String Matching Analysis in Antivirus Software

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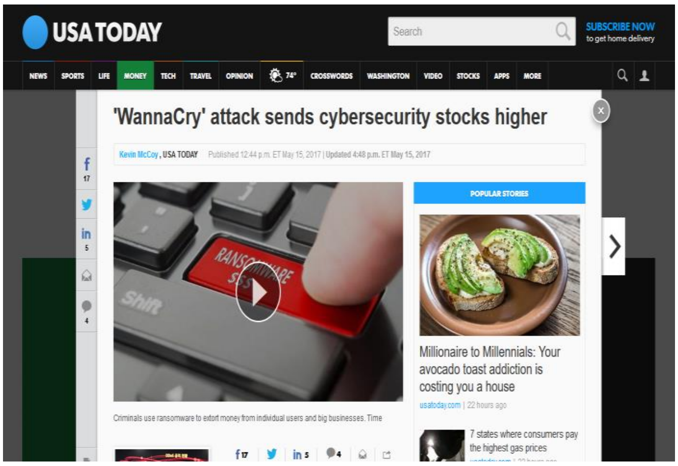
***Abstract*—Antivirus software is a class of program that will prevent, detect and remediate malware infections on individual computing devices and IT systems.[1] It uses string matching to do its job. String matching consists of finding one or more generally, all of the occurrences of a pattern in a text.[2]**

***Keywords*—Antivirus Software, String Matching, Knuth-Morris-Pratt Algorithm, Boyer-Moore Algorithm,**

I. Introduction

Recently, all medias reported about cyber attack because of virus that named as ransomware virus. Ransomware prevents users from accessing their devices and data till a certain amount is paid to its creator as ransom. Ransomware usually locks computers, encrypts the data on it and prevents other software and apps from running. The ransomware is WannaCry.[3]



Picture 1. One of medias that reported about WannaCry

http://www.express.co.uk/news/uk/805003/WannaCry-virus-cyber-attack-NHS-security-computer-hack-bitcoin-Check-Point-Technologies

Wannacry (or WannaCrypt) is a ransomware computer worm that targets the Microsoft Windows operating system. The virus was used to launch the WannaCry ransomware attack on Friday, 12 May 2017.[3] A lot of people feel unsafe due to the existence and government announced about how to protect our computers from the virus.

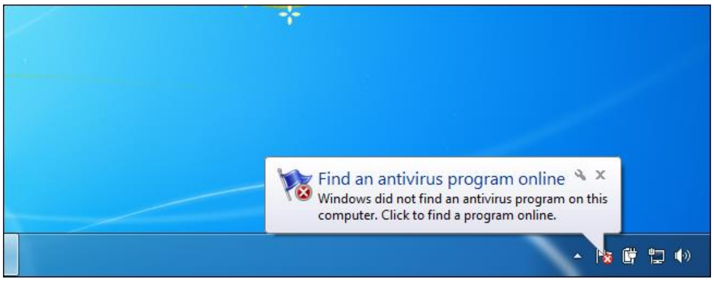
Picture 2. WannaCry

http://images.indianexpress.com/2017/05/wannacry.jpg

From the list of "how to protect our computers from ransomware", using antivirus is one of it. Antivirus programs are really important software in computers that use Windows as its operating system. An antivirus is a necessary part of multi-layered security strategy. The things that make antivirus essential are the constant stream of vulnerabilities for browsers, plug-ins, and the operating system itself.[4]

II. Theory

A. Antivirus Software



Picture 3. Antivirus Software

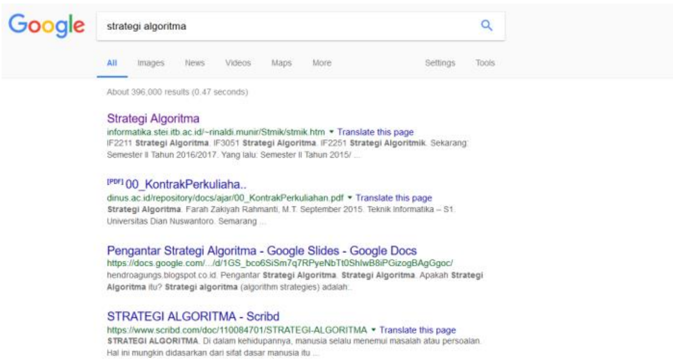
https://www.howtogeek.com/wp-content/uploads/2012/10/image10.png

Antivirus Software is a software that is made to prevent, detect, quarantine, and remove viruses and other malicious things like worms, trojans, and more. Antivirus software runs in the background on computer, checking every file opened. This is generally known as on-access scanning, background scanning, resident scanning, real-time protection, or something else.

