How to Break XML Encryption – Automatically

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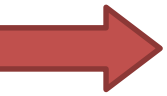
About Me and Our Institute

- Security Researcher at:
  - Chair for Network and Data Security
    - Prof. Dr. Jörg Schwenk
    - Web Services, Single Sign-On, (Applied) Crypto, SSL, crypto currencies
    - Provable security, attacks and defenses
  - Horst Görtz Institute for IT-Security
    - Further topics: embedded security, malware, crypto…
  - Ruhr University Bochum

- Penetration tests, security analyses, workshops…

Overview



1. What is a Web Service and XML Security
2. XML Signature Wrapping
3. Attacks on XML Encryption
4. Attacks on Symmetric Encryption Scheme
    1. Attack Scenario
    2. Plaintext Validity
    3. Using Web Service for Plaintext Validation
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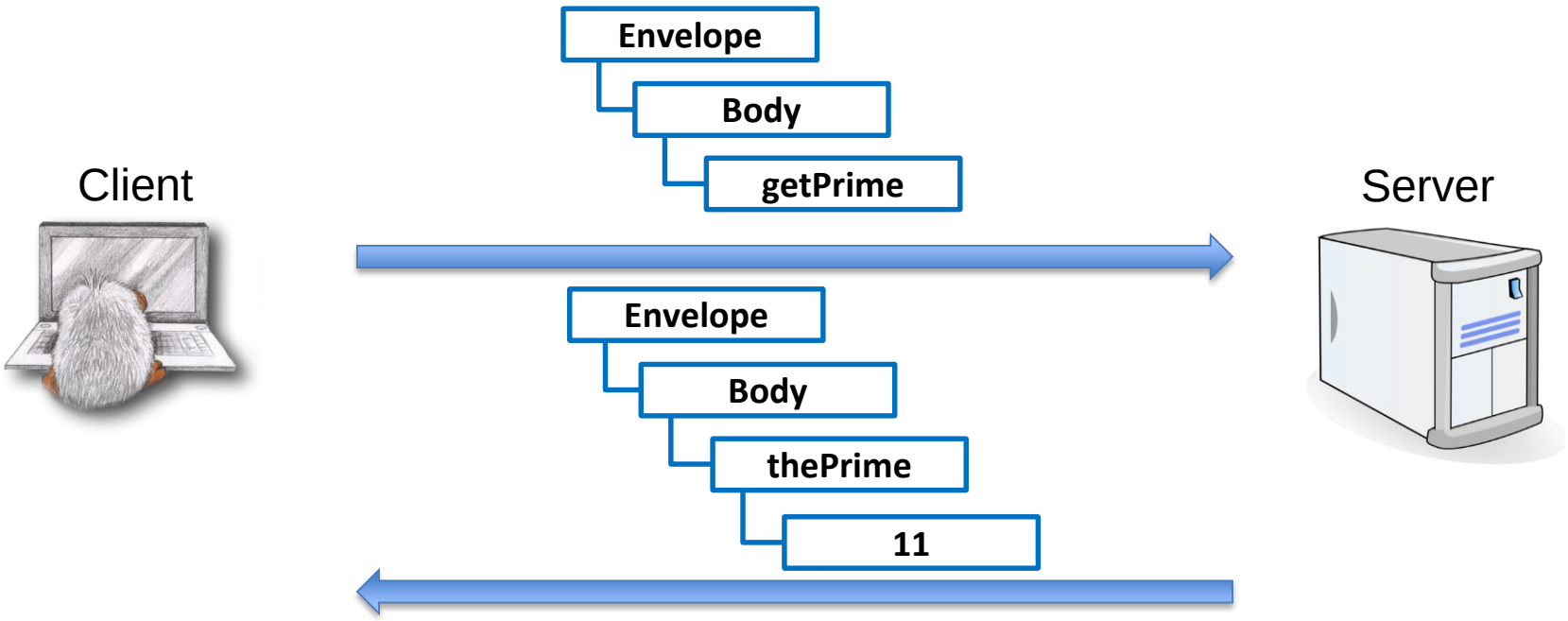
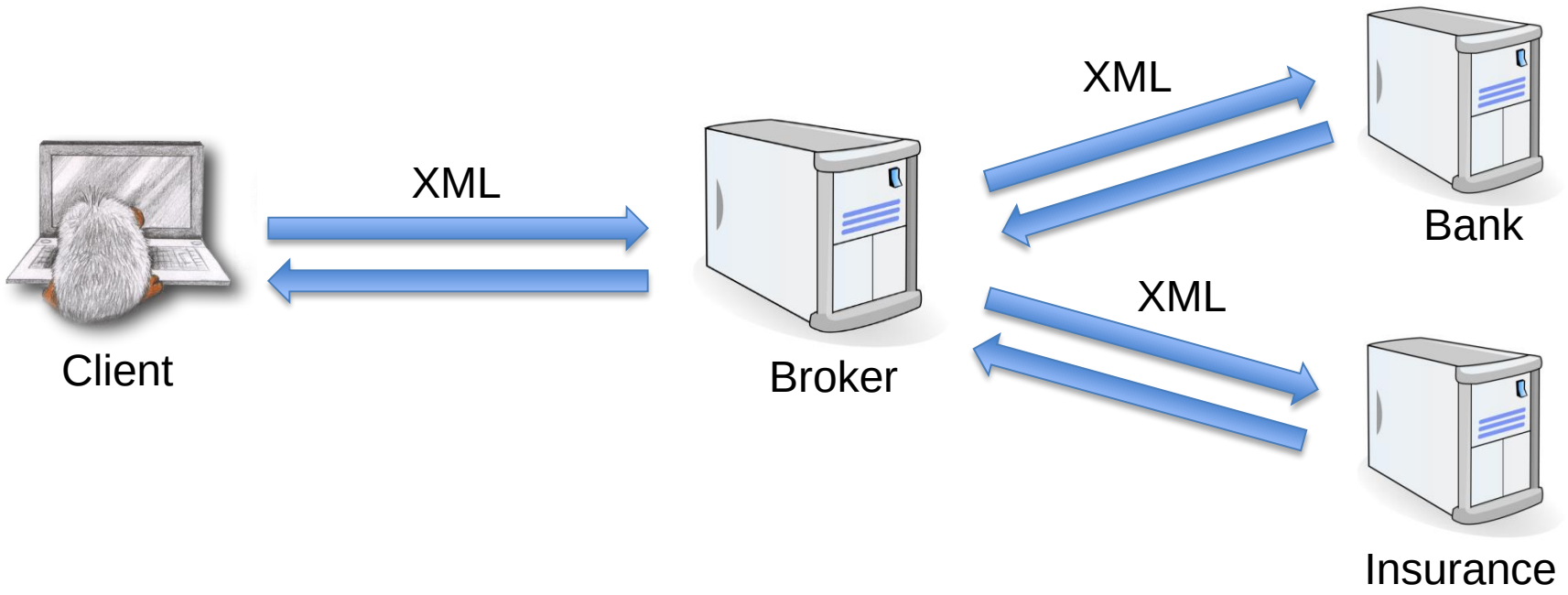
5. Countermeasures and Problems
6. WS-Attacker

What is a (SOAP) Web Service?

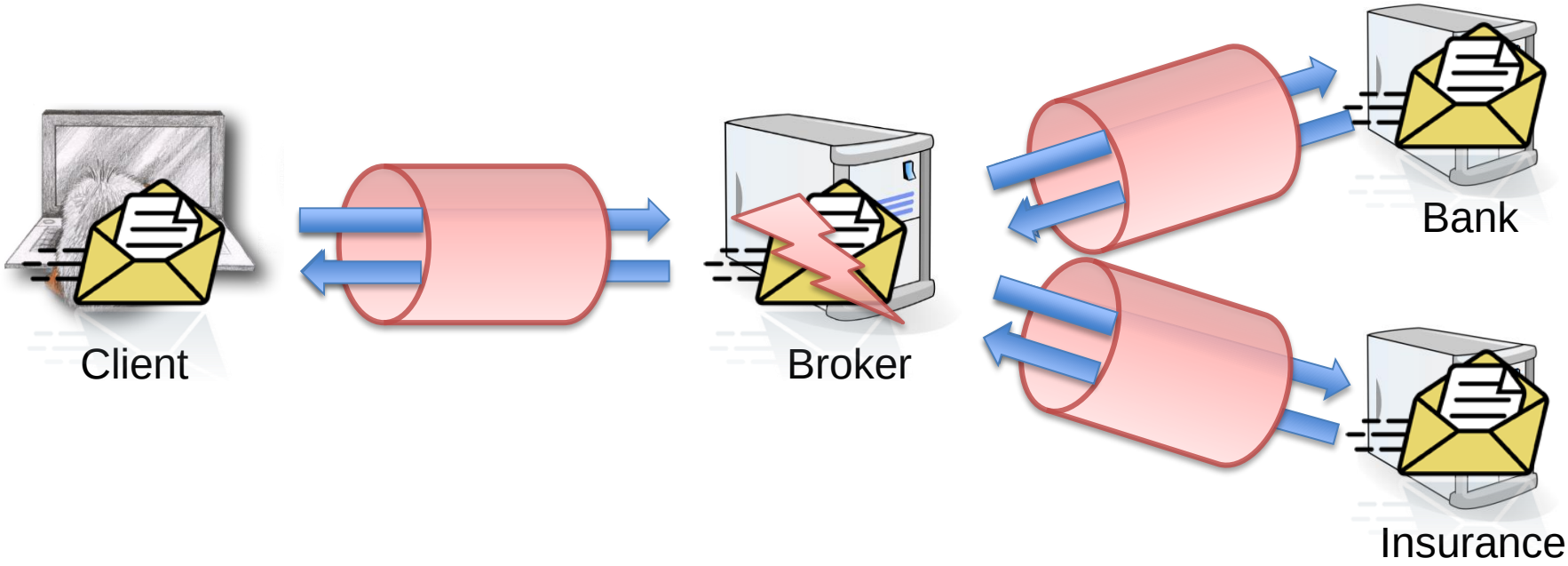


More complicated scenarios …



Security?

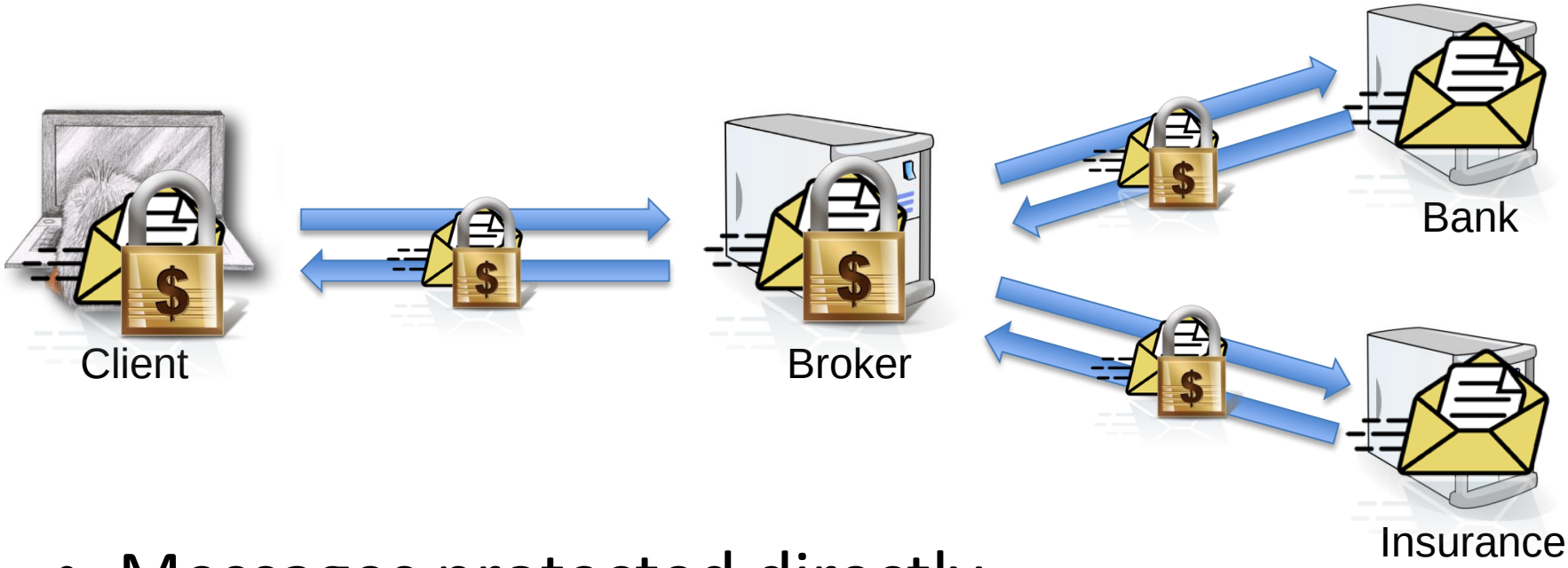
- SSL / TLS: Transport-Level Security



- Messages are only secured during transport

Motivation – XML Security

- Message Level Security



- Messages protected directly
- XML Security

XML Security

- Describes methods for applying cryptographic algorithms to XML
- **XML Signature**: protects authenticity and integrity
- **XML Encryption**: protects confidentiality
- Flexible

