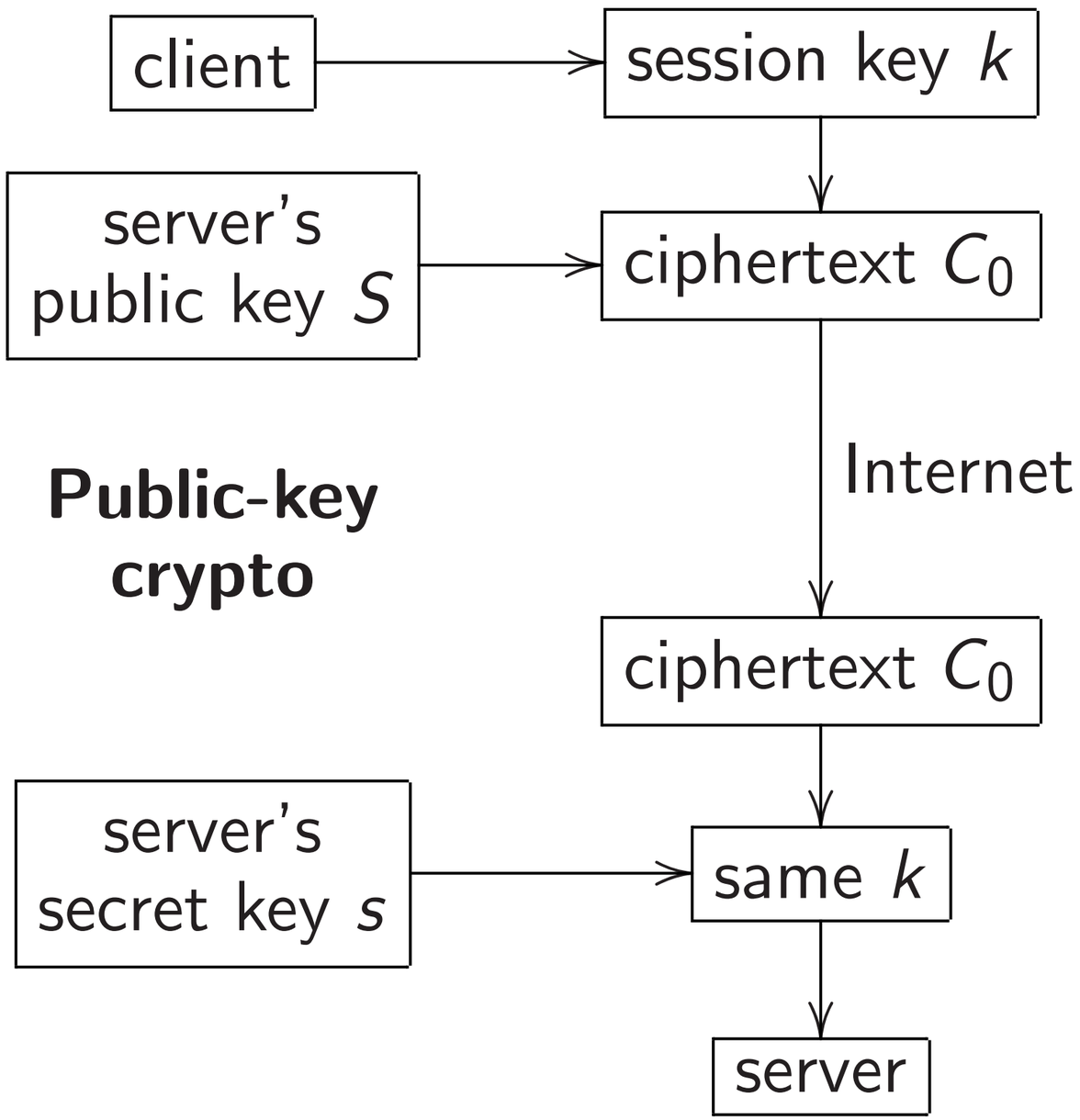
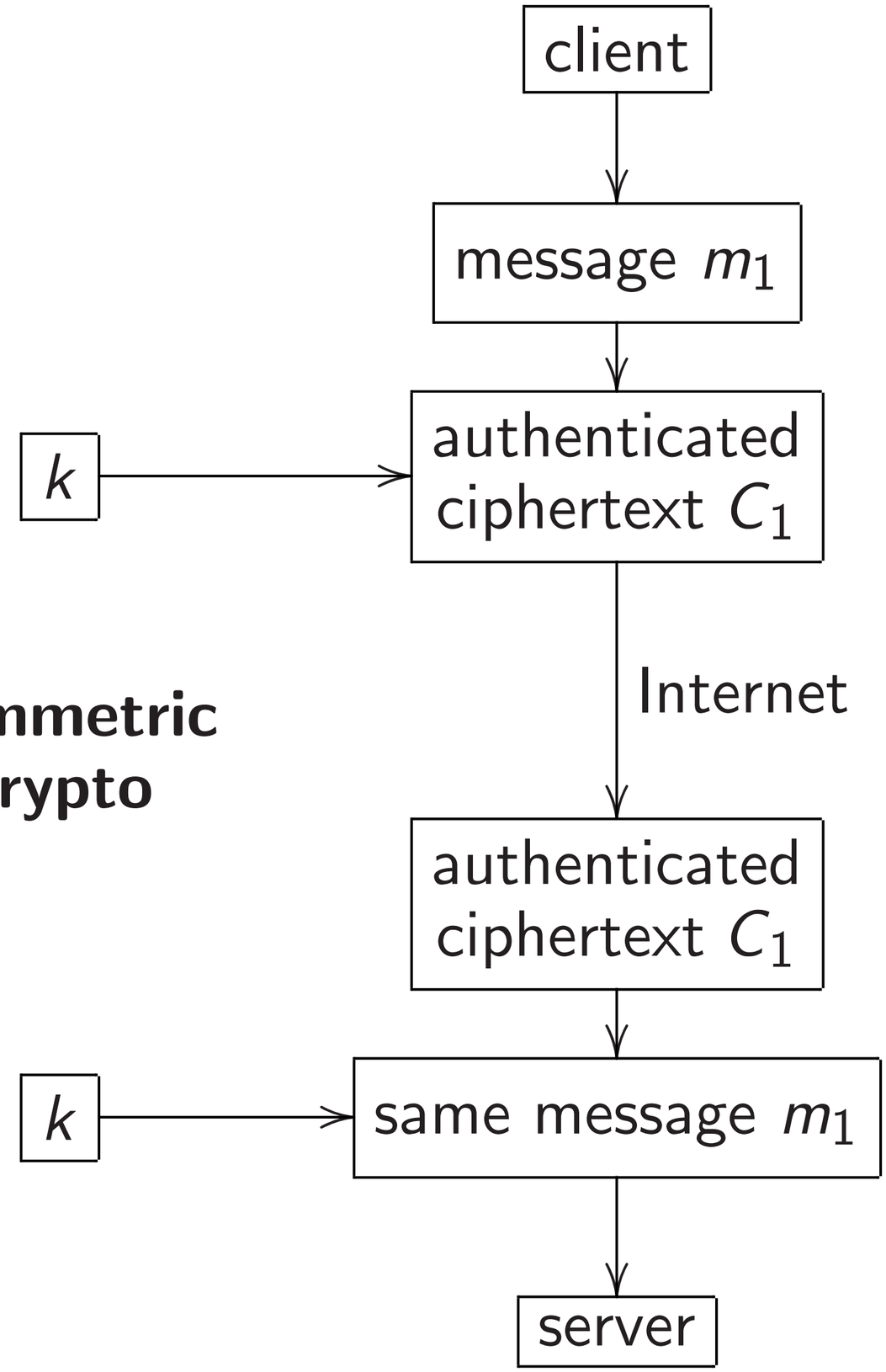
Symmetric crypto, part 2

D. J. Bernstein



Public-key crypto



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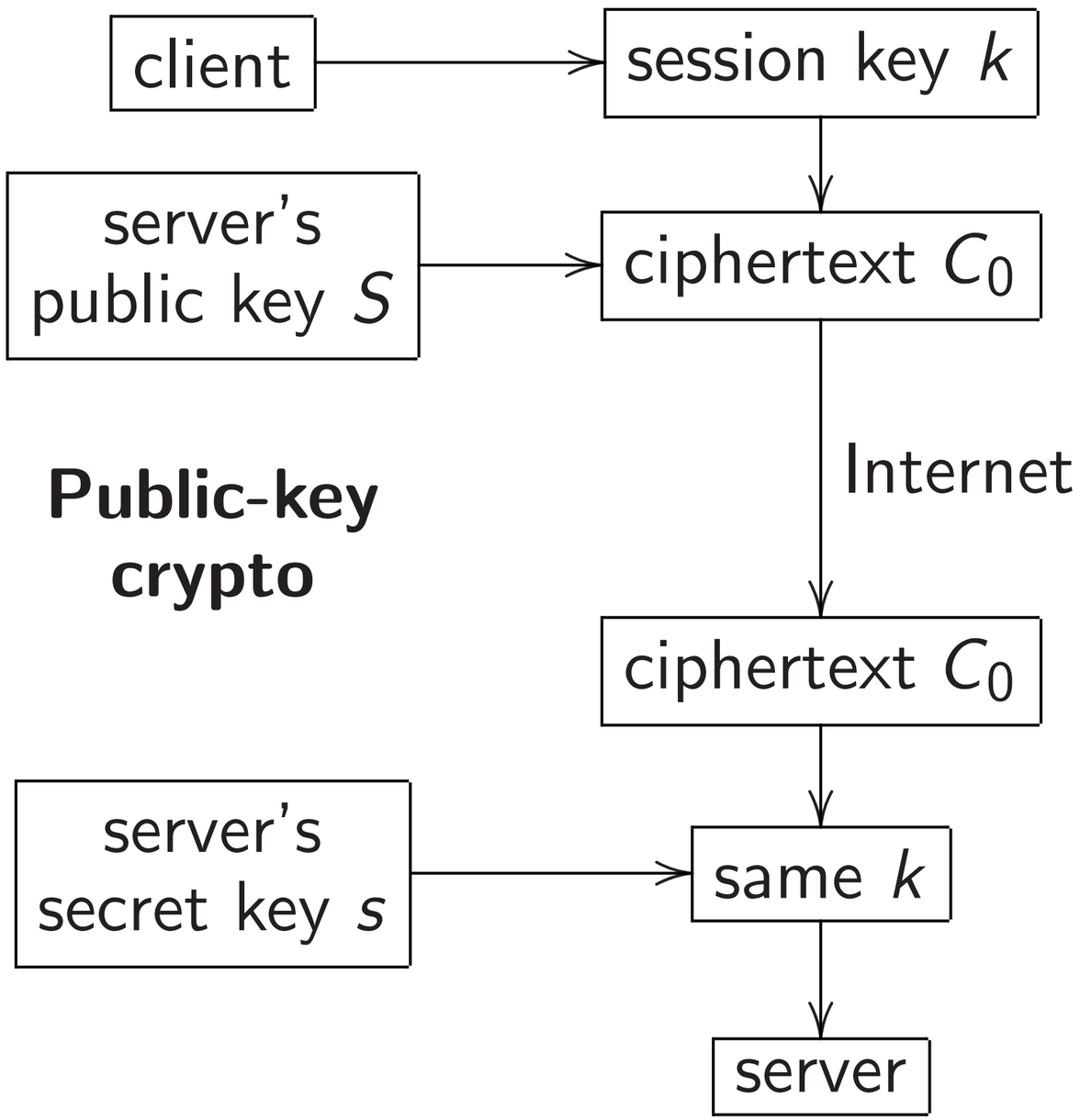

