How To Break XML Signature and XML Encryption

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OWASP
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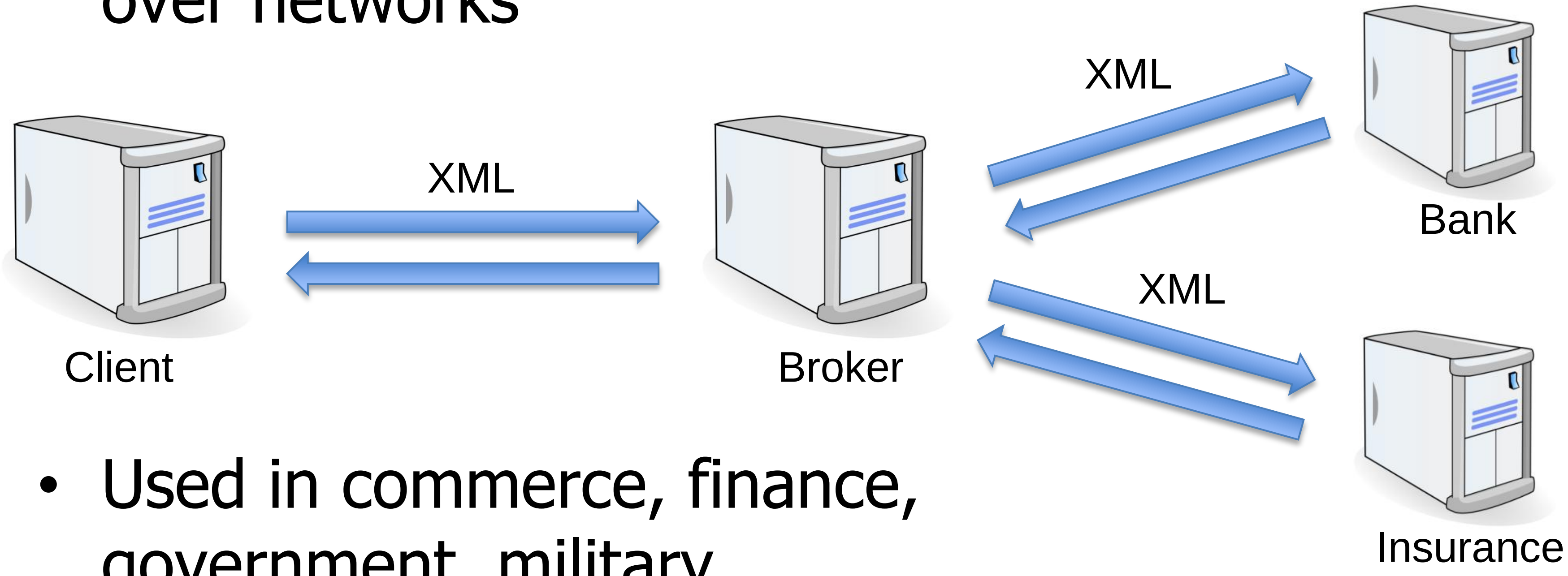
Motivation – Web Services

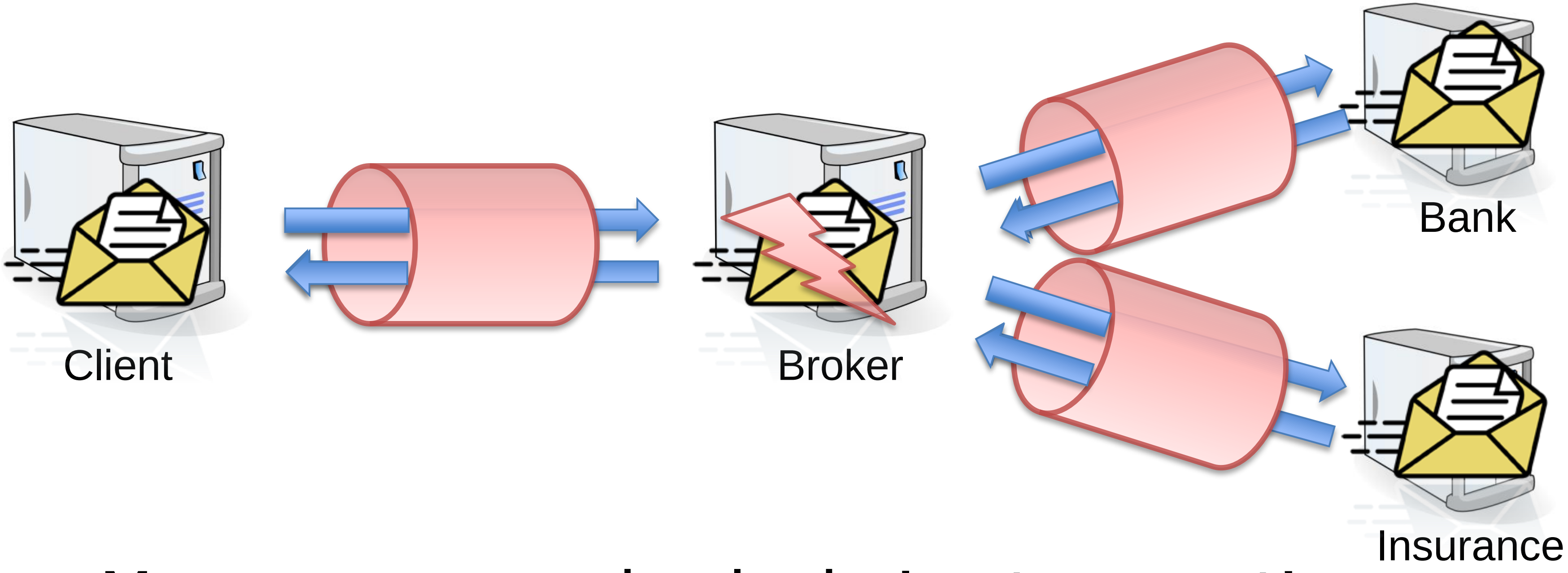
- Method for machine-to-machine communication over networks



- Used in commerce, finance, government, military, …
- XML-based message format

Motivation – XML Security

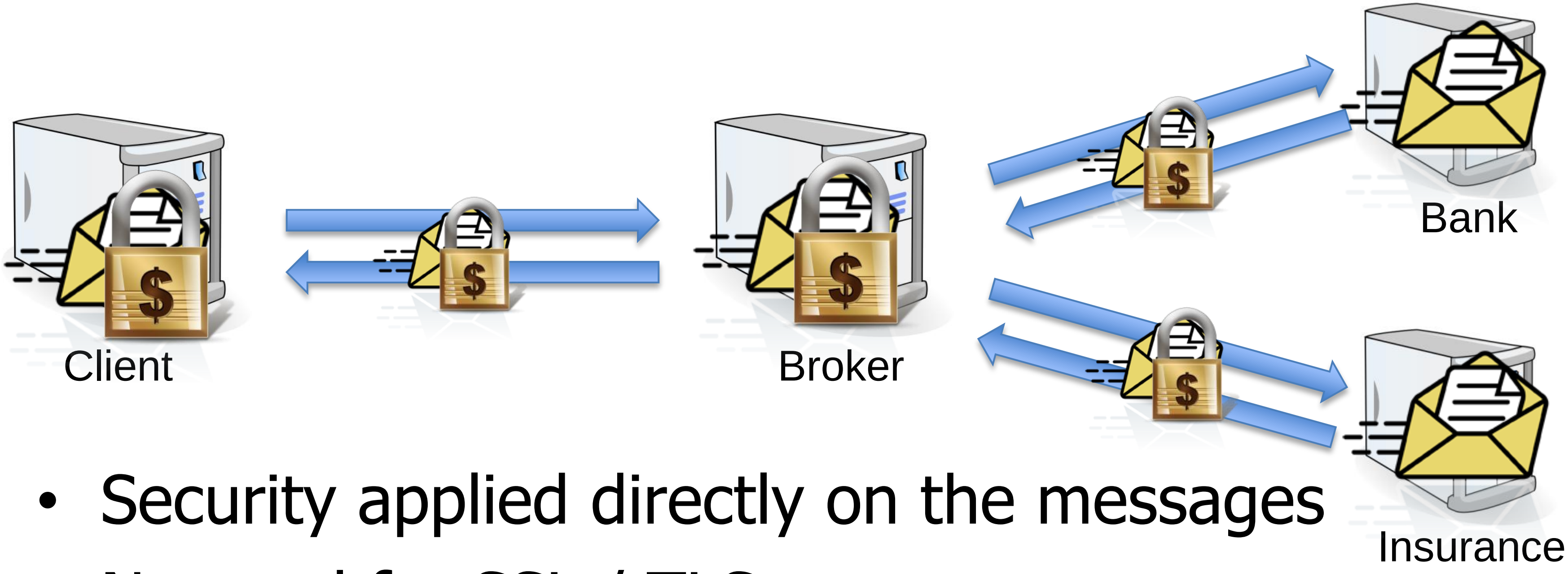
- SSL / TLS: transport-level security



- Messages secured only during transport!

Motivation – XML Security

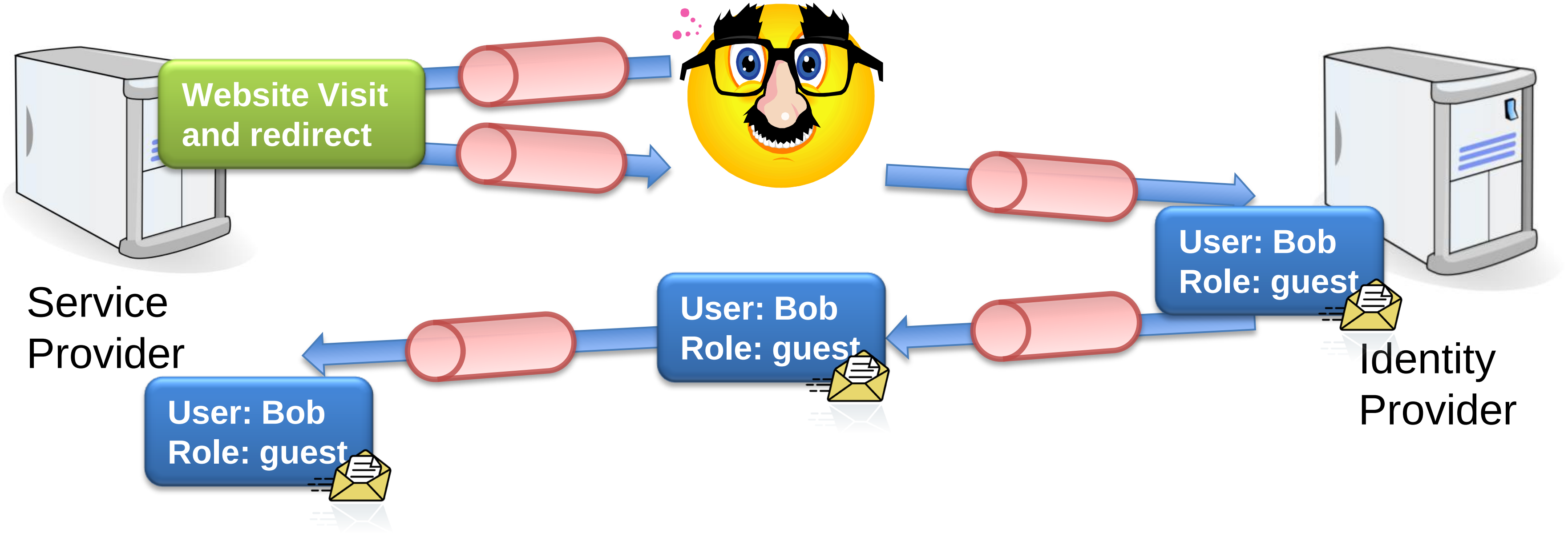
- Message level security



- Security applied directly on the messages
- No need for SSL / TLS
- Realized using XML Signature, XML Encryption