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

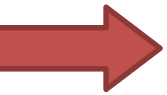
Dresdner Bank
Die Beraterbank

Sparkasse

COMMERZBANK

IBM WebSphere

Overview



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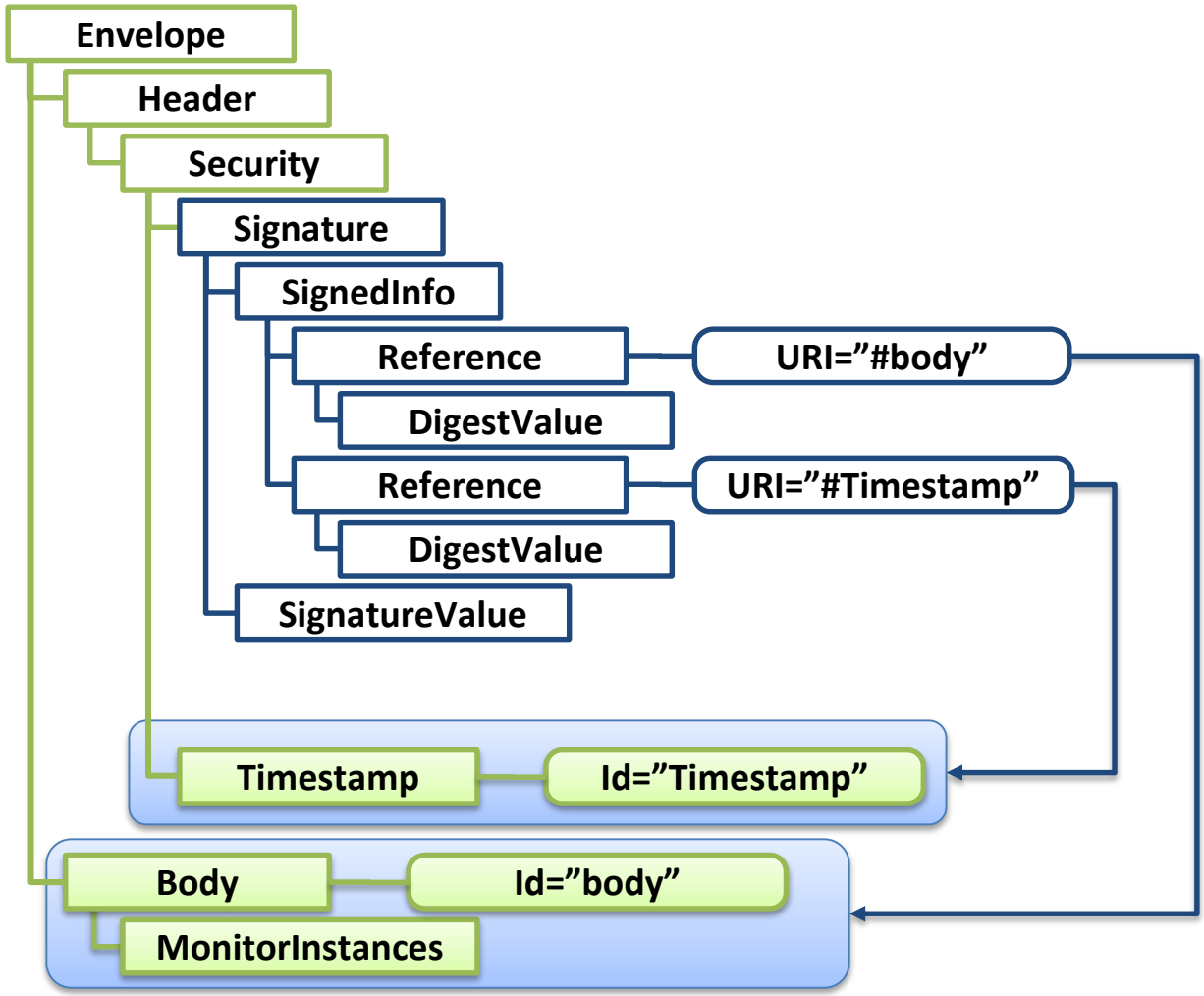
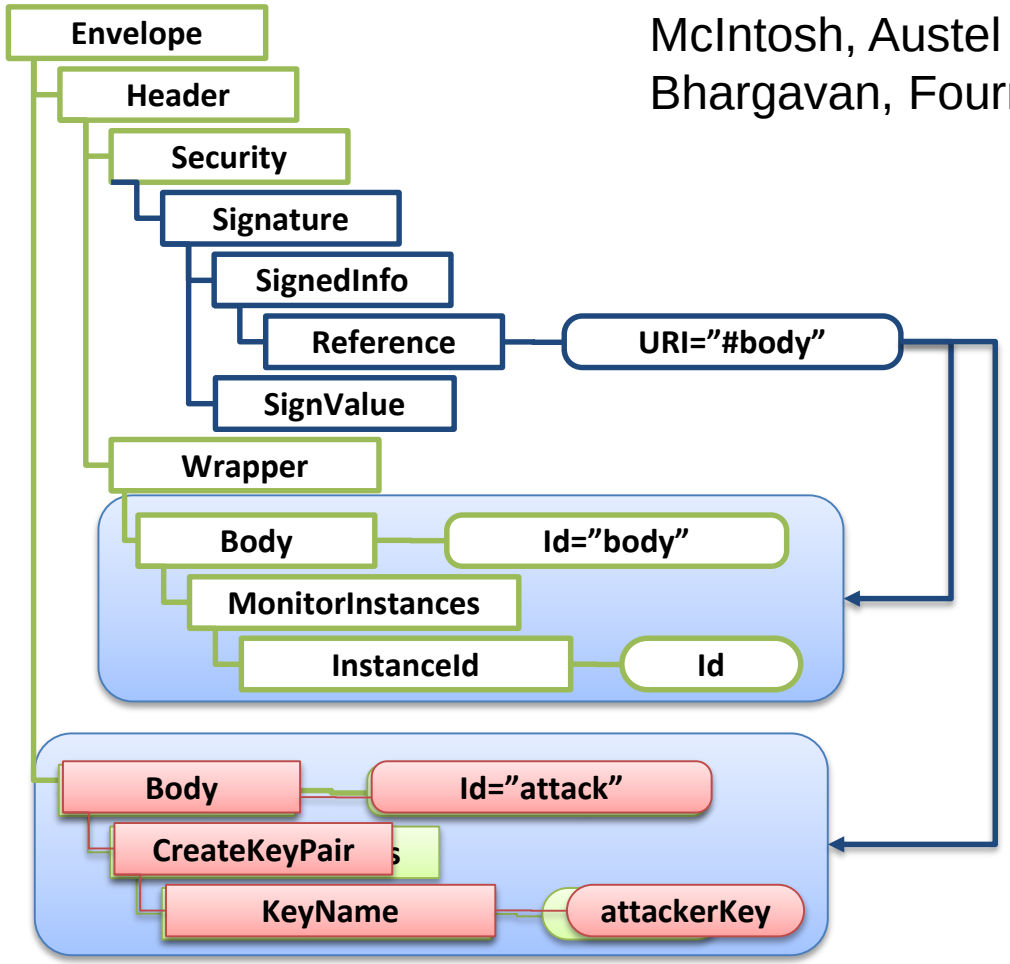
XML Signature



XML Signature Wrapping / Rewriting

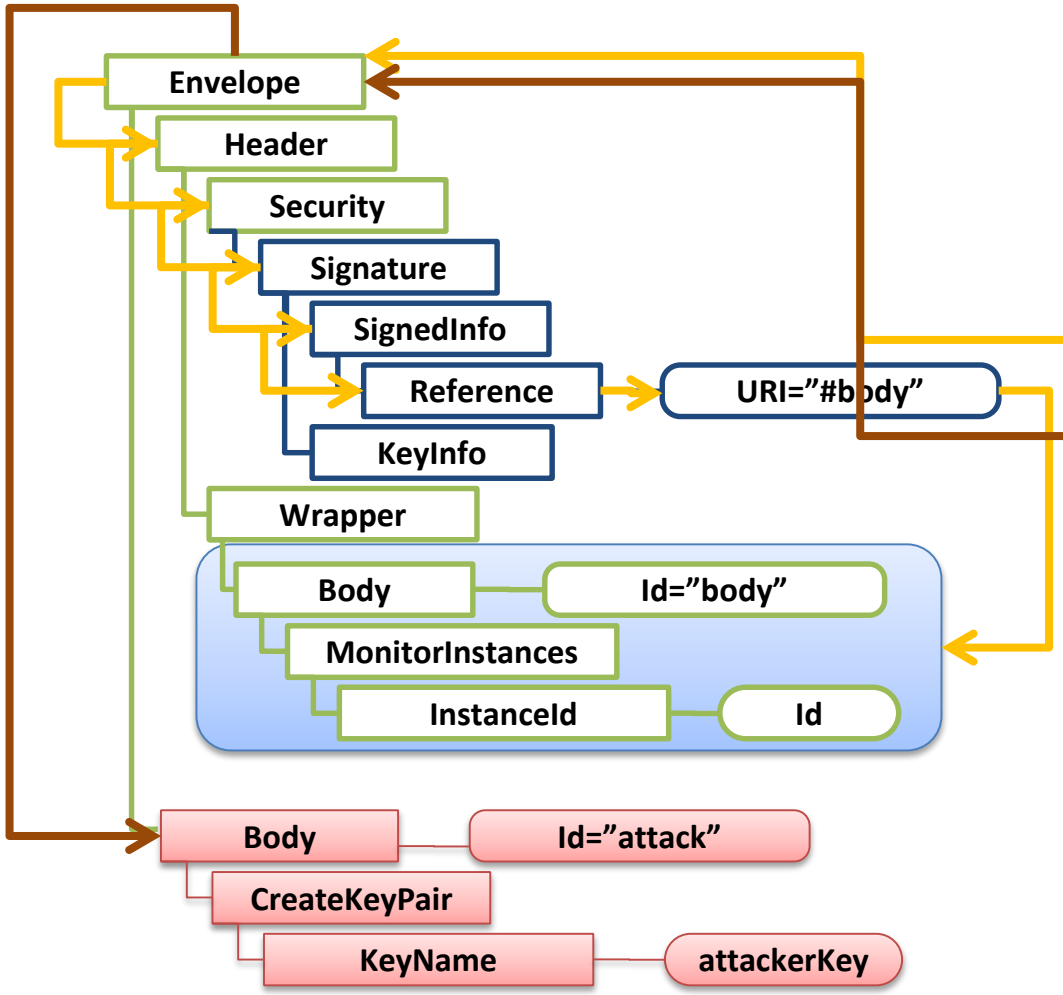


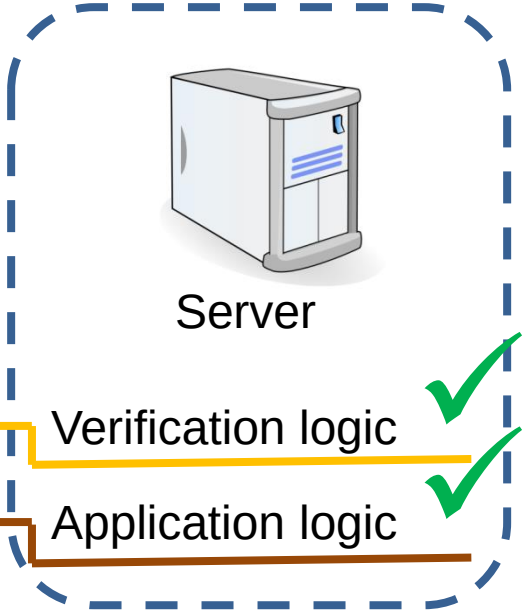
McIntosh, Austel (2005)
Bhargavan, Fournet, Gordon, O'Shea (2005)

XML Signature Wrapping

Why does the attack work?

