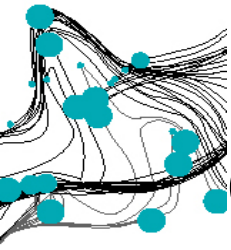
UNIVERSITY OF TWENTE.

PROGRAMMING

P5.3: SECURITY ENGINEERING (2)

MODULE 1.2: SOFTWARE SYSTEMS

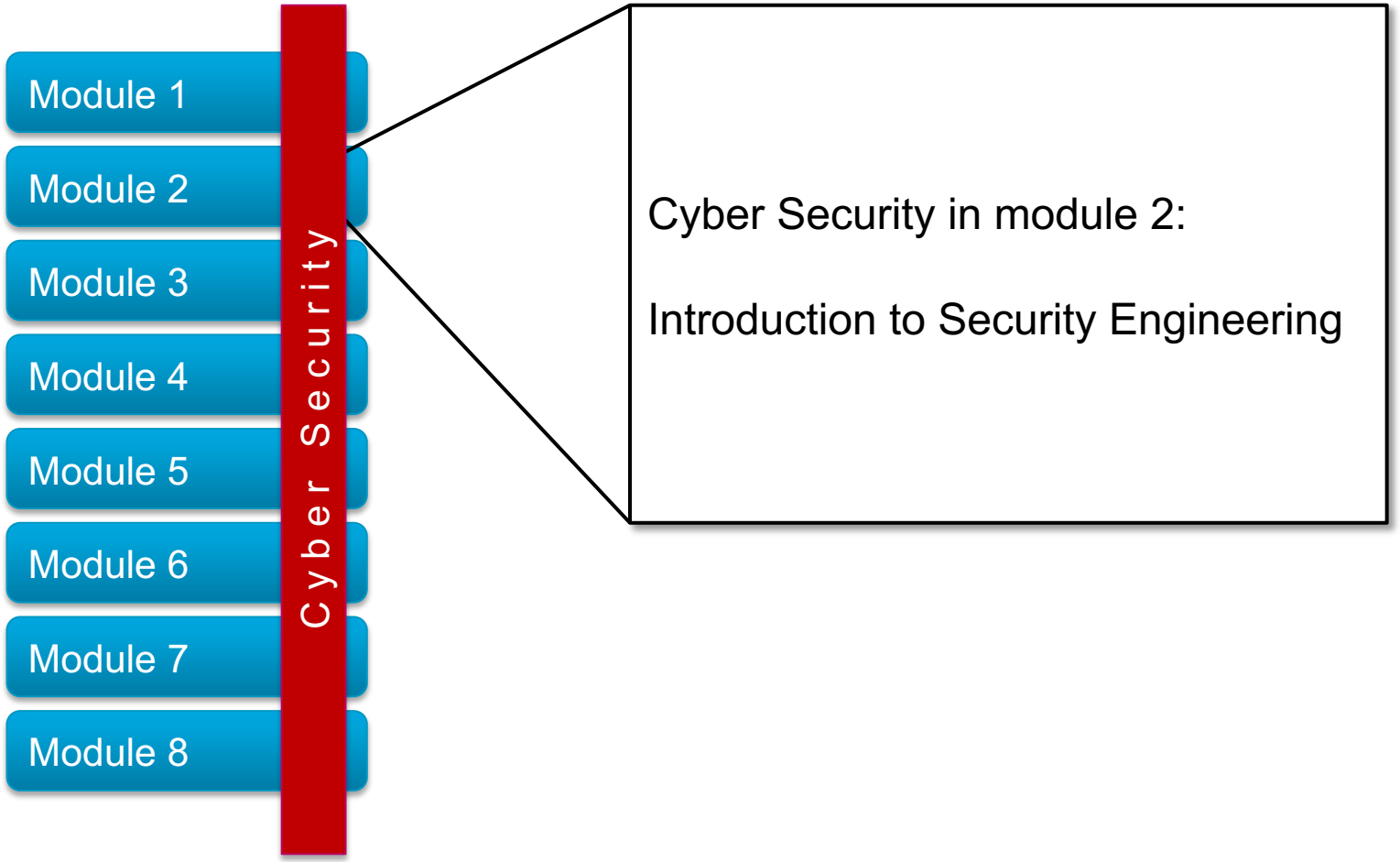
DECEMBER 13, 2019 – MAARTEN EVERTS



OVERVIEW PROGRAMMING LINE

Week 1 Values and variables Classes and objects	**Week 2** Classes and objects Testing	**Week 3** Interfaces and Inheritance Subtyping Security 1
Week 4 Arrays and lists List implementations Collections	**Week 5** Stream I/O and MVC Exceptions Security 2	**Week 6** Concurrency Project kick-off IDE Tips & Tricks
Week 7 Basic Networking Networking and multithreading GUIs	**Week 8/9** Advanced Java facilities Test	**Week 10** Project Test resit

CROSS-CUTTING CONCERN *CYBER SECURITY*



SECURITY PROPERTIES (RECAP)

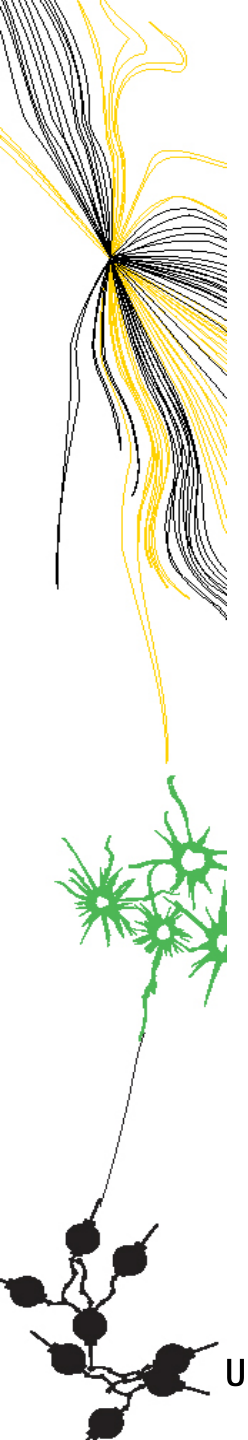
Confidentiality

Integrity

Availability

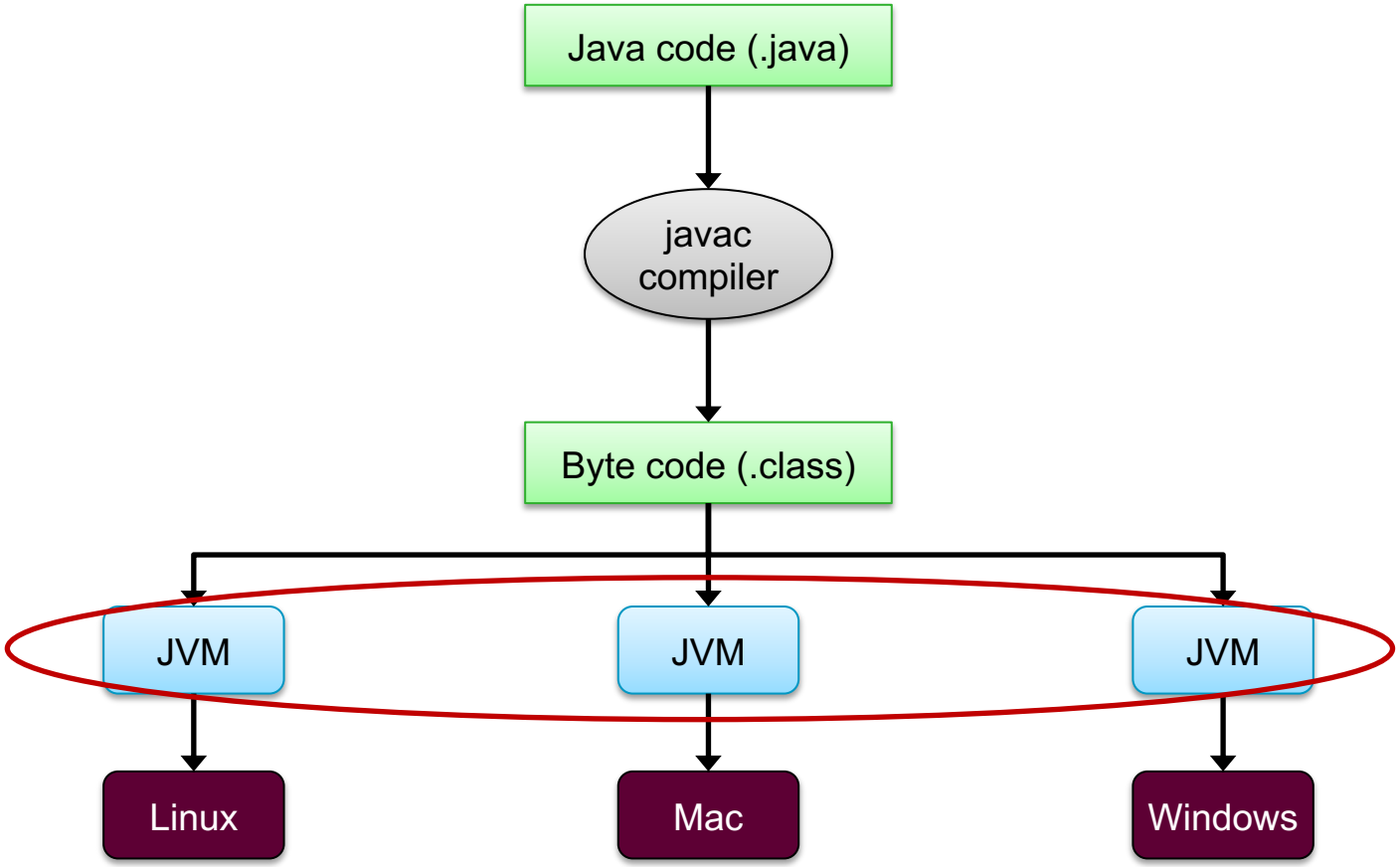
TODAY

- Java & Security
- Binary-to-text encodings (Hex & Base64)
- Hash functions
- Commitment (hash function application)
- HMAC (another hash function application)
- Side-channel attacks

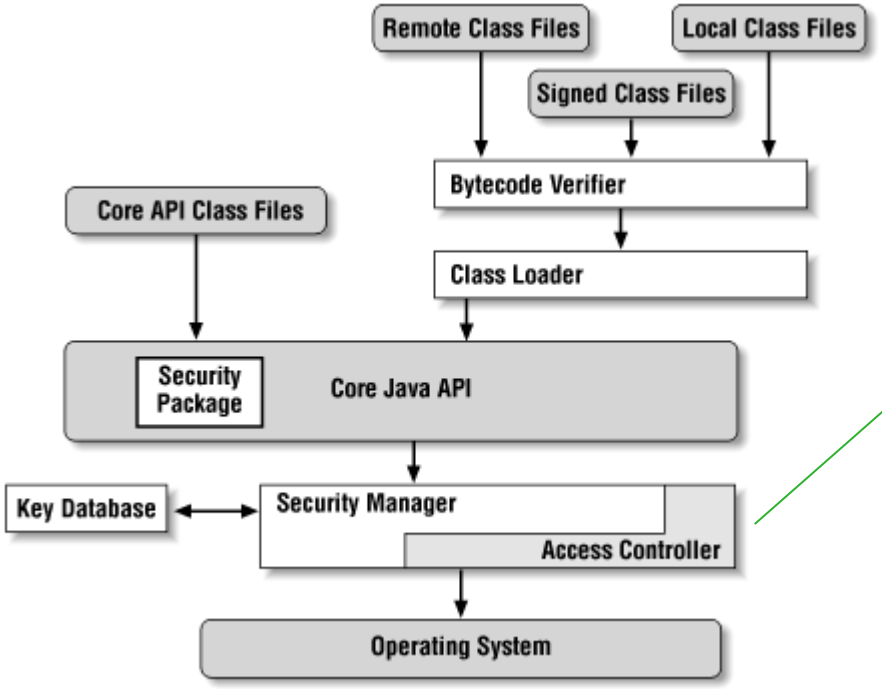


JAVA & SECURITY

SIMPLIFIED JAVA OVERVIEW



JVM SECURITY OVERVIEW



- Manages what resources (network, files, etc.) code can access.
- Allows for the creation of sandboxes.
- Has a bad track-record! (e.g., security of browser applets).

