Software Interfaces to Cryptographic Algorithms

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Research Group

Based on slides by Frank Piessens

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Overview

- Design Principles
- The native Windows CryptoAPI
  - Cryptography API: Next Generation (CNG)
- The Java Cryptography Architecture and Extensions (JCA/JCE)
- The .NET Cryptographic Library
- The OpenBSD Cryptographic Framework
- Key management issues
- Conclusion

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Crypto Timeline

- 1998: DES brute-forced in 22 hours
- 2000: AES selected as NIST standard
- 2001: RC4 weakness breaks WEP
- 2002: end-of-life of DES (inc. TripleDES), SHA2 introduced
- 2004: MD5, RIPEMD broken
- 2005: SHA1 broken
- 2012: SHA3 introduced

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Design Requirements

- **New algorithms get introduced**
  - The architecture should be extensible
- **Algorithms get broken**
  - Developers should be able to easily replace one algorithm with another

Design Principles

- **Algorithm independence**
  - Engine classes / Factory methods
- **Implementation independence**
  - Provider-based architecture
- **Implementation interoperability**
  - Transparent and opaque data types

Bottom Line: security mechanisms should be easy to change over time

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Opaque vs transparent data

- **Representation of data items like keys, algorithm parameters, initialization vectors:**
  - Opaque: chosen by the implementation object
  - Transparent: chosen by the designer of the cryptographic API
- **Transparent data allow for implementation interoperability**
- **Opaque data allow for efficiency or hardware implementation**

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Crypto frameworks and CSP's

- A ***cryptographic framework*** **defines:**
  - Engine classes (and possibly algorithm classes)
  - Transparent key and parameter classes
  - Interfaces for opaque keys and parameters
- A ***cryptographic service provider*** **defines:**
  - Implementation classes
  - Opaque key and parameter classes
  - Possibly methods to convert between opaque and transparent data

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The Windows CryptoAPI

- Introduced with Windows 95/Windows NT4
- C-based library
- Still used by most Windows programs today

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Cryptographic Service Providers

- **Pluggable libraries**
- **Implement different cryptographic algorithms**
- **Own a key database**
- **Windows and IE ship with a number of CSPs**
  - Depending from version to version and language to language

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Key databases

- **Stores persistent keys**
- **Contains a number of *key containers***
  - Has a unique name
  - One for each user
  - Applications can create new containers
- **Saved in a secure file**
  - With access control
  - Optional *'strong protection'*

Keys

- **Session keys**
  - Used for symmetric encryption
  - Volatile
- **Public/private key pairs**
  - Typically two pairs per user (one for key exchange, one for digital signatures)
- **They are opaque**
  - All you get is an identification number (handle)
  - You can export them, though

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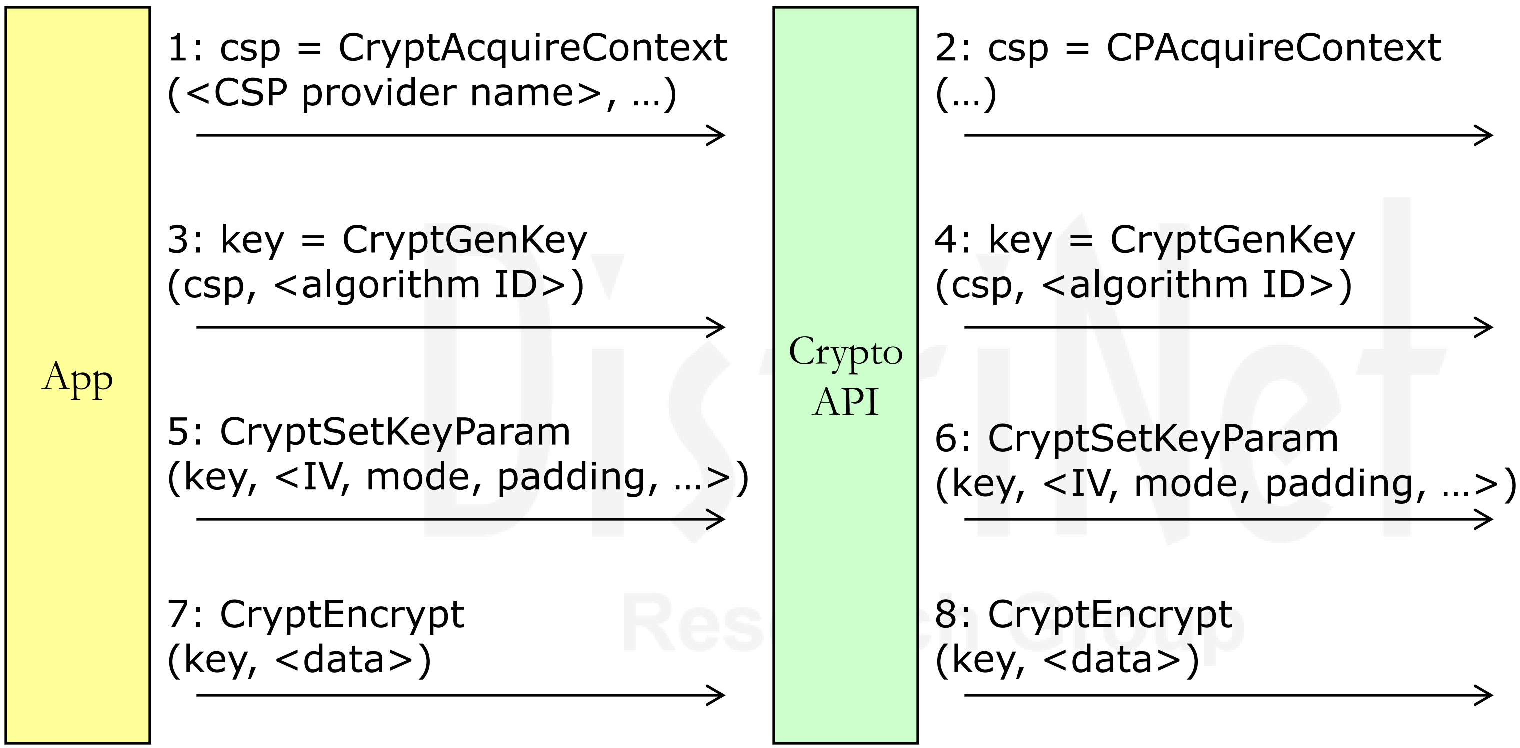
The Windows CryptoAPI

- **Example: encrypt data**



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Additional support for…

- **Cryptographic Message Syntax (CMS)**
- **Public key infrastructure**
- **Smart cards**
- **Authenticode**
- **XML signatures**
  - Windows 7 and higher

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Summary

- **To add an algorithm, a new CSP must be implemented**
  - Not easy
- **Impossible to write algorithm independent code**
  - There is no notion of 'a default algorithm'
  - However, there *are* defaults for implementations
- **A CSP is an island; you cannot modify its behavior**

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Cryptography: Next Generation

- **Introduced with Windows Vista**
- **Aims to replace Windows CryptoAPI**
  - Hence, also a C-based library
- **Has benefits over the CryptoAPI**
  - Easy plug-in creation, better extensibility
  - Crypto isolation
  - Support for algorithmic independence
    - In CMS, SSL/TLS, …, your application

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The JCA/JCE

- **Java Crypto API structured as a cryptographic framework with CSPs**
- **Split in:**
  - The *Java Cryptography Architecure (JCA)*
  - The *Java Cryptography Extensions (JCE)*
- **This split is because of US export-control regulations for cryptography**

