
CHES 2017
Capture the Flag
Challenge
The WhibOx Contest
An ECRYPT White-Box Cryptography Competition

Organisation

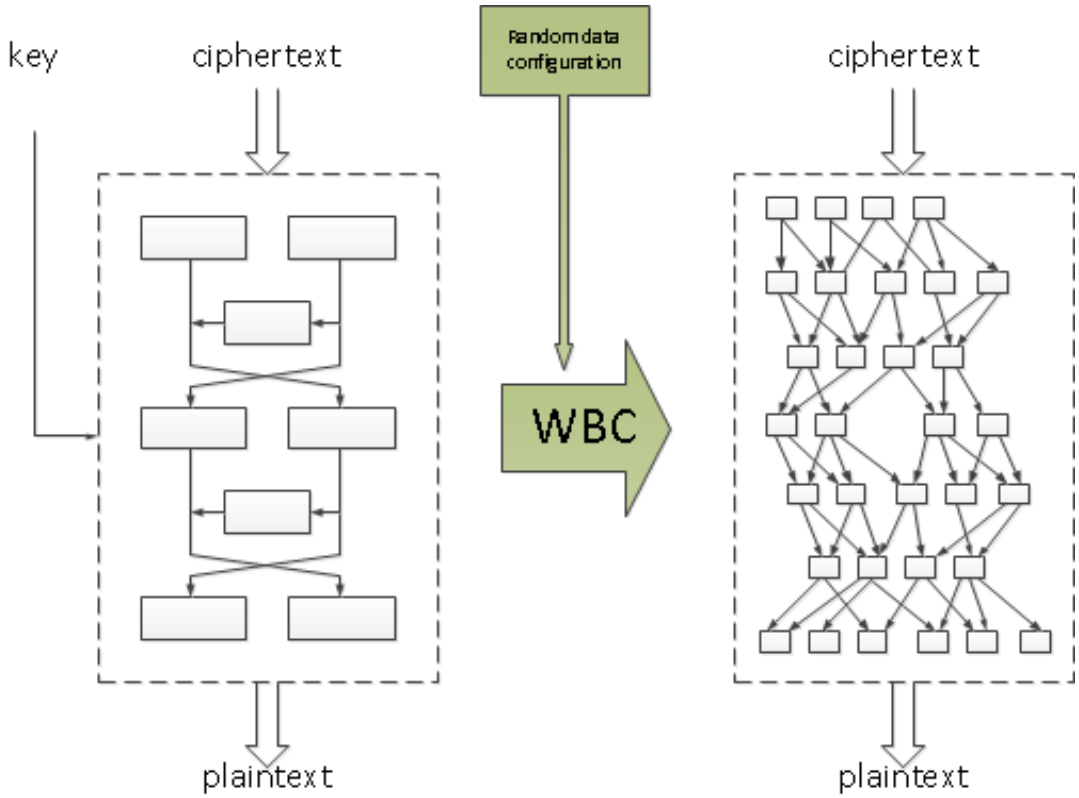
- Organised by the ECRYPT-CSA project

- Submission server developed by CryptoExperts

- Submission server hosted by TU Eindhoven

White-box crypto

- Obfuscation for crypto implementations
- Should at least be secure against key extraction
- Every published scheme broken
- Big trend in the industry (mobile payment, DRM, …)
- Deployed implementations based on secret technologies



(picture source: http://www.whiteboxcrypto.com/)

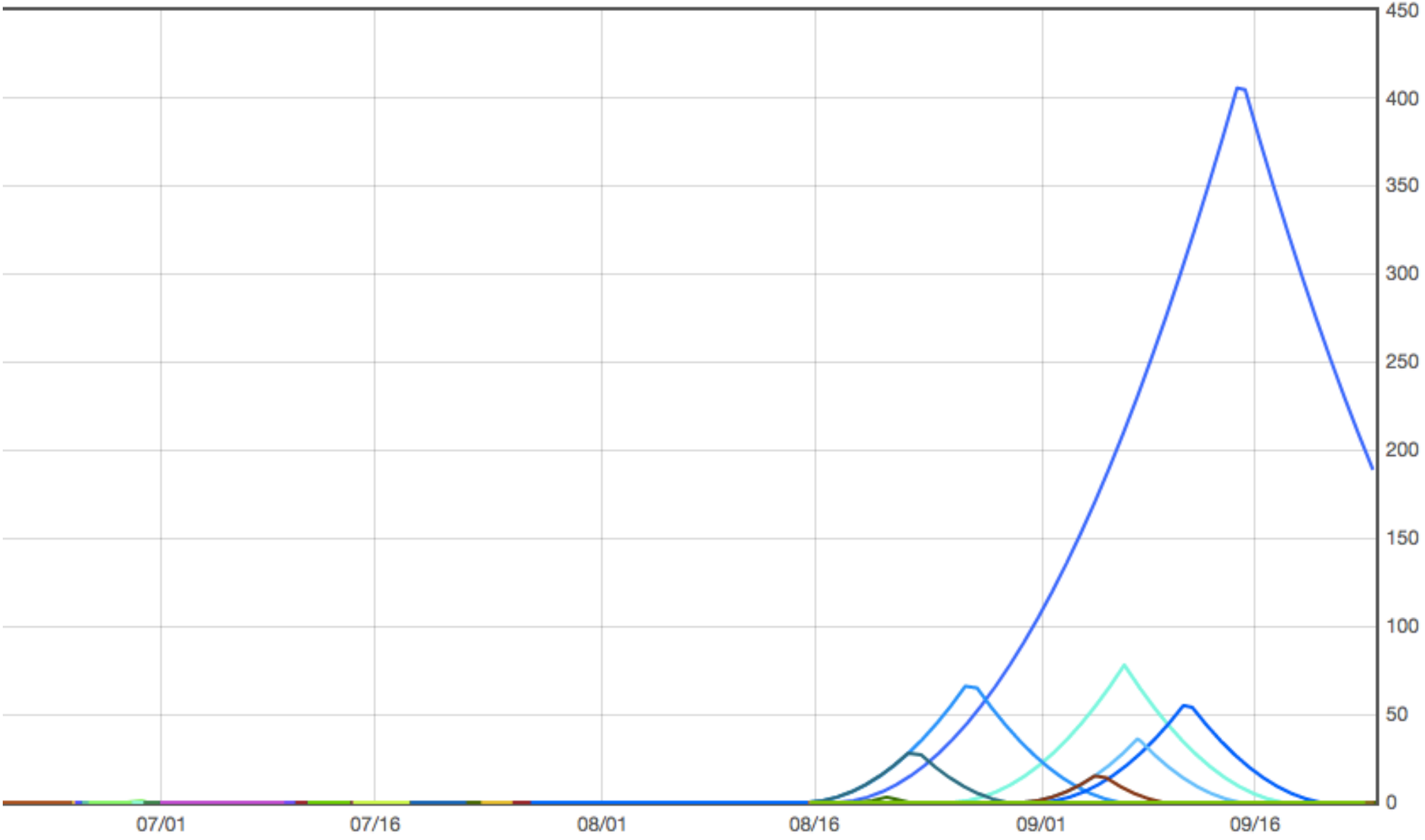
White-box contest

- Following an open discussion at the **WhibOx** workshop (co-located with CHES & CRYPTO 2016)
- Goal: confront designers and attackers of **practical white-box crypto**
- Designers can submit WB AES implementations st:
  - C **source code** at most **50MB**
  - **Executable** at most **20MB**
  - Use at most **20MB of RAM**
  - Run in at most **1sc**
- Attackers can try to recover the keys of submitted implem.