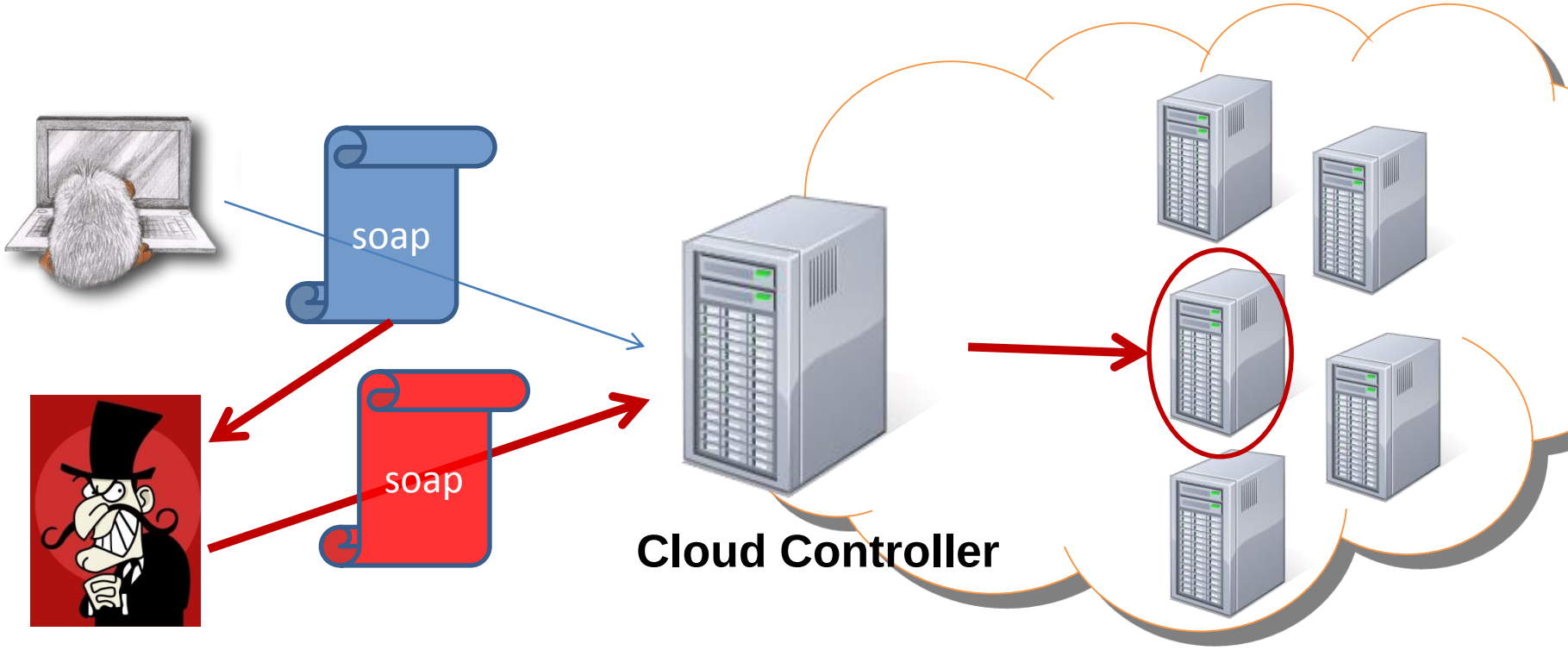
XML Signature Wrapping





XML Signature Wrapping

- Attacks on Amazon EC2 / Eucalyptus clouds
- Juraj Somorovsky, Mario Heiderich, Meiko Jensen, Jörg Schwenk, Nils Gruschka, Luigi Lo Iacono: **All Your Clouds Are Belong to Us – Security Analysis of Cloud Management Interfaces** - CCSW 2011.



Further Attacks: SAML

XXE

Signature Wrapping

Service Provider	AM1 ØSig	CF	XXEA	XSLTA	RA	XSW	TRC	AM3 CInj	Summary
Salesforce	×	×	×	×	×	×	×	×	×
Google Apps	×	×	×	×	×	×	×	×	×
Zoho	×	×	×	×	×	✓	×	×	✓
Zendesk	×	×	×	×	×	×	✓	×	✓
Clarizen	✓	×	✓	×	✓	✓	✓	×	✓
SAManage	×	×	✓	×	×	✓	✓	✓	✓
Shiftplanning	×	×	✓	×	×	×	✓	✓	✓
Panorama9	×	×	×	×	×	×	✓	×	✓
UserVoice (Marketing)	×	×	×	×	×	×	✓	×	✓
Instructure	×	×	×	✓	✓	✓	✓	×	✓
The Resumator	×	×	✓	×	×	×	✓	×	✓
BambooHR	×	×	×	×	×	×	✓	✓	✓
AppDynamics	×	×	✓	×	✓	✓	✓	×	✓
IdeaScale	×	×	✓	×	×	×	×	✓	✓
Panopto	×	×	×	×	×	✓	✓	×	✓
TimeOffManager	×	×	✓	×	✓	✓	✓	×	✓
HappyFox	×	×	×	×	×	✓	✓	×	✓
SpringCM	×	×	×	×	×	✓	×	×	✓
ScreenSteps Live	×	×	✓	×	×	✓	✓	×	✓
LiveHive	×	×	✓	×	✓	✓	✓	×	✓
Howlr	×	×	×	×	×	×	✓	✓	✓
CA Service Management	×	×	✓	×	✓	×	✓	✓	✓
Total	1	0	10	1	6	11	17	6	20/ 22

Vladislav Mladenov, Christian Mainka, Florian Feldmann, Julian Krautwald, Jörg Schwenk: **Your Software at my Service**, CCSW 2014

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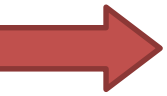

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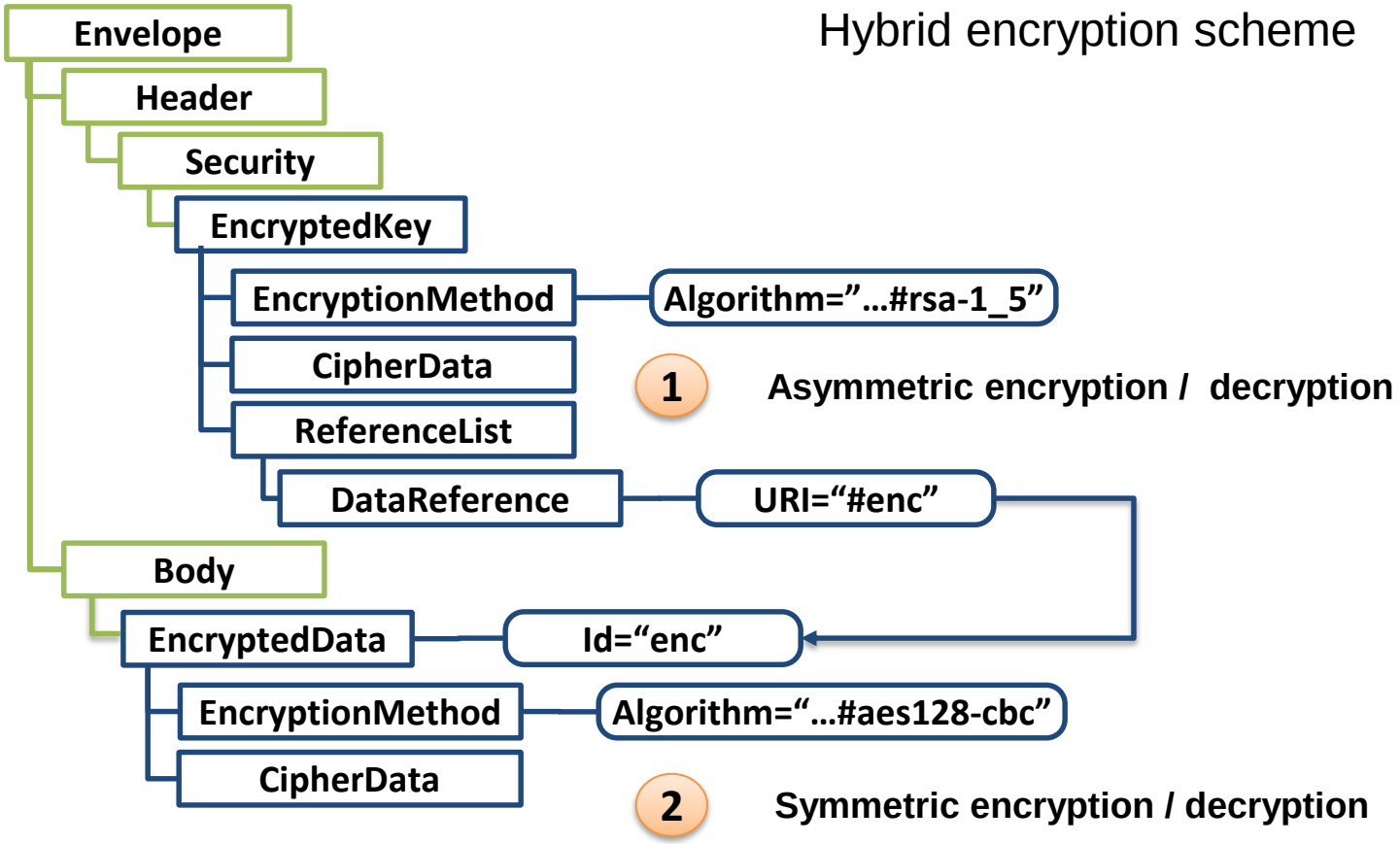
XML Encryption

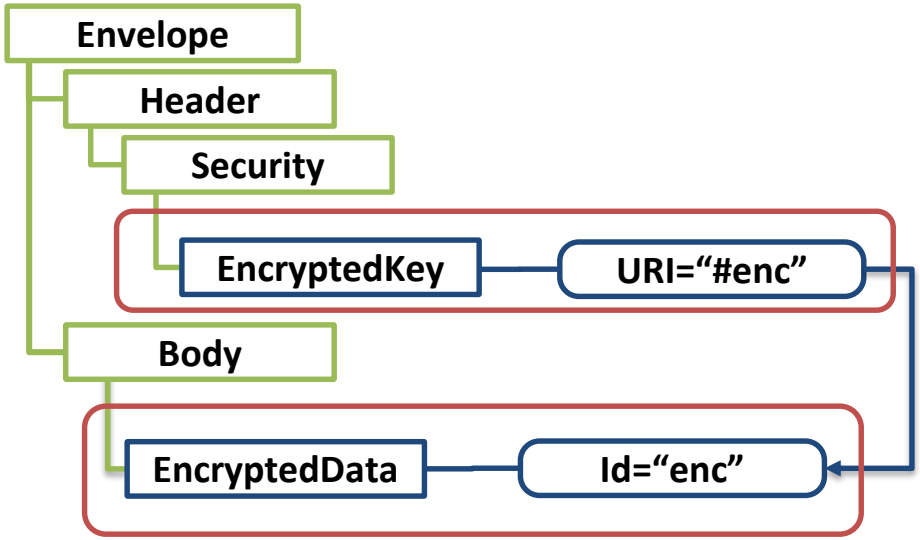


Hybrid encryption scheme

Attacks on XML Encryption

- Attacks on EncryptedKey
  - Bleichenbacher's Attack Strikes Again: Breaking PKCS#1 v1.5 in XML Encryption.
    Tibor Jager, Sebastian Schinzel, Juraj Somorovsky. ESORICS 2012