Engine classes

- **Abstraction for a cryptographic service**
  - Provide cryptographic operations
  - Generate/supply cryptographic material
  - Generate objects encapsulating cryptographic keys
- **Define the Cryptographic API**
- **Bridge pattern or inheritance hierarchy to allow for implementation independence**
- **Instances created by factory method**

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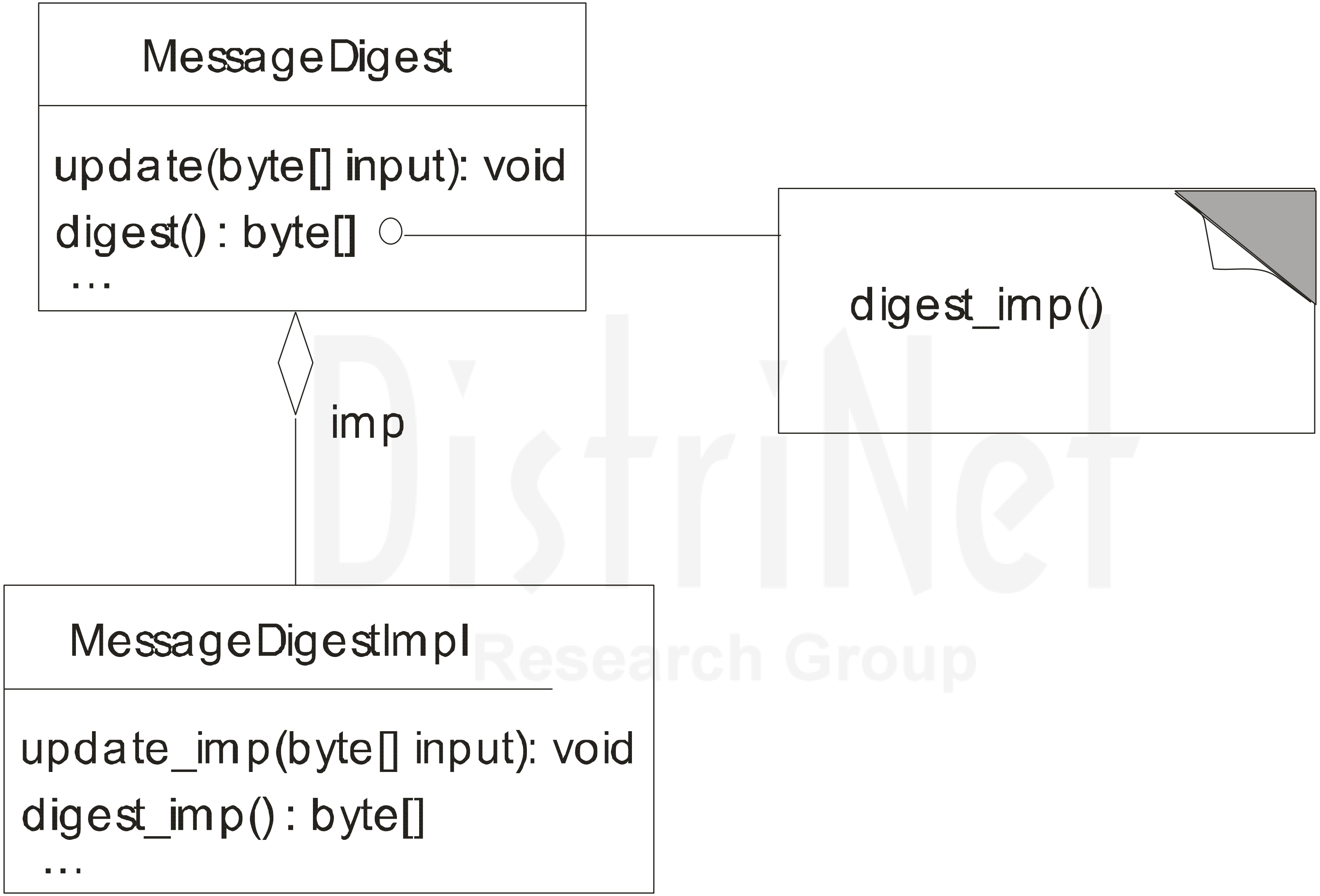
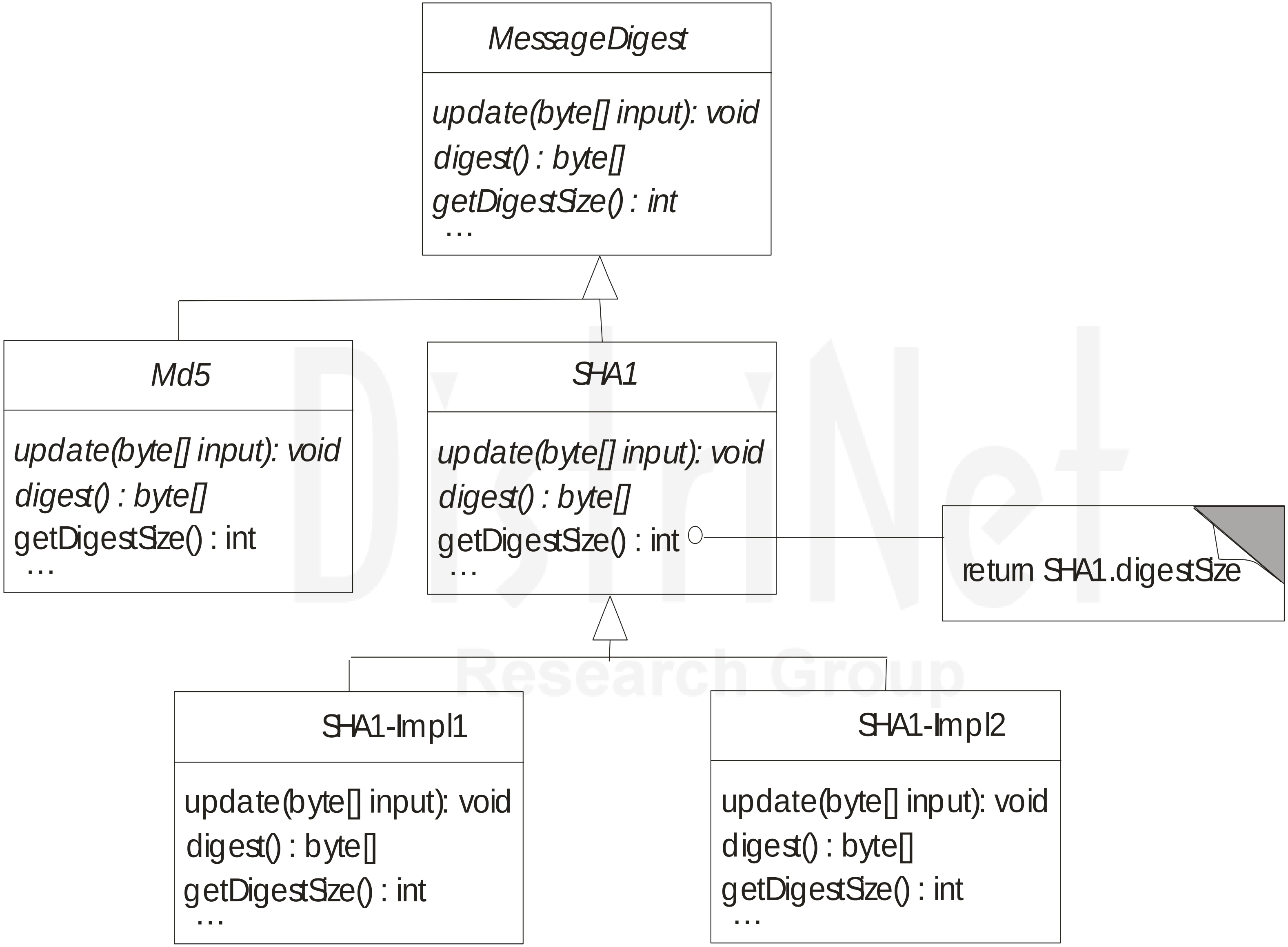
Bridge Pattern



