in Java, which has Eclipse rich platform and runs on multiple platforms such as MAC OS X, Linux and Windows	Runs in a browser or on a smartphone
Visualization of several cryptographic algorithms and cryptanalytical methods	Plug' n' Play interface enabling workflow and visual programming of the algorithms by vector based GUI	Provides platform to experiment comprehensively with cryptography. Primary purpose is to develop crypto plugins and integrate into JCT	Developed primarily to study fundamentals of historical ciphers. Suitable for working with longer texts and conducting analysis of encrypted messages

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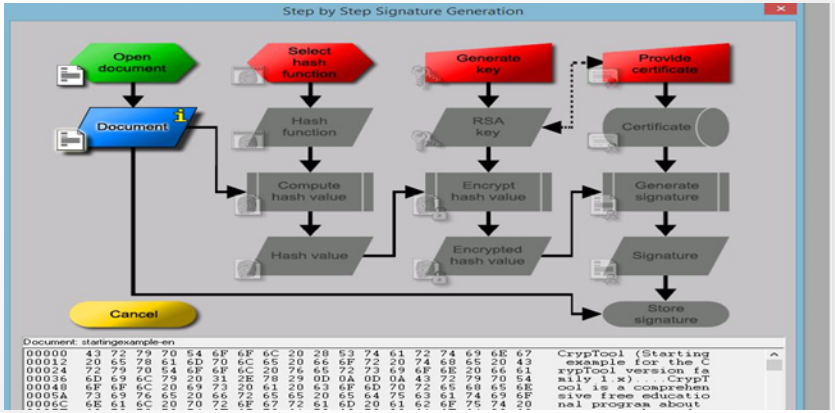
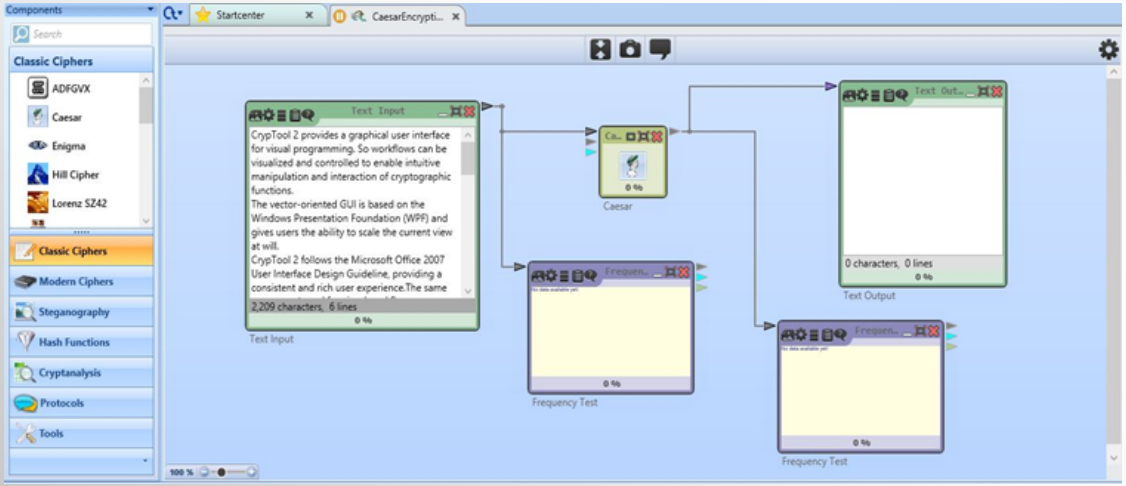
Previous Work (cont…)





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Previous Work (cont…)

- MAGMA
  - Known as Matrix Algebra on GPU and Multicore Architectures, this freely available software is designed for computations in algebra, geometry, number theory, etc.
  - Provides an environment to work with many different structures such as groups, rings, fields, graphs, etc.
  - Magma relies on features like integration, performance algebraic design, etc.
  - Can be used to encode public key operations used in SSL/TLS
  - Why not?

- SageMath
  - Free open-source mathematics software, which supports teaching in cryptography, algebra, geometry, etc.
  - Uses Python programming language as its base language
  - Features include text-based command line interface, different mathematical and number theory library functions
  - Available for multiple operating systems like Windows, Linux, Solaris, and OSX
  - Why not?