- Attacks on EncryptedData
  - How to Break XML Encryption.
    Tibor Jager, Juraj Somorovsky. CCS 2011



Adaptive chosen-ciphertext attacks

Adaptive chosen-ciphertext attack

Client

XML Encryption ciphertext C = Enc(M)

M = Dec(C)

Chosen ciphertext C_1

valid/invalid

Chosen ciphertext C_2

valid/invalid

…

(repeated several times)

Web Service

	CCS 2011	ESORICS 2012
Encryption	symmetric	asymmetric
Server-Queries	14 / plaintext byte	400k to 82M / key

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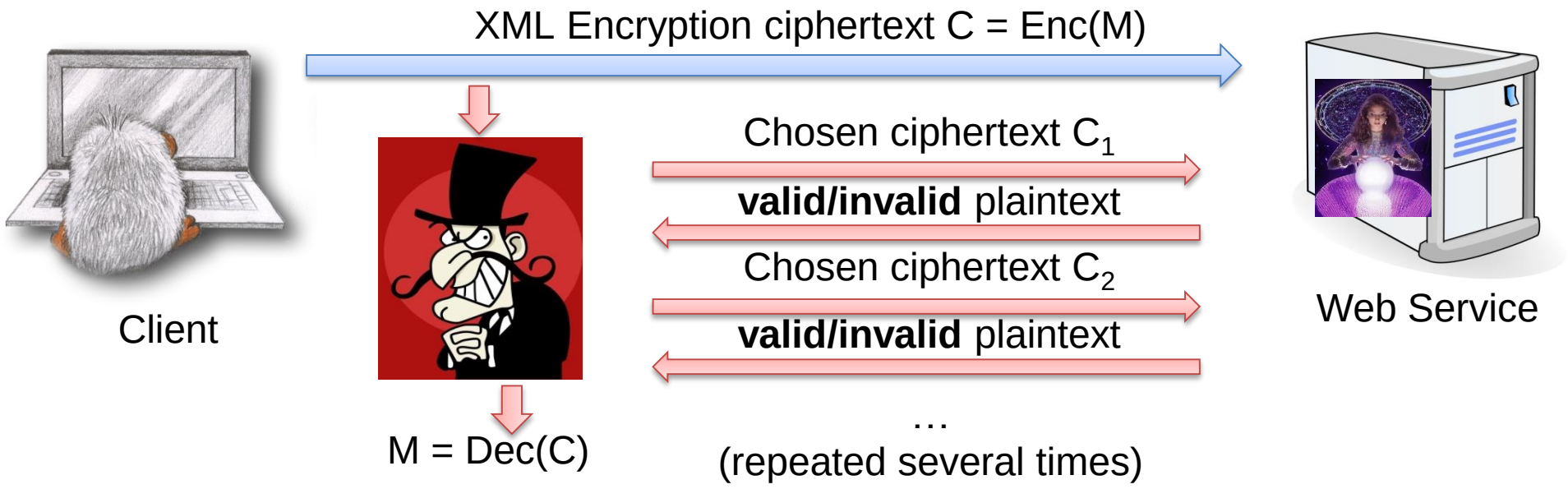
Attack Scenario



- What is a “valid” plaintext?
- How to use Web Service as “plaintext validity oracle”?
- How to use this oracle to decrypt C?

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Plaintext Validity

- XML is a text-based data format
- XML parsing
- Characters (usually) encoded in ASCII

ASCII

0x00	NUL	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	BEL	0x27	'	0x47	G	0x67	g
0x08	BS	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							n
0x0F							o
0x10							p
0x11							q
0x12							r
0x13							s
0x14							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	ESC	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

„Valid“ Plaintext contains only Type B characters

Not Parsable:

Type A

Parsable:

Type B

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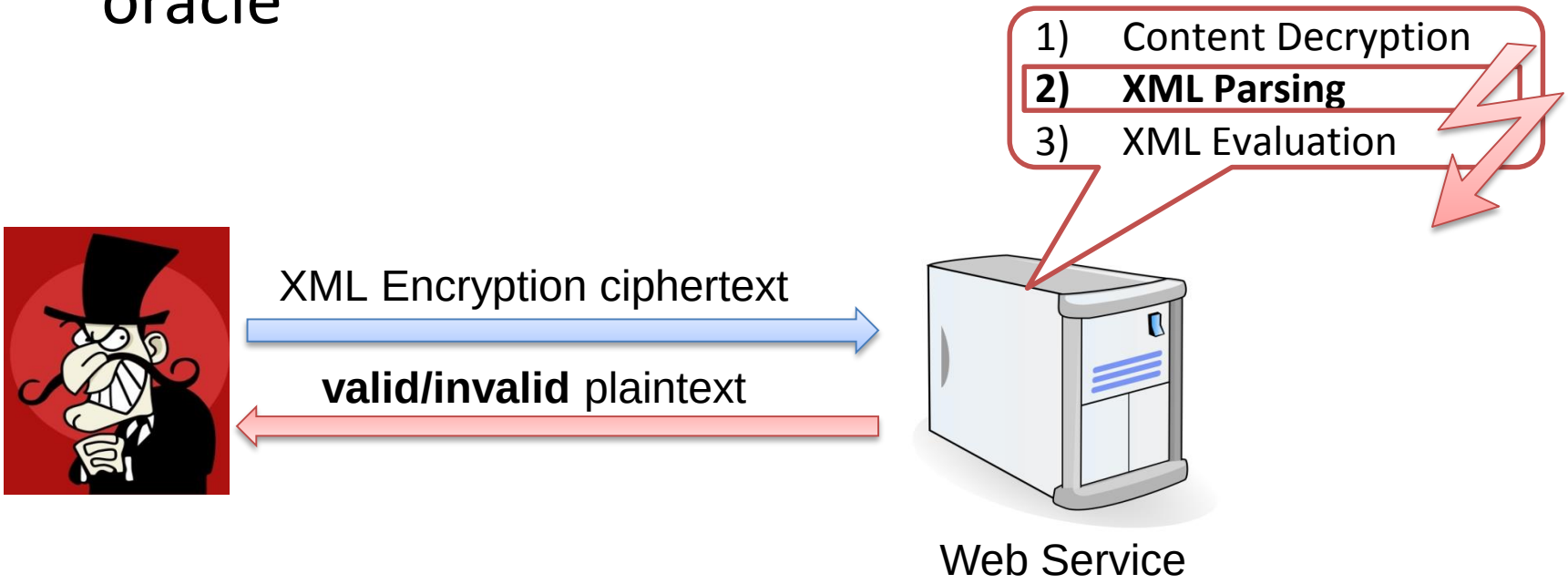
Validity Oracle

- Using Web Services Server as plaintext validity oracle



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

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

0x00	NUL	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	BEL	0x27	'	0x47	G	0x67	g
0x08	BS	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	ESC	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

Decrypting by checking plaintext validity

- ASCII exhibits nice pattern of Type A/B characters
- Suppose we can **flip** arbitrary plaintext bits and use a plaintext validity oracle

Decrypting by checking plaintext validity

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

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

0x00	NUL	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	BEL	0x27	'	0x47	G	0x67	g
0x08	BS	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	ESC	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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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	BEL	0x27	'	0x47	G	0x67	g
0x08	BS	0x28	(	0x48	H	0x68	h
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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
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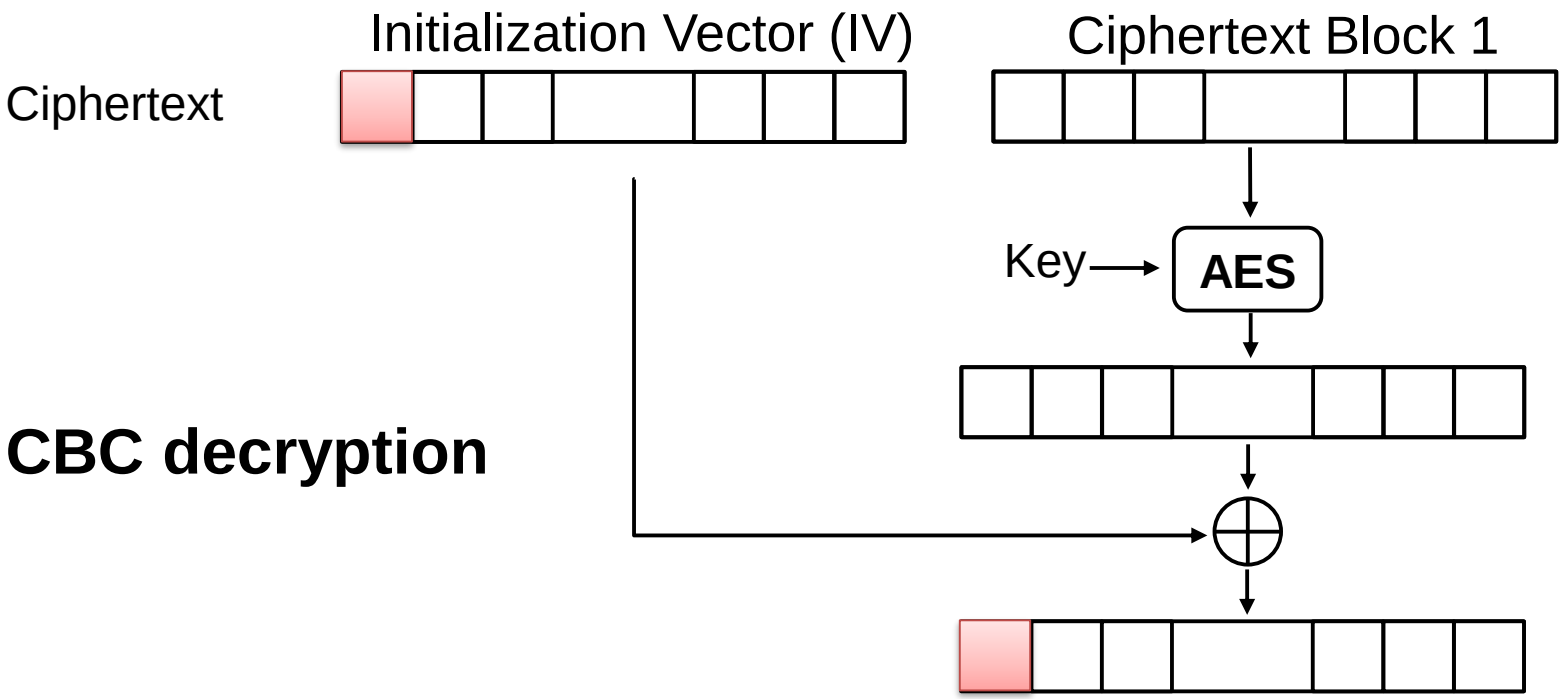
0x14	(Type A)	0x34	4	0x54	T	0x74	t
0x15	(Type A)	0x35	5	0x55	U	0x75	u
0x16	(Type A)	0x36	6	0x56	V	0x76	v
0x17	(Type A)	0x37	7	0x57	W	0x77	w
0x18	(Type A)	0x38	8	0x58	X	0x78	x
0x19	(Type A)	0x39	9	0x59	Y	0x79	y
0x1A	(Type A)	0x3A	:	0x5A	Z	0x7A	z
0x1B	ESC	0x3B	;	0x5B	[	0x7B	{
0x1C	(Type A)	0x3C	<	0x5C	\	0x7C	|
0x1D	(Type A)	0x3D	=	0x5D	]	0x7D	}
0x1E	(Type A)	0x3E	>	0x5E	^	0x7E	~
0x1F	(Type A)	0x3F	?	0x5F	_	0x7F	DEL

Type A

Type B

Why Flipping Possible?