Motivation – XML Security

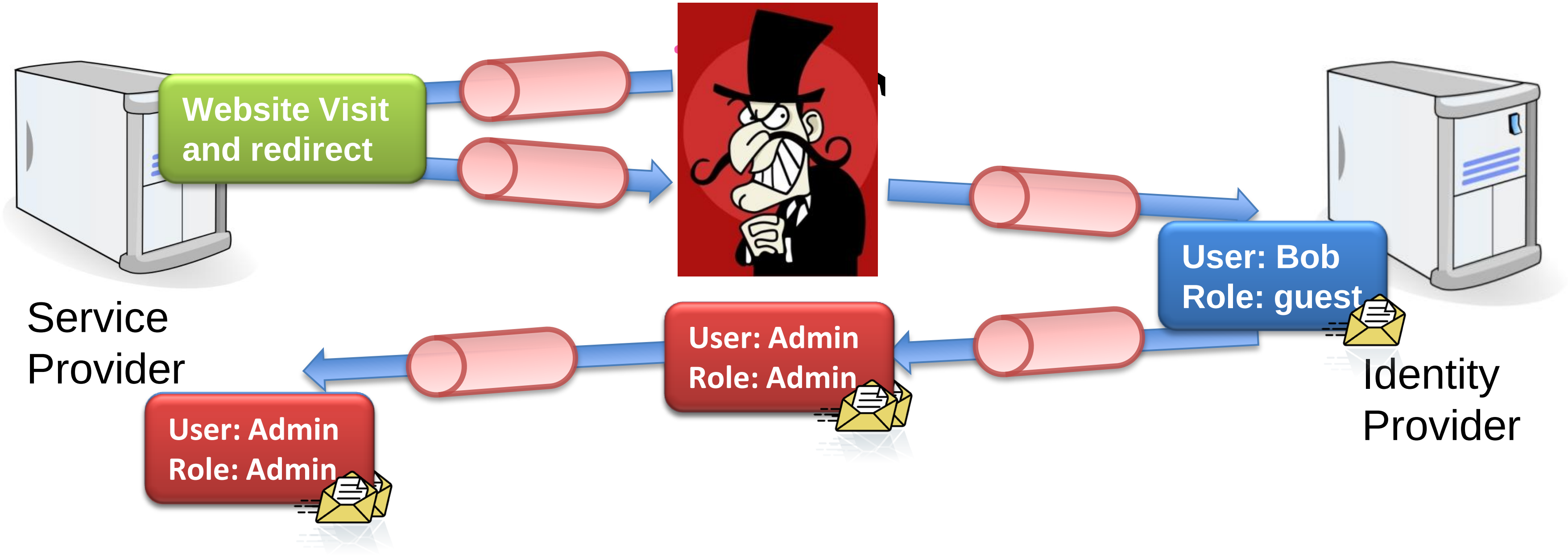
- Another example: Browser-based Single Sign-On



- Messages secured only during transport!

Motivation – XML Security

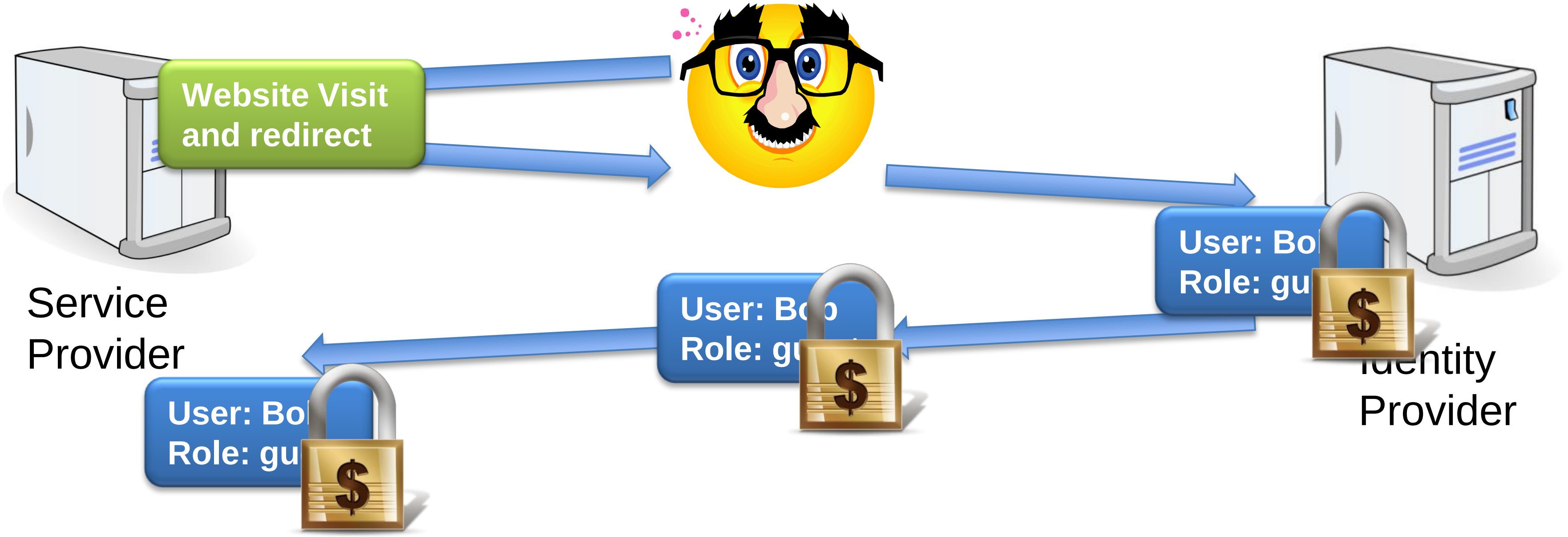
- Does SSL / TLS help?



- Need for message level security!

Motivation – XML Security

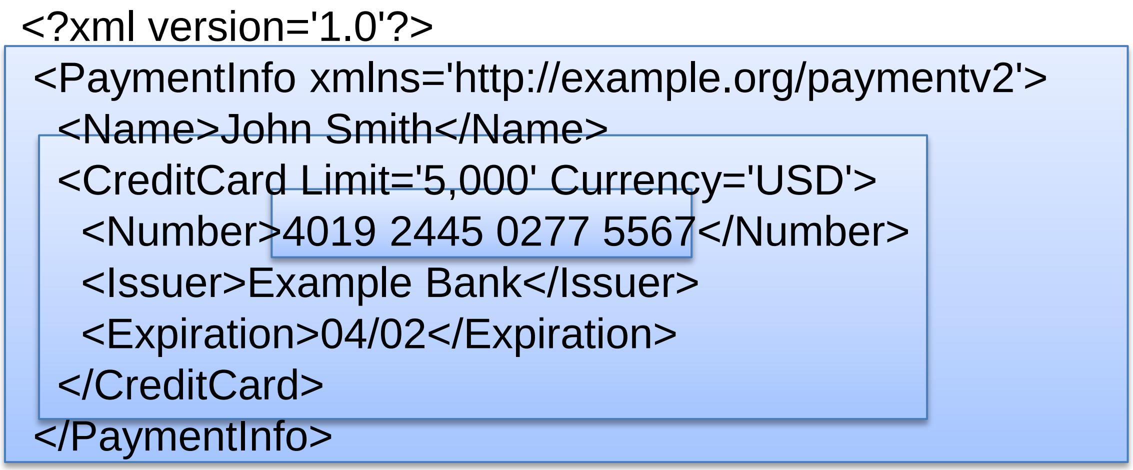
- Another example: Browser-based Single Sign-On



- Could be realized using XML Signature and XML Encryption

Motivation – XML Security

- W3C Standards: XML Signature and XML Encryption
- Describe various methods for applying cryptographic algorithms to XML documents



```
<?xml version='1.0'?>
 <PaymentInfo xmlns='http://example.org/paymentv2'>
  <Name>John Smith</Name>
  <CreditCard Limit='5,000' Currency='USD'>
   <Number>4019 2445 0277 5567</Number>
   <Issuer>Example Bank</Issuer>
   <Expiration>04/02</Expiration>
  </CreditCard>
 </PaymentInfo>
```

Overview

1. Breaking XML Signature
    - Cloud Computing Management Interfaces
    - Amazon EC2 SOAP Interface
    - XML Signature Wrapping on Eucalyptus and Amazon
    - Countermeasures and Conclusion
2. Breaking XML Encryption
    - Attack Scenario
    - Decrypting by checking plaintext validity
    - Application to CBC mode of operation in XML Encryption
    - Countermeasures and Conclusion
3. Conclusion

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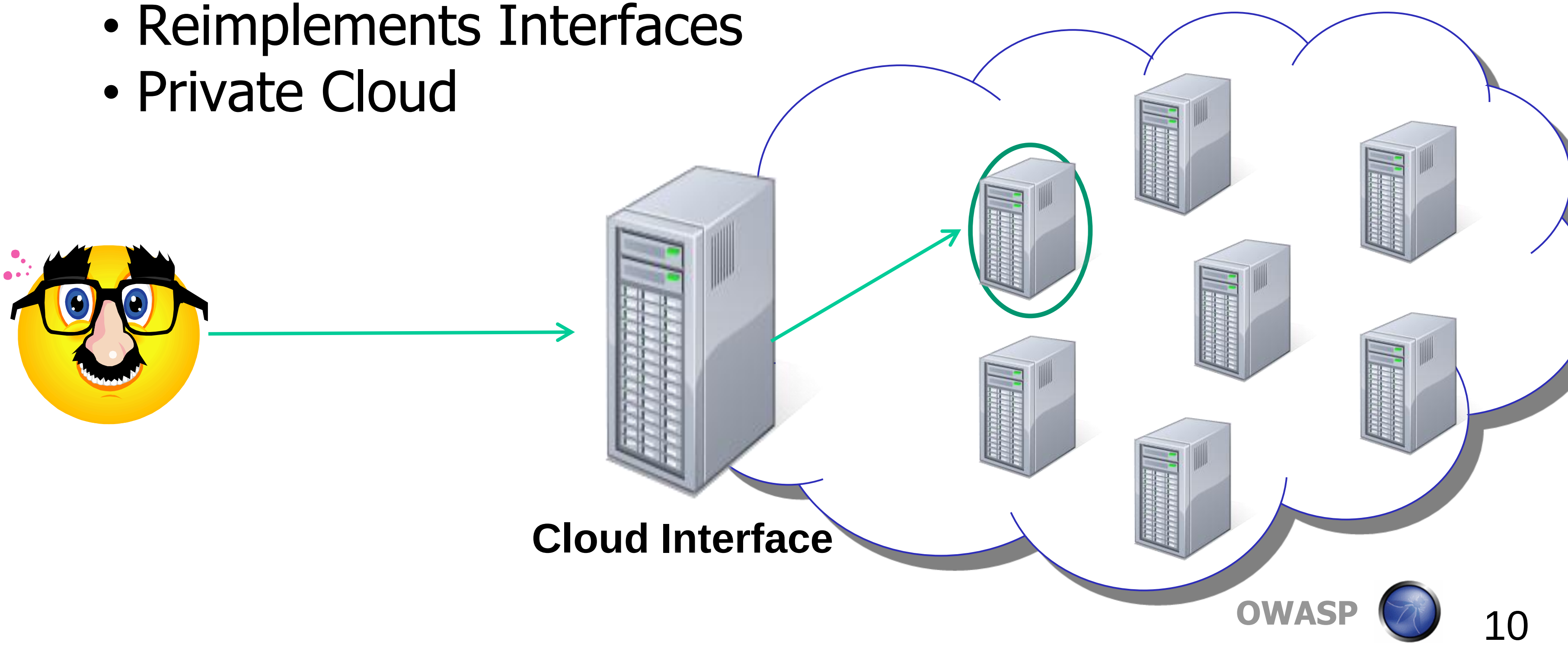
Cloud Computing Management Interfaces

