Speeding up GPU-based password cracking

SHARCS 2012

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Who am I?

Professional life

- Ethical hacker
  - KPMG IT Advisory
- Education
  - Master Computer Security at the Kerckhoffs Institute
- Expertise and experience
  - Computer and network security
  - Password cracking
  - Social Engineering

Spare time

Cracking password hashes with GPU's

Goals

- Show how password hashing schemes can be efficiently implemented on GPU's
- Impact on current authentication mechanisms
- Pose relevant questions immediately but save discussions for the end

Outline

- Background information on MD5-crypt and GPU
- Optimizations and speed-ups
- Results and improvements

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Motivation

Why password hashing schemes?

- Database leakage
  - Disgruntled employee
  - SQL injections
- Accessible storage
  - 'SAM' file (Windows)
  - 'passwd' file (Unix)

Why exhaustive search?

- Humans and randomness → ☹
- Humans and memorability → ☹
- Limited keyspace → enables exhaustive search

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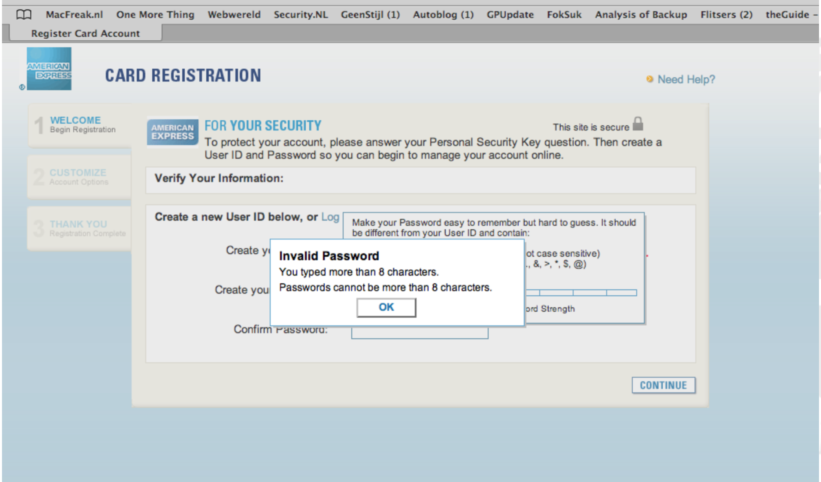

Motivation

Why MD5-crypt?

- Commonly used
  - Default Unix scheme, Cisco routers, RIPE authentication
- Basis for other hashing schemes and frameworks
  - SHA-crypt, bcrypt, PBKDF2

Why GPU?

- New API's support native arithmetic operations
- Designed for highly parallelized algorithms

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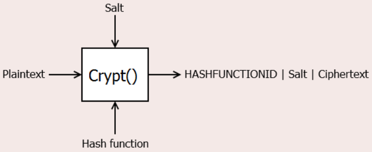
Password hashing schemes

Definition

$$PHS : \mathbb{Z}_2^m \times \mathbb{Z}_2^s \to \mathbb{Z}_2^n$$



Properties

- *Correct use of salts*
  Prevents from time-memory trade-off attacks
- *Slow calculation*
  Key-stretching
- *Avoid pipelined implementations*
  Hashing k passwords with the same salt should cost k times more computation time than hashing a single password

Avoid pipelined implementations

```
var salt = "btediz(KD+$$40";
this.setKey = function(key) {
    encryptionKey = key ;
        if ( !key )
            encryptionKey = null ;
        else {
            for(var i = 0; i < 100; i++)// loop to improve encryption strength
                encryptionKey = MD5(salt + encryptionKey);
        }
```

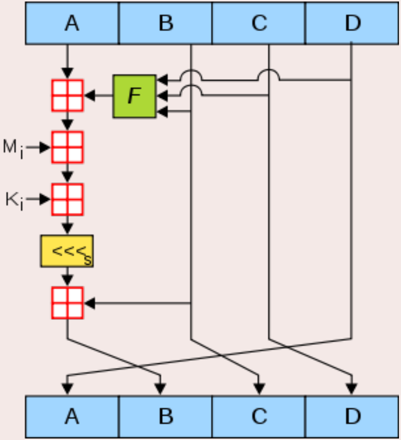
MD5-crypt

MD5-crypt

MD5-crypt("somesalt","password") =
1somesalt$W.KCTbPSiFDGffAGOjcBc.

