

Practical Padding Oracle Attacks

Juliano Rizzo Thai Duong

Black Hat Europe, 2010

XOR

$$0 \oplus 0 = 0$$

$$0 \oplus 1 = 1$$

$$1 \oplus 0 = 1$$

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Outline

- 1 Introduction
 - Review of CBC Mode
 - Padding Oracle attack
- 2 Finding padding oracles
 - Find potential padding oracles
 - Confirm the existence of padding oracles
- 3 Basic PO attacks
 - Cracking CAPTCHA
 - Decrypting JSF view states
- 4 Advanced PO attacks
 - Using PO to encrypt
 - Distributed cross-site PO attacks

CBC Mode

- CBC mode is a cryptography mode of operation for a block cipher.
- Allows encryption of arbitrary length data.
- Encryption and decryption are defined by:

$$C_i = e_K(P_i \oplus C_{i-1})$$

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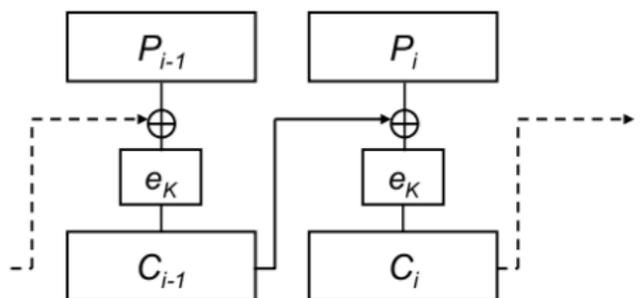
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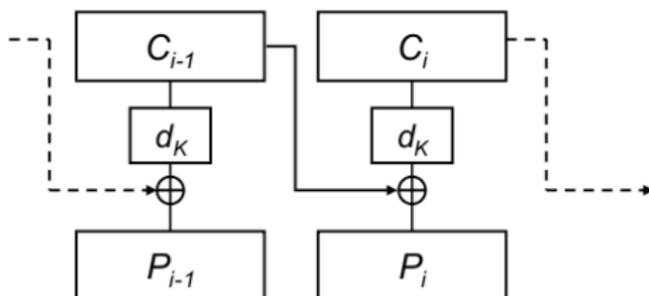
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CBC Mode



Typical block size n :
64 bits (DES, triple
DES) or 128 bits
(AES).



Typical key size:
56 bits (DES), 168 bits
(triple DES), 128, 192
or 256 bits (AES).

Padding

H	e	l	l	o		w	o
---	---	---	---	---	--	---	---

11 bytes of plaintext

r	l	d					
---	---	---	--	--	--	--	--

PKCS5 Padding



H	e	l	l	o		w	o
---	---	---	---	---	--	---	---

r	l	d	05	05	05	05	05
---	---	---	----	----	----	----	----

Encryption



Padding oracle attack

Introduction

- First introduced by Vaudenay at Eurocrypt 2002.
- Two assumptions:
 - Adversary can intercept padded messages encrypted in CBC mode.
 - Adversary has access to a padding oracle.

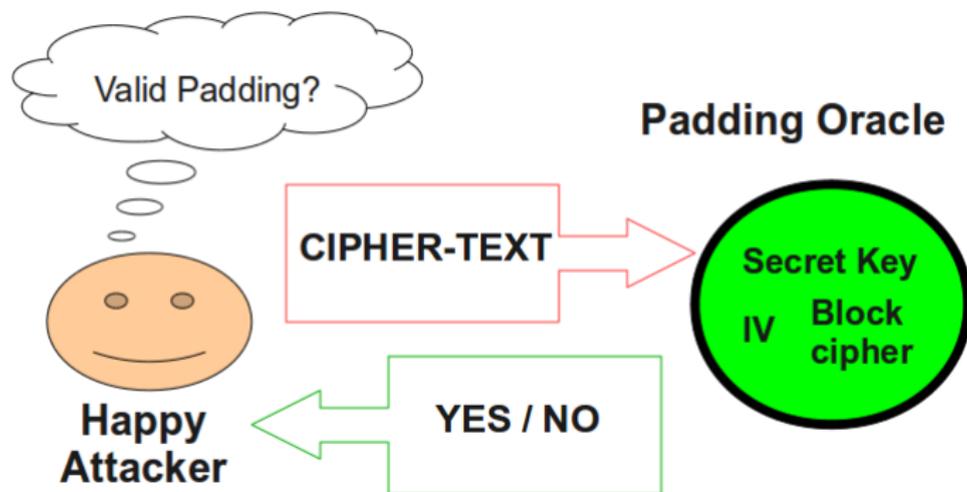
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What is a padding oracle?



