Analyzing (Java) Source Code for Cryptographic Weaknesses

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Obligatory “It's all about me” page

- 35+ years developer experience, 15+ yrs security experience
  - 17 yrs at (now Alcatel-Lucent) Bell Labs; left as DMTS
  - 3.5 yrs as independent contractor (C++ & Java)
  - 14 years AppSec & InfoSec experience at CenturyLink / Qwest
- Currently: Information Security Engineer at Wells Fargo on Secure Code Review team
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How I remain calm while public speaking

Geeks, in their “encrypted” underwear

(because you *never* want to seek geeks in their ***real*** underwear!)

What I will cover

- Basic crypto rules of thumb
- Weaknesses in using the following:
  - Pseudo random number generators
  - Secure hashes
  - Symmetric encryption
  - Asymmetric cryptography
    - Encryption
    - Digital signatures
- A more complete data flow analysis
- Various crypto gotchas

Major rules of thumb

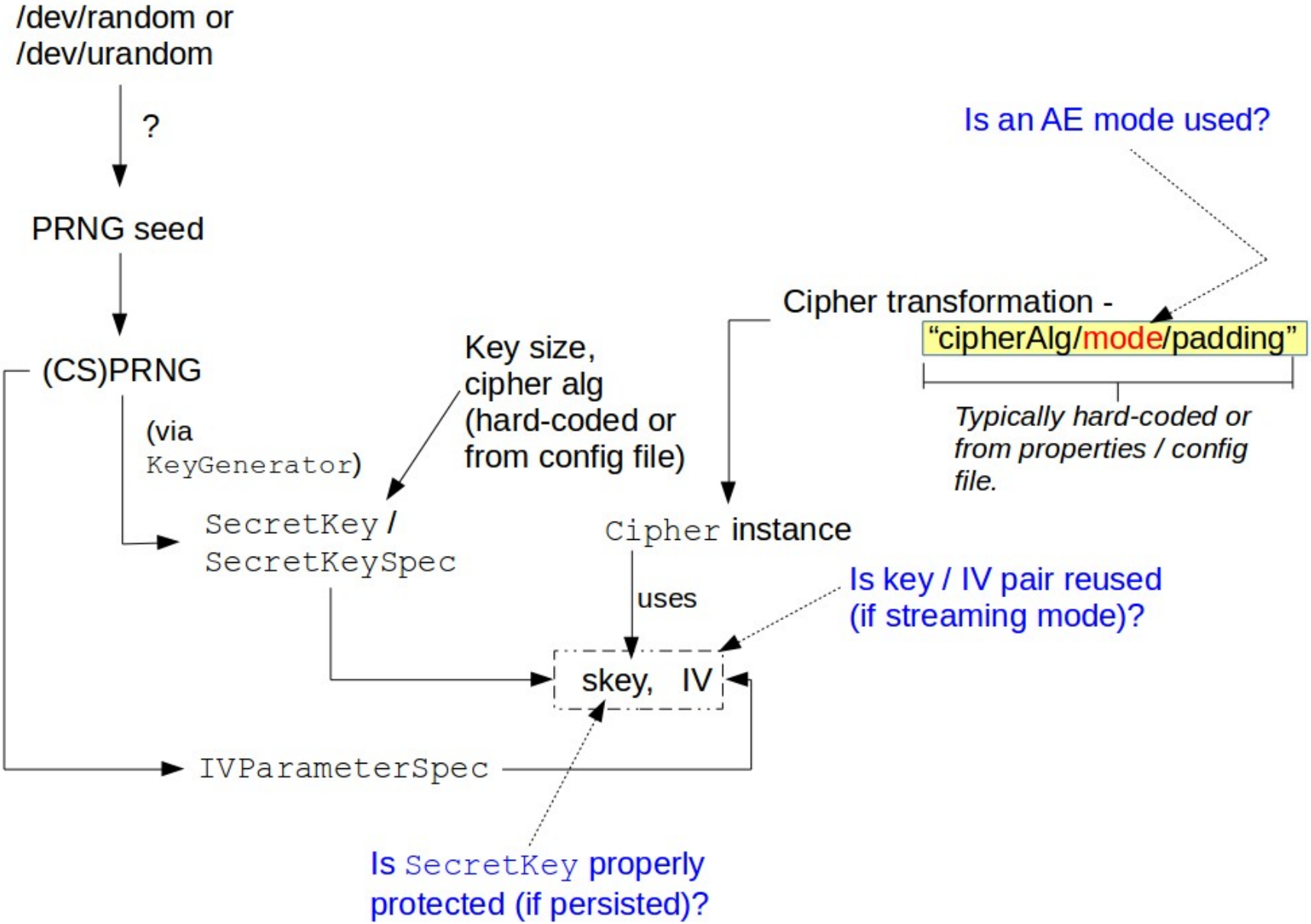
- Do not design your own cryptographic algorithms…***ever*** (unless you are a professional cryptographer)
  - You will get it wrong
  - Without expert peer review it likely will still be wrong
- Do not even *implement* your own cryptographic algorithms
  - Do you know what test vectors are?
  - Do you know what side-channel attacks are?
- Avoid shiny!
  - Algorithms usually take a few years of peer review to mature.
- But don’t get trapped by obsolete technology
  - Especially a concern for embedded software
- Beware providing too many options
- Schneier and Wagner’s “Horton Principle” (covered with authenticated encryption)

A simple example

```
public SecretKey generateKey(String alg, int keySizeInBits, SecureRandom prng) {
  KeyGenerator keyGen = KeyGenerator.getInstance(alg);
  keyGen.init(keySizeInBits, prng);
  return keyGen.generateKey();
}

public byte[] encrypt(SecretKey key, String plain) throws EncryptionException
{
  byte[] plaintext = plain.getBytes("UTF8");
  int keySize = key.getEncoded().length * 8;    // Convert to # bits
  SecretKeySpec encKey = new SecretKeySpec(key, "AES");     // Correct?
  Cipher cipher = Cipher.getInstance("AES/CBC/PKCS5Padding");
  IvParameterSpec ivSpec =
                new IvParameterSpec( prng.nextBytes( cipher.getBlockSize() );
  cipher.init(Cipher.ENCRYPT_MODE, encKey, ivSpec /* , prng */);
  byte[] raw = cipher.doFinal(plaintext.getBytes("UTF8"));
  return bitStringConcat(iv, raw);
}
```