Antivirus software was originally developed to detect and remove computer viruses. However, with the proliferation of other kinds of malware, antivirus software started to provide protection from other computer threats. In particular, modern antivirus software can protect from: malicious browser helper objects (BHOs), browser hijackers, ransomware, keyloggers, backdoors, rootkits, trojan horses, worms, malicious LSPs, dialers, fraudtools, adware and spyware.

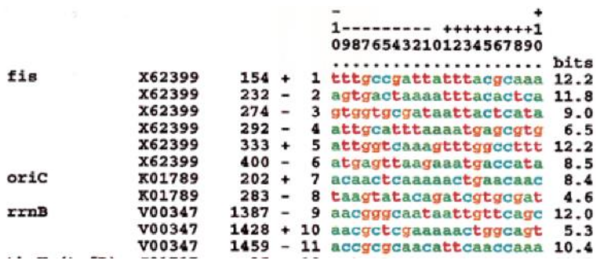
B. String Matching

String matching problem is defined as follows: given two strings which are a text and a pattern, and determining whether the pattern appears in the text or not.



Picture 4. Web Search Engine

This problem also known as “the needle in a haystack problem”. Examples of application in string matching are web search engine, bioinformatics, and searching in text editor.



Picture 5. Bioinformatics

http://4.bp.blogspot.com/_39NGKVWYg3o/TQ4Q1Tmi7XI/AAAAAAAABZo/-Dz96d48_6o/s1600/Screen%2Bshot%2B2010-12-19%2Bat%2B8.08.56%2BAM.png

There are some ways to overcome this problem, those are :

1. “Naive” method or Brute Force Algorithm

   Brute force is a straighforward way to find the solution. For every position in the text, consider it is a starting position of the pattern and find out if you get a match. Brute force algorithm is easy to understand and implement but it can be too slow in some cases. If the length of the text is n and the length of the pattern m, the worst case that it may take is O(n*m).

   Pattern : NOT

   Text : NOBODY NOTICED HIM

   NOBODY **NOT**ICED HIM

   1 NOT

   2 NOT

   3 NOT

   4 NOT

   5 NOT

   6 NOT

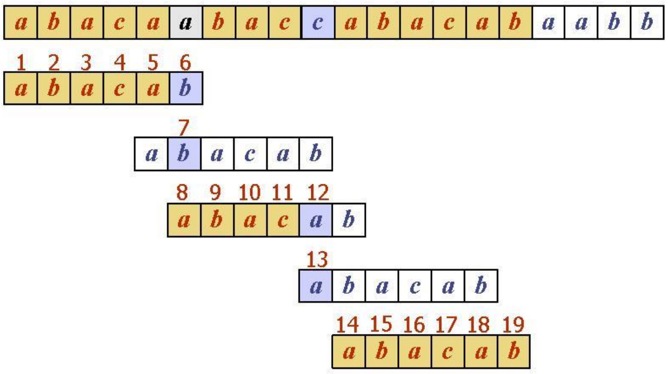
   7 NOT

   8 **NOT**

```
function brute_force(text[],
pattern[]){
  for(i = 0; i < n; i++) {
    for(j = 0; j < m && i + j < n; j++)
      if(text[i + j] != pattern[j])
break;
    if(j == m) // match found
  }
}
```

2. Knuth-Morris-Pratt Algorithm

The Knuth-Morris-Pratt (KMP) algorithm looks for the pattern in the text in a *left-to-right* order. The algorithm was conceived in 1970 by Donald Knuth and Vaughan Pratt, and independently by James H. Morris. The three published it jointly in 1977. The automaton used in KMP is just an array of “pointers” and separate “external” pointer to some index of that array. It is like brute force algorithm, but it shifts the pattern more intelligently than the brute force algorithm.



x	0	1	2	3	4	5
P[x]	a	b	a	c	a	b
f(x)	0	0	1	0	1	2

Picture 6. KMP Algorithm

https://koding4fun.files.wordpress.com/2010/05/kmpexample.jpg

In order to build the KMP automation (or the so called KMP "failure function"), it is needed to initialize an integer array F[]. The indexes represent the numbers under which the consecutive prefixes of the pattern are listed in the "list of prefixed".

