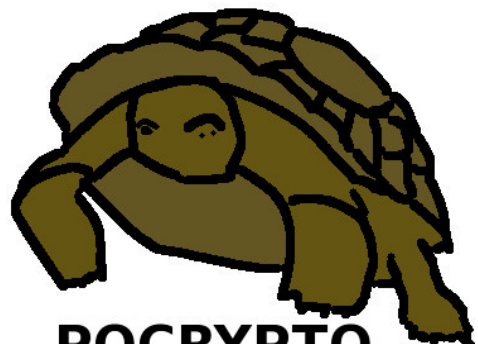
# The `libpqcrypto` software library for post-quantum cryptography

**Daniel J. Bernstein**
and many contributors



# Context

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- No data flow from secrets to branch conditions.
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  by Aldaya–García–Tapia–Brumley.
- No padding oracles.
  Stops, e.g., 2017 ROBOT attack.

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- Avoiding unnecessary randomness:
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- Eliminate low-security options.
  Stops, e.g., 2015 Logjam attack.

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  Simpler (and faster!) secure implementations.

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  Or is the goal "high-security signatures"?
- Use Curve25519, not NSA (NIST) curves.
  Simpler (and faster!) secure implementations.
- Use EdDSA (Ed25519), not NSA signatures.
  Avoid, e.g., hassle of implementing inversion.

# A modern cryptographic API

Most libraries provide simple all-in-one hashing:

```
const unsigned char m[...];
unsigned long long mlen;
unsigned char h[crypto_hash_BYTES];
crypto_hash_sha256(h,m,mlen);
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Huge impact of API upon usability: see 2017 Acar–Backes–Fahl–Garfinkel–Kim–Mazurek–Stransky.

# Implementation and deployment

Curve25519: iOS starting 2010; WhatsApp starting 2016; formal verif in Firefox starting 2017; etc.

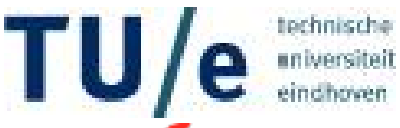
NaCl software library (forks: TweetNaCl, libsodium): Curve25519, audited implementations, modern API.

Competitions: Modern API required for submissions to CAESAR, NIST PQC, NIST Lightweight Crypto.

SUPERCOP benchmarking framework:
Modern API, no requirement of constant-time etc.
Currently 2556 implementations of 722 primitives.

# All done?

# The PQCRYPTO consortium











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Some broken systems in traditional PQ categories:

- Compact LWE, lattice-based encryption scheme.
- Edon-K, code-based encryption scheme.
- Giophantus, multivariate signature scheme.

Need detailed security analysis, not buzzwords.

# 50 signature systems in libpqcrypto

```
crypto_sign_dilithium{2,3,4}
crypto_sign_gui{184,312,448}
crypto_sign_luov{863256,890351,
    8117404,4849242,6468330,8086399}
crypto_sign_mqdss{48,64}
crypto_sign_picnicl{1,3,5}{fs,ur}
crypto_sign_qtesla{128,192,256}
crypto_sign_rainbow{1a,1b,1c,
    3b,3c,4a,5c,6a,6b}
crypto_sign_sphincs{f,s}{128,192,256}
    {haraka,sha256,shake256}
```

# 27 encryption systems in libpqcrypto

```
crypto_kem_bigquake{1,3,5}
crypto_kem_mceliece{6960119,8192128}
crypto_kem_kyber{512,768,1024}
crypto_kem_dags{3,5}
crypto_kem_frodokem{640,976}
crypto_kem_kindi{256342,256522,
    512222,512241,512321}
crypto_kem_newhope{512,1024}cca
crypto_kem_ntruhrss701
crypto_kem_{ntrulpr,sntrup}4591761
crypto_kem_ramstakers{216091,756839}
crypto_kem_{lightsaber,saber,firesaber}
```

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- a unified Python interface;
- command-line sig/verif/enc/dec tools;
- command-line benchmarking tools.

# C interface