Data Flow for Symmetric Encryption (Java)



Pseudo Random Number Generators (PRNG)

PRNG Weaknesses

- Having a good source of (pseudo) randomness is essential to good cryptography.
  - Poor randomness ==> broken crypto
  - Cryptographers demand a "cryptographically secure" PRNG (CSRNG)
    - java.util.Random is *not* a CSRNG
    - java.security.SecureRandom is a CSRNG
  - CSRNG must have unpredictable seed
    - Seed entropy must equal (and should exceed) the internal state of the CSRNG

PRNG Weaknesses: What to look for

- Using java.util.Random for *anything* related to crypto—this would include keys, IVs, nonces, etc.
- Seeding any CSRNG with insufficient entropy
  - If you initially require N-bits of randomness, then the entropy pool should have *at least* N-bits of randomness.
  - Generally not a problem with the default Oracle/Sun implementation of SecureRandom and SHA1PRNG.
    - Default SecurRandom CTOR uses /dev/urandom when available ***BUT*** may a problem if lots of randomness is required at boot time or if no /dev/urandom or /dev/random

Example of correct use / seeding of SecureRandom

```
SecureRandom csrng =
    SecureRandom.getInstance("SHA1PRNG",
                                        "BC");
csrng.setSeed(
                  csrng.generateSeed(  160/8 )
                );
```

For JDK 8 and later, consider using
    SecureRandom.getInstanceStrong()
instead of SecureRandom.getInstance().

Secure Cryptographic Hashing

Secure Hashes: Required properties

To be cryptographically useful, a hash function must have the following 3 properties:

- One-way function (AKA, pre-image resistance)
- Weak collision resistance (AKA, 2nd pre-image resistance)
- Strong collision resistance (AKA, collision resistance)

Secure Hashes: Pre-image Resistance

- For essentially all pre-specified outputs, it is *computationally infeasible* to find any input (i.e., the pre-image) that hashes to that output.

That is:

- For a given hash function H(x) and some output y such that y = H(x), it is *computationally infeasible* to find any input (pre-image) x.

Secure Hashes: Weak Collision Resistance

- It is *computationally infeasible* to find a second input that has the same output as any specified input.

That is:

- Given input x, it is *computationally infeasible* to find an x’ != x such that H(x) = H(x’).

Secure Hashes: Strong Collision Resistance

- It is *computationally infeasible* to find any two distinct inputs x and x’ that hash to the same output.
- That is:
  It’s *computationally infeasible* to find any x and x’ such that H(x) = H(x’).
  - Note: Unlike weak collision resistance, here there is a free choice of an adversary selecting *both* inputs.

Secure Hashing Weaknesses

- Recall the “computationally infeasible” in the preceding slides.
- Some algorithms are “broken”.
  - What does that mean?
    - *Any* of these 3 conditions are violated in a work factor better than a brute-force attack. Usually *only* focuses on [strong] collision resistance.
  - Degrees of brokenness
    - If a hash is n-bits, the best *theoretical brute-force* collision attack is $O(2^{n/2})$ (i.e., the “birthday attack”). If collisions can be found in less effort than this, the algorithm is technically considered “broken” even though the attack (currently) may be completely impractical .

Secure Hashing Weaknesses: What to look for (1/4)

- Use of completely broken algorithms: MD2, MD4, MD5 or algorithms that are not true message digests such as CRCs.
- Use of mostly broken algorithms: SHA1 (may be okay for legacy use for backward compatibility).

Secure Hashing Weaknesses: What to look for (1/3)

- If concerned about *local* attacks...
  - Time-dependent comparison of hashes
    - E.g., Bad: String.equals() or Arrays.equals()
    - MessageDigest.isEqual() is okay *after* JDK 1.6.0_17
- Calling MessageDigest.digest(byte[]) or update(byte[]) methods on unbounded input under adversary's control. (DoS attack)

Secure Hashing Weaknesses: What to look for (3/4)

- Misusing secure hash for message authentication codes (MAC):
  - MAC is a *keyed* hash, where the key is a secret key generally shared out-of-band.
  - Incorrect, naïve use:

MAC(key, message) := H(key || message)

Where '||' is bitwise concatenation.

Problem: Susceptible to "length extension attacks".

  - Correct use: Use an HMAC.

Secure Hashing Weaknesses: What to look for (4/4)

- Misusing a secure hash to mask data where enumeration of all or most of the input space is feasible.
  - E.g., Use SHA-256(SSN) to store as key in database or to track in log file.
  - Problem: If adversary can observe hashes, she can enumerate SHA-256 hashes of all possible SSNs and compare these to stored hashes.

Is use of MD5 *ever* okay?

- Best collision attack against it is now about $O(2^{24.1})$, which takes at most 5 or 6 seconds on a modern PC.
- But…okay in following cases:
  - Used as a PRNG when we only need something that is more or less unique and unpredictable; example IV generation used with CBC for symmetric ciphers.
  - Used as an HMAC construct as defined in RFC 2104
    - Bellare, Canetti & Krawczyk (1996): Proved HMAC security doesn’t require that the underlying hash function be collision resistant, but only that it acts as a pseudo-random function.

Symmetric Encryption

Symmetric Encryption Weaknesses

- Inappropriate cipher algorithms
  - You aren't still using RC4, are you?
- Insufficient key size: >= 128 bits
  - Java: DESede defaults to 2-key TDES (112-bit) unless the JCE Unlimited Strength Jurisdiction Policy files are installed.
- "ASCII" generated keys
- Failure to apply proper padding.
- Inappropriate use of cipher modes
  - Related: IV abuses
- Assuming confidentiality implies data integrity.