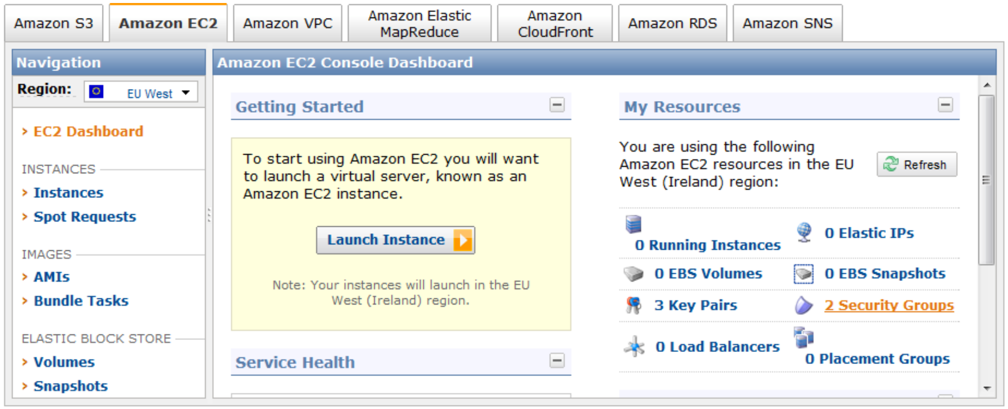
Cloud Computing:

- Amazon Web Services (2006):
  - Public Cloud
- Eucalyptus Cloud (2009):
  - Reimplements Interfaces
  - Private Cloud



Cloud Computing Management Interfaces

- Controlling of the cloud using different interfaces



To start using Amazon EC2 you will want to launch a virtual server, known as an Amazon EC2 instance.

Note: Your instances will launch in the EU West (Ireland) region.

You are using the following Amazon EC2 resources in the EU West (Ireland) region:

SOAP

REST

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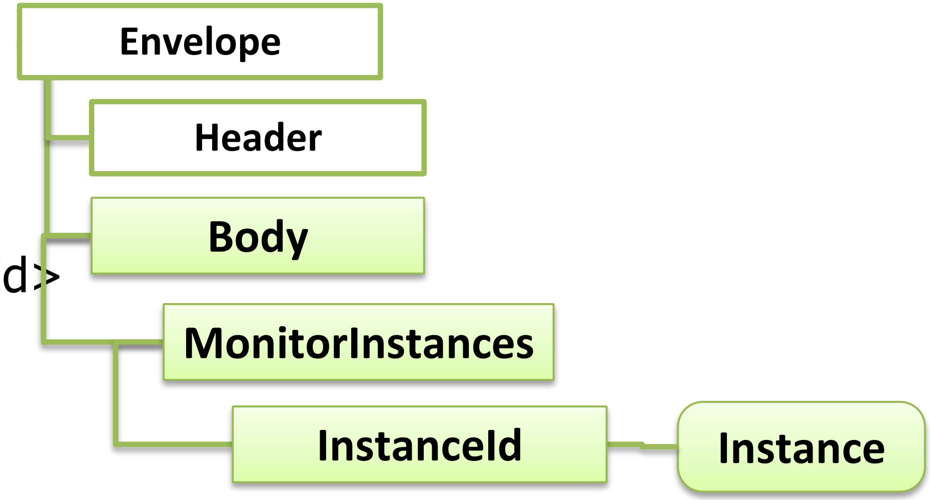
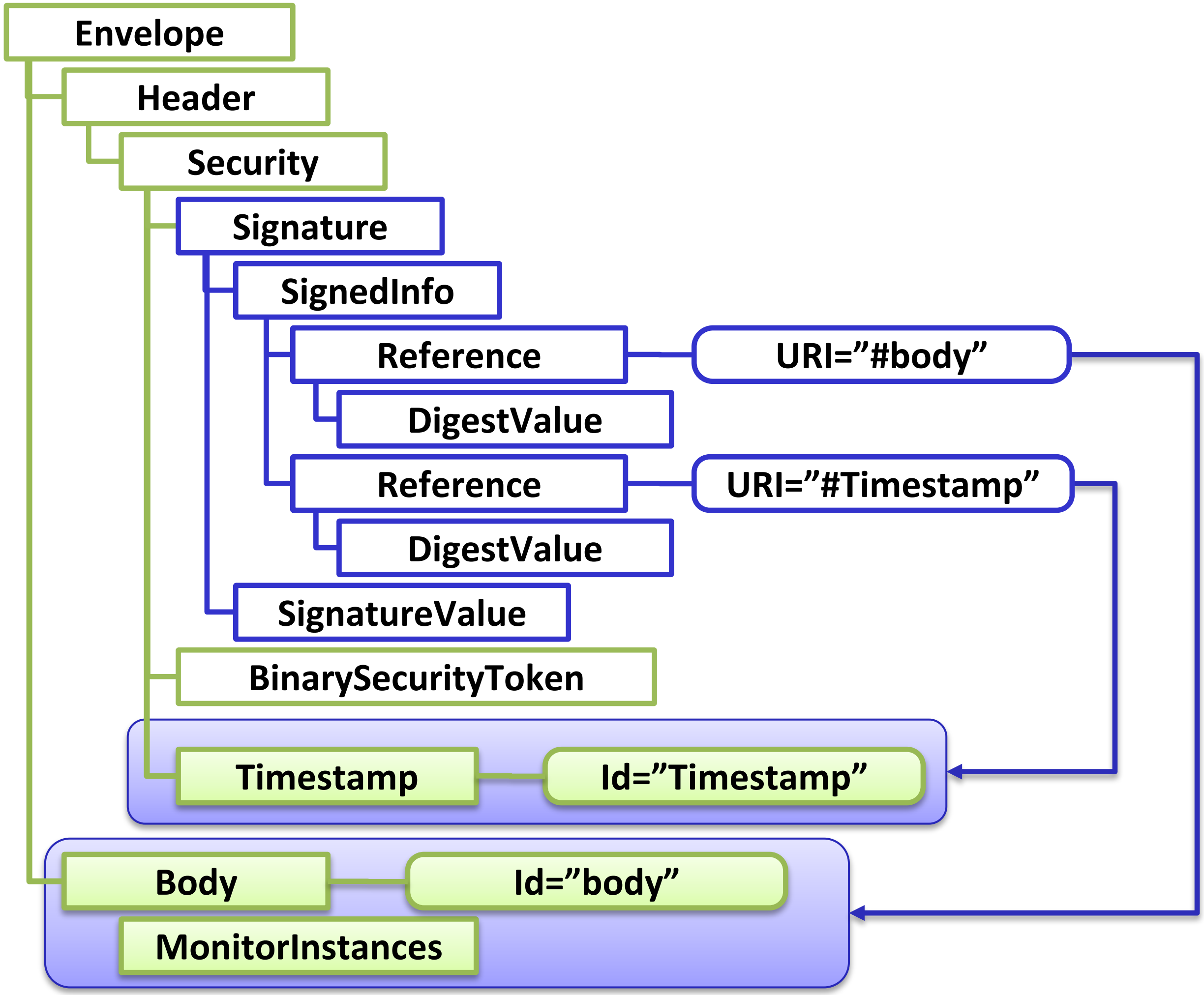
Amazon EC2 SOAP Interface

Monitoring of running instances:

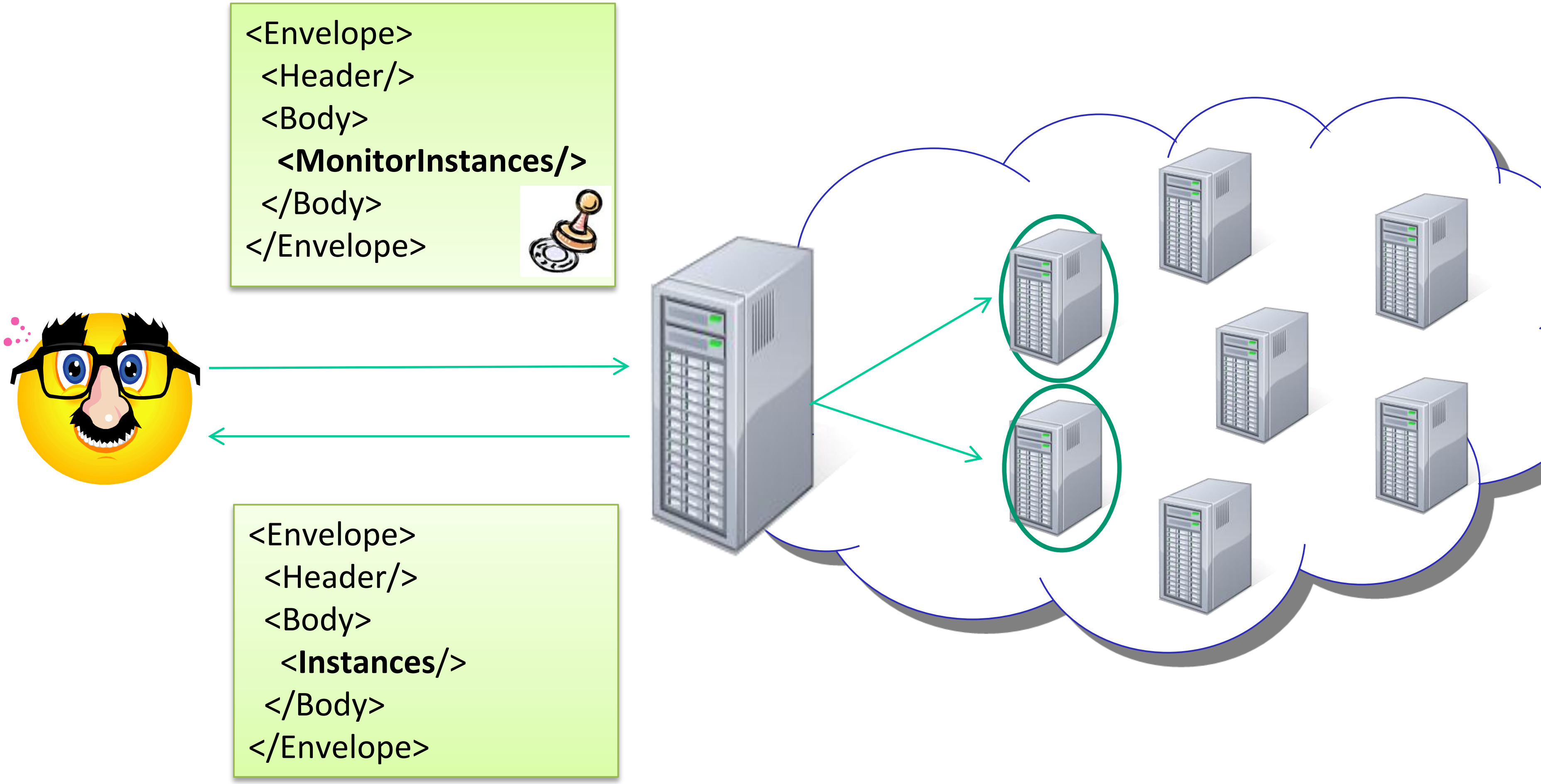
```
<Envelope>
  <Header />
  <Body>
    <MonitorInstances>
      <InstanceId> instance </InstanceId>
    </MonitorInstances>
  </Body>
</Envelope>
```



Amazon EC2 SOAP Interface - XML Signature



Amazon EC2 SOAP Interface - XML Signature



```
<Envelope>
  <Header/>
  <Body>
    <MonitorInstances/>
  </Body>
</Envelope>
```

```
<Envelope>
  <Header/>
  <Body>
    <Instances/>
  </Body>
</Envelope>
```