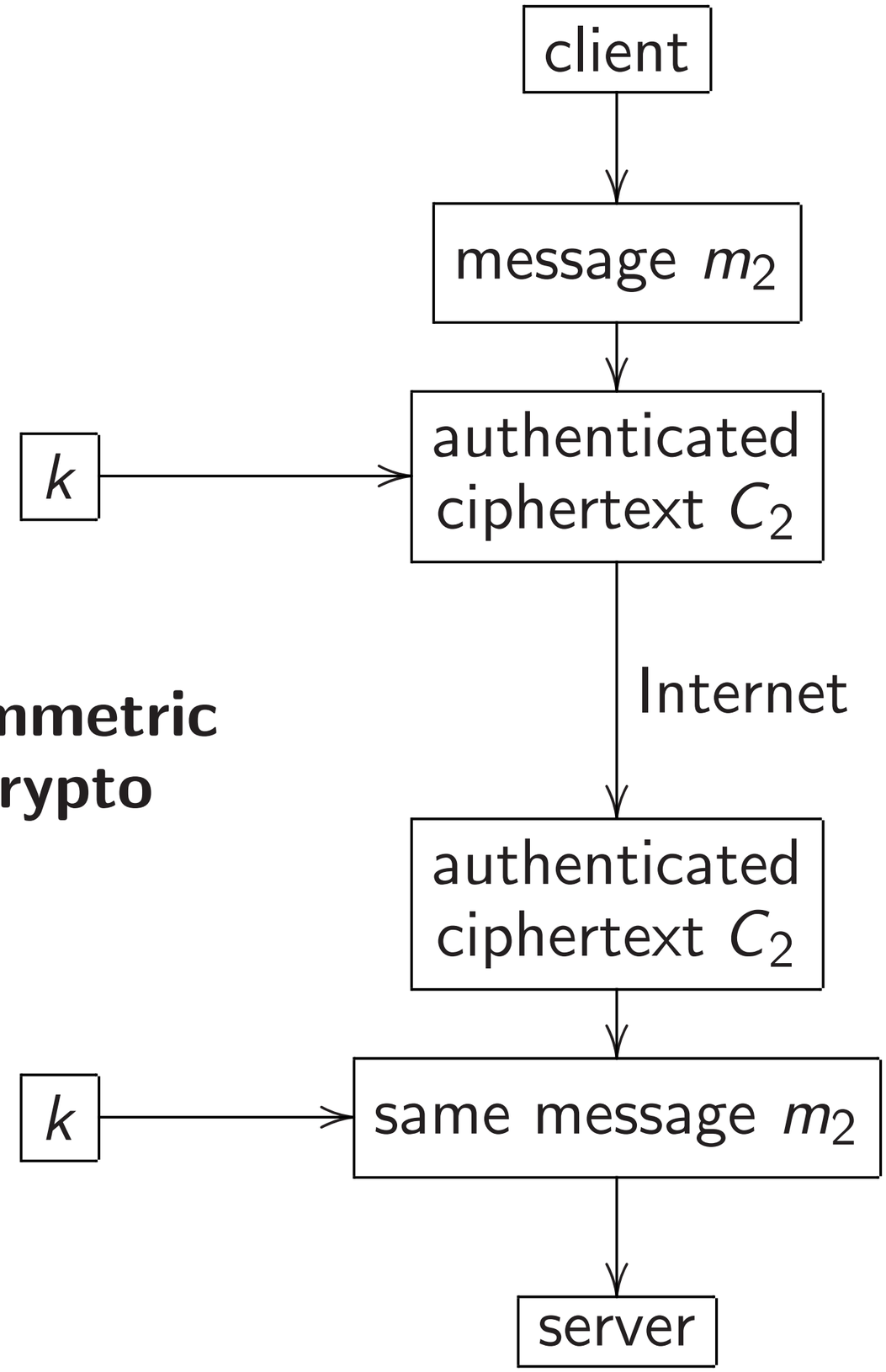

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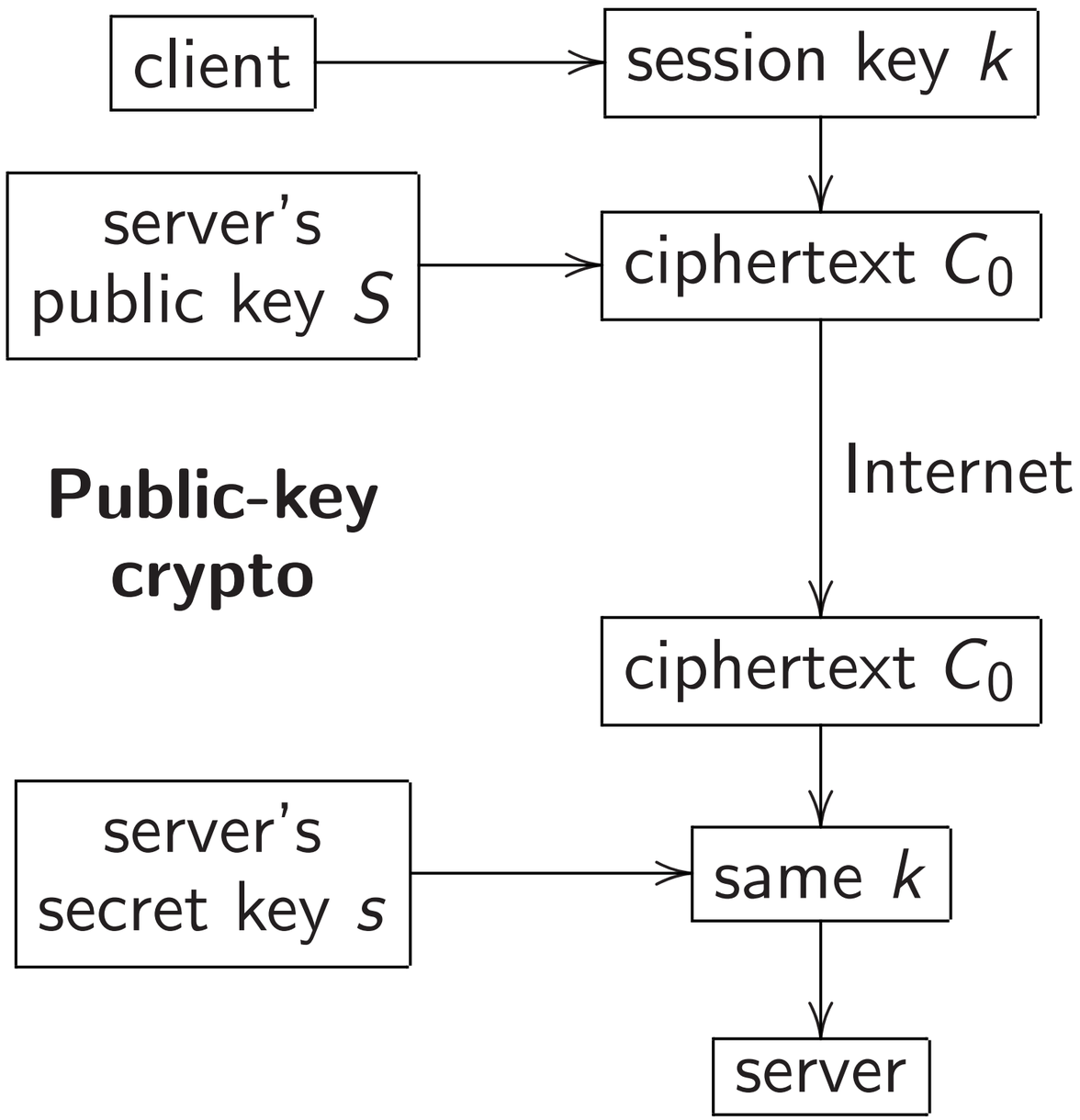

