RSAConference2018
San Francisco | April 16 – 20 | Moscone Center

MATTERS NOW

SESSION ID: CRYP-T08

WHY JOHNNY THE DEVELOPER CAN'T WORK WITH PUBLIC KEY CERTIFICATES

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Simple and Solvable Error

File does not exist.

File */etc/ssl/certs/certificate1.pem*
does not exist.

Clicking OK will solve everything and create
a secure solution with no bugs or vulnerabilities.

Cancel

OK

Annoying Security Control

Something happened and you need to click OK to get on with doing things.

Security error:
Permitted subtree violation

Certificate mismatch security identification administrator communication intercept liliputian snotweasel foxtrot omegaforce.

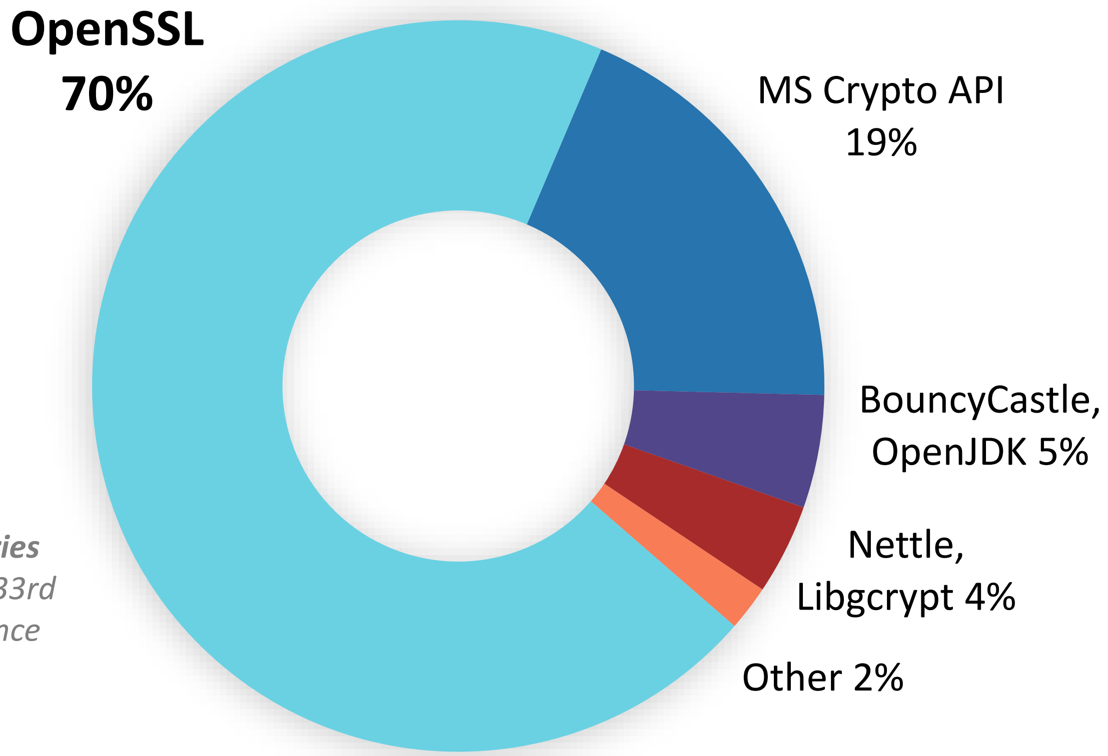
Show more technical crap

Cancel | OK

Joke adapted from
Johnatan Nightingale

Is it really that bad?

- Let's find out!
- What is the most used tool for generating certificates?



Source: Matus Nemec, Dusan Klinec, Petr Svenda, Peter Sekan and Vashek Matyas: ***"Measuring Popularity of Cryptographic Libraries in Internet-Wide Scans"***. In *Proceedings of the 33rd Annual Computer Security Applications Conference (ACSAC'2017)*, ACM, 2017.