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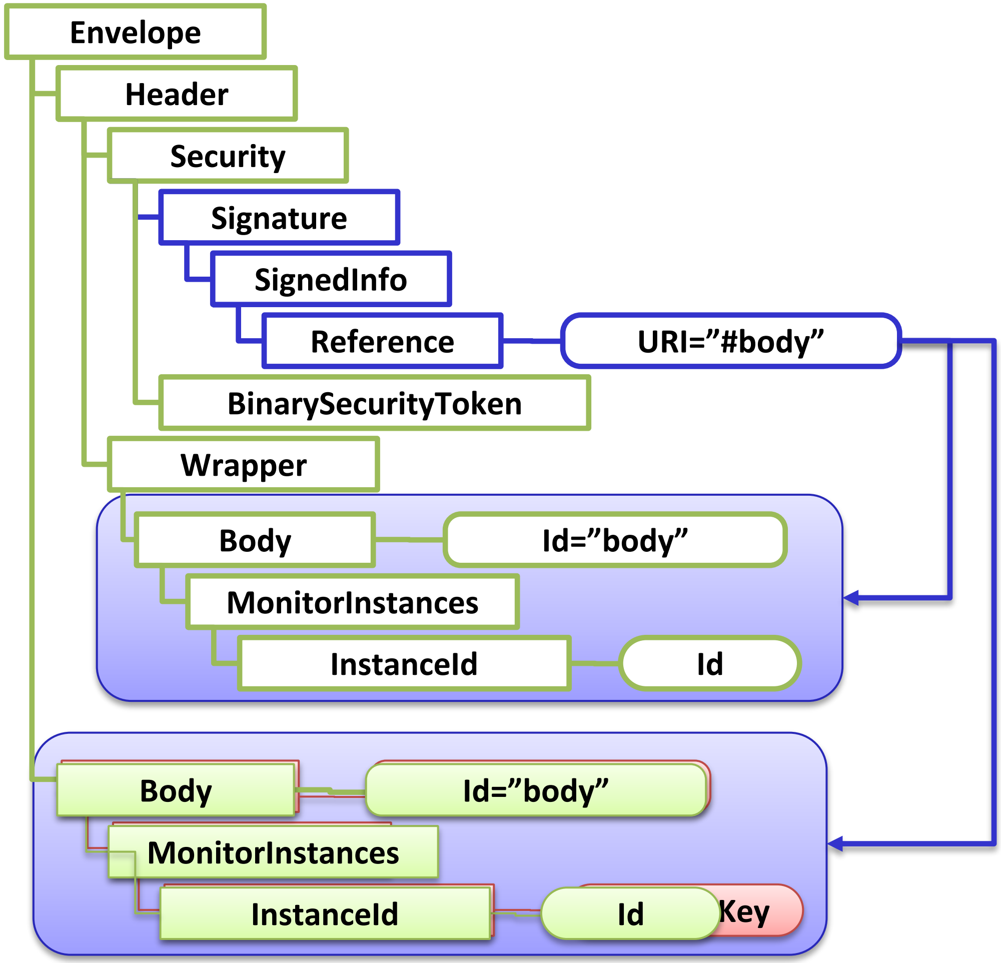
XML Signature Wrapping



The same attack on the Timestamp!

McIntosh and Austel. XML Signature Element Wrapping attacks, 2005

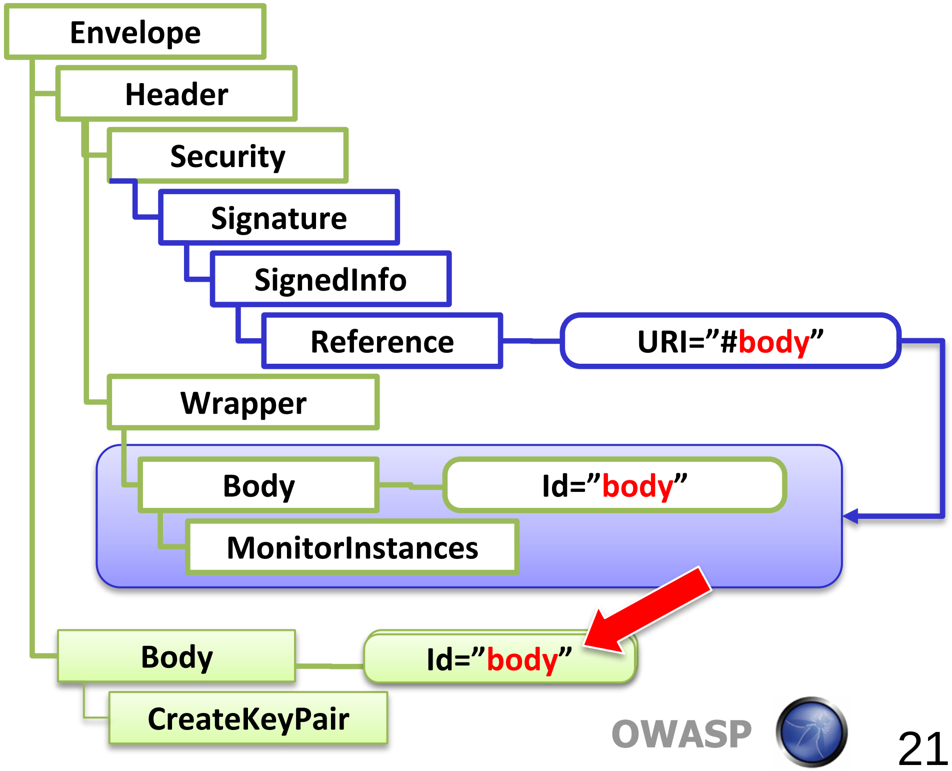
XML Signature Wrapping on Eucalyptus

- Attack by McIntosh and Austel directly applicable
- Eucalyptus: Open Source
- Reason: Problem in Apache Axis Web Services Framework

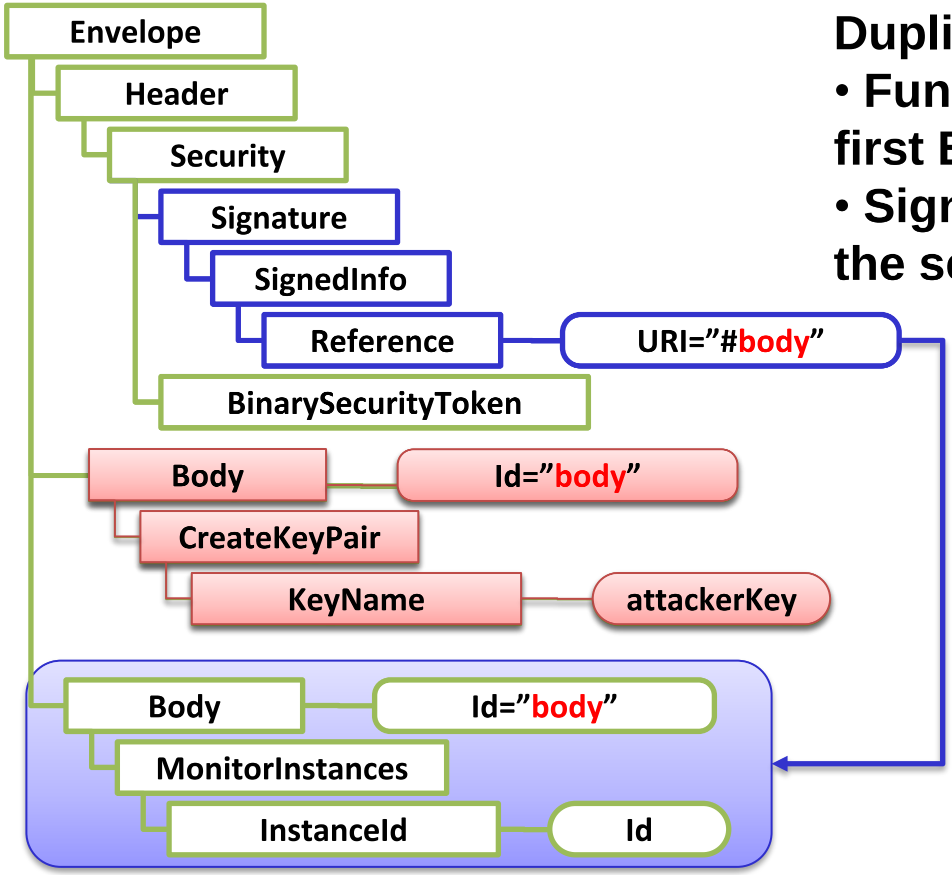
- CVE-2011-0730

XML Signature Wrapping on Amazon

- Attack from McIntosh & Austel does not work
- Amazon checks, if the Id of the signed element equals to the Id of the processed element
- But what happens if we use two elements with the same Id?
- Which element is used for signature validation?
- Which for function execution?



XML Signature Wrapping on Amazon



Duplicate the Body element:

- Function invocation from the first Body element
- Signature verification over the second Body element

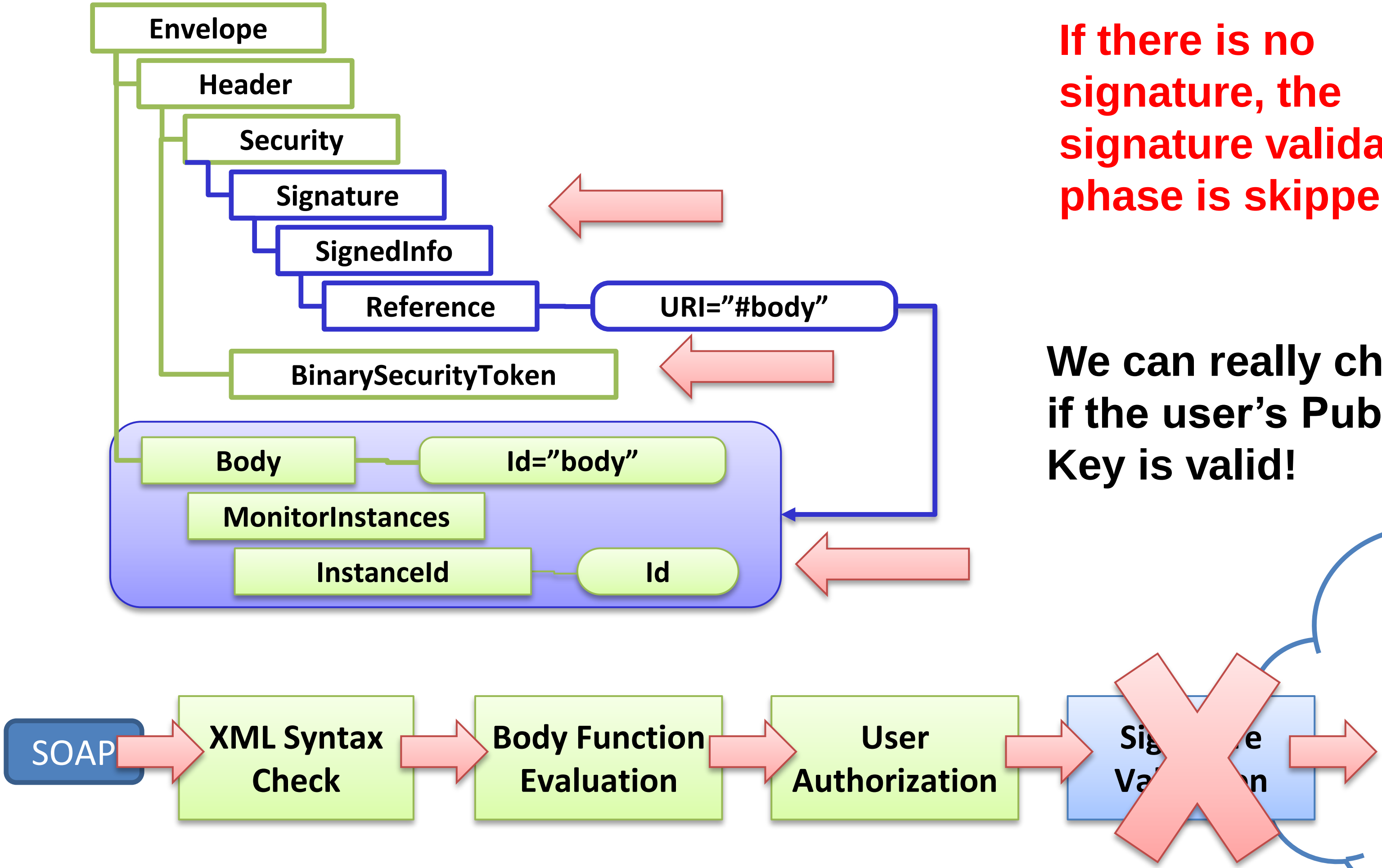
The same attack on the Timestamp!