Inheritance-based decoupling



Engine classes (JCA)

java.security.*

- **MessageDigest**
  hash functions
- **Signature**
- **SecureRandom**
- **KeyPairGenerator**
  generate new key pairs
- **KeyFactory**
  convert existing keys
- **CerticateFactory**
  generate certificates from encoded form
- **KeyStore**
  database of keys
- **AlgorithmParameters**
- **AlgorithmParameter-Generator**

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Engine classes (JCE)

javax.crypto.*

- **Cipher**

    encryption, decryption

- **Mac**
- **KeyGenerator**

    generate new symmetric keys

- **SecretKeyFactory**

    convert existing keys

- **KeyAgreement**

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Key classes

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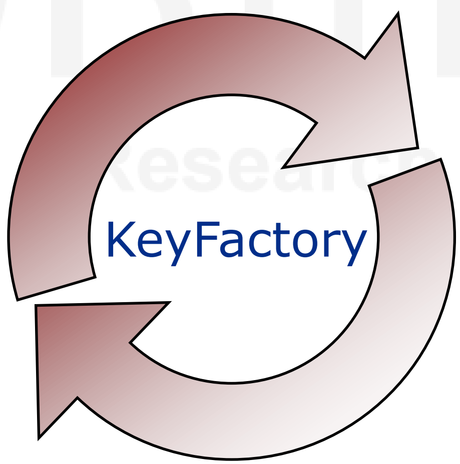
Opaque Representation

- No direct access to key material
- Encoded in provider-specific format
- **java.security.Key**

Transparent Representation

- Access each key material value individually
- Provider-independent format
- **java.security.KeySpec**



y = …
p = …
q = …
g = …

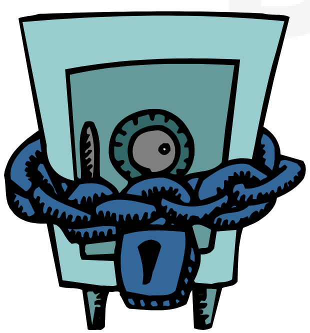
Parameter classes

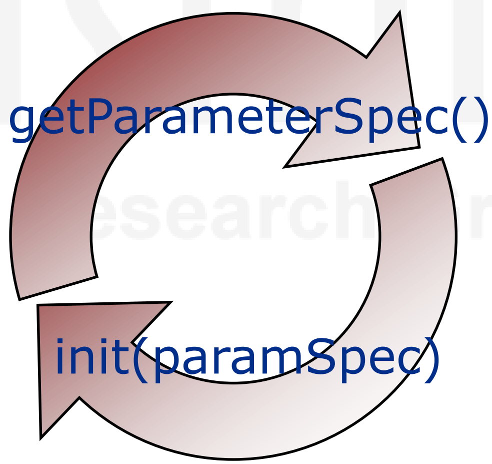
Opaque Representation

- No direct access to parameter fields
- Encoded in provider-specific format
- **AlgorithmParameters**

Transparent Representation

- Access each parameter value individually
- Provider-independent format
- **AlgorithmParameterSpec**





g = …
p = …
q = …

Overall structure of the framework

- Security class encapsulates configuration information (what providers are installed)
- Per provider, an instance of the provider class contains provider specific information (e.g. what algorithms are implemented in what classes)
- Factory method on the engine class interacts with the Security class and provider objects to instantiate a correct implementation object

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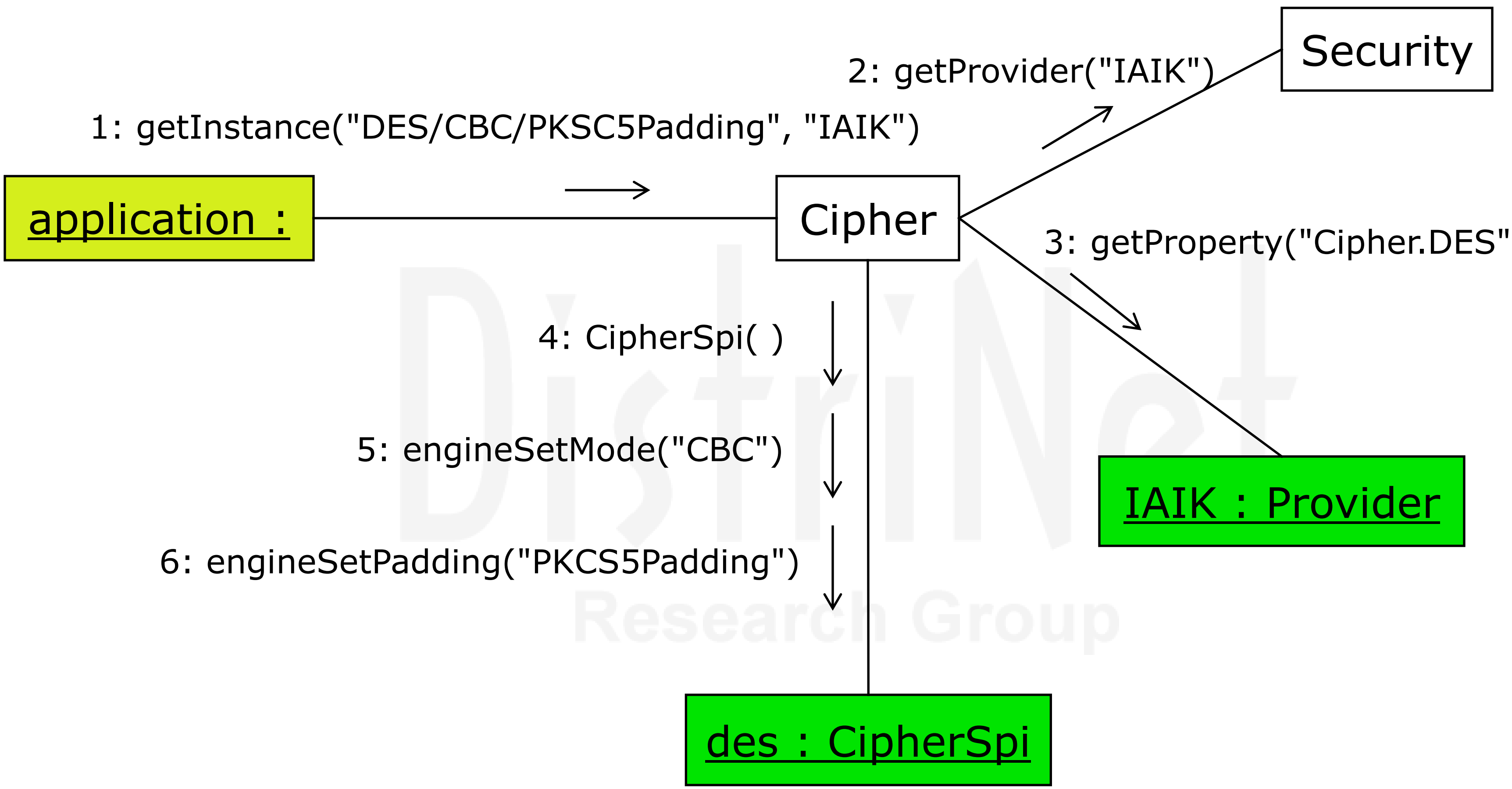
Example: creating ciphers