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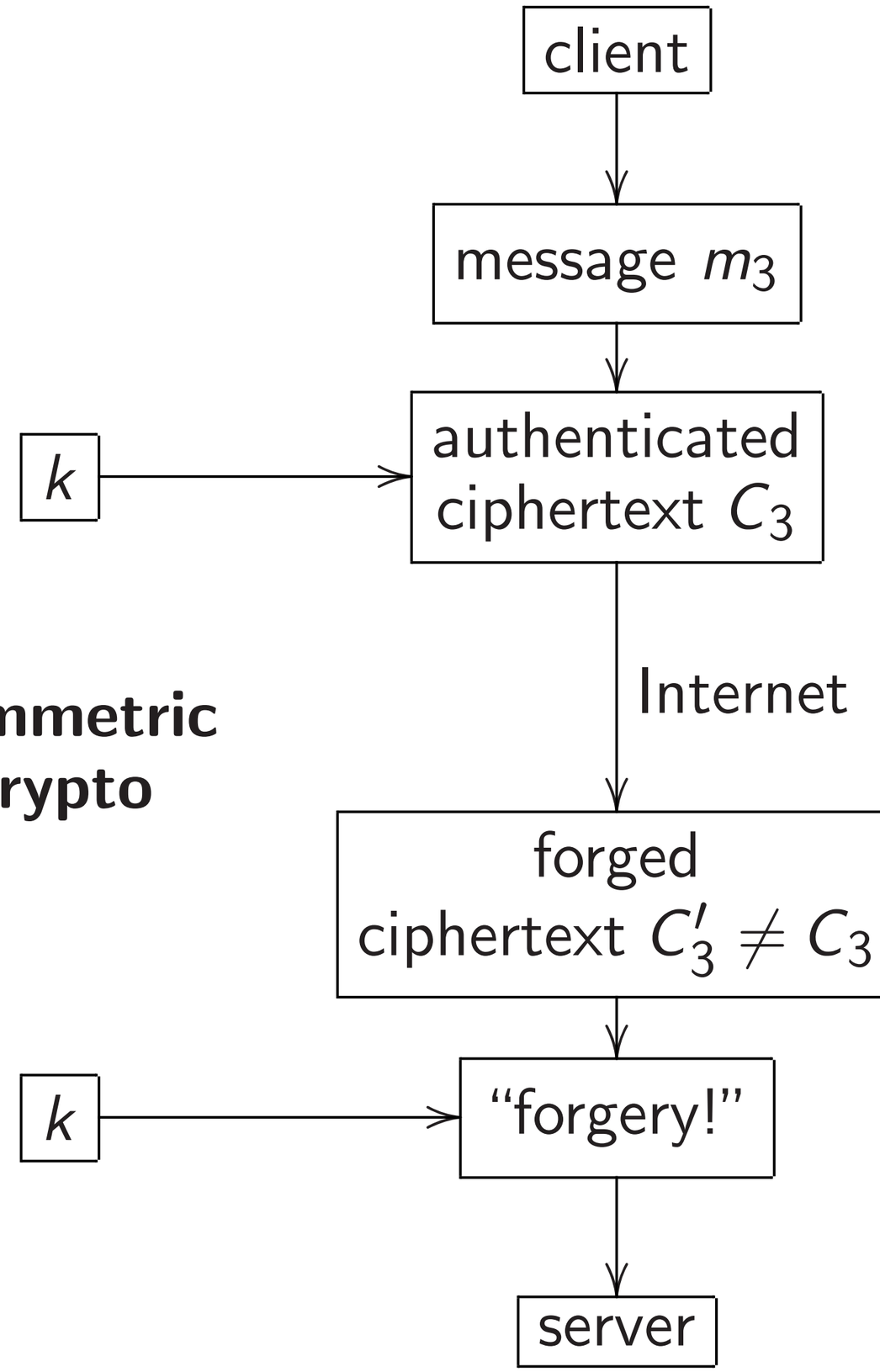

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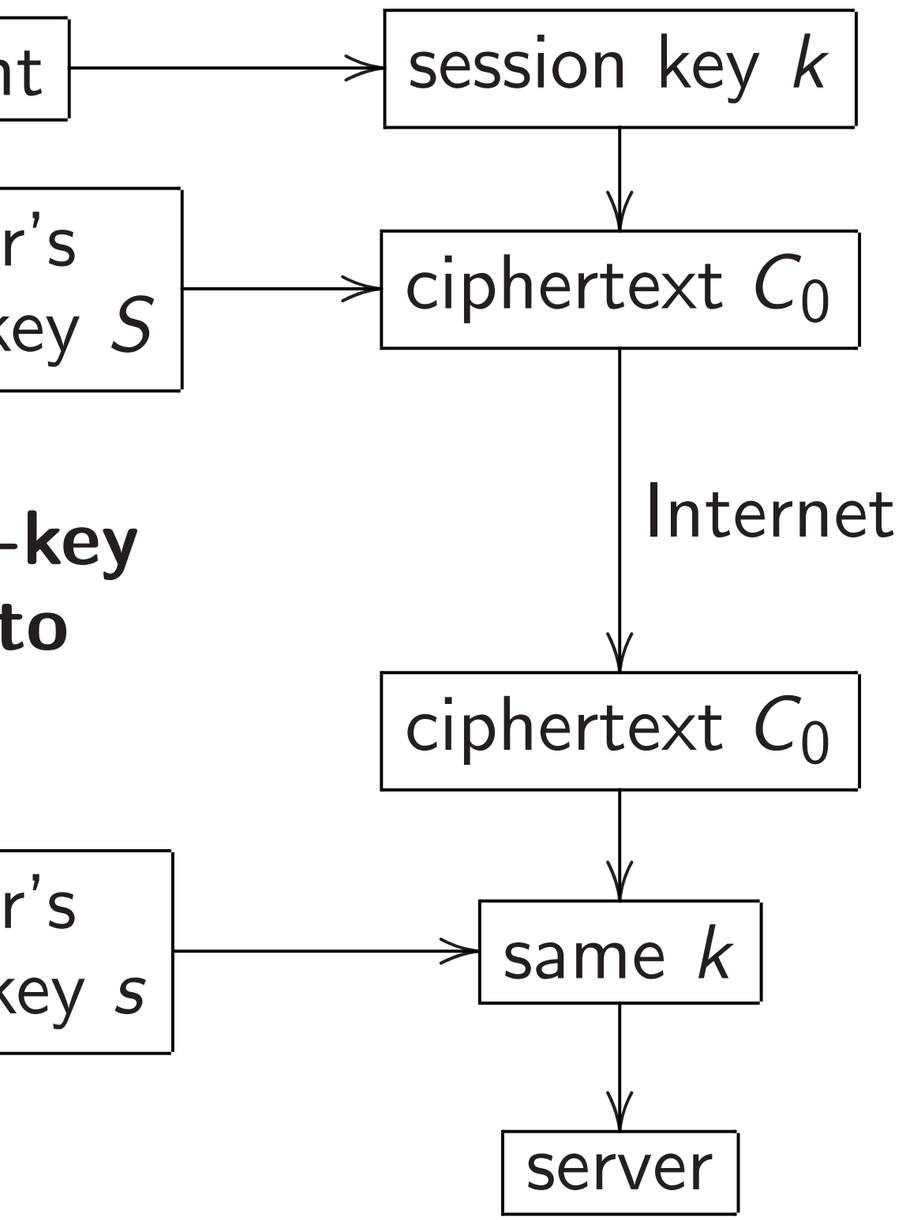

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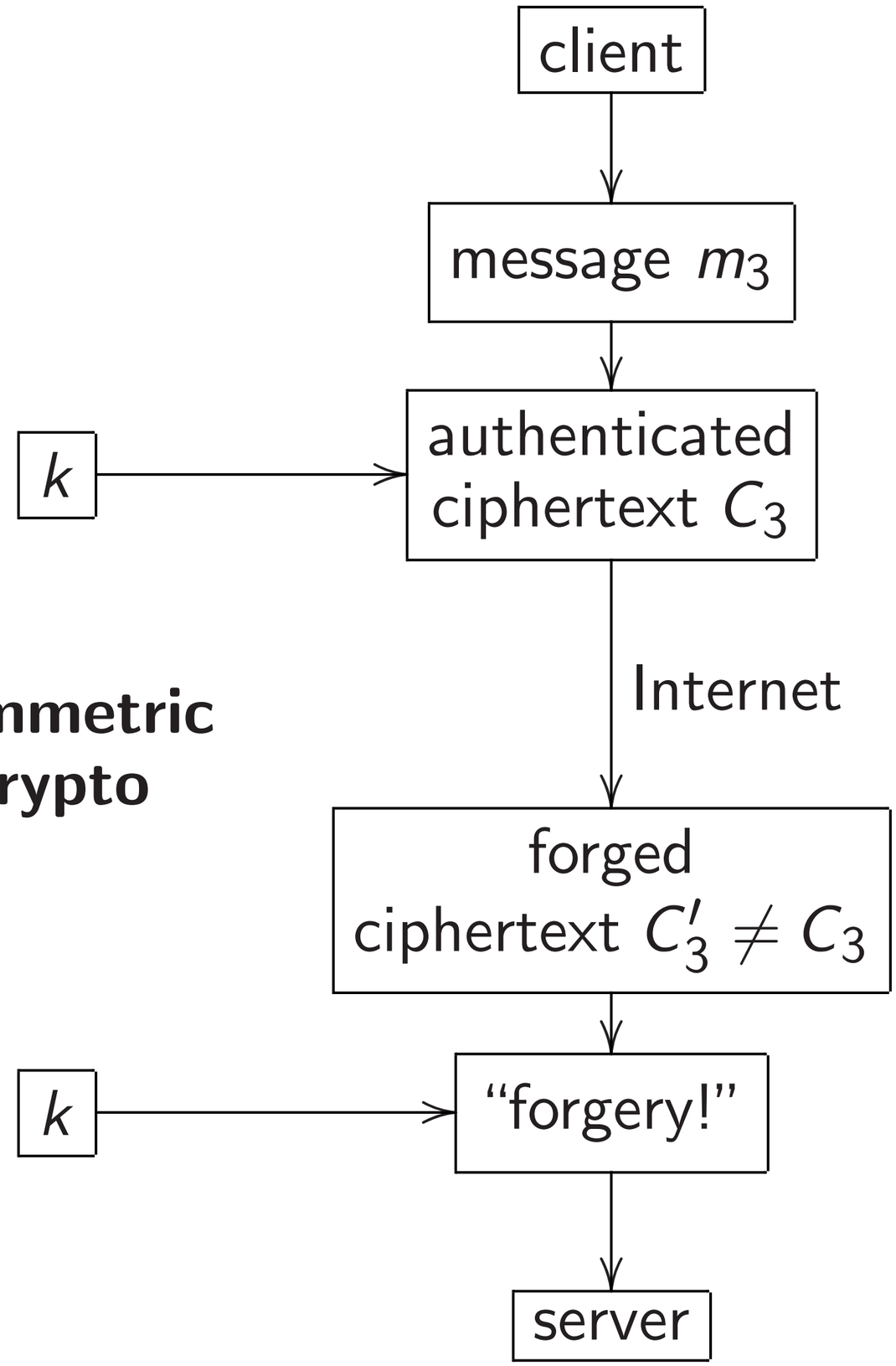