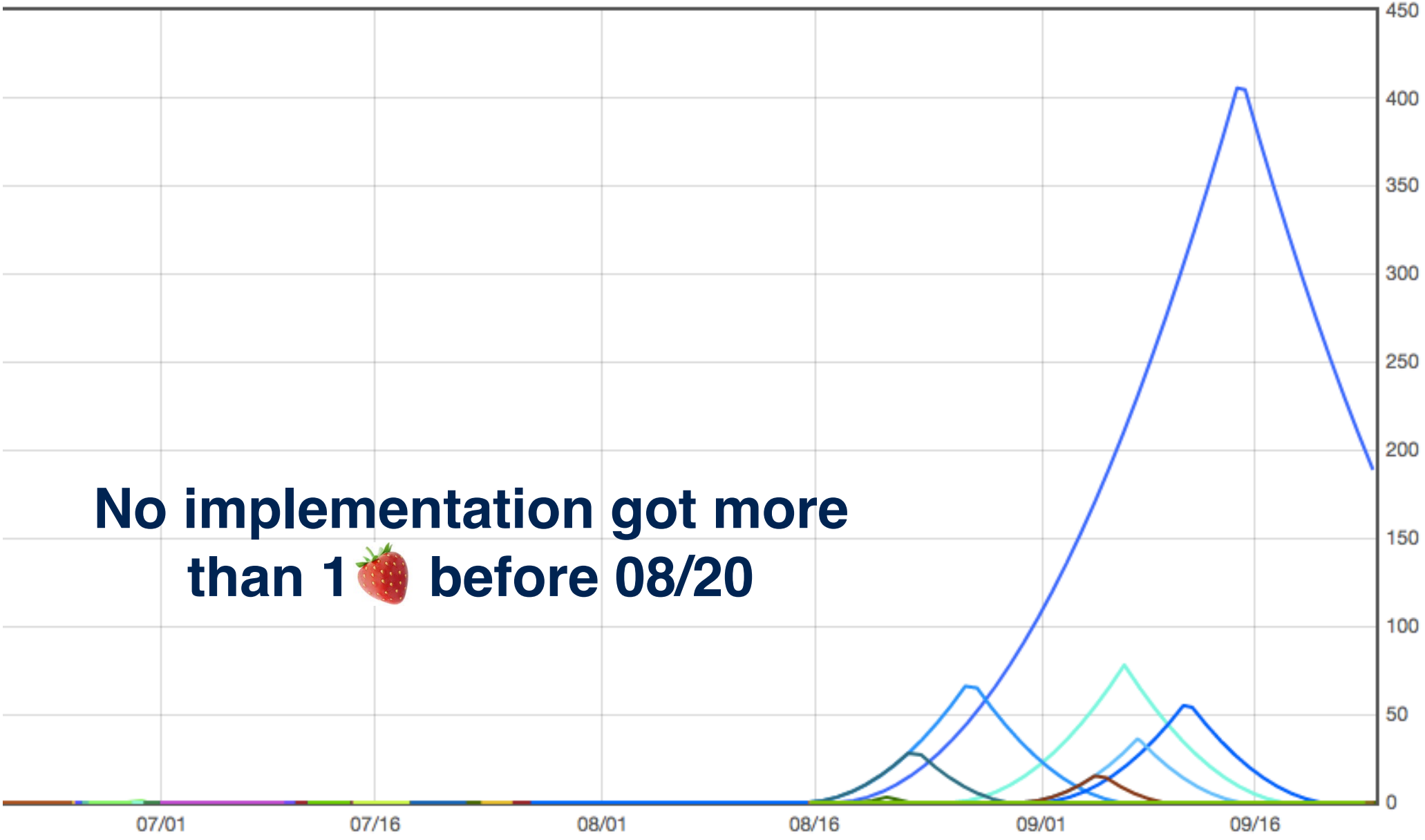
Contest rules

- A WB implem. gets 🍓 points as long as it stays unbroken
- ***n*** new 🍓 on day ***n*** (quadratic growth)
- When a WB implem. with ***q*** 🍓 is broken:
  - the attacker gets ***q*** 🍌 points (with max rule)
  - the 🍓 score of the implem. starts to decrease symmetrically down to **0**
  - the designer of the implem. gets ***q*** 🍓 points

Strawberry scores over time

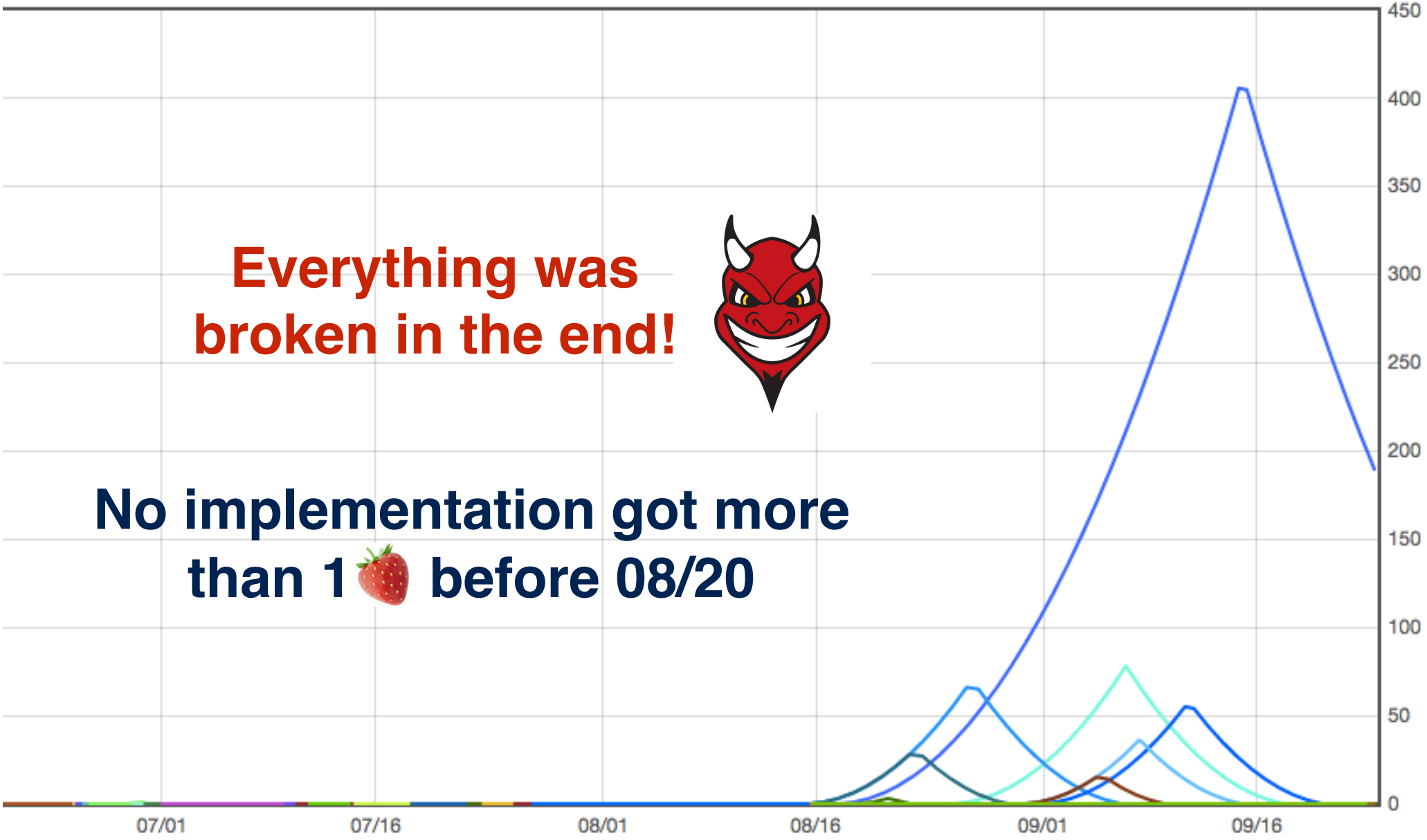


Strawberry scores over time



No implementation got more than 1 🍓 before 08/20

Strawberry scores over time



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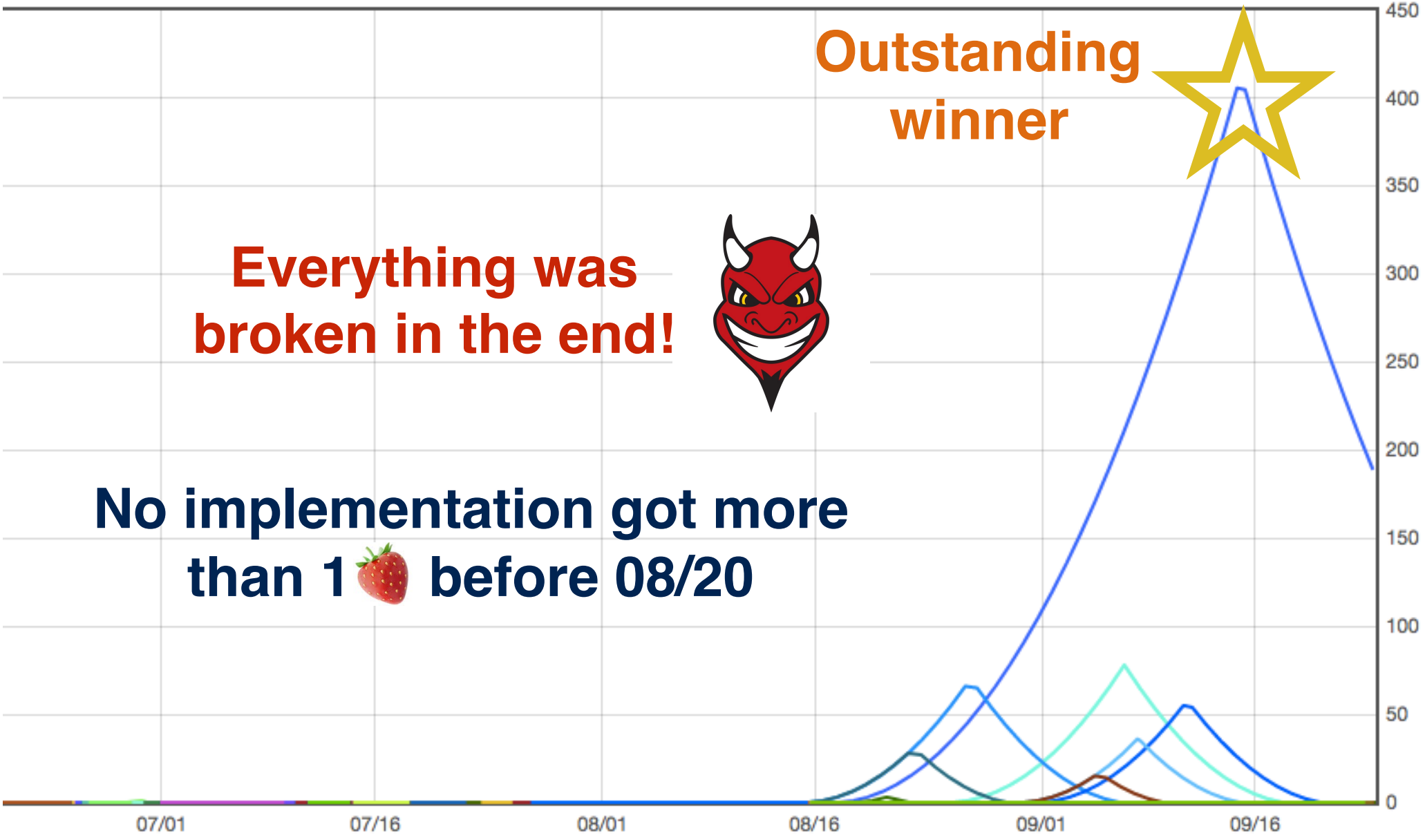