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- Adversary submits a CBC mode ciphertext C to oracle \tilde{D} .
- Oracle decrypts under fixed key K and checks correctness of padding.
- Oracle outputs VALID or INVALID according to correctness of padding:

$$\tilde{D}(C) = \begin{cases} 0, & \text{invalid} \\ 1, & \text{valid} \end{cases}$$

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Padding oracle attack

How does it work?

- For a long message, decrypt block by block. It's easy to parallelize the attack.
- For a block, decrypt the last byte first, then decrypt the next to last byte, and so on.
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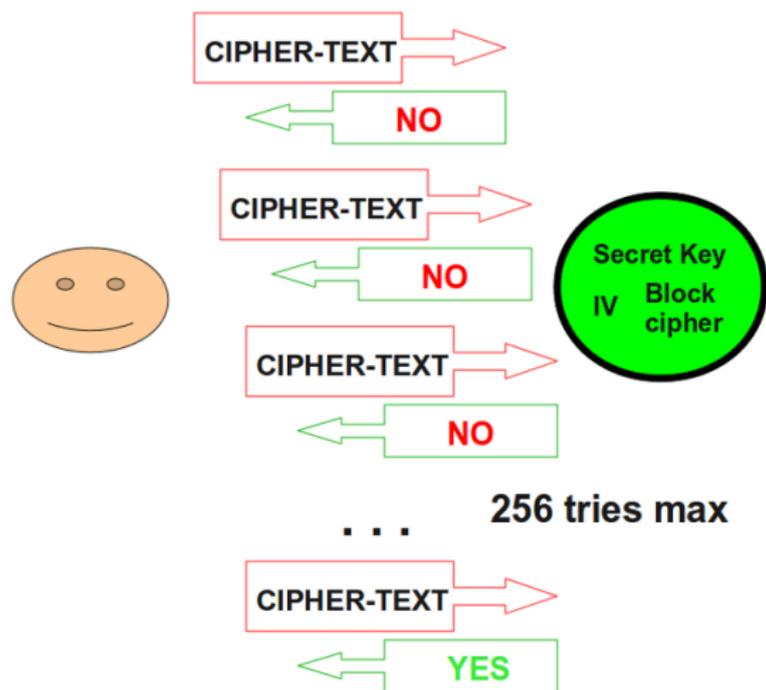
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Padding oracle attack

How to decrypt a block



Padding oracle attack

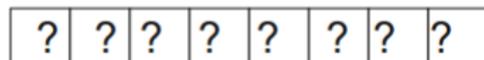
How to decrypt a block

Oracle CBC decryption process

Oracle query cipher-text



1. Decrypts control block



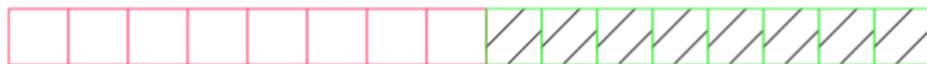
2. XOR with IV



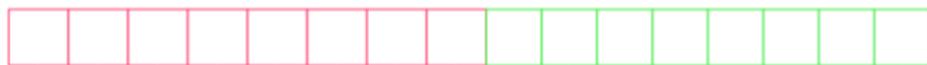
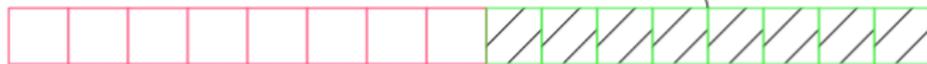
Padding oracle attack