Notice that after inizialization. F[i] contains information not only about the largest next partial match for the string under index i, but also about every parial match of it.

In terms of pseudocode, the initialization of the array F[] (the "failure function") may look like this:

```
function
build_failure_function(pattern[])
{
  // let m be the length of the
pattern

  F[0] = F[1] = 0; // always true

  for(i = 2; i <= m; i++) {
    // j is the index of the
largest next partial match
    // (the largest suffix/prefix)
of the string under
    // index i - 1
    j = F[i - 1];
    for( ; ; ) {
      // check to see if the last
character of string i -
      // - pattern[i - 1]
"expands" the current "candidate"
      // best partial match - the
prefix under index j
      if(pattern[j] == pattern[i -
1]) {
        F[i] = j + 1; break;
      }
      // if we cannot "expand"
even the empty string
      if(j == 0) { F[i] = 0;
break; }
      // else go to the next best
"candidate" partial match
      j = F[j];
    }
  }
}
```

The automaton consists of the initialized array F[] ("internal rules") and a pointer to the index of the prefix of the pattern that is the best (largest) partial match that ends at the current position in the text ("current state").

```
function
Knuth_Morris_Pratt(text[],
pattern[])
{
  // let n be the size of the
text, m the
  // size of the pattern, and F[]
- the
  // "failure function"


build_failure_function(pattern[]);

  i = 0; // the initial state of
the automaton is
         // the empty string

  j = 0; // the first character of
the text

  for( ; ; ) {
    if(j == n) break; // we
reached the end of the text

    // if the current character of
the text "expands" the
    // current match
    if(text[j] == pattern[i]) {
      i++; // change the state of
the automaton
      j++; // get the next
character from the text
      if(i == m) // match found
    }

    // if the current state is not
zero (we have not
```

```
    // reached the empty string
yet) we try to
    // "expand" the next best
(largest) match
    else if(i > 0) i = F[i];

    // if we reached the empty
string and failed to
    // "expand" even it; we go to
the next
    // character from the text,
the state of the
    // automaton remains zero
    else j++;
  }
}
```

3. Boyer-Moore Algorithm

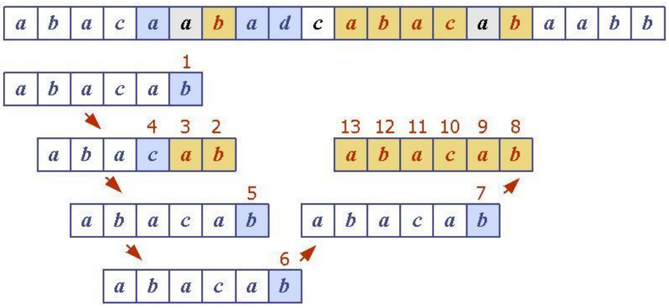
The Boyer–Moore string searching algorithm is an efficient string searching algorithm that is the standard benchmark for practical string search literature. It was developed by Robert S. Boyer and J Strother Moore in 1977. The Boyer-Moore pattern matching algorithm is based on two techniques.

1. The *looking-glass* technique

   find P in T by moving *backwards* through P, starting at its end

2. The *character-jump* technique

   when a mismatch occurs at T[i] == x, the character in pattern P[j] is not the same as T[i]



Picture 7. Boyer-Moore Algorithm

https://koding4fun.files.wordpress.com/2010/05/complete_example.jpg

Before we process the string, we need to preprocess the string first :

```
// The preprocessing function for
Boyer Moore's bad character
heuristic
void badCharHeuristic( char *str,
int size, int badchar[NO_OF_CHARS])
{
    int i;

    // Initialize all occurrences
as -1
    for (i = 0; i < NO_OF_CHARS;
i++)
         badchar[i] = -1;

    // Fill the actual value of
last occurrence of a character
    for (i = 0; i < size; i++)
         badchar[(int) str[i]] =
i;
}
```