ASCII Keys

- Keys generated from passwords or passphrases. E.g.,

```
String key = "#s0meSeCR3tK3y!!"; // Or from prop
SecretKeySpec skey =
    new SecretKeySpec( key.getBytes(), "AES");
Cipher cipher =
   Cipher.getInstance("AES/CBC/PKCS5Padding");
cipher.init(Cipher.ENCRYPT_MODE, skey);
...
```

Inappropriate cipher algorithms

- Check your corporate InfoSec policies
- Stick with NIST approved algorithms:
  - FIPS 140-2 Annex A: http://csrc.nist.gov/publications/fips/fips140-2/fips1402annexa.pdf
- Quick spot check: symmetric cipher that is not AES (or maybe TDES for legacy applications) should be considered potentially suspect.

Failure to apply proper padding

- What is padding and why is it needed?
- What happens if padding is omitted?
- Popular padding schemes

What is padding and why is it needed? (1/2)

- Why is padding needed?
  - Because some cipher modes (notably ECB and CBC) are “block mode” operations and can only operate on a *full* cipher block at a time.
- What is padding?
  - It’s additional data added ([almost?] always appended) to the *plaintext* before encryption and removed immediately after decryption.

What is padding and why is it needed? (2/2)

- When padding is specified it is *always* applied.
- Padding increases overhead of ciphertext by 1 cipher block size (which is significant when encrypting short plaintext messages).

What happens if padding is omitted?

- That’s the $64,000 question.
- The answer seems to be implementation specific. Possible approaches:
  - Refuse to encrypt plaintext not an integral multiple of the cipher’s block size (this is the JCE approach in Java, where an IllegalBlockSizeException will be thrown).
  - Silently do some kludgy internal implementation-specific padding .
  - Silently truncate excessive plaintext and do not encrypt it, but leave it just as plaintext.

Popular padding schemes

- For symmetric ciphers:
  - PKCS#7 & PKCS#5 (.NET uses PKCS7, Java uses PKCS5; *technically* PKCS5 is only defined for ciphers whose block size is 64 bits so Java is wrong!)
  - ISO 10126 (used in W3C's XML Encryption)
- For asymmetric ciphers:
  - PKCS#1 padding
  - OAEP (Optimal Asymmetric Encryption Padding)
    - In Java: OAEPWith<digest>AndMGF1Padding, where <digest> is MD5, SHA-1, SHA-256.
- NoPadding is appropriate for streaming modes.

Inappropriate use of cipher modes

Question: `Cipher.getInstance("AES")` … what's the default cipher mode?

- Block modes and stream modes
  - Block modes: ECB and CBC
  - Stream modes: pretty much everything else
- All modes except for ECB require an IV.
- Streaming modes: Must not reuse the same key / IV pair… ***EVER***!
- Streaming modes do not require padding.

Key / IV reuse in streaming mode (1/9)

- Stream ciphers and block ciphers operating in streaming modes create a cipher bit stream that is XOR'd with the plaintext stream.
- For a given key / IV pair, the same cipher bit stream is generated each time. Let's call this cipher bit stream, C(K, IV).
- Let the encryption function for such a streaming mode be designated as E(K, IV, msg).
  - Then E(K, IV, msg) = msg XOR C(K, IV)

Key / IV reuse in streaming mode (2/9)

- Let's see what happens if we encrypt 2 different plaintext messages, A and B, this way

  E(K, IV, A) = A XOR C(K, IV)
  E(K, IV, B) = B XOR C(K, IV)

- If an adversary intercepted both of these ciphertext results, they can compute the XOR of them, which is

  E(K, IV, A) XOR E(K, IV, B) =
  A XOR C(K, IV) XOR B XOR C(K, IV)

which, since XOR is commutative, is:

A XOR B XOR C(K, IV) XOR C(K, IV) = A XOR B

That is, the XOR of the 2 plaintext messages, A and B.

Key / IV reuse in streaming mode (3/9)

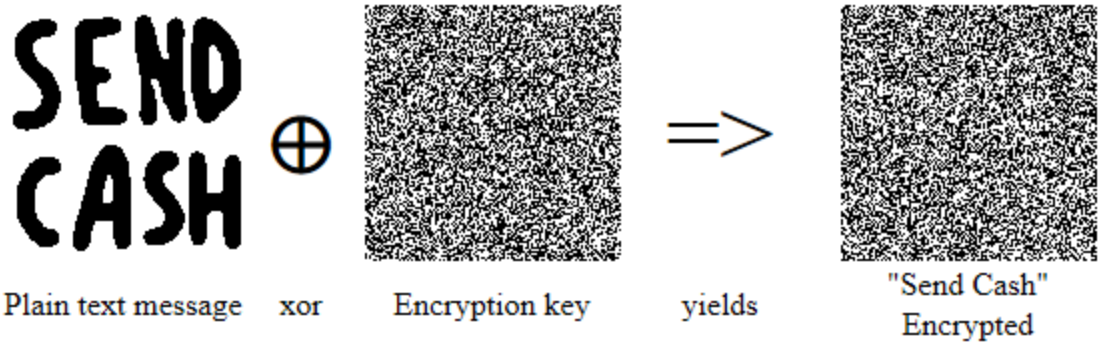
- So what do we do with the XOR of 2 plaintext messages, A and B?
- If messages A and B are both written in some normal language (or character set, like ASCII), we can make that as a guess and use frequency distribution of some anticipated language (or format, such as CC#s, etc.) and guess likely plaintext bits (characters). If the result resembles something intelligible (e.g., ASCII letter), guess was probably right.
- Modest computers can crack this in matter of few minutes for modest length messages.