How to decrypt a block

3. Decrypt target



4. XORs with control



Final "plain-text"

Padding oracle attack

Last byte decryption algorithm

Last byte decryption algorithm

- pick a few random bytes r_1, \dots, r_b , and take $i = 0$.
- pick $r = r_1 r_2 \dots r_{b-1} (r_b \oplus i)$.
- if $\delta(r|y) = 0$ then increment i and go back to previous step.
- replace r_b by $r_b \oplus i$.
- for $n = b$ down to 2
 - take $r = r_1 \dots r_{b-n} (r_{b-n+1} \oplus 1) r_{b-n+2} \dots r_b$
 - if $\delta(r|y) = 0$ then stop and output $(r_{b-n+1} \oplus n) \dots (r_b \oplus n)$
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Demo

Exploiting RubyOnRails ActiveSupport::MessageEncryptor

- Since RubyOnRails 2.3, to provide a simple way to encrypt information.
- Vulnerability: `encrypt` and `decrypt` functions.
- Use `encrypt_and_sign` and `decrypt_and_verify` instead.

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Finding potential padding oracles

Blackbox testing

- Crawl the target to find BASE64 strings that look like a ciphertext.
- Replace a byte in the last block of the ciphertext by a random value, and send to the target.
- See if there is any error message. Even a blank page is enough information.

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Google hacking



"Given final block not properly padded"

Search

About 7,890 results (0.16 s)

Advanced search

Everything

More

More search tools

[Cryptography - Given final block not properly padded \[Locked\]](#)

13 posts - 9 authors - Last post: 26 Sep 2008

BadPaddingException: **Given final block not properly padded** but when i use encrypted bytes array directly(not convert it into string), ...

[forums.sun.com](#) > [Security](#) > [Cryptography](#) - [Cached](#) - [Similar](#)

[BadPaddingException: Given final block not properly ...](#) - 26 Mar 2010

[javax.crypto.BadPaddingException: Given final block ...](#) - 25 Jan 2010

[Unexpected Exception in perform: Given final block ...](#) - 9 Nov 2009

[Given final block not properly padded](#) - 10 Mar 2007

[More results from forums.sun.com](#) »

[BadPaddingException with DES \(Security forum at JavaRanch\)](#)

22 posts - 14 authors - Last post: 28 Jun 2009

BadPaddingException: **Given final block not properly padded**. I encrypt my SealedObject using a DES key. This key is saved as a variable and ...

[www.coderanch.com/t/.../BadPaddingException-with-DES](#) - [Cached](#) - [Similar](#)

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Source code auditing

- Look for code that imports low level cryptography libraries.
- Look for known source code keywords like `javax.crypto.BadPaddingException`.
- Look for routines that perform encryption and decryption that have some code to handle error while decrypting.

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Confirm the existence of padding oracles

Determine the block size b

- All padding oracle attacks need a correct b .
- Most common block sizes are 8 and 16 bytes. Of course we can use trial and error.

How to determine the block size

- if $\text{len}(C) \% 16 = 8$, then stop and output 8.
- take $y = C[-16 :]$, i.e. y is the last sixteen bytes of C .
- if $\delta(C|y) = 1$, then stop and output 8.
- output 16.

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 - Pick a few random words r_1, \dots, r_b , and take $i = 0$.
 - Pick $r = r_1 r_2 \dots r_{b-1} (r_b \oplus i)$.
 - Send $r|y$ to the target, where y is a valid ciphertext block. Record the value of i , content length, and content type of the response. Increment i , and go back to step 3 until $i > 255$.
 - Now you have 256 responses. If all of them are the same, then the target is not easily showing you that it is vulnerable to padding oracle attack.
 - Otherwise, look at each value of i where the responses are different from the rest. Examine carefully each response to see what happened.