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Previous Work (cont…)

- GnuPG
  - Open source implementation of the OpenPGP, designed to operate with PGP - the e-mail encryption program
  - Hybrid encryption software that uses a combination of conventional symmetric-key cryptography for speed and public-key cryptography for an easy secure key exchange
  - Supports various algorithms like:
    - Public key: RSA, ElGamal, DSA
    - Secret key: 3DES, AES-128/192/256, IDEA, etc.
    - Hash: MD5, SHA-1, SHA-256/384/512
  - Supported applications includes:
    - GPG4win
    - GPGMail
    - GPGTools
  - Can be used as a basis for the developed program, however because OpenPGP is different than SSL/TLS and the code is written in a different language, the extension would require substantial effort

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Background of SSL/TLS

- What is SSL?
  - It is a cryptographic protocol that provides secure communication over an insecure network.
  - Establishes a link between the server and the client (generally a web server and the browser)
  - Makes use of certificates and asymmetric key cryptography to authenticate each party and to negotiate a symmetric key
  - Includes two sub protocols:
    - The Handshake protocol
      - Used to authenticate server/client and to generate session keys that will be used for the exchange of messages in the record protocol
    - The Record protocol
      - Used to exchange a series of messages between the authenticated server and client by using the cipher suites

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Background of SSL/TLS (cont…)

- Difference between SSL/TLS versions:

SSL Version 2.0	SSL Version 3.0
Vulnerable to Man-in-the-Middle (MITM) attack	Defends against MITM attack by including the hash of all previous handshake messages in the last handshake message. May be still vulnerable to MITM through the cipher suite rollback attack.
Uses weak MAC construction	Uses strong MAC construction
Client can only initiate the handshake at the beginning of the connection	Client can initiate a handshake in the middle of an open session as well
Restrict the server and client from sending chains of certificates	Allows the server and the client to send chains of certificates

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Background of SSL/TLS (cont…)

- TLS 1.0
  - An upgrade of SSL 3.0, hence uses standard HMAC compared to an older version of HMAC used by SSL 3.0
  - Key derivation functions and finished messages in the handshake protocol are different
- TLS 1.1
  - An upgrade to TLS 1.0
  - Implicit IV replaced with explicit IV for protecting against CBC attacks
  - Change in handling of padding errors
- TLS 1.2
  - MD5/SHA-1 combination in the PRFs and in the finished message was replaced by SHA-256
  - Addition of authenticated ciphers, AES-GCM and AES-CCM
  - Modified further to remove backward compatibility, meaning that TLS versions would never negotiate the use of SSL versions

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Background of SSL/TLS (cont…)

- SSL 3.0 is no longer considered secure due to its weakness against the POODLE attack

- BEAST attack can exploit web sites running SSL v3.0 and TLS v1.0, hence TLS v1.1 and TLS v1.2 considered more secure

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Background of SSL/TLS (cont…)

- Certification Authority (CA):
  - Is a trusted third party between the communicating parties
  - Certificates are digitally signed by the CA's private key and the opponent verifying party verifies the signature by using CA's public key; thus authenticating the contents of the certificate
  - Some of the certificate issuing companies include Symantec, VeriSign, Digicert and many more
  - In SSL/TLS, the certificates are exchanged during the handshake phase by the communicating parties for authentication purposes

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Background of SSL/TLS (cont…)

- Authentication and Key exchange algorithms:
  - Before the client and the server start exchanging any information, they must agree on the cipher suites
  - Several key exchange algorithms available for different SSL/TLS versions, where public/private key pairs are generated with
    - RSA, Diffie-Hellman, Ephemeral Diffie-Hellman, Elliptic Curve Diffie-Hellman, Ephemeral Elliptic Curve Diffie-Hellman, Anonymous Diffie-Hellman, Anonymous Elliptic Curve Diffie-Hellman
  - Public key certificates generated has varied key sizes as decided by the owner
  - Currently, 2048 bit public keys are considered much more secure and hence 1024 bit public keys are said to be no longer sufficiently secure

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Background of SSL/TLS (cont…)

Algorithm	SSL 2.0	SSL 3.0	TLS 1.0	TLS 1.1	TLS 1.2
RSA	Yes	Yes	Yes	Yes	Yes
DH-RSA	No	Yes	Yes	Yes	Yes
DHE-RSA	No	No	Yes	Yes	Yes
ECDH-RSA	No	No	Yes	Yes	Yes
ECDH-ECDSA	No	No	Yes	Yes	Yes
DH-DSS	No	Yes	Yes	Yes	Yes
DHE-DSS					