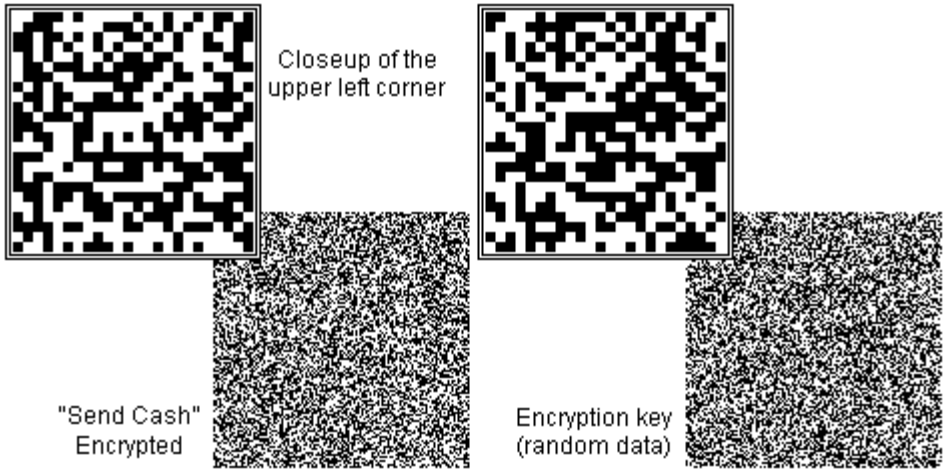
Key / IV reuse in streaming mode (4/9)

- The more ciphertexts created using the same key / IV pair and observed by an adversary, the better.
- Fixed message formats / structures (e.g., knowing you have all numeric fields such as SSN or credit card #) make it even more trivial.
- Eventually, both plaintexts (or shortest part if different lengths) get revealed.

Key / IV reuse in streaming mode (5/9)

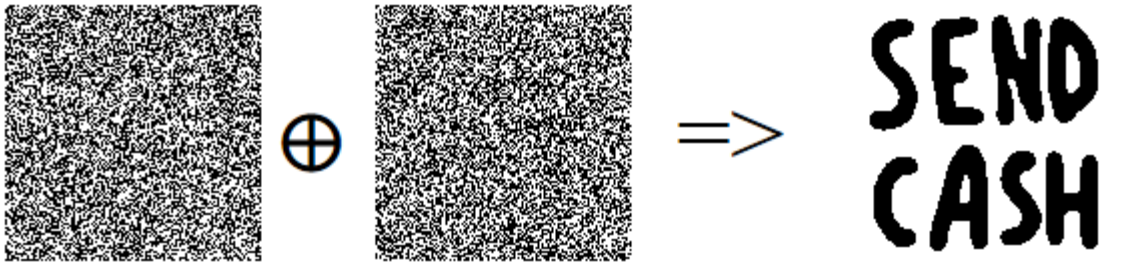
Next 4 slides from Dr. Rick Smith, Univ of St. Thomas, MN
http://courseweb.stthomas.edu/resmith/c/csec/streamattack.html





Key / IV reuse in streaming mode (6/9)

- To recover the original message (image), we XOR the encrypted “Send Cash” image with the encryption key again:

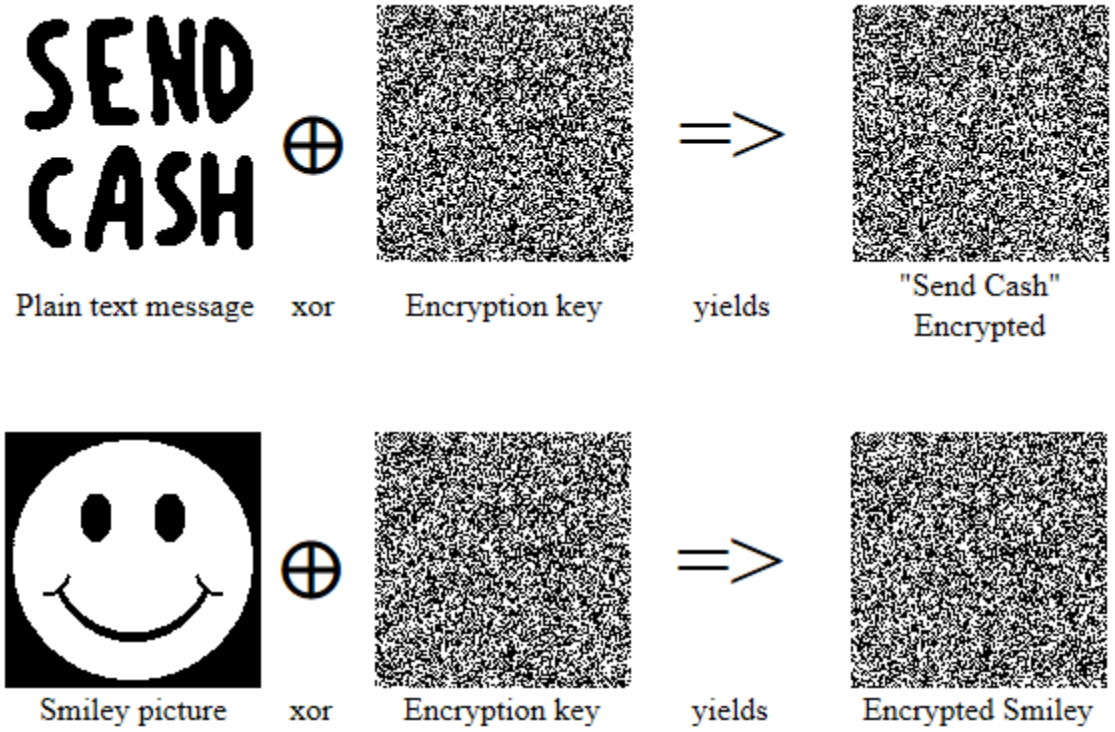


“Send Cash” encrypted

Encryption key

“Send Cash” Plaintext image

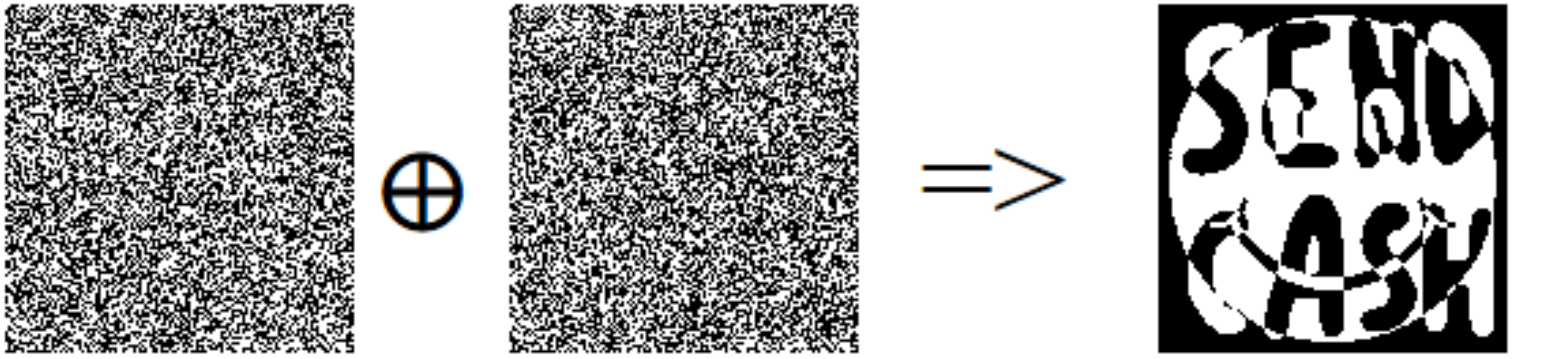
Key / IV reuse in streaming mode (7/9)



Note that we have the ***same*** encryption key XOR'ing both images.

Key / IV reuse in streaming mode (8/9)

Here’s what happens when we XOR the 2 images that both used the same encryption key together:



Key / IV reuse in streaming mode (9/9)

- *But wait!* It gets worse. It an application is doing this and an adversary can decrypt a message, they may be able to use a MITM attack to actually *alter* the ciphertext.
- Wikipedia example (Stream_cipher_attack):

(C(K) xor "$1000.00") xor ("$1000.00" xor "$9500.00") = C(K) xor "$1000.00" xor "$1000.00" xor "$9500.00" = C(K) xor "$9500.00"

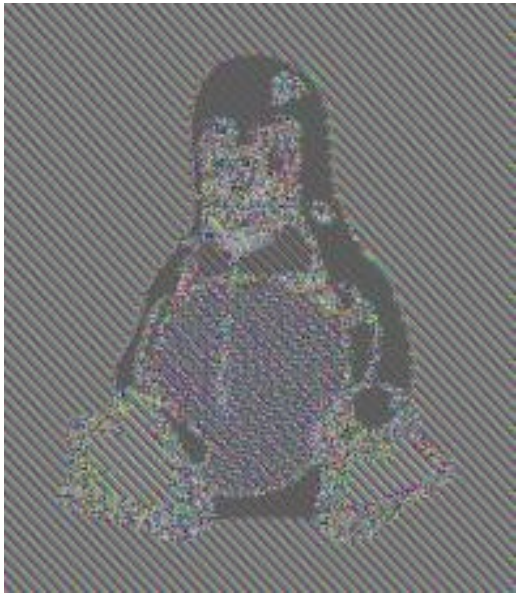
Inappropriate use of cipher modes: ECB

- ECB is the raw application of the cipher algorithm.
- Reasons why it is the most commonly misused:
  - First (and sometimes only) example in textbooks
  - Simplest to implement (no need to bother with IVs)
- Weaknesses:
  - Same plaintext blocks always encrypt to same ciphertext
  - Block replay attacks are possible

What's Wrong with ECB Mode?

Original Tux image

Tux image encrypted with ECB mode



Tux image encrypted with any other cipher mode

From: http://en.wikipedia.org/wiki/Block_cipher_mode_of_operation

ECB: Block Replay Attack (1/6)

- Adversary can modify encrypted message without knowing the key or even encryption algorithm.
  - Can mangle message beyond recognition.
    - Remove, duplicate, and/or interchange blocks
  - Can usurp meaning of message if structure known. Consider the following scenario...

ECB: Block Replay Attack (2/6)

[Example from Schneier, *Applied Cryptography*]*

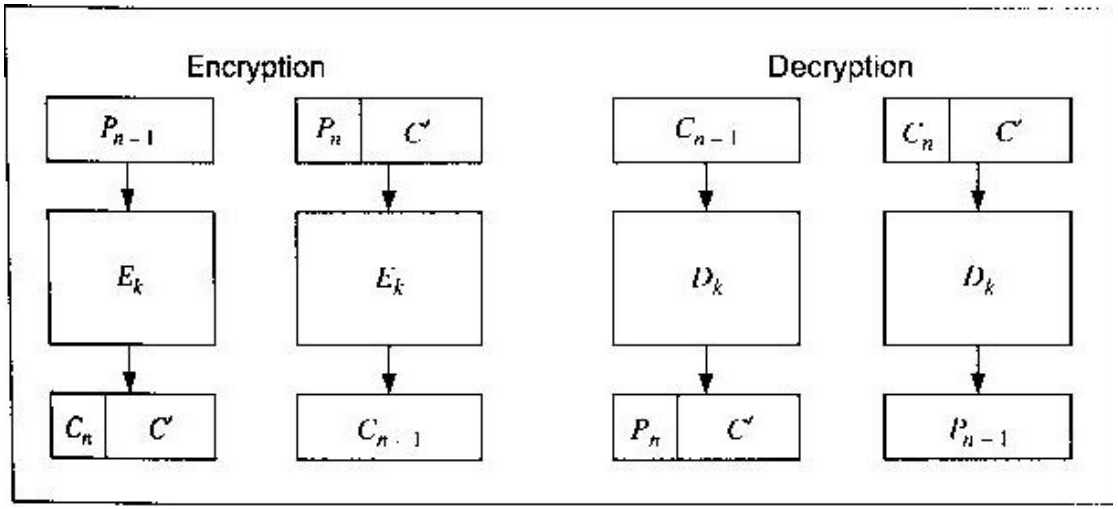
- Assume 8-byte encryption block size.
- Money transfer system to move $ btw banks
- Assume bank's standard message format is:

Bank 1: Sending	1.5 blocks
Bank 2: Receiving	1.5 blocks
Depositor's Name	6 blocks
Depositor's Acct #	2 blocks
Deposit Amount	1 block

---

* First discussed by C. Campell, *IEEE Computer*, 1978

ECB: Block Replay Attack (3/6)



Where, P_{n-1} is the last full plaintext block

P_n is the final, short, ciphertext block

C_{n-1} is the last full ciphertext block

C_n is the final, short ciphertext block

C' is just an intermediate result (not transmitted)

ECB: Block Replay Attack (4/6)

- Mallory is MITM agent, listening to comm channel between Bank of Alice and Bank of Bob.
- Mallory sets up accounts in both banks and deposits seed money in Bank of Alice.
- Mallory transfers some fixed amount of the seed money to Bank of Bob and records transaction.
- Repeats later, and looks for identical blocks; eventually isolates acct transfer authorization.