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Cracking CAPTCHA

A broken CAPTCHA system

- $ERC = e_{\kappa, IV}(rand())$.
- ...``...
- ERC is stored as either a hidden field or a cookie in the CAPTCHA form.
- Once a user submits, the server decrypts ERC , and compares it with the code that the user has entered. If equal, the server accepts the request; it denies the request otherwise.

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Cracking CAPTCHA

Bypass the broken CAPTCHA system

- Since the system decrypts any *ERC* sent to it, it is vulnerable to Padding Oracle attack.
- The only remaining problem now is to know when padding is *VALID*, and when it's not.
- Fortunately, most CAPTCHA systems would send back an error notification when they fail to decrypt *ERC*, i.e. padding is *INVALID*.
- In addition, when we modify *ERC* so that the padding is *VALID*, most systems would display an image with a broken code.
- Now we have a padding oracle, and we can use it to decrypt any *ERC*, thus bypass the CAPTCHA completely.

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Cracking CAPTCHA

CAPTCHA with secret IV

- Since $P_0 = IV \oplus d_{\delta}(C_0)$, we need to know the IV to get P_0 .
- If the IV is secret, we can't know P_0 , thus can't crack CAPTCHA systems whose P_0 contains part of the random code.
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Decrypting JSF view states

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- Like ASP.NET, JSF stores the state of the view in a hidden field.
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Padding oracle in JSF frameworks

- By default, all JSF frameworks would display a very detailed error message if it fails to decrypt a view state.

Padding oracle in default installations of JSF frameworks

- if we see `javax.crypto.BadPaddingException`, then it's INVALID padding
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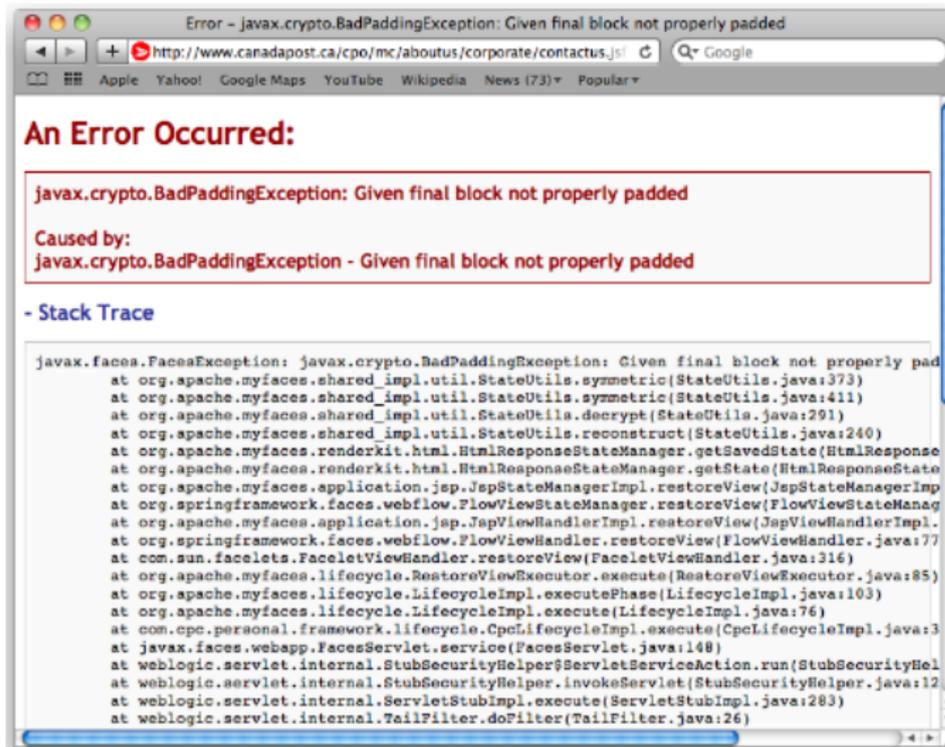
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Apache MyFaces error-page



The screenshot shows a web browser window with the title "Error - javax.crypto.BadPaddingException: Given final block not properly padded". The address bar shows the URL "http://www.canadapost.ca/cpo/mc/aboutus/corporate/contactus.jsf". The main content of the page is as follows:

An Error Occurred:

javax.crypto.BadPaddingException: Given final block not properly padded

Caused by:
javax.crypto.BadPaddingException - Given final block not properly padded

- Stack Trace

```
javax.faces.FacesException: javax.crypto.BadPaddingException: Given final block not properly padded
    at org.apache.myfaces.shared_impl.util.StateUtils.symmetric(StateUtils.java:373)
    at org.apache.myfaces.shared_impl.util.StateUtils.symmetric(StateUtils.java:411)
    at org.apache.myfaces.shared_impl.util.StateUtils.decrypt(StateUtils.java:291)
    at org.apache.myfaces.shared_impl.util.StateUtils.reconstruct(StateUtils.java:240)
    at org.apache.myfaces.renderkit.html.HtmlResponseStateManager.getSavedState(HtmlResponse
    at org.apache.myfaces.renderkit.html.HtmlResponseStateManager.getState(HtmlResponseState
    at org.apache.myfaces.application.jsp.JspStateManagerImpl.restoreView(JspStateManagerImp
    at org.springframework.faces.webflow.FlowViewStateManager.restoreView(FlowViewStateManag
    at org.apache.myfaces.application.jsp.JspViewHandlerImpl.restoreView(JspViewHandlerImpl
    at org.springframework.faces.webflow.FlowViewHandler.restoreView(FlowViewHandler.java:77
    at com.sun.facelets.FaceletViewHandler.restoreView(FaceletViewHandler.java:316)
    at org.apache.myfaces.lifecycle.RestoreViewExecutor.execute(RestoreViewExecutor.java:85)
    at org.apache.myfaces.lifecycle.LifecycleImpl.executePhase(LifecycleImpl.java:103)
    at org.apache.myfaces.lifecycle.LifecycleImpl.execute(LifecycleImpl.java:76)
    at com.cpc.personal.framework.lifecycle.CpcLifecycleImpl.execute(CpcLifecycleImpl.java:3
    at javax.faces.webapp.FacesServlet.service(FacesServlet.java:148)
    at weblogic.servlet.internal.StubSecurityHelper$ServletServiceAction.run(StubSecurityHel
    at weblogic.servlet.internal.StubSecurityHelper.invokeServlet(StubSecurityHelper.java:12
    at weblogic.servlet.internal.ServletStubImpl.execute(ServletStubImpl.java:283)
    at weblogic.servlet.internal.TailFilter.doFilter(TailFilter.java:26)
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Decrypting JSF view states

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- Most JSF frameworks allow developers to turn off error messages. Then we can use the following simple trick:

Padding oracle in JSF frameworks when error-page is turned off

- Say we want to decrypt block C_i of an encrypted view state $C_0|C_1|\dots|C_{n-1}$, then we send $C_0|C_1|\dots|C_{n-1}|C_{random}|C_i$ to the target.
- Since Java ignores those extra blocks while decrypting and deserializing view states, it's VALID padding if the target returns the same page as when the view state is unaltered.
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- This also works with SUN Mojarra and probably other JSF implementations.

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Using PO to encrypt

An introduction to CBC-R

- CBC-R turns a decryption oracle into an encryption oracle.
- We all know that CBC decryption works as following:

$$P_i = d_K(C_i) \oplus C_{i-1}$$

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- We can use a padding oracle to get $d_K(C_i)$, and we control C_{i-1} . In other words, we can produce any P_i as we want.

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How CBC-R works

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- choose a plaintext message $P_0|...|P_{n-1}$ that you want to encrypt.
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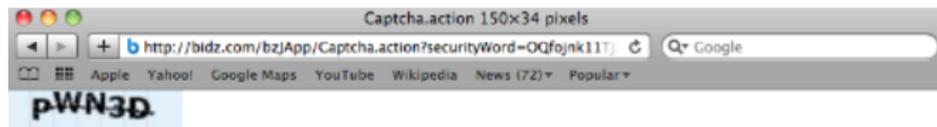
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