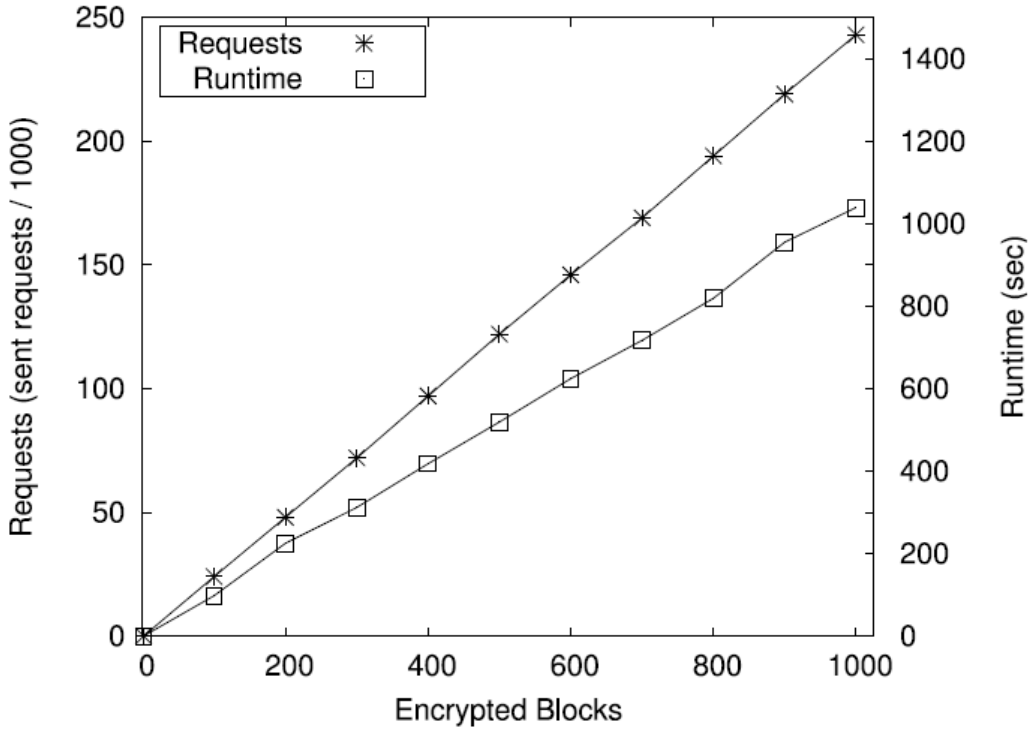
Cipher Block Chaining Mode



CBC decryption

- Flip arbitrary bits in plaintext
- Applied in padding oracle attacks

Performance



- 14 queries / byte

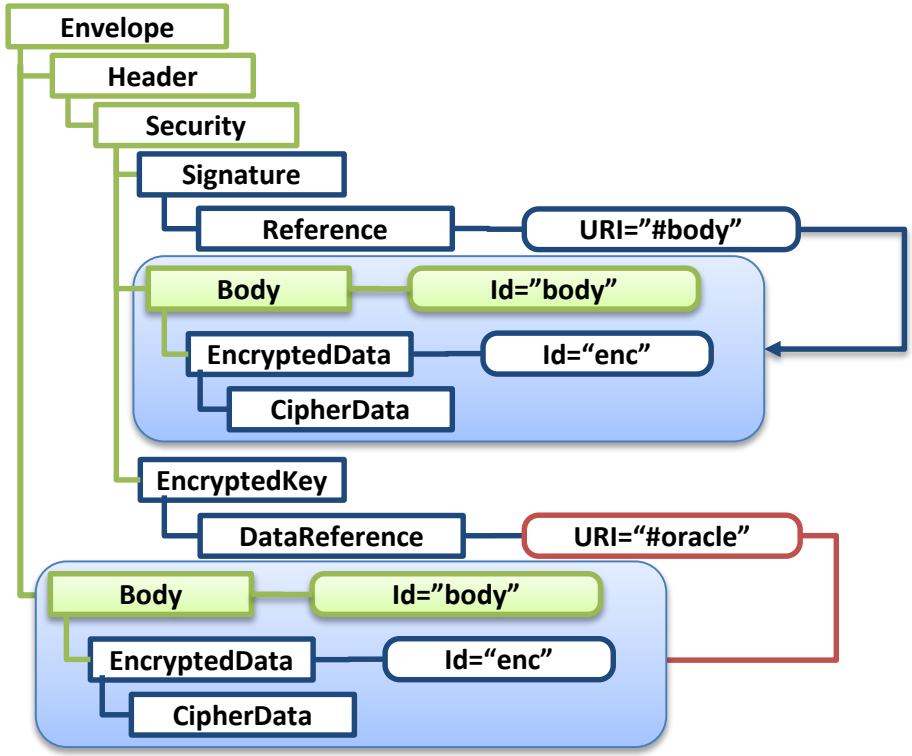
Overview

1. What is a Web Service and XML Security
2. XML Signature Wrapping
3. Attacks on XML Encryption
4. Attacks on Symmetric Encryption Scheme
    1. Attack Scenario
    2. Plaintext Validity
    3. Using Web Service for Plaintext Validation
    4. Decrypting by Checking Plaintext Validity
5. Countermeasures and Problems
6. WS-Attacker

Basic Idea

- Protect integrity and authenticity of ciphertexts
- Not easy…

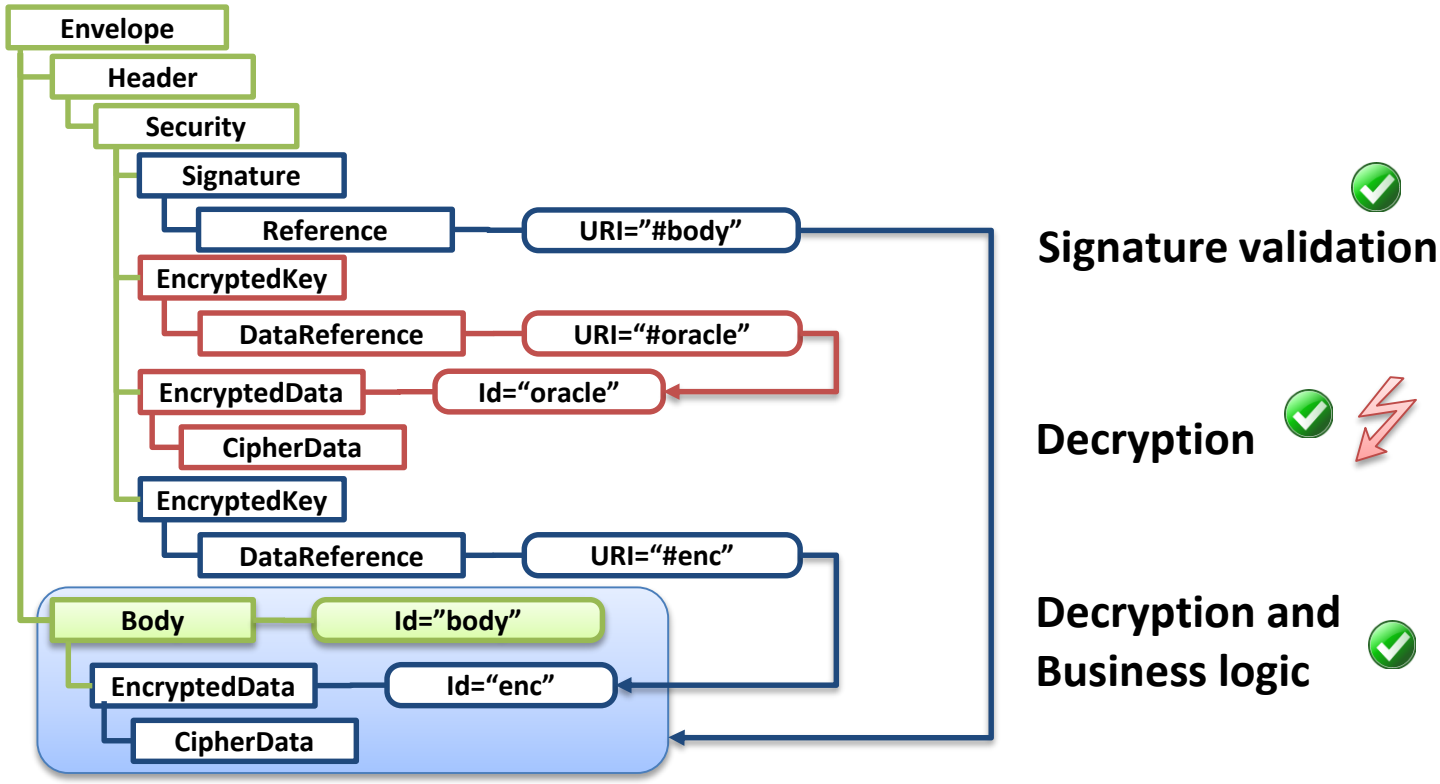
XML Signature Wrapping?



Signature validation

Decryption

XML Encryption Wrapping?



How to analyze Web Services Automatically?

Overview

1. What is a Web Service and XML Security
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    1. Attack Scenario
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WS-Attacker

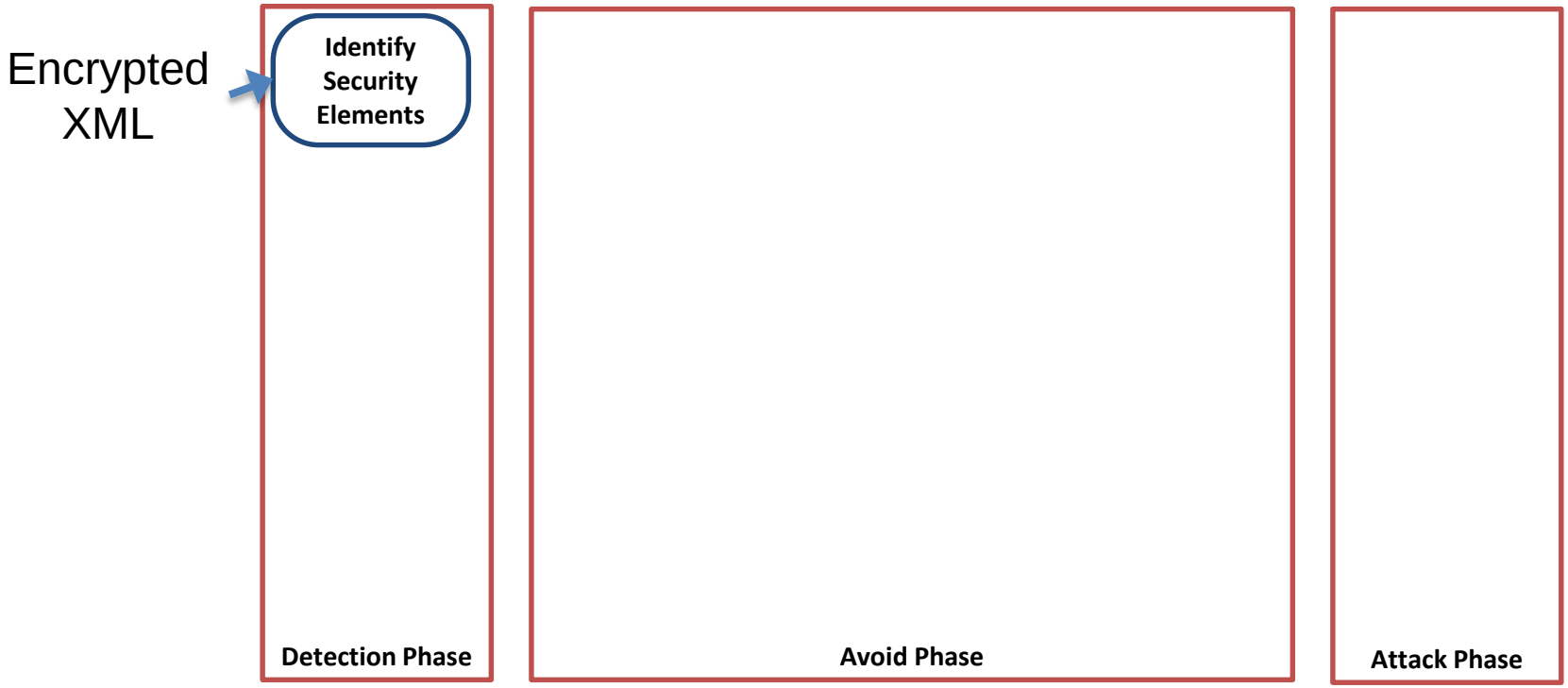
- Automatic penetration test tool for Web Services
- https://github.com/RUB-NDS/WS-Attacker
- Supports many attacks
  - New plugin for XML Encryption

