Lecture 23. Viruses and Secret Messages

- **Remember `sum.toy`?**

```
0E                                          starting address
0E:  B001     R0 <- 01                      R0 holds 1
0F:  B10A     R1 <- 0A                      R1 is n
10:  B201     R2 <- 01                      R2 is i
11:  B300     R3 <- 00                      R3 is sum
12:  2110     R1 <- R1 - R0                 n--
13:  6118     jump to 18 if R1 < 0          if (n < 0) goto End
14:  1332     R3 <- R3 + R2                 sum += i
15:  1220     R2 <- R2 + R0                 i++
16:  2110     R1 <- R1 - R0                 n--
17:  5013     jump to 13                    goto Top
18:  4302     print R3                      print sum
19:  0000     halt
```

```
% /u/cs217/bin/toy /u/cs217/toy/sum.toy
0037
```

- **Suppose an unknown source *modifies* `sum.toy` by appending the following code**

```
87:  8088     R0 <- 88          % /u/cs217/bin/toy /u/cs217/toy/sum.toy
88:  B108     R1 <- 08          8888
89:  F201     R2 <- R0<<R1      0037
8A:  C002     R0 <- R0^R2
8B:  4002     print R0
8C:  500E     jump to 0E
87
```

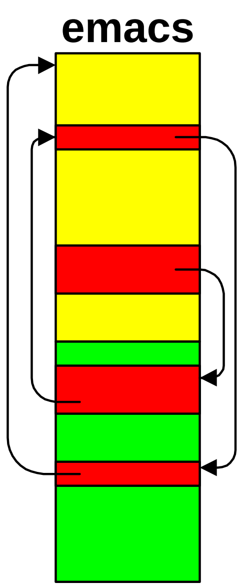
`sum.toy` is infected with the ‘8888’ virus

Infection Routes

- If a virus *V* can find a ***writable executable file*** *P*, it may be able to embed itself in *P*

  infect(*P*,*V*) A copy of *P* with *V* embedded so *V* gets initial control

  V's execution can be arbitrarily complex, perhaps involving self-modifying code to cover its tracks



- When infect(*P*,*V*) runs, *V* can do anything *P* can do, perhaps without visible effects

  Print '8888'

  Print

  `login:`

  On some other computer and wait for a user id; then print

  `Password:`

  Snarf the password entered, spawn another process running `/bin/login`, and leave town with a fresh user id and password; user just sees

  `login:`

  Scramble/delete your files

  Spawn a separate process running itself and find other executable files to infect

Detecting Viruses

- **Given a program *P*, how can you tell if it's infected? You can't**
- **Virus detection software looks for occurrences of *specific* viruses**

  e.g.,

  Is the instruction at location $87_{16} = 8088_{16}$? 'Infected with the 8888 virus'

  Oh oh… Viruses embed themselves in different ways and at different locations

  Must update virus detection software on a regular basis (daily?)

  Virus detection software does not solve the general problem 'is *P* infected?'
- **Suppose you have two versions of supposedly the same program, P_1 and P_2**

  Which one of P_1 or P_2 is infected?

  Do P_1 and P_2 produce the same output? (Even if one is infected)

  Both are *unsolvable* problems alà the Halting Problem
- **Is there any hope?**

  Intractable problems — those with only exponential-time algorithms — come to the rescue

Fingerprints

- **Suppose that given a file *P*, H(*P*) is a relatively small number that 'characterizes' *P***

  H(`/u/cs126/examples/compile.c`) = 364BFFB1$_{16}$

  H provides a *fingerprint* of `/u/cs126/examples/compile.c`

  Accept P_2, a copy of *P*, only if H(P_2) = 364BFFB1$_{16}$

- **H must be a *one-way hash function* with the following properties**

  Given *P*, it must be *easy* to compute H(*P*)

  Given H(*P*) , it must be *computationally infeasible* to reconstruct *P*

  Given *P* and a virus *V*, it must be computationally infeasible to arrange for H(infect(*P*,*V*)) = H(*P*); that is, to find two bit strings with equal fingerprints