Q: Have you ever used OpenSSL?

```
[xukrop@styx ~]$ openssl version
OpenSSL 1.1.0g-fips  2 Nov 2017
[xukrop@styx ~]$
[xukrop@styx ~]$ openssl x509 -help
Usage: x509 [options]
Valid options are:
 -help                  Display this summary
 -inform format         Input format - default PEM (one of DER, NET or PEM)
 -in infile             Input file - default stdin
 -outform format        Output format - default PEM (one of DER, NET or PEM)
 -out outfile           Output file - default stdout
 -keyform PEM|DER       Private key format - default PEM
 -passin val            Private key password/pass-phrase source
 -serial                Print serial number value
 -subject_hash          Print subject hash value
 -issuer_hash           Print issuer hash value
 -hash                  Synonym for -subject_hash
 -subject               Print subject DN
 -issuer                Print issuer DN
 -email                 Print email address(es)
 -startdate             Set notBefore field
```

Empirical experiment in usability

- 87 participants (👦) of DEVCONF.cz

(developer conference by Red Hat Czech)

Task:

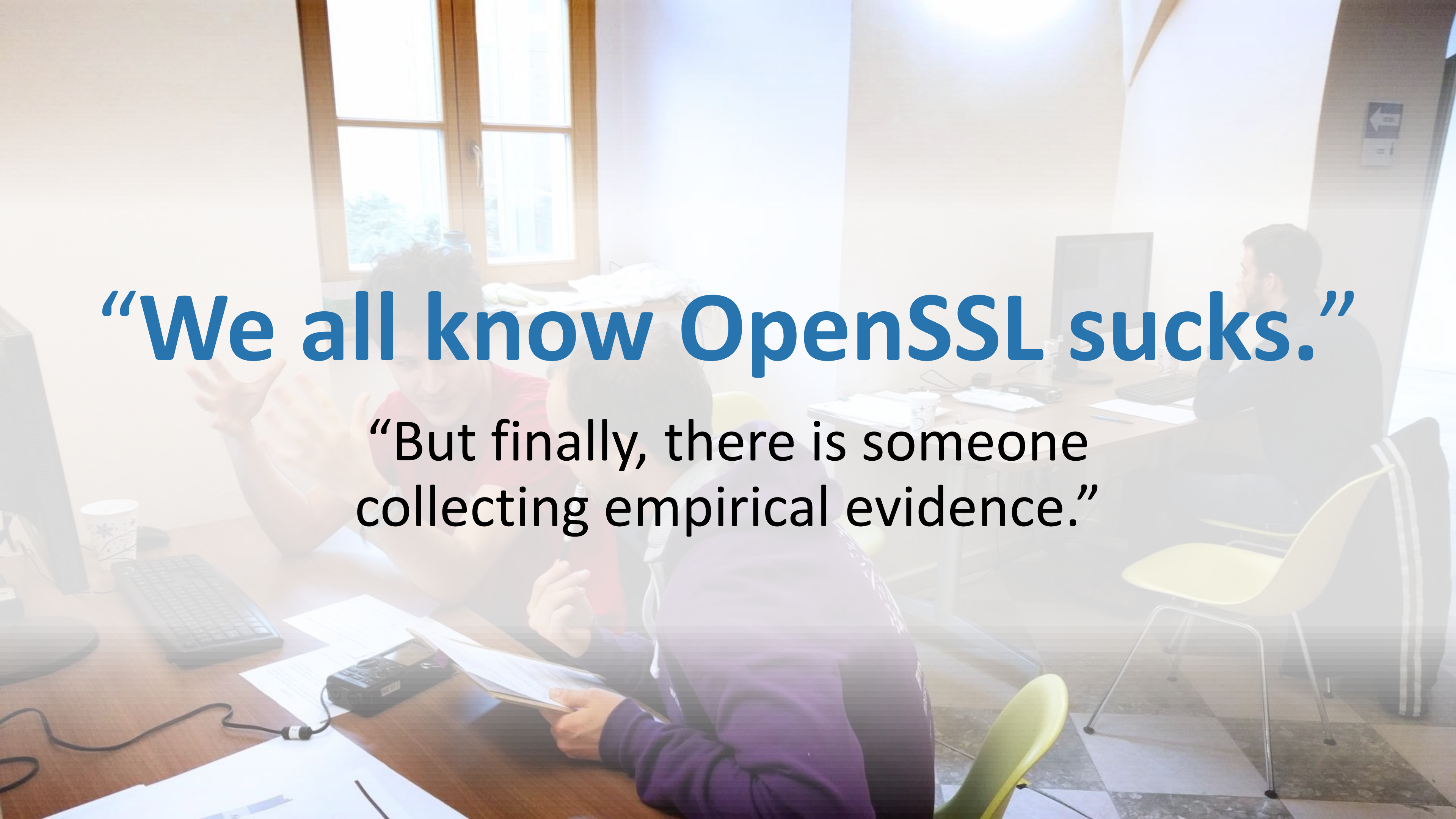
You are a software tester.
Use command line OpenSSL (v1.0.2g)

1. *… to issue a self-signed certificate.*
2. *… to validate 4 given certificates.*

Conference research booth at DEVCONF.cz

“Interacting with OpenSSL *voluntarily*?”