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Additional support

- **Secure streams**
  - For easy bulk encryption and decryption
- **Signed objects**
  - Integrity checked serialized objects
- **Sealed objects**
  - Confidentiality protected serialized objects
- **Working with certificates**
- **Keystores**

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Summary

- **Very easy integration of new classes**
  - Inherit from the correct class
- **Cryptographic configuration**
  - To set the defaults

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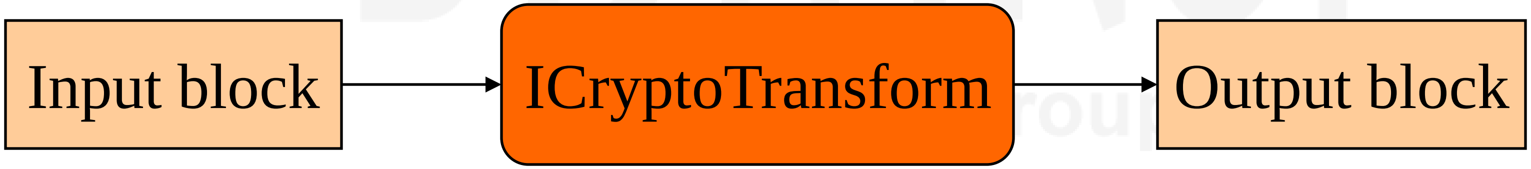
The .NET cryptographic library

- CSP based library that uses inheritance based decoupling
- Bulk data processing algorithms are all made available as ICryptoTransforms
- Essentially 2 methods: TransformBlock() and TransformFinalBlock()



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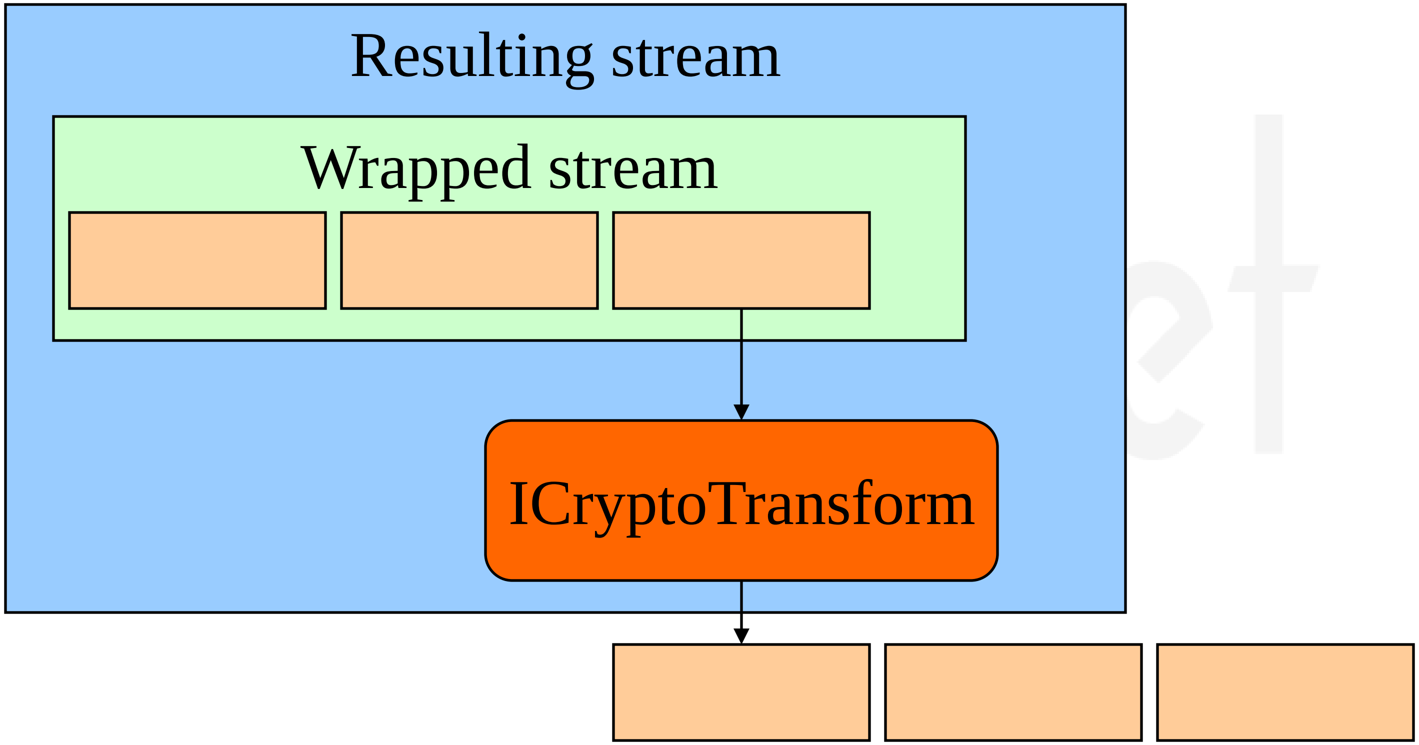
ICryptoTransform and CryptoStream

- ICryptoTransforms can wrap streams
  E.g. (in read mode)



Bulk data engine classes

- **SymmetricAlgorithm, with algorithm classes**
  - TripleDES, DES, Rijndael, …
- **HashAlgorithm, with algorithm classes**
  - SHA1, MD5, …
- **KeyedHashAlgorithm, with algorithm classes**
  - HMACSHA1, MACTripleDES, …

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Asymmetric engine classes

- **Generic AsymmetricAlgorithm engine class**
  - RSA, (EC)DSA and ECDH algorithm classes
- **Specialized engine classes for typical uses of asymmetric cryptography, that take care of padding and formatting**
  - AsymmetricKeyExchangeFormatter
  - AsymmetricSignatureFormatter

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Engine classes for key generation

- **RandomNumberGenerator**
  - For generating secure random numbers
- **DeriveBytes**
  - For deriving key material from passwords

Other functionality…

- **Facilities for interacting with Windows CryptoAPI / CNG**
  - To manage CryptoAPI Key containers manually
  - To call extended functionality in CryptoAPI
- **Configuration mechanism**
  - The factory methods that create engine classes are driven by a configuration file that can be edited to change default algorithms and implementations
- **On top of the .NET crypto API, an implementation of XML Digital Signatures is provided**