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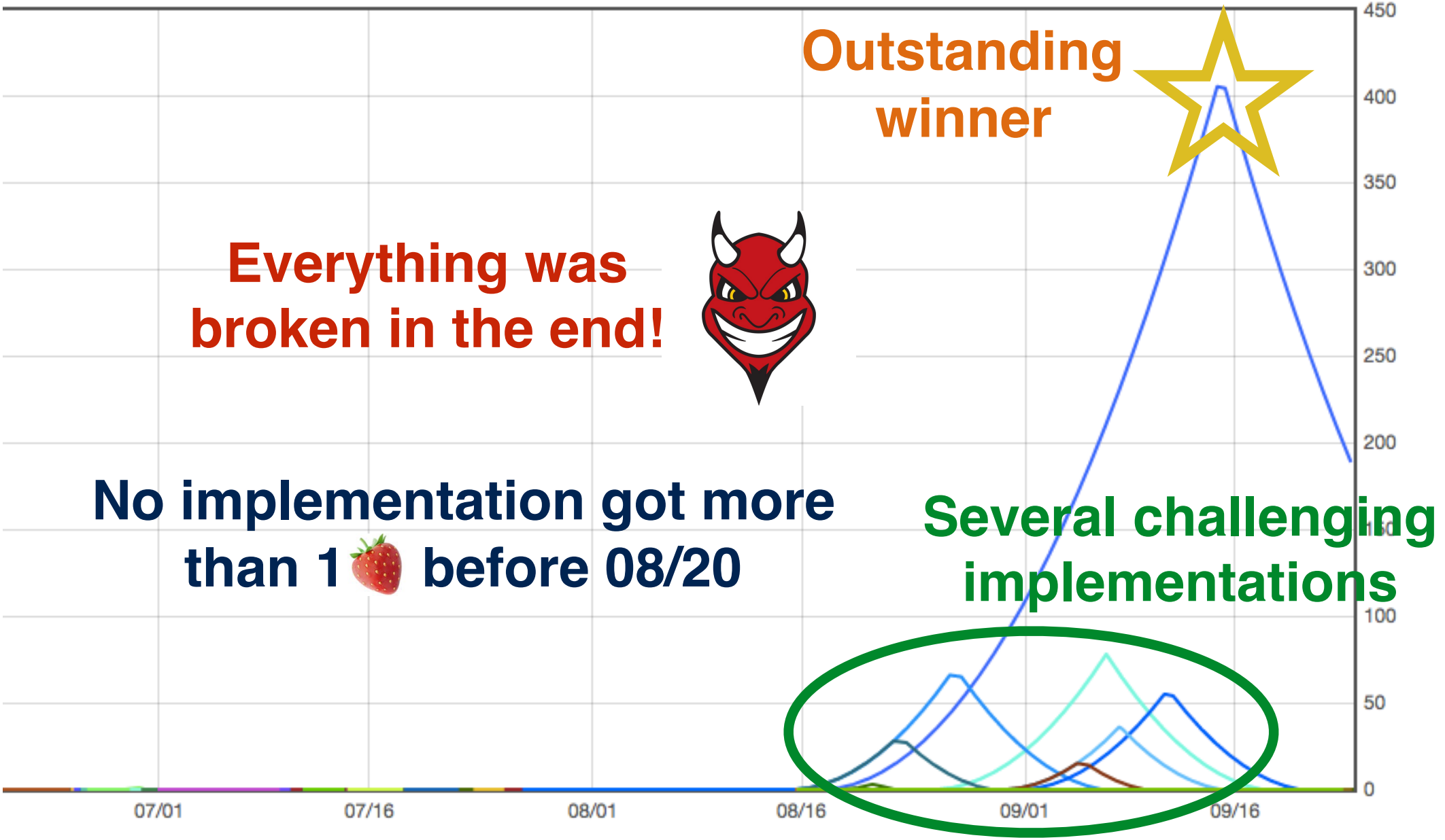
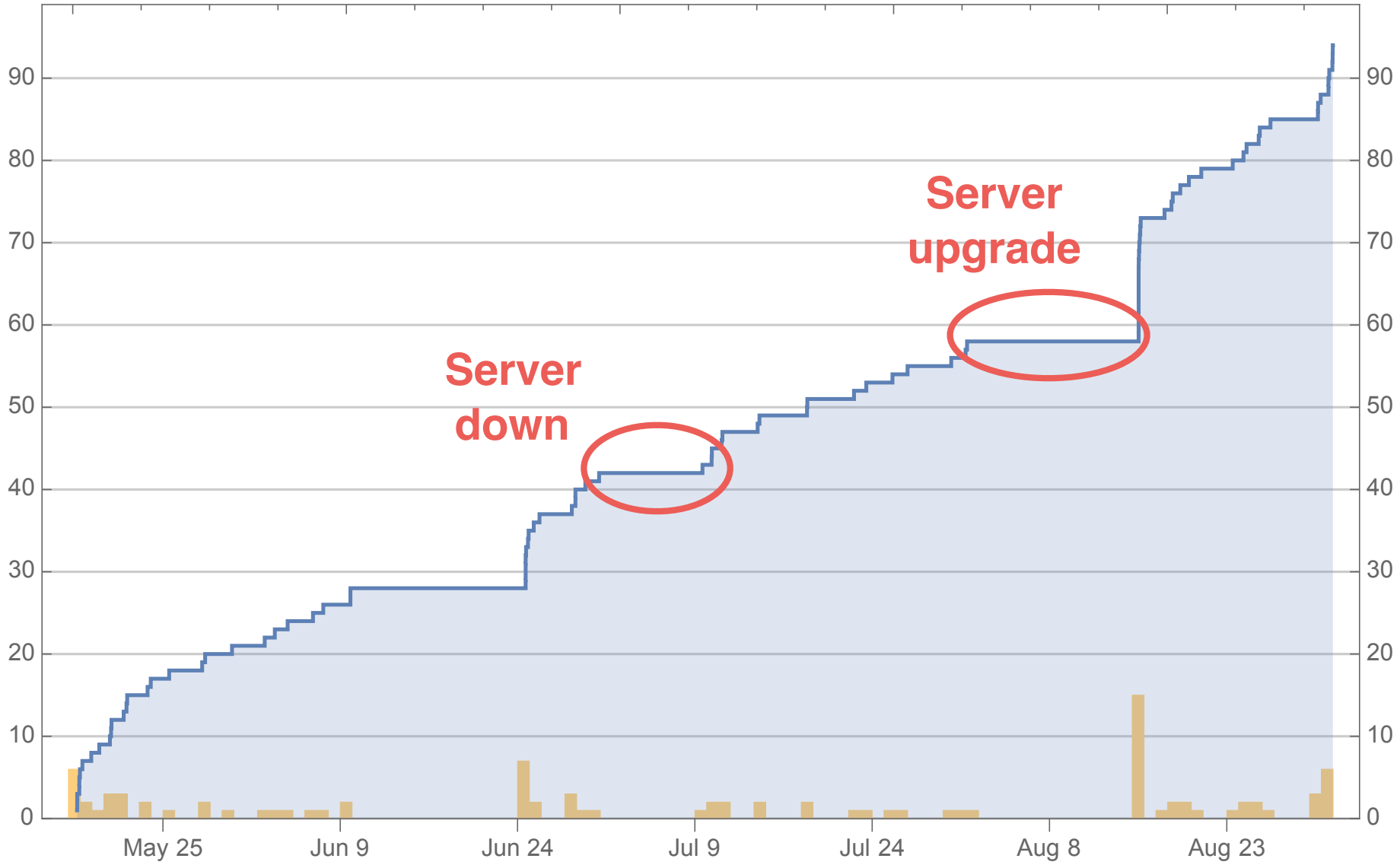