XML Signature Wrapping on Amazon - Analysis

- Amazon: No Open Source
- Analysis using the SOAP error messages
  - The timestamp has expired
  - The timestamp or body was not signed
  - The certificate holder could not be authorized
  - The signature was invalid
- SOAP error messages = really good source of information

- We sent different hand-crafted messages to the Amazon EC2 interface

XML Signature Wrapping on Amazon - Analysis

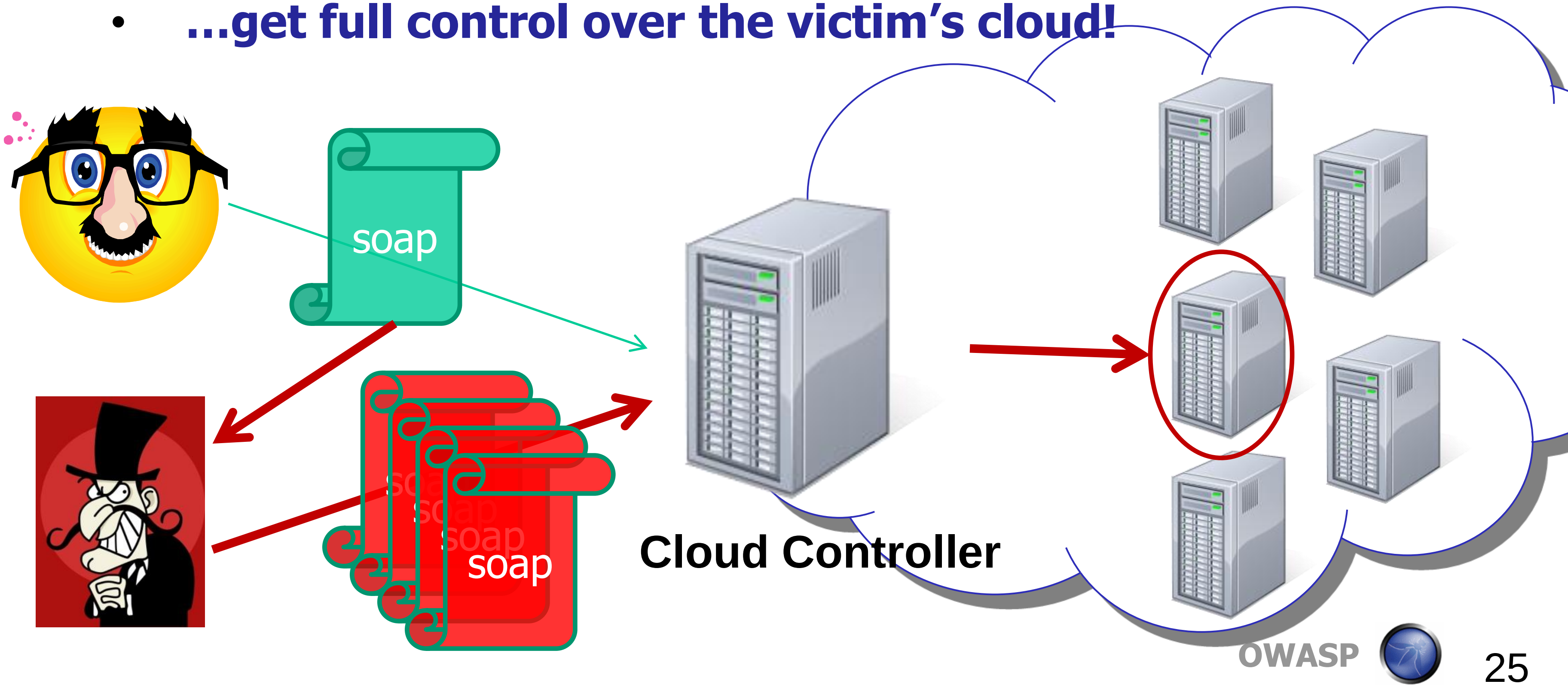


If there is no signature, the signature validation phase is skipped!

We can really check if the user’s Public Key is valid!

XML Signature Wrapping on Amazon - Analysis

- Works only for the Amazon EC2 / Eucalyptus SOAP interface
- One valid SOAP message is enough to:
  - Start and stop cloud instances
  - Download and upload virtual images
  - **...get full control over the victim's cloud!**



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XML Signature Wrapping - Conclusion

- We showed practical critical Signature Wrapping attacks on Amazon and Eucalyptus Cloud Interfaces
- All the vulnerabilities have been fixed
- XML Signature Wrapping attacks are known since 2005, but:
  - Are not in focus of research community
  - Nearly all implementations are vulnerable
- Please be aware of Signature Wrapping when applying XML Signatures
  - In Web Services
  - SAML (Single Sign-On)
  - Custom applications
- There are more attacks coming soon

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XML Encryption

- W3C standard for encrypting XML data (published in 2002)
- Describes various methods for applying
  - Symmetric ciphers (AES-CBC, 3DES-CBC)
  - Public-key encryption (e.g. RSA-PKCS#1)

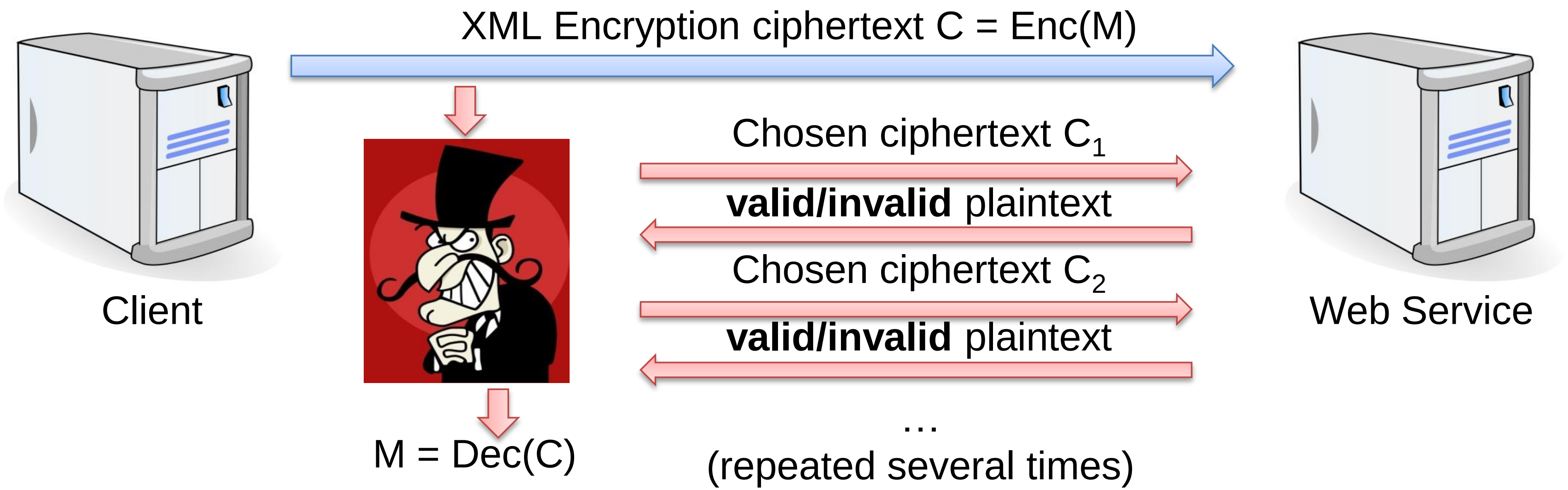
```
<PaymentInfo>
  <Name>John Smith</Name>
  <CreditCard Limit='5,000'>
    <Number>4019 ...5567</Number>
    <Issuer>Example Bank</Issuer>
    <Expiration>04/02</Expiration>
  </CreditCard>
</PaymentInfo>
```

```
<PaymentInfo>

  <EncryptedData Id="EncData">
    <EncryptionMethod Algorithm="...xmlenc#aes128-cbc"/>
    …<CipherValue>3bP...Zx0=</CipherValue>…
  </EncryptedData>

</PaymentInfo>
```

XML Encryption

- Attack on XML Encryption
- All major Web Services frameworks vulnerable
    - Apache Axis 2
    - RedHat JBoss
    - IBM WebSphere
    - Microsoft .NET
    - And more (recently discovered)
- Also applicable to XML-based Single Sign-On (recently discovered)

XML Encryption – Attack Scenario



What is a “valid” plaintext?

How to use Web Service as “plaintext validity oracle”?

How to use this oracle to decrypt C?

- How to create useful chosen ciphertexts C_1, C_2, …?

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Decrypting by checking plaintext validity

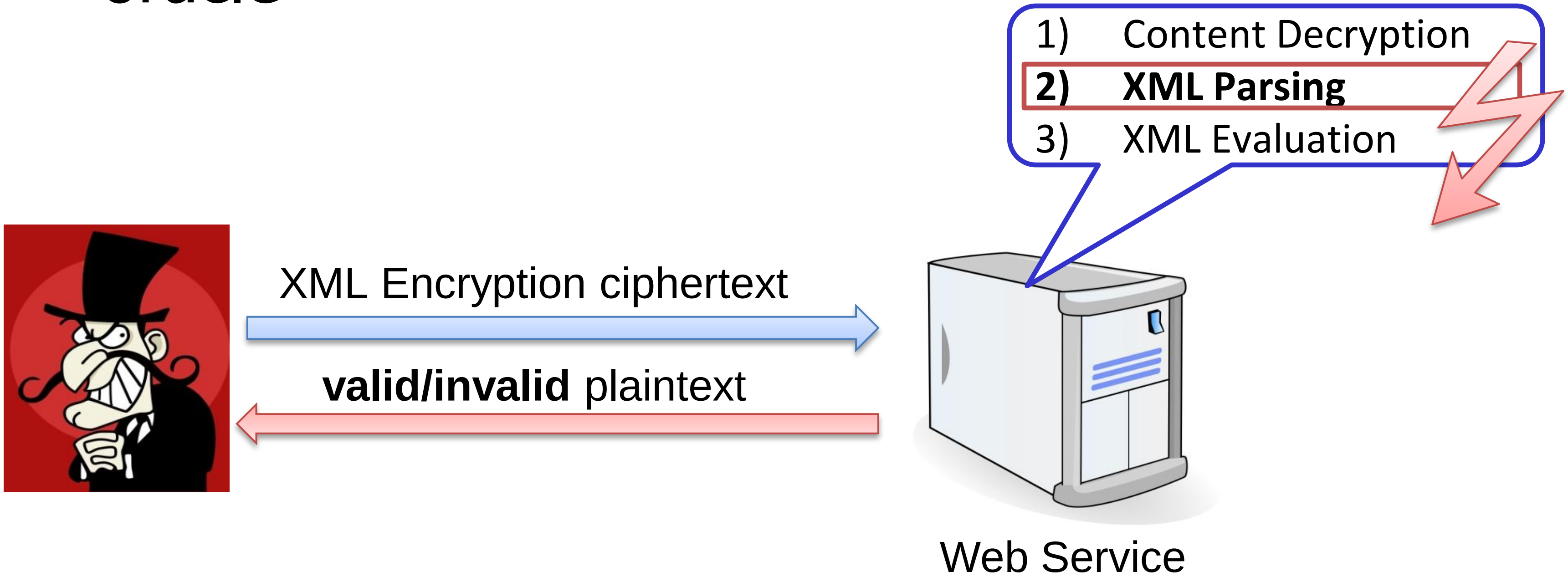
- XML is a text-based data format
- Characters (usually) encoded in ASCII
  - Type A: “special” characters