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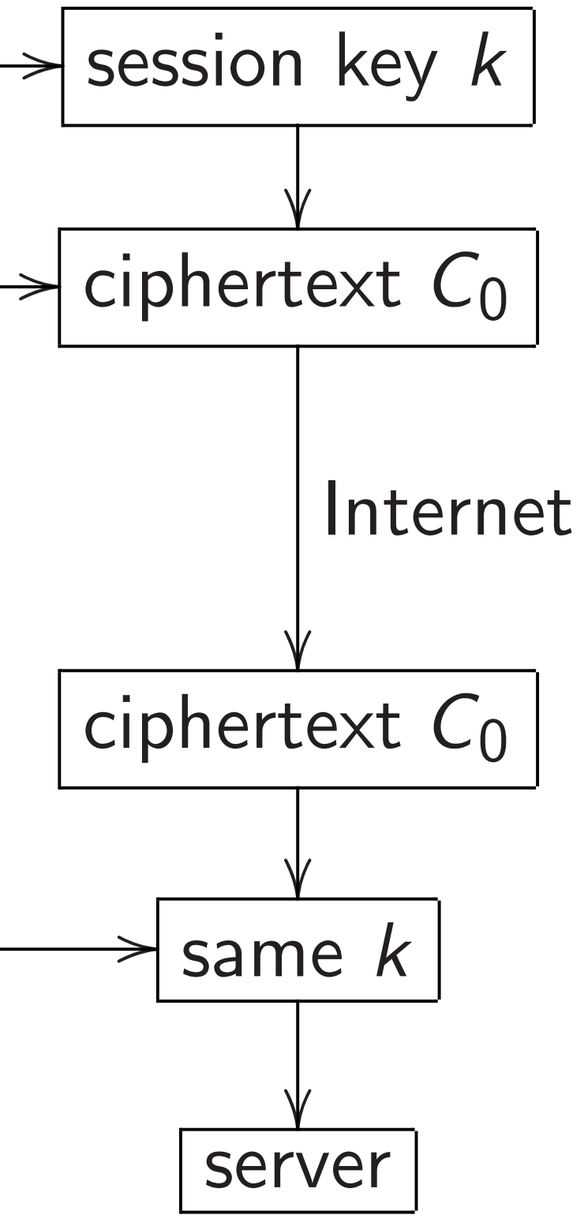

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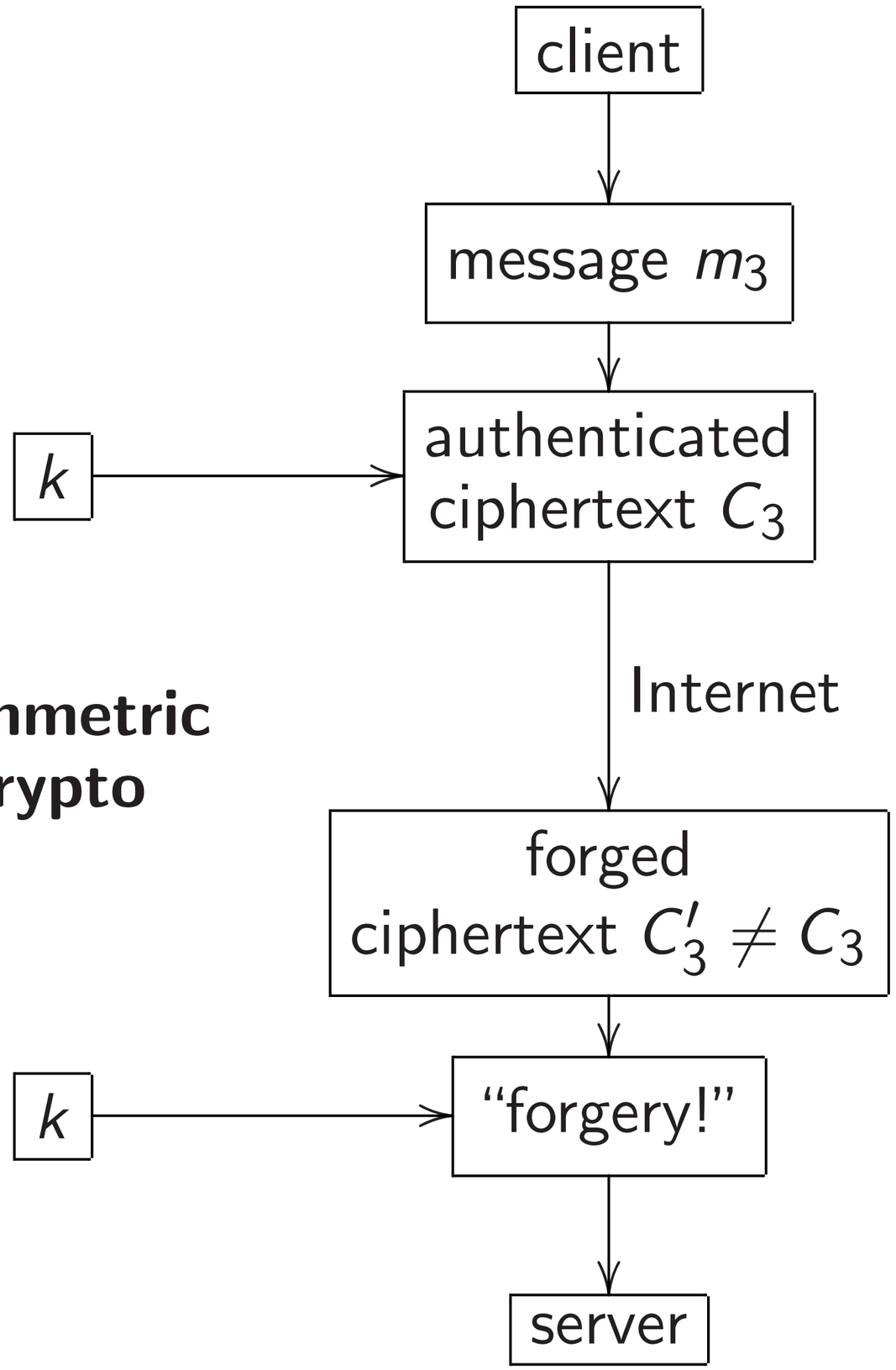

Symmetric crypto:

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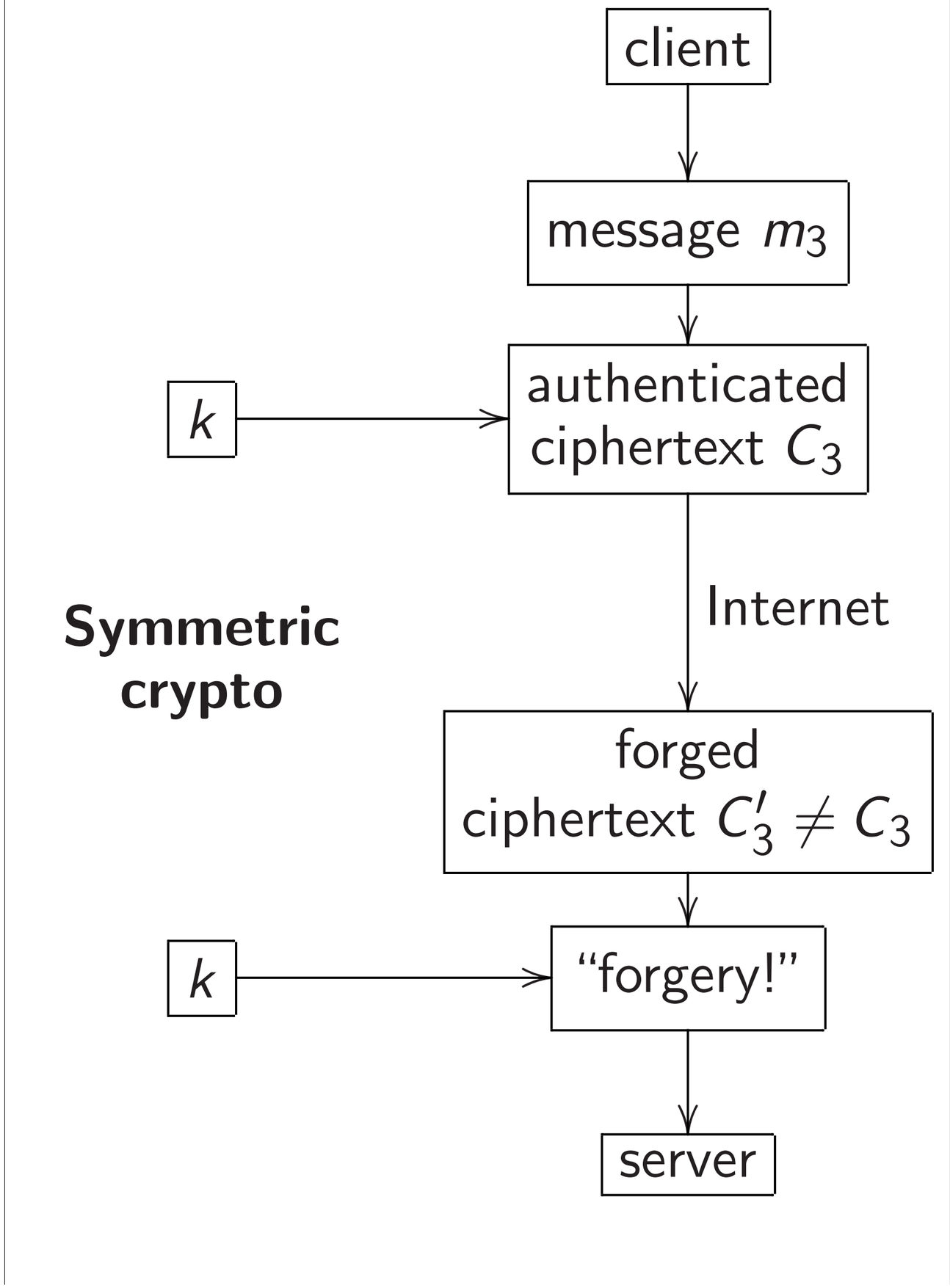