ECB: Block Replay Attack (5/6)

- Mallory can now insert those message blocks into communication channel at will. Each time, that fixed amount will be deposited in Mallory's account at the Bank of Bob.
- Two banks will notice by close of business when accts are reconciled. By that time, Mallory has already skipped town.

ECB: Block Replay Attack (6/6)

- Can *not* be defeated by simply prepending date/time stamp to bank transfer authorization message. Mallory can replay individual blocks lying on whole block boundaries (e.g., in this case the Depositor's Name and account #).
- *Can* be defeated by adding secure *keyed* hash to entire message (or using another cipher mode).

ECB: What to look for

- No cipher mode specified at all. E.g.,

Cipher cipher = Cipher.getInstance(“AES”);

In Java, this is the same as:

Cipher cipher =
    Cipher.getInstance(“AES/ECB/PKCS5Padding”);

- No evidence that an IV is used
  - In Java, look for *absence* of both IVParameterSpec and Cipher.getIV()
  - Check lengths of resulting encryption
    - Generally IV is prepended to the raw ciphertext. (Exception might be where IV is fixed (bad) or determined algorithmically; discussed later.)

ECB: Is it ever okay?

- Yes, when:
  - Encrypting plaintext with a less than 1 cipher block and ciphertext attacks not feasible:
    - Blowfish and DES (and hence DESede) block size: 64 bits
    - AES block size (and most other AES candidates): 128 bits
  - When encrypting random data
    - E.g., nonces, session IDs, *random* secret keys; maybe passwords if strong passwords enforced (LOL).
- AND padding is used when appropriate (random data)
- AND block replay attacks are not an issue
- OR, using it for asymmetric encryption (more later)

If use of ECB *seems* okay…

- Make sure it is not used in a scenario where a block replay attack is possible.
- Ask yourself:
  - Are multiple blocks of ciphertext encrypted with ECB used?
  - Are these multiple ciphertext blocks exposed to an “adversary”?
  - Will block re-ordering ever fail tobe detected in any cases? (I.e., is data integrity not always ensured?)
- If answer to these is “yes” for all questions, block replay is probably possible.

Detour: Authenticated Encryption

- Encryption provides confidentiality, not integrity. (Integrity aka authenticity)
- Approaches to authenticated encryption
  - Encrypt-then-MAC (EtM): Encrypt, then apply MAC over IV+ciphertext and append the MAC.
  - Encrypt-and-MAC (E&M): Encrypt the plaintext and append a MAC of the plaintext.
  - MAC-then-Encrypt (MtE): Append a MAC of the plaintext and encrypt them both together.
- Decryption operation applied in reverse order.
- EtM built into some cipher modes such as CCM, GCM, EAX, etc.

Horton Principle

- David Wagner and Bruce Schneier
- Relevant when considering what to data to include in a MAC
- Semantic authentication: “Authenticate what is meant, not what is said”
  - Avoid unauthenticated data: either don’t send / rely on it, or include it in the MAC
  - Relevant in message formats and protocols
- E.g., Alice sends: “metadata||IV|| ciphertext||MAC”

Horton Principle: ESAPI

Order	Size (in octets)	Field
1	4	KDF PRF & version #
2	8	timestamp
3	2	xformLen
4	xformLen octets	cipherXform
5	2	keysize
6	2	blocksize
7	2	ivLen
8	ivLen octets	*IV*
9	4	ciphertextLen
10	ciphertextLen octets	rawCiphertext
11	2	macLen
12	macLen octets	*MAC*

MAC = HMAC-SHA256(authKey, IV || rawCipherText)
where '||' denotes concatenation.

Symmetric Encryption Weaknesses: CBC

- Overall, CBC probably most robust mode when used correctly.
- Use correctly means:
  - Random key and random IV with padding
  - HMAC over the IV+ciphertext applied as "encrypt-then-MAC" approach.
- Common mistakes:
  - Fixed IV or predictable IV (e.g., counter, time, etc.)
  - Failure to MAC correctly (e.g., no MAC at all, encrypt-and-MAC, or MAC-then-encrypt)

More on Authenticated Encryption (AE)

- Common uses:
  - EtM: IPSec (and ESAPI 2.x :-)
  - E&M: SSH
  - MtE: SSL/TLS
- Of the 3 approaches, only EtM is proven to be strong against all known attacks.
- References:
  - http://cseweb.ucsd.edu/~mihir/papers/oem.pdf
  - http://en.wikipedia.org/wiki/Authenticated_encryption

Why is AE needed?

- When ciphertext's authenticity is in doubt, certain cryptographic attacks are possible that will either divulge the plaintext (or portions thereof) or possibly even real the secret key.
- Padding oracle attack, Serge Vaudenay, 2002
  - Originally discussed as deficiency in IPSec and SSL
  - Dismissed as being impractical until Rizzo and Duong research and POET software in 2010

Detour: Random Oracle

- Think “oracle” as in “Oracle of Delphi”, not as in Oracle, the software company.
  - Complexity theory: Oracle is an abstraction used to study decision problems.
  - Black box that decides yes / no to a given query.
- In cryptography, an oracle responds to a unique query with a truly random response,
  - But, the same query is answered the same each time it is submitted.
  - Cryptographers try to show a system is secure if modeled as a random oracle.
  - If one can distinguish a system is *different* than a random oracle, it is biased and therefore insecure.

