NTNU | Norwegian University of Science and Technology

LEGACY CRYPTO 1

TTM4205 – Lecture 5

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Uniped Observation

I am completing a course in University Pedagogy (Uniped) this year, and today, I have so-called *collegial coaching*. This means that a few other lecturers from different departments at NTNU will observe my lecture and provide feedback afterward. They are **not** observing you.

Reference Group

I am looking for (at least) three students to form a reference group in this course, preferably students from different programs. We will meet three times during the semester, and your feedback is extremely valuable.

Send me an email and/or talk to me in the break :)

Open PhD Position

Figure: https://www.jobbnorge.no/en/available-jobs/job/246480/phd-candidate-in-cryptography-engineering

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Legacy Crypto is...

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- Crypto regulated by export control
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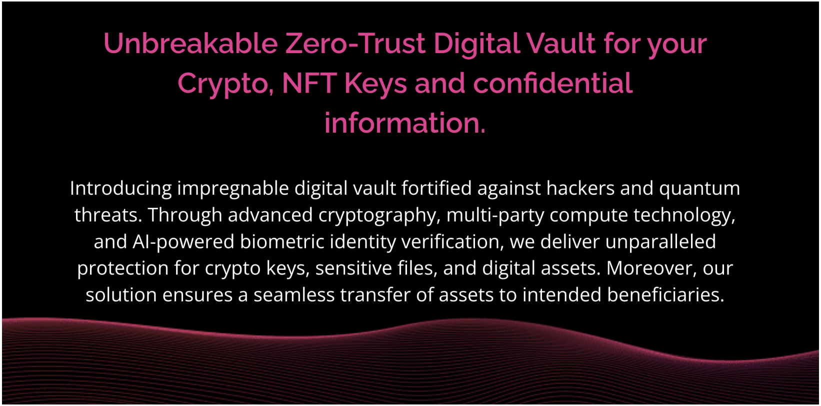
- Key escrow and surveillance
- Downgradable crypto protocols

Legacy Crypto $\neq$ Crypto Legacy



Two Categories

Secret Key Crypto

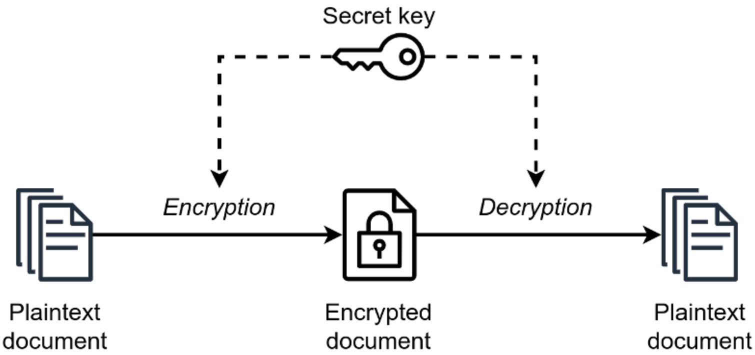
Public Key Crypto

Today

Secret Key Crypto

Public Key Crypto

Secret Key Crypto



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Crypto Wars

Essentially $30+$ year ongoing debate between policymakers and technologists about encryption and surveillance

Typically portrayed as "Safety" vs. "Privacy" to get "Security"

Crypto War I

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- The US government allows crypto from ~ 2000

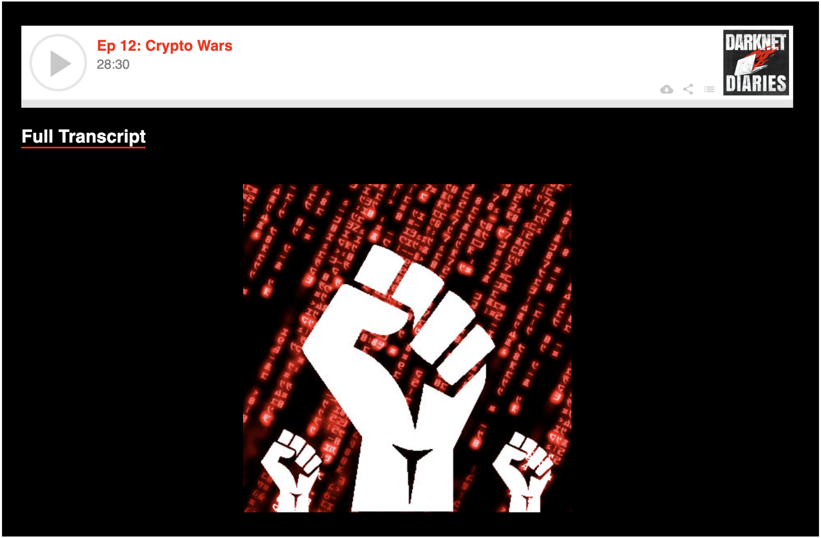

Figure: https://darknetdiaries.com/episode/12

Crypto War II

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- Standardized crypto backdoored by NSA (next lecture)

