High-Speed Cryptography

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Joint work with Daniel J. Bernstein, Tanja Lange

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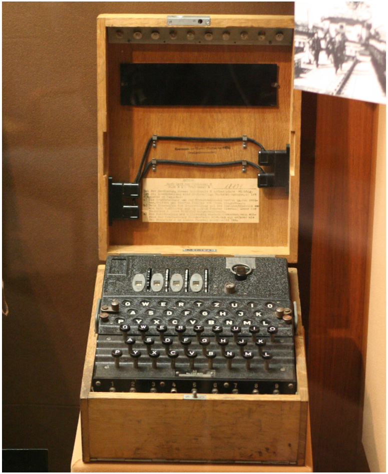
Graduate Seminar

Part I

Introduction to high-speed cryptography

The Enigma

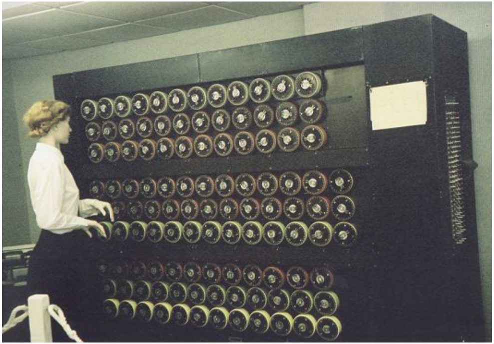
- Encryption device used by the German troops in WWII
- Developed by Scherbius, patented in 1928
- Variants with different number of rotors



Source: `http://en.wikipedia.org/wiki/File:Kriegsmarine_Enigma.png`, CC-by-sa-3.0

The Bombes

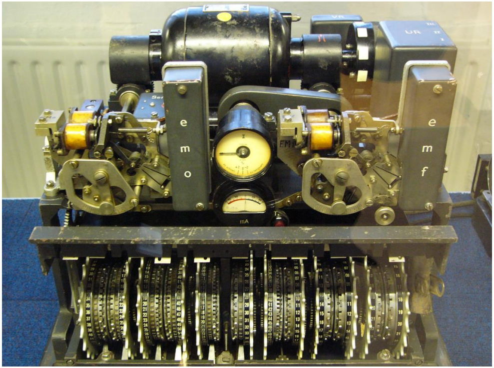
- Computing devices in Bletchley Park (UK)
- Used by the English to break the Enigma ciphers
- Large influence on the U-boat war



Source: `http://en.wikipedia.org/wiki/File:TuringBombeBletchleyPark.jpg`, GNU FDL 1.2

The Lorenz cipher machine

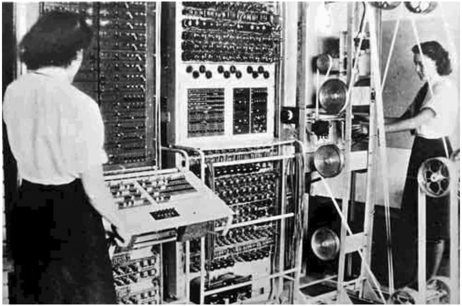
- Used by German army for high-level communication from ∼1942
- Extension to a Lorenz teleprinter
- Used a stream cipher



Source:
`http://en.wikipedia.org/wiki/File:Lorenz-SZ42-2.jpg`,
public domain

The Colossus

- First electronic digital information processing machine
- Used in Bletchley Park to break the Lorenz cipher from 1944



Source: `http://en.wikipedia.org/wiki/File:Colossus.jpg`, public domain

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- ... or for cryptanalysis, i.e. breaking encryptions (Bombes, Colossus)
- Still today dedicated hardware is developed for encryption:
  - Various VIA processors feature the "PadLock Engine", hardware for the "Advanced Encryption Standard" (AES), hash algorithms, and more
  - Intel Processors since Westmere have built-in hardware support for AES (AES-NI instructions)
  - Even more common on embedded microprocessors to have hardware support for crypto

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  - Huge demand for high-speed software implementations of cryptography

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- "Serpent is generally the slowest of the finalists in software speed for encryption and decryption"
- Similar for currently running SHA-3 competition: software speed one of the most important selection criteria

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Definition

The term *high-speed cryptography* means the design and implementation of secure and fast cryptographic software for off-the-shelf computers.

