Argon2 for password hashing and cryptocurrencies

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Recall why we need Argon2

Keyless password authentication:

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

Problems:

- Password files are often leaked unencrypted;
- Passwords have low entropy ("123456");
- Regular cryptographic hash functions are cracked on GPU/FPGA/ASIC.

Dictionary attacks on passwords

Dictionary attacks 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.

ASIC-equipped crackers are the threat from the near future.

ASICs have high entry costs, but FPGA and GPU are employed too.

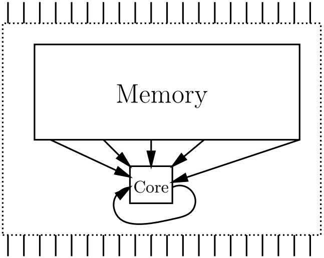
Proc.	Thr.	Argon2d (1 pass) cpb	Argon2d (1 pass) Memory (GB/s)	Argon2i (3 passes) cpb	Argon2i (3 passes) Memory (GB/s)
i7-4500U	1	1.3	2.5	4.7	2.6
i7-4500U	2	0.9	3.8	2.8	4.5
i7-4500U	4	0.6	5.4	2	5.4
i7-4500U	8	0.6	5.4	1.9	5.8

Table: Speed and memory bandwidth of Argon2(d/i) measured on 1 GB memory filled. Core i7-4500U — Intel Haswell 1.8 GHz, 4 cores

Solution

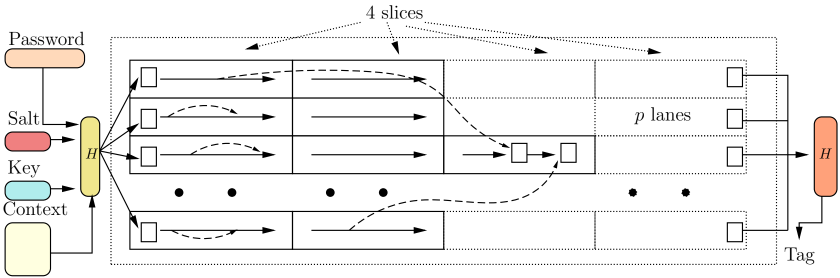
Since 2003, *memory-intensive* computations have been proposed.

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



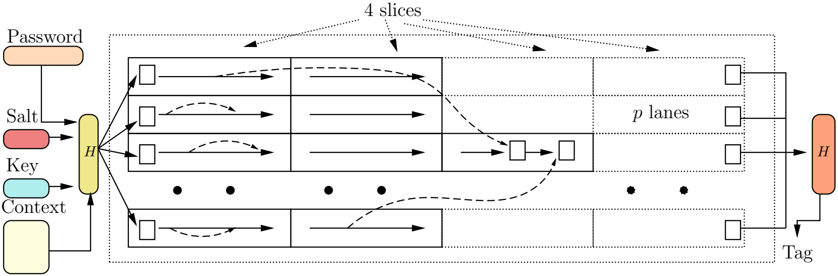
With large memory on-chip, the ASIC advantage vanishes.

Argon2, the winner of Password Hashing Competition



Two variants: Argon2d and Argon2i.

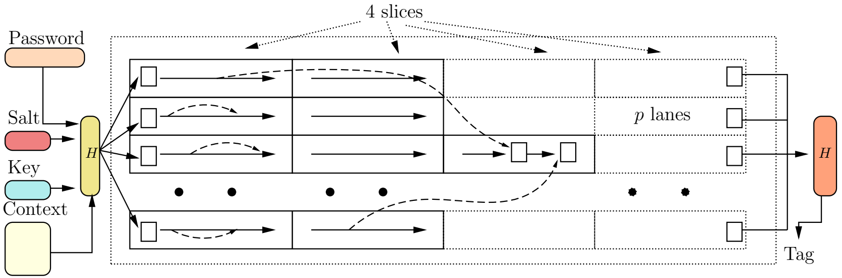
- Argon2d uses data-dependent addressing ($\phi(j) = X[j-1]$);
- Argon2i uses data-independent addressing ($\phi(j) = \text{Blake2b}(j)$);
- The block size is 8192 bits;
- The compression function is based on the Blake2b permutation, enriched with 32-bit multiplications;
- Arbitrarily level of parallelism.



Several enhancements from the version that won the PHC:

- Total memory up to 4 TB;
- Different way to take pseudo-random data for the reference block index from the previous block (Argon2i);
- In second and later passes over the memory, new blocks are XORed into old ones, not overwrite (rules out some attacks, see the last slide).

Feedback requested



- Should there be any H other than Blake2b (internally Blake2b has to stay anyway)?
- Should we allow salts shorter than 8 bytes?
- Should we restrict password hashing to Argon2i only?

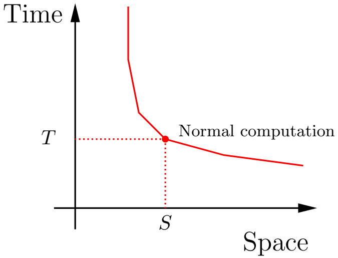
Argon2 with SHA-3

Some people ask what if full SHA-3 or its internal (reduced-round) permutations is used instead of Blake2b-based one:

- Keccak permutation, 3 of 24 rounds: the same time;
- Keccak permutation, 6 of 24 rounds: 50% slower;
- Keccak permutation,12 of 24 rounds: 2.5x slower;
- full Keccak permutation, 24 of 24 rounds: 5x slower;
- Full SHA-3: about 10x slower.

- Collision and preimage resistance – follows from the use of full Blake2b and collision resistance of $P(x) + x$ for the internal permutation P.
- Tradeoff resistance assumed from public scrutiny.

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



$$T = f(1/S).$$

Linear f means equal trading of space for time.

Tradeoff has attack quality γ if

$$\gamma = \frac{ST}{S_{new}\,Tnew}.$$

ASIC implementing this tradeoff will have advantage γ in time-area product (proportional to the running costs of dictionary attacks).

Status of Argon2 under recent attacks

Timeline:

- 2014: Ranking tradeoff method (making a computing graph low-depth by storing certain vertices).
- Jan 2015: Application of ranking method to Argon2i and Argon2d.
- Jul 2015: Argon2 selected as the winner.
- Jan 2016: Corrigan-Gibbs et al. publish "optimization attack" (patched in version 1.3).
- Feb 2016: Alwen and Blocki publish a depth-reducing attack.
- Mar 2016-Jul 2016: no progress.

Attack quality – the reduction in the time-area product for Argon2-implementing ASICs. Here are ranking (2015) and other (2016) attacks on Argon2i.

Passes	Quality			
	Ranking	AB 1 GB	AB 16 GB	Optimization
Not recommended				
1	10	2.4	4.5	5
2	4	1.3	2.5	4
Recommended				
3	2.5	0.9	1.8	-
4	-	0.75	1.4	-
5	-	0.6	1.2	-

Details in Section 3.6 of the Argon2 specification.

Summary of tradeoff security

Argon2d (1 pass, data-dependent):

- No generic attacks;
- Tradeoff attack: area-time product may be reduced by the factor of 1.5 (ranking method).

Argon2i (1 or 2 passes, never recommended):

- Optimization attack [Corrigan-Gibbs et al. 2016], 1/5 of memory with no penalty.

Argon2i (3 or more passes):

- Sandwich attack [Alwen-Blocki'16]: 1.8 factor for 3 passes, less than 1.4 for others.
- Ranking tradeoff attack: 2.5 factor for 3 passes.

Paranoid users can have 5-6 passes or more.