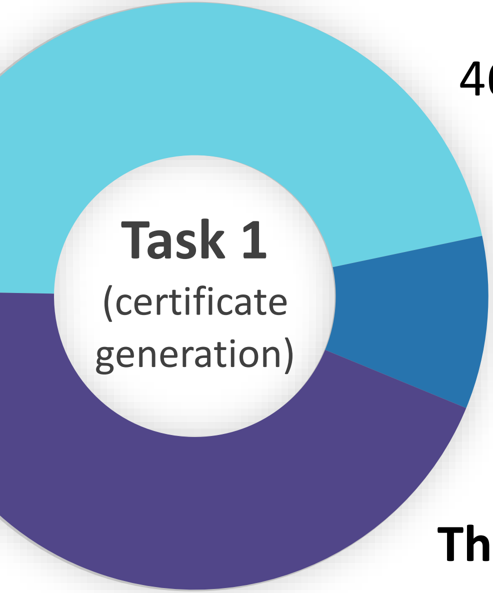
“Sorry, not even for research.”



“We all know OpenSSL sucks.”

“But finally, there is someone collecting empirical evidence.”

Task success



Succeeded
46% (39/87)

Did not succeed
10% (8/87)

Thought that they succeeded but did not
44% (37/87)

Incorrect
10% (7/72)

Success
19% (14/72)

Ignoring OS cert store
71% (51/72)

Created certificates

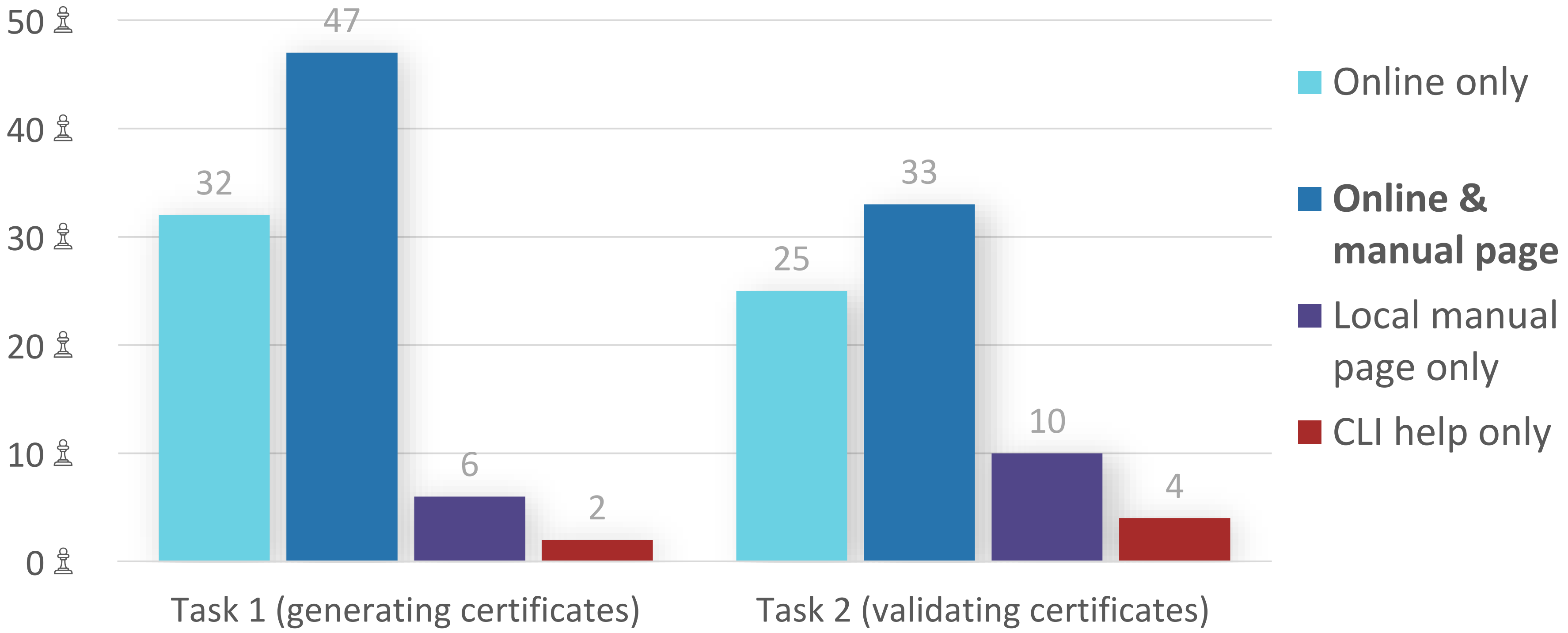
4096-bit key
20% (16/82 👨)