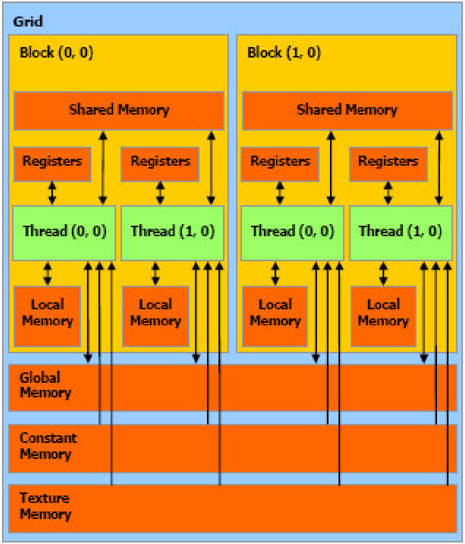
- Key-stretching
  - 1002 calls to *MD5-compression function*
  - Concatenates password, salt and intermediate result pseudo randomly

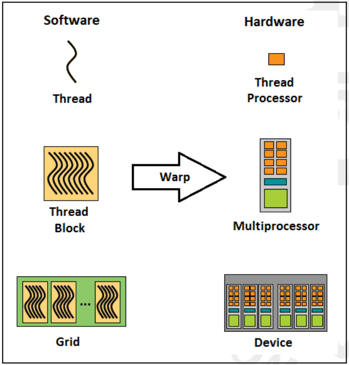
MD5-compression round



Source: Wikipedia

CUDA and memory model





Attacker model

Assumptions

- Attacker model
  - Plaintext password recovery
  - Exhaustive search (ciphertext only)
  - No time-memory trade-off
- Hardware
  - One CUDA enabled GPU: NVIDIA GTX 295
  - 480 thread processors
  - 60 streaming multiprocessors
- Password generation
  - Password length < 16
  - Performance measured in unique password checks per second

Our optimizations

Our optimizations

- Memory → Fast shared memory
- Algorithm wise → Precompute intermediate results
- Execution configuration → Block- and gridsizes
- Maximizing parallelization → Password hashing is embarrassingly parallel
- Instructions → Modulo arithmetic is expensive
- Control flow → Branching is expensive

Algorithm optimizations

- Password length < 16 → One call to MD5compress()
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Memory optimizations

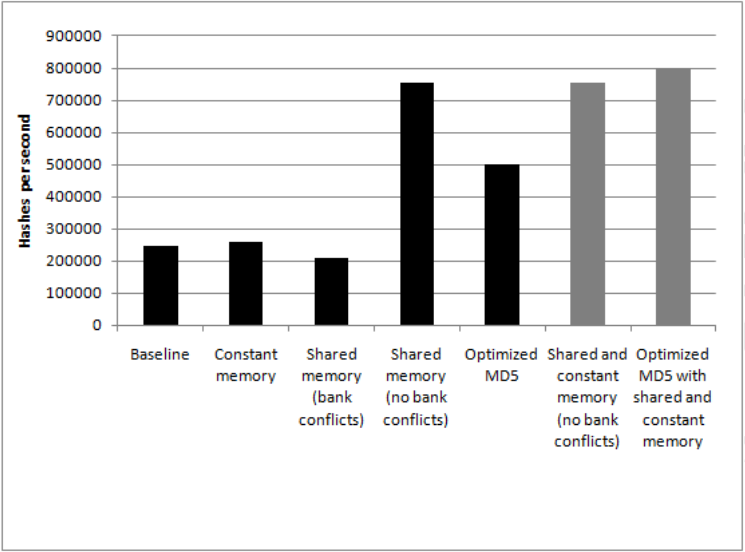
Constant memory

- Default: variables stored in *local memory*
  - Physically resides in global memory (500 clock cycles latency)
- Cached on chip
- As fast as register access (1 clock cycle latency per warp)

Shared memory

- User managed cache
  - On chip (2 clock cycles latency per warp)
  - Shared by all threads in a block
  - Small (16384 Bytes per multiprocessor)
  - Accessed via 16 *banks*

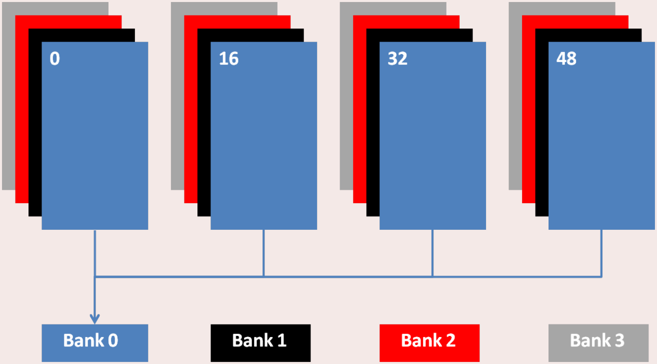
Memory and algorithm optimizations



Bank conflicts

Problem

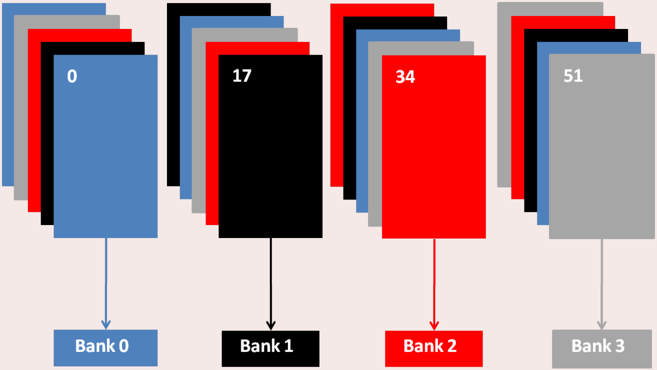
```
int shared[THREADS_PER_BLOCK][16];
int *buffer = shared[threadId];
```