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Background of SSL/TLS (cont…)

- Different cipher suites security against known attacks:

Cipher			Protocol Version				
Type	Algorithm	Strength	SSL 2.0	SSL 3.0	TLS 1.0	TLS 1.1	TLS 1.2
Block Cipher with Modes of Operation	AES GCM	256, 128	N/A	N/A	N/A	N/A	Secure
	AES CBC		N/A	N/A	Depends	Secure	Secure
	Camellia GCM	256, 128	N/A	N/A	N/A	N/A	Secure
	Camellia CBC		N/A	N/A	Depends	Secure	Secure
	3DES CBC	112	Insecure	Insecure	Low Strength	Low Strength	Low Strength

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Background of SSL/TLS (cont…)

Cipher			Protocol Version				
Type	Algorithm	Strength	SSL 2.0	SSL 3.0	TLS 1.0	TLS 1.1	TLS 1.2
	DES CBC	56	Insecure	Insecure	Insecure	Insecure	N/A
		40	Insecure	Insecure	Insecure	N/A	N/A
	RC2 CBC	40	Insecure	Insecure	Insecure	N/A	N/A
Stream cipher	RC4	128	?	?	?	?	?
		40	Insecure	Insecure	Insecure	N/A	N/A

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Background of SSL/TLS (cont…)

- Data Integrity: Different MACs are used to provide data integrity during the data transmission
  - Takes arbitrary length of message to be authenticated as input, along with the secret key and outputs a MAC of fixed size length
- HMAC – Keyed-hash message authentication code:
  - Specific construction for calculating MAC that involves a cryptographic hash (e.g., MD5, SHA-1) in combination with the secret key

Algorithm	SSL 2.0	SSL 3.0	TLS 1.0	TLS 1.1	TLS 1.2
HMAC-MD5	Yes	Yes	Yes	Yes	Yes
HMAC-SHA1	No	Yes	Yes	Yes	Yes
HMAC-SHA256/384	No	No	No	No	Yes

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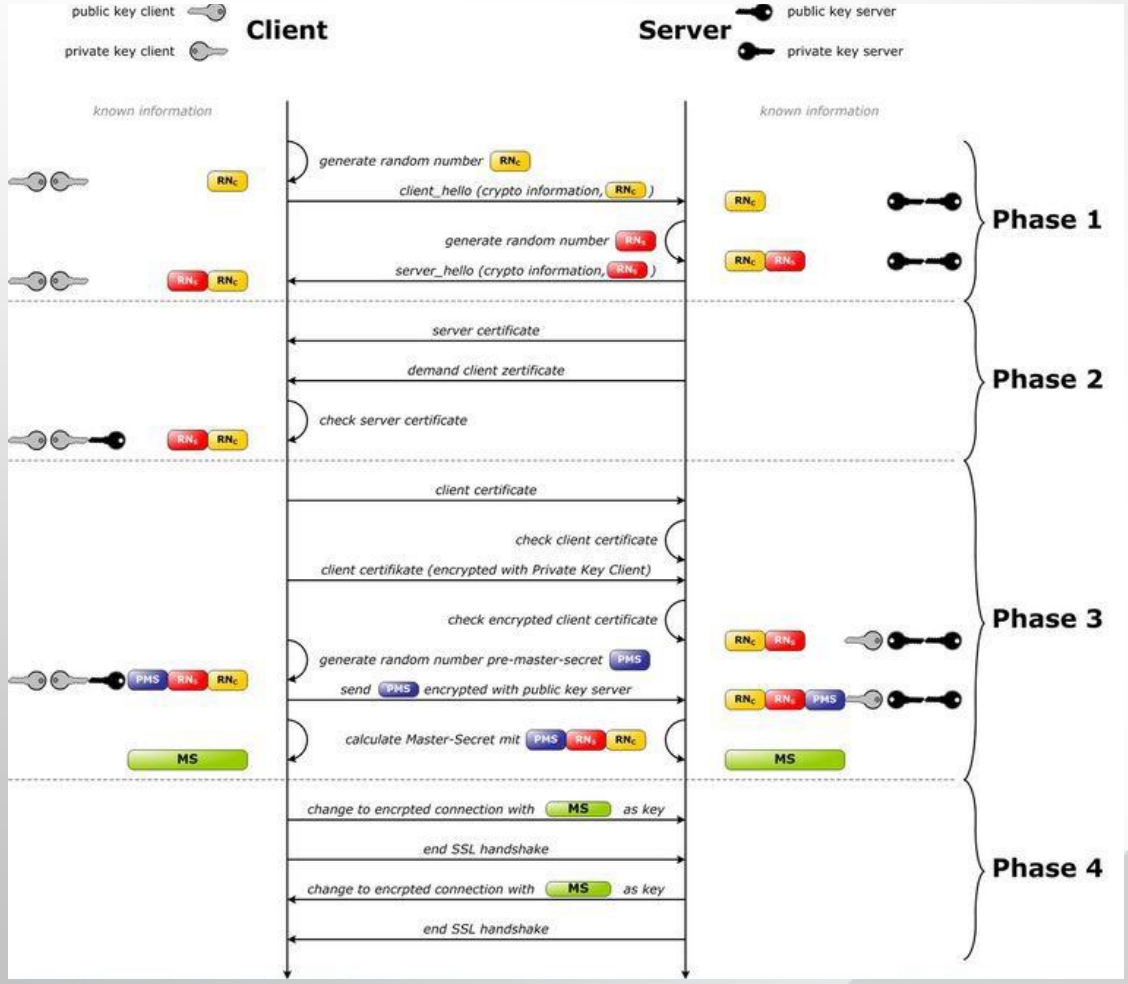
Background of SSL/TLS (cont…)