2048-bit key
42% (34/82 👨)

1024-bit key
38% (30/82 👨)

- Organization = “Internet Widgits Pty Ltd.”: 42% certificates (27/65 👨)
  - cca 260 000 such certificates online (Censys.io dataset 2018-02-28)

Used resources



Stack Exchange: 73% people (58/79 ♙)

stackoverflow Questions Developer Jobs Tags Users Search…

How to create a self-signed certificate with openssl?

744

504

I'm adding https support to an embedded linux device. I have tried to generate a self-signed certificate with these steps:

```
openssl req -new > cert.csr
openssl rsa -in privkey.pem -out key.pem
openssl x509 -in cert.csr -out cert.pem -req -signkey key.pem -days 1001
cat key.pem>>cert.pem
```

This works, but I get some errors with, for example, google chrome:

> This is probably not the site you are looking for!
> The site's security certificate is not trusted!

Am I missing something? Is this the correct way to build a self-signed certificate?

ssl openssl certificate ssl-certificate x509certificate

WISC knowledge base: 40% people (29/72)

University of Wisconsin KnowledgeBase

DoIT UW MyUW PEOPLE

Middleware KnowledgeBase

Search the KB... All Topics SEARCH Advanced

Quick Links

- DoIT Help Desk
- Main KB
- Middleware @ DoIT
- NetID Login Service Docs

Verifying that a Certificate is issued by a CA

How to use OpenSSL on the command line to verify that a certificate was issued by a specific CA, given that CA's certificate

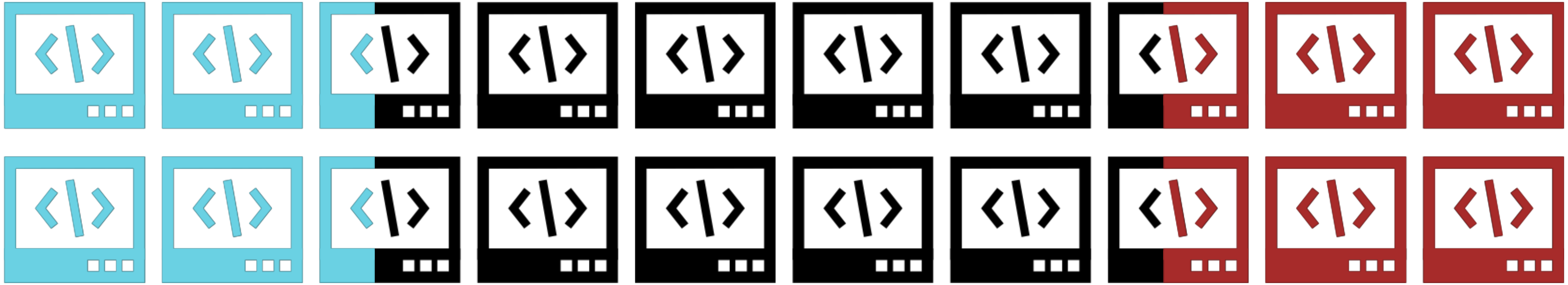
```
$ openssl verify -verbose -CAfile cacert.pem  server.crt
server.crt: OK
```

If you get any other message, the certificate was not issued by that CA.