Symmetric crypto: main obj

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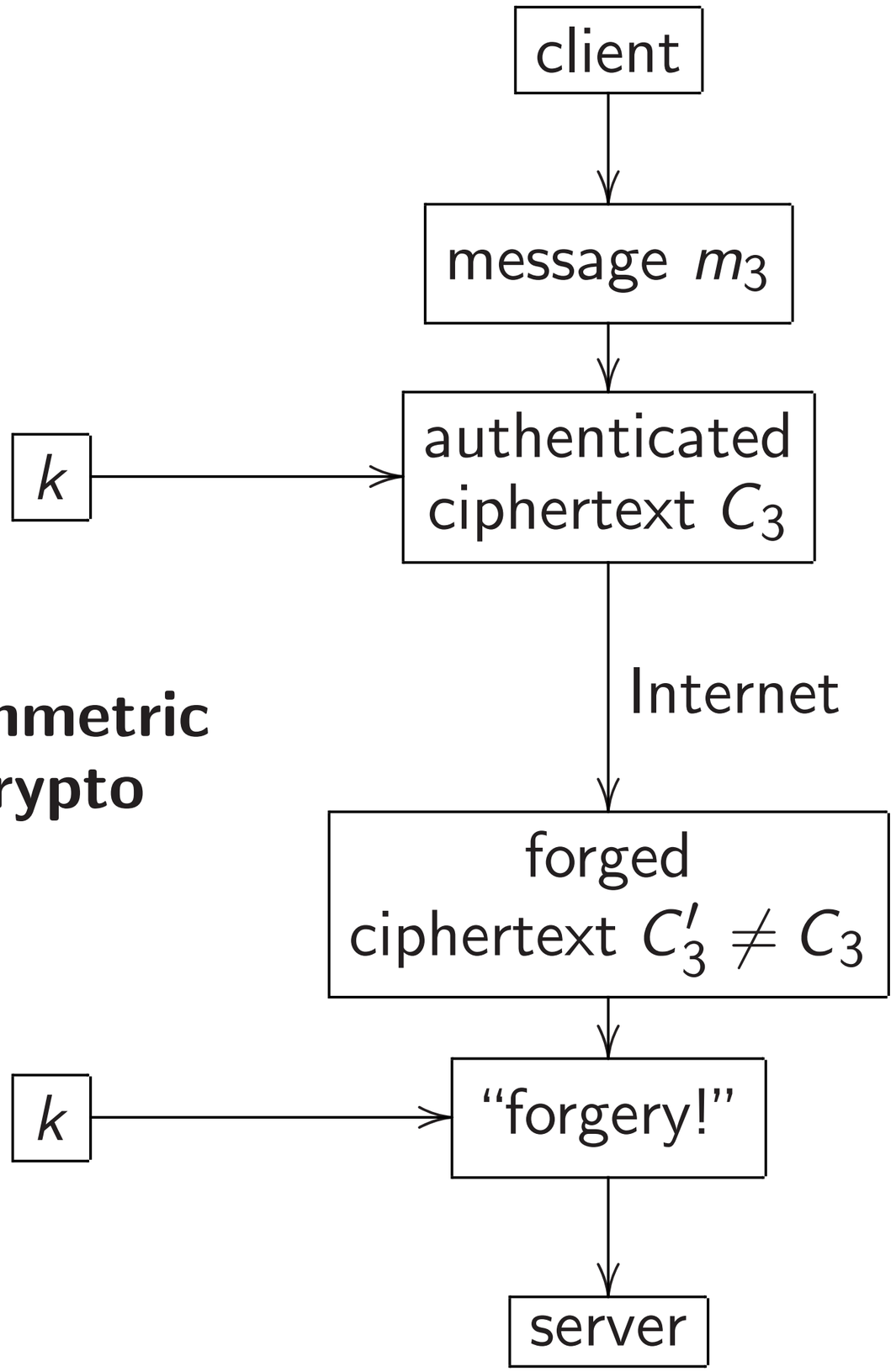

Symmetric crypto

Symmetric crypto: main objectives

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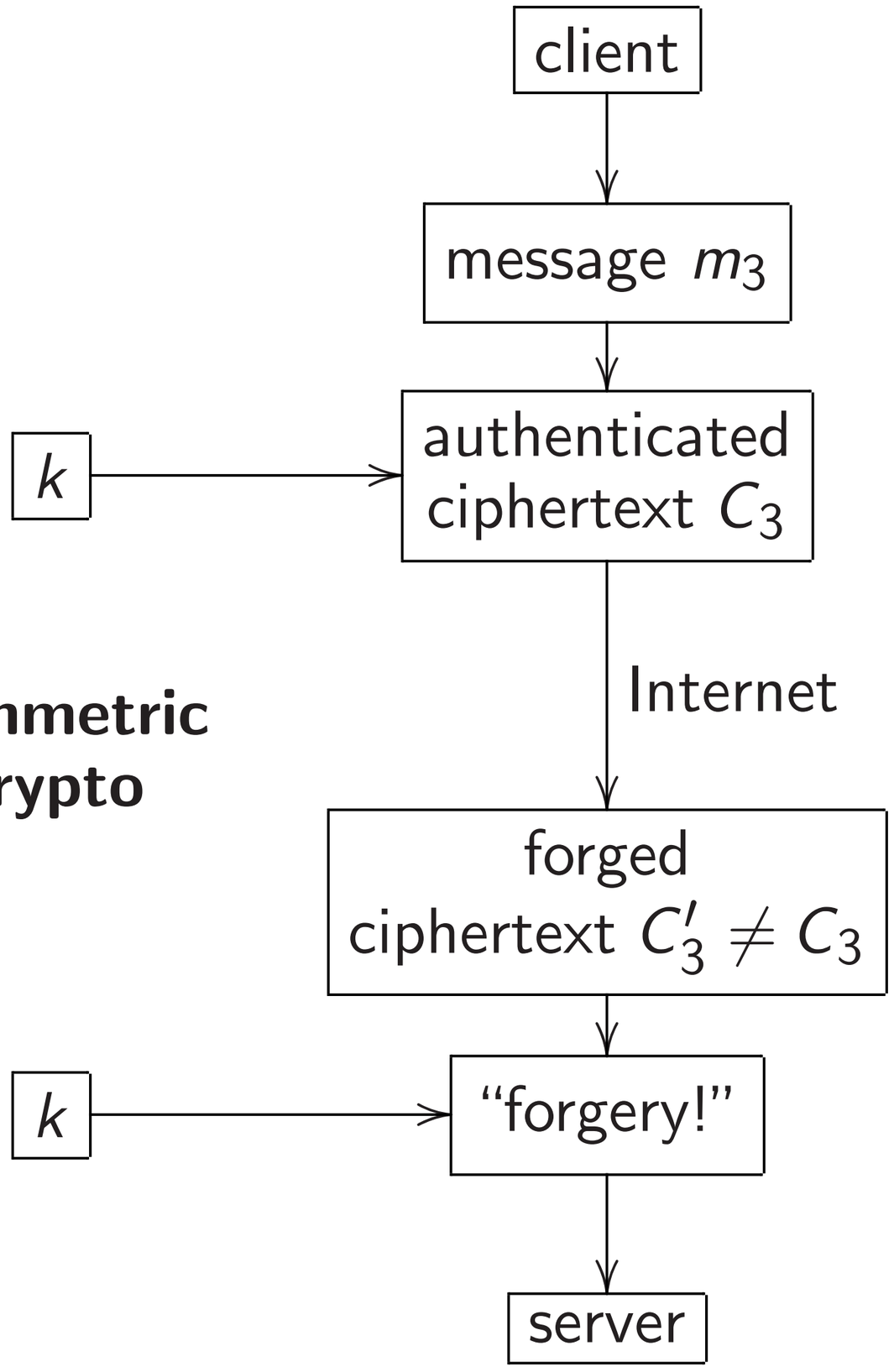