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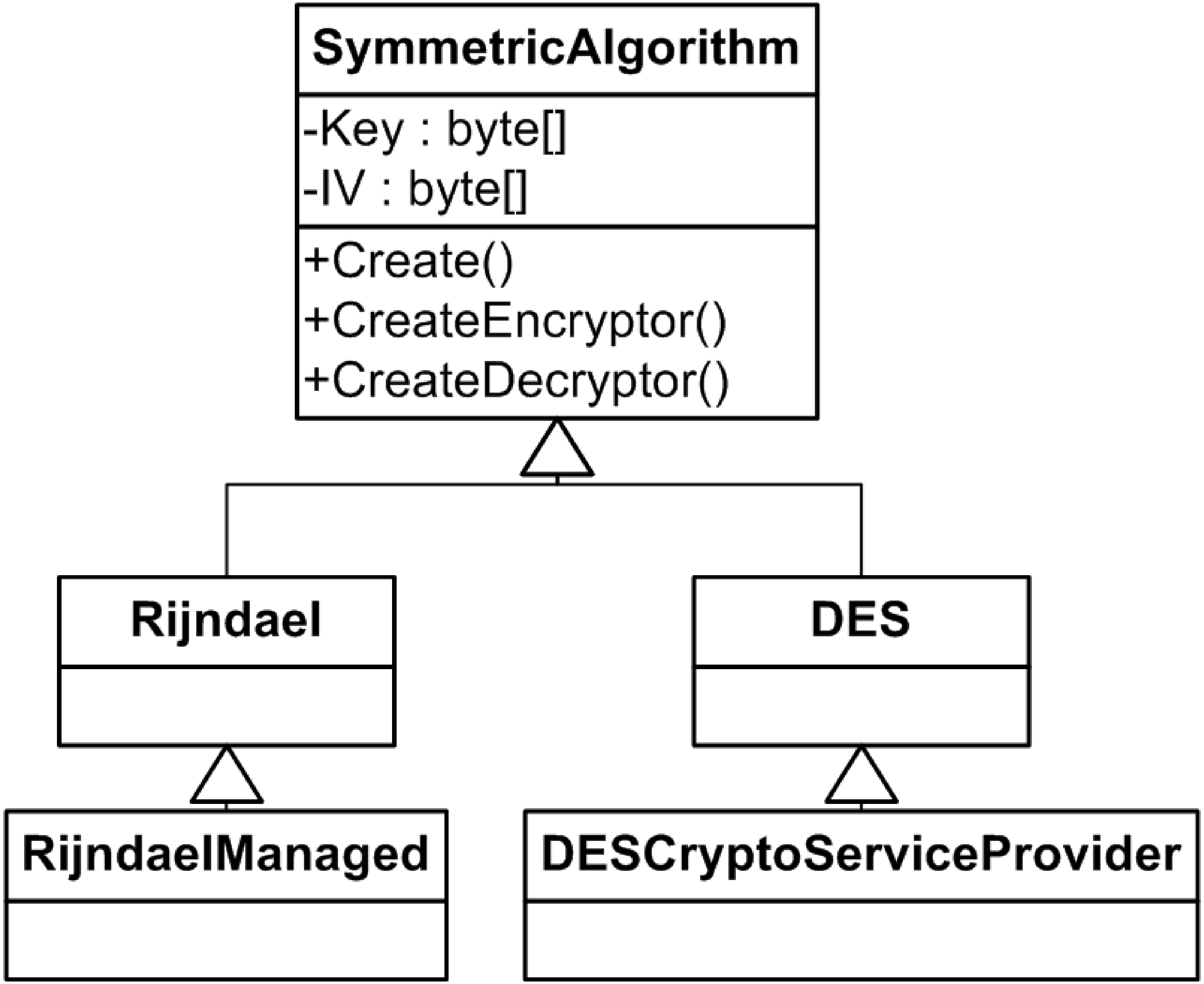
Differences between Java and .NET

- **.NET class structure is much simpler**
  - Hardly support for opaque keys
  - Wrappers around the CryptoAPI
  - Perhaps too simple?

Problems with transparent keys



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Problems with transparent keys

```
SymmetricAlgorithm algo
    = SymmetricAlgorithm.Create();
algo.Key = …                ◄ PROBLEM
algo.IV = …
encryptor = algo.CreateEncryptor();
encryptor.TransformBlock(…);
```


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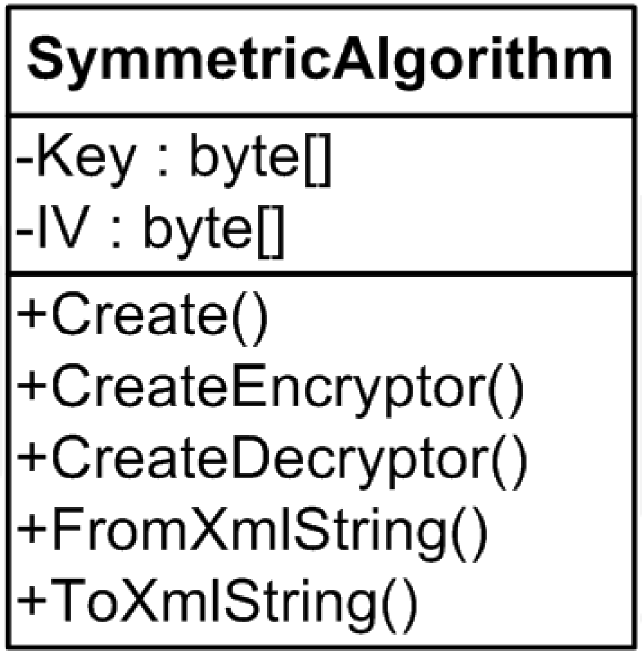
Problems with transparent keys

- **Solution: add opaque key support**



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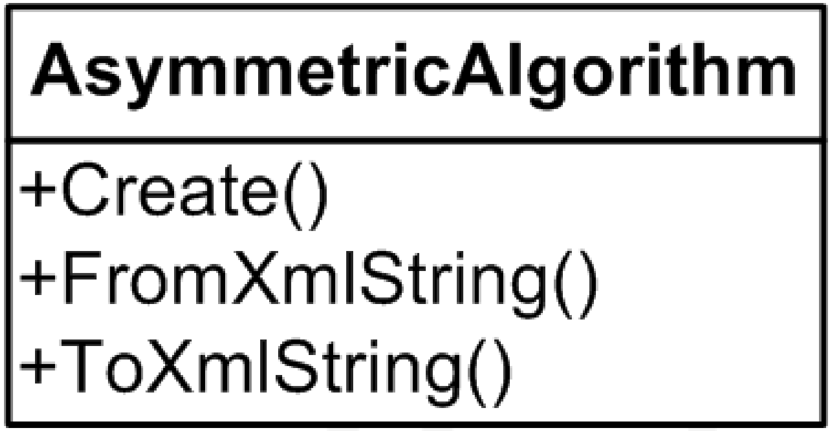
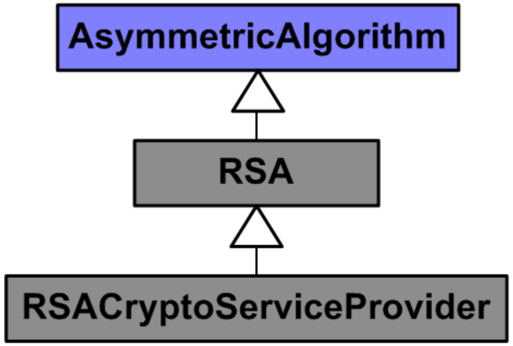
Problems with transparent keys

```
SymmetricAlgorithm algo
    = SymmetricAlgorithm.Create();

algo.FromXmlString(…);

encryptor = algo.CreateEncryptor();

encryptor.TransformBlock(…);
```

Problems with wrapper code





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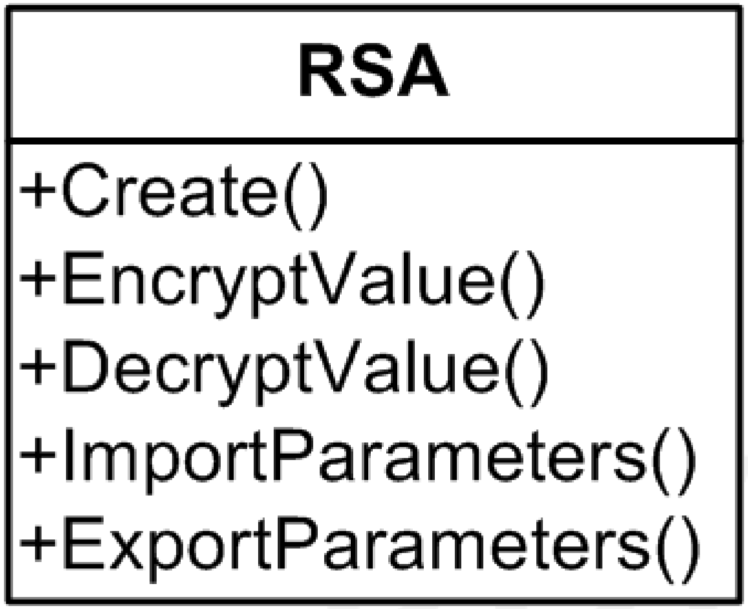
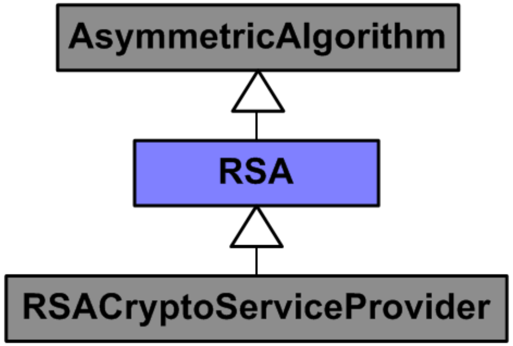
Problems with wrapper code