See Also:

- How to turn a X509 Certificate in to a Certificate Signing Request
- Verifying that a Private Key Matches a Certificate

Web pages used



- Describing security implications: 23% web pages
- Explaining individual parameters: 27% web pages

- Changes after copy-paste: 9% people (8/87 👨)

Q: How to display manual page for this?

openssl verify -CAfile ca.pem cert.pem

1.	man openssl	?%	(?/53 👨)
2.	man openssl verify	28%	(15/53 👨)
3.	man openssl.verify	2%	(1/53 👨)
4.	man openssl-verify	8%	(4/53 👨)
5.	man verify	100%	(53/53 👨)

OpenSSL manual page

```
OPENSSL(1)                     OpenSSL                     OPENSSL(1)

NAME
       openssl - OpenSSL command line tool

SYNOPSIS
       openssl command [ command_opts ] [ command_args ]

       openssl list [ standard-commands | digest-commands | cipher-commands |
       cipher-algorithms | digest-algorithms | public-key-algorithms]

       openssl no-XXX [ arbitrary options ]

DESCRIPTION
       OpenSSL is a cryptography toolkit implementing the Secure Sockets Layer (SSL
       v2/v3) and Transport Layer Security (TLS v1) network protocols and related
       cryptography standards required by them.

       The openssl program is a command line tool for using the various
       cryptography functions of OpenSSL's crypto library from the shell.  It can
       be used for
```

Has the world moved on?

Our work

- *man openssl verify* now works
- Fixed URLs for online documentation
- Research into better error messages

OpenSSL team

- High-level *help* command
- *-help* argument for each command
- Improved defaults (key lengths, …)

Takeaways I.

OpenSSL usability is poor.

(But better than other tools.)

Improvement is possible!

Takeaways II.

People may not know they failed if the tool *does not tell them*.

Takeaways III.

Documentation
(manuals, tutorials, Q&A forums, …)
matters a lot.

Stack Overflow
is a seriously used resource.

What should you do next?

USING security products?

- Ask your developers what they find unusable.
- Investigate past vulnerabilities: Caused by tool unusability?
- Report usability issues back to developers.

DEVELOPING security products?

- In your project, strive for good “developer experience” (DX).
- Ask users on usability feedback.
- Organize a usability lab study to improve your product.

RSAConference2018

NOW MATTERS

#RSAC

CARE FOR YOUR DEVELOPERS. DEVELOPER EXPERIENCE (DX) MATTERS.

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#RSAC

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Cryptographers' Track (CT-RSA)

MATTERS NOW

Improved Factorization of $N = p^r q^s$

Jean-Sébastien Coron,

Rina Zeitoun

Speaker: Mehdi Tibouchi

UNIVERSITÉ DU LUXEMBOURG

IDEMIA

Agenda

1. State-of-the-art / Motivations
2. Reminder on Coppersmith / BDH Methods
3. [CFRZ16] Method to factorize $N = p^r q^s$
4. An Improvement to Factorize $N = p^r q^s$

Outline

1. State-of-the-art / Motivations
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RSA Cryptosystem / Signature

RSA Key Generation

- Generate two large primes p and q
- Compute $N = p \times q$
- Select (e, d) such that $ed \equiv 1 \mod \phi(N)$

Encryption/Decryption Process

$$C \equiv m^e \mod N \quad \longrightarrow \quad m \equiv C^d \mod N$$

$\boxed{\text{Factorize } N = p \times q \quad \Rightarrow \quad \text{Break RSA}}$

State-of-the-art: Modulus $N = p^r q$

Decryption with Modulus $N = p^r q$ [Takagi98]

- For equivalent security, use a smaller prime p
  - ☞ **Decryption** becomes **faster**

[Takagi98] *Fast RSA-type cryptosystem modulo $p^k q$.* Takagi, 1998.

State-of-the-art: Modulus $N = p^r q$

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Vulnerability of $N = p^r q$ [BDH99]

- **BDH method:** Factoring $N = p^r q$ for Large r
  - ☞ **Condition:** $r \simeq \log q$

[Takagi98] *Fast RSA-type cryptosystem modulo $p^k q$.* Takagi, 1998.

[BDH99] *Factoring $N = p^r q$ for Large r.* Boneh, Durfee, Howgrave-Graham, 1999.

What About Modulus $N = p^r q^s$?

Decryption with Modulus $N = p^r q^s$ [LKYL00]

- Decryption is even faster
  - ☞ For an 8192-bit $N = p^2 q^3$: decryption is 15 times faster

[LKYL00] *A Generalized Takagi-Cryptosystem with a Modulus of the Form* $p^r q^s$. Lim, Kim, Yie, Lee, 2000.