Figure: https://youtu.be/bB68G8tLh38

Crypto War III

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- Wants to use AI to discover illegal online content
- Swiss Police in 2022: "80 % of reports are false"
- No one knows what is target of scanning $=$ backdoor

Keys Under Doormats:

MANDATING INSECURITY BY REQUIRING GOVERNMENT ACCESS TO ALL DATA AND COMMUNICATIONS

Harold Abelson, Ross Anderson, Steven M. Bellovin, Josh Benaloh, Matt Blaze, Whitfield Diffie, John Gilmore, Matthew Green, Susan Landau, Peter G. Neumann, Ronald L. Rivest, Jeffrey I. Schiller, Bruce Schneier, Michael Specter, Daniel J. Weitzner

Figure: `https://spar.isi.jhu.edu/~mgreen/paper-keys-under-doormats.pdf`

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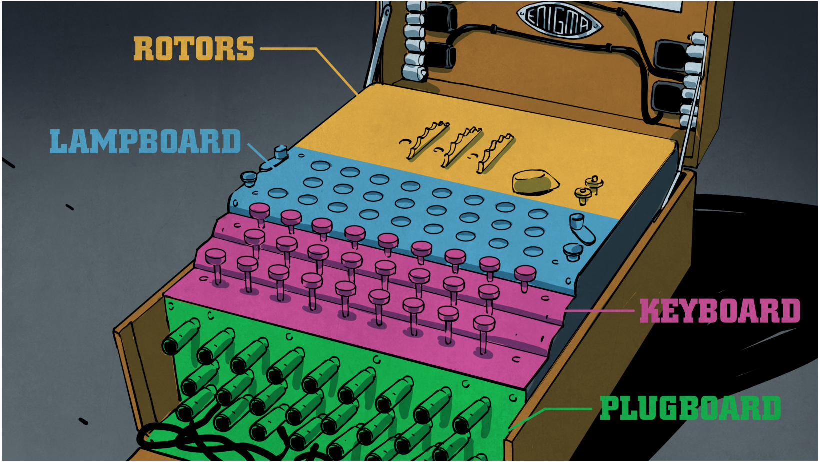
Enigma Machine



Code Table

Geheim!

Nicht ins Flugzeug mitnehmen!