Padding Oracle Attack (1/7)

- A chosen-ciphertext attack (CCA), generally performed as a side-channel attack performed against the padding of the ciphertext.
- The “side-channel” acts as the “oracle”... simplistically, the oracle might be something like “is the padding correct”.
  - Ideally, this should be indistinguishable from a random oracle. When it is not, it is something that leaks a bit (or more) of information to the adversary.

Padding Oracle Attack (2/7)

- Side-channel can be:
  - Different error messages or exceptions
  - Error message or exception only on certain failures
    - To user or to log file (WYTM?)
  - Subtle differences in timing, CPU utilization, memory consumption, memory cache hits, etc.

Padding Oracle Attack (3/7)

- What can a padding oracle attack reveal?
  - The plaintext
  - Sometimes, allow encrypting arbitrary plaintext
  - With some additional work, sometimes the actual encryption key! (Rizzo and Duong)
- How can it be prevented?
  - By using an AE cipher mode like CCM or GCM
  - By using an EtM approach like IPSec or ESAPI
    - With EtM, want separate (derived) keys for encryption and MAC operations.
    - No “oracles” present when decryption error occurs.

Padding Oracle Attack (4/7)

- How does it work?
  - Explanation would add about 15-25 minutes to this talk. Search for “oracle padding attack” on YouTube.
  - Suggested references:
    - Holyfield’s OWASP presentation: http://blog.gdssecurity.com/storage/presentations/Padding_Oracle_OWASP_NYC.pdf
    - Dan Boneh lecture (padding oracle in TLS; 14 minute total): https://www.youtube.com/watch?v=evrgQkULQ5U

Padding Oracle Attack (5/7)

- Requirements for *padding oracle* attack
  - Must be using padding! (Duh!)
  - Some usable *oracle* must be available to the adversary that leaks information if padding error during decryption
    - Examples: Different error messages, different exception types, measurable timing differences, different messages logged, etc.
  - Adversary *must* be able to manipulate the ciphertext (or IV and ciphertext)
    - Usually an adaptive chosen ciphertext attack variation used
    - Examples: Encrypted HTTP parameters

Padding Oracle Attack (6/7)
Spotting a potential padding oracle vulnerability: What to look for

- Follow the logic of what happens when a BadPaddingException occurs.
  - Is this logic different in any way than any other decryption error?
    - Exception type or message
    - Logged message contents (or even length difference)
    - Timing difference (timing side-channel)
      - 20 milliseconds or so is sufficient if we can take sufficient measurements to factor out the statistical network lag.

Padding Oracle Attack (7/7): Removing timing side channels as oracles

- Ideally, rewrite the code to eliminate the timing differences by going through the same logic for all error cases.
  - May not always be possible, especially if side channel is in another 3rd party library.
- Add small, but random sleeps for all cases
  - Approximate delay dependent on timing difference
- Ensure all take same amount of time by sleeping for N – t seconds where ‘t’ is amount of time taken for execution and N is something large (e.g., 2 seconds).

Symmetric Encryption Weaknesses: Assuming confidentiality implies data integrity

- Only true if one is using an AE cipher mode such as CCM or GCM (the only 2 AE modes that are NIST approved) or using a correctly implemented EtM approach.
- If confidentiality is not required, better (and faster) to just use an HMAC.
- Look for cases where plaintext is already known to attacker and encryption is used to prevent tampering.

Asymmetric Cryptography: Encryption

Three common algorithms for asymmetric encryption

- RSA – based on the integer factorization problem
- ElGamal – based on the Diffie-Hellman key exchange and the discrete logarithm problem
- Elliptic curve – based on the elliptic curve logarithm problem
- Will only focus on RSA
  - Because it won't make your head explode
  - EC is nuanced and not well supported (in Java at least)
    - Oracle does not yet support Elliptic Curve Integrated *Encryption* (ECIE) in Java 7, but only Elliptic Curve Diffie-Hellman (ECDH) and Elliptic Curve Digital Signature Algorithm (ECDSA).

Cipher modes for asymmetric encryption (applies to all algs) (1/2)

- Asymmetric cipher algorithms are on the order of 1000 times slower then their symmetric cipher counterparts.
- Therefore,
  - We very rarely (some would say never) encrypt more than 1 block of plaintext.
  - Usually only symmetric encryption keys, occasionally passwords.
- Implying,
  - We *always* use ECB mode.

Cipher modes for asymmetric encryption (applies to all algs) (1/2)

- Therefore, other modes need not apply.
- Cryptographer David Hopwood's comment on using asymmetric ciphers with modes *other than* ECB:

Some existing JCE providers will accept the use of a block cipher mode and padding with an asymmetric cipher (e.g. "RSA/CBC/PKCS#7"); this is not recommended, and new providers MUST reject this usage.

Common Asymmetric Padding Schemes

- No padding
- PKCS#1 v1.5 (simply called “PKCS1Padding” in Java)
- Optimal Asymmetric Encryption Padding (OAEP)

Asymmetric Ciphers and Chosen Plaintext Attacks (1/3)

- All asymmetric ciphers are prone to chosen plaintext attacks (CPA).
  - CPA is a cryptanalytic attack where an attacker can chose which plaintext to encrypt and then observe the resulting ciphertext.
  - CPA is always possible with asymmetric ciphers because we assume the algorithm details is known as well as the *public* key.

Asymmetric Ciphers and Chosen Plaintext Attacks (2/3)

- Why might this be a problem?
  - Normally it's not because we usually are encrypting highly unpredictable plaintext that is too large to be enumerated.
    - E.g., symmetric session keys, cryptographic hash values
  - It becomes a problem when the is highly regular or short enough to enumerate all possible values

Asymmetric Ciphers and Chosen Plaintext Attacks (3/3)

- Real-life (bad) example
  - Application uses RSA algorithm to encrypt credit-card #s and store the resulting ciphertexts in application DB.
  - Consider inside attacker with access to DB records (e.g., DBA, developer, tester) as well as the *public* key.
  - Attacker encrypts all possible credit card #s with public key and saves mapping of plaintext / ciphertext pairs.
  - Lookup into application DB records via CC# ciphertext allows discovery of credit card holder as well as revealing plaintext CC#.