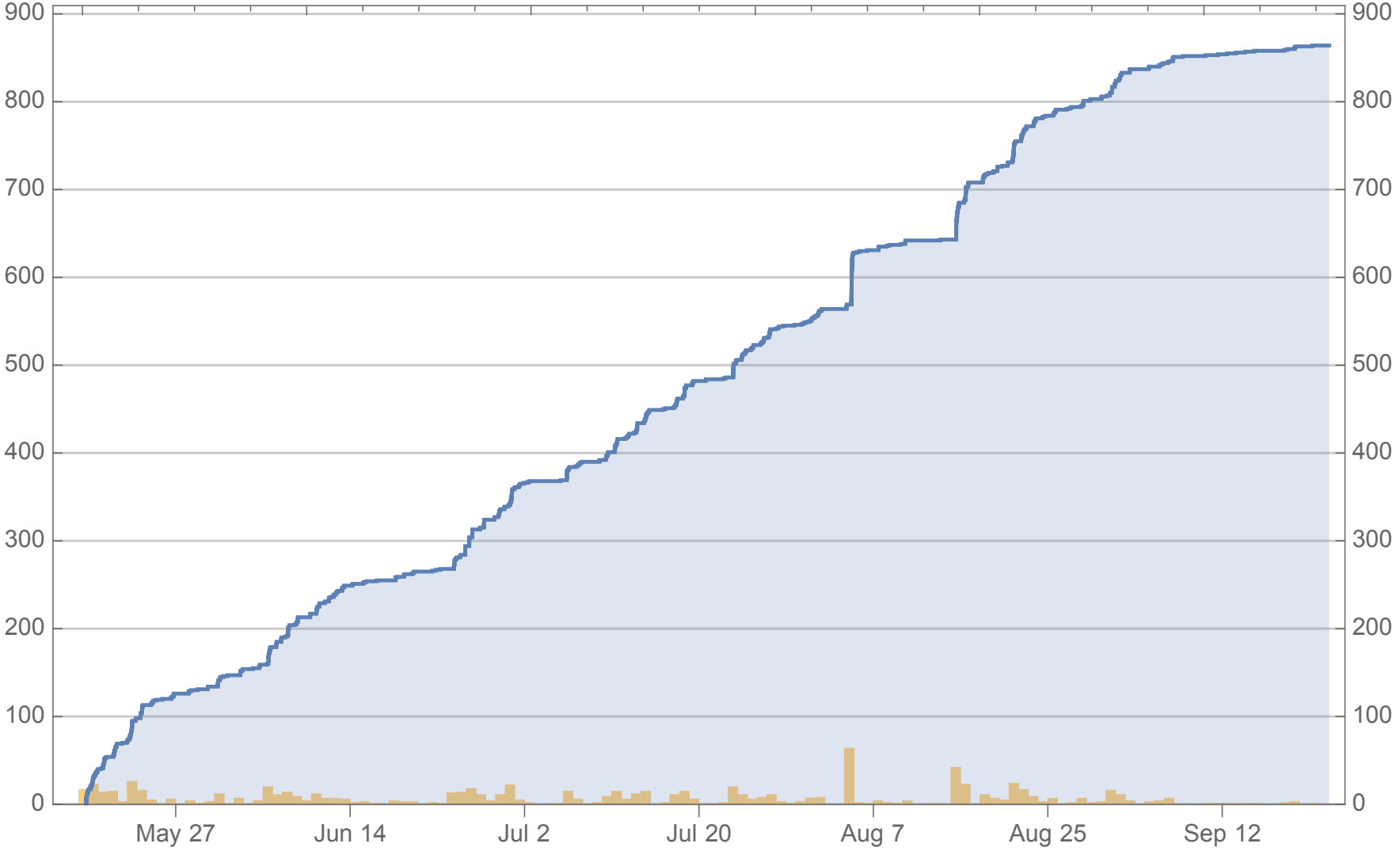
Submissions over time



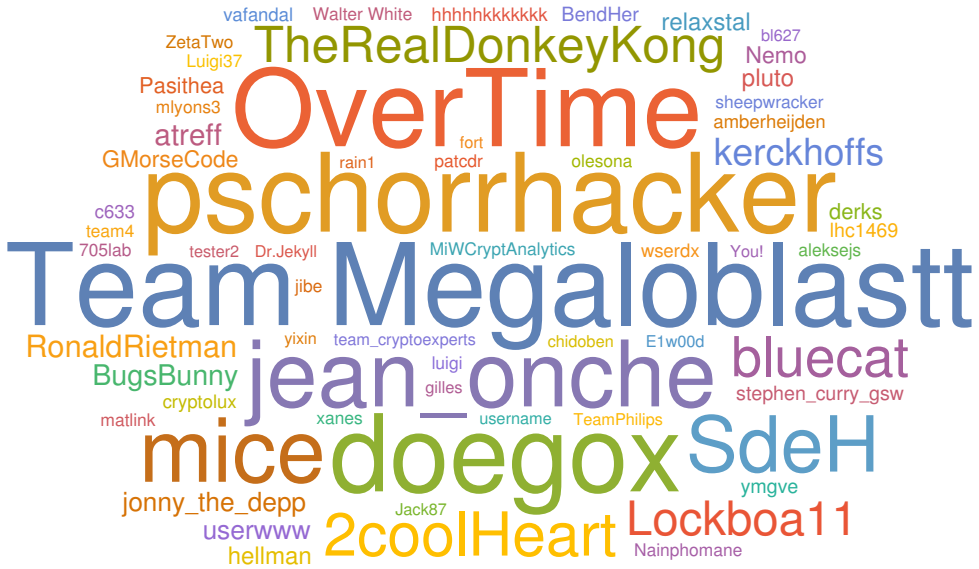
Submitters

20	chaes	1	uglyalgae
7	kluxc3qa1	1	tester
7	**GMorseCode**	1	test1234
5	negainoido	1	T33
4	**bluecat**	1	Stradivarius
4	alec	1	Qe1d28d67
3	therealvalensteam	1	**olesona**
3	ssmiler	1	Mr.Hyde
3	**BugsBunny**	1	Milky
2	**yixin**	1	**Luigi37**
2	**team4**	1	JustTesting
2	sebastien−riou	1	Guntram
2	**Nemo**	1	grothendieck
2	lulu	1	fumiste
2	geronimo	1	double
2	Feeker	1	dequeue
2	coder1987	1	**cryptolux**
2	**aleksejs**	1	**BendHer**
1	yyx	1	Alt

Number of breaks over time

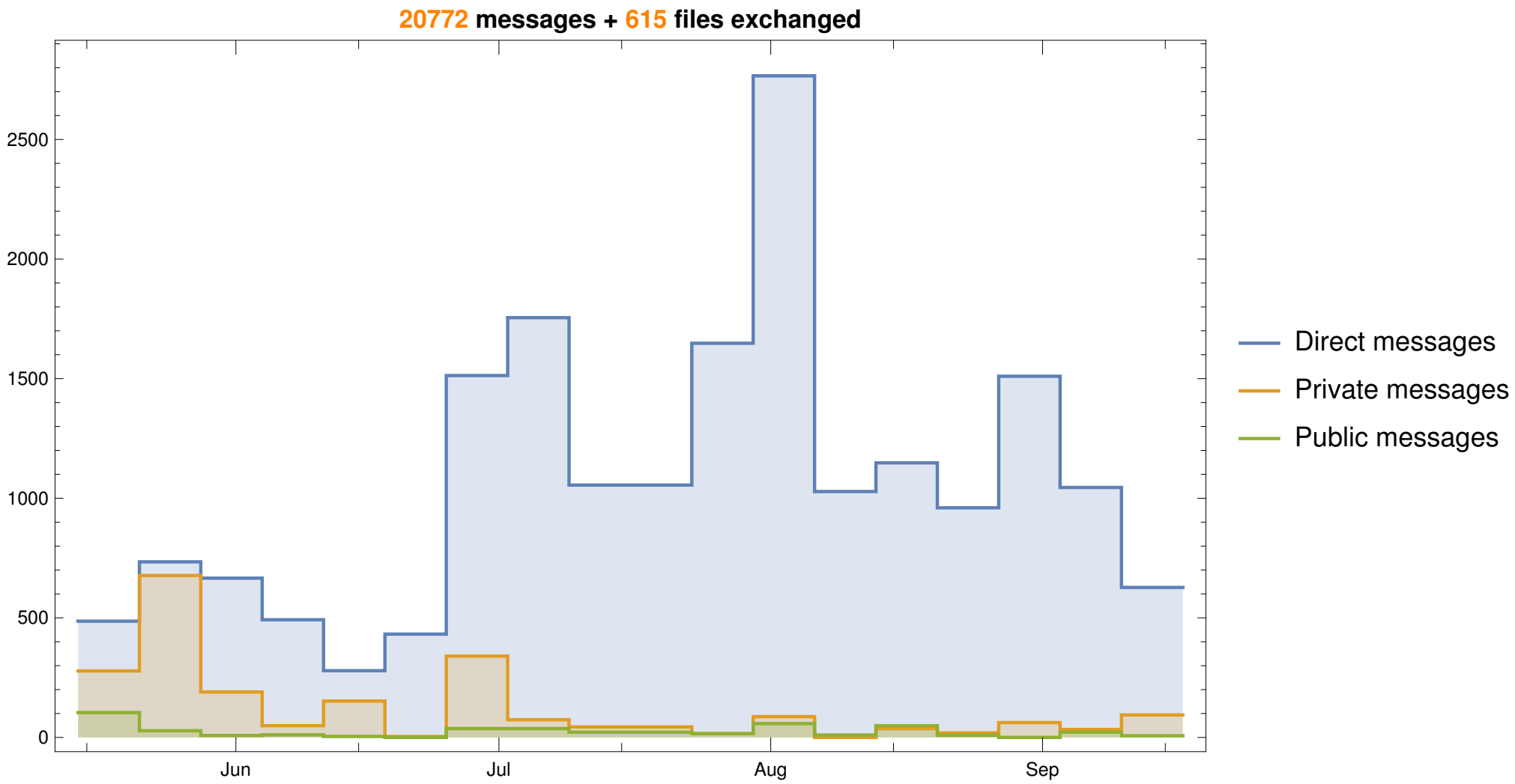


Breakers



89	Team Megaloblastt	3	c633
85	pschorrhacker	3	amberheijden
83	OverTime	2	ZetaTwo
83	doegox	2	xanes
69	jean_onche	2	Walter White
66	mice	2	**team4**
56	SdeH	2	sheepwracker
41	2coolHeart	2	patcdr
36	**bluecat**	2	**olesona**
31	TheRealDonkeyKong	2	Nainphomane
29	Lockboa11	2	mlyons3
20	kerckhoffs	2	MiWCryptAnalytics
14	RonaldRietman	2	matlink
13	atreff	2	**Luigi37**
12	**BugsBunny**	2	luigi
10	userwww	2	jibe
10	jonny_the_depp	2	**aleksejs**
8	relaxstal	2	705lab
8	pluto	1	You!
8	hellman	1	**yixin**
7	**Nemo**	1	username
7	**GMorseCode**	1	tester2
6	Pasithea	1	TeamPhilips
6	derks	1	team_cryptoexperts
4	ymgve	1	rain1
4	stephen_curry_gsw	1	Jack87
4	lhc1469	1	gilles
4	**BendHer**	1	fort
3	wserdx	1	E1w00d
3	vafandal	1	Dr.Jekyll
3	hhhhhkkkkkkk	1	chidoben
3	**cryptolux**	1	bl627

Slack activity



Challenges were broken 9.33 times on average

#Breaks	Most broken
39	wizardly_shannon
37	angry_meitner
20	hopeful_liskov quirky_keller
18	elegant_sinoussi
16	stupefied_varahamihira
14	famous_stonebraker practical_cori
13	eloquent_indiana
12	festive_jennings modest_clarke zealous_ardinghelli determined_goldwasser nostalgic_noether vigilant_heyrovsky

#Breaks	Least broken
5	mystifying_galileo silly_feynman priceless_stallman relaxed_allen musing_lalande compassionate_albattani smart_ardinghelli angry_jones nervous_montalcini
3	sad_goldstine bright_morse
2	relaxed_brown hungry_clarke vibrant_goldberg
1	jolly_davinci competent_agnesi adoring_poitras

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1	jolly_davinci competent_agnesi adoring_poitras

Third (11 days / 66 🍓)

Second (12 days / 78 🍓)

Winner (28 days / 406 🍓)

Strawberry scoreboard

Rank	id		Name	Strawberries Peak	User
#1	777		adoring_poitras	406 🍓	cryptolux
#2	815		competent_agnesi	78 🍓	grothendieck
#3	753		bright_morse	66 🍓	sebastien-riou
#4	877		vibrant_goldberg	55 🍓	chaes
#5	845		hungry_clarke	36 🍓	team4

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#4	877		vibrant_goldberg	55	chaes
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Winners:
Alex Biryukov
Aleksei Udovenko
(U. Luxembourg)

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Still anonymous

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#4	877			🍓	chaes
#5	845				team4

Brent Carmer, Tancrède Lepoint, Alex Malozemoff, Mariana Raykova (iO with degraded parameters)

Banana scoreboard

Rank	User	Bananas
#1	team_cryptoexperts	406
#2	cryptolux	78
#3	You!	55
#4	Team Megaloblastt	44
#5	jean_onche	28

Banana scoreboard

Rank	User	Bananas
#1	team_cryptoexperts	406
#2	cryptolux	
#3	You!	
#4	Team Megalobi	44
#5	jean_onche	28

Winners:
Louis Goubin, Pascal Paillier, Matthieu Rivain, Junwei Wang (CryptoExperts)

Banana scoreboard

Rank	User	Bananas
#1	team_cryptoexperts	406
#2	cryptolux	
#3	You!	
#4		
#5		

Louis
Matthi

We didn't cheat!

