Cryptographic software engineering, part 1

Daniel J. Bernstein

This is easy, right?

1. Take general principles of software engineering.
2. Apply principles to crypto.

Let's try some examples ...

1972 Parnas "On the criteria to be used in decomposing systems into modules":

"We propose instead that one begins with a list of difficult design decisions or design decisions which are likely to change. Each module is then designed to hide such a decision from the others."

e.g. If number of cipher rounds is properly modularized as

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#define ROUNDS 20
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diff = 0;
for (i = 0;i < 16;++i)
  diff |= x[i] ^ y[i];
return 1 & ((diff-1) >> 8);
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Notice that the language
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/* compare the tag */
int i;
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    x[1] = x0;
  } else {
    x[0] = x0;
    x[1] = x1;
  }
}
```

Safe compiler won't allow this.

Branch timing leaks secrets.


```
void sort2(int32 *x)
{ int32 x0 = x[0];
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  int32 c = (x1 < x0);
  x[0] = (c ? x1 : x0);
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Syntax is different but "?:"
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if (x1 < x0) x[0] = x1;
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] = x1;
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16

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Safe compiler won't allow this:
won't allow `secret` data
to be used as an array index.

Cache timing is not constant:
see earlier attack examples.

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rt2(int32 *x)
 x0 = x[0];
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[0] = x1;
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18

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  x[0] = x0 + c;
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Does safe compiler allow
multiplication of secrets?

Recall that multiplication
takes variable time on, e.g.,
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"1-bit signed right shift": $(b_{31}, b_{31}, \ldots, b_3, b_2, b_1)$.

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This code is incorrect!
Fails for input -2^{31},
because "-x" produces -2^{31}.

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Why this works: the bits
$(b_{31}, b_{30}, \ldots, b_2, b_1, b_0)$
represent the integer $b_0 + 2b_1 + 4b_2 + \cdots + 2^{30}b_{30} - 2^{31}b_{31}$.

"1-bit signed right shift":
$(b_{31}, b_{31}, \ldots, b_3, b_2, b_1)$.

"31-bit signed right shift":
$(b_{31}, b_{31}, \ldots, b_{31}, b_{31}, b_{31})$.


```
int32 ispositive(int32 x)
{ return isnegative(-x); }
```

This code is incorrect!
Fails for input -2^{31},
because "-x" produces -2^{31}.

Can catch this bug by testing:

```
int64 x; int32 c;
for (x = INT32_MIN;
     x <= INT32_MAX;++x) {
  c = ispositive(x);
  assert(c == -(x > 0));
}
```

t-time comparisons

```
snegative(int32 x)
n x >> 31; }
```

−1 if x < 0, otherwise 0.

s works: the bits
$, \ldots, b_2, b_1, b_0)$
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Side not

```
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  retur
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mparisons

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(int32 x)
; }
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$b_1, b_0)$
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22

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23

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Second part is evaluated
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25

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int32 issmaller(int32 x,i
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Generalization of `ispositive`.
Wrong for inputs $(0, -2^{31})$.

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Caught quickly by random tests:

```
for (j = 0;j < 10000000;++j) {
  x += random(); y += random();
  c = issmaller(x,y);
  assert(c == -(x < y));
}
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snonzero(int32 x)
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int32 x)
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Some verification strategies:

- Think this through.
- Write a proof.
- Formally verify proof.
- Automate proof construction.
- Test many random inputs.
- A bit painful: test all inputs.
- Faster: test `int16` version.

```
ssmaller(int32 x,int32 y)
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```
= 0;j < 10000000;++j) {
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void mi
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  int32
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  c ^= a
  c >>=
  c &= a
  *x = a
  *y = b
}

void so
{ minma
```

```
int32 x,int32 y)
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```

rect!

ispositive.

$(0, -2^{31})$.

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void minmax(int3
{ int32 a = *x;
  int32 b = *y;
  int32 ab = b ^
  int32 c = b -
  c ^= ab & (c ^
  c >>= 31;
  c &= ab;
  *x = a ^ c;
  *y = b ^ c;
}

void sort2(int32
{ minmax(x,x + 1
```

```
nt32 y)
); }


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+j) {
dom();
```



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int32 i
{ int32
  c ^= i
  retur
}

void so
{ long
  for (
    for
      m
}
```

Safe con

if array

```
int32 x,int32 y)
 y;
y;
 x);
ive(c);
```

strategies:

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16 version.


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void minmax(int32 *x,int32 *y)
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```
int32 ispositive
{ int32 c = -x;
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  return isnegat
}

void sort(int32
{ long long i,j;
  for (j = 0;j <
    for (i = j -
      minmax(x +
}
```

Safe compiler will

if array length `n` is

```
nt32 y)
```

ion.

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.

```
void minmax(int32 *x,int32 *y)
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```
int32 ispositive(int32 x)
{ int32 c = -x;
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}

void sort(int32 *x,long l
{ long long i,j;
  for (j = 0;j < n;++j)
    for (i = j - 1;i >= 0
      minmax(x + i,x + i
}
```

Safe compiler will allow this
if array length n is not secr

```
void minmax(int32 *x,int32 *y)
{ int32 a = *x;
  int32 b = *y;
  int32 ab = b ^ a;
  int32 c = b - a;
  c ^= ab & (c ^ b);
  c >>= 31;
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  *x = a ^ c;
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```
int32 ispositive(int32 x)
{ int32 c = -x;
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}

void sort(int32 *x,long long n)
{ long long i,j;
  for (j = 0;j < n;++j)
    for (i = j - 1;i >= 0;--i)
      minmax(x + i,x + i + 1);
}
```

Safe compiler will allow this
if array length `n` is not `secret`.