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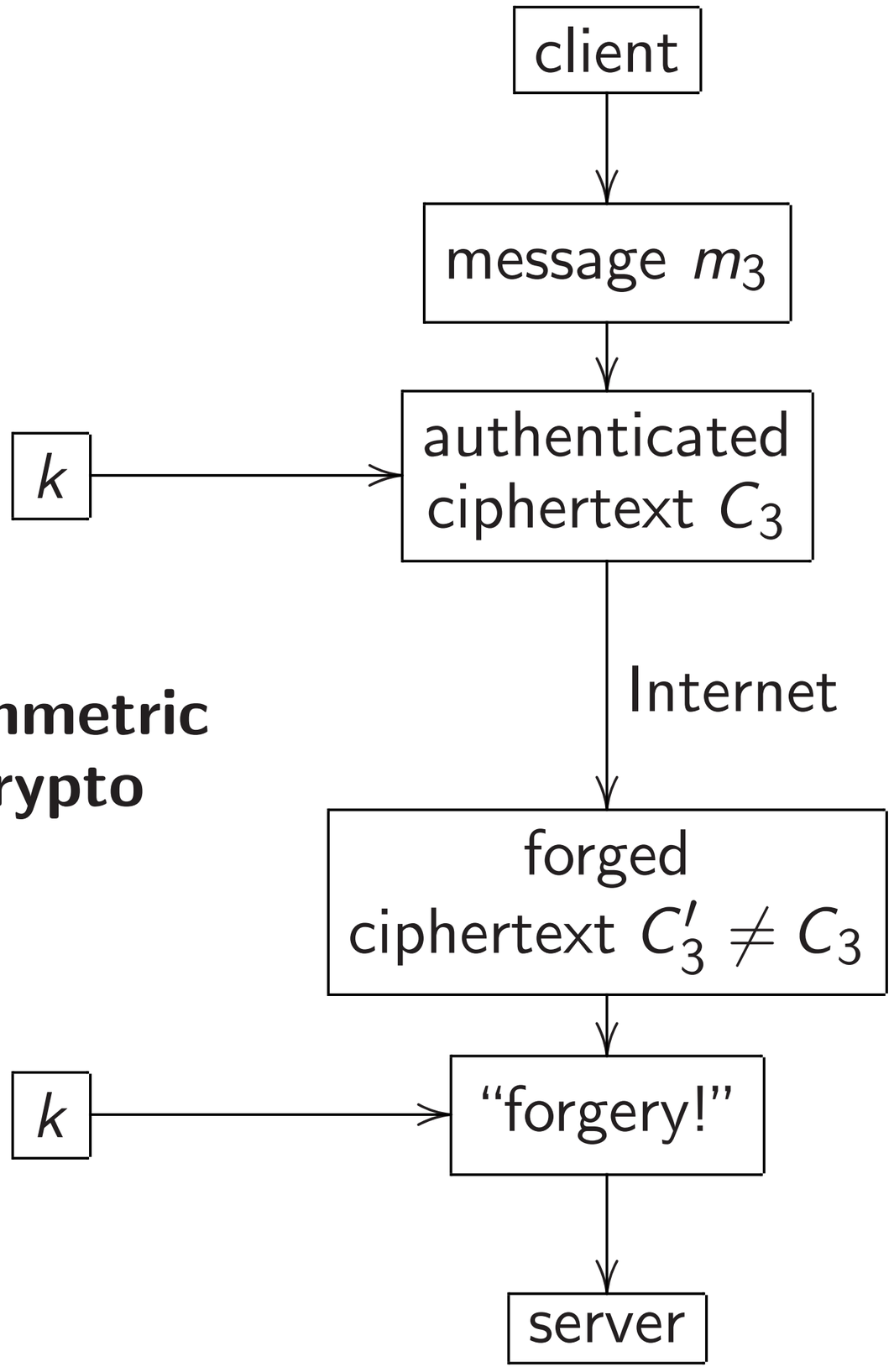

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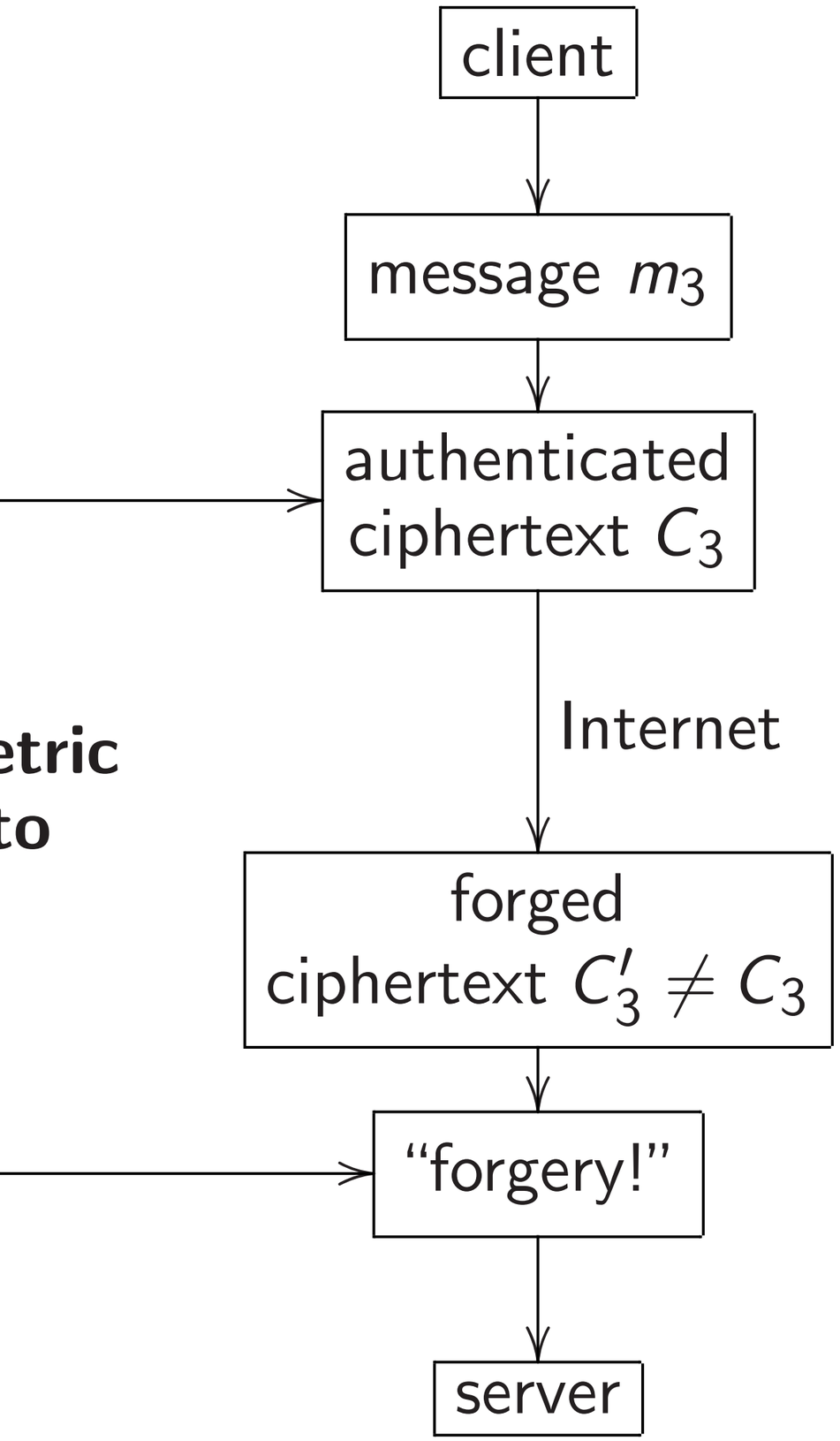
Real client messages are lost.
This damages **availability**.



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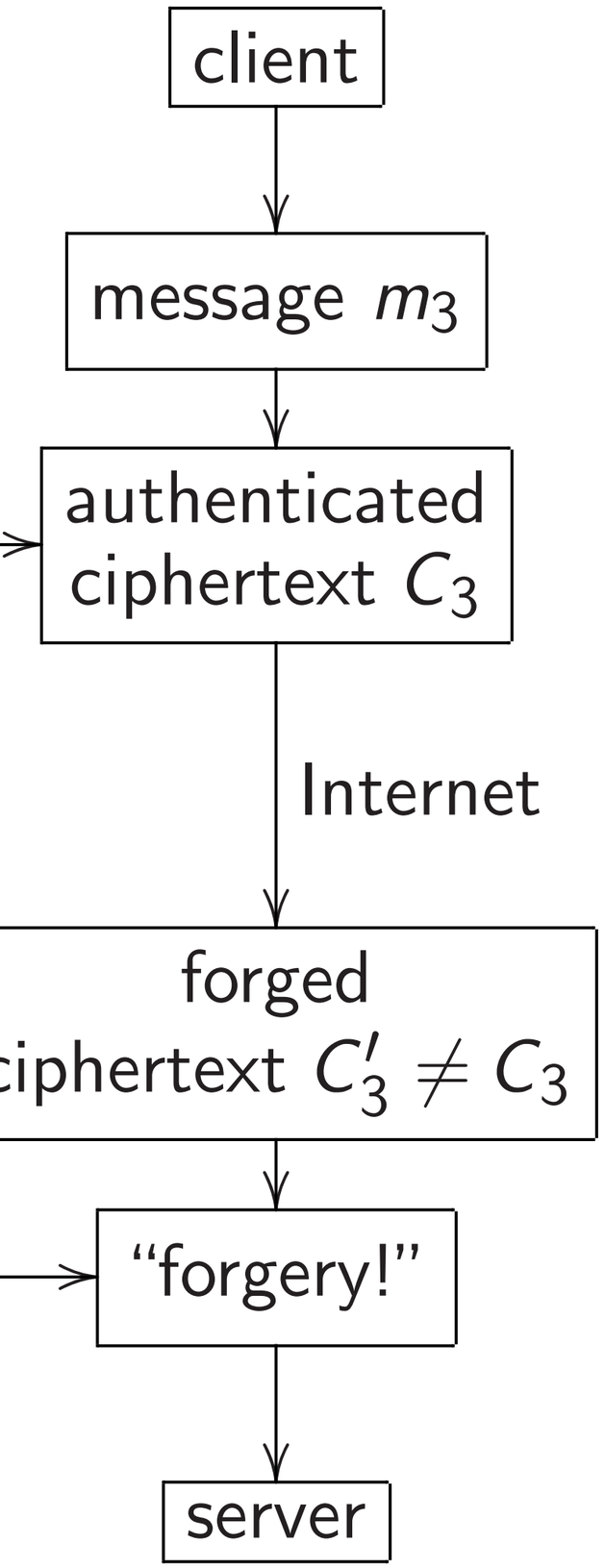

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This would be the whole picture
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PRF ("pseudorandom function"):
Attacker can't distinguish
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that returns $F(k,i)$ given i.
Server is called an **oracle**.

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If block size is big then
PRP $\Rightarrow$ PRF $\Rightarrow$ PRG.