Sonder-Maschinenschlüssel BGS

08 ❊

Datum	Walzenlage			Ringstellung			Steckerverbindungen										Kenngruppen			
31.	I	II	V	10	14	02	BF	SD	AY	HG	OU	QC	WI	RL	XP	ZK	yqv	vuc	xxo	gvf
30.	V	IV	I	04	25	01	DI	ZL	RX	UH	QK	PC	VY	GA	SO	EM	mqy	vts	gvt	csx
29.	III	V	II	13	11	06	ZM	BQ	TP	YX	FK	AR	WH	SO	NJ	DG	aky	vdv	oyo	tzt
28.	I	III	II	09	16	12	NE	MT	RL	OY	HV	IU	GK	FW	PZ	XC	nfh	vco	tur	wnb
27.	III	II	I	06	03	15	BF	GR	SZ	OM	WQ	TY	HE	JU	XN	KD	bec	jmv	vtp	xdb
26.	I	III	V	19	26	08	GS	VD	CQ	LE	HI	BO	JP	UZ	FT	RN	wvu	yem	buz	rjk
25.	II	I	IV	05	01	16	KA	ZH	QP	GR	MF	LJ	OT	EN	BD	YW	ktv	muq	cqm	cpm
24.	III	II	IV	22	02	06	PI	KM	JB	YU	QS	OV	ZA	GW	CH	XF	zcd	iwo	urp	glg
23.	IV	III	II	08	11	07	SX	TD	QP	HU	FB	YN	CO	IK	WE	GZ	epm	mgz	vqg	vsm
22.	I	V	II	13	02	26	GP	XH	IW	BO	NU	MD	SA	ZK	QR	LT	aam	mvy	jqq	wqm
21.	IV	I	V	17	24	03	XC	AQ	OT	UZ	HD	RG	KM	BL	NS	JW	ltl	blu	frk	xrh
20.	IV	I	III	15	22	12	PO	TV	QC	ZS	EX	WR	BJ	DK	FU	LA	non	lic	oxr	usr
19.	V	I	III	13	24	21	HA	GM	DI	VK	JP	YU	EF	TB	ZL	XQ	ecd	ciq	uvr	ppt
18.	IV	V	I	23	09	20	XF	PZ	SQ	GR	AJ	UO	CN	BV	TM	KI	fjh	zts	uqu	cft
17.	III	II	V	21	24	15	UT	ZC	YN	BE	PK	JX	RS	GF	IA	QH	oub	eci	pyf	rqi
16.	IV	III	V	07	01	13	IN	YJ	SD	UV	GF	BH	TK	QE	AR	OP	kex	paw	flw	onw
15.	I	IV	II	15	04	25	TM	IJ	VK	OY	NX	PR	WL	GA	BU	SF	sdr	pbu	byv	khb
14.	III	II	IV	10	23	21	WT	RE	PC	FY	JA	VD	OI	HK	NX	ZS	mhz	lff	lnq	giy
13.	V	I	II	14	04	12	AN	IV	LH	YP	WM	TR	XU	FO	ZB	ED	rqh	ucm	ldi	ods
12.	II	V	I	07	19	02	HR	NC	IU	DM	TW	GV	FB	ZL	EQ	OX	asy	xza	uvc	fmr
11.	I	V	IV	13	15	11	NX	EC	RV	GP	SU	DK	IT	FY	BL	AZ	gyd	iuq	ocb	vef
10.	V	II	I	09	20	19	FN	TA	YJ	SO	EG	PC	VD	KI	XH	WZ	pyz	ace	pru	uyc
9.	I	IV	V	14	10	25	VK	DW	LH	RF	JS	CX	PT	YB	ZG	MU	nyh	fbd	ohs	jrp
8.	IV	V	I	22	04	16	PV	XS	ZU	EQ	BW	CH	AO	RL	JN	TD	tck	rts	nro	mkl
7.	V	I	IV	18	11	25	TS	IK	AV	QP	HW	FM	DX	NG	CY	UE	mhw	lwb	mdm	ybe
6.	IV	I	III	02	17	20	KZ	FI	WY	MP	DS	HR	CU	XE	QV	NT	uwu	vdk	lrh	mgd
5.	I	V	IV	26	09	14	VW	LT	PB	FO	ZK	GS	RI	QJ	HM	XE	suw	tsv	nfp	yjc
4.	IV	III	V	07	01	12	QS	YA	XW	KR	MP	HT	DU	OV	CL	FZ	uby	usi	mhh	mwb
3.	I	II	V	05	16	03	FW	DL	NX	BV	KM	RZ	HY	IQ	EC	JU	tns	von	grw	axl
2.	III	I	II	12	22	17	DW	UO	PY	GR	FS	EQ	KT	CL	AI	ZB	smz	lbl	bkc	sym
1.	I	III	II	04	18	06	ZN	OM	CR	UI	KP	WQ	SE	JV	LX	TF	ghr	vqv	cya	ayl

Security of Enigma

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- Choose three rotors out of five

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- Impossible to break until recent years...

Flaws of Enigma

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- A plaintext letter can never be encrypted to itself
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- Each contradiction removed millions of settings
- It took two hours to brute force a key each day
- Alan Turing and his team broke the code in 1941

Facts about Enigma

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- There are roughly 300 (publicly known) copies
- Some versions of Enigma have four rotors
- The auction value is between 3 and 5 MNOK

Enigma at NTNU

More Enigma

Figure: Numberphile: https://youtu.be/G2_Q9FoD-oQ, and at Computerphile: https://youtube.com/playlist?list=PLzH6n4zXuckodsatCTEuxaygCHizMS0_I

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Legacy Ciphers

We have several newer ciphers developed in the 1990s and early 2000s that were the leading standard for many years, and we still find them in a variety of protocols and products that are still used on or connected to the Internet today.

There has been a variety of attacks, and here are some...

MD5

- Hash function outputting 128 bits
- Designed by Ron Rivest in 1991
- First specific collisions found in 2004
- First general collisions found in 2006
- Used to create fake X509 certificates
- Revoked in most (!) applications by 2014 (!)