* We didn't host the server
* Sources on GitHub
* Junwei's presentation next
* White-paper coming soon

Banana scoreboard

Rank	User	Bananas
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#4	Team Megaloblastt	
#5	jean_onche	28

Still anonymous

Reveal Secrets in Adoring Poitras

A victory of reverse engineering and cryptanalysis over challenge 777

Louis Goubin[1,4] Pascal Paillier[1]
Matthieu Rivain[1] Junwei Wang[1,2,3]

[1]CryptoExperts

[2]University of Luxembourg

[3]University of Paris 8

[4]University of Versailles-St-Quentin-en-Yvelines

CHES 2017, Rump Session, Taipei

CryptoExperts

UNIVERSITÉ DU LUXEMBOURG

UNIVERSITÉ PARIS 8 VINCENNES-SAINT-DENIS

ECRYPT NET

Outline

0. Downloading and Compiling the Code
1. Cleaning the Code
2. De-Virtualization
3. From Bitwise Program to Boolean Circuits
4. Boolean Circuits Minimization
5. Data Dependency Analysis
6. Algebraic Analysis

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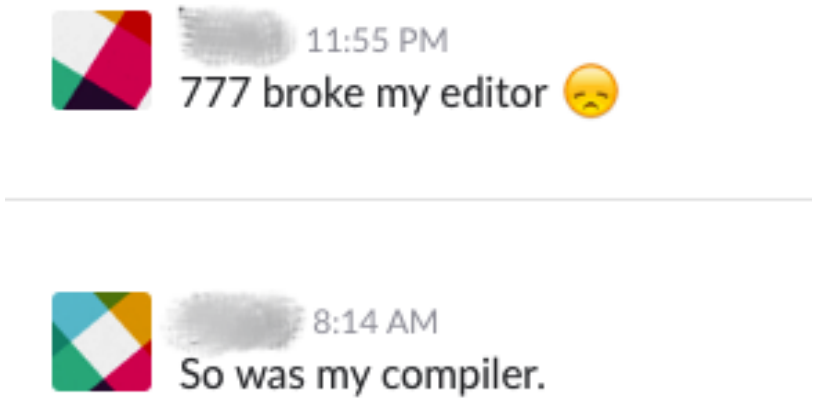
Downloading and Compiling the code Code

- Browsers stuck at loading it...
- Editors are broken by it...
- Some compilers (e.g., llvm) keep compiling and reporting warnings...



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Untidy Code

More than 1k functions

Readability Processing

- Duplicate / redundancy / unused codes elimination
- Functions / variables renaming
- Constants rewriting
- Code combination

Readability Processing

- Duplicate / redundancy / unused codes elimination
- Functions / variables renaming
- Constants rewriting
- Code combination

Only 20 functions are remaining

```
void copy(uint KLedyCW, uint lRjmjY) {int_arr[(a+KLedyCW) & 0x3ffff] = int_arr[lRjmjY & 0x3ffff];}
void encode(uint owhjO, uint nlBqXn) {assign(owhjO, in_ptr[nlBqXn]);}
void decode(uint hFqeIO, uint jvXpt) {out_ptr[hFqeIO]=int_arr[(a+jvXpt)&0x3ffff];}
void rshift_xor(uint HcCOL, uint ISRfdIp, uint ufYFMX) { int_arr[HcCOL&0x3ffff]^=1&(int_arr[(a+ISRfdIp)&0x3ffff]>>ufYFMX); /*prir
void lshift_xor(uint NcJBw, uint OMQBXqa, uint AyoLFz) { uint dyfS=(int_arr[(a+AyoLFz)&0x3ffff])&1;int_arr[(a+NcJBw)&0x3ffff]^=dy

void expand_bit(uint SteQlD, uint ZubEP, uint ZiQz) {int_arr[(a+SteQlD)&0x3ffff]=-((int_arr[(a+ZubEP)&0x3ffff]>>ZiQz)&1);}

uint lookup1(uint AKBKig) {return int_arr[(a+AKBKig)&0x3ffff];}
uint lookup2(uint WAdV, uint ZcVdJ) {return int_arr[(WAdV+ZcVdJ)&0x3ffff];}

void assign(uint UbEJi, uint UmwjUhO) {int_arr[(a+UbEJi)&0x3ffff]=UmwjUhO;}
void assign_a(uint wEOkx) {a = wEOkx;}
void assign_b(uint fnmqxL) {b=int_arr[fnmqxL]&0x07fff;}
void update_a() {a=lookup2(1592,mix(b)); printf("%lu\n",a);}
void update_b() {b=0x7fff&lookup2(522,mix(b));}

void mistery(uint wJxea, uint QBGXUN) {uint t = (~int_arr[(a+QBGXUN)&0x3ffff])&0x7fff; assign(wJxea,lookup2(2979,mix(t)));}

// bitwise operation
void xor(uint oEHmwk, uint KCZu, uint MtCA) {int_arr[(a+oEHmwk)&0x3ffff]=int_arr[(a+KCZu)&0x3ffff]^int_arr[(a+MtCA)&0x3ffff];}
void and(uint bmmFp, uint UNFg, uint PqCtZYZ) {uint t = int_arr[(a+UNFg)&0x3ffff]&int_arr[(a+PqCtZYZ)&0x3ffff];}
void or(uint eTGI, uint udoXFs, uint mezPNN) {int_arr[(a+eTGI)&0x3ffff]=int_arr[(a+udoXFs)&0x3ffff]|int_arr[(a+mezPNN)&0x3ffff];}
void not(uint YfnT, uint JKTw) {int_arr[(a+YfnT)&0x3ffff]=~int_arr[(a+JKTw)&0x3ffff];}

// jump
void goto_f(uint LKhOC) {pc = bop + LKhOC;}
void jump_if(uint DbvJO, uint FleFNIf, uint LeHf) { if(lookup2(2979,mix(b))==lookup2(DbvJO, FleFNIf) || count >= 64) {printf("%d
```

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Universal Turing Machine

```
2262 uint kIKfgI, VDpRwo;
2263 uchar *JqcadL;
2264 uchar *xkpRp, *Puix;
2265 uchar *sutlnu;
2266 uchar *unYAQ;
2267 const char pDeoW[] = "äSTXUS}BS&ýÖ:eK±Ï¿üì¡÷¿žåPê‹˜Ùþç•Àâ]'•0DC3¾ŽBELttSOâvvŸþK„ÓSIä±K_GÅàx    ETB¿íf
2268 uint ooGoRv[sizeof(pDeoW)/sizeof(uint)];
2269 char JGNNvi[] = "SOH\0\n\0\0\0\0\0\0STXSOHxSUBSOH\0\0\0\0\0ÿ\0\0\0\0\0\0\0STXSOHETX\0P\0\0\0\0\0\0
2270 uchar *klspCVy = (uchar*)JGNNvi;
2271 void aLLl() {
2272 unYAQ = klspCVy;
2273 sutlnu = klspCVy + sizeof(JGNNvi)/sizeof(uchar);
2274 JqcadL = klspCVy;
2275 while (JqcadL < sutlnu) {
2276 uchar eMmr = *JqcadL++;
2277 if (eMmr == 0) {
2278 void (*QiEb)();
2279 QiEb = (void*)funcptrs[*JqcadL++];
2280 uint *AnezsV = (uint*)JqcadL;
2281 JqcadL += eMmr*8;
2282 QiEb();
2283 }
2284 else if (eMmr == 1) {
2285 void (*QiEb)(uint);
2286 QiEb = (void*)funcptrs[*JqcadL++];
2287 uint *AnezsV = (uint*)JqcadL;
2288 JqcadL += eMmr*8;
2289 QiEb(AnezsV[0]);
2290 }
2291 ...
2327 }
2328 void AES_128_encrypt(uchar *OLjd, uchar *xzptiF) {
2329 for(kIKfgI = 0; kIKfgI < sizeof(ooGoRv)/sizeof(uint); kIKfgI++) ooGoRv[kIKfgI] = gBXW[kIKfgI];
2330 xkpRp = OLjd;
2331 Puix = xzptiF;
2332 if (sizeof(klspCVy))
2333 aLLl();
2334 else
2335 1;// c;
2336 }
```

⇒ UTM(RASP)