- The Handshake protocol:



Background of SSL/TLS (cont…)

- Authenticate the server to the client
- Allow the client and server to select the cryptographic algorithms, or ciphers, that they both support
- Optionally authenticate the client to the server
- Use public-key encryption techniques to generate shared secrets
- Establish an encrypted SSL connection

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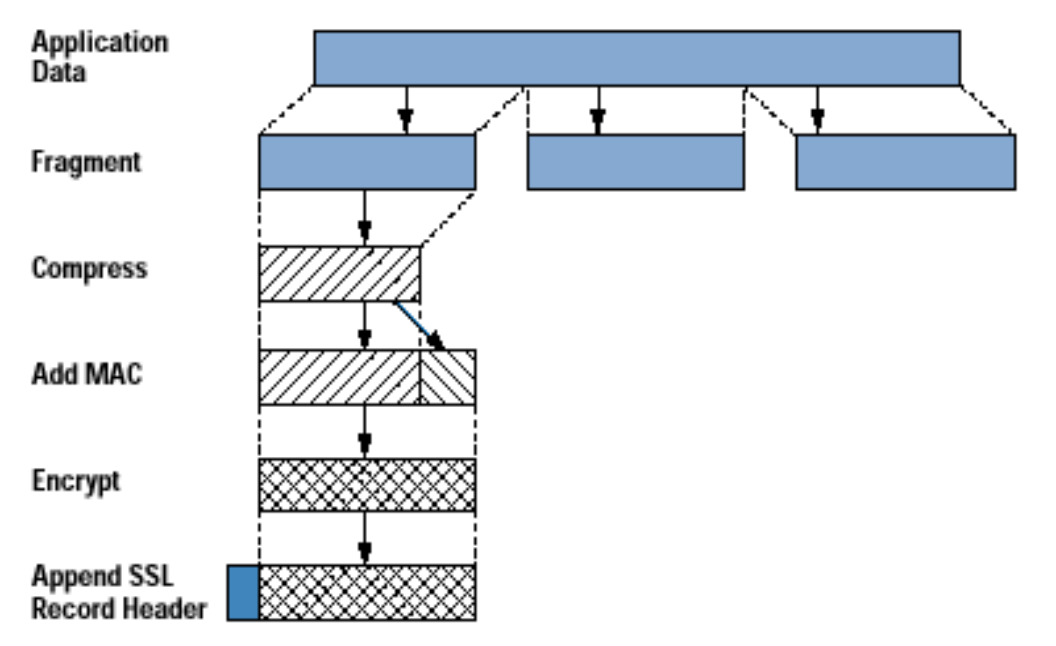
Background of SSL/TLS (cont…)

- The Record Protocol:



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Attacks on SSL/TLS

- There are significant attacks possible on SSL/TLS.