What high-speed crypto is *not*
(at least not in this talk)

- Design of cryptographic primitives targeting high performance
- Implementing crypto in hardware
- Making crypto faster by choosing low-security *functions*
- Making crypto faster by low-security *implementations*

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  - Secure software
- Considerations of subtle interactions between these levels (e.g., a certain set of high-level parameters may only be "good" for certain microarchitectures)

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- Opens the door for a *timing attack*: Attacker measures the time, draws conclusions about secret data (e.g., the key)

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- Again: The attacker can influence the cache, measure time...

Part II

The security impact of a new cryptographic library

Crypto software state of the art

- Well studied and understood cryptographic algorithms (AES, SHA-256, RSA-2048)
- Breaking these algorithms considered infeasible
- Various implementations available in public cryptographic libraries (e.g., OpenSSL)
- Common best practice: Use these libraries

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- Common best practice: Use these libraries
- Cryptography is still a disaster, many complete failures of confidentiality and integrity

The NaCl library

- We designed and implemented a new cryptographic library: NaCl
- Stands for "Networking and Cryptography library", pronounced "salt"
- Acknowledgements: Code contributions from Matthew Dempsky (Mochi Media), Niels Duif (TU Eindhoven), Emilia Käsper (KU Leuven, now Google), Adam Langley (Google), Bo-Yin Yang (Academia Sinica)

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- Send c to Bob
- Bob uses Alice's public key and his private key to verify and recover m

Alice using a typical cryptographic library

- Generate random AES key
- Use AES key to encrypt packet
- Hash encrypted packet
- Read RSA private key from wire format
- Use key to sign hash
- Read Bob's public key from wire format
- Use key to encrypt AES key, signature etc.
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- Plus more code: allocate storage, handle errors etc.

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- C NaCl: Similar, using pointers; no memory allocation, no failures

Bob using NaCl

```
m = crypto_box_open(c,n,pk,sk);
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- Initial key-pair generation:

```
pk = crypto_box_keypair(&sk);
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- Verification

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- NaCl systematically avoids *all* loads from addresses that depend on secret data
- `ctgrind` (2010 by Langley): tool to validate this automatically

No secret branch conditions

- 2011 paper by Brumley, Tuveri: minutes to steal another machine's OpenSSL ECDSA key
- Attack exploits timing variation from secret branch conditions
- Most cryptographic libraries have many small-scale variations in timing, e.g. from `memcmp`
- NaCl systematically avoids *all* branch conditions that depend on secret data

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- NaCl does not decrypt unless message is authenticated
- Verification rejects forgeries in constant time

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- NaCl retrieves all randomness from `/dev/urandom`, the OS random-number generator
- Reviewing this code is much more tractable than reviewing RNG code in every security library

Avoiding unnecessary randomness

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- Eliminates this kind of disaster
- Also simplifies testing

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- NaCl pays attention to cryptanalysis and makes very conservative choices of cryptographic primitives

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  - Example 4: `https://sourceforge.net/account` is proteced by SSL, but `https://sourceforge.net/develop` redirects to `http://sourceforge.net/develop`, turning of cryptography
- NaCl has no low-security options:
  - `crypto_box` always encrypts *and* authenticates
  - no RSA-1024, not even RSA-2048

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- 80000 1500-byte packets/second fill up a 1Gbps link

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- Many packets to the same public key can gain speed: Split `crypto_box` into `crypto_box_beforenm` and `crypto_box_afternm`
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- Batch verification for signatures: double verification speed for a batch of 64 valid signatures

More information

NaCl Website: http://nacl.cr.yp.to
All code is in the public domain: Use it any way you want!

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Paper "*The security impact of a new cryptographic library*" will be online soon at http://cryptojedi.org/papers/#coolnacl