What About Modulus $N = p^r q^s$?

Decryption with Modulus $N = p^r q^s$ [LKYL00]

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  - ☞ For an 8192-bit $N = p^2 q^3$: decryption is 15 times faster

Problem: Factorization of $N = p^r q^s$

- Factorization of $N = p^r q^s$ in polynomial time
  - ☞ Left as an open problem in [BDH99]

[LKYL00] *A Generalized Takagi-Cryptosystem with a Modulus of the Form $p^r q^s$.* Lim, Kim, Yie, Lee, 2000.

[BDH99] *Factoring $N = p^r q$ for Large r.* Boneh, Durfee, Howgrave-Graham, 1999.

[CFRZ16] Result

Polynomial time factorization of $N = p^r q^s$ with $r > s$ if:

$$r \simeq \log^3 \max(p, q)$$

Based on Lattice Attacks

CFRZ method

BDH method

Coppersmith method

[CFRZ16] *Factoring* $N = p^r q^s$ *for Large* r *and* s. Coron, Faugère, Renault, Zeitoun, CT-RSA 2016.

[CFRZ16] Result

Polynomial time factorization of $N = p^r q^s$ with $r > s$ if:

$$r \simeq \log^3 \max(p, q)$$

Based on Lattice Attacks

$$\begin{tikzcd}
 & \text{CFRZ method} \arrow[dl, Rightarrow] \arrow[dr, Rightarrow] & \\
\text{BDH method} \arrow[rr, Rightarrow] & & \text{Coppersmith method}
\end{tikzcd}$$

[CFRZ16] *Factoring* $N = p^r q^s$ *for Large* r *and* s. Coron, Faugère, Renault, Zeitoun, CT-RSA 2016.

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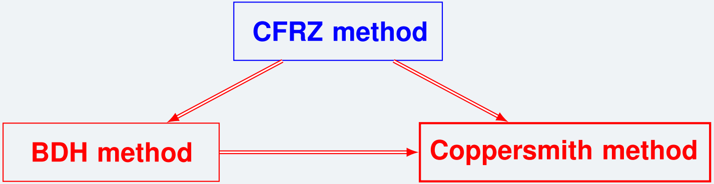


[CFRZ16] *Factoring $N = p^r q^s$ for Large r and s.* Coron, Faugère, Renault, Zeitoun, CT-RSA 2016.

Outline

1. State-of-the-art / Motivations
2. Reminder on Coppersmith / BDH Methods
3. [CFRZ16] Method to factorize $N = p^r q^s$
4. An Improvement to Factorize $N = p^r q^s$

Coppersmith's Theorem

The Problem (Univariate Modular Case)

- **Input:**
  - A polynomial $f(x) = x^\delta + a_{d-1}x^{\delta-1} + \cdots + a_1 x + a_0$
  - N an integer of unknown factorization
- **Find:**
  - All integers x_0 such that $f(x_0) \equiv 0 \mod N$

Coppersmith's Theorem

The Problem (Univariate Modular Case)

- **Input:**
  - A polynomial $f(x) = x^\delta + a_{d-1}x^{\delta-1} + \cdots + a_1 x + a_0$
  - N an integer of unknown factorization
- **Find:**
  - All integers x_0 such that $f(x_0) \equiv 0 \mod N$

Coppersmith's Theorem for the Univariate Modular case

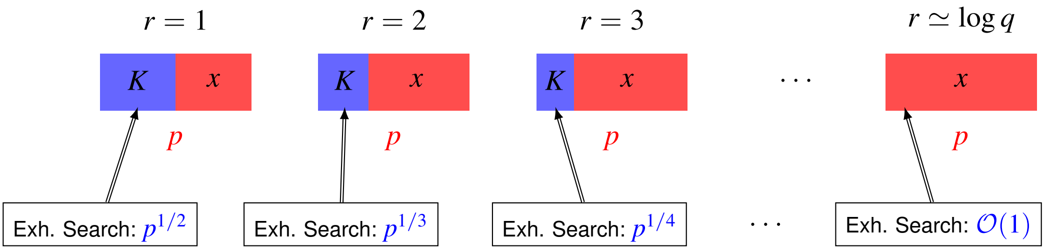
- The solutions x_0 can be found in polynomial time in $\log(N)$ if