```
unsigned char pk[pqcrypto_sign_gui184_PUBLICKEYBYTES];
unsigned char sk[pqcrypto_sign_gui184_SECRETKEYBYTES];
#define mlen 7
unsigned char m[mlen] = "hello\n";
unsigned char sm[pqcrypto_sign_gui184_BYTES + mlen];
unsigned long long smlen;
unsigned char t[sizeof sm];
unsigned long long tlen;
int main()
{
  if (pqcrypto_sign_gui184_keypair(pk,sk)) abort();
  if (pqcrypto_sign_gui184(sm,&smlen,m,mlen,sk)) abort();
  if (pqcrypto_sign_gui184_open(t,&tlen,sm,smlen,pk)) abort();
  if (tlen != mlen) abort();
  if (memcmp(t,m,mlen)) abort();
  return 0;
}
```

# Python interface

Generate key pair:

```
pk,sk = pqcrypto.sign.gui184.keypair()
```

Sign message `m`:

```
sm = pqcrypto.sign.gui184.sign(m,sk)
```

Recover message from signed message:

```
m = pqcrypto.sign.gui184.open(sm,pk)
```

If verification fails: exception and **no output**.

# A larger Python example

Test script to sign and recover a message under a random key pair:

```
import pqcrypto
sig = pqcrypto.sign.gui184
pk,sk = sig.keypair()
m = b"hello world"
sm = sig.sign(m,sk)
assert m == sig.open(sm,pk)
```

# Command-line signature interface

Generate key pair:

```
pq-keypair-gui184 5>publickey 9>secretkey
```

(Shell uses numbers to identify multiple outputs.
Also makes tool easy to use from other languages.)

Sign message:

```
pq-sign-gui184 <message 8<secretkey >sm
```

Recover message from signed message:

```
pq-open-gui184 <sm 4<publickey >message
```

# Benchmarking one system

```
$ pq-size-gui184
gui184 size
 publickey 422122
 secretkey 14985
 signature 45
$ pq-speed-gui184
gui184 speed
 keypair 375801649 378277969 389764325
 sign 13406823 18715903 40190324
 open 141531 141698 142025
$ pq-notes-gui184
gui184 implementation crypto_sign/gui184/pclmulqdq
gui184 version -
gui184 compiler gcc -fPIC -Wall -march=native
  -mtune=native -O3 -fomit-frame-pointer -fwrapv
```

# Benchmarking all systems

```
$ pq-size-all
dilithium2 size publickey 1184 secretkey 2800 signature 2044
dilithium3 size publickey 1472 secretkey 3504 signature 2701
dilithium4 size publickey 1760 secretkey 3856 signature 3366
gui184 size publickey 422122 secretkey 14985 signature 45
gui312 size publickey 1990045 secretkey 41755 signature 63
gui448 size publickey 5903405 secretkey 94757 signature 83
luov4849242 size publickey 7536 secretkey 32 signature 1746
luov6468330 size publickey 19973 secretkey 32 signature 3184
luov8086399 size publickey 40248 secretkey 32 signature 4850
luov8117404 size publickey 100989 secretkey 32 signature 521
luov863256 size publickey 15908 secretkey 32 signature 319
luov890351 size publickey 46101 secretkey 32 signature 441
mqdss48 size publickey 62 secretkey 32 signature 32882
mqdss64 size publickey 88 secretkey 48 signature 67800
picnicl1fs size publickey 33 secretkey 49 signature 34004
```

# Benchmarking all systems

```
picnicl1ur size publickey 33 secretkey 49 signature 53933
picnicl3fs size publickey 49 secretkey 73 signature 76744
picnicl3ur size publickey 49 secretkey 73 signature 121817
picnicl5fs size publickey 65 secretkey 97 signature 132828
picnicl5ur size publickey 65 secretkey 97 signature 209478
qtesla128 size publickey 4128 secretkey 2112 signature 3104
qtesla192 size publickey 8224 secretkey 8256 signature 6176
qtesla256 size publickey 8224 secretkey 8256 signature 6176
rainbow1a size publickey 152097 secretkey 100209 signature 64
rainbow1b size publickey 163185 secretkey 114308 signature 78
rainbow1c size publickey 192241 secretkey 143385 signature 104
rainbow3b size publickey 564535 secretkey 409463 signature 112
rainbow3c size publickey 720793 secretkey 537781 signature 156
rainbow4a size publickey 565489 secretkey 376141 signature 92
rainbow5c size publickey 1723681 secretkey 1274317 signature 204
rainbow6a size publickey 1351361 secretkey 892079 signature 118
```

# Benchmarking all systems