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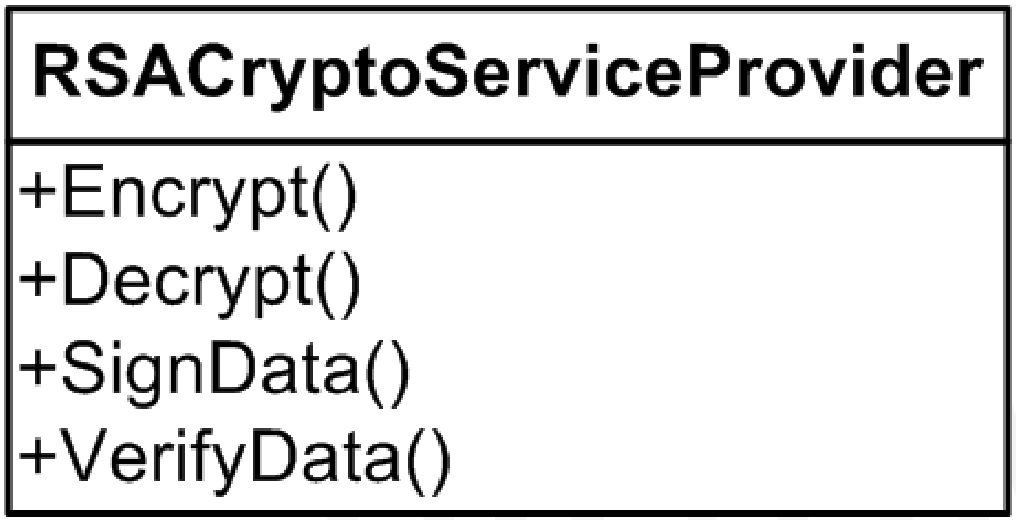

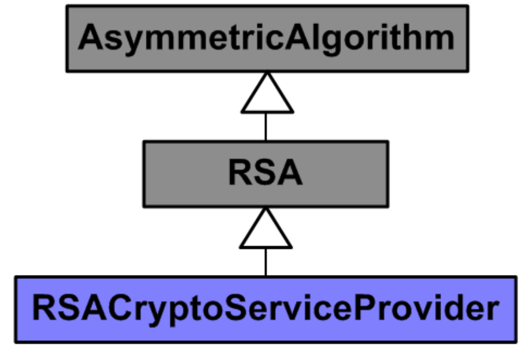

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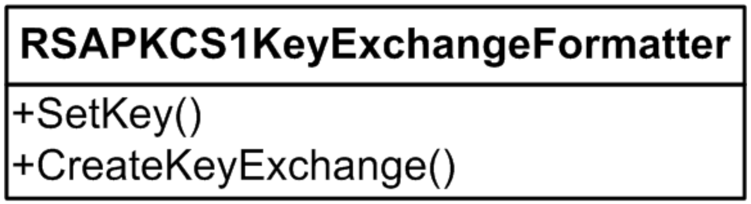

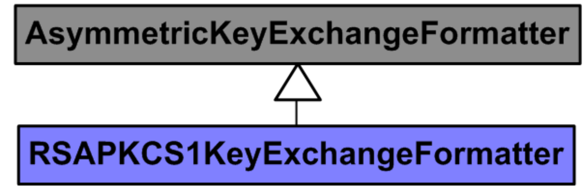

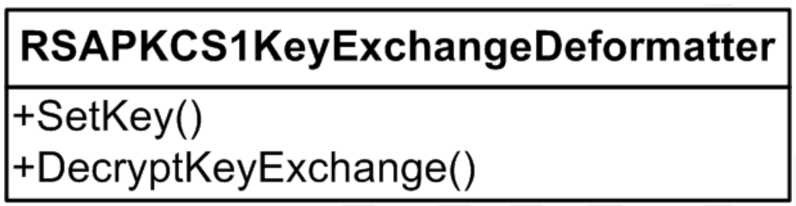

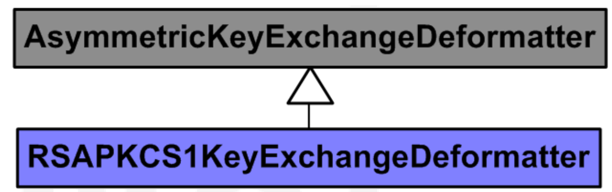

- **RSAOAEPKeyExchangeFormatter/Deformatter**
- **RSAPKCS1SignatureFormatter/Deformatter**
- **DSASignatureFormatter/Deformatter**

Problems with wrapper code

```
public byte[] CreateKeyExchange(...) {

if (rsaKey is RSACryptoServiceProvider) {
  return
   ((RSACryptoServiceProvider)rsaKey).Encrypt(...);
} else {
  <perform padding>
  return rsaKey.EncryptValue(<padded bytes>);
}

}
```