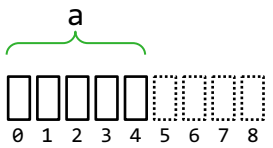
From: http://www.onjava.com/pub/a/onjava/excerpt/java_security_ch1/index.html?page=4

JAVA'S SECURITY ADVANTAGES (COMPARED TO C)

Runtime constraints & bounds checking

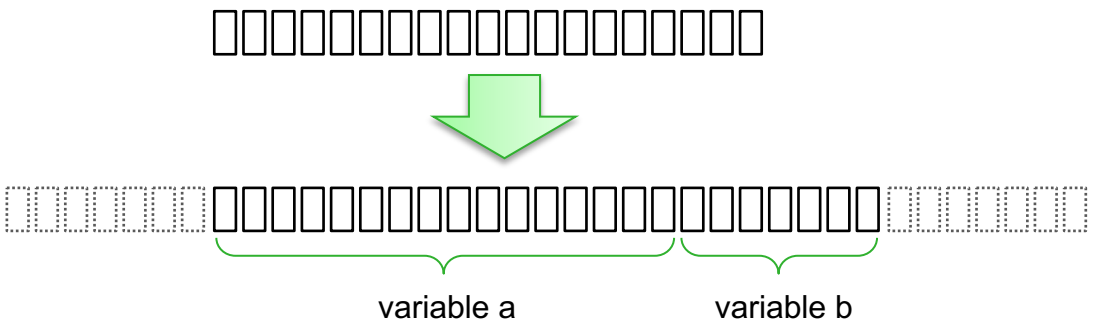
```
int a[] = new int[5];
a[8]= 3;
```

```
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException: 8
            at module2.security.example.Main.main(Main.java:7)
            …
```



JAVA'S SECURITY ADVANTAGES (COMPARED TO C)

- Less susceptible to buffer overflows
  This could happen in C:



- No pointer arithmetic in Java

Brief Listing of the Top 25

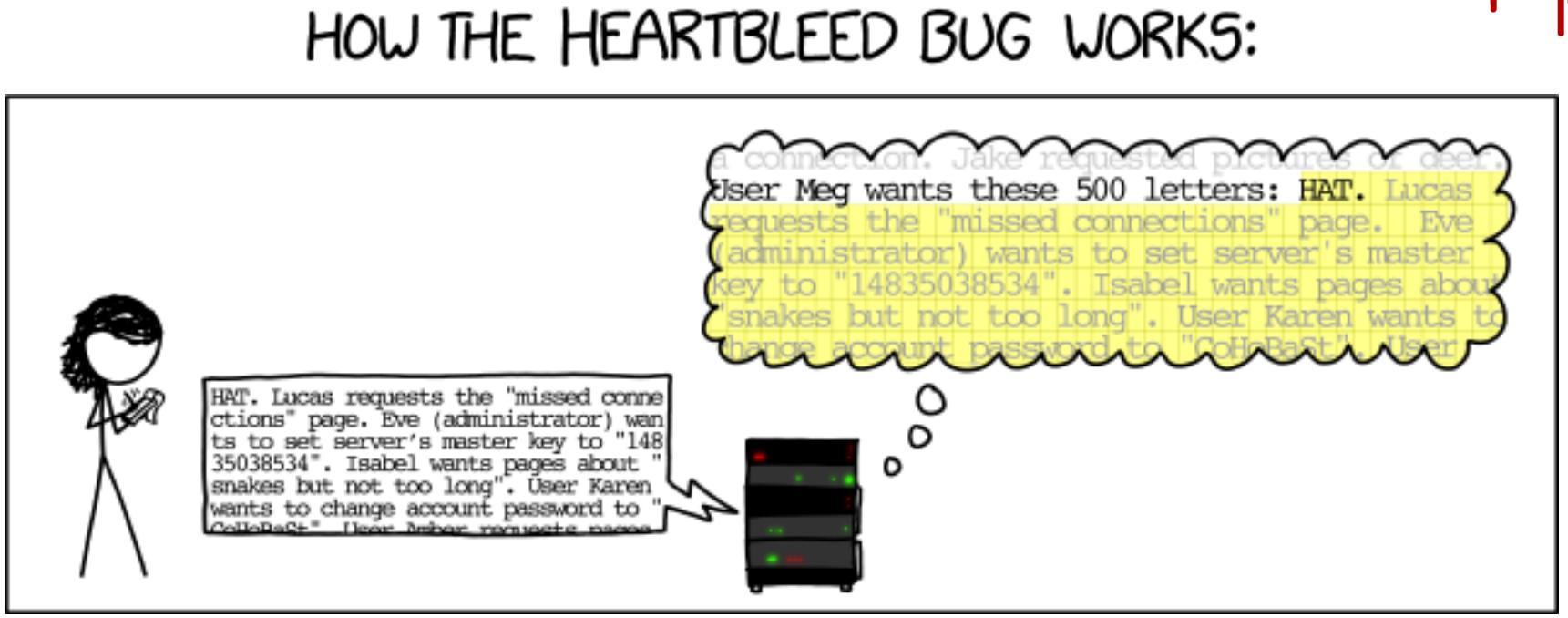
This is a brief listing of the Top 25 items, using the general ranking.

NOTE: 16 other weaknesses were considered for inclusion in the Top 25, but their general scores were not high enough. They are listed in a separate "On the Cusp" page.

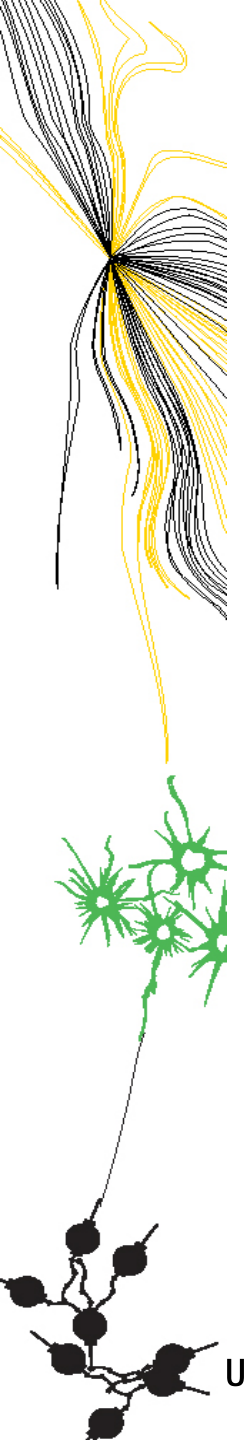
Rank	Score	ID	Name
[1]	93.8	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
[2]	83.3	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
[3]	79.0	CWE-120	Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')
[4]	77.7	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
[5]	76.9	CWE-306	Missing Authentication for Critical Function
[6]	76.8	CWE-862	Missing Authorization
[7]	75.0	CWE-798	Use of Hard-coded Credentials
[8]	75.0	CWE-311	Missing Encryption of Sensitive Data
[9]	74.0	CWE-434	Unrestricted Upload of File with Dangerous Type
[10]	73.8	CWE-807	Reliance on Untrusted Inputs in a Security Decision
[11]	73.1	CWE-250	Execution with Unnecessary Privileges
[12]	70.1	CWE-352	Cross-Site Request Forgery (CSRF)
[13]	69.3	CWE-22	Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal')
[14]	68.5	CWE-494	Download of Code Without Integrity Check
[15]	67.8	CWE-863	Incorrect Authorization

http://cwe.mitre.org/top25/

EXAMPLE OF ADVANTAGES OF BOUNDS CHECKING



From: http://xkcd.com/1354/



BINARY-TO-TEXT ENCODINGS

REPRESENTING BINARY DATA (BYTE ARRAYS)

A byte-array:

```
byte[] data;
```

How to print its content?

Turning Strings into byte-arrays (using default encoding).

```
byte[] data = "Software Systemen".getBytes();
```

As a list of numbers?

```
23, 24, 37, 64, 62
```

ASCII control characters		
00	NULL	(Null character)
01	SOH	(Start of Header)
02	STX	(Start of Text)
03	ETX	(End of Text)
04	EOT	(End of Trans.)
05	ENQ	(Enquiry)
06	ACK	(Acknowledgement)
07	BEL	(Bell)
08	BS	(Backspace)
09	HT	(Horizontal Tab)
10	LF	(Line feed)
11	VT	(Vertical Tab)
12	FF	(Form feed)
13	CR	(Carriage return)
14	SO	(Shift Out)
15	SI	(Shift In)
16	DLE	(Data link escape)
17	DC1	(Device control 1)
18	DC2	(Device control 2)
19	DC3	(Device control 3)
20	DC4	(Device control 4)
21	NAK	(Negative acknowl.)
22	SYN	(Synchronous idle)
23	ETB	(End of trans. block)
24	CAN	(Cancel)
25	EM	(End of medium)
26	SUB	(Substitute)
27	ESC	(Escape)
28	FS	(File separator)
29	GS	(Group separator)
30	RS	(Record separator)
31	US	(Unit separator)
127	DEL	(Delete)

ASCII printable characters					
32	space	64	@	96	`
33	!	65	A	97	a
34	"	66	B	98	b
35	#	67	C	99	c
36	$	68	D	100	d
37	%	69	E	101	e
38	&	70	F	102	f
39	'	71	G	103	g
40	(	72	H	104	h
41	)	73	I	105	i
42	*	74	J	106	j
43	+	75	K	107	k
44	,	76	L	108	l
45	-	77	M	109	m
46	.	78	N	110	n
47	/	79	O	111	o
48	0	80	P	112	p
49	1	81	Q	113	q
50	2	82	R	114	r
51	3	83	S	115	s
52	4	84	T	116	t
53	5	85	U	117	u
54	6	86	V	118	v
55	7	87	W	119	w
56	8	88	X	120	x
57	9	89	Y	121	y
58	:	90	Z	122	z
59	;	91	[	123	{
60	<	92	\	124	|
61	=	93	]	125	}
62	>	94	^	126	~
63	?	95	_		

REPRESENTING NUMBERS (RECAP MODULE 1)

$0 \cdot 2^7 + 1 \cdot 2^6 + 1 \cdot 2^5 + 0 \cdot 2^4 + 1 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0$	$1 \cdot 8^2 + 5 \cdot 8^1 + 5 \cdot 8^0$	$1 \cdot 10^2 +$	$6 \cdot 16^1 + 13 \cdot 16^0$
01101101_2	155_8	1	$6D_{16}$
binary (base 2)	octal (base 8)	d (b	hexadecimal (base 16)

0_{10}	=	0_{16}
1_{10}	=	1_{16}
2_{10}	=	2_{16}
3_{10}	=	3_{16}
4_{10}	=	4_{16}
5_{10}	=	5_{16}
6_{10}	=	6_{16}
7_{10}	=	7_{16}
8_{10}	=	8_{16}
9_{10}	=	9_{16}
10_{10}	=	A_{16}
11_{10}	=	B_{16}
12_{10}	=	C_{16}
13_{10}	=	D_{16}
14_{10}	=	E_{16}
15_{10}	=	F_{16}

ASCII/UTF-8 representation: ‘m’

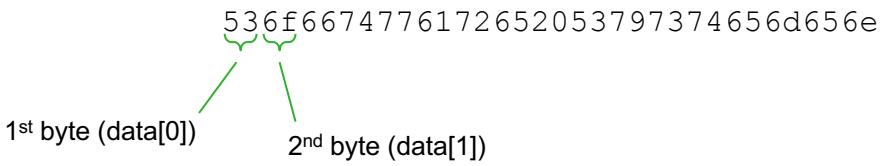
REPRESENTING BINARY DATA (BYTE ARRAYS)

A byte-array:

```
byte[] data;
```

How to print its content?