- Approach:
  1. Analyze message security
  2. Remove signature protection
  3. Attack (symmetric / asymmetric)

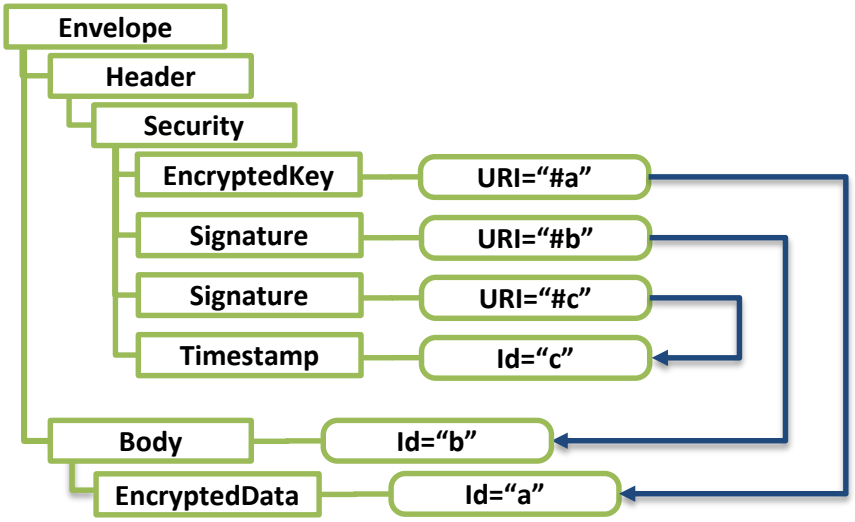
WS-ATTACKS.ORG

RUB

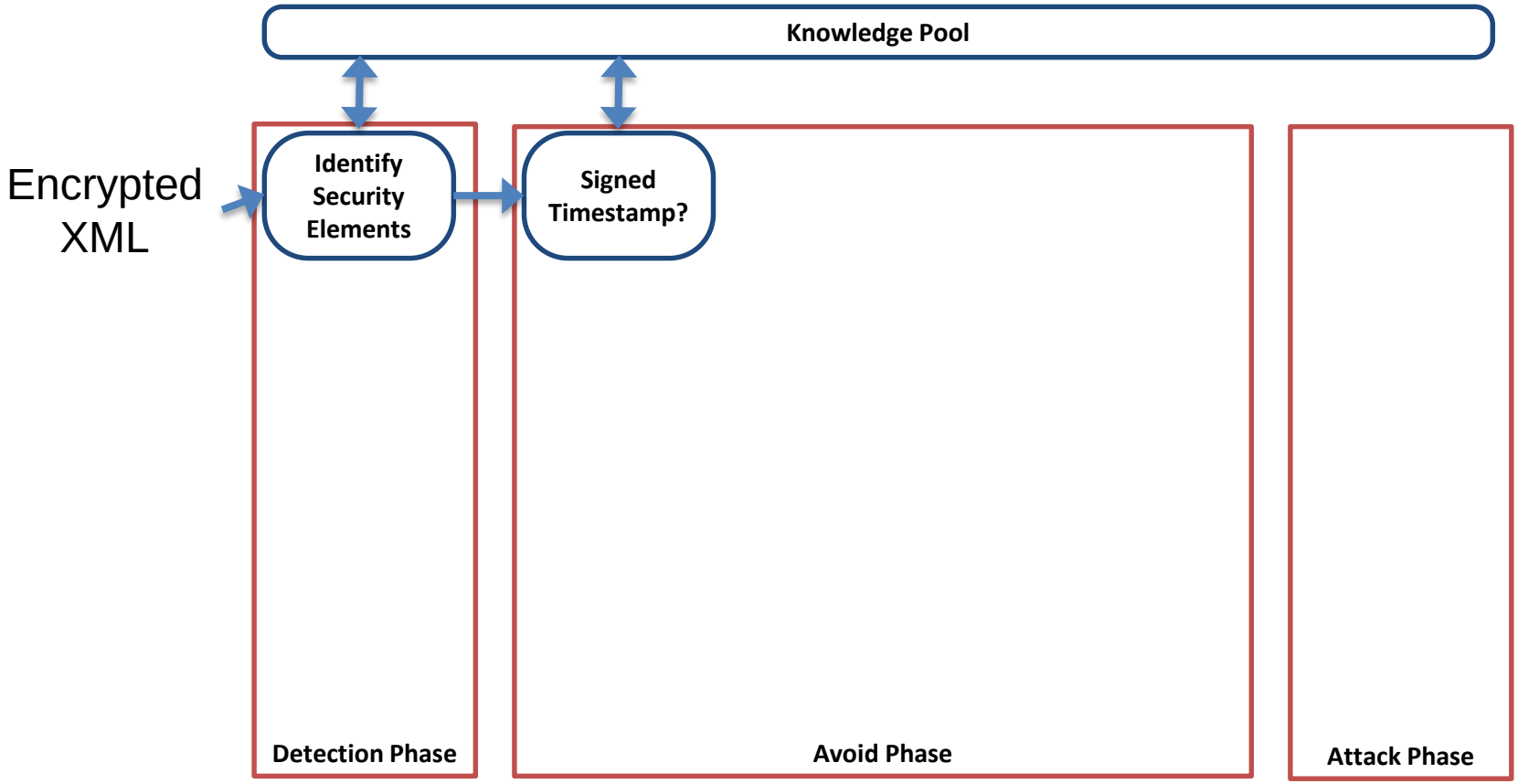
Automated Attack Workflow



Detection Phase (Offline)

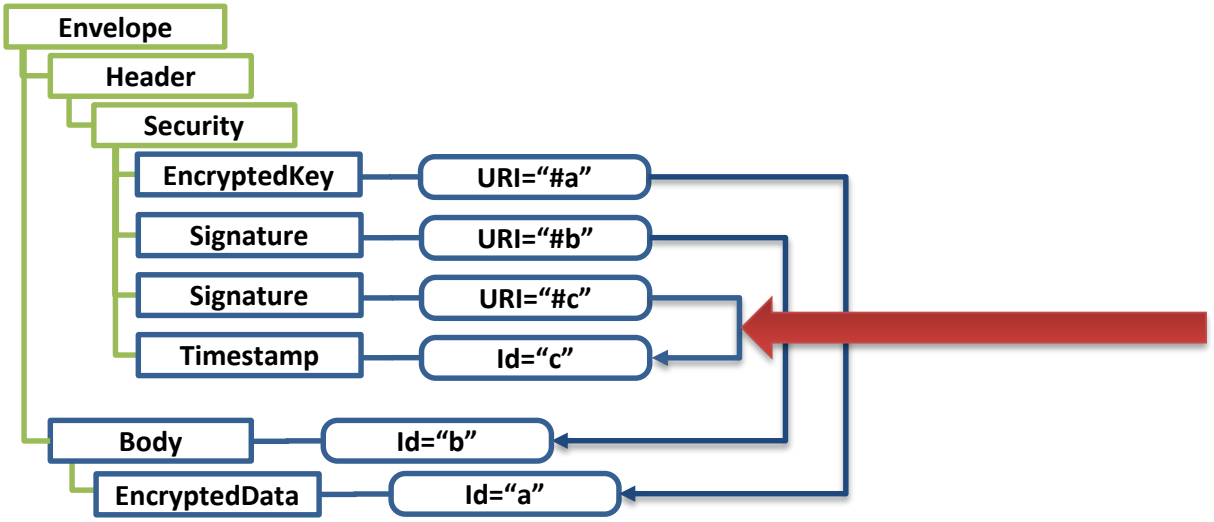


Automated Attack Workflow

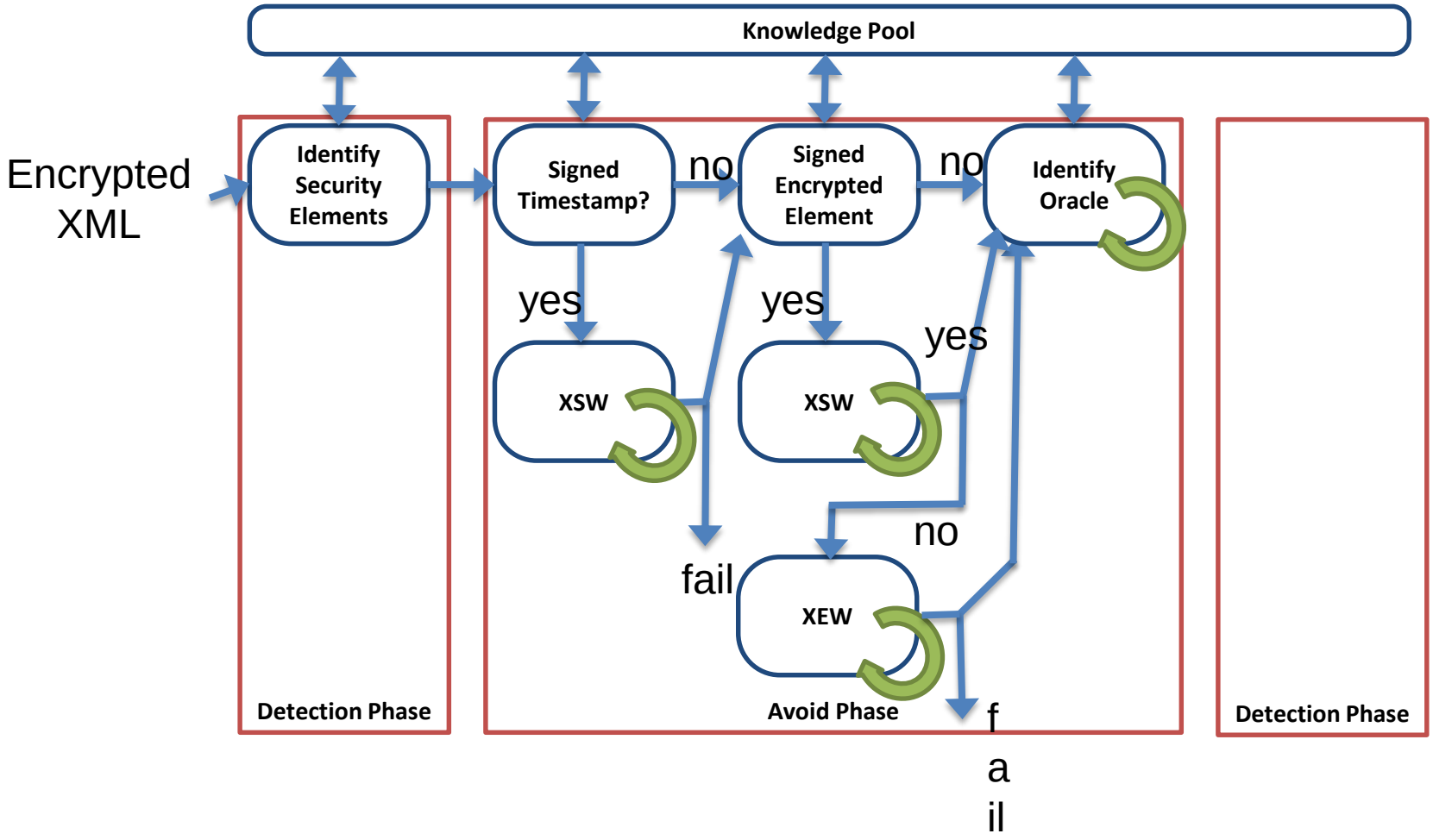


RUB

Detection Phase (Offline)