Universal Turing Machine (2)

```
2262 uint kIKfgI, VDpRwo;
2263 uchar *JqcadL;
2264 uchar *xkpRp, *Puix;
2265 uchar *sutlnu;
2266 uchar *unYAQ;
2267 const char pDeoW[] = "äSTXUS}BS&ýÖ:eK±Ï¿üì¡÷¿žåPê‹˜Ùþç•Àâ]'•0DC3¾ŽBELttSOâvvÝÞK„ÓSIä±K_GÂàx    ETB¿íf
2268 uint ooGoRv[sizeof(pDeoW)/sizeof(uint)];
2269 char JGNNvi[] = "SOH\0\n\0\0\0\0\0\0STXSOHxSUBSOH\0\0\0\0\0ÿ\0\0\0\0\0\0\0STXSOHETX\0P\0\0\0\0\0\0
2270 uchar *klspCVy = (uchar*)JGNNvi;
2271 void aLLl() {
2272 unYAQ = klspCVy;
2273 sutlnu = klspCVy + sizeof(JGNNvi)/sizeof(uchar);
2274 JqcadL = klspCVy;
2275 while (JqcadL < sutlnu) {
2276 uchar eMmr = *JqcadL++;
2277 if (eMmr == 0) {
2278 void (*QiEb)();
2279 QiEb = (void*)funcptrs[*JqcadL++];
2280 uint *AnezsV = (uint*)JqcadL;
2281 JqcadL += eMmr*8;
2282 QiEb();
2283 }
2284 else if (eMmr == 1) {
2285 void (*QiEb)(uint);
2286 QiEb = (void*)funcptrs[*JqcadL++];
2287 uint *AnezsV = (uint*)JqcadL;
2288 JqcadL += eMmr*8;
2289 QiEb(AnezsV[0]);
2290 }
2291 ...
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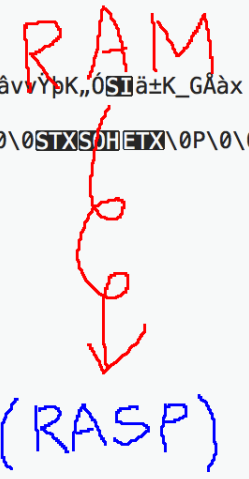
2329 for(kIKfgI = 0; kIKfgI < sizeof(ooGoRv)/sizeof(uint); kIKfgI++) ooGoRv[kIKfgI] = gBXW[kIKfgI];
2330 xkpRp = OLjd;
2331 Puix = xzptiF;
2332 if (sizeof(klspCVy))
2333 aLLl();
2334 else
2335 1;// c;
2336 }
```



CryptoExperts

Universal Turing Machine (3)

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2263 uchar *JqcadL;
2264 uchar *xkpRp, *Puix;
2265 uchar *sutlnu;
2266 uchar *unYAQ;
2267 const char pDeoW[] = "äSTXUS}BS&ýÖ:eK±Ï¿üìi÷¿žåPê‹˜Ùþç•Àâ]'•0DC3¾ŽBELttS0âvvYÞK„ÓSIä±K_GÂàx    ETB¿íf
2268 uint ooGoRv[sizeof(pDeoW)/sizeof(uint)];
2269 char JGNNvi[] = "SOH\0\n\0\0\0\0\0\0\0STXSOHxSUBSOH\0\0\0\0\0ÿ\0\0\0\0\0\0\0STXSOHETX\0P\0\0\0\0\0\0
2270 uchar *klspCVy = (uchar*)JGNNvi;
2271 void aLLl() {
2272 unYAQ = klspCVy;
2273 sutlnu = klspCVy + sizeof(JGNNvi)/sizeof(uchar);
2274 JqcadL = klspCVy;
2275 while (JqcadL < sutlnu) {
2276 uchar eMmr = *JqcadL++;
2277 if (eMmr == 0) {
2278 void (*QiEb)();
2279 QiEb = (void*)funcptrs[*JqcadL++];
2280 uint *AnezsV = (uint*)JqcadL;
2281 JqcadL += eMmr*8;
2282 QiEb();
2283 }
2284 else if (eMmr == 1) {
2285 void (*QiEb)(uint);
2286 QiEb = (void*)funcptrs[*JqcadL++];
2287 uint *AnezsV = (uint*)JqcadL;
2288 JqcadL += eMmr*8;
2289 QiEb(AnezsV[0]);
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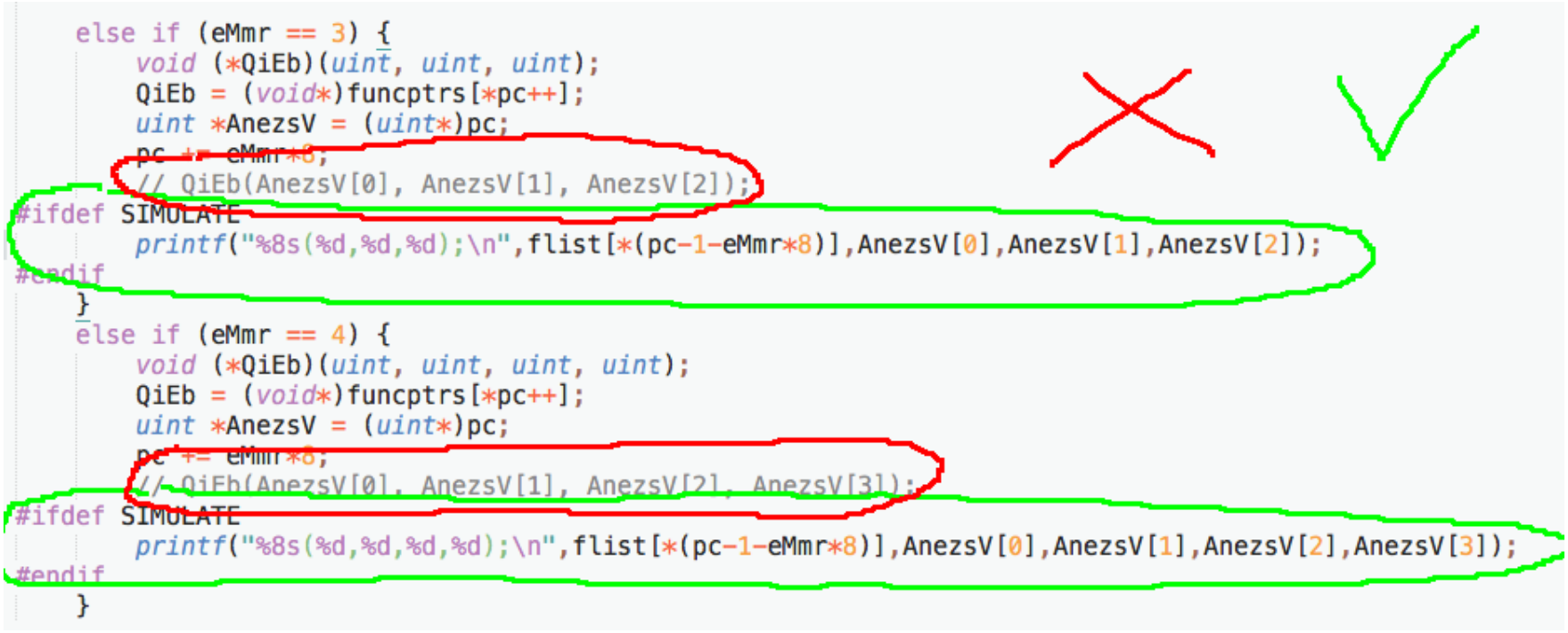
2328 void AES_128_encrypt(uchar *OLjd, uchar *xzptiF) {
2329 for(kIKfgI = 0; kIKfgI < sizeof(ooGoRv)/sizeof(uint); kIKfgI++) ooGoRv[kIKfgI] = gBXW[kIKfgI];
2330 xkpRp = OLjd;
2331 Puix = xzptiF;
2332 if (sizeof(klspCVy))
2333 aLLl();
2334 else
2335 1;// c;
2336 }
```

De-virtualization - Simulate the UTM

```
    else if (eMmr == 3) {
        void (*QiEb)(uint, uint, uint);
        QiEb = (void*)funcptrs[*pc++];
        uint *AnezsV = (uint*)pc;
        pc += eMmr*8;
        // QiEb(AnezsV[0], AnezsV[1], AnezsV[2]);
#ifdef SIMULATE
        printf("%8s(%d,%d,%d);\n",flist[*(pc-1-eMmr*8)],AnezsV[0],AnezsV[1],AnezsV[2]);
#endif
    }
    else if (eMmr == 4) {
        void (*QiEb)(uint, uint, uint, uint);
        QiEb = (void*)funcptrs[*pc++];
        uint *AnezsV = (uint*)pc;
        pc += eMmr*8;
        // QiEb(AnezsV[0], AnezsV[1], AnezsV[2], AnezsV[3]);
#ifdef SIMULATE
        printf("%8s(%d,%d,%d,%d);\n",flist[*(pc-1-eMmr*8)],AnezsV[0],AnezsV[1],AnezsV[2],AnezsV[3]);
#endif
    }
```

De-virtualization - Simulate the UTM