Hexadecimal!



Turning Strings into byte-arrays (using default encoding).

```
byte[] data = "Software Systemen".getBytes();
```

ASCII control characters		
00	NULL	(Null character)
01	SOH	(Start of Header)
02	STX	(Start of Text)
03	ETX	(End of Text)
04	EOT	(End of Trans.)
05	ENQ	(Enquiry)
06	ACK	(Acknowledgement)
07	BEL	(Bell)
08	BS	(Backspace)
09	HT	(Horizontal Tab)
10	LF	(Line feed)
11	VT	(Vertical Tab)
12	FF	(Form feed)
13	CR	(Carriage return)
14	SO	(Shift Out)
15	SI	(Shift In)
16	DLE	(Data link escape)
17	DC1	(Device control 1)
18	DC2	(Device control 2)
19	DC3	(Device control 3)
20	DC4	(Device control 4)
21	NAK	(Negative acknowl.)
22	SYN	(Synchronous idle)
23	ETB	(End of trans. block)
24	CAN	(Cancel)
25	EM	(End of medium)
26	SUB	(Substitute)
27	ESC	(Escape)
28	FS	(File separator)
29	GS	(Group separator)
30	RS	(Record separator)
31	US	(Unit separator)
127	DEL	(Delete)

ASCII printable characters					
32	space	64	@	96	`
33	!	65	A	97	a
34	"	66	B	98	b
35	#	67	C	99	c
36	$	68	D	100	d
37	%	69	E	101	e
38	&	70	F	102	f
39	'	71	G	103	g
40	(	72	H	104	h
41	)	73	I	105	i
42	*	74	J	106	j
43	+	75	K	107	k
44	,	76	L	108	l
45	-	77	M	109	m
46	.	78	N	110	n
47	/	79	O	111	o
48	0	80	P	112	p
49	1	81	Q	113	q
50	2	82	R	114	r
51	3	83	S	115	s
52	4	84	T	116	t
53	5	85	U	117	u
54	6	86	V	118	v
55	7	87	W	119	w
56	8	88	X	120	x
57	9	89	Y	121	y
58	:	90	Z	122	z
59	;	91	[	123	{
60	<	92	\	124	|
61	=	93	]	125	}
62	>	94	^	126	~
63	?	95	_		

Use more printable characters: base64

ASCII control characters		
00	NULL	(Null character)
01	SOH	(Start of Header)
02	STX	(Start of Text)
03	ETX	(End of Text)
04	EOT	(End of Trans.)
05	ENQ	(Enquiry)
06	ACK	(Acknowledgement)
07	BEL	(Bell)
08	BS	(Backspace)
09	HT	(Horizontal Tab)
10	LF	(Line feed)
11	VT	(Vertical Tab)
12	FF	(Form feed)
13	CR	(Carriage return)
14	SO	(Shift Out)
15	SI	(Shift In)
16	DLE	(Data link escape)
17	DC1	(Device control 1)
18	DC2	(Device control 2)
19	DC3	(Device control 3)
20	DC4	(Device control 4)
21	NAK	(Negative acknowl.)
22	SYN	(Synchronous idle)
23	ETB	(End of trans. block)
24	CAN	(Cancel)
25	EM	(End of medium)
26	SUB	(Substitute)
27	ESC	(Escape)
28	FS	(File separator)
29	GS	(Group separator)
30	RS	(Record separator)
31	US	(Unit separator)
127	DEL	(Delete)

ASCII printable characters					
32	space	64	@	96	`
33	!	65	A	97	a
34	"	66	B	98	b
35	#	67	C	99	c
36	$	68	D	100	d
37	%	69	E	101	e
38	&	70	F	102	f
39	'	71	G	103	g
40	(	72	H	104	h
41	)	73	I	105	i
42	*	74	J	106	j
43	+	75	K	107	k
44	,	76	L	108	l
45	-	77	M	109	m
46	.	78	N	110	n
47	/	79	O	111	o
48	0	80	P	112	p
49	1	81	Q	113	q
50	2	82	R	114	r
51	3	83	S	115	s
52	4	84	T	116	t
53	5	85	U	117	u
54	6	86	V	118	v
55	7	87	W	119	w
56	8	88	X	120	x
57	9	89	Y	121	y
58	:	90	Z	122	z
59	;	91	[	123	{
60	<	92	\	124	|
61	=	93	]	125	}
62	>	94	^	126	~
63	?	95	_		

A MORE (SPACE) EFFICIENT BINARY-TO-TEXT ENCODING: BASE64

6 bits per character: 2^6 = 64 different characters (26 + 26 + 10 + 2)

Value	Char	Value	Char	Value	Char	Value	Char
0	A	16	Q	32	g	48	w
1	B	17	R	33	h	49	x
2	C	18	S	34	i	50	y
3	D	19	T	35	j	51	z
4	E	20	U	36	k	52	0
5	F	21	V	37	l	53	1
6	G	22	W	38	m	54	2
7	H	23	X	39	n	55	3
8	I	24	Y	40	o	56	4
9	J	25	Z	41	p	57	5
10	K	26	a	42	q	58	6
11	L	27	b	43	r	59	7
12	M	28	c	44	s	60	8
13	N	29	d	45	t	61	9
14	O	30	e	46	u	62	+
15	P	31	f	47	v	63	/

Text content	M	a	n
ASCII	77 (0x4d)	97 (0x61)	110 (0x6e)
Bit pattern	0 1 0 0 1 1 0 1	0 1 1 0 0 0 0 1	0 1 1 0 1 1 1 0
Index	19	22	5	46
Base64-encoded	T	W	F	u

Note: padding is needed!

BASE64 EXAMPLES

```
byte[] data = "Software Systemen".getBytes();
```

Base64 ⇨ `U29mdHdhcmUgU3lzdGVtZW4=`

```
byte[] data = "Software Systemen 2018".getBytes();
```

Base64 ⇨ `U29mdHdhcmUgU3lzdGVtZW4gMjAxOA==`

```
byte[] data = " Software Systemen 2018".getBytes();
```

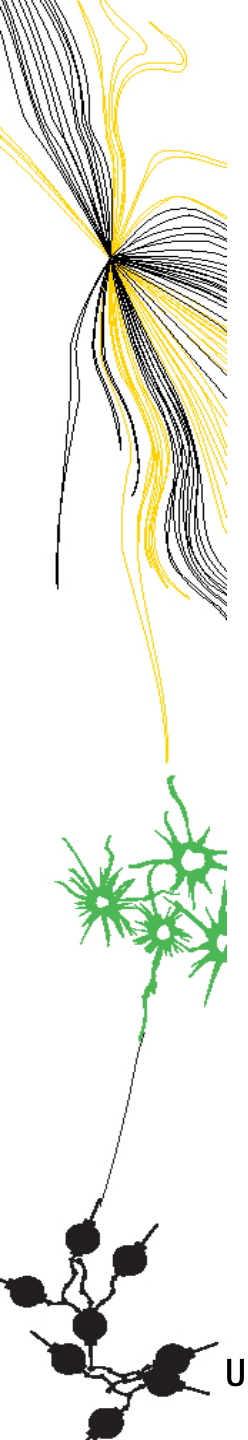
Base64 ⇨ `IFNvZnR3YXJlIFN5c3RlbWVuIDIwMTg=`

padding

NOTES ON ENCODING

- Use libraries for this! (e.g., Apache Commons Codec library)

- Superfluous remark: encoding is not encryption!

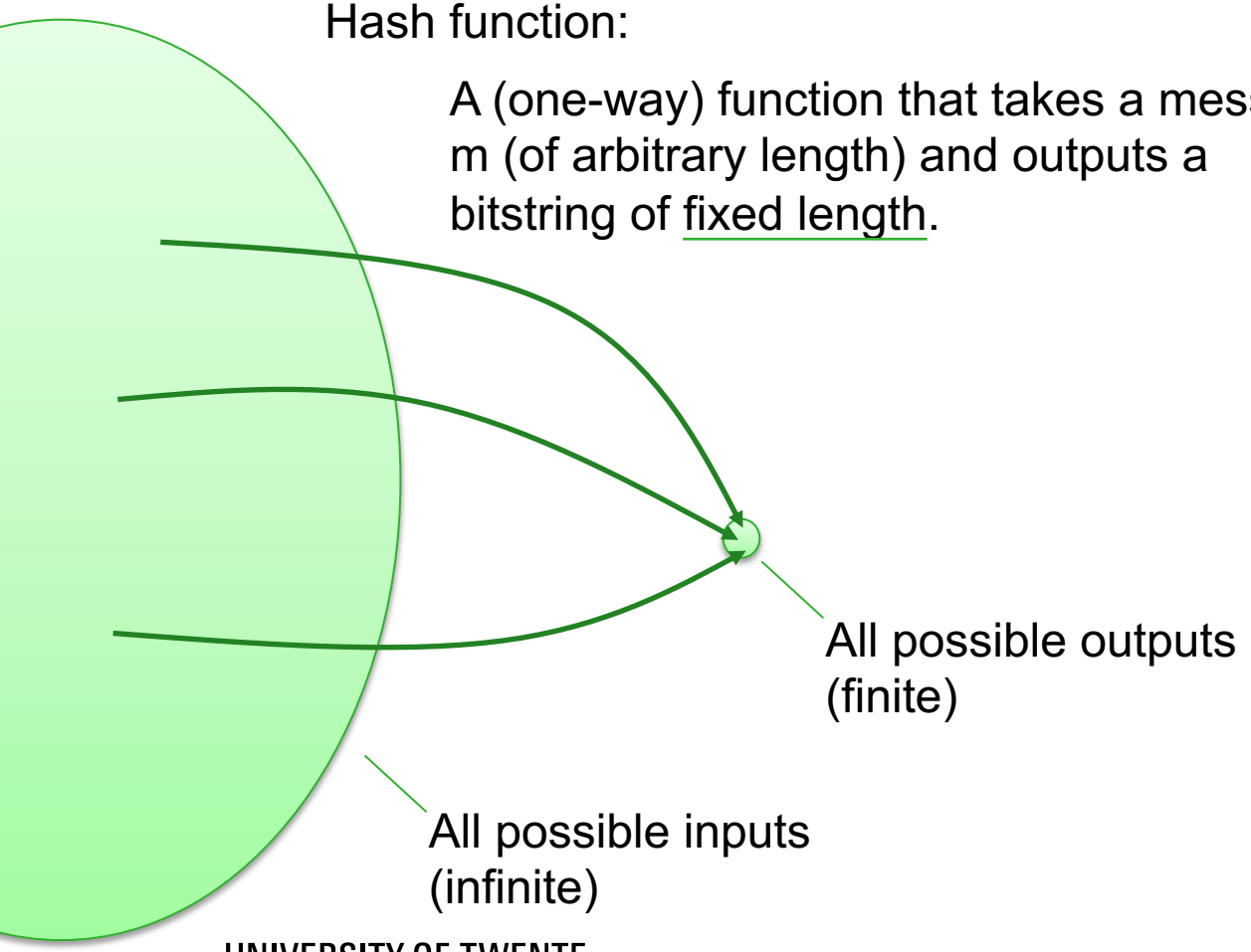


CRYPTOGRAPHIC HASH FUNCTIONS

CRYPTOGRAPHIC HASH FUNCTIONS

Hash function:

A (one-way) function that takes a message m (of arbitrary length) and outputs a bitstring of fixed length.