    EOF, BEL, ACK, …, <, &, …
  - Type B: other

    A,B,C, …, a,b,c, …, 1,2,3, …, !, %, …
- This talk:
  “Valid” plaintext contains **no Type-A** character

Decrypting by checking plaintext validity

- Using Web Services Server as plaintext validity oracle



1) Content Decryption

2) XML Parsing

3) XML Evaluation

XML Encryption ciphertext

valid/invalid plaintext

Web Service

- Invalid plaintext => Parsing error
- Parsing error => Fault message (or another side channel)

Consider ASCII character $M_1 = (0,b_1,b_2,b_3,b_4,b_5,b_6,b_7)$

0x00	(Type A)	0x20		0x40	@	0x60	'
0x01	(Type A)	0x21	!	0x41	A	0x61	a
0x02	(Type A)	0x22	"	0x42	B	0x62	b
0x03	(Type A)	0x23	#	0x43	C	0x63	c
0x04	(Type A)	0x24	$	0x44	D	0x64	d
0x05	(Type A)	0x25	%	0x45	E	0x65	e
0x06	(Type A)	0x26	&	0x46	F	0x66	f
0x07	(Type A)	0x27	'	0x47	G	0x67	g
0x08	(Type A)	0x28	(	0x48	H	0x68	h
0x09	HT	0x29	)	0x49	I	0x69	i
0x0A	LF	0x2A	*	0x4A	J	0x6A	j
0x0B	(Type A)	0x2B	+	0x4B	K	0x6B	k
0x0C	(Type A)	0x2C	,	0x4C	L	0x6C	l
0x0D	CR	0x2D	-	0x4D	M	0x6D	m
0x0E	(Type A)	0x2E	.	0x4E	N	0x6E	n
0x0F	(Type A)	0x2F	/	0x4F	O	0x6F	o
0x10	(Type A)	0x30	0	0x50	P	0x70	p
0x11	(Type A)	0x31	1	0x51	Q	0x71	q
0x12	(Type A)	0x32	2	0x52	R	0x72	r
0x13	(Type A)	0x33	3	0x53	S	0x73	s
0x14	(Type A)	0x34	4	0x54	T	0x74	t
0x15	(Type A)	0x35	5	0x55	U	0x75	u
0x16	(Type A)	0x36	6	0x56	V	0x76	v
0x17	(Type A)	0x37	7	0x57	W	0x77	w
0x18	(Type A)	0x38	8	0x58	X	0x78	x
0x19	(Type A)	0x39	9	0x59	Y	0x79	y
0x1A	(Type A)	0x3A	:	0x5A	Z	0x7A	z
0x1B	(Type A)	0x3B	;	0x5B	[	0x7B	{
0x1C	(Type A)	0x3C	<	0x5C	\	0x7C	|
0x1D	(Type A)	0x3D	=	0x5D	]	0x7D	}
0x1E	(Type A)	0x3E	>	0x5E	^	0x7E	~
0x1F	(Type A)	0x3F	?	0x5F	_	0x7F	DEL

Type A

Type B

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Decrypting by checking plaintext validity

- ASCII exhibits nice pattern of Type A/B characters
- Suppose we can transform Enc(M) into Enc(M ⊕ msk) for any msk
  - **We can flip arbitrary plaintext bits, given only the ciphertext**
- Approach: Given C = Enc(M),
  1. Modify plaintext character-wise
  2. Query the “oracle” with each modified ciphertext
  3. Observe whether plaintext remains “valid” or not

Decrypting by checking plaintext validity

- **Example**
- We have eavesdropped a ciphertext
  C = Enc(“ACMCCS11”)
- We recover M = “ACMCCS11” character-wise
- How to determine (b_1,b_2) of M_1 = “A”?

Consider ASCII character $M_1 = (0, b_1, b_2, b_3, b_4, b_5, b_6, b_7)$

0x00	(Type A)	0x20		0x40	@	0x60	'
0x01	(Type A)	0x21	!	0x41	A	0x61	a
0x02	(Type A)	0x22	"	0x42	B	0x62	b
0x03	(Type A)	0x23	#	0x43	C	0x63	c
0x04	(Type A)	0x24	$	0x44	D	0x64	d
0x05	(Type A)	0x25	%	0x45	E	0x65	e
0x06	(Type A)	0x26	&	0x46	F	0x66	f
0x07	(Type A)	0x27	'	0x47	G	0x67	g
0x08	(Type A)	0x28	(	0x48	H	0x68	h
0x09	HT	0x29	)	0x49	I	0x69	i
0x0A	LF	0x2A	*	0x4A	J	0x6A	j
0x0B	(Type A)	0x2B	+	0x4B	K	0x6B	k
0x0C	(Type A)	0x2C	,	0x4C	L	0x6C	l
0x0D	CR	0x2D	-	0x4D	M	0x6D	m
0x0E	(Type A)	0x2E	.	0x4E	N	0x6E	n
0x0F	(Type A)	0x2F	/	0x4F	O	0x6F	o
0x10	(Type A)	0x30	0	0x50	P	0x70	p
0x11	(Type A)	0x31	1	0x51	Q	0x71	q
0x12	(Type A)	0x32	2	0x52	R	0x72	r
0x13	(Type A)	0x33	3	0x53	S	0x73	s
0x14	(Type A)	0x34	4	0x54	T	0x74	t
0x15	(Type A)	0x35	5	0x55	U	0x75	u
0x16	(Type A)	0x36	6	0x56	V	0x76	v
0x17	(Type A)	0x37	7	0x57	W	0x77	w
0x18	(Type A)	0x38	8	0x58	X	0x78	x
0x19	(Type A)	0x39	9	0x59	Y	0x79	y
0x1A	(Type A)	0x3A	:	0x5A	Z	0x7A	z
0x1B	(Type A)	0x3B	;	0x5B	[	0x7B	{
0x1C	(Type A)	0x3C	<	0x5C	\	0x7C	|
0x1D	(Type A)	0x3D	=	0x5D	]	0x7D	}
0x1E	(Type A)	0x3E	>	0x5E	^	0x7E	~
0x1F	(Type A)	0x3F	?	0x5F	_	0x7F	DEL

Type A

Type B

OWASP

Consider ASCII character $M_1 = (0,b_1,b_2,b_3,b_4,b_5,b_6,b_7)$

0x00	(Type A)	0x20		0x40	@	0x60	'
0x01	(Type A)	0x21	!	0x41	A	0x61	a
0x02	(Type A)	0x22	"	0x42	B	0x62	b
0x03	(Type A)	0x23	#	0x43	C	0x63	c
0x04	(Type A)	0x24	$	0x44	D	0x64	d
0x05	(Type A)	0x25	%	0x45	E	0x65	e
0x06	(Type A)	0x26	&	0x46	F	0x66	f
0x07	(Type A)	0x27	'	0x47	G	0x67	g
0x08	(Type A)	0x28	(	0x48	H	0x68	h
0x09	HT	0x29	)	0x49	I	0x69	i
0x0A	LF	0x2A	*	0x4A	J	0x6A	j
0x0B	(Type A)	0x2B	+	0x4B	K	0x6B	k
0x0C	(Type A)	0x2C	,	0x4C	L	0x6C	l
0x0D	CR	0x2D	-	0x4D	M	0x6D	m
0x0E	(Type A)	0x2E	.	0x4E	N	0x6E	n
0x0F	(Type A)	0x2F	/	0x4F	O	0x6F	o
0x10	(Type A)	0x30	0	0x50	P	0x70	p
0x11	(Type A)	0x31	1	0x51	Q	0x71	q
0x12	(Type A)	0x32	2	0x52	R	0x72	r
0x13	(Type A)	0x33	3	0x53	S	0x73	s
0x14	(Type A)	0x34	4	0x54	T	0x74	t
0x15	(Type A)	0x35	5	0x55	U	0x75	u
0x16	(Type A)	0x36	6	0x56	V	0x76	v
0x17	(Type A)	0x37	7	0x57	W	0x77	w
0x18	(Type A)	0x38	8	0x58	X	0x78	x
0x19	(Type A)	0x39	9	0x59	Y	0x79	y
0x1A	(Type A)	0x3A	:	0x5A	Z	0x7A	z
0x1B	(Type A)	0x3B	;	0x5B	[	0x7B	{
0x1C	(Type A)	0x3C	<	0x5C	\	0x7C	|
0x1D	(Type A)	0x3D	=	0x5D	]	0x7D	}
0x1E	(Type A)	0x3E	>	0x5E	^	0x7E	~
0x1F	(Type A)	0x3F	?	0x5F	_	0x7F	DEL

Type A

Type B

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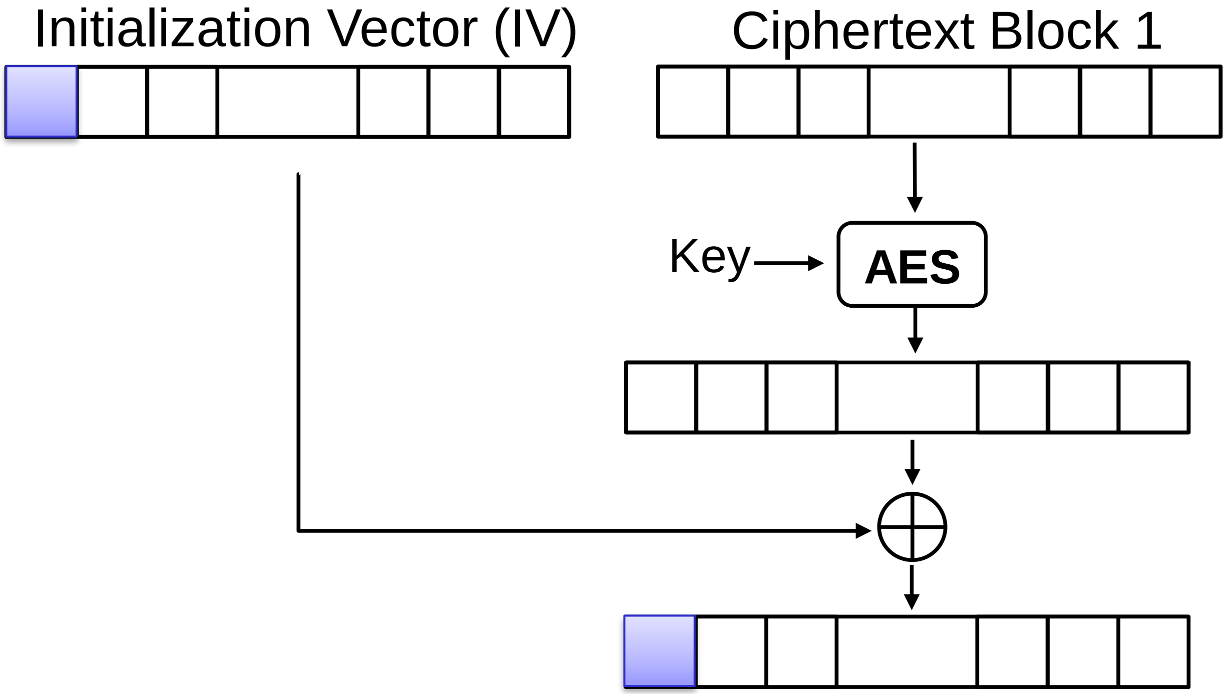
Computing Enc(M $\oplus$ msk) from Enc(M)