- Cipher Suite Rollback Attack
  - A MITM attacker can alter the ClientHello message, which contains cipher suites supported by the client, strip off the undesirable cipher suites and replace it with the weaker ones
  - The server either rejects the connections if the cipher suites provided by the client (modified by the attacker) are not acceptable, or accepts the weaker ones
  - This attack was mitigated with SSL 3.0

- Version Rollback Attack
  - This attack is possible by modifying the list of cipher suites by the attacker, making a ClientHello message of SSL 3.0 look like a ClientHello message of SSL 2.0

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Attacks on SSL/TLS (cont…)

- Forces the server to switch back to a more vulnerable SSL 2.0, thus allowing a way for more attacks to be done with the downgraded version
- As a mitigation, the PreMasterSecret of the ClientKeyExchange message contains the SSL/TLS version

- HeartBleed Attack
  - Attack specific to the implementation of the open source SSL/TLS library called OpenSSL
  - Exploit allowed the attackers to steal private keys from the server and allow anyone to sniff into the memory of the system that used the vulnerable OpenSSL version
  - Buffer Overflow was the flaw in the code, that compromised the private keys, passwords and other sensitive information of the users
  - Was mitigated by correcting the code and with the subsequent release of its next version

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Attacks on SSL/TLS (cont…)

- Man-in-the-middle Attack
  - With the anonymous DH key exchange taking place, the attacker could perform MITM attack easily as there is no authentication involved
  - Can get a hold of the public parameters of both communicating parties and act as an intermediary for both of them
  - Neither of the communicating parties would be able to know that they are not communicating with each other and instead with the attacker
  - Successful breach of confidentiality and integrity of the message.

- POODLE, BEAST, CRIME are some of the other types of attacks possible with SSL/TLS

Development Tools and Libraries

- Used the same development platform as CrypTool 2 – C# as the programming language with .NET Framework 4.0
  - Provides a way to develop Windows client applications, XML web services, client-server applications, etc.
  - Provides a great platform to develop GUI rich and client based applications
- Used Visual Studio 2013 as the IDE
- For rich GUI, Windows Presentation Foundation (WPF) has been used

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Development Tools and Libraries (cont…)

- WPF provides a platform to develop rich client applications
  - Allows the developers to create an application with vast range of elements like labels, textboxes, radiobuttons, checkboxes, etc.
  - Employs XAML to define interface elements; is responsible for the visual presentation of an application
  - Also supports built-for-user interfaces like 2D/3D rendering, animation and graphics with the elements, audio, video, etc.
  - Served as a perfect source for developing the program

Development Tools and Libraries (cont…)

- OpenSSL
  - Open source cryptography library that provides implementation of SSL/TLS protocols
  - Written in C language, it implements various basic cryptographic algorithms that sets the base for using it to develop different cryptographic applications
  - Implemented by most of the systems across the globe that rely on secure communication
  - Offers a command line interface which is used for the generation of public/ private keys, certificates, calculating message digests, etc.

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Development Tools and Libraries (cont…)

- MSDN (Microsoft Developer Network):
  - Contains a security library named "System.security.cryptography," which has APIs, source codes, and other programming information related to all the cryptographic algorithms and other security features
  - Available for free download as a package with Microsoft development tools, like Visual Studio
  - Contains different classes that has constructors, methods and properties allowing the complete functionality of a defined module