HASH FUNCTION PROPERTIES

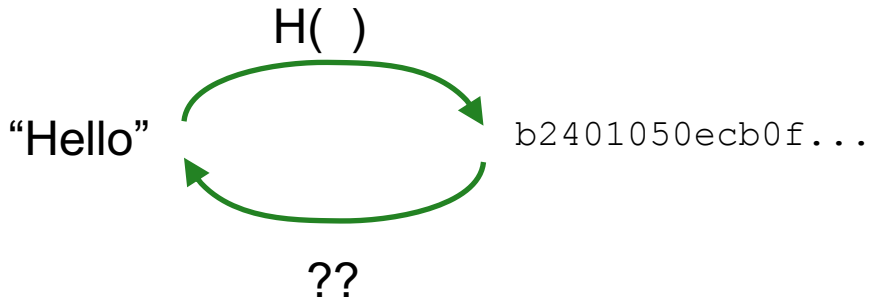
A “good” hash has the following properties:

1. One-way
2. Second preimage resistant
3. Collision resistant

[Based on slides by Bart Jacobs]

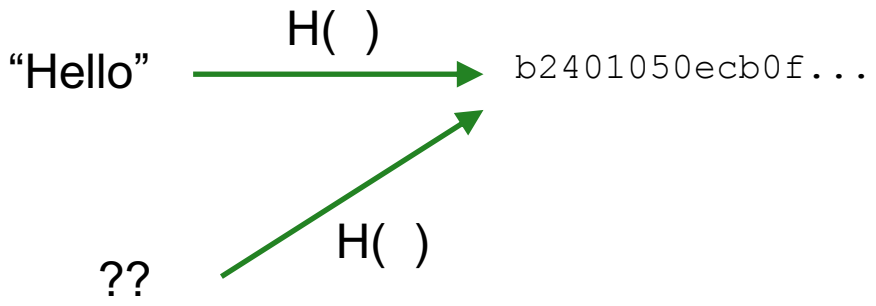
1: ONE-WAY

It is difficult (computationally infeasible) to
invert the hash function.



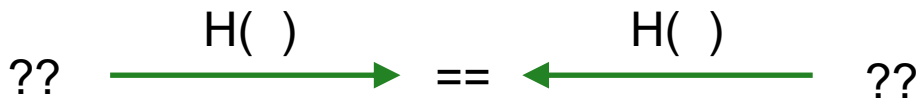
2: SECOND PREIMAGE RESISTANT

It is difficult (computationally infeasible) to
find a second input that hashes a given value.

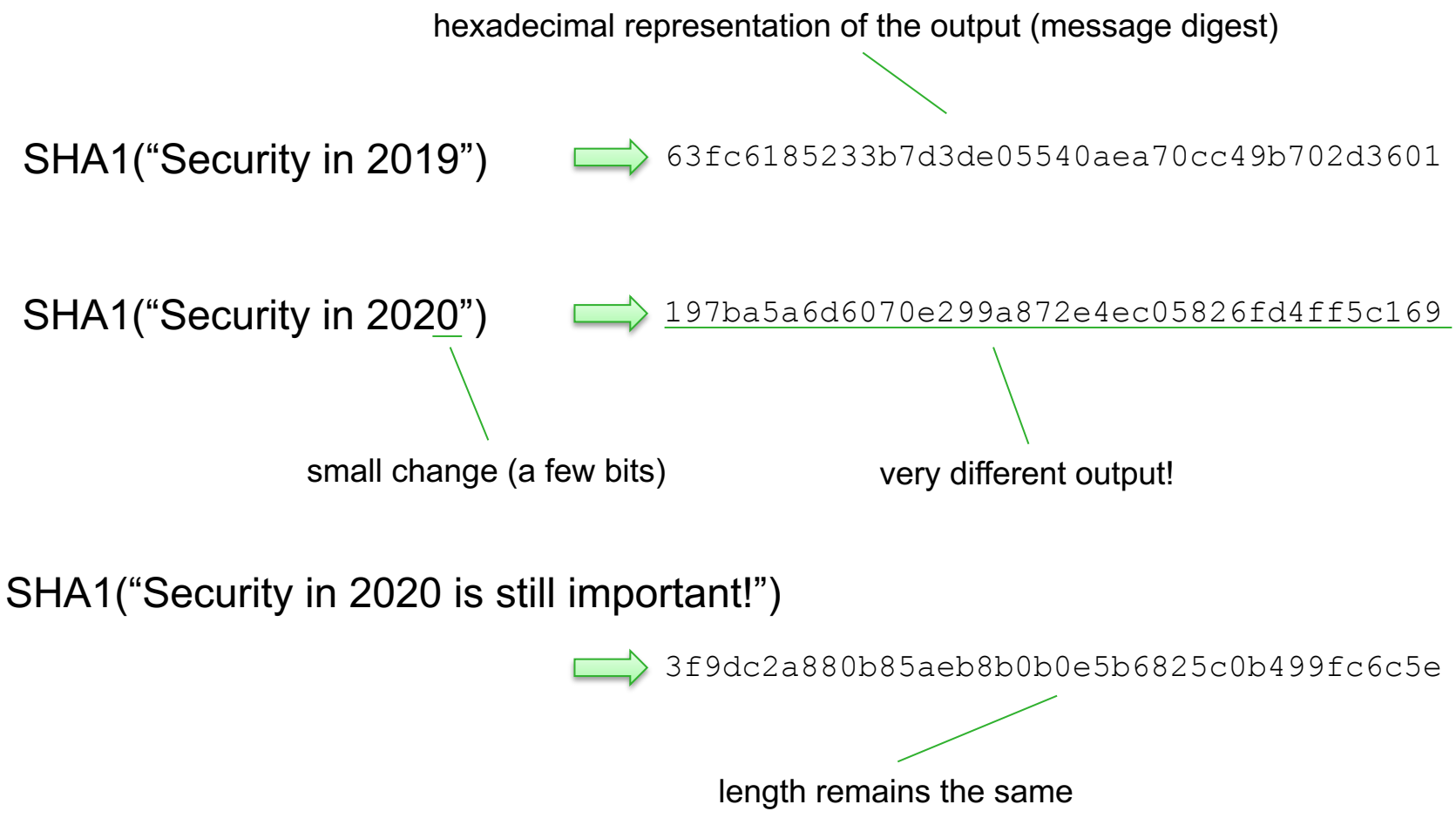


3: COLLISION RESISTANT

It is difficult (computationally infeasible) to
find two inputs with the same hash value.



HASH FUNCTION EXAMPLES



HASH FUNCTIONS

MD5		Broken DO NOT USE! (collisions found)
SHA-1		Theoretical attacks & more (avoid if possible, will soon be deprecated)
SHA-2 family (e.g., SHA-256)		Still safe (for now), your best bet
SHA-3		Recent standard, somewhat ‘unproven’

USES OF HASH FUNCTIONS

Digital signatures — See module 1

HMAC — Coming up

Integrity checks

Content Addressable Storage — Version control, e.g., git

Magnet links:

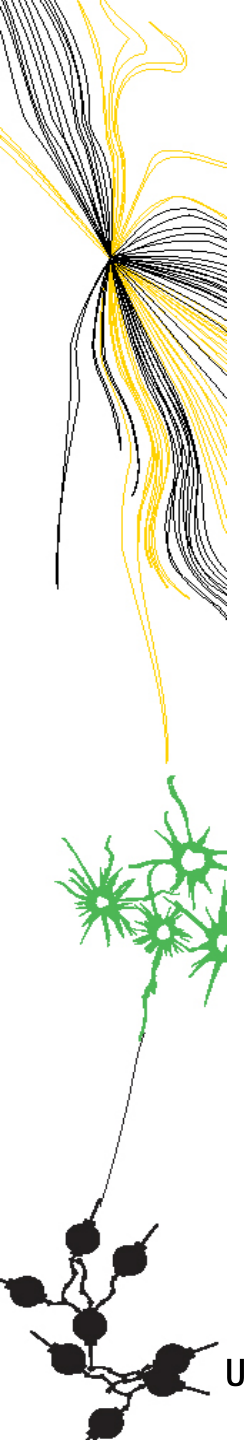
magnet:?xt=urn:sha1:YNCKHTQCWBTRNJIV4WNAE52SJUQCZO5C

Storing passwords — See assignments P-6.24-30

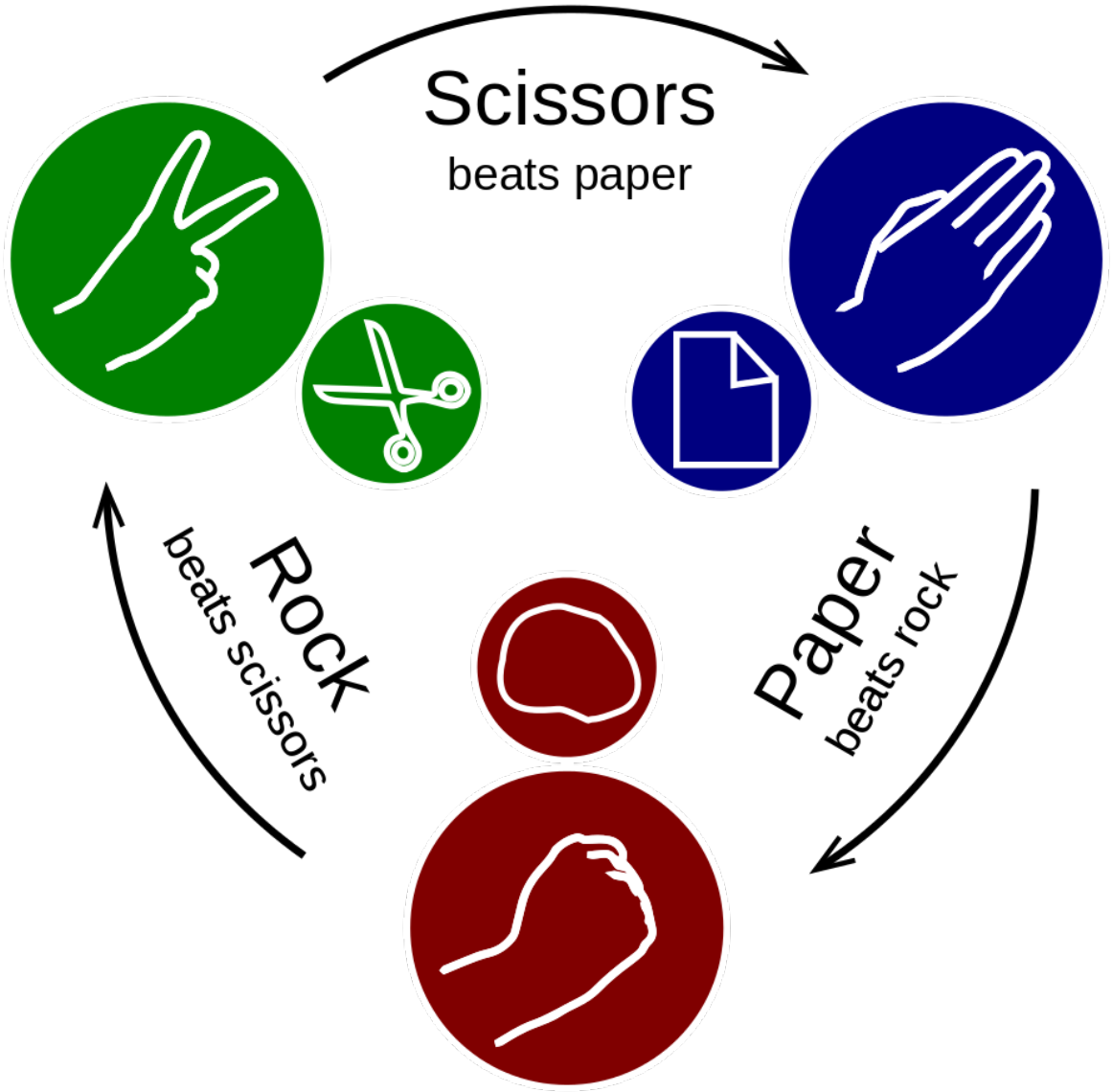
Commitments — Let's play with that!