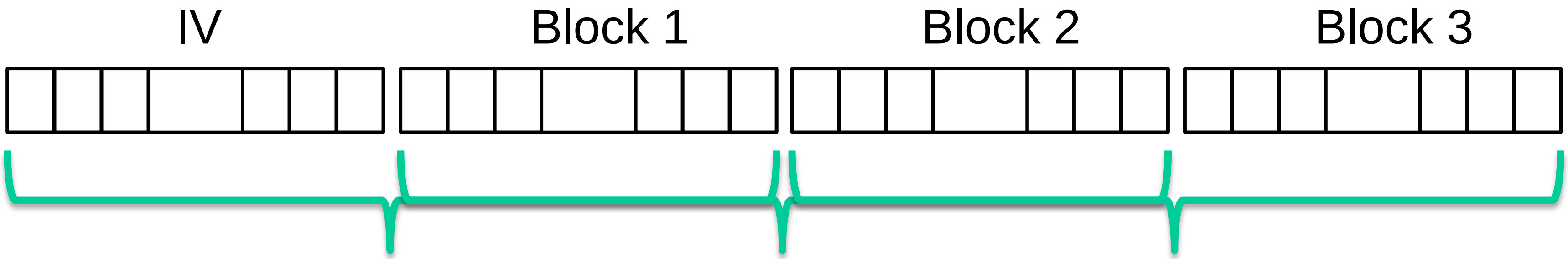
- XML Encryption uses block ciphers in *cipher-block chaining* (CBC) mode
- Known weakness of CBC
  - Padding oracle attacks
    (Vaudenay Eurocrypt 2002, and many more)
  - Error oracle attacks
    (Mitchell ISC 2005)
  - Chosen-plaintext attacks on SSL
    (Bard Cryptology ePrint 2004, Duong and Rizzo Ekoparty 2011)

Computing Enc(M ⊕ msk) from Enc(M)



- Transform encryption of M into encryption of M ⊕ msk for arbitrary msk!
- Applicable only to single-block ciphertexts

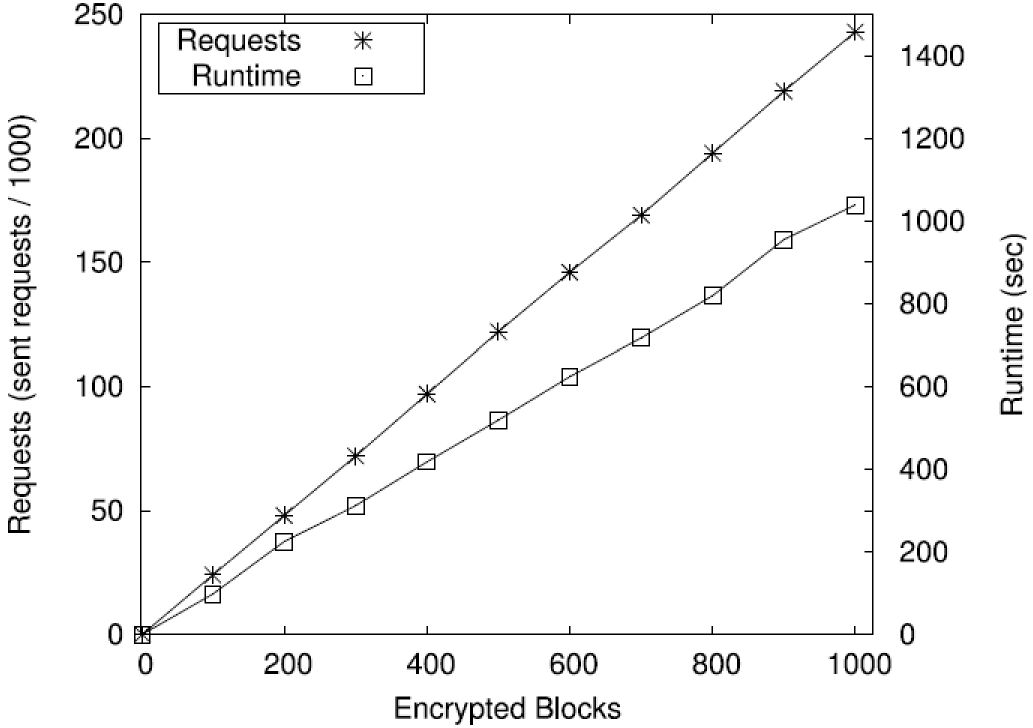
Multi-block ciphertexts



- CBC: Each block serves as IV for next block
  - Long ciphertexts “consist of many single-block ciphertexts”
- Apply single-block attack to decrypt longer ciphertexts block-wise
  - Decrypt Block 1
  - Decrypt Block 2 with Block 1 as IV
  - Decrypt Block *i+1* with Block *i* as IV

Experimental Results

Apache Axis 2, localhost, random plaintexts:



- Timing depends on system performance, network latency, ...
- Approx. 14 server requests/plaintext byte
  - Padding oracle attacks: ca. 128 requests/byte

Improvements and Variations

- XML schema is often public
  - Known structure of XML document
  - Skip blocks containing known plaintext
- Reduced plaintext set
  - Numbers, Base64, “Yes”/”No”, etc.
  - Less plaintext validity checks
- *Encryption* is possible, too
  (Following Rizzo and Duong, Usenix WOOT 2010)

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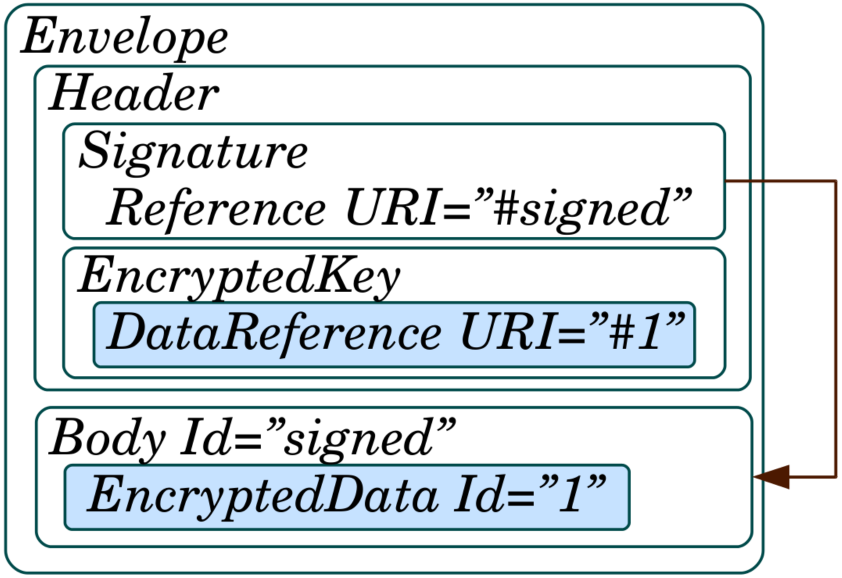
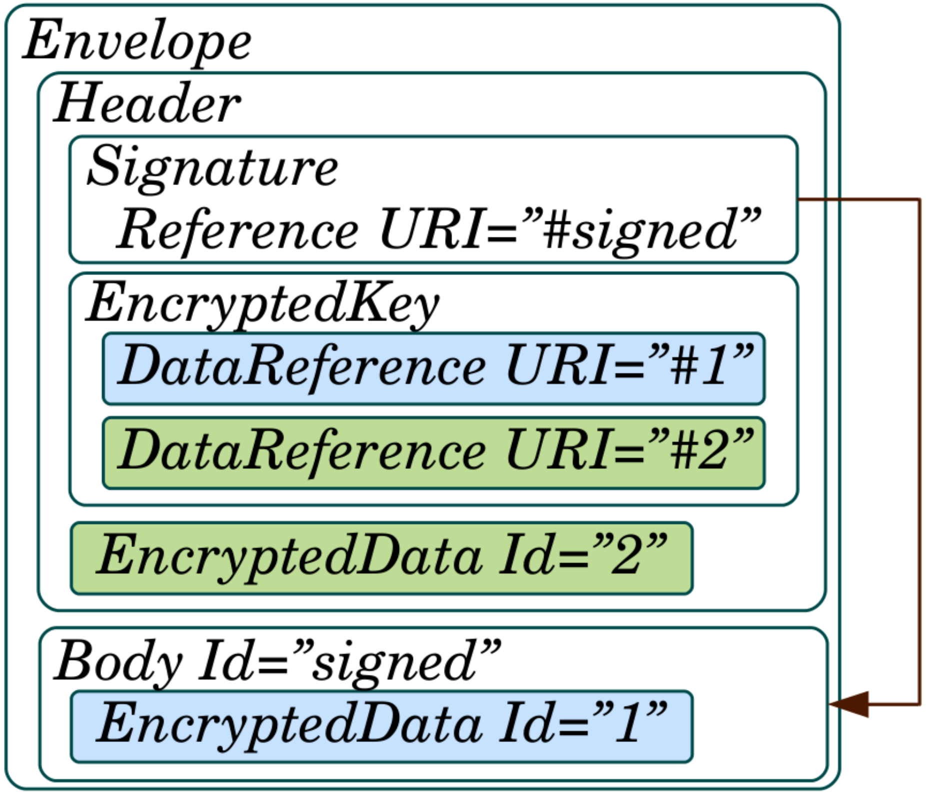
Countermeasures

- XML Signature
  - Signature Wrapping attacks
  - **Encryption Wrapping attack:** WS-Security Policy says, what must be encrypted…but it says not, what must not be encrypted





Countermeasures

- Authenticated encryption!
  - Not a standard-conformant option

Breaking XML Encryption – Conclusion

- Attack on XML Encryption
  - Applicable in particular to Web Services
  - All major WS frameworks are vulnerable
- No generic *ad-hoc* countermeasure
- W3C plans update of XML Encryption standard

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Conclusion

- XML Security applies cryptographic primitives on the message level
- It brings advantages in many applications: business process scenarios, Single Sign-On …
- However, the attacks exist…
  1. XML Signature Wrapping: pay attention when applying XML Signatures in your applications
  2. XML Encryption is broken:
     - You can use XML Signatures to ensure authenticity: XML Signature and XML Encryption Wrapping?
     - There are different countermeasures, but they are application and scenario specific
     - New standard with another chaining mode coming soon