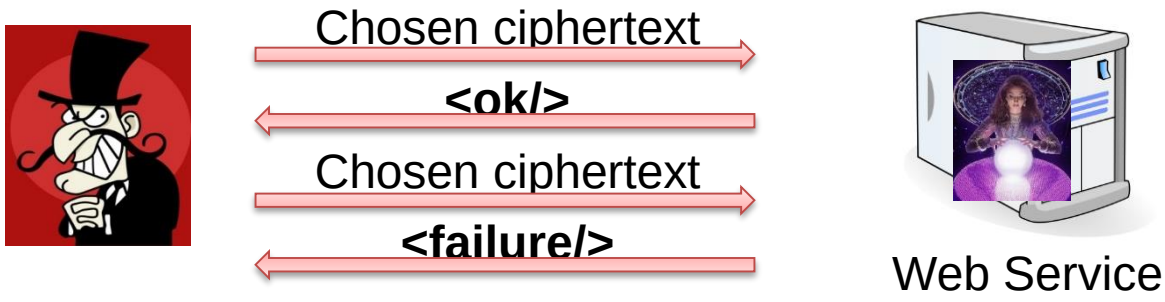


Automated Attack Workflow



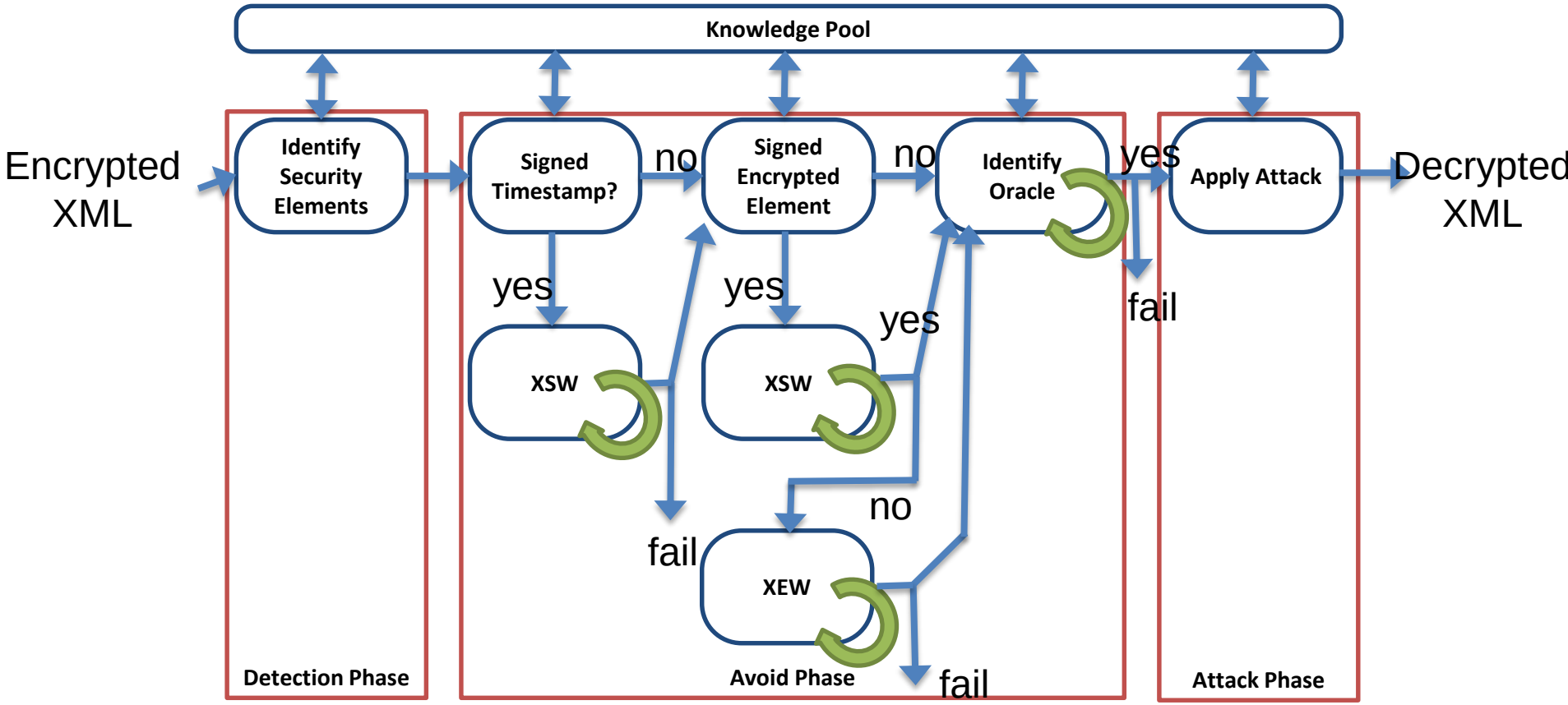
Identify Oracle

- Map Server Responses to „valid“ or „invalid“



- Implementation dependent!

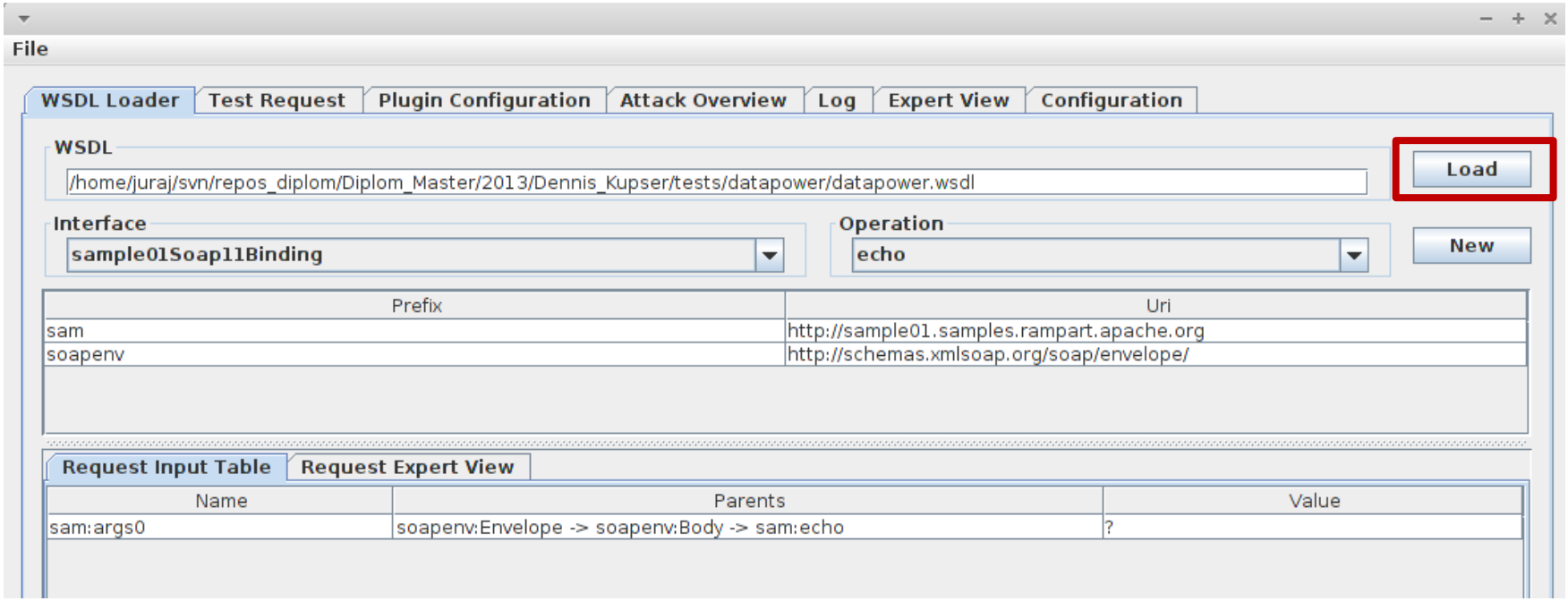
Automated Attack Workflow



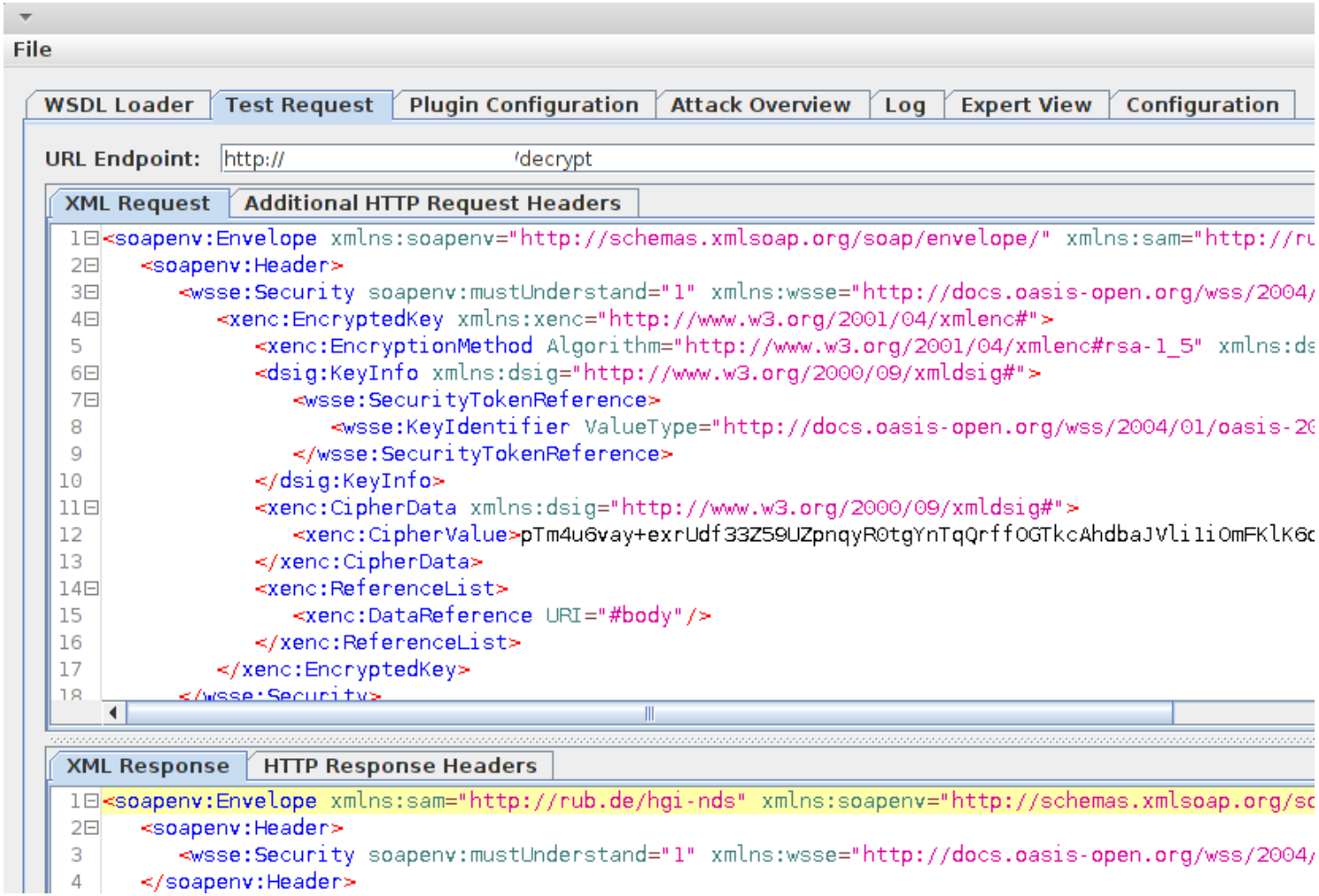
Results

System	Asymmetric Attack	Symmetric Attack	Countermeasures applicable?
Apache Axis2 1.6.2		✓	
Apache CXF 2.7.10	✓	✓	yes
Axway Gateway 7.3.1	✓	✓	yes
IBM Datapower XI50		✓	yes
Microsoft WCF			yes