$$|x_0| < N^{1/\delta}$$

BDH Method to factorize $N = p^r q$

☞ **Extension of Coppersmith method for unknown modulus**

- Write $p = K \cdot t + x$
- Solve $f(x) = (K \cdot t + x)^r \equiv 0 \mod p^r$



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[CFRZ16] Result

Polynomial time factorization of $N = p^r q^s$ with $r > s$ if:

$$r = \Omega(\log^3 \max(p, q))$$

Decompose r and s, Apply BDH or Coppersmith

$$N = p^r q^s = (p^\alpha q^\beta)^u p^a q^b = P^u Q$$

[CFRZ16] *Factoring $N = p^r q^s$ for Large r and s.* Coron, Faugère, Renault, Zeitoun, CT-RSA 2016.

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$\Rightarrow$ Apply BDH or Coppersmith method depending on a and b

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$$N = p^r q^s = (p^\alpha q^\beta)^u p^a q^b = P^u Q$$

$\Rightarrow$ Apply BDH or Coppersmith method depending on a and b

☞ $u = \Omega(\log Q) \quad \Rightarrow \quad r = \Omega(\log^3 \max(p, q))$

[CFRZ16] *Factoring $N = p^r q^s$ for Large r and s.* Coron, Faugère, Renault, Zeitoun, CT-RSA 2016.

[CFRZ16] Method to Factorize $N = p^r q^s$

First Step: Decompose r and s

$$\begin{cases} r = \boxed{u} \cdot \boxed{\alpha} + \boxed{a} \\ s = \boxed{u} \cdot \boxed{\beta} + \boxed{b} \end{cases}$$

$$\underbrace{u}_{\text{large}} \quad \underbrace{\alpha, \beta}_{\text{small}} \quad \underbrace{a, b}_{\text{small}}$$

[CFRZ16] Method to Factorize $N = p^r q^s$

First Step: Decompose r and s

$$\begin{cases} r = \boxed{u} \cdot \boxed{\alpha} + \boxed{a} \\ s = \boxed{u} \cdot \boxed{\beta} + \boxed{b} \end{cases}$$

large | small | small

☞ Use LLL

[CFRZ16] Method to Factorize $N = p^r q^s$

First Step: Decompose r and s

$$\begin{cases} r = \boxed{u} \cdot \boxed{\alpha} + \boxed{a} \\ s = \boxed{u} \cdot \boxed{\beta} + \boxed{b} \end{cases}$$

large | small | small

☞ Use LLL

Rewrite N from new decomposition

$$N = p^r q^s = p^{u \cdot \alpha + a} q^{u \cdot \beta + b} = p^{u \cdot \alpha} q^{u \cdot \beta} p^a q^b = (p^\alpha q^\beta)^u p^a q^b = P^u Q$$

[CFRZ16] Method to Factorize $N = p^r q^s$

First Step: Decompose r and s

$$\begin{cases} r = \boxed{u} \cdot \boxed{\alpha} + \boxed{a} \\ s = \boxed{u} \cdot \boxed{\beta} + \boxed{b} \end{cases}$$

large | small | small

☞ Use LLL

Rewrite N from new decomposition

$$N = p^r q^s = p^{u\cdot\alpha+a} q^{u\cdot\beta+b} = p^{u\cdot\alpha} q^{u\cdot\beta} p^a q^b = (p^\alpha q^\beta)^u p^a q^b = P^u Q$$

Last Step: recover p and q

Recover P → Compute $Q = N/P^u$ → Retrieve p and q

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Our Result

Polynomial time factorization of $N = p^r q^s$ with $r > s$ if:

$$r = \Omega(\log q)$$

Our Result

Polynomial time factorization of $N = p^r q^s$ with $r > s$ if:

$$r = \Omega(\log q)$$

The idea: Decompose N^α instead of N

[CFRZ16]:

- Write $N = P^u Q$
- Apply BDH/Copp. on N
- Condition: $u = \Omega(\log Q)$

This paper:

- Write $N^\alpha = P^r q$
- Apply BDH on N^α
- Condition: $r = \Omega(\log q)$

Our Improvement to Factorize $N = p^r q^s$

First Step: Find α and β

Since $\gcd(r, s) = 1$, there exist $\alpha, \beta \in \mathbb{N}$ such that:

$$\alpha \cdot s - \beta \cdot r = 1$$

Our Improvement to Factorize $N = p^r q^s$

First Step: Find α and β

Since $\gcd(r, s) = 1$, there exist $\alpha, \beta \in \mathbb{N}$ such that:

$$\alpha \cdot s - \beta \cdot r = 1$$

Rewrite N^α from new decomposition

$$N^\alpha = (p^r q^s)^\alpha = p^{\alpha r} q^{\alpha s} = p^{\alpha r} q^{\beta r + 1} = (p^\alpha q^\beta)^r q = P^r q$$