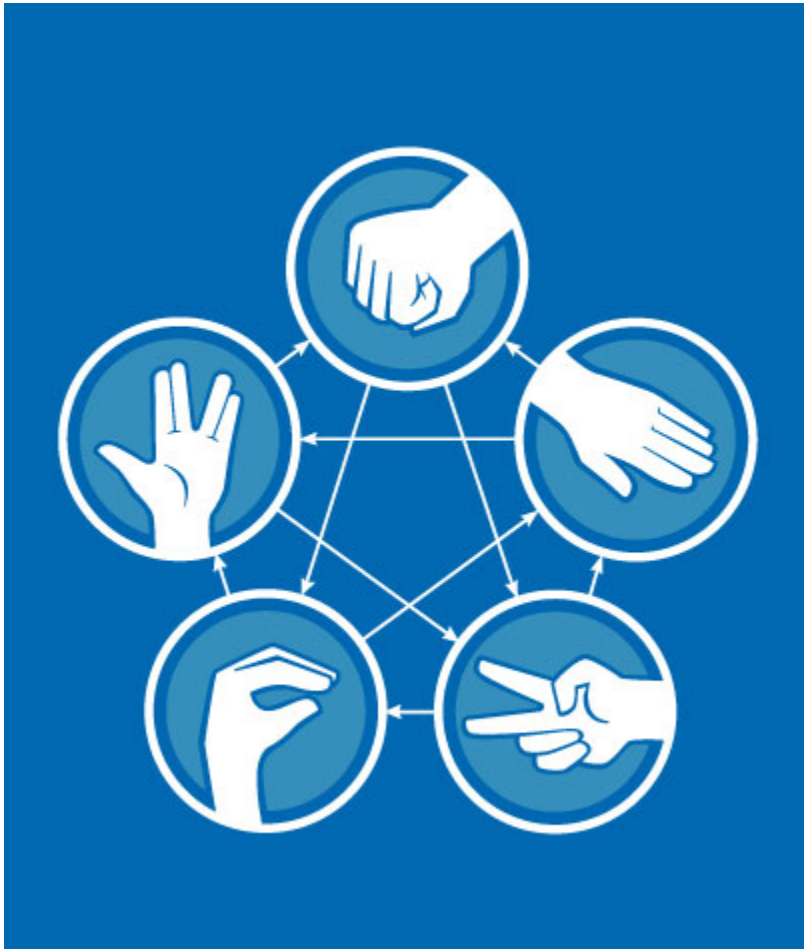
HASH FUNCTIONS IN JAVA

```
byte[] inputData = "The data to hash".getBytes();
MessageDigest md = null;
md = MessageDigest.getInstance("SHA-256");
md.update(inputData);
byte[] digest = md.digest();
```

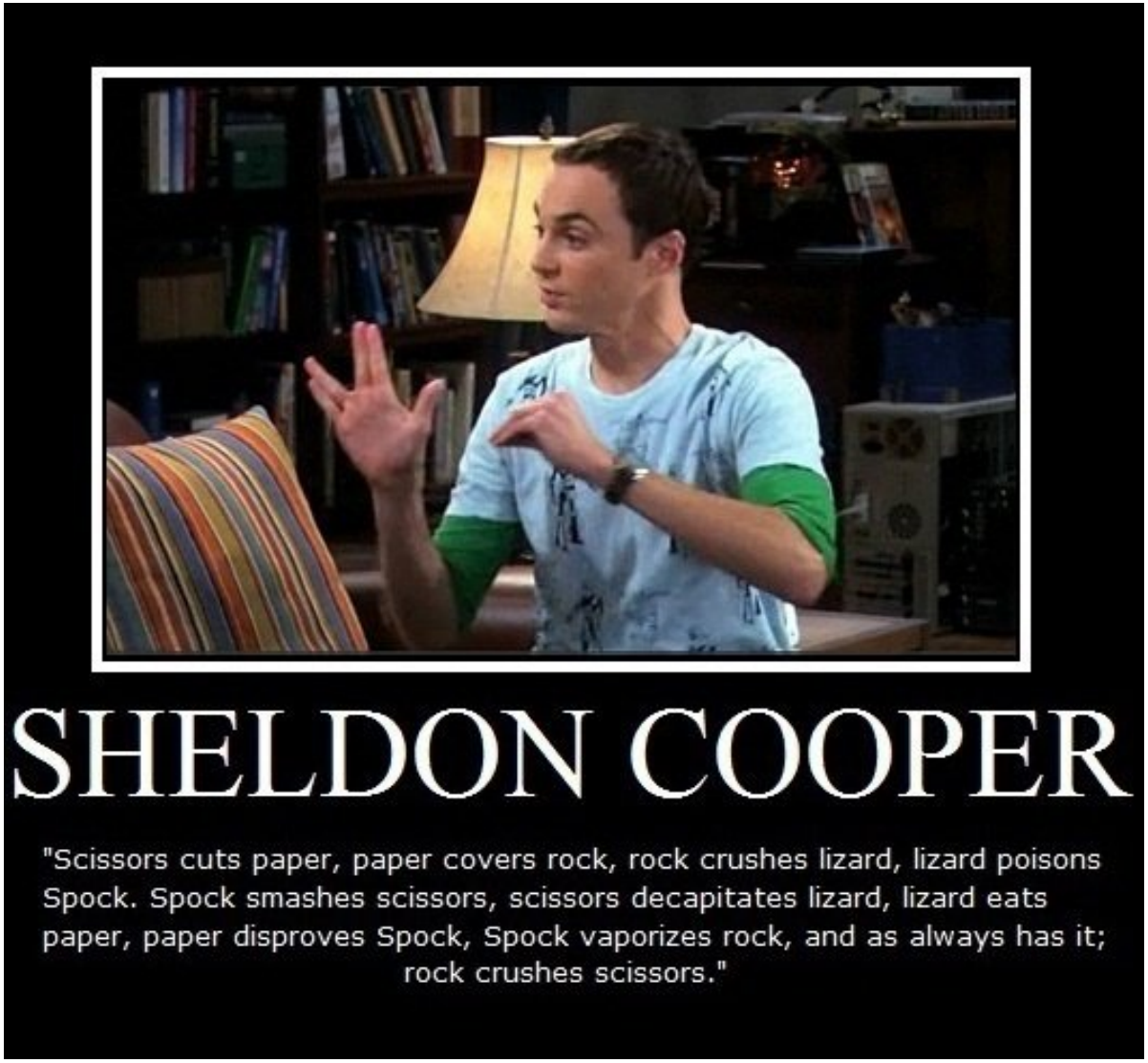


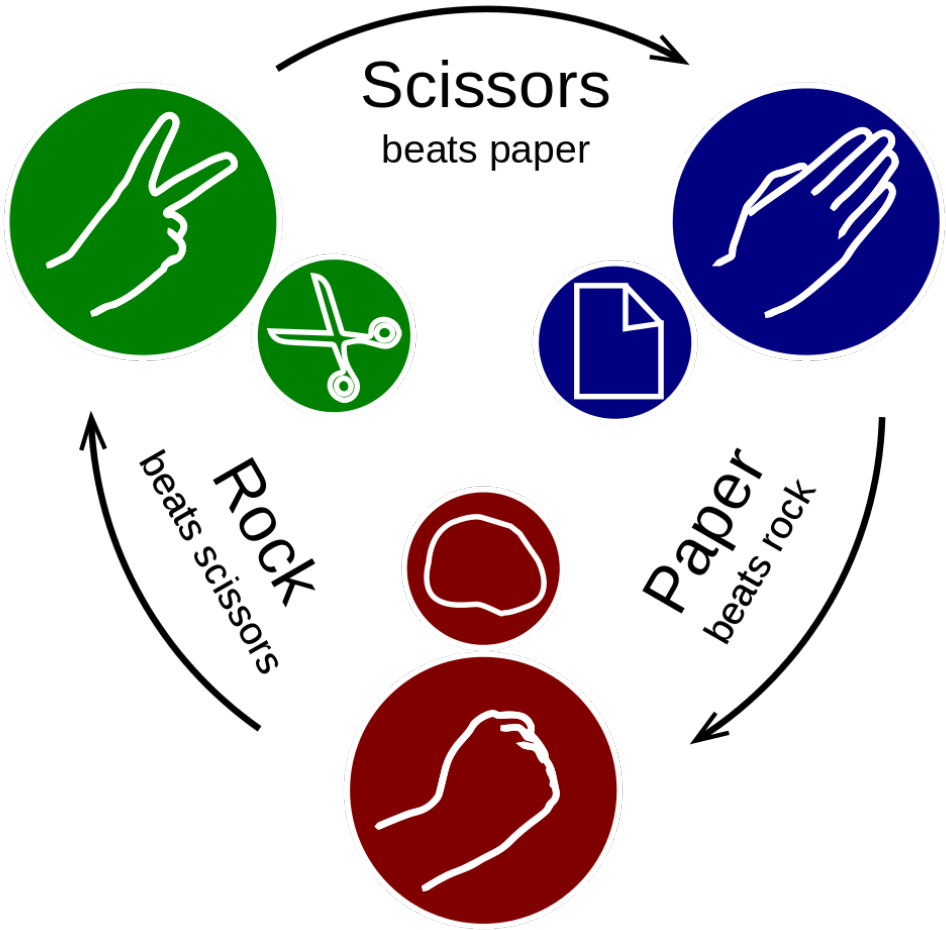
COMMITMENTS


Scissors
beats paper
Paper
beats rock
Rock
beats scissors



UNIVERSITY OF TWENTE.

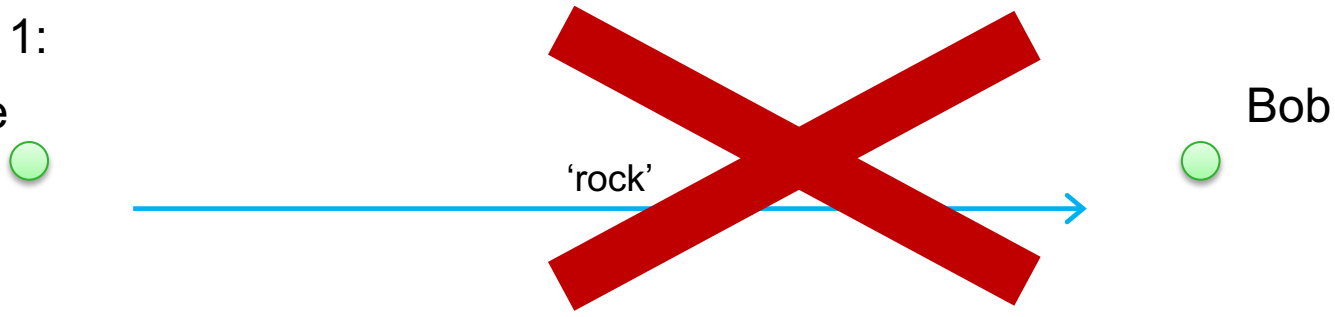

SHELDON COOPER
"Scissors cuts paper, paper covers rock, rock crushes lizard, lizard poisons Spock. Spock smashes scissors, scissors decapitates lizard, lizard eats paper, paper disproves Spock, Spock vaporizes rock, and as always has it; rock crushes scissors."