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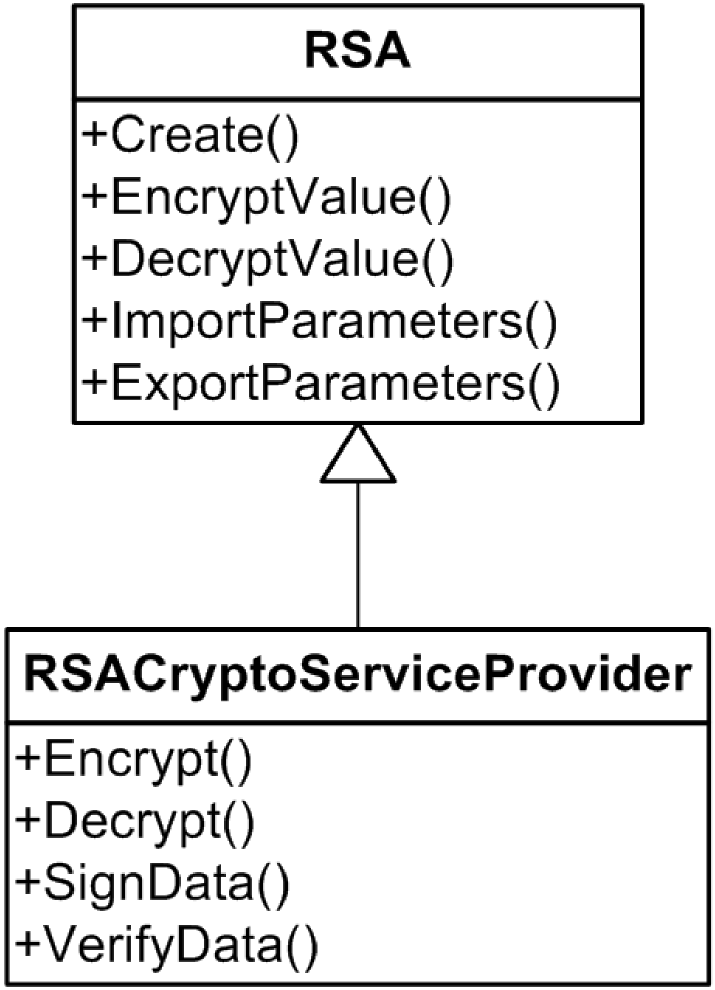
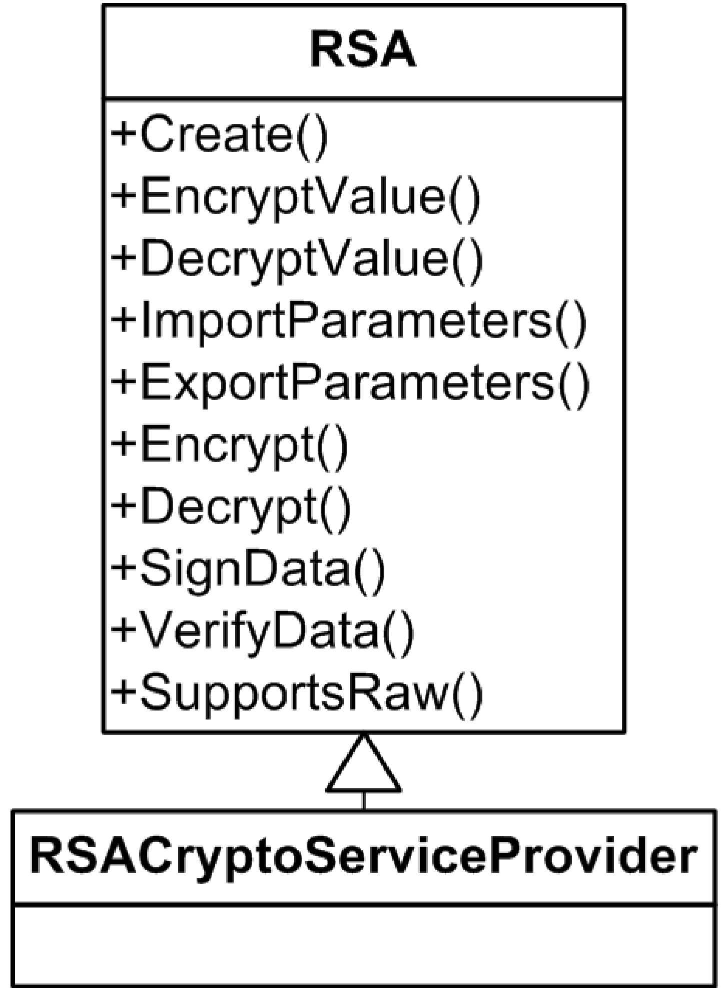
Problems with wrapper code

- **Problem: only RSACryptoServiceProvider gets a ‘special’ treatment**
  - Custom RSA implementations ***must*** support raw RSA

Problems with wrapper code

- **Solution:**





Problems with wrapper code

```
public byte[] CreateKeyExchange(...) {

if ( ! rsaKey.SupportsRaw) {
  return rsaKey.Encrypt(...);
} else {
  <perform padding>
  return rsaKey.EncryptValue(<padded bytes>);
}

}
```

Summary

- Extensible class hierarchy
- Cryptographic configuration support
- Some small issues
  - Can be resolved with some minor tweaks

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OpenBSD

- **NetBSD spin-off**
- **Focues on security**
  - Cryptography is the cornerstone of the system
  - Defensive programming
    - Periodically go through source

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The OpenBSD Crypto Framework

- **OpenBSD Cryptographic Framework (OCF)**
  - “Asynchronous service virtualization layer”
  - Resides in kernel
  - Offers uniform access to crypto hardware
  - Used by
    - Producers (crypto hardware)
    - Consumers (other kernel modules)

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The OpenBSD Crypto Framework

- **Two modi operandi**
  - Session-based
    - Symmetric crypto, hasing
    - Session caching features
  - Individual operations
    - Asymmetric crypto

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The OpenBSD Crypto Framework

- **Producers**
  - Are drivers
  - Registers with OCF
    - Supported algorithms
    - Other capabilities (chaining, RNG, …)
  - One pseudo-driver
    - Software crypto

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The OpenBSD Crypto Framework

- **Consumers**
  - Other modules in kernel (e.g. IPSec)
  - Send asynchronous requests to the OCF
    - Get notified when the work is complete
    - Synchronous requests not supported

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The OpenBSD Crypto Framework

- **A consumer doesn’t know which producer it’s talking to**
  - The OCF takes care of this automatically
  - Enables load-balancing
  - Enables session-migration
    - When hardware is added/removed (i.e. PCMCIA card)
    - On-demand
  - Important difference between OCF and Java/.NET/CryptoAPI

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The OpenBSD Crypto Framework

- **This is a kernel framework**
- **User-level support is added through the /dev/crypto interface**
  - Synchronous!
  - Based on ioctl() calls
  - Not very user friendly
  - Frameworks like OpenSSL offer abstractions over /dev/crypto

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Summary

- Extensible (through device drivers)
- Crypto configuration is done by the framework behind the scenes
  - Applications do not see the different ‘CSPs’

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Key management issues

- Generating keys
- Key length
- Storing keys
- Key establishment
- Key renewal
- Key disposal

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Generating keys

- **Algorithm security = key secrecy**
- **Key should be hard or impossible to guess**
  - Human password → dictionary attack!
  - Better: hash of entire pass-phrase
  - Machine-generated → use cryptographically secure pseudo-random generator

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Key length

- **Trade-off: information value ↔ cracking cost**
- **Symmetric algorithms**
  - $1 000 000 investment in VLSI-implementation

56 bits	64 bits	128 bits
1 hour	10 days	10^{17} years

- **RSA**

Year	*vs. Individual*	*vs. Corporation*	*vs. Government*
2000	1024	1280	1536
2005	1280	1536	2048
2010	1280	1536	2048

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Storing keys

- **Simplest: human memory**
  - Remember key itself
  - Key generated from pass-phrase
- **Use Operating System access control**
- **Key embedded in chip on smart card**
- **Storage in encrypted form**
  - *Key encryption* keys ↔ *data encryption* keys
- **Limit key lifetime depending on**
  - Value of the data
  - Amount of encrypted data

Key establishment

- **Key agreement = Two parties compute a secret key together**
  - E.g. Diffie – Hellman protocol
- **Key distribution or transport = One party generates a key and distributes it in a secure way to all authorized parties**