Our Improvement to Factorize $N = p^r q^s$

First Step: Find α and β

Since $\gcd(r, s) = 1$, there exist α, $\beta \in \mathbb{N}$ such that:

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$$N^\alpha = (p^r q^s)^\alpha = p^{\alpha r} q^{\alpha s} = p^{\alpha r} q^{\beta r + 1} = (p^\alpha q^\beta)^r q = P^r q$$

Last Step: Apply BDH and recover p and q

$$\boxed{\text{Recover } P} \Longrightarrow \boxed{\text{Compute } q = N^\alpha / P^r} \Longrightarrow \boxed{\text{Compute } p = (N/q^s)^{1/r}}$$

Complexity comparison:

Time complexities for factoring $N = p^r q^s$, where $\log p \approx \log q$

Condition on $N = p^r q^s$	[CFRZ16]	New Method
$r = \Omega(\log q)$		$\mathcal{O}(\log^{12.5} N)$
$r = \Omega(\log^3 q)$	$\mathcal{O}(\log^8 N)$	$\mathcal{O}(\log^{14.25} N)$

Generalization for k prime factors

Factoring $N = \prod_{i=1}^{k} p_i^{r_i}$ for large r_i

- **Condition** to find a non-trivial factor of N in time polynomial (with $r = \max\{r_i\}$ and $p = \max\{p_i\}$):

$$r = \Omega(\log^{\theta_k} p)$$

where $$\theta_k = 2(k-1)\left(1 + \sum_{i=1}^{k-2}\prod_{j=i}^{k-2} j\right) + 1$$

k	2	3	4	5	6
θ_k in [CFRZ16]	3	17	61	257	1301
New θ_k	1	9	31	129	651

Experiments for $N = p^r q^s$ with 128-bit primes p and q

	Method	Decomposition	Bits given	Dim.	LLL_f	LLL_c	Est. time
$N = p^5q^3$	[CFRZ16]	$N = (p^2q)^3p^{-1}$	57	52	17s	3.5s	$1.6 \cdot 10^{10}$ years
	New	$N^2 = (p^2q)^5q$	**46**	**78**	**0.3h**	**29s**	**$6.5 \cdot 10^7$ years**
$N = p^7q^4$	[CFRZ16]	$N = (p^2q)^4p^{-1}$	51	57	45s	2.4s	$1.7 \cdot 10^8$ years
	New	$N^2 = (p^2q)^7q$	**43**	**92**	**1.9h**	**291s**	**$8.1 \cdot 10^7$ years**
$N = p^8q^3$	[CFRZ16]	$N = (p^2q)^4q^{-1}$	51	61	86s	4.2s	$3 \cdot 10^8$ years
	New	$N^3 = (p^3q)^8q$	**57**	**95**	**6h**	**320s**	**$1.4 \cdot 10^{12}$ years**
$N = p^9q^5$	[CFRZ16]	$N = (p^2q)^5p^{-1}$	48	61	113s	4.2s	$3.7 \cdot 10^7$ years
	New	$N^2 = (p^2q)^9q$	**43**	**108**	**3.9h**	**801s**	**$2.2 \cdot 10^8$ years**

☞ Still unpractical but asymptotically polynomial-time for large r

Conclusion and Remarks

Conclusion

- Improvement over [CFRZ16] method to factorize $N = p^r q^s$ for large r
- Generalization for moduli $N = \prod p_i^{r_i}$

Conclusion and Remarks

Conclusion

- Improvement over [CFRZ16] method to factorize $N = p^r q^s$ for large r
- Generalization for moduli $N = \prod p_i^{r_i}$

Remarks

- Much simpler than [CFRZ16]
  - Coppersmith's method is not used anymore
  - Bézout instead of LLL used to find good decomposition of r and s
- For 128-bit primes, unpractical compared to ECM factorisation
- But ECM scales exponentially while our method is polynomial
  - For large p and q, our algorithm must outpace ECM