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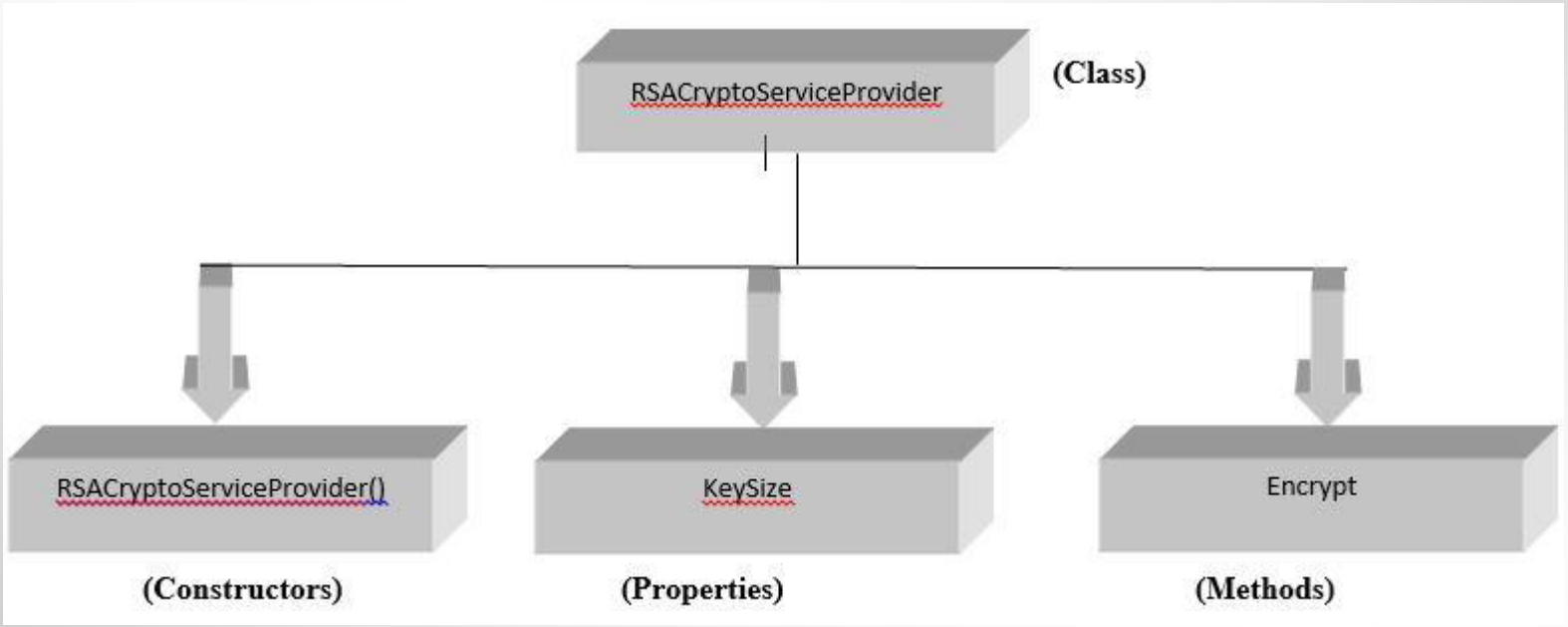
Development Tools and Libraries (cont…)

- Tree structure of MSDN library, which defines its hierarchy:



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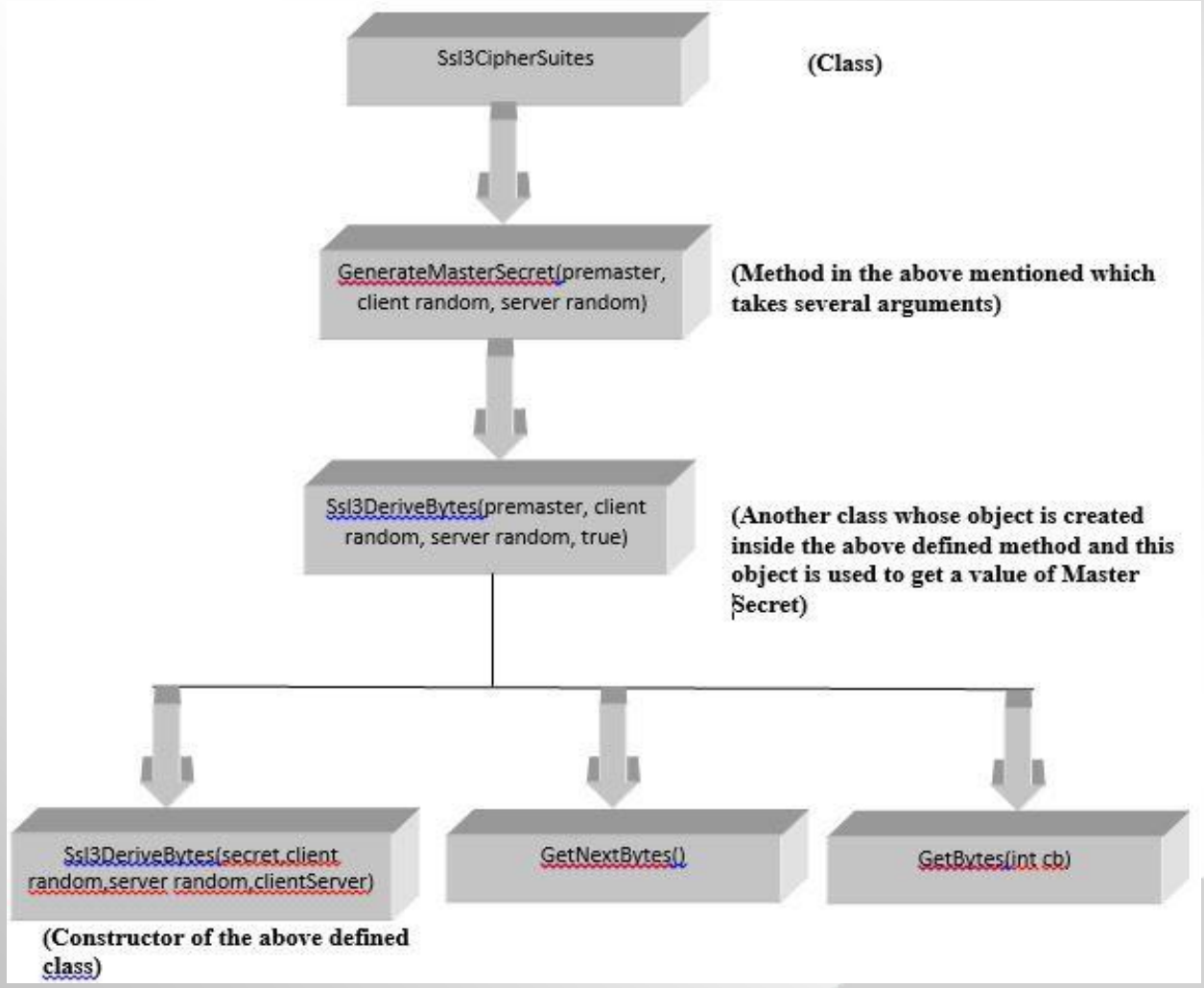
Development Tools and Libraries (cont…)