MD5

Year	Identical-prefix collision cost	Chosen-prefix collision cost
< 2004	2^{64} generic	2^{64} generic
2004	**2^{40} [WY05]**	–
2005	2^{37} [Kli05]	–
2006	2^{32} [Kli06, Ste06]	**2^{49} [SLdW07c]**
2007	2^{25} [Ste07]	–
2008	2^{21} [XLF08]	–
2009	2^{16} [SSA+09]	2^{39} [SSA+09]
2020	2^{16} [SSA+09]	2^{39} [SSA+09]

Figure: https://www.marc-stevens.nl/research/papers/CC21Chapter-S.pdf

SHA-1

- Hash function outputting 160 bits
- Designed by the NSA in 1995
- First specific collisions found in 2017
- First general collisions found in 2020
- Revoked in most (!) applications by 2020 (!)

SHA-1

Year	Identical-prefix collision cost		Chosen-prefix collision cost	
< 2005	2^{80}	generic	2^{80}	generic
2005	2^{69}	[WYY05b]	–	
	$(u : 2^{63}$	[WYY05a])	–	
2007	$(u : 2^{61}$	[MRR07])	–	
2009	$(w : 2^{52}$	[MHP09])	–	
2013	2^{61}	[Ste13b]	2^{77}	[Ste13b]
2017	$\mathbf{G : 2^{63.1}}$	**[SBK+17]**	–	
2019	–		$G : 2^{67}$	[LP19]
2020	2^{61} / $G : 2^{61.2}$	[Ste13b] / [LP20]	$\mathbf{G : 2^{63.4}}$	**[LP20]**

Figure: https://www.marc-stevens.nl/research/papers/CC21Chapter-S.pdf

RC4

- Symmetric stream cipher using at least 40 bit keys
- Designed by Ron Rivest in 1987 (public in 1994)
- Used in the WEP (1997), WPA (2003), SSL/TLS (1995)
- Detectable bias after only 256 bytes of data
- Long list of attacks. Broken in WEP in 2004.
- Revoked in most (!) applications by 2015 (!)

3DES

- DES: Symmetric block cipher using 56 bit keys
- Proposed in 1981, standardized in 1995 by NIST
- 3DES: Using DES three times with three keys
- Meet-in-the-Middle attack: 112 bits of security
- Revoked in most applications by 2019

AES-CBC

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- CPA secure (theory), not CCA (practice), patched
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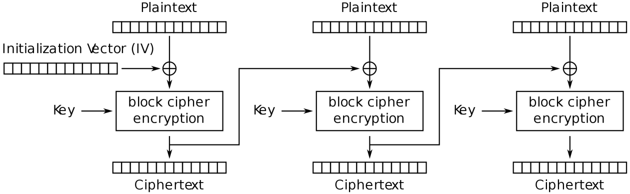
- Revoked from some applications (e.g. TLS) in 2018

AES-CBC



Cipher Block Chaining (CBC) mode encryption

CBC Attack

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CBC Attack

- Each block must be of exactly 128 bits
- Shorter message leads to padding at the end
- Add one byte ends with 01, two with 02, etc. ...
- An API outputs errors when wrong padding
- The error message or timing might leak info...

CBC Attack

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- Let C_2 be an encryption of X that you want to decrypt

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- Choose random C_1 and ask for $C_1|C_2$ to be decrypted

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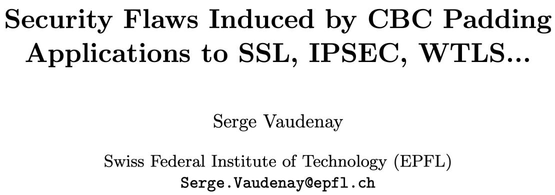
- Vary last byte of C_1 until correct to find last byte of X
- Find next byte by $C_1[15] = X[15] \oplus 02$ and vary $C_1[14]$
- Continue until you have all bytes of X, max $128 \cdot 16$ trials

CBC Attack



Security Flaws Induced by CBC Padding
Applications to SSL, IPSEC, WTLS...

Serge Vaudenay

Swiss Federal Institute of Technology (EPFL)
Serge.Vaudenay@epfl.ch

Figure: https://www.iacr.org/cryptodb/archive/2002/EUROCRYPT/2850/2850.pdf

Questions?