```
rainbow6b size publickey 1456225 secretkey 1016868 signature 147
sphincsf128haraka size publickey 32 secretkey 64 signature 16976
sphincsf128sha256 size publickey 32 secretkey 64 signature 16976
sphincsf128shake256 size publickey 32 secretkey 64 signature 169
sphincsf192haraka size publickey 48 secretkey 96 signature 35664
sphincsf192sha256 size publickey 48 secretkey 96 signature 35664
sphincsf192shake256 size publickey 48 secretkey 96 signature 356
sphincsf256haraka size publickey 64 secretkey 128 signature 4921
sphincsf256sha256 size publickey 64 secretkey 128 signature 4921
sphincsf256shake256 size publickey 64 secretkey 128 signature 49
sphincss128haraka size publickey 32 secretkey 64 signature 8080
sphincss128sha256 size publickey 32 secretkey 64 signature 8080
sphincss128shake256 size publickey 32 secretkey 64 signature 808
sphincss192haraka size publickey 48 secretkey 96 signature 17064
sphincss192sha256 size publickey 48 secretkey 96 signature 17064
sphincss192shake256 size publickey 48 secretkey 96 signature 170
```

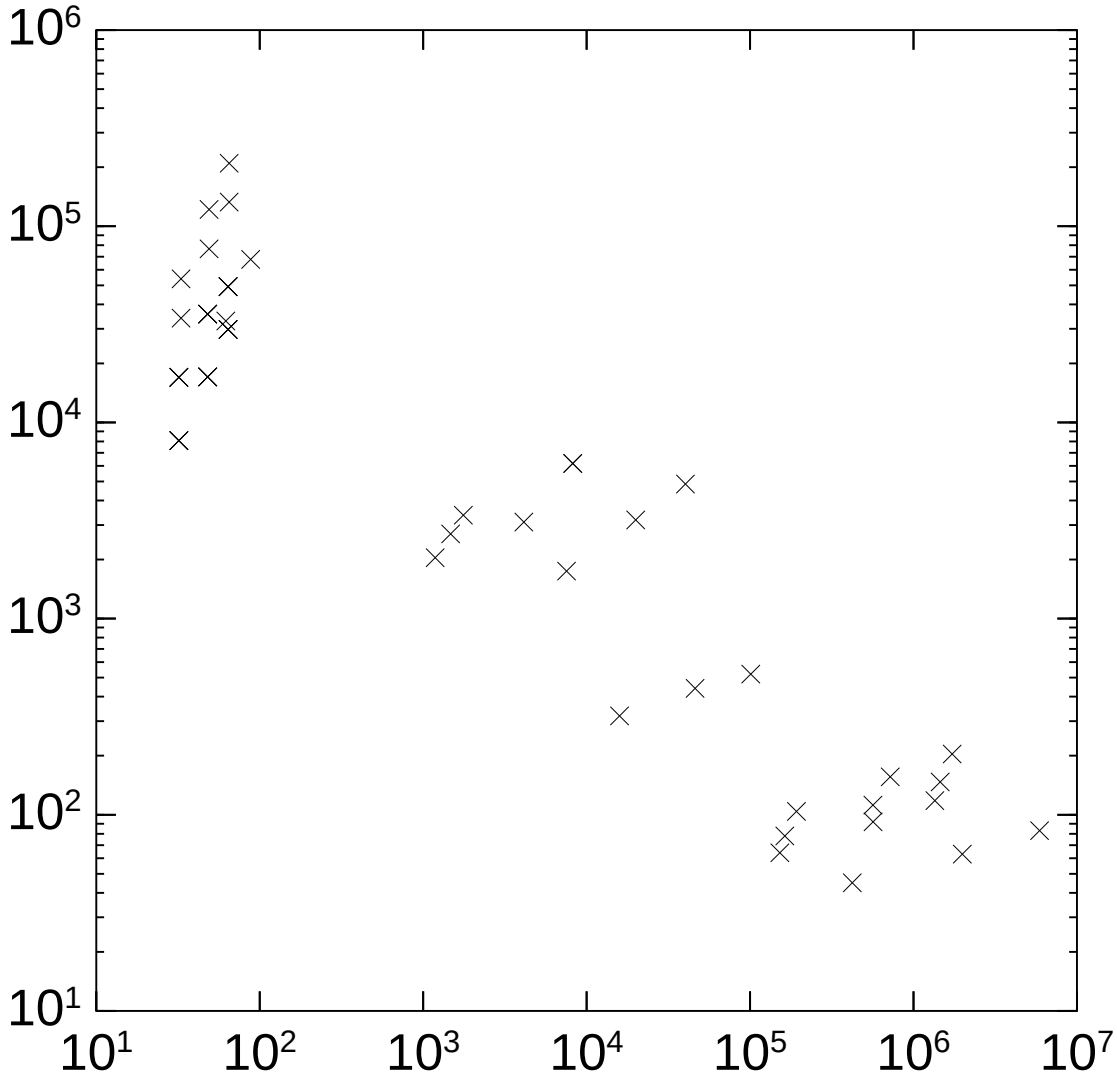
# Benchmarking all systems