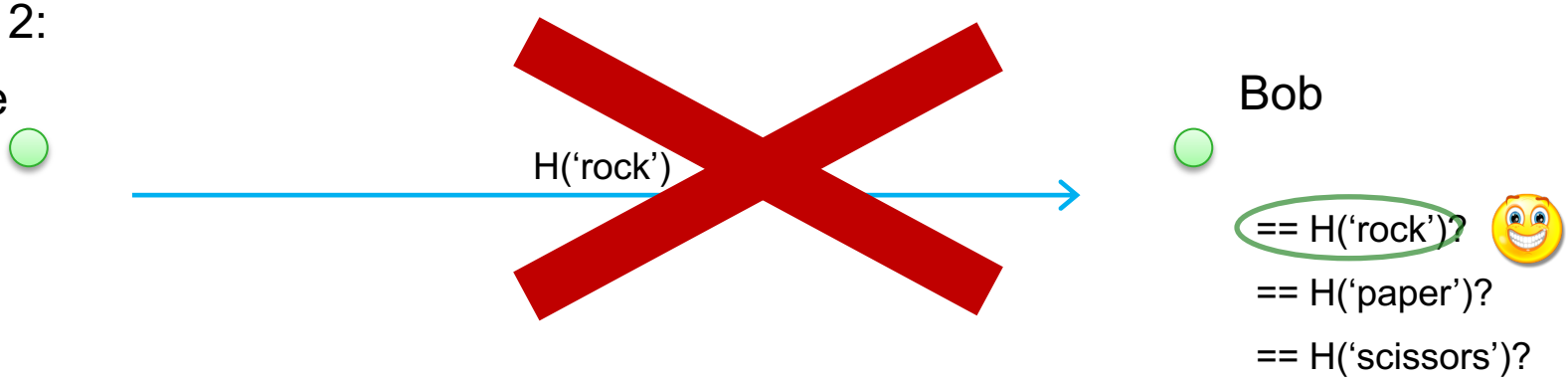
How to play rock-paper-scissors over the phone?

Let's try

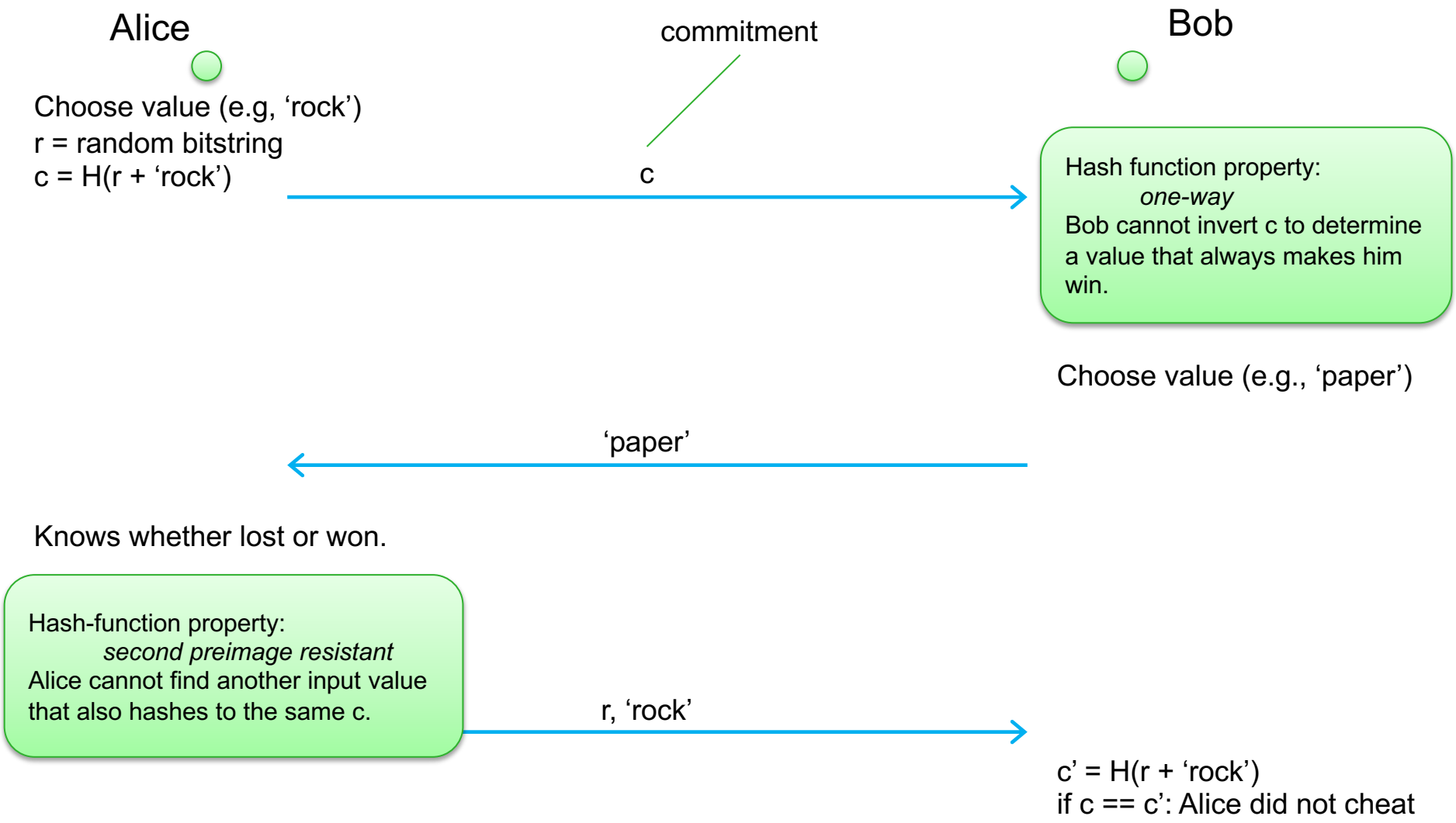
Attempt 1:

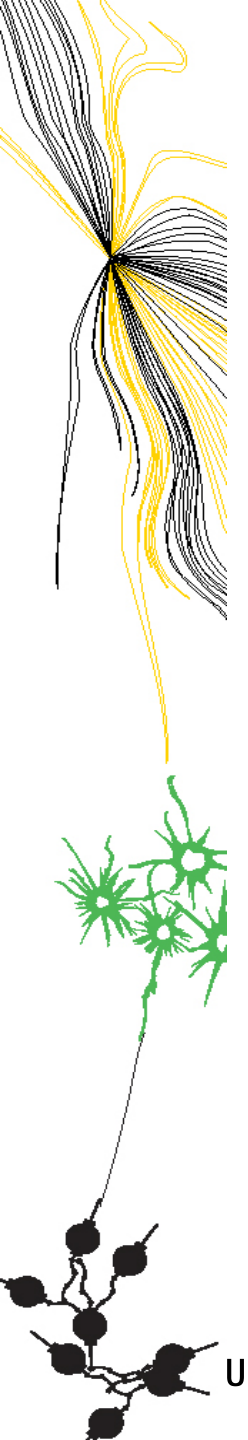


Attempt 2:



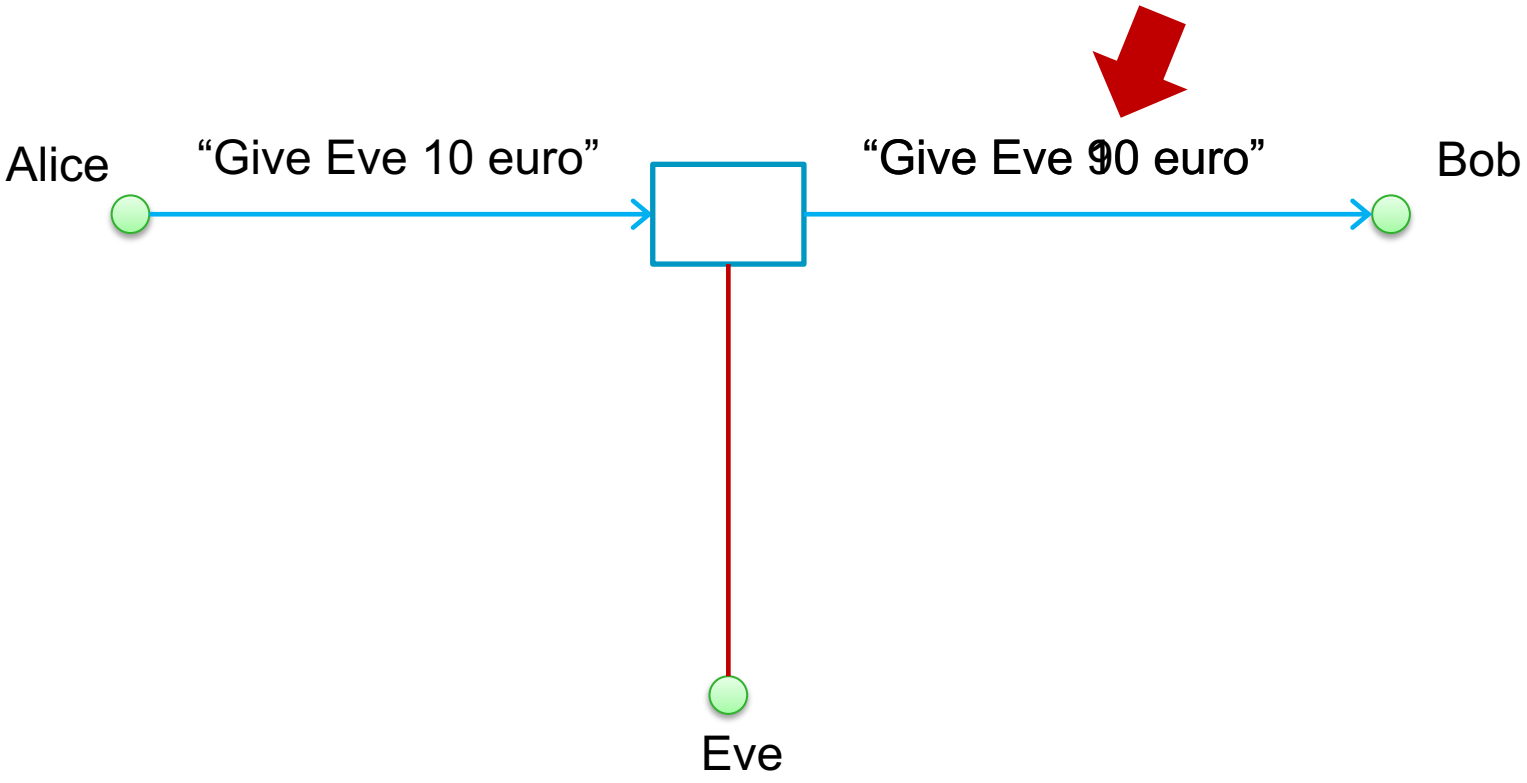
For example: `83751e164d08f068c33ca43d2cf0d9198b2432d4`



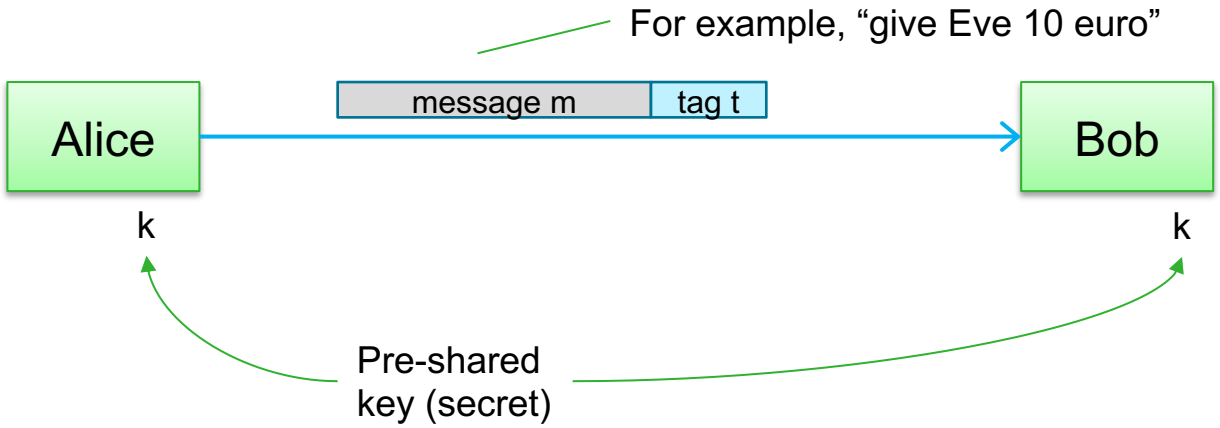


HMAC

INTEGRITY EXAMPLE (RECAP)



MESSAGE AUTHENTICATION CODES (MACS)



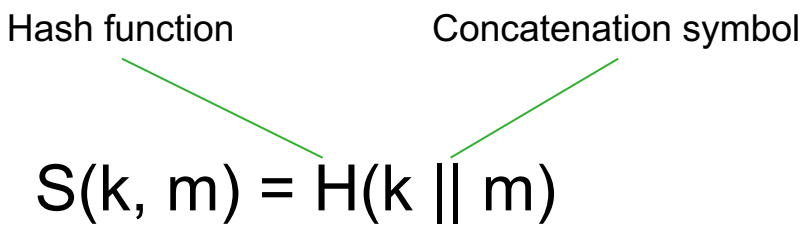
$t \leftarrow S(k, m)$ $V(k, m, t) \stackrel{?}{=}$ ‘yes’

- Attacker cannot produce a valid tag for a *new* message
- Given (m,t), attacker cannot produce (m, t’) for t’ ≠ t

} Ensuring integrity

[Based on slides by Dan Boneh]

MAC FROM HASH FUNCTION (NAIVE FIRST ATTEMPT)



Without k, it should not be possible to produce a valid tag for another message, right? Or is it?