Bank conflicts

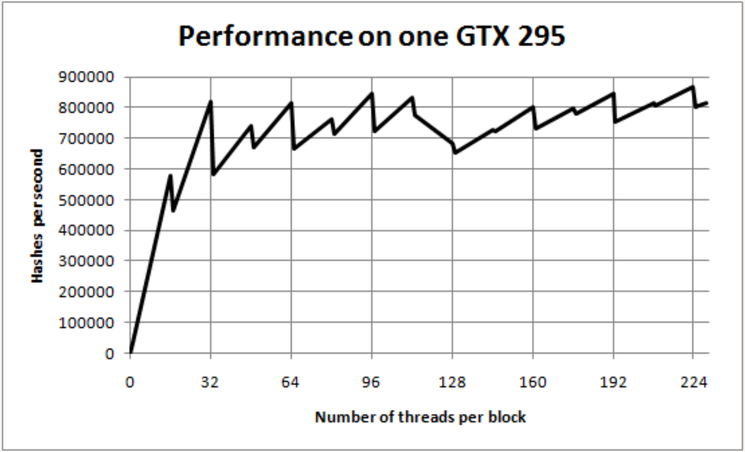
Solution

```
int shared[THREADS_PER_BLOCK][16+1];
int *buffer = shared[threadId]+1;
```

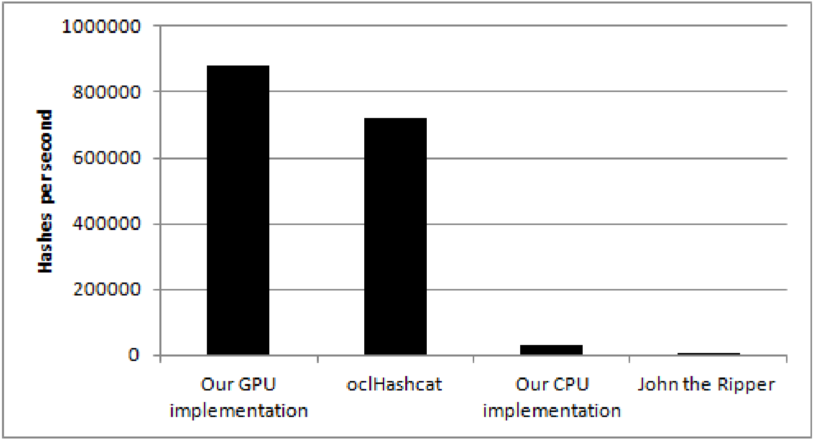


Execution configuration optimizations

Influence on our implementation



Comparison with CPU implementations



Comparison with other implementations

Other implementations

Work	Cryptographic type	Algorithm	Speed up GPU over CPU
Bernstein et al. [2, 1]	Asymmetric	ECC	4-5
Manavski et al. [5]	Symmetric	AES	5-20
Harrison et al. [3]	Symmetric	AES	4-10
Harrisonet al. [4]	Asymmetric	RSA	4
This work	Hashing	MD5-crypt	25-30

Consequences for password safety

Influence on password classes

Length	26 characters	36 characters	62 characters	94 characters
4	0,5 Seconds	2 Seconds	16 Seconds	2 Minutes
5	13 Seconds	1 Minute	17 Minutes	2 Hours
6	5 Minutes	41 Minutes	18 Hours	10 Days
7	2 Hours	1 Days	46 Days	3 Years
8	2 Days	37 Days	8 Years	264 Years
9	71 Days	4 Years	488 Years	20647 Years
10	5 Years	132 Years	30243 Years	2480775 Years

Conclusions

Should we worry?

- Yes, if your password length is < 9 characters
- Increase entropy in passwords $\rightarrow$ password policy
  - Advantage: old schemes still usable
  - Disadvantage: humans and randomness $\rightarrow$ ☹
  - Disadvantage: humans and memorability $\rightarrow$ ☹
  - What is a *good* policy?
- Increase complexity by at least 4 orders of magnitude
  - Advantage: MD5-crypt still usable
  - Disadvantage: passwords not backwards compatible
  - Disadvantage: Moore's law
  - Switch to SHA-crypt or PBKDF2

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Future work

Future work

- Optimizations
  - Additional algorithm optimizations
  - Newer hardware
  - Time-Memory Trade-Off
- Heterogenous crack clusters
  - Consisting of a mix of GPU's, CPU's, mobile devices, etc.
  - Large distributed environments → *Jungle computing* or *Amazon's EC2*
  - OpenCL
- Other schemes and applications
  - SHA-crypt, bcrypt, etc.
  - Frameworks as PBKDF2

Questions and discussion

Thank you for your attention!

