Argon2 and Egalitarian Computing

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I. Unfair battle
Attackers have always been more powerful than defenders:

- Large and variable resources;
- One weakness is sufficient;
- Can spend much time.
Defenders can

- Harden the protection (e.g. increase the key length);
- Sometimes restrict the attack vector (e.g. limit the exposure time).

Secure cryptographic algorithm with sufficient key length – solution for many confidentiality, integrity, signatures, etc.
Sometimes, however, we do not have (long) keys.

- Reliance on human memory (password-based data protection, password-based authentication, PINs, etc.);

Brute-force attacks become possible (e.g., guess a PIN).

Moreover, integrity might become a problem in

- Unencrypted networks (P2P, blockchain).
Brute-force attacks (such as key guessing) are most efficient on custom hardware: multiple computing cores on large ASICs.

Practical example of SHA-2 hashing (Bitcoin):
• $2^{32}$ hashes/joule on ASIC;
• $2^{17}$ hashes/joule on laptop.

Consequences:
• Keys lose 15 bits;
• Passwords become 3 lowercase letters shorter;
• PINs lose 5 digits.

ASIC-equipped attackers are the threat from the near future. ASICs have high entry costs, but FPGA and GPU are employed too.
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We need to slow down such attackers without burdening the defenders.
II. Argon2 for passwords
Keyless password authentication:

- User registers with name $l$ and password $p$;
- Server selects hash function $H$, generates salt $s$, and stores $(l, H(s, p))$;
- User sends $(l, p')$ during the login;
- Server matches $(l, H(s, p'))$ with its password file.

Problems:

- Password files are often leaked unencrypted;
- Passwords have low entropy (e.g., "123456");
- Regular cryptographic hash functions are cracked on GPU/FPGA/ASIC;
- Many iterations of SHA-256 do little help as this slows down everyone.
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Since 2003, *memory-intensive* computations have been proposed.

Computing with a lot of memory would require a very large and expensive chip.

With large memory on-chip, the ASIC advantage vanishes.
Time-space tradeoffs and memory-hardness

Clearly, there should be no memoryless equivalent (thus memory-hardness).

*Time-space tradeoff*: how time grows if space is reduced.

$$T = f\left(\frac{1}{S}\right).$$

Linear $f$ means equal trading of space for time. We want $f$ to be superpolynomial.
password Hashing competition (2013-2015)

requirements for a new scheme:
- maximum cracking cost per password on all platforms;
- tunable time, memory parameters.
- security against time-space tradeoffs;
- transparent design;
- flexibility.
- ideally, side-channel protection (missing in scrypt) and tunable parallelism.

Timeline
- 2013: Call for submissions.
- Feb 2014: 24 submissions.
- Dec 2014: 9 second-phase candidates.
- Jul 2015: 1 winner (argon2), 4 special recognitions: catena, lyra2, yescript and makwa (delegation hashing).
How we designed Argon2
To facilitate analysis, we selected the simplest secure mode of operation:

- Fill memory blockwise;
- Each block is a function of a previous and some older (reference) block;
- The reference index may (better tradeoff protection) or may not (side-channel protection) depend on the input;
- Weak and wide compression function $G$. 
Properties:

- Preimage and collision resistance;
- Adjustable and inseparable parallelism;
- Core: larger and shorter variant (1/5) of Blake2b;
- Exponential time-space tradeoff.

*Any part of the Argon2 chain is memory-hard.*
Performance

We took a number of steps to speed up the memory filling on the x64 architecture:

- Wide registers and SIMD instructions;
- 1 KB blocks;
- Number of Blake2 rounds balanced with the memory latency.

Multithreaded Argon2 securely fills memory at 0.65 cycles/byte.

Memory bandwidth up to 5.5 GB/sec.

Try

https://github.com/P-H-C/phc-winner-argon2 [C89]
https://github.com/khovratovich/Argon2 [C++11]
Apparently, this method of slowing down password crackers has other applications...
III. Egalitarian computing
Why egalitarian

Bitcoin dream

- An egalitarian currency where every user could mine money on his own laptop...
Why egalitarian

Bitcoin dream

• An egalitarian currency where every user could mine money on his own laptop...

...and reality:

• A bunch of users with factory-size rigs and their own power plants control > 50% of network in a single pool.
Argon2 ensures that both defenders and attackers hash passwords on the same platform (x86).
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This is desirable for some other tasks to slow down brute force on custom hardware:

- Password-based protocols (key agreement, secret sharing);
- Password-based encryption;
- Proofs of work for cryptocurrencies/blockchain;
- Client puzzles for denial-of-service protection.

*Proof-of-work* – a certificate that confirms that the prover made a certain amount of computations (typically to slow him down for certain time). Clearly the cost of the work must not fluctuate across platforms.
Equihash

Memory-hard proof-of-work based on Generalized Birthday (k-XOR) problem [NDSS 2016]

Wagner’s algorithm

H

Difficulty filter

\(0, n, k\)

\((x_1, x_2, \ldots)\)

\(V\)

\(I\)

\(A\)

Wagner’s algorithm for \(2^k\)-XOR

x86/GPU-oriented 700-MB proof is 120 bytes long.

Good for ASIC-resistant client puzzles.

Apparently, any NP-complete problem is a natural candidate for a memory-hard proof-of-work…
Egalitarian computing ensures that legitimate users and attackers are equal as they are forced to use the same platform.
Suppose you develop a scheme where the exact output value is not important (encryption, signature, etc.).

*Amalgamate* the computation with a memory-hard function such as Argon2.

If you already use some CPU time, why not using the available memory for that period?
Alter the computing: inject memory-hard blocks in between the subfunction calls.

Maybe even feed them back to Argon2 (may need strengthen the compression function).
Memory-hard encryption
Memory-hard encryption

Password-based disk encryption:

- Encryption by chunks with password-based key;
- Trial decryption requires only a few blockcipher calls;
- Passwords can be tried offline.

We propose to bind it to a memory-hard function to make encryption and decryption run on the same hardware and non-outsourcable.
Disk encryption with memory-hard function based on Zaverucha’s idea of using All-or-Nothing transform (or another scheme without online decryption):

- Any chunk size;
- Any memory size;
- No way to precompute either part.
MTP: memory-hard proof-of-work based on Argon2

The PC-oriented 2 GB-proof is 180 KB long (faster but longer than Equihash).

Parallelism inevitable so bandwidth-hardness.
Egalitarian computing

- deems 6-letter passwords secure;
- brings back 80-bit keys;
- renders DoS attacks harder;
- suffrages blockchain users.

It is a chance to revert Moore’s law.
Some dirty crypto in

- Tradeoff (time-space) cryptanalysis (Asiacrypt 2015);
- Memory-hardness proofs (ePrint on scrypt);
- Memory-hard modes of operation (Argon2 – Euro S&P 2016);
- Asymmetric proof-of-work based on (NP-)hard problems (NDSS 2016);
- Memory-hard obfuscation and white-box cryptography (Asiacrypt 2014).
God may have made men, but Samuel Colt made them equal

Use Egalitarian Computing