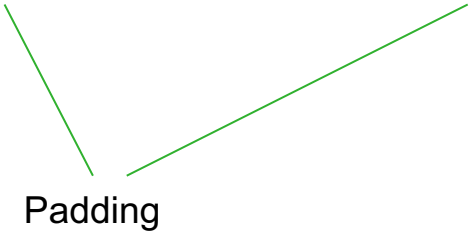
Why is this not secure?

Given H(k || m), an attacker can compute
H(k || m || PB || w) for any w.

Padding bytes

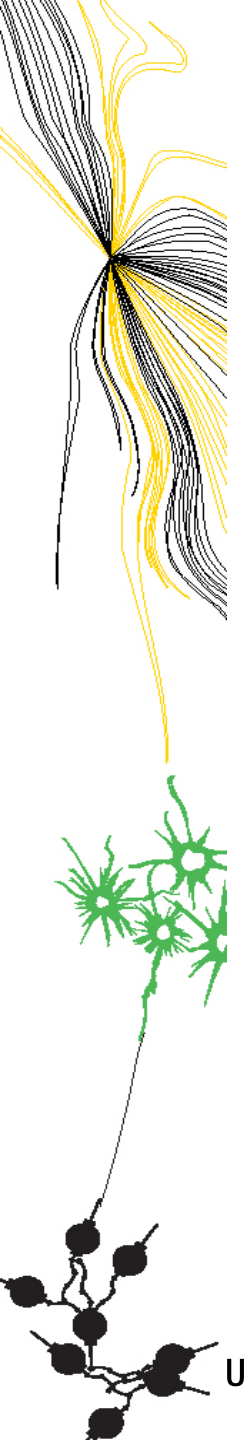
HMAC: STANDARDIZED MAC FROM HASH

$$S(k, m) = H(k \oplus \text{opad} \,||\, H(\, k \oplus \text{ipad} \,||\, m)\,)$$



HMAC IN JAVA

```
String HMAC_ALGORITHM = "HmacSHA1";
Mac mac = Mac.getInstance(HMAC_ALGORITHM);
byte[] keyBytes = "HelloWorld".getBytes();
SecretKeySpec signingKey = new SecretKeySpec(keyBytes, HMAC_ALGORITHM);
mac.init(signingKey);
byte[] messageMac = mac.doFinal("Hello World, a signed message.".getBytes());
```



SIDE-CHANNEL ATTACKS

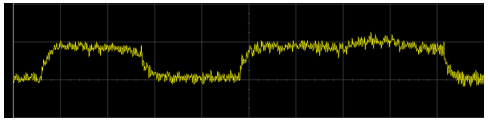
SIDE-CHANNEL ATTACKS

Whenever your program deals with secret information, it may leak information about them:

Timings

Power usage

Cache misses



⇨ One of the reasons to use proper libraries!

SIDE-CHANNEL ATTACK EXAMPLE

Suppose:

- A simple networked service
- Password-protected
- Password is sent in plaintext — For simplicity, typically a bad idea
- Password: exactly 8 characters (a-z, A-Z, 0-9)

```
public boolean checkPassword(String input)
```

Number of different characters: 26+26+10 = 62

Number of possible passwords: 62^8 = 218340105584896 (≈ $2*10^{14}$)

SIDE-CHANNEL ATTACK EXAMPLE

```
private String secretPassword = "Secret12";
public boolean checkPassword(String input) {
    if (input.length() != secretPassword.length()) {
        return false;
    }
    for (int i = 0; i < input.length(); i++) {
        if (input.charAt(i) != secretPassword.charAt(i)) {
            return false;
        }
    }
    return true;
}
```

Suppose: 1 iteration ~10µs

Given timing information:

input = “AAAAAAAA” vs. input = “SecAAAAA”?

input = “AAAAAAAA” vs. input = “BAAAAAAA”?

input = “AAAAAAAA” vs. input = “SAAAAAAA”?

input = “SAAAAAAA” vs. input = “SeAAAAAA”?

input = “SeAAAAAA” vs. input = “SecAAAAA”?

Algorithm for side-channel attack!

8*62 = 496 attempts

vs.

62^8 = 218340105584896 attempts

Meltdown and Spectre

Vulnerabilities in modern computers leak passwords and sensitive data.

Meltdown and Spectre exploit critical vulnerabilities in modern processors. These hardware vulnerabilities allow programs to steal data which is currently processed on the computer. While programs are typically not permitted to read data from other programs, a malicious program can exploit Meltdown and Spectre to get hold of secrets stored in the memory of other running programs. This might include your passwords stored in a password manager or browser, your personal photos, emails, instant messages and even business-critical documents.

Meltdown and Spectre work on personal computers, mobile devices, and in the cloud. Depending on the cloud provider's infrastructure, it might be possible to steal data from other customers.

Meltdown

Meltdown breaks the most fundamental isolation between user applications and the operating system. This attack allows a program to access the memory, and thus also the secrets, of other programs and the operating system.

If your computer has a vulnerable processor and runs an unpatched operating system, it is not safe to work with sensitive information without the chance of leaking the

Spectre

Spectre breaks the isolation between different applications. It allows an attacker to trick error-free programs, which follow best practices, into leaking their secrets. In fact, the safety checks of said best practices actually increase the attack surface and may make applications more susceptible to Spectre

Spectre is harder to exploit than Meltdown, but it is also harder to mitigate. However, it is possible to prevent

Security

Meltdown, Spectre bug patch slowdown gets real – and what you can do about it

Chip flaw fixes not so insignificant after all

By Thomas Claburn in San Francisco 9 Jan 2018 at 00:45 129 SHARE ▼

Analysis Having shot itself in the foot by prioritizing processor speed over security, the chip industry's fix involves doing the same to customers.

The patches being put in place to address the Meltdown and Spectre bugs that affect most modern CPUs were supposed be airy little things of no consequence. Instead, for some unlucky people, they're anchors.

Having helped find the flaws, Google insisted the software fixes that have begun to appear "introduce minimal performance impact," and insisted the performance hit will diminish over time.

Intel said as much in its statement, claiming "any performance impacts are workload-dependent, and, for the average computer user, should not be significant and will be mitigated over time."

Most read


Ticketmaster tells customer it's not at fault for site's Magecart malware pwnage


Windows 10 can carry on slurping even when you're sure you yelled STOP!


Having swallowed its pride and started again with 10nm chips, Intel teases features in these 2019-ish processors


Here's 2018 in a nutshell for you... Russian super robot turns out to be man in robot suit


It is with a heavy heart that we must inform you hackers are targeting 'nuclear, defense, energy, financial' biz

USING CRYPTOGRAPHY – WORDS OF WARNING

DO NOT invent your own crypto!

- It will be broken!
- Only do it for fun (and learning)!

DO NOT even implement cryptographic primitives yourself!

- So many details to get right
- “It is typically not the math that is broken, it’s the implementation”

Rules of thumb

- Data at rest: use pgp/gpg
- Data in motion: use (SSL/)TLS

But be careful!

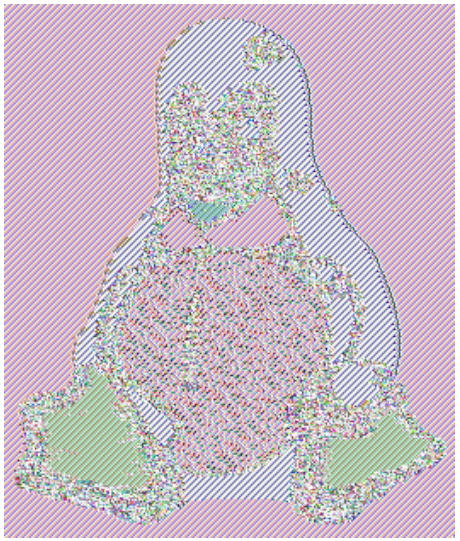
USE *high-level* cryptographic libraries!

- NaCl (“salt”): http://nacl.cr.yp.to/
- Keyczar: http://www.keyczar.org/

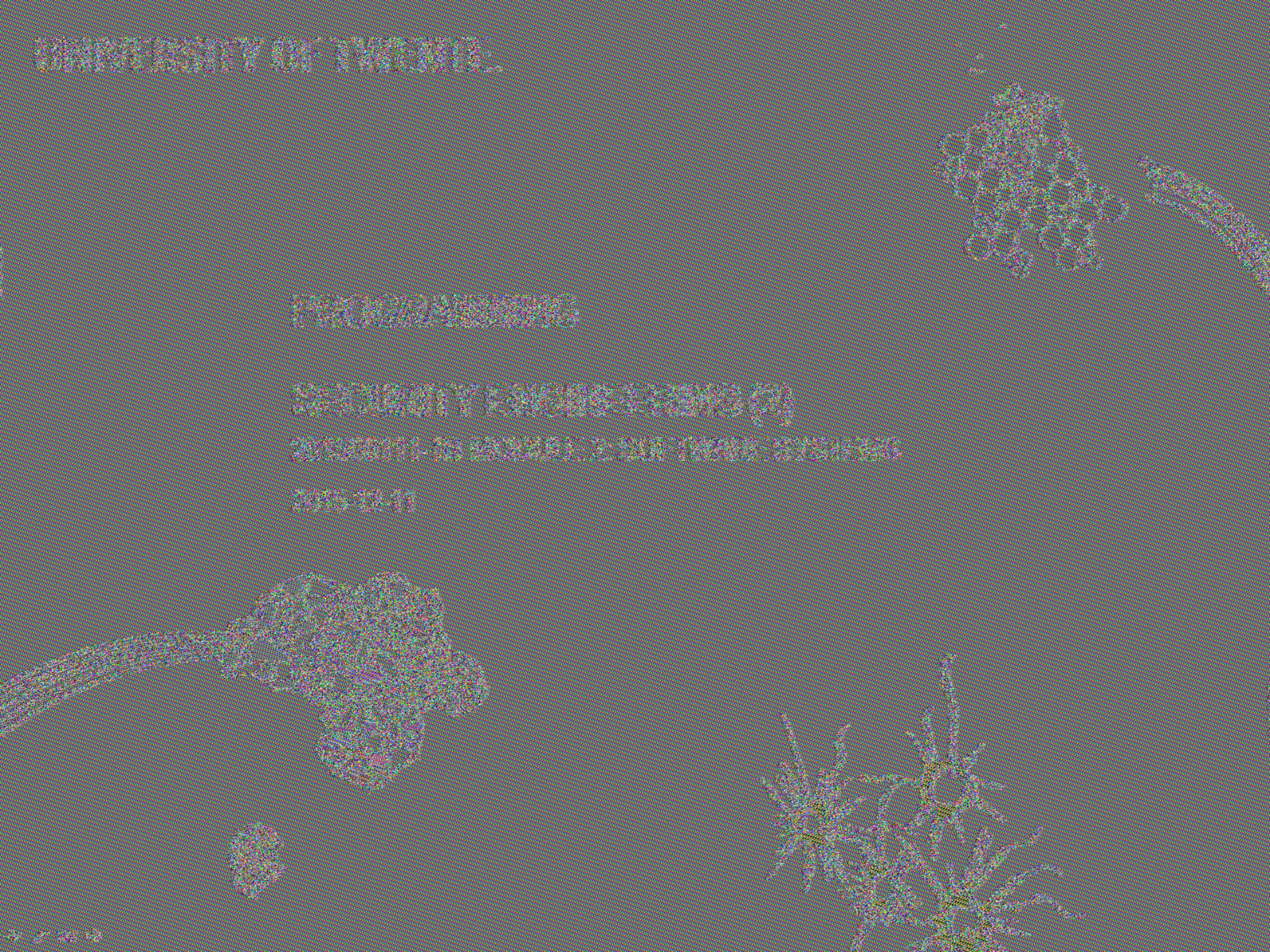
Preferably open source!