And then the algorithm :

```
void search( char *txt,  char *pat)
{
    int m = strlen(pat);
    int n = strlen(txt);

    int badchar[NO_OF_CHARS];

    /* Fill the bad character array by
calling the preprocessing
       function badCharHeuristic() for
given pattern */
    badCharHeuristic(pat, m, badchar);

    int s = 0;  // s is shift of the
pattern with respect to text
    while(s <= (n - m))
    {
        int j = m-1;

        /* Keep reducing index j of
pattern while characters of
           pattern and text are matching
at this shift s */
        while(j >= 0 && pat[j] ==
txt[s+j])
            j--;

        /* If the pattern is present at
current shift, then index j
```

```
            will become -1 after the
above loop */
        if (j < 0)
        {
            printf("\n pattern occurs at
shift = %d", s);

            /* Shift the pattern so that
the next character in text
               aligns with the last
occurrence of it in pattern.
               The condition s+m < n is
necessary for the case when
               pattern occurs at the end
of text */
            s += (s+m < n)? m-
badchar[txt[s+m]] : 1;

        }

        else
            /* Shift the pattern so that
the bad character in text
               aligns with the last
occurrence of it in pattern. The
               max function is used to
make sure that we get a positive
               shift. We may get a
negative shift if the last occurrence
               of bad character in
pattern is on the right side of the
               current character. */
            s += max(1, j -
badchar[txt[s+j]]);
    }
}
```

III. Antivirus Software String Matching Analysis

A. How Antivirus Software Work

Antivirus software scans files in your computer for certain pattern that may indicate a malicious things. It looks for pattern based on the virus signatures or definition of known malware that saved in the antivirus software. Antivirus makers have updated malware data every day, so it is necessary to update and have the lastest antivirus software installed.

When it is installed, it should scan computers periodically, so the computers will be safe from harming things. In every antivirus softwares, it can scan computers in two ways, those are :

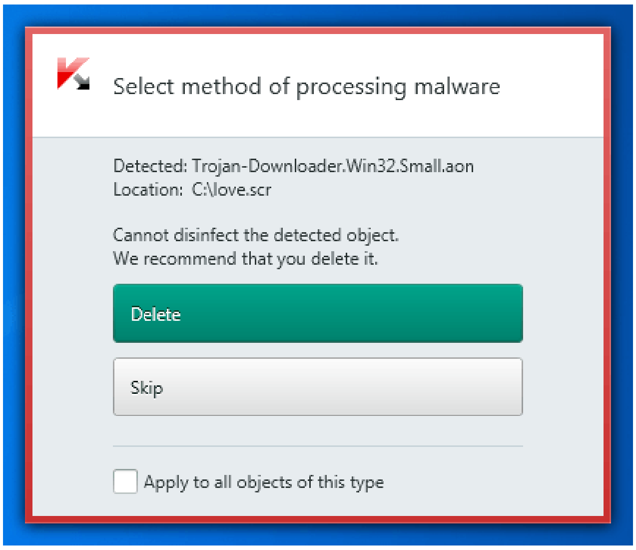
1. Automatic scans

   Most antivirus software can be configured to do this kind of scan.

2. Manual scans

   If the antivirus software can't do the automatic scans, so it have to be asked to scan manually.

Antivirus software will alert computer's users if it has found malware and ask for the opinion whether want to clean the file or the other options that provide by the antivirus software. In some cases, the antivirus software will attempt to remove the malware without asking first.

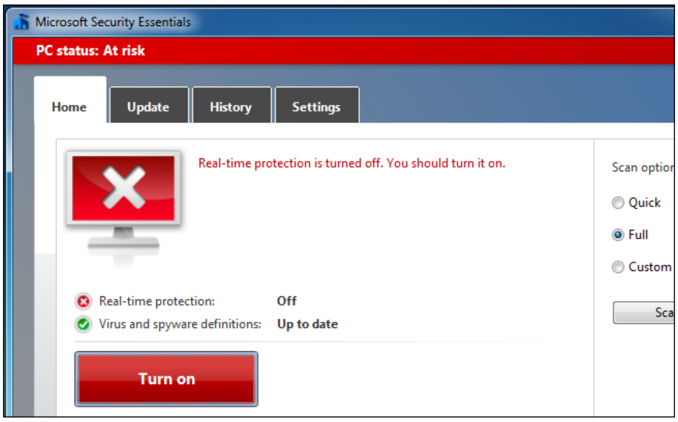


Picture 8. Asking users

https://46qasb3uw5yn639ko4bz2ptr8u-wpengine.netdna-ssl.com/files/2016/10/malanov-3.png