- Any questions?
- Contact: Sprengers.Martijn@kpmg.nl

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Execution configuration optimizations

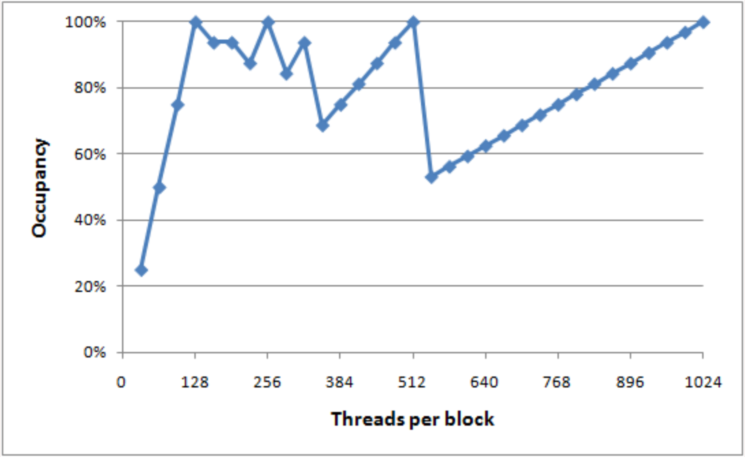
Occupancy

$$\text{Occupancy} = \frac{\text{Active warps per multiprocessor } W_\alpha}{\text{Maximum active warps per multiprocessor } W_{max}}$$

- W_α restricted by *register* and *shared memory* usage
- W_{max} restricted by hardware (32 in our case)
- Programmer can influence W_α by setting the number of threads per block T_b correctly

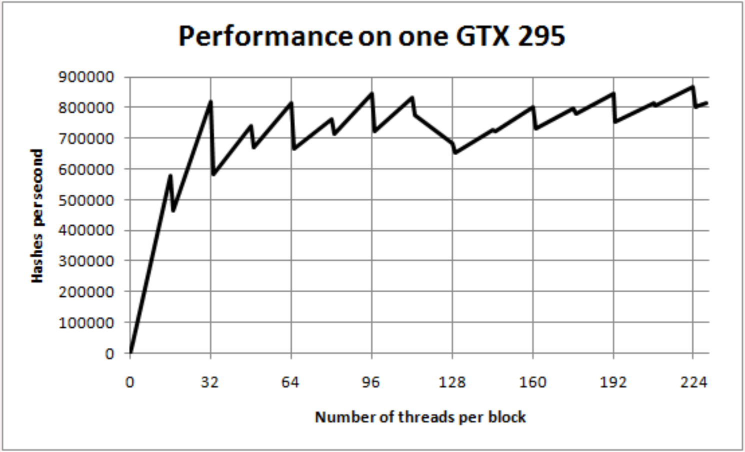
Execution configuration optimizations

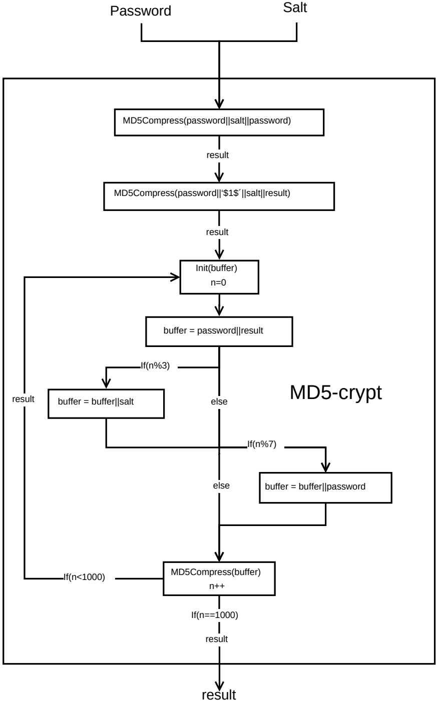
Theoretical calculation



Execution configuration optimizations

Influence on our implementation




Password
Salt
MD5Compress(password||salt||password)
result
MD5Compress(password||'1´||salt||result)
result
Init(buffer)
n=0
buffer = password||result
If(n%3)
buffer = buffer||salt
else
result
MD5-crypt
If(n%7)
buffer = buffer||password
else
MD5Compress(buffer)
n++
If(n<1000)
If(n==1000)
result
result