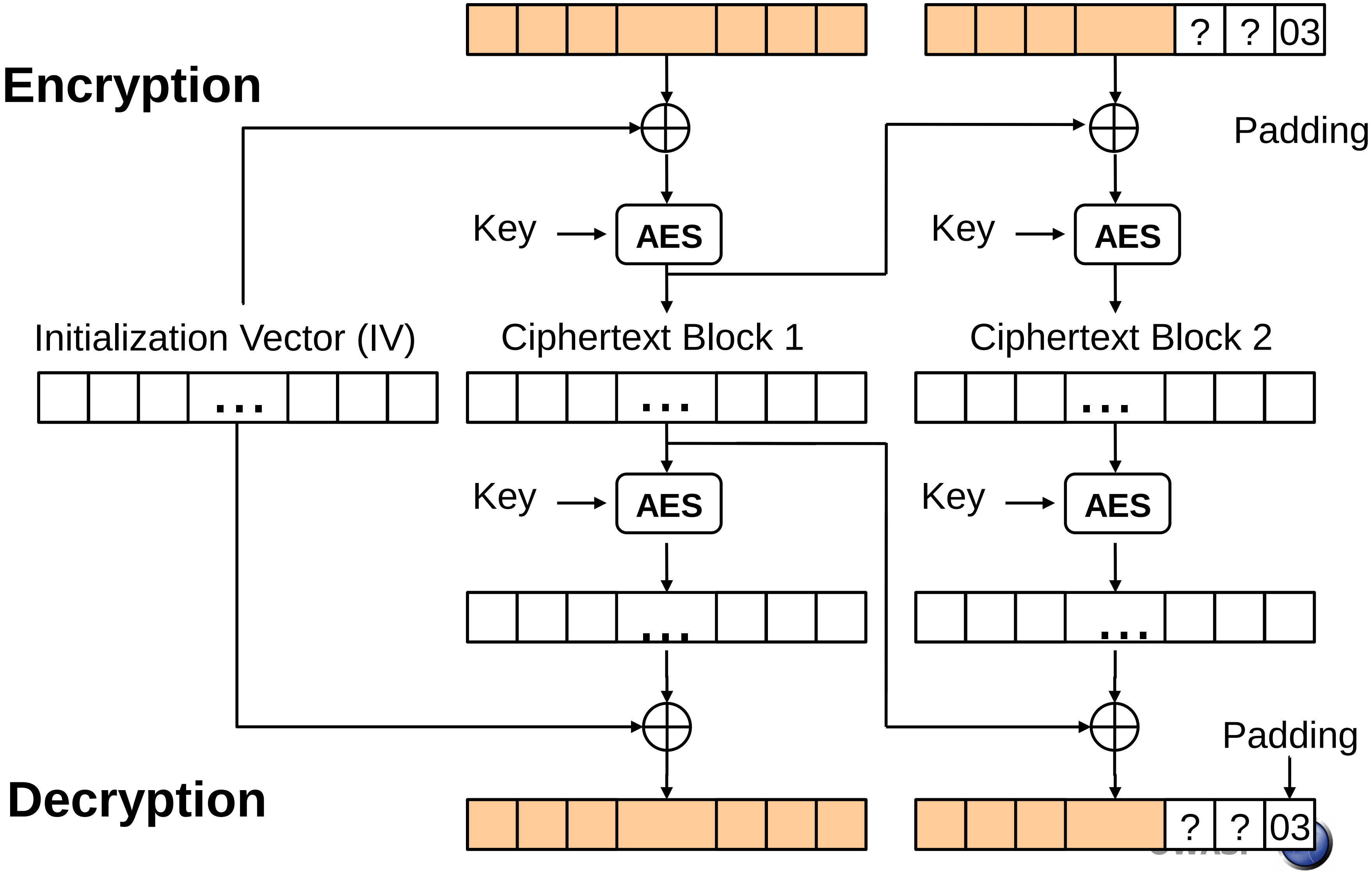
Responsible disclosure

- Attack disclosed in Feb 2011 to:
  - W3C, Apache, IBM, RedHat JBoss, Microsoft, governmental CERTs, vendor-sec mailing list, …
  - All have confirmed that attack is applicable
- Intensive cooperation with some developers
  - More than 100 e-mails since Feb 2011
- In contact with W3C working group
  - Authenticated encryption planned for v2.0

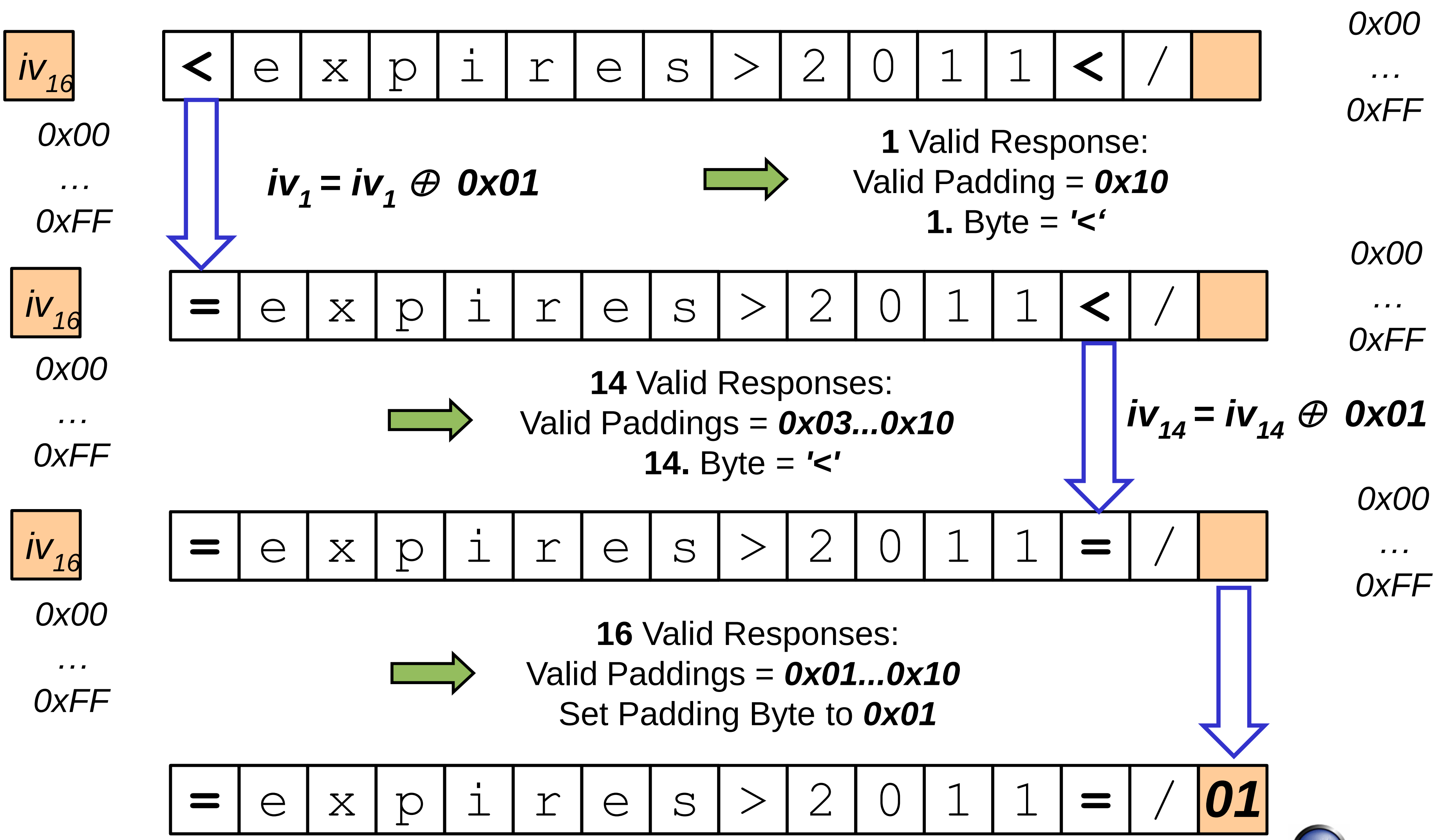
XML Signature Wrapping - Countermeasures

- Amazon Countermeasure + checking for duplicate Ids:
  - Not as easy as it seems to be
  - Id vs ID vs wsu:Id ….?
  - XML Entities?
- See what is signed:
  - Validate signature first
  - Forward only validated document parts
  - XML message becomes not well-formed, could lead to problems e.g. in XML Security Gateways
- Usage of XPath for position fixation
  - Another attacks [Jensen et al.: The curse of namespaces in the domain of xml signature]

CBC and padding in XML Encryption



Extracting ‘<‘



iv_{16}

0x00 … 0xFF

<	e	x	p	i	r	e	s	>	2	0	1	1	<	/	

0x00 … 0xFF

$iv_1 = iv_1 \oplus 0x01$

1 Valid Response:
Valid Padding = ***0x10***
1. Byte = ***'<‘***

iv_{16}

0x00 … 0xFF

=	e	x	p	i	r	e	s	>	2	0	1	1	<	/	

0x00 … 0xFF

14 Valid Responses:
Valid Paddings = ***0x03…0x10***
14. Byte = ***'<'***

$iv_{14} = iv_{14} \oplus 0x01$

iv_{16}

0x00 … 0xFF

=	e	x	p	i	r	e	s	>	2	0	1	1	=	/	

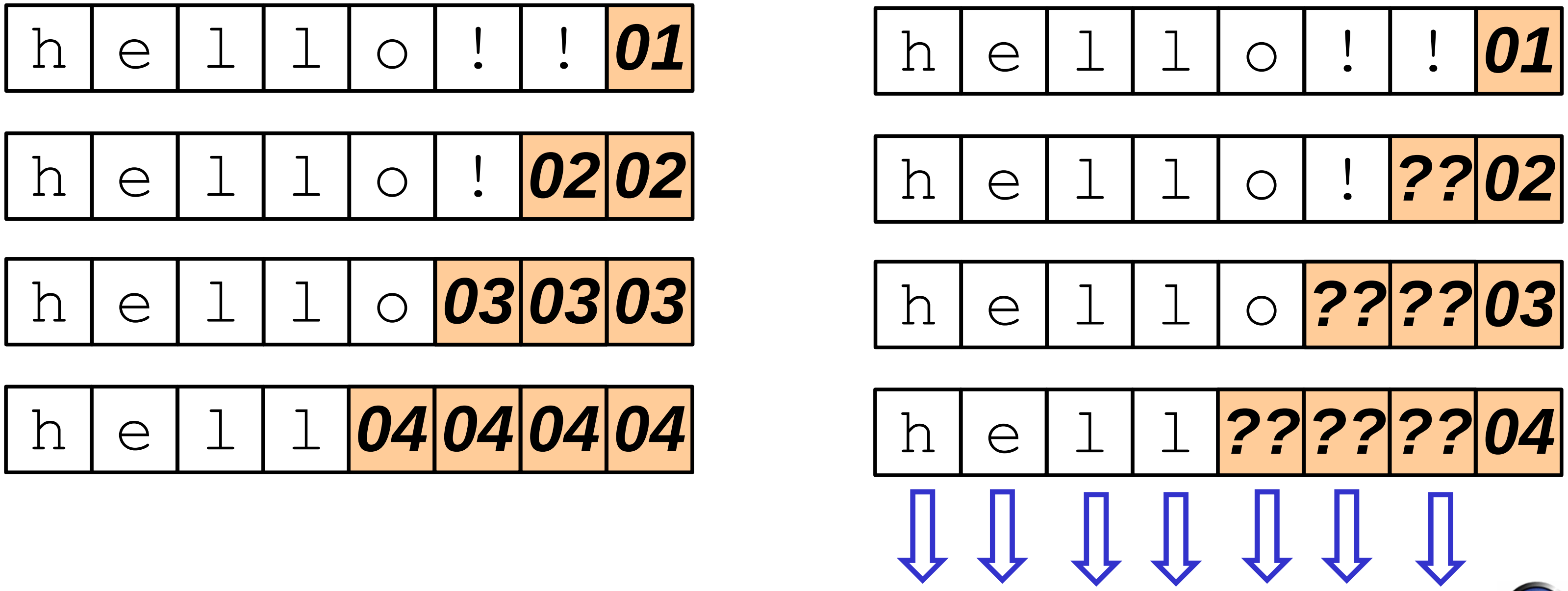
0x00 … 0xFF

16 Valid Responses:
Valid Paddings = ***0x01…0x10***
Set Padding Byte to ***0x01***

=	e	x	p	i	r	e	s	>	2	0	1	1	=	/	***01***

Difference to Vaudenay’s attack

- Misused security responses caused by incorrect **PKCS** padding
- Vaudenay: IPSEC, SSL, WTLS
- Rizzo and Duong: .NET Framework, JSF View States, Captchas



h	e	l	l	o	!	!	**01**
h	e	l	l	o	!	**02**	**02**
h	e	l	l	o	**03**	**03**	**03**
h	e	l	l	**04**	**04**	**04**	**04**

h	e	l	l	o	!	!	**01**
h	e	l	l	o	!	**??**	**02**
h	e	l	l	o	**??**	**??**	**03**
h	e	l	l	**??**	**??**	**??**	**04**