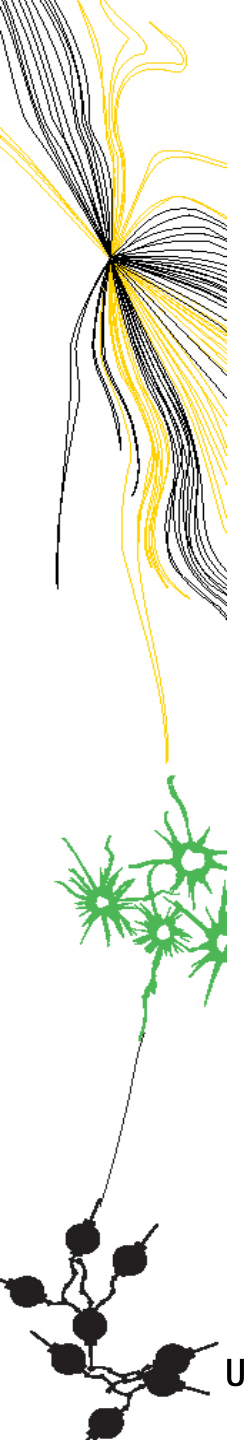
WHY?

"We'll just use encryption, AES appears to be good, yes?"



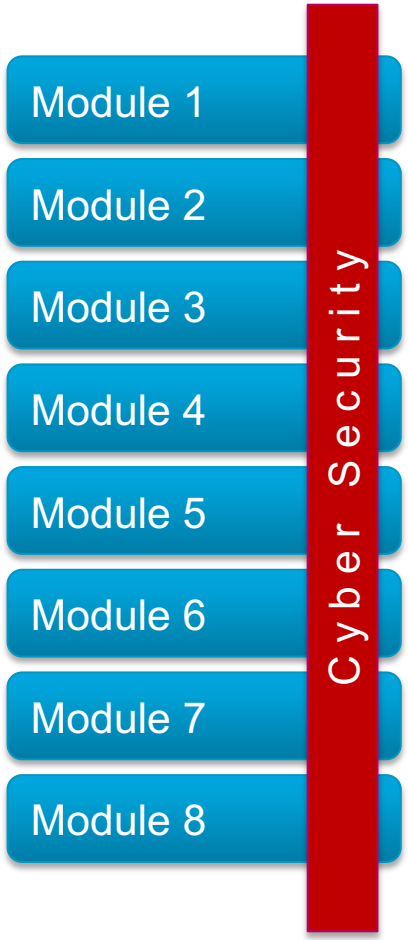
AES in the ECB mode-of-operation
applied to a image

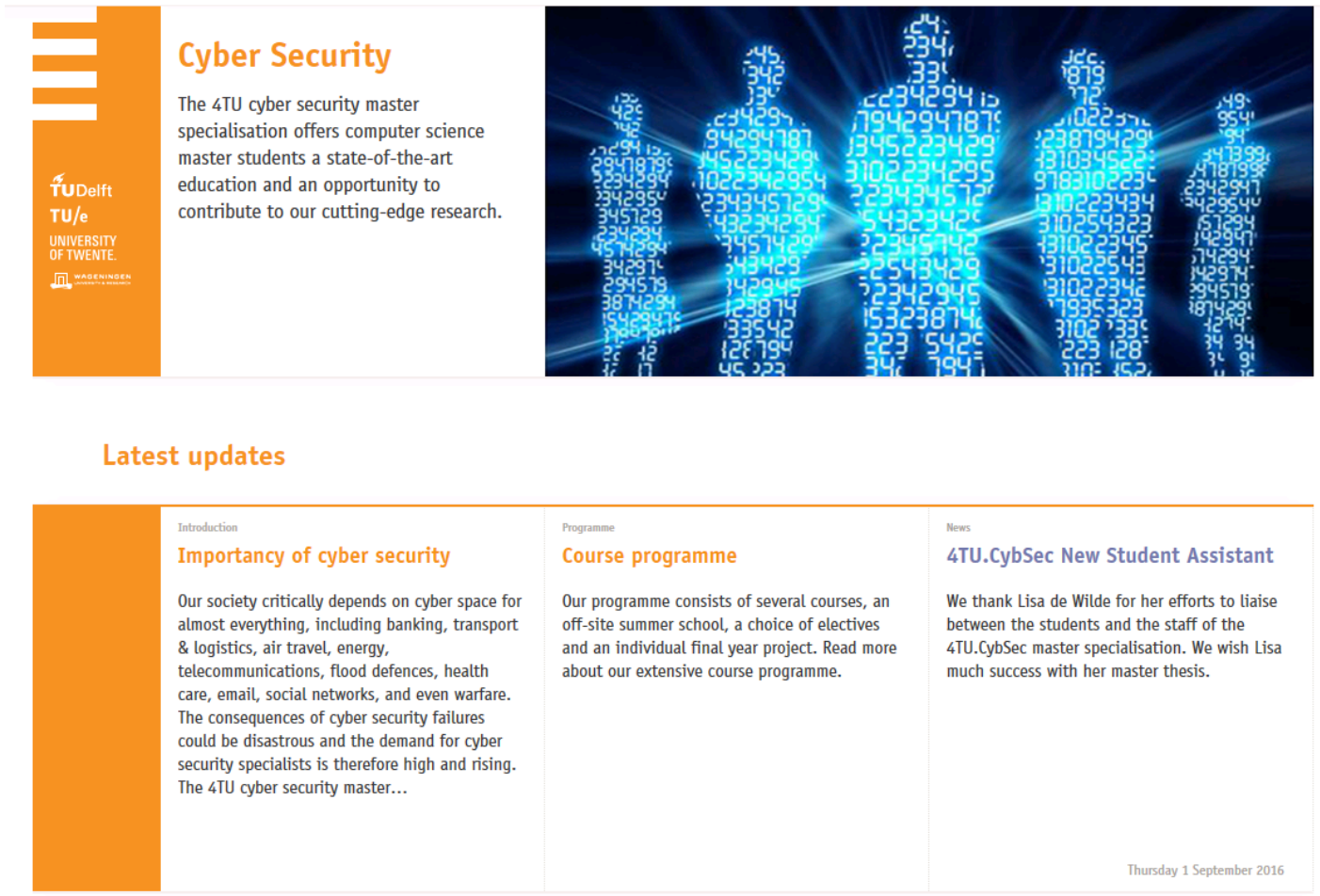




WANT MORE SECURITY?

SECURITY IN OTHER MODULES

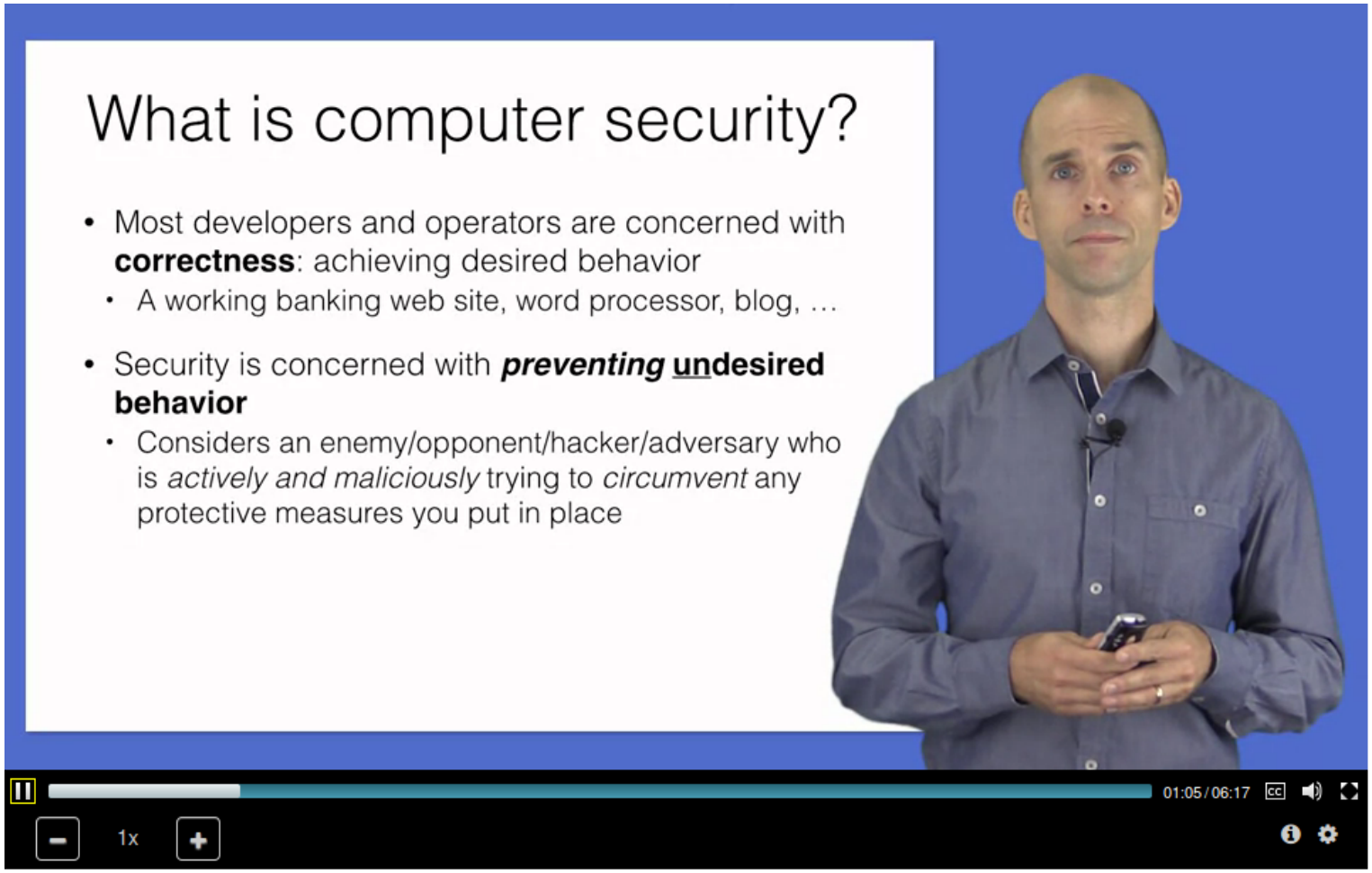




The new 4TU cyber security master specialisation:
https://www.4tu.nl/cybsec/en/

MOOC: Coursera's course on Cryptography by Dan Boneh (Stanford)
https://www.coursera.org/course/crypto

coursera



MOOC: Coursera's course on Software Security by Michael Hicks
https://www.coursera.org/course/softwaresec

coursera

Twente Hacking Squad:
See http://scs.ewi.utwente.nl/home/TwenteHackingSquad/ for more info.

LAB EXERCISES RELATED TO SECURITY

- P-5.7-9 (Hex & Base64 encoding)
- P-6.4-10 (Password cracking & how to properly store them)
- P-7.6 (Networked attack)
- P-7.17 (Bonus: crypto attack)

Also read the text surrounding the exercise!