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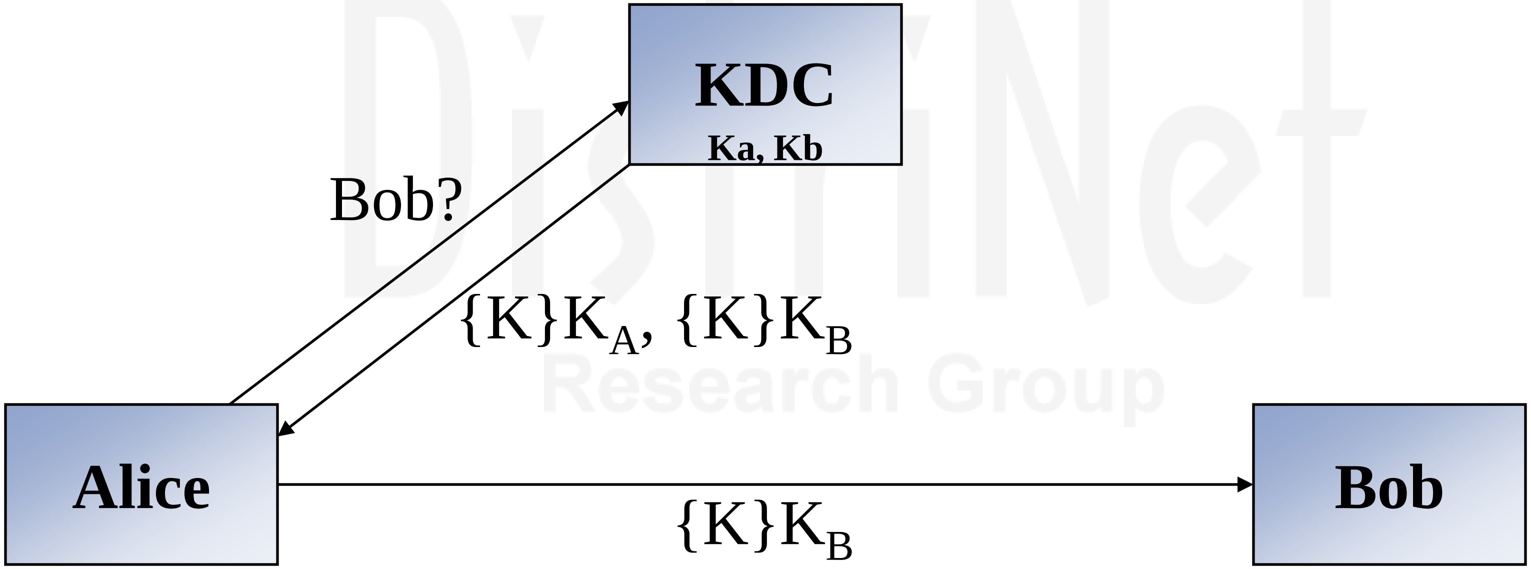
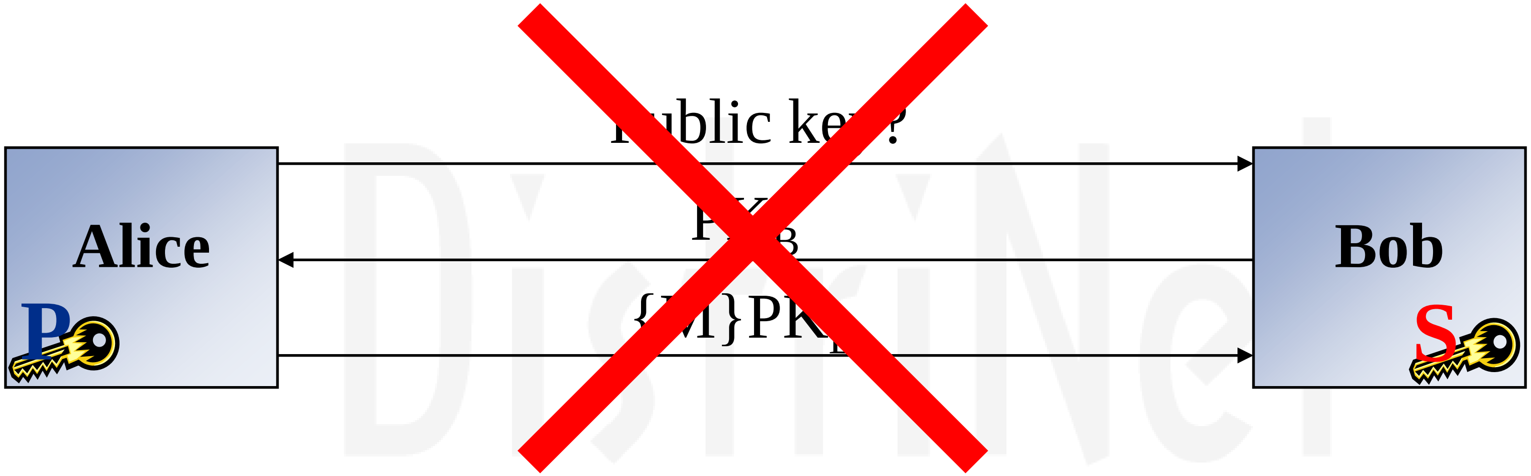
Key distribution

- **Using symmetric encryption**
  - Trusted party: Key Distribution Center (KDC)
  - General idea (oversimplified:)



Key distribution

- **Using public-key encryption**
  - No need for KDC?



– Man-in-the-middle attack!

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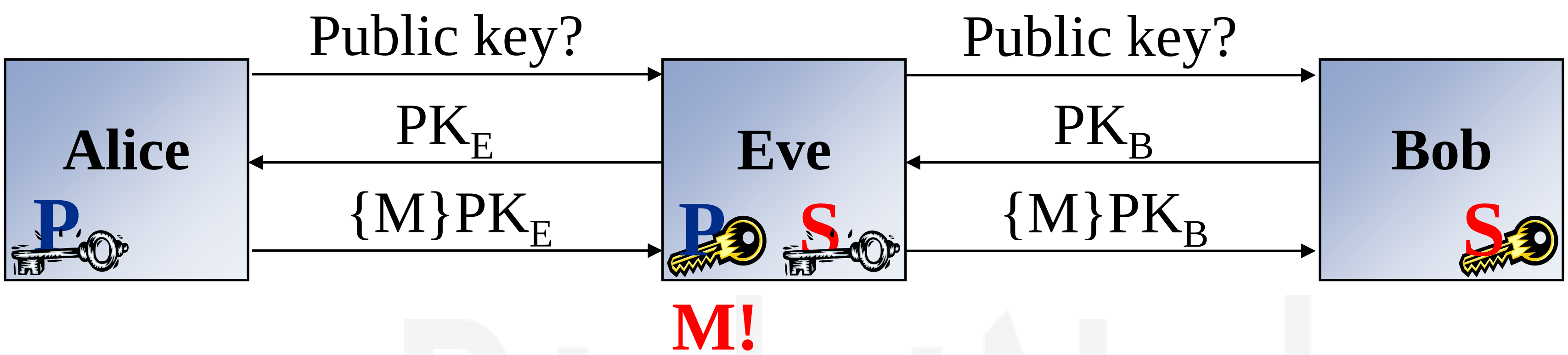

- **How can Alice be sure she got Bob’s public key?**
  - Solution: Certificates

    Public Key Infrastructure (PKI)
  - Discussed later

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Key renewal

- **Best practice:**
  - Limit the amount of data encrypted with a single key
  - Limit the amount of time a key is in use
- **Hence:**
  - Need for mechanisms to renew keys

Key disposal

- **Once a key is no longer used, what should happen?**
  - Short-term keys:
    - Dispose in a secure way
  - Long-term keys:
    - Encryption:
      - Re-encrypt old data, or store key securely
    - Signing
      - Signing key should be disposed of securely
      - Verification key should be stored securely

Summary

- **Good key management is essential to achieve any security from cryptography**
- **Inappropriate**
  - Key generation
  - Key storage
  - Or key establishment

is often the cause of security breaches

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Overview

- Design Principles
- The native Windows CryptoAPI
  - Cryptography API: Next Generation (CNG)
- The Java Cryptography Architecture and Extensions (JCA/JCE)
- The .NET Cryptographic Library
- The OpenBSD Cryptographic Framework
- Key management issues
- Conclusion

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Conclusion

- **Cryptographic primitives offer well-defined but complex security guarantees**
  - Precisely saying what security a crypto primitive offers is non-trivial
- **As a consequence, cryptographic primitives are hard to use correctly**
  - Mainstream developers should typically **not** use them
  - Use API to higher-level protocols instead

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