```
    else if (eMmr == 3) {
        void (*QiEb)(uint, uint, uint);
        QiEb = (void*)funcptrs[*pc++];
        uint *AnezsV = (uint*)pc;
        pc += eMmr*8;
        // QiEb(AnezsV[0], AnezsV[1], AnezsV[2]);
#ifdef SIMULATE
        printf("%8s(%d,%d,%d);\n",flist[*(pc-1-eMmr*8)],AnezsV[0],AnezsV[1],AnezsV[2]);
#endif
    }
    else if (eMmr == 4) {
        void (*QiEb)(uint, uint, uint, uint);
        QiEb = (void*)funcptrs[*pc++];
        uint *AnezsV = (uint*)pc;
        pc += eMmr*8;
        // QiEb(AnezsV[0], AnezsV[1], AnezsV[2], AnezsV[3]);
#ifdef SIMULATE
        printf("%8s(%d,%d,%d,%d);\n",flist[*(pc-1-eMmr*8)],AnezsV[0],AnezsV[1],AnezsV[2],AnezsV[3]);
#endif
    }
```

We get a bitwise-based program (600k operations).

Outline

0. Downloading and Compiling the Code
1. Cleaning the Code
2. De-Virtualization
3. From Bitwise Program to Boolean Circuits
4. Boolean Circuits Minimization
5. Data Dependency Analysis
6. Algebraic Analysis

Bitwise-based program

Input: plaintext bits $(b_1, b_2, \cdots, b_{128})$
Output: ciphertext bits $(c_1, c_2, \cdots, c_{128})$

for $i = 1$ to 128 **do**
  $t[addr_{1,i}] \leftarrow 0\mathrm{b}b_i b_i b_i \cdots b_i$ ▷ expand b_i to unsigned long integer (64 bits)
  for $j = 1$ to 64 **do**
    $t[addr_{2,i} + j * 2^{12}] \leftarrow t[addr_{1,i}]$
  end for
end for

BitwiseOperationLoop1 ▷ loop for 64 times
BitwiseOperationLoop2
...
BitwiseOperationLoop2573

for $i = 1$ to 129 **do**
  $t[addr_{3,i}] \leftarrow v_i$ ▷ $v_i \in \mathtt{GF}(2)$ is a constant
  for $j = 1$ to 64 **do**
    $tmp \leftarrow t[addr_{4,i} + j * 2^{12}] \oplus t[addr_{5,i} + j * 2^{12}]$
    $t[addr_{3,i}] \leftarrow t[addr_{3,i}] \oplus$ Parity(tmp) ▷ Parity computes the number of 1-bit modulo 2
  end for
end for

BitwiseOperationLoop2574
...
BitwiseOperationLoop2582

for $i = 1$ to 128 **do**
  $c_i \leftarrow t[addr_{6,i}]$
end for

From Bitwise Program to Boolean Circuits

- 64 (loop length) * 64 (number of bits in a unsigned long integer) independent AES computations operated in boolean circuits
- 3 out of 64*64 are the real and identical AES computations (e.g., bit 42 of loop 26)
- Hence, the bitwsie-based program can be simplified as a boolean circuits with 600k gates (XOR, AND, OR, NOT).

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Boolean Circuits Minimization