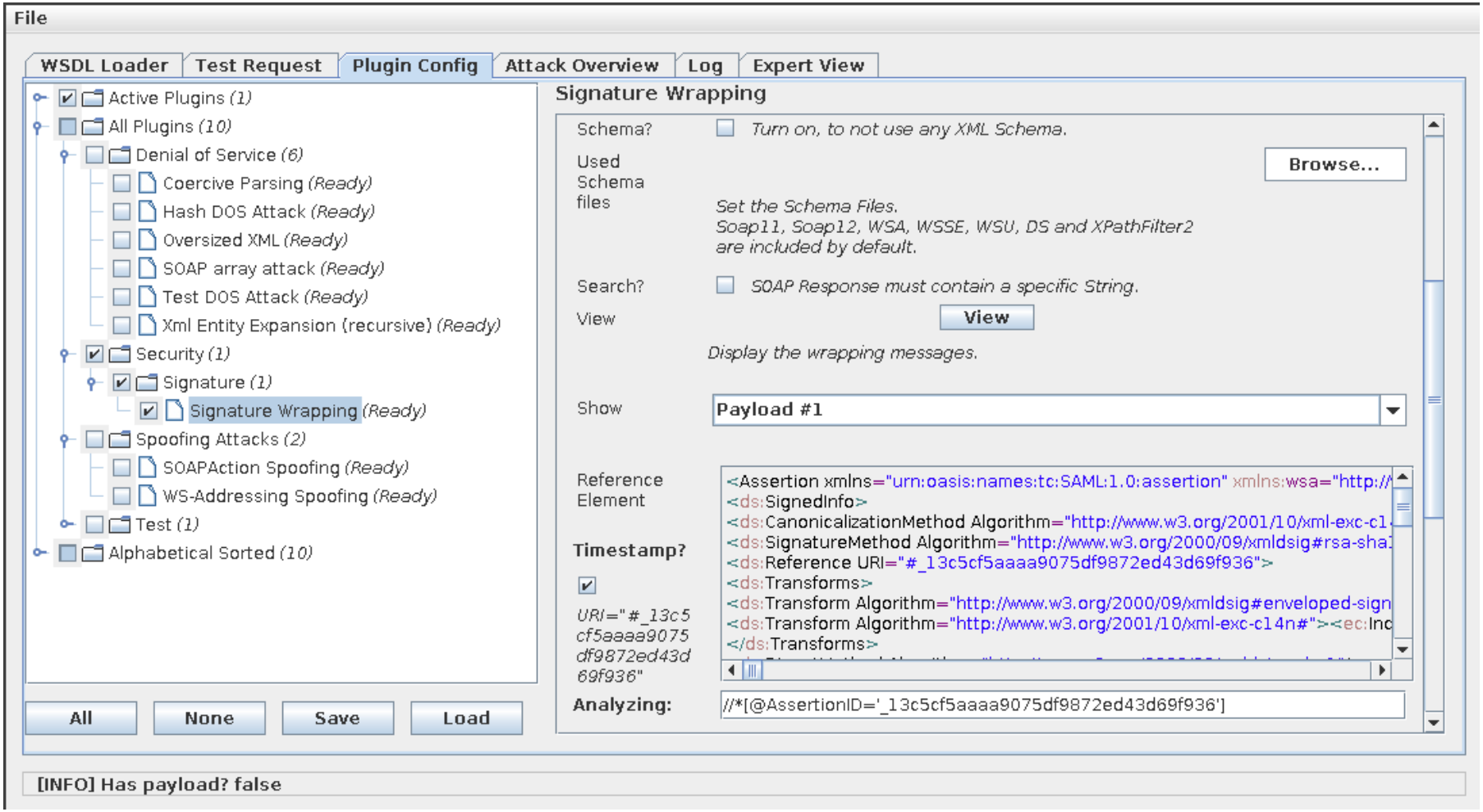
Load WSDL


File
WSDL Loader
Test Request
Plugin Configuration
Attack Overview
Log
Expert View
Configuration
WSDL
/home/juraj/svn/repos_diplom/Diplom_Master/2013/Dennis_Kupser/tests/datapower/datapower.wsdl
Load
Interface
sample01Soap11Binding
Operation
echo
New
Prefix
Uri
sam
http://sample01.samples.rampart.apache.org
soapenv
http://schemas.xmlsoap.org/soap/envelope/
Request Input Table
Request Expert View
Name
Parents
Value
sam:args0
soapenv:Envelope -> soapenv:Body -> sam:echo
?

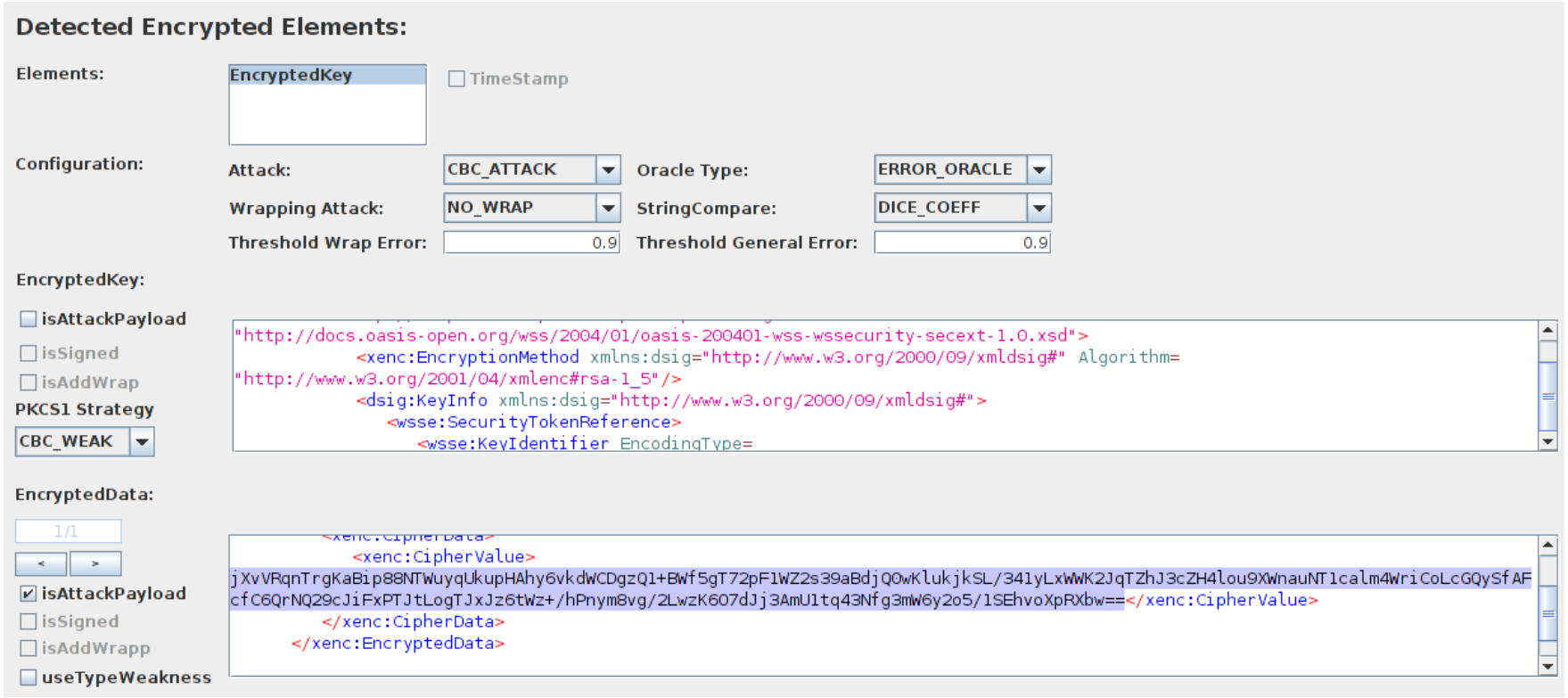
Send Test Request



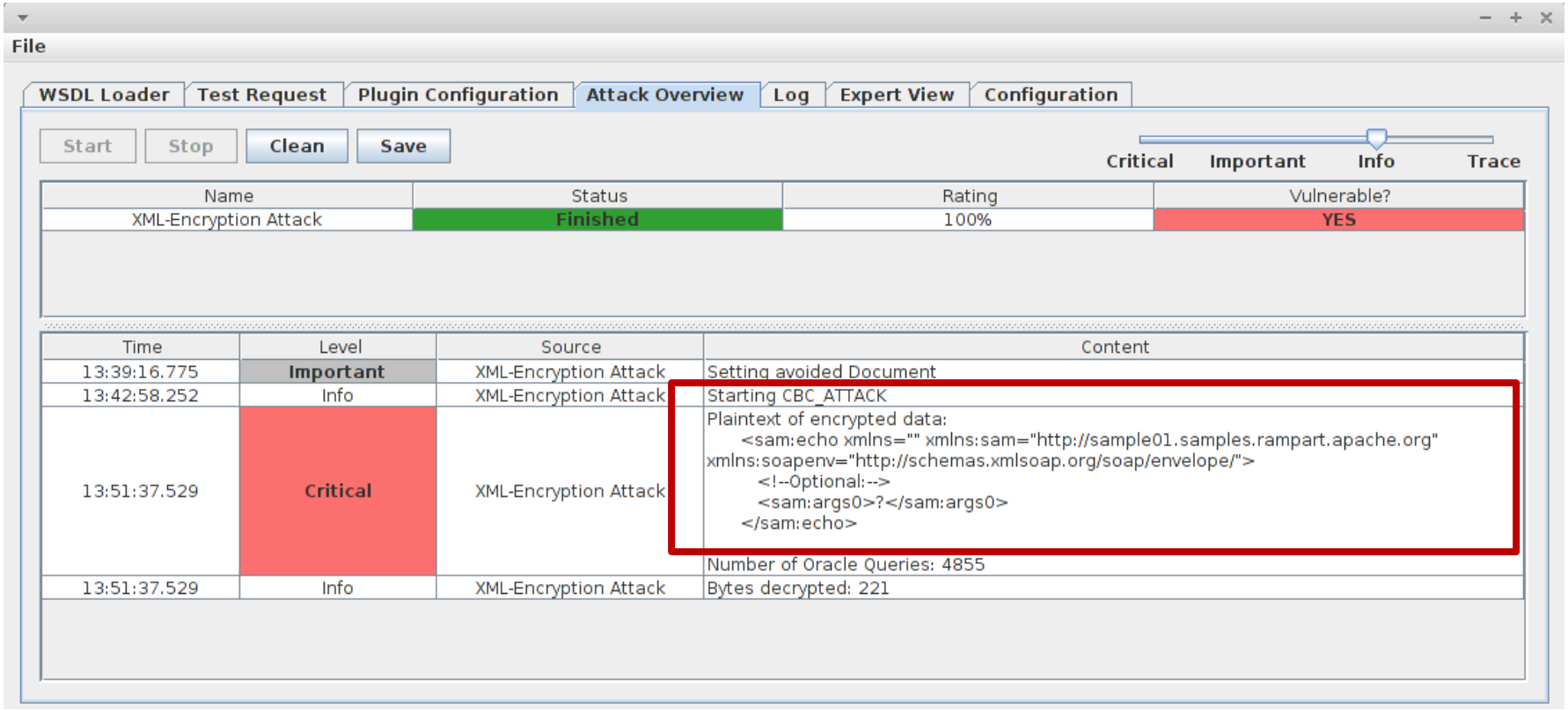
Choose Attacks



Configure XML Encryption



Start Attack

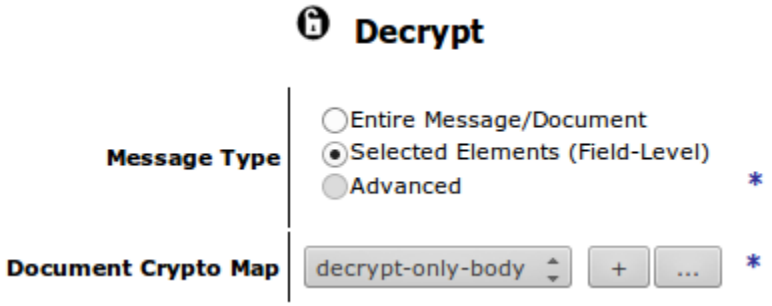


Playing with WS-Attacker

- https://github.com/RUB-NDS/WS-Attacker
- Use Apache Axis2 and Apache Rampart
- Examples:
  - http://web-in-security.blogspot.de/

Countermeasures

- AES-CBC, RSA-PKCS#1 v1.5 insecure!
- XML Encryption updated (Version 1.1)
  - AES-GCM added
- Use of secure algorithms: RSA-OAEP, AES-GCM
- If secure algorithms not available, only decrypt signed XML ciphertexts
  - Example: IBM Datapower



Conclusion

- XML – especially XML Security – is complex
- WS-Attacker for evaluation:
  - https://github.com/RUB-NDS/WS-Attacker
- Our approach applicable to other scenarios
  - SAML, JSON, Web Crypto…
- Prefer authenticated encryption (AES-GCM instead of AES-CBC)