- **Good one-way hash functions produce fingerprints with at least 128 bits**

  MD5(`compile.c`) `979a7c5c ae9f12e2 702fc6ad 9ad4493a`

  SHA(`compile.c`) `85025ddc bb5c8da7 44598fe0 d8b5e16d a75cb560`

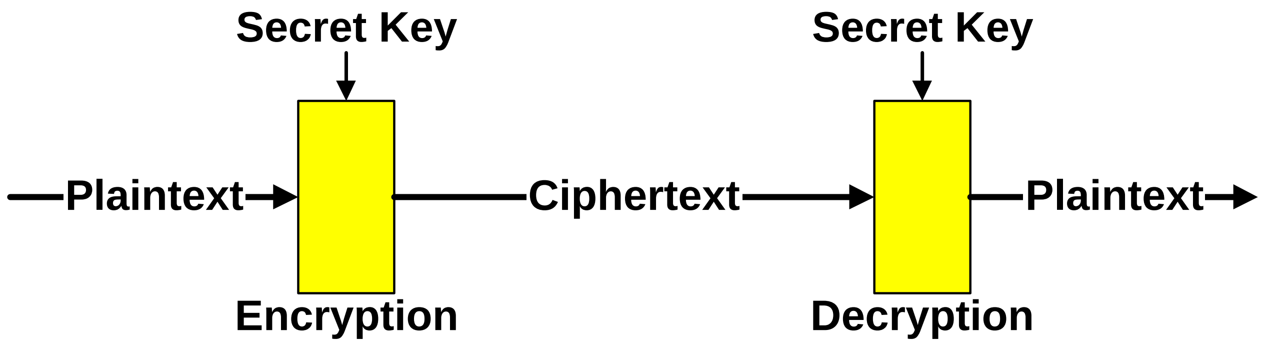
Fingerprints on the Internet

```
% ftp ftp.cs.princeton.edu
ftp> cd /pub/packages/cii
ftp> ls
README
cii10.tar.gz
cii10.tar.Z
cii10.zip
ftp> get README |more
...
The distribution directory contains the following files and
directories. MD5 fingerprints for the files in this directory are
listed below.
...
MD5 (cii10.tar.Z) = ba5b3c3b6c43061e4519c85f103be606
MD5 (cii10.tar.gz) = e3769aeca75ec52427e1b807e02aae3e
MD5 (cii10.zip) = fa71f475c97a4bfae66767012367c77f
Sat Aug 24 13:15:49 EDT 1996
ftp> get cii10.zip
ftp> quit
% md5 cii10.zip
MD5 (cii10.zip) = fa71f475c97a4bfae66767012367c77f
```

- **This isn't foolproof — intruders can intercept Internet packets and substitute different fingerprints**

Cryptography

- **A *__cryptosystem__* keeps secret messages (and files) from prying eyes**



‘Please send money’ **24 F8 A7 86 63 2E 28 0A 68 25 B1 73 5F E0 70 99 E2** **‘Please send money’**

Key: 01 23 45 67 89 AB CD EF

- **Modern cryptosystems exclusive-OR key with plaintext: $C = P\ \hat{}\ K$**

```
void encrypt(char *buf, int len, char *key, int keylen) {
    int i = 0;

    for (i = 0; len-- > 0; i = (i + 1)%keylen)
        *buf++ ^= key[i];
}
```

Works for encryption *__and__* decryption: $C\ \hat{}\ K = (P\ \hat{}\ K)\ \hat{}\ K = \mathrm{P}\ \hat{}\ (K\ \hat{}\ K) = P\ \hat{}\ 0 = P$!

Watch out! Sending many 0s in plaintext gives attackers pure key: $C = 0\ \hat{}\ K = K$

Cryptography, cont'd

- **Repeated use of a relatively short key isn't secure; most systems use the key to generate a long stream of pseudo-key, which is XOR'd with the plaintext**
- **Assume the worst: Attackers know the algorithm, the length of the key, and have the ciphertext**
- **Security rests on the strength of the algorithm and the security of the *key***
- **Best systems force attackers to use *inefficient* algorithms, which require trying try all 2^n *n*-bit keys; just use large *n***
- **Designing secure cryptosystems sounds easy, but it's not; don't trust amateurs!**
- **Key distribution is just as hard as encryption: What's the best way to exchange keys with your trusted correspondents and keep them secret? There isn't one…**
- **For lots of details, read B. Schneier, *Applied Cryptography: Protocols, Algorithms, and Source Code* in C, 2nd ed., Wiley, 1996**

Public-Key Cryptosystems

- ***Public-key*** **cryptosystems avoid the key distribution problem by using** ***two keys***

  Everyone knows your public key, *P*

  Only you know your secret key, *S*

  To send *M*: **Send $P_{drh}(M)$ via any medium**

  To read *M*: **I read $S_{drh}(M)$**

- **List public keys in the phone book, or its equivalent**

```
% finger -l drh@cs.princeton.edu
...
-----BEGIN PGP PUBLIC KEY BLOCK-----
Version: 2.6.1
mQBNAi1uT8gAAAECAK8TOxmBQ6XhoJXrGPtDKzhZkIqSRh3pMimt8nUh1nSfByec
KittyH02STppLwncD47j8KK6Cm5hriyzusnX/hkABRG0JkRhdmlkIFIuIEhhbnNv
biA8ZHJoQGNzLnByaW5jZXRvbi5lZHU+
=JFCd
-----END PGP PUBLIC KEY BLOCK-----
```