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```
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{
  uint32
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  for (i
    c +=
    x +=


    y +=


  }
  b[0] =
}
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```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
         ^ (
    y += x+c ^ (
         ^ (
  }
  b[0] = x; b[1]
}
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void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0
             ^ (y>>5)+k[1
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uint32:
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c += d:

^: xor; $\oplus$
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integer $b_0 + 2b_1 +$

+: addition mod 2

c += d: same as c

^: xor; $\oplus$; additio
each bit separately

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<<4: multiplicatio
$(0, 0, 0, 0, b_0, b_1, \ldots$

>>5: division by 3
$(b_5, b_6, \ldots, b_{31}, 0,$

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`uint32`: 32 bits $(b_0, b_1, \ldots$
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`+`: addition mod 2^{32}.

`c += d`: same as `c = c + d`.

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`<<4`: multiplication by 16, i.
$(0, 0, 0, 0, b_0, b_1, \ldots, b_{27})$.

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```
crypt(uint32 *b,uint32 *k)


2 x = b[0], y = b[1];
2 r, c = 0;
r = 0;r < 32;r += 1) {
= 0x9e3779b9;
= y+c ^ (y<<4)+k[0]
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= x; b[1] = y;
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TEA is a **64-bit b**
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Functionality

TEA is a **64-bit block cipher** with a **128-bit key**.

`uint32`: 32 bits $(b_0, b_1, \ldots, b_{31})$ representing the "unsigned" integer $b_0 + 2b_1 + \cdots + 2^{31} b_{31}$.

`+`: addition mod 2^{32}.

`c += d`: same as `c = c + d`.

`^`: xor; $\oplus$; addition of each bit separately mod 2. Lower precedence than + in C, so spacing is not misleading.

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Wait, ho

```
void en
{
  uint3
  uint3
  for (
    c +=
    x +=
    y +=
  }
  b[0] =
}
```

$b_0, b_1, \ldots, b_{31}$)

unsigned"

$\cdots + 2^{31} b_{31}$.

2^{32}.

= c + d.

n of

y mod 2.

than + in C,

misleading.

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2, i.e.,

0, 0, 0, 0).

Functionality

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Wait, how can we

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
                ^ (
    y += x+c ^ (
                ^ (
  }
  b[0] = x; b[1]
}
```

$, b_{31})$

b_{31}.

C,

.

e.,

Functionality

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Wait, how can we decrypt?

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0
                ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
                ^ (x>>5)+k[3
  }
  b[0] = x; b[1] = y;
}
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Functionality

TEA is a **64-bit block cipher** with a **128-bit key**.

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```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

nality

a **64-bit block cipher**
28-bit key.

28-bit key (namely
[1],k[2],k[3]);
laintext (b[0],b[1]).

64-bit **ciphertext**
[0],b[1]).

ciently **encrypt**:
intext) $\mapsto$ ciphertext.

ciently **decrypt**:
hertext) $\mapsto$ plaintext.

Wait, how can we decrypt?

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

Answer:

```
void de
{
  uint3
  uint3
  for (
    y -
      x -
      c -
  }
  b[0] =
}
```

lock cipher

y.

(namely
,k[3]);
b[0],b[1]).

phertext

.

crypt:

ciphertext.

crypt:

→ plaintext.

Wait, how can we decrypt?

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

Answer: Each step

```
void decrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    y -= x+c ^ (
             ^ (
    x -= y+c ^ (
             ^ (
    c -= 0x9e377
  }
  b[0] = x; b[1]
}
```

er

]).

13

Wait, how can we decrypt?

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

14

Answer: Each step is inverti

```
void decrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 32 * 0x9e
  for (r = 0;r < 32;r +=
    y -= x+c ^ (x<<4)+k[2
             ^ (x>>5)+k[3
    x -= y+c ^ (y<<4)+k[0
             ^ (y>>5)+k[1
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```

Wait, how can we decrypt?

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
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  }
  b[0] = x; b[1] = y;
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```


Answer: Each step is invertible.

```
void decrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 32 * 0x9e3779b9;
  for (r = 0;r < 32;r += 1) {
    y -= x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
    x -= y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```

ow can we decrypt?

```
crypt(uint32 *b,uint32 *k)


2 x = b[0], y = b[1];
2 r, c = 0;
r = 0;r < 32;r += 1) {
= 0x9e3779b9;
= y+c ^ (y<<4)+k[0]
      ^ (y>>5)+k[1];
= x+c ^ (x<<4)+k[2]
      ^ (x>>5)+k[3];


= x; b[1] = y;
```


Answer: Each step is invertible.

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void decrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 32 * 0x9e3779b9;
  for (r = 0;r < 32;r += 1) {
    y -= x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
    x -= y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```

Generali
(used in
1973 Fe

```
x += fu
y += fu
x += fu
y += fu
...
```

Decrypti

```
...
y -= fu
x -= fu
y -= fu
x -= fu
```

decrypt?

```
t32 *b,uint32 *k)


], y = b[1];
0;
 32;r += 1) {
9b9;
y<<4)+k[0]
y>>5)+k[1];
x<<4)+k[2]
x>>5)+k[3];


 = y;
```


Answer: Each step is invertible.

```
void decrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 32 * 0x9e3779b9;
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    y -= x+c ^ (x<<4)+k[2]
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             ^ (y>>5)+k[1];
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```

Generalization, **Fe**

(used in, e.g., "Lu

1973 Feistel–Copp

```
x += function1(y
y += function2(x
x += function3(y
y += function4(x
...
```

Decryption, invert

```
...
y -= function4(x
x -= function3(y
y -= function2(x
x -= function1(y
```

```
nt32 *k)

1];

1) {

]

];

2]

3];
```


Answer: Each step is invertible.

```
void decrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 32 * 0x9e3779b9;
  for (r = 0;r < 32;r += 1) {
    y -= x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
    x -= y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```

Generalization, **Feistel netw**
(used in, e.g., "Lucifer" fron
1973 Feistel–Coppersmith):

```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each s

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```

Answer: Each step is invertible.

```
void decrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 32 * 0x9e3779b9;
  for (r = 0;r < 32;r += 1) {
    y -= x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
    x -= y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    c -= 0x9e3779b9;
  }
  b[0] = x; b[1] = y;
}
```


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```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each step:

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```

Each step is invertible.

```
crypt(uint32 *b,uint32 *k)


2 x = b[0], y = b[1];
2 r, c = 32 * 0x9e3779b9;
r = 0;r < 32;r += 1) {
= x+c ^ (x<<4)+k[2]
      ^ (x>>5)+k[3];
= y+c ^ (y<<4)+k[0]
      ^ (y>>5)+k[1];
= 0x9e3779b9;


= x; b[1] = y;
```


Generalization, **Feistel network** (used in, e.g., "Lucifer" from 1973 Feistel–Coppersmith):

```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each step:

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```

TEA aga

```
void en
{
  uint3
  uint3
  for (
    c +=
    x +=
      y +=
  }
  b[0] =
}
```

b is invertible.

```
t32 *b,uint32 *k)


], y = b[1];
32 * 0x9e3779b9;
 32;r += 1) {
x<<4)+k[2]
x>>5)+k[3];
y<<4)+k[0]
y>>5)+k[1];
9b9;


 = y;
```


Generalization, **Feistel network** (used in, e.g., "Lucifer" from 1973 Feistel–Coppersmith):

```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each step:

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```

TEA again for cor

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
             ^ (
    y += x+c ^ (
             ^ (
  }
  b[0] = x; b[1]
}
```

```
ble.

nt32 *k)

1];
e3779b9;
 1) {
2]
3];
0]
];
```


Generalization, **Feistel network** (used in, e.g., "Lucifer" from 1973 Feistel–Coppersmith):

```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each step:

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```

TEA again for comparison

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0
                ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
                ^ (x>>5)+k[3
  }
  b[0] = x; b[1] = y;
}
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Generalization, **Feistel network** (used in, e.g., "Lucifer" from 1973 Feistel–Coppersmith):

```
x += function1(y,k);
y += function2(x,k);
x += function3(y,k);
y += function4(x,k);
...
```

Decryption, inverting each step:

```
...
y -= function4(x,k);
x -= function3(y,k);
y -= function2(x,k);
x -= function1(y,k);
```


TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

zation, **Feistel network**
, e.g., "Lucifer" from
istel–Coppersmith):

```
nction1(y,k);
nction2(x,k);
nction3(y,k);
nction4(x,k);
```

ion, inverting each step:

```
nction4(x,k);
nction3(y,k);
nction2(x,k);
nction1(y,k);
```


TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

XORTE

```
void en
{
  uint3
  uint3
  for (
    c +
    x ^
    y ^
  }
  b[0] =
}
```

istel network

cifer" from
ersmith):

```
,k);
,k);
,k);
,k);
```

ing each step:

```
,k);
,k);
,k);
,k);
```


TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

XORTEA: a bad c

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x ^= y^c ^ (
             ^ (
    y ^= x^c ^ (
             ^ (
  }
  b[0] = x; b[1]
}
```

work

n

tep:

TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

XORTEA: a bad cipher

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x ^= y^c ^ (y<<4)^k[0
             ^ (y>>5)^k[1
    y ^= x^c ^ (x<<4)^k[2
             ^ (x>>5)^k[3
  }
  b[0] = x; b[1] = y;
}
```

TEA again for comparison

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void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
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    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
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XORTEA: a bad cipher

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void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
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  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x ^= y^c ^ (y<<4)^k[0]
             ^ (y>>5)^k[1];
    y ^= x^c ^ (x<<4)^k[2]
             ^ (x>>5)^k[3];
  }
  b[0] = x; b[1] = y;
}
```

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```
crypt(uint32 *b,uint32 *k)

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```


XORTEA: a bad cipher

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{
  uint32 x = b[0], y = b[1];
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  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x ^= y^c ^ (y<<4)^k[0]
             ^ (y>>5)^k[1];
    y ^= x^c ^ (x<<4)^k[2]
             ^ (x>>5)^k[3];
  }
  b[0] = x; b[1] = y;
}
```

"Hardwa

xor circu

mparison

```
t32 *b,uint32 *k)

], y = b[1];
0;
 32;r += 1) {
9b9;
y<<4)+k[0]
y>>5)+k[1];
x<<4)+k[2]
x>>5)+k[3];

 = y;
```