- Mentalis.org Library
  - Free, open-source library that contains security library called Mentalis.org security library
  - Primary purpose for using this library was that it provided security related functions in C# for .NET development.
  - Supports authentication, cryptography and smartcard framework to connect and communicate with smart cards

Development Tools and Libraries (cont…)

- Library consists of:
  - SecureSocket Library
  - CertificateServices Library
  - Crypto Library

Development Tools and Libraries (cont…)



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Implementation

- Simulation of SSL protocol – the handshake protocol and the record protocol
- Visualization of its working
- Supported algorithms –
  - Public-Key algorithms: RSA, DH
  - Symmetric Key algorithms - DES, 3DES, RC2, AES-128/256
  - Hash Algorithms - MD5, SHA-1/256/384/512

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Demonstration!

Implementation (cont…)

- Use of library function in the developed program

Button	Library used	Underlying Class	Function defined under the class
Certify Server Primary function associated with the button: Certify()	MSDN	RSACryptoServiceProvider RSAParameters	ImportParameters(RSAParameters parameters) ExportParameters(bool IncludePrivateParameters)
Verify Server Certificate Primary Function associated with the button: verifySignature(byte[] signedData, string name)	MSDN	RSACryptoServiceProvider RSAParameters	ImportParameters(RSAParameters parameters) ExportParameters(bool IncludePrivateParameters)

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Implementation (cont…)

Generate Master Secret Primary function associated with the button: **genmastersecret_client_click()**	Mentalis .org	Ssl3CipherSuites	GenerateMasterSecret (byte[] premaster, byte[] clientRandom, byte[] serverRandom)

Limitations and Future Work

- Limitations:
  - Could not directly extend CrypTool 2 because of the code complexity and time constraints

- Library limitations:
  - Several library limitations restrict some major features related to SSL/ TLS
  - AES–GCM mode not included in the MSDN library; thus the cipher suite combination with AES-GCM not supported
  - MSDN library is not implemented taking into account particular SSL/ TLS versions

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Limitations and Future Work

- For symmetric algorithms, RC4 algorithm not included as a part of MSDN
- For asymmetric key algorithms, Diffie-Hellman (not Elliptic Curve Diffie-Hellman) is not included in the MSDN library. Hence it had to be implemented manually

- Conclusions:
  - Successful implementation of the Handshake and Record Layers
  - Use of security libraries and their functions gives built-in functionality to perform required cryptographic operations
  - Better understanding through Simulation
  - Very useful as a learning module and as an educational tool

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Future Work

- Implementing the Alert protocol and the change CipherSpec protocol in order to complete the entire SSL implementation
- Developing a laboratory exercise based on this program
- Inclusion of Man-in-the-middle attack as a part of the implementation
- Use of OpenSSL library might enhance the functionality and add many more features to the program

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Questions

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