- Constant variable detection and propagation
- Dead code elimination
- Deduplication
- "Potential" pseudorandomness detection and removal
- Repeat the above steps until no more constant / duplicate / "potential" pseudorandomness can be detected

Finally, the circuits is reduced to 280k boolean gates (53% smaller)

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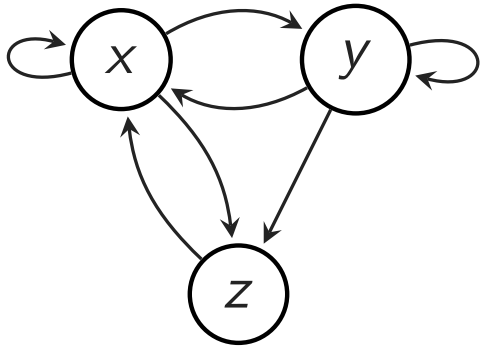
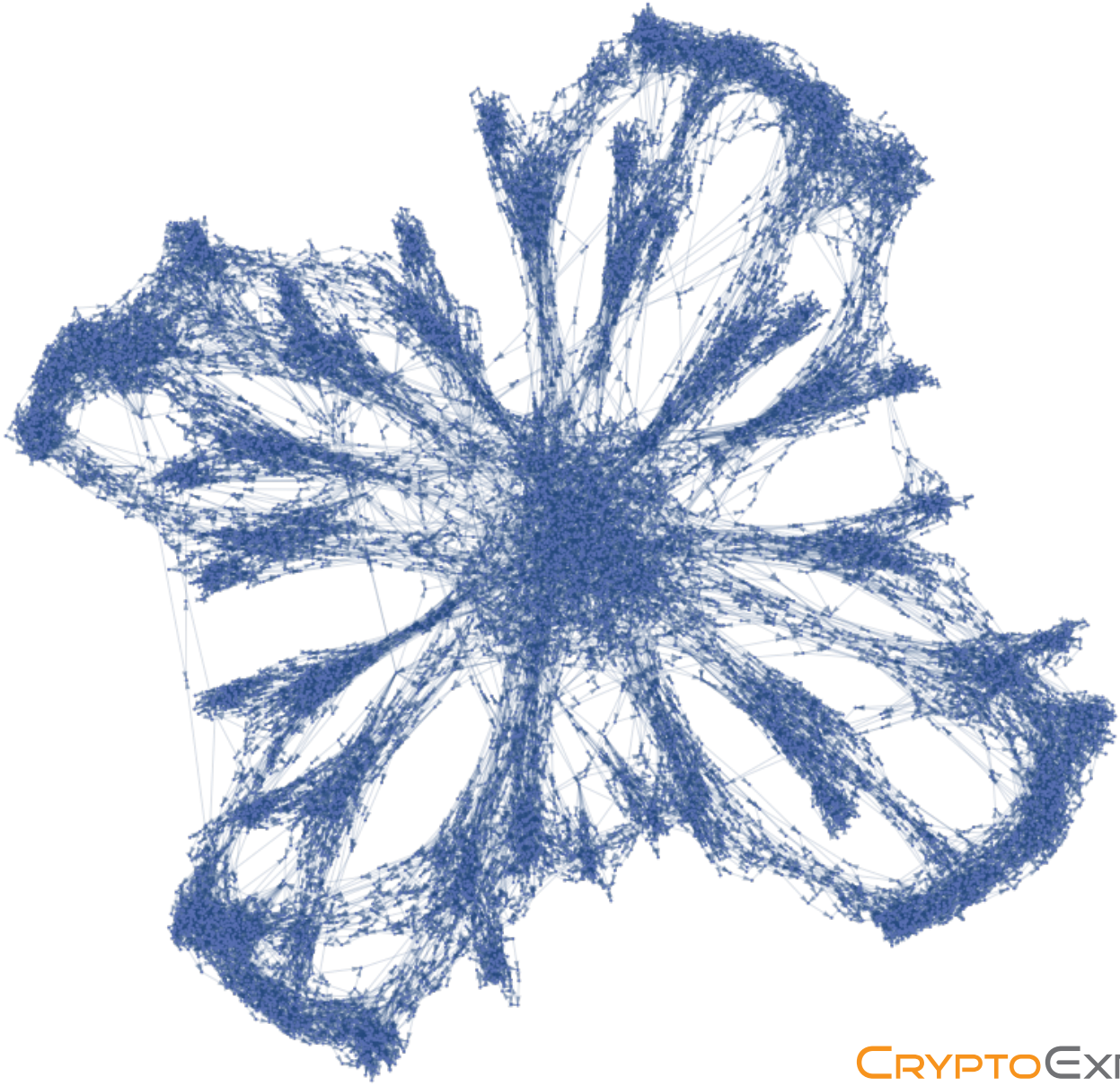
Data Dependency Graph (DDG)

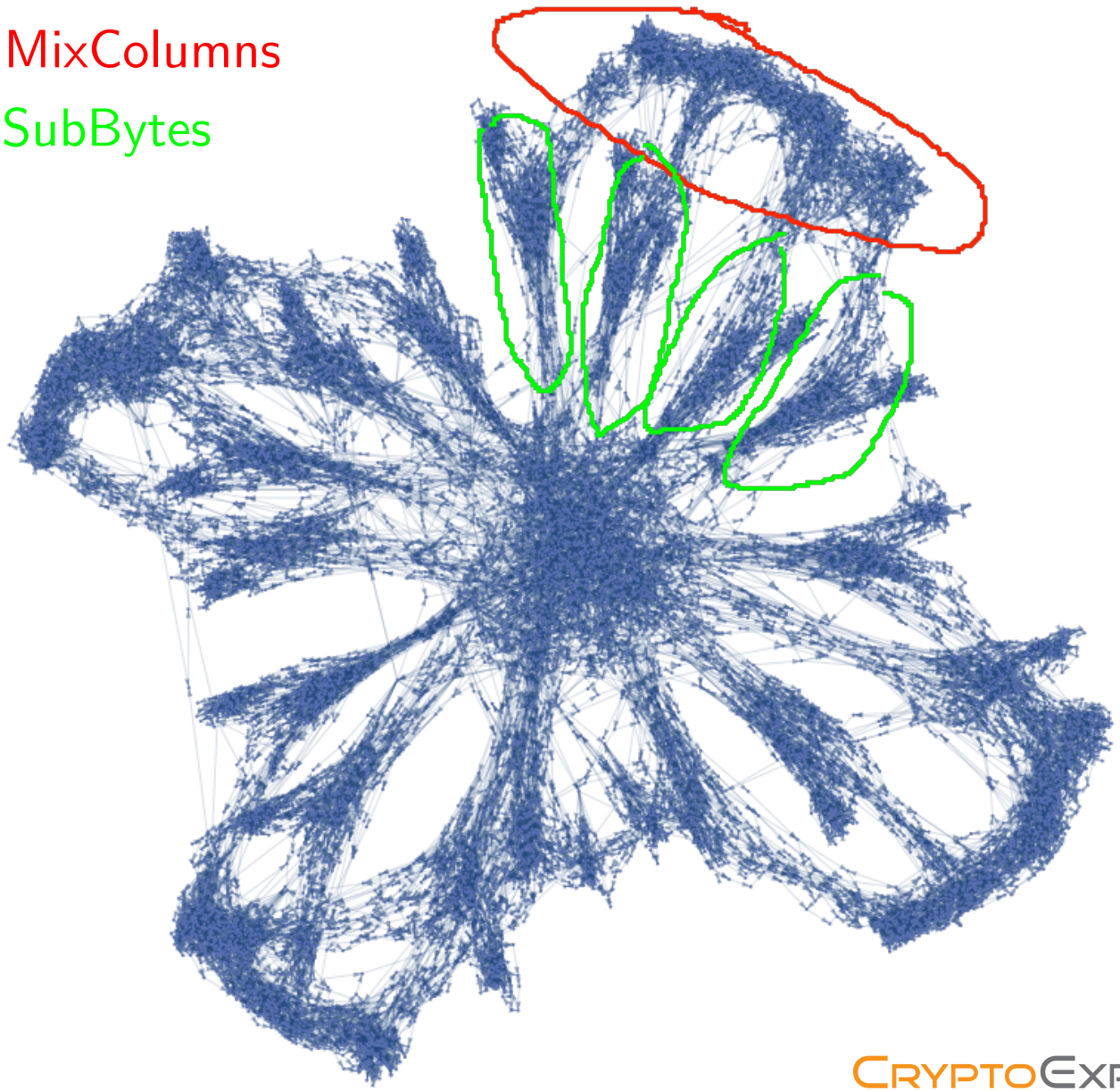
$$x = a;$$
$$y = b;$$
$$x = y + x;$$
$$y = x * y;$$
$$z = x - y;$$
$$x = z * x;$$



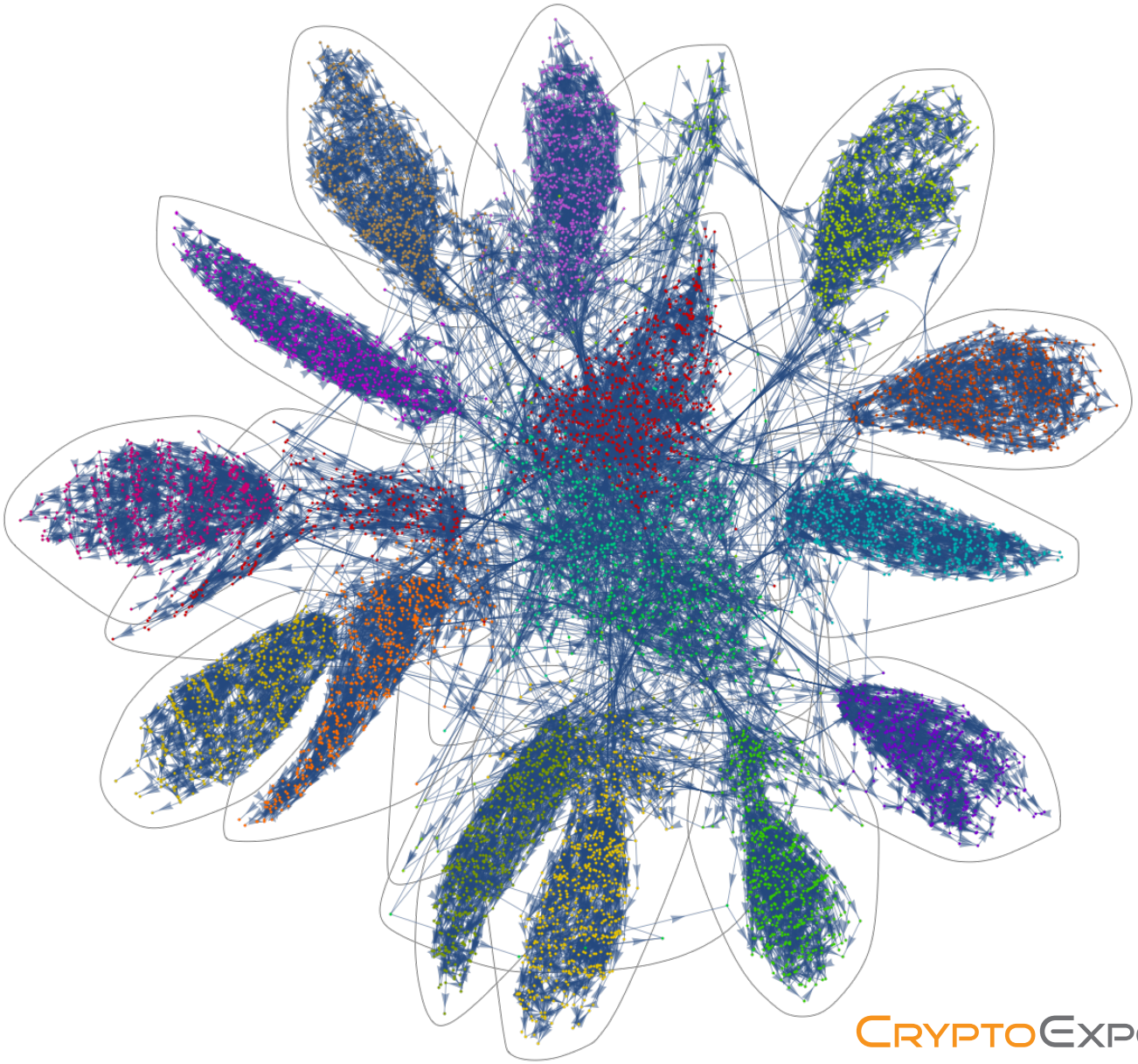
DDG of the Circuits (First 5%)



First Round Computation of AES



Extracting the Branches (Clustering)



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Assumption

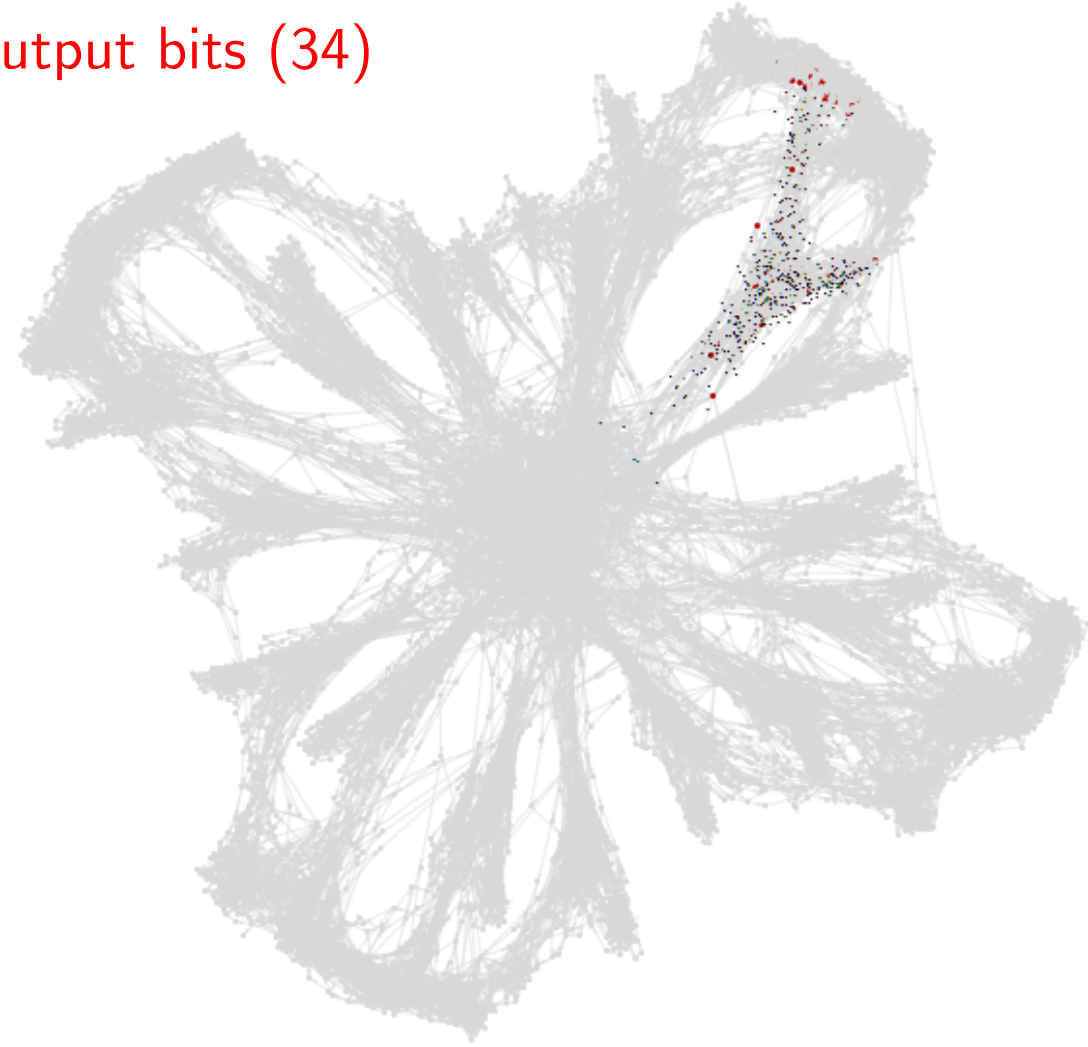
Assumption (Informal)

Each of the green "branch" corresponds to an individual S-Box computation in the first round of AES, the t-bit output $(s_1, s_2, \cdots, s_t)$ of which is a linear encoding of a real S-Box output bit.

Output Bits of A Branch

Bits in a branch (530)

S-Box output bits (34)



Solve a Systems of Linear Equations

$$\begin{bmatrix} s_1^{(1)} & s_2^{(1)} & \dots & s_{34}^{(1)}, 1 \\ s_1^{(2)} & s_2^{(2)} & \dots & s_{34}^{(2)}, 1 \\ \vdots & \vdots & \ddots & \vdots \\ s_1^{(n)} & s_2^{(n)} & \dots & s_{34}^{(n)}, 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_{34} \\ a_{35} \end{bmatrix} = \begin{bmatrix} \mathtt{SBox}(x^{(1)} \oplus \hat{k})[i] \\ \mathtt{SBox}(x^{(2)} \oplus \hat{k})[i] \\ \vdots \\ \mathtt{SBox}(x^{(n)} \oplus \hat{k})[i] \end{bmatrix}$$

If $n \geq 35 + 8 + \lambda$, $\Pr[\text{“}\hat{k} \neq k^* \text{ has a solution”}] \leq 2^{-\lambda}$.

Results

```
In[488]:= LinearBreak[data]

key=0x0
key=0x10
key=0x20
key=0x30
key=0x40
key=0x50
key=0x60
key=0x70
key=0x80
key=0x90
key=0xa0
key=0xb0
key=0xc0
!!!!!!!!!!!!! 2 - 0 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 1 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 2 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 3 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 4 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 5 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 6 - 0xcf !!!!!!!!!!!!!
!!!!!!!!!!!!! 2 - 7 - 0xcf !!!!!!!!!!!!!
key=0xd0
key=0xe0
key=0xf0
```

Thank you!