Asymmetric Cryptography: Digital Signatures

Digital Signature Issues

- There are standard attacks and specialized attacks on digital signatures in general and on specific digital signature schemes in particular. Not detailed here. See *Handbook of Applied Cryptography* if interested.
- Biggest problem is one of impersonation.
  - How can Alice verify that Bob's public key actually belongs to Bob and vice-versa.
  - Several easy attacks (MITM, social engineering, etc.)

Digital Signatures: Other problems

- The private (signing) key is not properly secured.
- Alice may have multiple keys, especially over her lifetime, as she moves from job to job and one email address to another.
- If public key is not in a structure that ensures authenticity (e.g., a certificate in a key store with a passphrase) if can be changed.

What to look for

- Usually in Java, key pair is kept in a key store file. (In .NET, it often is just in a special XML file and not secured.)
- If in key store file, check:
  - Is private key secured with passphrase (to prevent loss of confidentiality)?
  - Is key store itself secured with (preferrably different) passphrase (to prevent tampering)?
- If Alice's key in X.509 cert, does Bob properly validate cert?

Miscellaneous Topics

Rekeying Frequency

- PCI DSS 2.0 and later says that you *must* change symmetric crypto keys *at least* yearly? Is that enough?
- Steve Bellovin says in http://osdir.com/ml/encryption.general/2005-02/msg00005.html:
  - For 3DES in CBC mode, rekey at least every 2^{32} * 64-bits of plaintext
  - For AES in CBC mode, every 2^{64} * 128-bits
  - General: every $2^{N/2}$ * cipher_block_size bits, where N is key size in bits.

TLS / SSL

- Dodgy things to look for:
  - Null cipher suites ==> No encryption!
  - Assuming that SSLSocket / SSLSocketFactory correctly do server authentication
    - They correctly (in most cases) validate the server-side certificate, BUT
    - Early versions fail to do host name verification, so MITM attacks are still possible.
  - Same is true for URL and HttpUrlConnection when using an “https:” URL and early versions of Apache HttpClient

TLS/SSL Null Cipher Suites

- 8 in total
  - TLS_RSA_WITH_NULL_SHA256
  - TLS_ECDHE_ECDSA_WITH_NULL_SHA
  - TLS_ECDHE_RSA_WITH_NULL_SHA
  - SSL_RSA_WITH_NULL_SHA
  - TLS_ECDH_ECDSA_WITH_NULL_SHA
  - TLS_ECDH_RSA_WITH_NULL_SHA
  - TLS_ECDH_anon_WITH_NULL_SHA
  - SSL_RSA_WITH_NULL_MD5
- All disabled by default in JDK 7; all but the first disabled by default in JDK 6.

SSLSocket and Server Authentication

- SSLSocket (or any other SSLSocket subclass) created by SSLSocketFactory does not do host name verification or cert pinning by default. Hence, MITM attacks are possible.
  - Must implement your own. Two approaches:
    - Subclass SSLSocket; see http://www.velocityreviews.com/forums/t958287-adding-hostname-verification-to-sslsocket.html

Specifying JCE Providers

- Java has a concept of security providers.
  - Statically added via:
    - JRE: $JAVA_HOME/lib/security/java.security
    - JDK: $JAVA_HOME/jre/lib/security/java.security
  - Dynamically added via:
    - Security.addProvider(Provider provider)
    - Security.insertProviderAt(Provider provider, int pos)
    - Various getInstance() methods take Provider as 2nd arg
- Determined by position; defaults to what is in java.security.
- This concept extends to crypto providers

What could possibly go wrong?

```
import org.bouncycastle.jce.provider.*;
...
int pos = Security.addProvider(
    new BouncyCastleProvider()  );
```

Static setting in java.security

- Default list of providers ordered by preference:

```
security.provider.1=sun.security.provider.Sun
security.provider.2=sun.security.rsa.SunRsaSign
security.provider.3=sun.security.ec.SunEC
...
security.provider.9=sun.security.smartcardio.SunPCSC
security.provider.10=sun.security.mscapi.SunMSCAPI
security.provider.11=org.bouncycastle.jce.provider.BouncyCastleProvider
```

How about this?

```
import org.bouncycastle.jce.provider.*;
...
Security.insertProviderAt(
    new BouncyCastleProvider(), 1 );
```

Equivalent static setting in java.security

- Equivalent as if we did this:

security.provider.1=org.bouncycastle.jce.provider.BouncyCastleProvider
security.provider.2=sun.security.provider.Sun
security.provider.3=sun.security.rsa.SunRsaSign
security.provider.4=sun.security.ec.SunEC
...
security.provider.10=sun.security.smartcardio.SunPCSC
security.provider.11=sun.security.mscapi.SunMSCAPI

What could possibly go wrong?

- Consider this in Logger.getLogger() method in *rogue* copy of log4j.jar someone downloaded:

```
...
Security.insertProviderAt(
new MyEvilProvider(), 1 );
...
```

How do we address this?

- Specify the Provider instance as part of the getInstance() methods; e.g.,

```
Cipher.getInstance("AES/CBC/PKCS5Padding",
                   new BouncyCastleProvider() );
```

OR

- Use a Java Security Manager and restrict what classes may call Security.addProvider() and Security.insertProviderAt()

What to look for

- Calls to either
  Security.addProvider()

OR

  Security.insertProviderAt()

without the use of a Java Security Manager (JSM)

Caveat: Java Security Manager is rarely used and if it is used, usage of a properly restrictive security policy is hardly ever set. Also, if the jars are not signed and validated before use, using the JSM matters little.

Additional References

- New OWASP Dev Guide, chapter 11 (Cryptography) [still a work in progress]
  - https://github.com/OWASP/DevGuide/blob/master/03-Build/0x11-Cryptography.md
  - And those references therein

Questions?

(Now or email me at kevin.w.wall@gmail.com)