- **For all public-key algorithms**

  $S(P(M)) = M$ **for all** M
  All *S*, *P* pairs must be distinct
  Deriving *S* from *P* must be as hard as reading *M*
  $P(M)$ **and** $S(M)$ **must be efficient**

RSA Public-Key Cryptosystem

- **The RSA cryptosystem uses arithmetic on very large integers**

  P is N, p

  S is N, s where $N \approx 200$ digits, p and $s \approx 100$ digits

- **To choose N, p, s**

  Pick 3 100-digit *secret* prime numbers, x, y, s
  The largest is s

  $x = 47$, $y = 79$, $s = 97$

  $N = x \times y$

  $N = 47 \times 79 = 3713$

  Choose p so that $(p \times s) \bmod ((x - 1)(y - 1)) = 1$

  $p \times 97 \bmod (46 \times 78) = 1$
  $37 \times 97 \bmod 3588 = 1$
  $3589/3588 = 1$ remainder 1

- **Attackers see only N and p**

  To find s, attackers must *factor* N into its prime factors x and y

  It is *believed*, but not proven, to be infeasible to factor N if it's sufficiently large

  Factoring 200-digit numbers probably takes $\approx 10^9$ years

- **Are there enough primes for everyone? Yes: $\approx 10^{150}$ primes with ≤ 512 bits (≈ 155 decimal digits)**

RSA Encryption

- To ***encrypt*** ***M***, use ***N*** and the ***public*** key, ***p***

  Encode M in numbers $< N$

  For each M_i, $C_i = M_i^p \bmod N$ the remainder of M_i^p when divided by N

  For $N = 3713$, $p = 37$, $s = 97$

M	Please send money
	P l e a s e _ s e n d _ m o n e y _
Encode:	1612 0501 1905 0019 0514 0400 1315 1405 2500
Encrypt:	2080 0057 1857 3706 1584 0888 2067 0591 1277

$1612^{37} =$ 47,044,232,358,938,497,020,498,996,761,564,680,247,331,818,
462,325,046,870,527,453,082,869,350,611,474,961,064,423,374,
436,277,844,788,137,937,637,623,201,792

$1612^{37} \bmod 3713 = 2080$, etc.

RSA Decryption

- **To *decrypt* *M*, use *N* and the *private* key, *s***

  For each C_i, $M_i = C_i^s \bmod N$

  Decode numbers to reveal *M*

  For $N = 3713$, $p = 37$, $s = 97$

	Please send money
C:	**2080 0057 1857 3706 1584 0888 2067 0591 1277**
Decrypt:	**1612 0501 1905 0019 0514 0400 1315 1405 2500**

$57^{97} =$ **208,862,754,025,291,103,893,549,722,030,506,307,840,035,159, 185,066,358,136,864,739,390,751,752,973,213,714,581,100,145, 330,888,003,488,562,198,990,224,718,358,613,240,589,340,493,287, 521,060,551,858,632,460,253,869,992,608,057**

$57^{97} \bmod 3713 = 501$

Decode:	**1612 0501 1905 0019 0514 0400 1315 1405 2500**
	P L E A S E _ S E N D _ M O N E Y _

- **This example is from R. Sedgewick, *Algorithms in C*, Addison-Wesley, 1990**
- **For details on multiple-precision arithmetic, see D. R. Hanson, *C Interfaces and Implementations*, Addison-Wesley, 1997**

PGP

- **PGP — Pretty Good Privacy — is widely used public-key cryptosystem available for PCs, UNIX systems, etc.**

```
you% cat | pgp -fea drh
Pretty Good Privacy(tm) 2.6.2 - Public-key encryption for the masses.
Can I have more time on the current
programming assignment?
--frazzled in Princeton
^D
-----BEGIN PGP MESSAGE-----
Version: 2.6.2
hEwDriyzusnX/hkBAgChqSkxFkFwyMFyCwrcl87jHzXshOdrDQYTDQbRwwVcGZIy
A83TTPYzFGU3yHHnNVWQHAejJDRJRHPaEXRNEUiPpgAAAGjcN7B2zmqgvJeW1iR2
dTOVQtmusN9Ez32CdYD8ub/3b7smX8q+NCBm13/83TexSgyudPaqPoifd7q0N96z
kL4tSAmcJHwfzyiM/RJ+2p41YgcgAqFgaB2NTHaowYQXpG4qNg3nMSTxOg==
=5u0S
-----END PGP MESSAGE-----

you% cat | pgp -fea drh | mail drh@cs

drh% inc
Incorporating new mail into inbox...
  92+ 09/04 To:drh@fs.CS.Prin  <<-----BEGIN PGP MESSAGE-----
drh% show | pgp -fd
Can I have more time on the current
programming assignment?
--frazzled in Princeton
```