XORTEA: a bad cipher

```
void encrypt(uint32 *b,uint32 *k)
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```

"Hardware-friendli

xor circuit is cheap

```
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1];

 1) {

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];

2]

3];
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A: a bad cipher

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crypt(uint32 *b,uint32 *k)

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2 r, c = 0;
r = 0;r < 32;r += 1) {
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= y^c ^ (y<<4)^k[0]
      ^ (y>>5)^k[1];
= x^c ^ (x<<4)^k[2]
      ^ (x>>5)^k[3];

= x; b[1] = y;
```


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Very fast attack:
if $b_4 = b_1 \oplus b_2 \oplus b_3$ then
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This breaks PRP (and PRF):
uniform random permutation
(or function) F almost never has
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t output bit is

$k_1 \oplus k_3 \oplus k_{10} \oplus k_{11} \oplus k_{12} \oplus$
$_1 \oplus k_{30} \oplus k_{32} \oplus k_{33} \oplus k_{35} \oplus$
$_3 \oplus k_{44} \oplus k_{52} \oplus k_{53} \oplus k_{62} \oplus$
$_7 \oplus k_{69} \oplus k_{76} \oplus k_{85} \oplus k_{94} \oplus$
$\oplus k_{101} \oplus k_{108} \oplus k_{117} \oplus k_{126} \oplus$
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TEA aga

```
void en
{
  uint3
  uint3
  for (
    c +=
    x +=
    y +=
  }
  b[0] =
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```

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TEA again for cor

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
                 ^ (
    y += x+c ^ (
                 ^ (
  }
  b[0] = x; b[1]
}
```

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dd.

$\oplus k_{12} \oplus$
$\oplus k_{35} \oplus$
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$\oplus k_{94} \oplus$
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TEA again for comparison

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void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0
             ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
             ^ (x>>5)+k[3
  }
  b[0] = x; b[1] = y;
}
```

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  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

a matrix M

efficients in $\mathbf{F}_2$

t, for all (k, b),

$\mathrm{A}_k(b) = (1, k, b)M$.

$\mathrm{A}_k(b_1) \oplus \mathrm{XORTEA}_k(b_2)$

$b_1 \oplus b_2)M$.

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$b_1 \oplus b_2 \oplus b_3$ then

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  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
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    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

LEFTEA

```
void en
{
  uint3
  uint3
  for (
    c +
    x +
    y +
  }
  b[0] =
}
```

M

n $\mathbf{F}_2$

(k, b),

$1, k, b)M$.

$\text{XORTEA}_k(b_2)$

M.

b_3 then

$\text{XORTEA}_k(b_2) =$

$\text{XORTEA}_k(b_4)$.

(and PRF):

ermutation

most never has

$F(b_3) \oplus F(b_4)$.

TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

LEFTEA: another

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void encrypt(uin
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  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
             ^ (
    y += x+c ^ (
             ^ (
  }
  b[0] = x; b[1]
}
```

$_k(b_2)$

$(b_2) =$
$_k(b_4)$.

):
n
r has
(b_4).

TEA again for comparison

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
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First out

$1 \oplus k_0 \oplus$

nparison

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Addition is not $\mathbf{F}_2$

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First output bit is

$1 \oplus k_0 \oplus k_{32} \oplus k_{64}$

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TEA aga

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void en
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  uint3
  uint3
  for (
    c +
    x +

    y +

  }
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}
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bad cipher

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t32 *b,uint32 *k)


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TEA again for cor

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
              ^ (
    y += x+c ^ (
              ^ (
  }
  b[0] = x; b[1]
}
```

r

```
nt32 *k)

1];


1) {


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];
2]
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TEA again for comparison

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TEA4: a

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void en
{
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-linear,

2 is $\mathbf{F}_2$-linear.

$_4 \oplus k_{96} \oplus b_{32}$.

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TEA4: another bad cipher

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void encrypt(uint32 *b,ui
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  uint32 x = b[0], y = b[
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Fast atta

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$\mathrm{TEA4}_k(x + 2^{31}, y$

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Trace x, y differences
through steps in computation.

$r = 0$: multiples of $2^{31}, 2^{26}$.

$r = 1$: multiples of $2^{21}, 2^{16}$.

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Uniform random function F:
$F(x + 2^{31}, y)$ and $F(x, y)$ have
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PRF advantage $1/2$.
Two pairs (x, y): advantage $3/4$.

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 = y;
```


Fast attack:
$\mathrm{TEA4}_k(x + 2^{31}, y)$ and
$\mathrm{TEA4}_k(x, y)$ have same first bit.

Trace x, y differences
through steps in computation.
$r = 0$: multiples of $2^{31}, 2^{26}$.
$r = 1$: multiples of $2^{21}, 2^{16}$.
$r = 2$: multiples of $2^{11}, 2^{6}$.
$r = 3$: multiples of $2^{1}, 2^{0}$.

Uniform random function F:
$F(x + 2^{31}, y)$ and $F(x, y)$ have
same first bit with probability $1/2$.

PRF advantage $1/2$.
Two pairs (x, y): advantage $3/4$.

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but rapidly lose effectiveness.
Very far from full TEA.

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Hard question in cipher design:
How many "rounds" are
really needed for security?

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  uint32
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  for (i
    c +=
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  }
  b[0] =
}
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TEA again for cor

```
void encrypt(uin
{
  uint32 x = b[0
  uint32 r, c =
  for (r = 0;r <
    c += 0x9e377
    x += y+c ^ (
                ^ (
    y += x+c ^ (
                ^ (
  }
  b[0] = x; b[1]
}
```

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More sophisticated attacks:
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TEA again for comparison

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
  for (r = 0;r < 32;r +=
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0
             ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
             ^ (x>>5)+k[3
  }
  b[0] = x; b[1] = y;
}
```

More sophisticated attacks:
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  }
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```

REPTEA

```
void en
{
  uint3
  uint3
  for (
    x +=
      y +=
  }
  b[0] =
}
```

d attacks:
of differences;
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$\delta + \epsilon) -$
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REPTEA: another

```
void encrypt(uin
{
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  for (r = 0;r <
    x += y+c ^ (
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```

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TEA again for comparison

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void encrypt(uint32 *b,uint32 *k)
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}
```

REPTEA: another bad ciphe

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0x9e3779b
  for (r = 0;r < 1000;r +
    x += y+c ^ (y<<4)+k[0
             ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
             ^ (x>>5)+k[3
  }
  b[0] = x; b[1] = y;
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void encrypt(uint32 *b,uint32 *k)
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  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
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crypt(uint32 *b,uint32 *k)


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  }
  b[0] = x; b[1] = y;
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```

REPTEA

where I_k

nparison

```
t32 *b,uint32 *k)


], y = b[1];
0;
 32;r += 1) {
9b9;
y<<4)+k[0]
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  }
  b[0] = x; b[1] = y;
}
```

$\mathrm{REPTEA}_k(b) = I$

where I_k does x+=

```
nt32 *k)

1];

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Collect outputs $\mathrm{REPTEA}_k(b)$.

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This is a **slide attack.**
TEA avoids this by varying c.

A: another bad cipher

```
crypt(uint32 *b,uint32 *k)

2 x = b[0], y = b[1];
2 r, c = 0x9e3779b9;
r = 0;r < 1000;r += 1) {
= y+c ^ (y<<4)+k[0]
      ^ (y>>5)+k[1];
= x+c ^ (x<<4)+k[2]
      ^ (x>>5)+k[3];

= x; b[1] = y;
```


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```
void en
{
  uint3
  uint3
  for (
    c +=
    x +=

    y +=

  }
  b[0] =
}
```

bad cipher

```
t32 *b,uint32 *k)

], y = b[1];
0x9e3779b9;
 1000;r += 1) {
y<<4)+k[0]
y>>5)+k[1];
x<<4)+k[2]
x>>5)+k[3];

 = y;
```


$\text{REPTEA}_k(b) = I_k^{1000}(b)$

where I_k does `x+=...;y+=...`

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What about origin

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    c += 0x9e377
    x += y+c ^ (
         ^ (
    y += x+c ^ (
         ^ (
  }
  b[0] = x; b[1]
}
```

er

```
nt32 *k)

1];
9;
= 1) {
]
];
2]
3];
```


$\text{REPTEA}_k(b) = I_k^{1000}(b)$

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What about original TEA?

```
void encrypt(uint32 *b,ui
{
  uint32 x = b[0], y = b[
  uint32 r, c = 0;
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             ^ (y>>5)+k[1
    y += x+c ^ (x<<4)+k[2
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  }
  b[0] = x; b[1] = y;
}
```

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Good chance that some b in list also has $a = I_k(b)$ in list. Then $\text{REPTEA}_k(a) = I_k(\text{REPTEA}_k(b))$.

For each (b, a) from list:
Try solving equations $a = I_k(b)$, $\text{REPTEA}_k(a) = I_k(\text{REPTEA}_k(b))$ to figure out k. (More equations: try re-encrypting these outputs.)

This is a **slide attack.**
TEA avoids this by varying c.

What about original TEA?

```
void encrypt(uint32 *b,uint32 *k)
{
  uint32 x = b[0], y = b[1];
  uint32 r, c = 0;
  for (r = 0;r < 32;r += 1) {
    c += 0x9e3779b9;
    x += y+c ^ (y<<4)+k[0]
             ^ (y>>5)+k[1];
    y += x+c ^ (x<<4)+k[2]
             ^ (x>>5)+k[3];
  }
  b[0] = x; b[1] = y;
}
```

$\mathrm{A}_k(b) = I_k^{1000}(b)$

$_k$ does x+=...;y+=....

of 2^{32} inputs b.

outputs $\mathrm{REPTEA}_k(b)$.

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Related

$\mathrm{TEA}_{k'}(b$

where $(k$

$(k[0] + 2$

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=...;y+=....

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Related keys: e.g.

$\mathrm{TEA}_{k'}(b) = \mathrm{TEA}_k$

where $(k'[0], k'[1],$

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= x; b[1] = y;
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