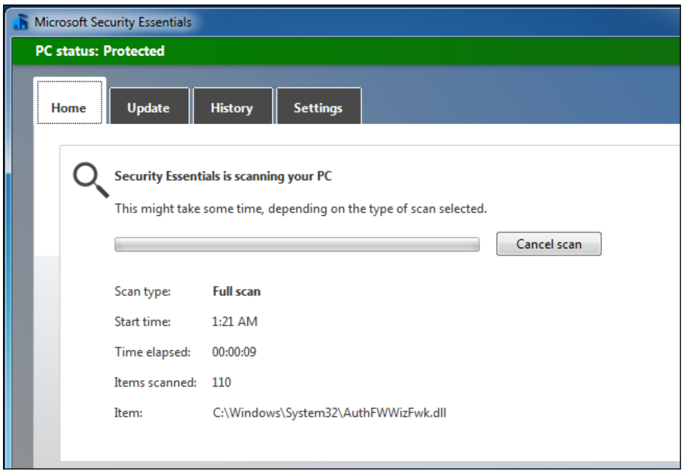
There are many vendors that produce antivirus software. The example of antivirus softwares are smadav, avg, etc. By installing antivirus software, it will increase the level of protection in the computer.

Antivirus works by matching the files that were scanned with the virus signatures that it have. If there is matching part of the virus signature and the file, the file will be recognize as a virus. So, it is important to update the virus signature in the antivirus software.



Picture 9. Antivirus Software

https://www.howtogeek.com/wp-content/uploads/2012/10/image11.png



Picture 10. Antivirus Software

https://www.howtogeek.com/wp-content/uploads/2012/10/image12.png

Virus Signature

Virus signature is a unique string of bits, or the binary pattern, of a virus. The virus signature is like a fingerprint in that it can be used to detect and identify specific viruses. Anti-virus software uses the virus signature to scan for the presence of malicious code.[5] A virus signature is a continuous sequence of bytes that is common for a certain malware sample. That means it's contained within the malware or the infected file and not in unaffected files.

Example of virus signature :

1. 1024-PrScr #1=8cc0488ec026a103002d800026a30300
2. 1024-PrScr #2=a172041f3df0f07505a10301cd0526a1
3. 1024-PrScr #3=00012ea30300b4400e1fba0004b90004e8e8007230
4. 1024-PrScr #4=babf00b82125cd2133c08ec0b8f0f026
5. 1210-Prudent=2f040175d00e0e1f07bed3042bc92e8a0446410ac0
6. Etc

Antivirus will use the virus signature as a pattern and search for the pattern in files that it scanned.

Picture 11. A characteristic sequence of bytes

https://blog.kaspersky.com/signature-virus-disinfection/13233/

B. String Matching in Antivirus Software

. As mentioned in part A, the antivirus software find candidate of viruses with string matching.

1. Brute Force Algorithm

e	1	0	2	4	-	P	r	S	c
1	0	2	4	-	P	r	S	c	
	1	0	2	4	-	P	r	S	c

2. KMP Algorithm

e	1	0	2	4	-	P	r	S	c
1	0	2	4	-	P	r	S	c	
	1	0	2	4	-	P	r	S	c

3. BM Algorithm

e	1	0	2	4	-	P	r	S	c
1	0	2	4	-	P	r	S	c	
	1	0	2	4	-	P	r	S	c

IV. CONCLUSION

String matching is one of algorithm behind antivirus software. It used to search for virus in bunch of files. The antivirus software will scan every matching files with the pattern in virus signature and quarantine malicious files.

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PERNYATAAN

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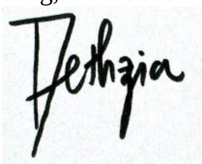
Bandung, 17 Mei 2017



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