```
sphincss256haraka size publickey 64 secretkey 128 signature 2979
sphincss256sha256 size publickey 64 secretkey 128 signature 2979
sphincss256shake256 size publickey 64 secretkey 128 signature 29
bigquake1 size publickey 25482 secretkey 14772 ciphertext 201 se
bigquake3 size publickey 84132 secretkey 30860 ciphertext 406 se
bigquake5 size publickey 149800 secretkey 41804 ciphertext 492 s
dags3 size publickey 11616 secretkey 2973704 ciphertext 2144 ses
dags5 size publickey 11616 secretkey 2973704 ciphertext 2144 ses
firesaber size publickey 1312 secretkey 3040 ciphertext 1472 ses
frodokem640 size publickey 9616 secretkey 19872 ciphertext 9736
frodokem976 size publickey 15632 secretkey 31272 ciphertext 1576
kindi256342 size publickey 1184 secretkey 1472 ciphertext 1824 s
kindi256522 size publickey 1984 secretkey 2304 ciphertext 2752 s
kindi512222 size publickey 1456 secretkey 1712 ciphertext 2544 s
kindi512241 size publickey 1728 secretkey 2112 ciphertext 2752 s
kindi512321 size publickey 2368 secretkey 2752 ciphertext 3392 s
```

# Benchmarking all systems

```
kyber1024 size publickey 1440 secretkey 3168 ciphertext 1504 ses
kyber512 size publickey 736 secretkey 1632 ciphertext 800 sessio
kyber768 size publickey 1088 secretkey 2400 ciphertext 1152 sess
lightsaber size publickey 672 secretkey 1568 ciphertext 736 sess
mceliece6960119 size publickey 1047319 secretkey 13908 ciphertex
mceliece8192128 size publickey 1357824 secretkey 14080 ciphertex
newhope1024cca size publickey 1824 secretkey 3680 ciphertext 220
newhope512cca size publickey 928 secretkey 1888 ciphertext 1120
ntruhrss701 size publickey 1138 secretkey 1418 ciphertext 1278 s
ntrulpr4591761 size publickey 1047 secretkey 1238 ciphertext 117
ramstakers216091 size publickey 27044 secretkey 54056 ciphertext
ramstakers756839 size publickey 94637 secretkey 189242 ciphertex
saber size publickey 992 secretkey 2304 ciphertext 1088 sessionk
sntrup4591761 size publickey 1218 secretkey 1600 ciphertext 1047
```

# Signature size ($y$) vs. public-key size ($x$)



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- Reducing code volume: e.g., SHA-3 merge.
- Long term: **Reduce** number of primitives.

# Some links

https://libpqcrypto.org: libpqcrypto

https://pqcrypto.eu.org: PQCRYPTO

https://github.com/mupq/pqm4: PQCRYPTO's ARM Cortex-M4 library (FrodoKEM-640-cSHAKE, KINDI-256-3-4-2, Kyber-768, NewHope-1024-CCA-KEM, NTRU-HRSS-KEM-701, Saber, SIKE-p571, Streamlined NTRU Prime $4591^{761}$, Dilithium-III, qTesla-I, qTesla-III-size, qTesla-III-speed, SPHINCS+-SHAKE256-128s)

https://github.com/mupq/pqhw: PQCRYPTO's FPGA implementations of NewHope-1024, BLISS